H2020 Work Programme

D6.6 – LESSONS LEARNT ABOUT INTEGRATION OF WH/C IN DHNS LEAD PARTNER: RADET

Date: November 30th, 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847097. The content of publication is the sole responsibility of the author(s). The European Commission or its services cannot be held responsible for any use that may be made of the information it contains.

Project title			
Supporting new Opportunities for Waste Heat And cold valorisation Towards EU decarbonization			
Project acronym	SO WHAT	**Start / Duration**	June 2019 (36 months)
Coordinator	RINA Consulting – RINA-C		
Website	www.sowhatproject.eu		

Deliverable details			
Number	D6.6		
Title	Lessons learnt about integration of WH/C in DHNs		
Work Package	2		
Dissemination level[1]	PU = Public	**Nature**	Report
Due date (M)	M42 – 30.11.2022	**Submission date (M)**	November 30th, 2022
Deliverable responsible	TERMOFICARE		

[1] PU = Public
CO = Confidential, only for members of the consortium (including Commission Services)

	Beneficiary
Deliverable leader	
Contributing Author(s)	Eden Mamut (MEDGreen) Liviu Popa, Bogdan Orozan, Cristian Nedelea, Eugen Ionescu (Termoficare) Francisco Morentin, Iciar Bernal, Paula Serrano (CAR)
Reviewer(s)	
Final review and quality approval	

Document History			
Date	**Version**	**Name**	**Changes**

Abbreviations

°C: Celsius degrees

B2B: Business to Business

B2C: Business to Consumer

CAPEX: CAPital EXpenditure

CHP: Combined Heat and Power

COP: Coefficient of Performance

DH: District Heating

DHCN: District Heating and Cooling Networks

EII: Energy Intensive Industries

ESCO: Energy Service COmpany

EU: European Union

OPEX: OPerating EXpense

RES: Renewable Energy Sources

ROI: Return On Investment

SME: Small and Medium Enterprises

WH/C: Waste Heat/Cold

WHR: Waste Heat Recovery

Executive summary

This document represents the Deliverable dedicated to summarizing the outcomes of the activities that have been carried-out in WP 6 - SO WHAT impact analysis and maximisation of lessons learnt.

The main objective of WP6 was to conduct the impact analysis of the industrial WH/C recovery and RES integration solutions promoted by the SO WHAT tool and project, as well as to compile the derived conclusions into a set of lessons learnt and useful recommendations. S

The deliverable was structured in 6 chapters and conclusions dedicated to define a framework for the evaluation of the WHC recovery solutions in DHNs, the analysis of the situation in some EU MS and presentations of some demo cases.

The document includes some of the results of the study of the paradigm change from a public and industrial perspective regarding WH/C and surplus RES recovery. Particular focus have been put to explore those opportunities associated to the level of environmental commitment which act as economic drivers of the industrial activity, affecting investments and business decisions.

The studies have underlined the existence of two major trends within the EU. From one side, in Western European countries there is a trend of increasing emphasis on the development of DHNs that is supported by the commitment of the EC for energy efficiency, mitigation of CO_2 emissions, security and accessibility of energy to all citizens. But, there is also another trend mostly in Eastern European Countries with a history in centralized planning where the DH systems have been developed since 1960's and after 1990's it has been a process of restructuring and re-engineering for adaptation to the new conditions of market economy.

In the document, there is presented the case of Romania where in 1989 there were operational 315 DH systems and at present there are less than 50, creating a very big impact regarding the complexity and lack of viable solutions to manage large scale systems.

It looks like there is a big opportunity to concentrate on developing such solutions under the frame of the Horizon Europe Mission: Climate-neutral and smart cities that could have a huge impact at a very large geographical scale.

The activities within this project have demonstrated that there are many examples of innovative solutions like the case in Constanta, where the restructuring of the DHNs can be dome by integrating RES but, still there are barriers in the mentalities and practices of local authorities that are adopting classical conventional solutions that assure simple solutions for funding the required investments.

TABLE OF CONTENTS

1 Introduction to District Heating and Cooling

1.1 Definition of District Heating and Cooling

The definition that was considered the most appropriate for the purpose of the present study is that [1]: "***District Heating and Cooling (DHC)*** *is one of the main infrastructures* [of an urban agglomeration,] *allowing decarbonisation by integrating renewable and carbon neutral energy sources and technologies and participating in energy system integration. It allows to combine a variety of energy efficiency and decarbonisation solutions and leverage them to yield high greenhouse emissions reduction and energy savings. These solutions include the efficient integration of local renewable energy sources and the use of various forms of excess heat and cold sources (also called waste heat and cold) that otherwise would remain untapped. Modern and efficient district heating and cooling is well-placed to benefit from and implement an overall multi-energy system approach, including in connection with city planning. It can also provide flexibility on the electricity market via power-to-heat solutions such as electric boilers or large-scale heat pumps, especially when coupled with thermal storage, or via combined heat and power (CHP) plants, to accommodate renewable electricity production for example*."

The types of DHC depend on the followings [2]:

A. Type of heat / cold end-users: urban and/or residential, tertiary, industrial, farming (greenhouses);

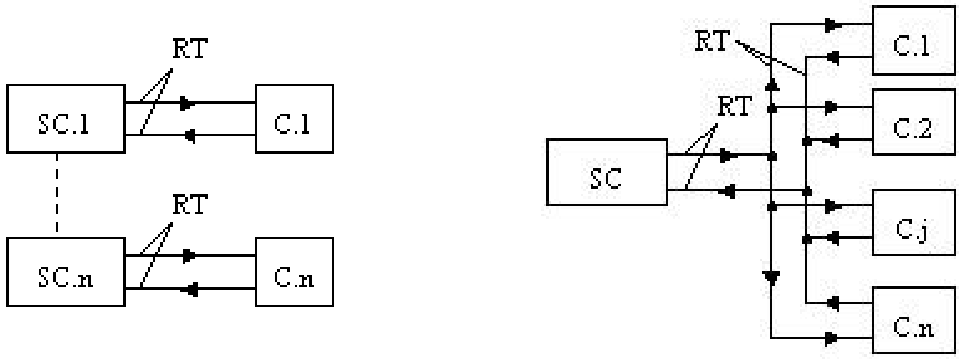
B. Degree of centralization/decentralization of heat/cold supply:
- Individual H/C system: a source feeds a single end-user, which can be represented by a building (house) or an apartment within a common building. In general, individual systems depend on the heat supplied contour and the administrative-legal aspects of the property. Their main feature is that from a legal point of view, they supply only one consumer.
- Centralized H/C systems: a source feeds several end-users, and this is reflected also from a legal point of view. The degree of centralization depending on the case: from the heat supply of several individual end-users located in a central building, to the grouping of several buildings, of some neighborhoods in the case of urban end-users, to some cities or villages, or of industrial platform(s).
- Mixed H/C systems: some end-users have individual sources and others are fed in centralized systems, from one or more zone heat sources or a single source.

C. The nature of the thermal agent used for heat supply: systems with hot water (with nominal temperature below 100 °C), systems with hot water (with nominal temperature between 110...160 °C), systems with steam (at different steam parameters – pressure, temperature), systems in the form of cold, for air conditioning or for technological purposes, systems with warm/hot air as a thermal agent for the transport and distribution of heat;

D. Heat production technology, used at the heat source(s):
- Thermal plants, only for heat supply;
- Cogeneration plants – used for the simultaneous supply of heat and power;

- Trigeneration systems, with trigeneration plants – the simultaneous supply of heat, cold and power.

The architectures of the DHC systems are presented in the followings. In the case of individual heating or cooling systems (a), each source is connected to the end-users by individual transport and distribution pipes (RT). In the case of centralized systems (b), the distribution and transport piping network is shared.



a) b)

Figure 1: Comparative Architecture of Individual and Centralized Heating Systems

The centralized systems may include re-heating or re-cooling stations (PT) around several groups of end-users and the transport and distribution piping is split in primary loop (RTP) and secondary loops (RTS)

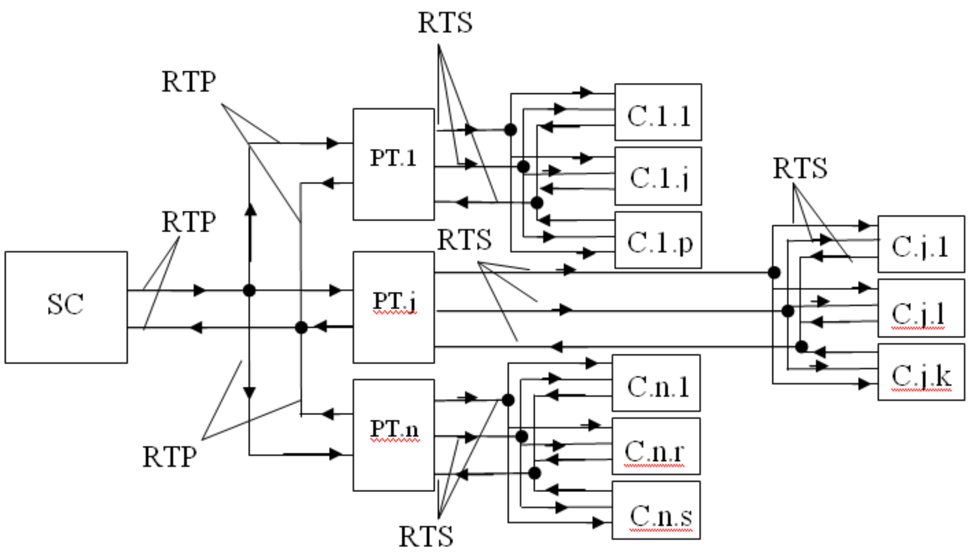


Figure 2: Centralized Heating Systems with reheating stations

For improving the flexibility of the distribution process, the DHC systems may be conceived with individual re-heating or re-cooling modules (MT) connected to each individual end-user. In this way, practically the secondary distribution and transport loops are eliminated and the termal energy is transported only by the primary loops (RTP).

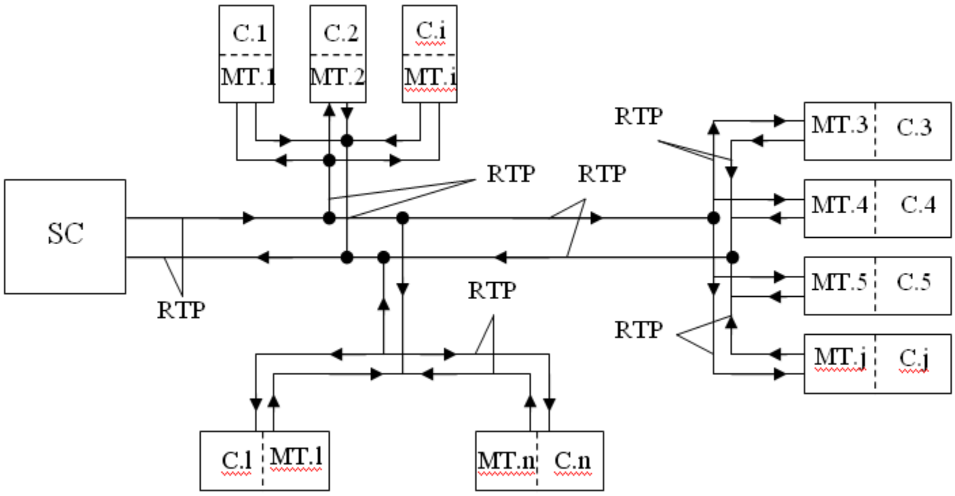


Figure 3: Centralized Heating Systems with Thermal Modules

As a conclusion the individual systems are characterized by the following features:

- requires a heat source for each physical/legal end-user;
- location of the heat source at the site of the end-user to whom it is intended;
- heat production technologies must satisfy environmental conditions and all other restrictions determined by proximity to consumers: source of fire, noise, etc.;
- the various categories of heat users can be provided by the same source, or by heat sources specialized for the various consumptions.

The centralized systems are characterized by the following features:

- the heat/cold source is developed for several different physical/legal users;
- the location of the heat/cold source might be in the area of the related users, or outside it, depending on the degree of centralization adopted for the heat supply and the mutual position of the consumers in relation to that of the heat source/sources;
- heat/cold consumption is provided simultaneously by the same heat source(s), to which the respective users are connected.

1.2 Advantages and Disadvantages of DHC versus individual systems

The advantages of the DHC systems are the followings:

- reduction of restrictions regarding the quality and storage of the used fuel, in the case of liquid and/or solid fuels;
- by overlapping the heat/cold demands of different types, of various users, the total maximum dimensioning value of the capacity of the heat/cold source/sources is reduced and the total annual demand is flattened, with the following consequences:
    - the investment in the heat/cold source(s) is reduced, relative to the total of the maximum heat flows delivered;
    - the average annual load of the production facilities increases, increasing their average annual operating efficiency, thus reducing the specific variable costs for the produced heat/cold;

- specific average maintenance costs are reduced;
- local environmental pollution is reduced, simultaneously with the reduction of specific investments related to the adoption of the respective measures, in order to ensure compliance with the same threshold values of the pollution emissions. This means, in the end, the reduction of environmental emissions associated to each end-user.
- the total investment is reduced - at the level of the consumer/consumption area - necessary to ensure the same total capacity for heat;cold supply.
- reduction of the total energy bill – at the level of the assembly/consumption area, for the same total amount of heat/cold provided to consumers.

The disadvantages of the DHC systems are the followings:

- extend the average heat transport distance on the whole system with the following consequences:
    - increase the heat losses during transport;
    - increase the energy consumption related to heat transport;
    - in order to adequately satisfy, over time, the heat demand of all end-users fed by such systems, both in terms of quality and quantity, such systems require automatic adjustment systems, structured in several stages: centralized - at the source, decentralized, at the level of the re-heating or re-cooling stations (if there is the case), followed by an individual one at the level of each end-user. This complicates and increases the costs related to the process control in such systems;
- In the absence of individual adjustment, the end-user cannot adapt the heat/cold consumption to individual needs or payment capacity. Also, the heat/cold supply, at any time, is not only decided by the conditions imposed by each individual consumer, but also by some general regulations, valid for the whole system.
- the heat/cold bill for each individual end-user has two components:
    - the share related to the amount of heat/cold actually received by the end-user at the level of the local metering system;
    - share of the common costs related to the operation of the entire system, established for the normal state - technical and functional - of the system as a whole. In this respect it is required the transparency of the DHC operator based of appropriate contracts and accountability and at the same time there is a strong need for regulations, monitoring and arbitration ensured by an independent authority;
- the initial investment, on the whole DHC system is higher than in the case of individual systems, which associated risks;
- the specific cost of heat/cold to end-users depends on the simultaneity of several factors specific to the local conditions of SCAC, among which the most important are the followings:

the number of connected end-users, the structure, size and simultaneity of the maximum consumption values provided by the system;

1.3 The continuous evolution of DHC

In the textbooks, there is mentioned that the first DH system was developed in Europe, in Dresden in 1900. Since then, the evolution of the DH and later DC systems was marked by technological and managerial evolution phases that have been summarized in the figure below.

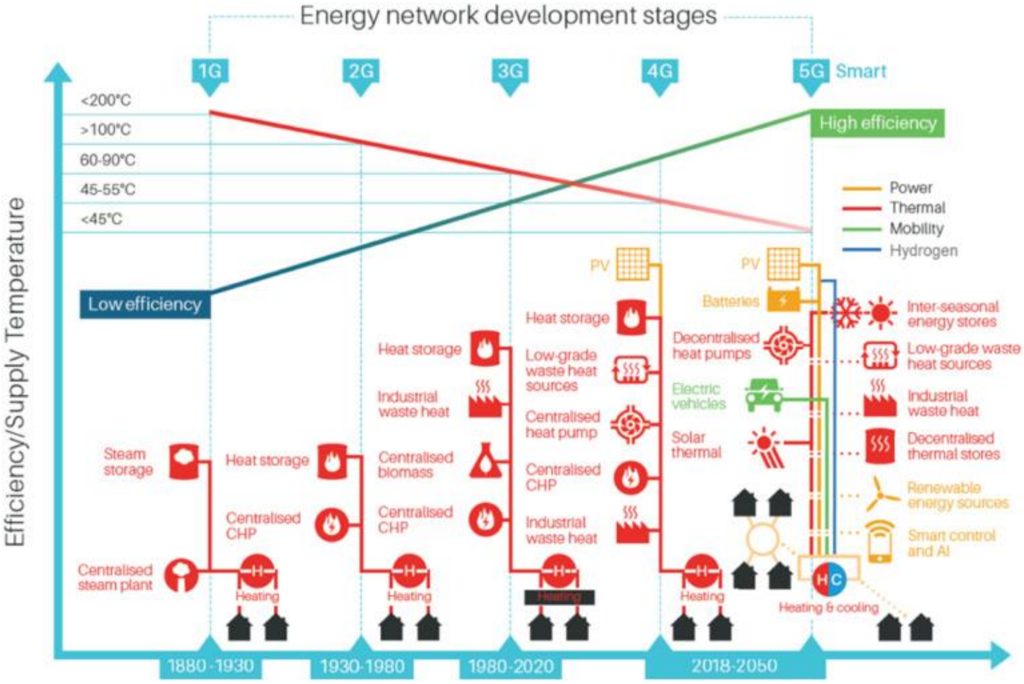


Figure 4: Continuous evolution graph of the DH systems

At present, the evolution of DHC systems is guided by the vision of a fifth generation coined as 5GDHC also called cold district heating that capitalizes the achievements in the previous phases of development facilitating the integration of industrial waste heat and cold and intermittent renewable energy sources with associated storage facilities. In the new evolution phase the main idea is to further integrate electric mobility vehicles and hydrogen energy systems and to distribute heat ans cold at near ambient ground temperature. This basic idea, in principle, minimizes heat losses to the ground and reduces the need for extensive insulation. The connected buildings are supposed to use heat pumps in individual plant rooms to extract heat from the ambient circuit when it needs heat and uses the same heat pump in reverse to reject heat when it needs cooling. In periods of simultaneous cooling and heating demands this allows waste heat from cooling to be used in heat pumps at those buildings which need heating. The overall temperature within the ambient circuit is preferably controlled by heat exchange with an aquifer or another low temperature water source to remain within a temperature range from 10 °C to 25 °C.

As public utilities, the DHC systems must assure to all end-users that are serving, the required quantity and quality of heat or cold, at the minimal cost and with minimal use of resources and environmental impact over a lifecycle approach from production to the end-use.

As it is well known, the objective of the EU adopted by the European Climate Law and Green Deal, is to achieve climate neutral economy by 2050, and set an intermediate target for 2030 to achieve at least 55% greenhouse gas reduction by 2030. The "Fit for 55" package adopted in July 2021 proposes to raise the EU renewable energy target from 32% to 40% and the EU energy efficiency target from 32,5% to 39% (a 9% energy consumption reduction, if expressed against the 2020 baseline). One of the key challenges and contributor to achieve those objectives will be the decarbonisation of the heating and cooling (H&C) sector, currently representing half of the EU's final energy consumption and mainly relying on fossil fuels [A.1].

2 DHC status overview in some of the EU MS

2.1 Specific countries detailed status

For preparing this paragraph, the project consortium members have been invited to submit a summary of the situation in their countries.

The reports have been reproduced in the followings.

2.1.1 Status overview of the DHC development in Spain

According to the **"Country by Country" 2019 study by Euro Heat and Power [3]**, in Spain, *only 0.15% of the final demand for thermal energy was satisfied with DHN systems*, which makes Spain an emerging market in this sector. With every passing year, the situation for District Heating & Cooling Networks (DH&CNs) is becoming more and more favourable. Every year, new DH&CN are settled seeking the benefits of increasing energy efficiency in generation, renewable energies integration, exploitation of local resources and waste heat from waste flows that would otherwise be lost and integration of high efficiency production systems. From that first district level supply until the current scene, DH&CNs are experiencing an ongoing increase in influence as thermal energy supply systems.

Currently **ADHAC (Association of Heat and Cold Network Companies)** carries out the development of the **Census of heat and cold networks in Spain**, which is updated to keep a real follow-up of the situation in the country. Last **2021 version [4]** shows the most updated description of the DH&CN market in Spain. Reviewing the panorama throughout these years, in almost ten years the number of districts installed has grown steadily from *46* to *494 DH&CNs*.

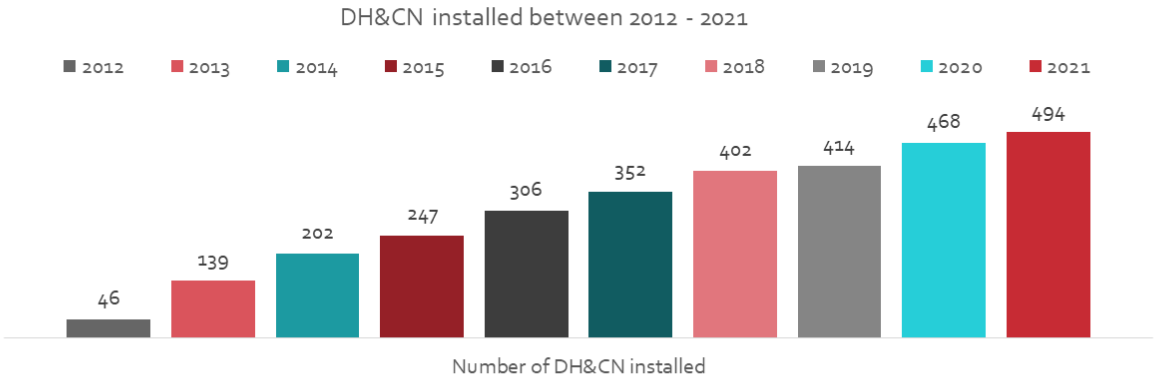


Figure 5: Evolution of District Networks installed in Spain from 2012 to 2021

In terms of *installed capacity*, the evolution in the same period of years has been *more than 1000 MW*. However, the statistics that are presented reflect only the district networks that have been added in this mentioned census, for this reason, it must be considered that reality is represented by a greater number of networks, including the ones that has not been registered.

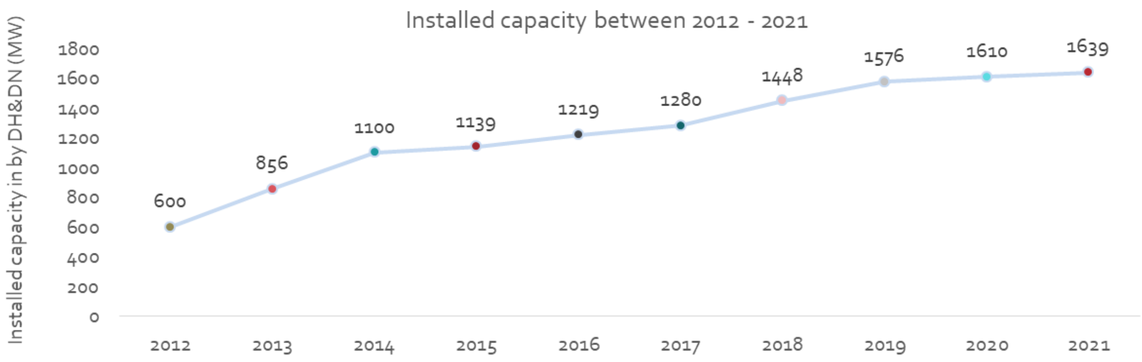


Figure 6: Evolution of installed DHC capacity in Spain from 2012 to 2021

In the *current 2021 framework*, there are more than **5.800 buildings** supplied by these networks that represents more than **810 km** of piping connections. The number of DN installed has grown **5,5%** and a **2%** in installed capacity, compared to the previous year. Thanks to this new 26 DN installed (total of 494 DN) in 2021, **285.000 tons** of CO_2 emissions were avoided due to the **92%** average savings from fossil fuels.

The *network typology* of this networks are for heating, heating & cooling and cooling supply. In Spain the **91%** of them are for only heating (757,5 MW of installed capacity), being the other **8%** for heating & cooling (880 MW) and to a lesser extent, with **1%** of the total, only cooling systems (1,9MW).

In Spain, there is a predominance of the thermal energy needs in the tertiary and residential sector over the industrial and this is reflected in the *users typology* connected to the district systems.

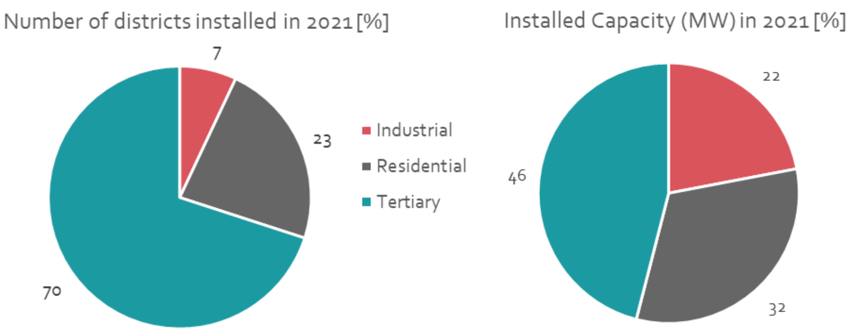


Figure 7: District users typology in Spain (2021)

Almost the **70 %** of the users belongs to the tertiary sector, this represents mostly half of the total installed capacity, followed by the residential sector. In addition, **57%** of the census networks are public owned.

What is remarkable about Spanish districts is the *energetic mix* framework. Currently, **8** in every **10** networks are performed with renewable energy as its principal source and more than **77%** use **biomass** over other fuels.

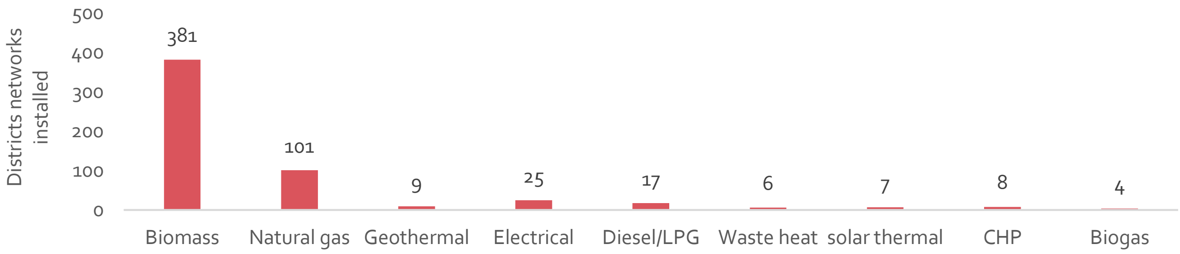


Figure 8: Energy sources in Spain DH&CN (2021)

In conclusion, almost 75% of the installed capacity in district networks is used for heating while the other 25% is used for cooling. DH&CN is still insignificant (less than 0,5%) compared with the national heating demand. However, in Spain 80% of the energy sources used in DH&CN are renewable, with a high penetration of biomass as the main fuel. Resources like waste heat, although there are at the moment DHN working with this source, its potential is still far from being exploited.

2.1.2 Status overview of the DHC development in Portugal

The energy management approach in Portugal has been for the last 60 years very much dependent on the centralized decisions. It was the problem of the supply and the issue of the rural electrification and later the natural gas distribution.

In the 50's Portugal created an important programme on hydroelectricity focussed on the Northern Portugal, i.e., closer to Porto. As the major consumption was at that time around Lisbon and there was no grid to carry the electricity down there, the Government decided to impose electricity as the unique energy commodity for the city of Porto, transportation excluded. That was favoured through lower prices than those for the rest of the country. That situation of almost a 100% electrical city (building stock and industry) lasted until the end of the 80's.

In 2001, emerged in Portugal a programme on for the promotion of renewable electricity aiming at expanding the use of wind energy and co-generation, namely through biomass, and a bit of solar photovoltaic. The original hydro programme added with the wind program led to the situation where Portugal had in 2010 over 20% of its installed power in renewable sources and manages from time to time to have full days over 90% of the electricity based on renewable.

The energy efficiency was declared of interest for the national authorities by the early eighties with energy audits and the definition of energy values-target for each type of industry. Therefore, the industry from the energy point of view became the 'good student'.

The transportation had beneficiated from some progress in public transport infrastructures, both in the Lisbon and Porto areas but its effect couldn't become so visible as with the economic growth of the last 20 years the motorization of the population made the increase of individual use of the car to explode. So, nowadays, efficiency in transport is a major issue in Portugal given the growth of the two large metropolis with over 30% of the population and still an unfriendly public transportation system.

Building sector is the last to be addressed. In this sector a basic distinction must be made for Portugal's context. On the one side, residential buildings, and some small institutional buildings such as small schools and, on the other side, the other buildings using centralized energy systems, either for heating or cooling, plus mechanical ventilation. In the residential buildings, by the early eighties, and before, there was no tradition of having energy systems installed. Even for heating. The residential heating needs were very poorly supported by fireplaces, small electrical or butane gas apparatus and some extra clothing. That was sensed to be supported on the effect, of course, of good orientation of buildings and windows towards the sun as the traditional architecture shows. In Portugal, on the contrary of the common judgement, even a well-designed building needs some heating in winter while the needs for cooling in is residual.

I this context, there were several approaches to create efficient energy systems close to the demand, namely, district heating/cooling networks.

In the case of Porto, the creation of a district heating and cooling network was seen as a infrastructural need to face the city's commitment in terms of GHG reduction targeting energy intensive buildings such as institutional buildings, mainly hospitals, and around 100 major office buildings. For lack of funding this project didn't go ahead.

That was also the experience at 'Parque das Nacões' area in Lisbon, former Expo'98. The needs of the housing buildings were not relevant both for heating and cooling. And the office buildings were particularly demanding of cooling. The Lisbon district heating and cooling network is so far the only existing system district heating and cooling network existent in Portugal.

There are some reasons that can explain the difficulty for DHN to succeed in Portugal, and the first one has to do with the relatively mild climate existent in the country that leads to low energy demand for heating purposes. However, there is a high potential for district cooling since the energy demand for HVAC is rapidly growing.

Regulation and statics (RES, Fuels, heat recovery technologies…)

In general terms, there is no history of direct incentive nor regulation for the recovery of excess heat and cold in the Portuguese energy policies. Alongside electrification, high-temperature heat from renewable cogeneration and solar thermal for low/medium-temperature heat needs are the main drivers of decarbonization in 2050.

In the industry sector there is however a substantial use of cogeneration where the heat recovery is mostly used for industrial processes.

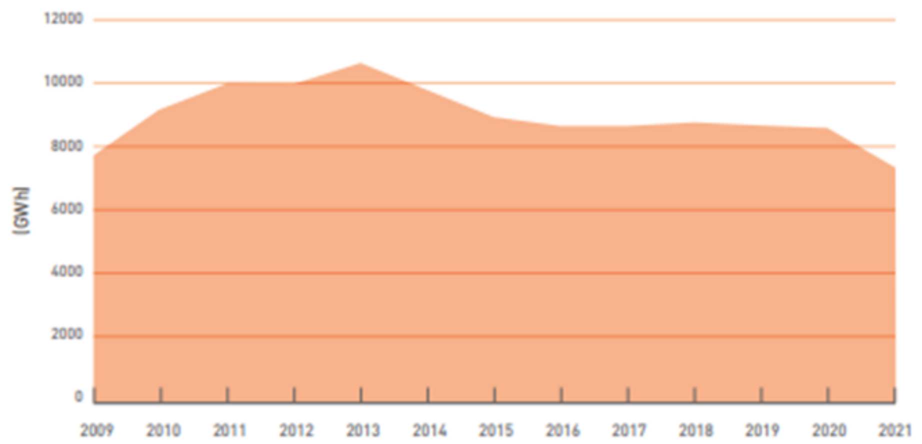


Figure 9 – evolution of thermal energy use from cogeneration in Portugal [source: COGEN Portugal].

In 2021, the energy use for cogeneration was 41% renewable, with a special contribution from biomass.

In the recently approved Recovery and Resilience Plan (RRP), there is already an new approach towards waste heat and cold recovery. In particular, in 2022 the RRP launched a call for proposals related with decarbonization in the industry sector, with a list of of technological characteristics and approaches that may be present in potentially eligible projects where the recovery of heat or cold and use of waste heat from nearby industries (in industrial symbiosis) are particularly enhanced.

2.1.3 Status overview of the DHC development in Belgium

Belgium is a federal state, composed of communities and regions and with three-level structure. At the top level, there are Federal State, the Communities and Regions (Flanders, Walloon and Brussels). They are on an equal footing but have powers and responsibilities for different fields. The next level down is occupied by the provinces and at the bottom level, there are the communes, which is the level of administration that is closest to the people.

- **Overview evolution of regulatory framework for heating or cooling networks**

The Decree basis of the Flemish energy policy can be found in the **Energy Decree of 8th May 2009** containing general provisions regarding energy policy. The implementation of the provisions is reported in the **Decree of the Flemish Government of 19th November 2010**.

The definition of "**heating and cooling networks**" according to the Energy Decree is important because it determines which systems must comply with legal obligations. The regulatory framework applies to all systems that fall under the definition of a heating or cooling network in the Energy Decree, art. 1.1.3.,133. It can be noticed that networks where the heat distribution takes place entirely within the same industrial site are excluded by this definition. And the distribution of heat from a production installation to several customers within one building is not regarded as a heat network. While, collective boiler rooms that serve several buildings, whether or not within their own (non-industrial) site (e.g. heat networks on campus sites, sites with buildings for social housing), do fall under the definition.

In Belgium, both the regions and the federal government are responsible for the energy market. The **local transposition of the EED 2012/27/**EU has been carried out from the three Regions in 2015 and updated in 2020. Updated information about the local situation are reported in dedicated EU studies about heating and cooling. [3]

From 17th November 2020, **cost allocation for a central source for heating, cooling or hot tap water** has been defined. These rules apply in:

- apartment buildings or multifunctional buildings with a common source what serves different users within that building;
- buildings with several users that are connected to a heating or cooling network or to a central source that serves different buildings.

The **connection to a heat or cold network** can be of two types:

- the heat/cold supplier has a contract directly with the individual end user. In that case, the supplier invoices based on the metered consumption and the agreed prices and the rules for cost allocation do not have to be followed;
- the heat/cold supplier has a contract with the association of co-owners (VME) and the VME divides the common costs among the individual units. In that case, the cost allocation rules apply.

The Royal Decree of 5th May 2022 setting **social maximum prices for the supply of heat** to protected residential customers was published in the Belgian Official Gazette (pp. 44720- 44721) on 24th May 2022. This royal decree states that heat companies supplying heat to residential protected customers must do so at the maximum prices set in accordance with this decree. The introduction of a social tariff for heat, analogous to a social tariff for natural gas and electricity, is important to protect vulnerable people from very high energy prices. Moreover, this legislation will also help make heat networks more attractive for e.g. social housing companies.

For what concerns the application of SoWhat tool, it can be noted that there are ongoing discussions about the maximal cost of district heating for non-protected customers that can influence the business cases of district heating networks. In certain projects, the cost of the heat is not coupled to natural gas prices, but in most other projects the heat tariffs are based on the 'not-more-than-other principle' (Niet meer dan anders - NMDA). This protects users from higher prices than with natural gas-based heating. The maximum price paid by heat customers is on average no higher than the price paid when heating with a modern, natural gas-fired central heating system.

- **Building and renovation**

Since 2014 all buildings in Flanders for which an urban planning permit is requested or a notification is made must meet certain energy performance standards. These standards are called the EPB requirements. EPB stands for '**Energy Performance and Indoor Climate'**. The size of the minimum share and the quality requirements that apply depends on the date of the building permit application, the nature of the works (new construction or major energy renovation) and the destination (residential building or non-residential building). Decree of the Flemish Government of 19 November 2010; Residential: art.9.1.12/2; Non-residential: art.9.1.12/3.

In addition to the mandatory share of renewable energy, there is also a 'mandatory renewable energy feasibility study' for large buildings. For new buildings with a usable floor area greater than 1000 m², the feasibility of renewable energy technologies has to be investigated. The scope explains which techniques to investigate, depending on the function and size of the building. Decree of the Flemish Government of 19 November 2010; art 9.1.13 and 9.1.14.

With the aim of promoting the SoWhat tool application and the replication it is important to highlight the following aspects of the regulatory framework that influence the waste heat recovery and the use of renewable energy sources in this context:

- waste heat is considered when EPB is calculated, but there is correction factor that makes connecting to a district heating network less attractive for owners of building;
- the waste heat use is not defined as renewable energy source in EPB, the renewable energy share of waste is %. As an exception, the renewable share of waste incineration plats, which fall under 6.1.10 of the Energy Decree, is equal to amount of electricity production from the organic-biological part of residual waste, namely 47.78%.

These aspects make joining a district heating network less attractive than, for example, to install an individual heat pump powered by renewable energy.

- **Energy efficiency in industry**

As the most important policy instrument to improve the energy efficiency of energy-intensive industry in Flanders without undermining its growth opportunities, the Flemish Government on 19 November 2002 signed the benchmarking covenant as an energy policy agreement in accordance with art. 7.7.1. of the Energy Decree.

The target group of the **benchmarking covenant** is the large energy-intensive establishments (annual primary energy consumption of at least 0.5 PJ) and the establishments that fall under the European directive on tradable emission allowances. By entering into the benchmarking covenant, the companies have entered into an obligation to bring and/or maintain the energy efficiency of their process installations at the world's top level by 2012.

By analogy with the benchmarking covenant for the large energy-intensive sites, the audit covenant has been elaborated as an **energy policy agreement for the medium-sized energy-intensive sites**. On 10 June 2005, the Flemish Government gave its final approval to the audit covenant. The aim is to strive for a win-win situation for companies and government. Companies that join the audit covenant voluntarily have an audit carried out to map out their energy saving potential. In addition, they undertake to effectively implement all economically justifiable energy-saving measures, as included in the energy policy agreement.

According to the provisions of the Energy Decision (art. 6.5.1 to art. 6.5.8) and VLAREM II (section 4.9.1.), every energy-intensive company with an annual energy consumption > 0.1 PJ is obligated to have an energy plan. This plan must be updated every four years and is the object of a declaration of conformity. Additionality compared to the current regulations are expressed in the IRR limits for profitable and potentially profitable investments. In the new energy policy agreements, the limits for profitable investments are lower than in the Energy Planning Decree. An IRR limit of 14% is used for the VER companies, the IRR limit is 12.5% for non-VER companies. The limit for a potentially profitable investment is set at an IRR of 10%. The energy plan can also be added to an environmental permit application in case of the obligation to do so. For energy-intensive companies, which have voluntarily signed an energy policy agreement (EBO, EnergieBeleidsOvereenkomsten) for embedding energy efficiency permanently in the Flemish energy-intensive industry (non-ETS companies and ETS companies), an EBO-energy plan, revised by a notified internal or external energy expert and by a notified body (VBBV), replaces the above mentioned conform energy plan. This plan is based on an audit, performed every four years.

Consultations with the sectors of the energy-intensive industry have shown that these limits are considered ambitious but achievable. After all, feasibility is a second important pillar of a voluntary energy policy agreement (covenant). Due to the feasibility of the engagement for potential entrants to the energy policy agreements, it can be stated that the degree of accession to these new energy policy agreements will be high. In this way, these voluntary agreements ensure that the energy-intensive industry of Flanders will remain at the forefront of energy efficiency and that energy efficiency improvements in these industrial sites will be realized faster and more far-reaching than through current legislation (Energy Planning Decree) a result, it is also not necessary to adjust the definition of a profitable investment in the context of the Energy Planning Decree.

New provisions in the energy policy agreements concern the potential studies for qualitative cogeneration and cooling and heating networks, as well as the implementation of energy management measures, the so-called broadening themes. This type of studies could support the kind of investments that are promoted in So What.

An additional driver towards increased energy efficiency could be private and public Energy Services Companies (ESCOs). The development of the Belgian national and regional ESCO and EPC market is driven by the European climate policy and objectives, the 20-20-20 targets. On a more detailed level, the National Energy Efficiency Action Plan (NEAAP) and Regional Energy Efficiency Action Plan (REEAP) in Brussels, Flanders and Wallonia create an implementing framework that allows for more growth in the national and regional ESCO and EPC market and remove barriers for its successful development. Whereas the ESD created a general framework supporting energy services and ESCO development, the EED has set new targets and created initiatives to stimulate an accelerated growth driven by Europe, based on evidence that EPC is a key tool to reach the European climate and energy transition objectives.[4]

- **Non-economic barriers**

  - Lack of financial funding

- Low priority to non-core business
- Lack of trust between the stakeholders
- Different views of the value of the heat
- Lack of knowledge about heating issues
- Lack of knowledge about the amount of excess heat
- Lack of knowledge about business arrangements
- Requirement for a short payback period
- **Political** - Belgian policy is mainly pushing for the investment in solar thermal, heat pumps and CHP. District heating is indirectly pushed for in policies for zero-emissions new buildings. Residual heat and cold is not mentioned in policy and RES targets are relatively moderate.
- **Economic** - Natural gas, and other fossil fuels, are the strongest competitors to waste heat and waste cold in the thermal sector. The lack of existing infrastructure to recover waste heat and cold induces large investments cost and longer payback times which could discourage investors.
- **Social** - The price and availability of energy are the two aspects that Belgians are most concerned about when it comes to energy. Main health issues today are particulate matter and NOx emissions from fossil fuels in urban areas.
- **Technological** - The potential for RES is low, especially in the heating and cooling sector, so waste heat and cold coupled with RES is not such a viable option. However, there is large technical potential for waste heat in Belgium. District heating is in a developing phase.
- **Legal** - Social tariffs and taxes primarily incentivize natural gas as an energy carrier.
- **Environmental** - Environmental concerns mentioned in the heating and cooling sector are mainly
- The **long-term commitment of the end users** to use the heat. The end user companies may feel that they will be too dependent on one supplier. The end users can't guarantee that they are in production in 10 years, or that they will need as much heat in the future.
- **The price of the heat** (CAPEX/OPEX). One main barrier is the competition from natural gas, and the end user's unwillingness to pay for the heat if it is the same price as natural gas.
- When building DHN in Belgium, there are very **few contractors available**, since these contractors also build the gas grid. The prices of constructing the infrastructure can vary a lot depending on when and where the project is planned.
- **DHN is an unknown technology** at the demo site. Umicore is more familiar with the existing steam network, which the company have had for 40-50 years.
- It is not the core business for Umicore, and thereby it is difficult to get capital when **competing with the core business investments**.
- **Lack of regulations and economic incentives**. Natural gas is cheaper. Subsidies will be needed to balance the economy
- **Problem to deploy the pipes**. The deployment requires several regulations (river regulations etc) which are handled by regional authorities. The administration related to processes are considered as barriers. In the existing heat networks in Belgium permission for the use of the public undergrounds has to be granted by the regional government. Because of the big impact that a DHN has tot the public underground it is a difficult and time consuming process to get this permission. In case the private ESCO company will be responsible for the deployment and distance to the administration will thereby be bigger barriers according to several of the demo sites. For the Belgian demo sites the industries consider that the end users may feel too dependent on one heat supplier or that they can´t guarantee that they are

still in production/will have the same heat demand in for example 10 years. Thereby contractual lengths with medium to long term commitments between different actors could be a barrier. Different views of suitable contract lengths are ranked as an important or essential barrier according to the demo sites.

- **Unknown technology/lack of experience.** In countries or demo site regions with no or limited traditions of district heating the lack of experience is highlighted as a main barrier (Spain, Portugal and one in Belgium). The lack of experience relates to the construction phase, but also to operation and maintenance. According to the PESTLE analysis district heating is indirectly pushed for in policies for zero-emissions new building in Belgium. **Not core business, lack of funding for other investments.** Two of the demo sites (Belgium and UK) describes it difficult for the industries (in this case manufacturing and steel) to get capital to issues regarding to energy efficiency when competing with the core business investments. There is a lack of funding, capital and manpower for non-core investments even if there is a good business case. This is a main barrier to develop excess heat collaborations.

Barriers regarding regulations. In the countries or regions with no or limited tradition of building DHN, lack of regulations is mentioned as barriers.. In case the private ESCO company will be responsible for the deployment and the distance to the administration will thereby be bigger.

Requirements for a short payback period for investments is ranked as an essential barrier according to all demo sites.

Difficulties to agree on pricing is ranked as an essential barrier according to all but one of the demo sites.

Lack of knowledge or understanding of each other's systems, processes etc is ranked as essential to all demo sites except for RADET in Romania.

2.1.4 Status overview of the DHC development in Sweden

The following sections gives an overview of the history and development of waste heat and cold recovery in district heating networks in Sweden, and in the two demo site constituting the Swedish Lighthouse cluster in particular. Regulations concerning excess heat recovery as well as district heating statistics are also presented.

History and evolution

The first Swedish district heating system started 1948 in Karlstad[2] and the district heating supplied has increased steadily since the start in the 1950s, see Figure [3].

[2] Werner, Sven, *District heating in Sweden – achievements and challenges*, Cited 2022, Available from: http://hh.diva-portal.org/smash/get/diva2:375359/FULLTEXT01.pdf

[3] Energiföretagen, *Totala fjärrvärmeleveranser per år 1955-2021*, Cited 2022, Available from: https://www.energiforetagen.se/statistik/fjarrvarmestatistik/fjarrvarmeleveranser/

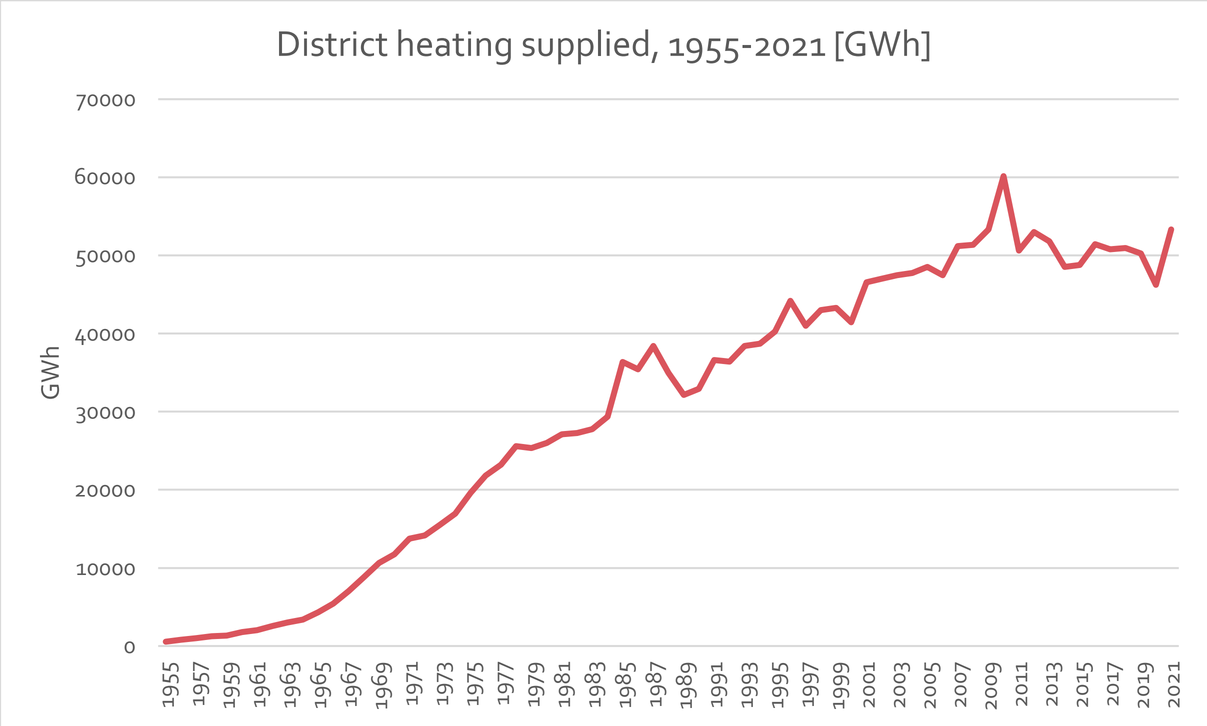


Figure 10 District heating supplied in Sweden between 1955 and 2021

The strong increase in district heating, despite the fact that specific energy demand for buildings have decreased, can be explained by four major policy activities in Sweden: 1) municipal electricity departments started district heatig systems to have heat sinks for future CHPs. (1948-1970); 2) national housing policy programme to trigger the building of one million dwellings in ten years – a majority of these were connected to the district heating systems (1965-1974); 3) national energy policy programme to reduce oil dependency for heating (1980s) and 4) national climate change policy programme to reduce GHG emissions (1990s), including a relatively high carbon dioxide tax[4].

Today the main share of the district heating supplied is used by the residential and commercial sectors, as displayed in Figure 11.

[4] Werner, Sven, *District heating in Sweden – achievements and challenges*, Cited 2022, Available from: http://hh.diva-portal.org/smash/get/diva2:375359/FULLTEXT01.pdf

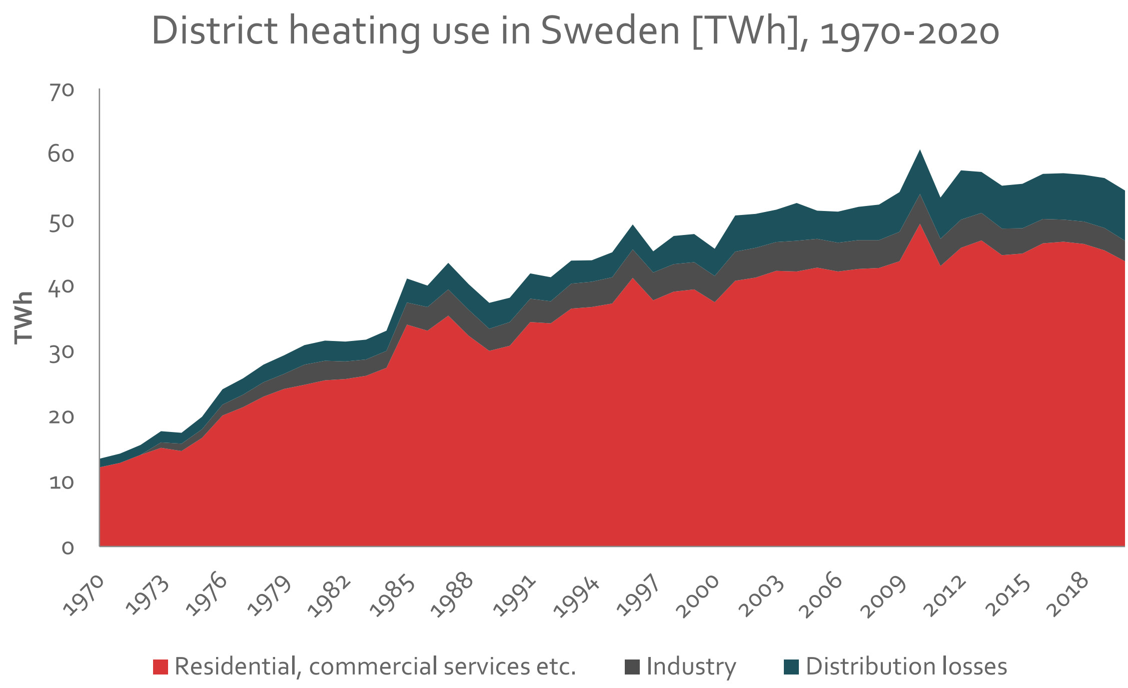


Figure 11 Use of district heating in Sweden from 1970 [5]

Along with the increase in district heating use, the share of waste heat of the total energy supplied for district heating production has increased and is now around 8%, see Figure 12. The all time high for the waste heat share was 12 % in 2004. The first industrial waste heat recovery was implemented in Helsingborg 1974 and industrial waste heat recovery are now in operation in around 70 locations[6]. The main contributors of waste heat in Sweden is the energy intensive industry; pulp and paper, iron and steel, chemical and refinery. As a consequence, the waste heat is delivered at high temperatures[7].

[5] Energimyndigheten, *Energiläget 2022*, Cited 2022, Available from: https://www.energimyndigheten.se/statistik/energilaget/?currentTab=1#mainheading

[6] Werner, Sven, *District heating and cooling in Sweden*, Cited 2022, Available from doi:10.1016/j.energy.2017.03.052

[7] Broberg and Sommarin, *Potential för användning av lågtempererad värme för uppvärmning av växthus – industriell restvärme och värme från returen på fjärrvärme (RISE Rapport :2022:71)*, Cited 2022, Available from: https://www.diva-portal.org/smash/get/diva2:1657610/FULLTEXT01.pdf

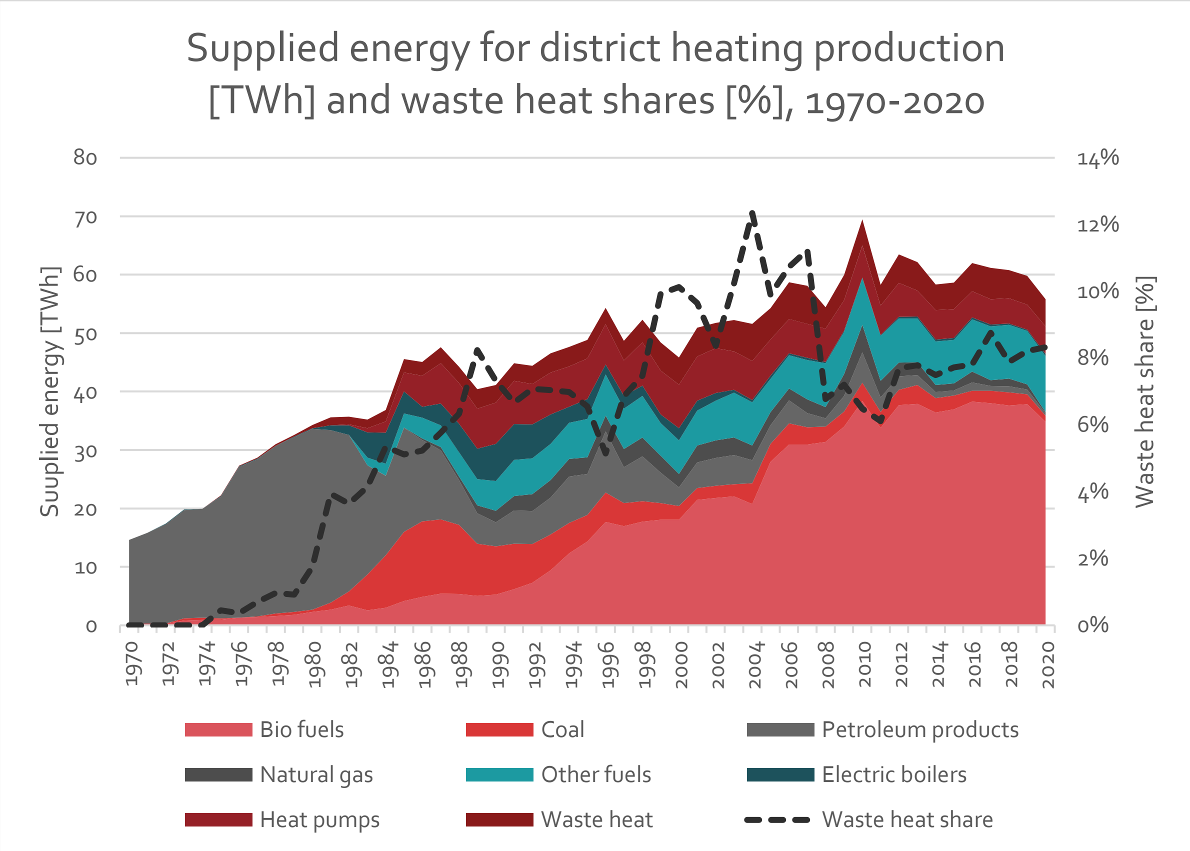


Figure 12 Supplied energy for district heating production and waste heat share since 1970 [8]

The excess heat recovery of the Swedish demo site in Gothenburg, represented by Göteborg Energi (GOTE), was established in the 1980s. Today the main sources of industrial excess heat for the district heating grid of Gothenburg are two refineries: ST1 and Preem (SO WHAT D3.1). The main reason that the two refineries joined the excess heat collaboration was their need to cool away heat from the refinery process. For GOTE the collaboration meant that they could avoid investments in heat boilers and to phase out peak production units that operated winter-time (SO WHAT D3.3).

In the demo site of Varberg the waste heat recovery from the pulp mill Södra Cell Värö (SCV) was started in 2001. Previous to that the excess heat from the pulp mill was cooled off and released to the surroundings, but with a new water purification process the water needed to be cooled of even further and this gave additonal incentives for waste heat recovery collaborations. The collaboration developed over time with investments made by both parties (SO WHAT D3.3). Today, the excess heat from the pulp mill is the main source of heat in the district heating grid of Varberg (SO WHAT D3.1).

In SO WHAT D3.1 the barriers to heat recovery collaborations experienced by the Lighthouse cluster were summarized. The barriers were grouped into two types of barriers: 1) barriers that could detoriate the business case (such as large initial cost for piping and high transactional cost in terms of required time to design contracts) and 2) non-economic barriers (such as barriers to agree on price and quality of the heat, planned revions/stops in excess heat supply, contracutal lenghts). An enabling

[8] Energimyndigheten, *Energiläget 2022*, Cited 2022, Available from: https://www.energimyndigheten.se/statistik/energilaget/?currentTab=1#mainheading

factor for the successful Swedish collaborations was a trust between the collaborating parties, which in turn was enhanced by a close cooperation and transparency. One key to building trust was to increase the understanding of each others technical systems.

In SO WHAT D3.3 the contractual arrangements to overcome the listed barriers were identified. According to GOTE and VEAB the perceived time frame from idea to implementation was 3-4 years, of which at least a year for designing the contractual arrangements. Contractual arrangements included pricing of the excess heat/cold, contractual lengths, excess cold valorisation etc.

Regulation and statics (RES, Fuels, heat recovery technologies…)

There are no specific policy measures towards WH/C recovery, but several different tools guide the development in this direction. The following policy measures are the main tools for the transition, these measures are presented more in detail in SO WHAT D6.3:

- National Energy and Climate Plan (NECP)
- CO2 and energy taxation
- EU Emission Trading System (EU ETS)
- The environmental objectives system: 16 environmental quality objectives
- *Klimatklivet* (the Climate Leap initiative)
- *Industriklivet* (the Industrial Leap initiative)
- Renewable Electricity Certificate (REC)

The general aim of Swedish policy is to be technology neutral and let market-based mechanisms decide which technology that is most suitable and economically viable in order to reduce the emissions. There is thereby no specific support system for WH/C recovery. Although *Klimatklivet* and *Industriklivet* are two support systems where this type of technology can be granted support, depending on the technology.

The regulatory framework related to district heating and cooling in Sweden is presented in SO WHAT D6.2. Waste heat recovery is explicitly mentioned in the law on certain cost-benefit analyses in the energy area (2014:268). The law states that all district heating companies and industries planning for a new plant or a larger upgrade of their system are obliged to carry out a cost-benefit analysis in order to scan the possibilities to receive and/or deliver waste heat. The law is applicable during certain prerequisites; that stakeholders are within a certain radius, that they can deliver temperatures over a certain level and that the plant's installed capacity is over 20 MW[9].

[9] Energimyndigheten, *Lagen om vissa kostnadsnyttoanalyser på energiområdet*, Cited 2022. Available from: https://www.energimyndigheten.se/energieffektivisering/lagar-och-krav/lagen-om-vissa-kostnadsnyttoanalyser-pa-energiomradet/

2.1.5 Status overview of the DHC development in Romania

The development of DH systems Romania has been initiated in the 1950s as part of the National Plans for the development of the National Economy and Industry that was harmonized with the plans for urban development, plans for strategic investments and National Defense Strategies. From the beginning the concept was based on the use of cogeneration technologies in the power utilities and integration of industrial waste heat in the centralized heating systems for urban agglomerations. There are mentioned 4 phases of development of the Energy Sector in Romania until 1990 as 1950 – 1960, 1960 – 1970, 1970 – 1980 and 1980 – 1990. It has been a continuous evolution of the technologies and accumulation of experience but, the management systems were trapped in a centralized, state-owned administration companies. Therefore, the systems have been kept around the breakeven points, with very seldom investments.

In the 1990, there were estimated 315 cities with DH systems and about 2.7 mil. household connected to them but, the problems that were not solved in the previous decades and the long process of the shift from the centralized economy to the market economy opened a very difficult period for the utility companies in Romania.

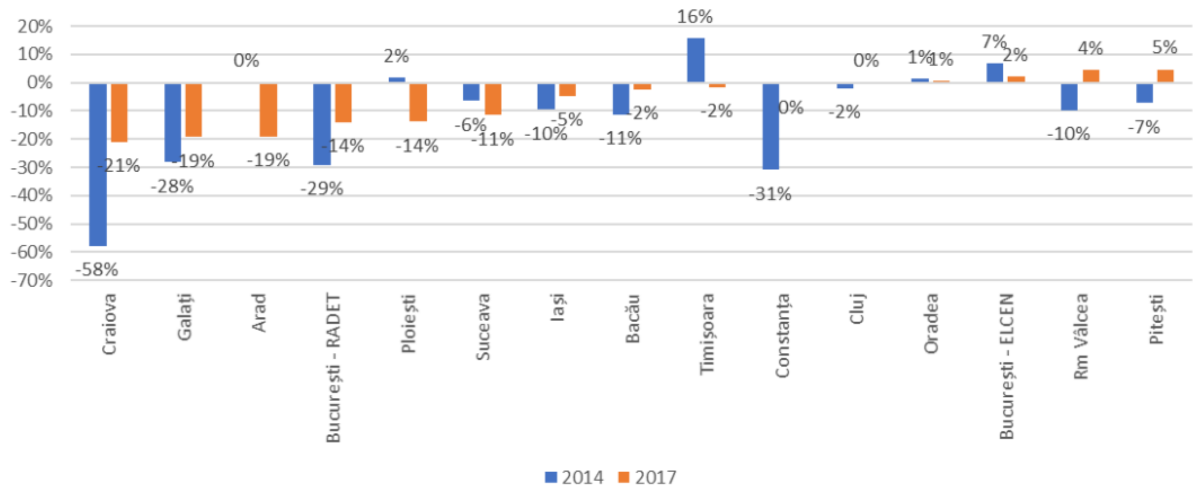


Figure 13. Profit rate evolution of the DH administration companies in Romania

The problems of the utility companies consisted on outdated infrastructures due to the lack of investments so the average efficiencies of the heat sources was is in the range of 50 – 55%, the losses in the transport and distribution networks are estimated in the range of 25 – 40% and the losses at the end-users due to the lack of proper thermal insulation, appropriate metering and individual adjustment of the consumed heat, are in the range of 40%.

From financial point of view, a study supported by the World Bank was estimating that the state subsidies for the DH utility companies between 2013 and 2017 has been of 0.75% of the GDP. In the same study there are presented the evolution of the profit rate of the DH utility companies from the main cities in Romania as may be seen in the figure above[10]

---

[10] file:///H:/2022/Fisiere/Implementing%20Projects/soWHat/Deliverables/D%206.6/FINALTermoficare-Pol-Brief-78.pdf

Therefore, 47 cities have at present DH systems under operation, 15 of them have more than 10,000 end users, 18 have between 1000 and 10,000 connected users and 14 with less than 1000 end-users. According to the current records, 1,095,551 end-users are connected to the DH systems including 10,902 companies, 2,437 public institutions and 1,082,212 households and dwellings.

As reference, in the followings, it is presented the situation of the DH utility administrator from the city of Constanta, the second large city of Romania.

The Constanta cogeneration power plant has been erected between 1960 and 1970 and in 1970 the DH system has been inaugurated in 1970 with the first phase of development covering the city centre.

Figure 14. The DH system of Constanta city

In 1989, the DH system of Constanta had a number of 90,000 connected dwellings and most of the socio-economic institutions of the municipality. At the same time, the DH system was serving most of the important industrial companies.

The total length of the main transport network was in the range of 76 km, transporting hot water (125/70 °C) with diameters between 200 and 1000 mm. The secondary transport and distribution network for heating and domestic hot water was in the length of 225 km with diameters between 15 and 250 mm.

The pick demand of thermal energy of the DH system in winter was of 585 Gccal/h and 75 Gcal/h in summer. Additionally, the Constanta Power Plant was supplying steam of 10 to 16 bar and 250 °C for industrial companies. To cover such a demand, the Constanta Power plant included 2 boilers of 420 t/h (140 bar, 540 °C) and 1 boiler of 525 t/h (157 bar, 540 °C)), 2 condensing steam turbines of 50 MW and one condensing steam turbine of 125/150 MW. The pick demand of thermal energy during the winter was covered by 5 boilers of 100 Gcal/h of pressurized hot water and 2 boilers of 105 t/h of steam (16.5 bar and 250 °C) for industrial users. The boilers were dual fuel as heavy oil or natural gas.

After 1990, due to a mix of factors the number of served end-users, decreased continuously. In 2021 the total thermal energy that was distributed by Termoficare was of 572 000 Gcal. Therefor, taking into account the overall losses, the final price of the thermal energy reached 300 Euro/Gcal.

For protecting the strategic infrastructure of DH, the local authority is subsidizing the price of the thermal energy with 90 Euro/Gcal.

Moreover, the Municipality started a program of major investments in the following infrastructure components:

- Heat source by developing a Feasibility Study for a new gas fired cogeneration Power Plant;
- Primary heat distribution loop connecting the main heat source with the re-heating stations. A first phase of the investment is under implementation with a budget of 50 mil Euros;
- Upgrding of the re-heating stations and the secondary distribution loops.

The aim of such a program is to develop the infrastructure at the state of art in order to reduce the operation costs and to offer a reliable solution for reconnecting the dwellings and other end-users.

3 Waste Heat Recovery into DHNs overview

As explained in the introduction, reducing the heating and cooling sector's emissions is critical to fight against changes in climate and reduce air pollution. And in this regard district heating and cooling systems are one of the most suitable strategies since they allow to increase the energy efficiency versus individual systems. But also, they can scale up the use of renewable energy and take advantage of the recovered waste heat. These two measures will produce the decreasing of the utilisation of fossil fuels in the heating and cooling sector. But the focus of this report is only WH recovery and not the possible integration of renewable energy sources.

In this chapter a literature review of the different aspects and considerations around the use of recovered waste heat in district heating systems will be presented.

3.1 Boundaries and contextualisation

As a starting point it can be considered a possible discussion on what is and what is not waste heat. Or in other words a definition of waste heat definition.

The first possible definition would be the academic definition [5]. Waste heat is the unused heat given to the surrounding environment (in the form of thermal energy) by a heat engine in a thermodynamic process in which it converts heat to useful work. The second law of thermodynamics states that waste heat must be produced when converting a temperature difference into mechanical energy (which is often turned into electrical energy in power plants). Waste heat is inevitable for any heat engine and the amount it produces compared to the amount of input heat are factors that make up its thermal efficiency.

Other possible definition to be considered is the legal definition in the EU policies and directives documents. In this case, since the 2009 EU Directive [6] for the promotion of the use of energy from Renewable Sources did not include a specific definition of waste heat, in the past three possible definitions were considered as indicated in the next table.

Commission	'waste heat or cold' means heat or cold which is generated as by-product in **industrial** or **power generation installations** and which would be dissipated unused in air or water without access to a district heating or cooling system;
Council	'waste heat or cold' means heat or cold which is generated as by-product in **industrial**, **tertiary sector** or **power generation** installations, **except where combined heat and power generation is used**, and which would be dissipated unused in air or water without access to a district heating or cooling system;
European Parliament	'waste heat or cold' means **unavoidable** heat or cold which is generated as by-product in **industrial installations** or power generation installations (**after the use of high-efficiency cogeneration or where cogeneration is not feasible**), or from the **tertiary sector**, and which would be dissipated unused in air or water without access to a district heating or cooling system;

The next remarks can be deducted from the comparison of these three previous definitions:

- Although the three definitions consider the "by-product" concept (unintended but inevitable secondary result), some of the definitions limits the definition of what is WHC based on the way this by-product is recovered.
- The tertiary sector can not be considered a source of waste heat or cold in the Commission definition.
- Council definition excludes the possibility that waste heat could be directed to CHP. This last issue, clearly negatively affects the Waste-to-Energy and the Cogeneration sectors.

Finally, the **11th of December of 2018, the new version of the Renewable Energy Directive (RED II)** [7] included in its article 2 (Definition 9) the next definition of waste heat and cold:

'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;*

It is important to remark the next comments [8] about this Recast RED definition:

This WH definition does not depend on the fuel mix of the source, whether biomass, renewable electricity or fossil fuels.

Only unavoidable losses are counted as waste heat. An unavoidable waste stream cannot be reduced through energy efficiency measures or recovered and used inside the same facility. It can only be used by sending it off site or expanding the facility to include new processes. Before considering off-site use, the technical and economic feasibility of applying energy efficiency options and on-site use has to be analysed, and all "reasonable" efficiency measures must be implemented first. In the longer term therefore, advances in Best Available Technology (affecting the definition of what is "reasonably" unavoidable) will affect the availability of waste heat for sale.

Waste heat and cold must be a by-product, i.e. not the intended purpose of the system but an inevitable result:

a) Importantly, the originally designed heat production from a heat or cogeneration plant cannot be considered waste heat, though unavoidable waste heat from such a plant can. Also, only the heat from the condenser can be counted as waste heat; the heat stream before the condenser does not qualify as waste heat. Note that this guidance applies even where cogeneration has been installed in order to use waste heat from another process.

b) Waste heat from a metro system can be considered a by-product of transport activity; waste heat from a mining operation can be considered a by-product of mining activity. However, waste heat from the mine water left over in a disused mine would not be considered waste heat (because the activity in question has ceased) but could be considered a kind of ambient heat instead. Geothermal energy that takes advantage of such infrastructure should also be accounted for separately.

c) Heat from wastewater can be accounted for as waste heat as long as it is a by-product of the treatment activity. However, heat from sewage is considered ambient heat and therefore renewable but not waste heat. It would not be feasible to account separately for the share of sewage heat that is a by-product of industry.

Without a district heating or cooling network, waste heat would be dissipated. While end uses (or sinks) are not specified, the definition implies that only DHC networks of one kind or another are recognised under the recast RED. According to Article 2(19) of the recast RED, "district heating" or "district cooling" means the distribution of thermal energy in the form of steam, hot water or chilled liquids, from central or decentralised sources of production through a network to multiple buildings or sites, for the use of space or process heating or cooling.

a) The consumption must be off site, i.e. by a different economic entity. For example, using heat from a production facility for an office building belonging to the same company would be internal recovery rather than waste heat.

b) Waste heat must be sold. There are situations where waste heat is provided free of charge, for example during summer months. Waste heat, or any other form of energy, provided free of charge is not accounted for in energy statistics however.

c) Waste heat must go to a heat network of some kind, i.e. more than one customer and more than one building or site. Supply of heat to one building only is excluded from DHC and therefore from the definition of waste heat under the recast RED. Situations where only one customer is connected should not be reported either. In other words, "closed" industrial networks are excluded.

As an example, the next figure [4] shows an example of the heat flows in a cogeneration plant, indicating (in yellow) how only the heat from the condenser can be counted as waste heat.

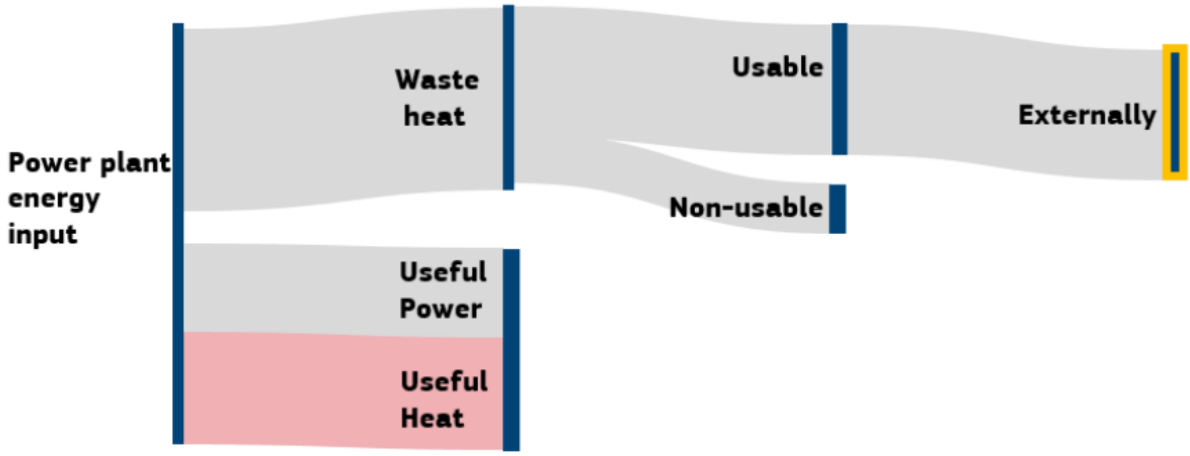


Figure 15: Cogeneration heat flows. Recast RED waste heat definition. [8]

It is important to remark that the exclusion of recovered heat from heat or cogeneration plants or any use case where "closed" industrial networks are involved is only referred to being "considered" as waste heat. It does not mean at all, that these types of thermal energy transfers (with or without associated economic trading) are forbidden. There are several of successful study cases where the economic and environmental benefits are clearly evaluated, but the impact of this cases must not be considered under the WHR statistics but under other statistics like geothermal, system or retrofitting or any other classification.

From the reporting perspective, the Eurostat DHC template (row 9) covers heat recovery units recovering heat from chemical and other processes (e.g. other industrial processes, manufacturing, data centres, metro systems, or any other process). Only units that recover heat in order to use it for district heating, and if this surplus heat would otherwise have been dissipated unused into the air or water, are to be reported there. Heat produced by cogeneration plants is not to be reported.

So, since now the current EU definition of waste heat and cold includes also the tertiary sector, it can be established the next classification of waste heat: [9]

Conventional waste heat sources

In this category is included the power plants and industrial processes, especially the energy intensive industries (cement, ceramics, chemicals, minerals and ores, non-ferrous metals, pulp and paper, refining, steel and metal plants). In these industrial processes the possible waste heat is usually readily available, it is clearly identified and the temperature levels in the recovered streams are much higher than the temperature levels required in DH applications. Indeed. in some cases, temperature levels are high enough to consider the simultaneous production of power and heat with the original waste heat stream.

Unconventional waste heat sources

This second category typically includes rejected heat from cooling systems in, e.g., data centers, buildings, food production, and supermarkets. It also covers rejected heat from metro ventilation systems, sewage channels and wastewater treatment facilities. Some of these heat sources are especially relevant to DH, as they are located close to urban infrastructures. For these types of sources, the waste heat potential is not so easy to identify and often temperature levels are lower.

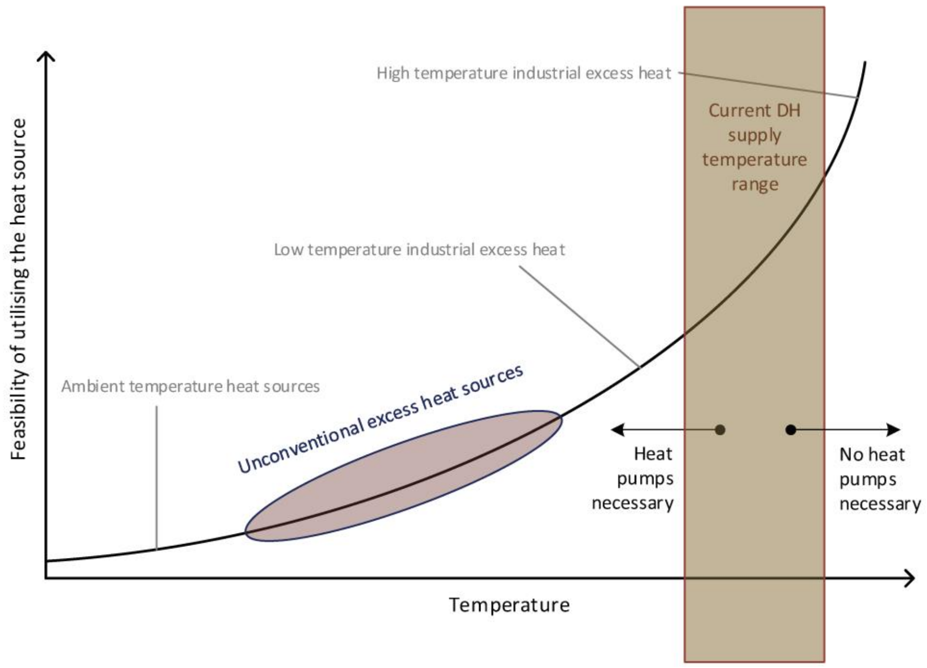


Figure 16: Principal diagram illustrating the increased feasibility of heat sources with increased temperatures [10]

The heat sources with temperatures similar or higher to that of the DH system can be used directly, while other heat sources need to be boosted by, e.g., electrical heat pumps. The closer the heat sources are to the required temperature in the DH systems, the lower the energy needed to boost the temperature. Figure X [6] illustrates the principal concept of using excess heat sources in DH systems. However, with the move towards the 4th Gen DH concept, lower temperature heat sources become relevant as well. These sources typically need boosting from heat pumps to achieve the relevant temperature level. The closer the source temperature is to the temperature required by the DH system, the better the seasonal coefficient of performance (SCOP).

The utilisation of heat pumps allows to recover heat from a much broader range of heat sources whose temperatures are typically below 70ºC. In this case, even though a HP is necessary, the employment of waste heat as a source brings the benefit of lower electricity consumption and lower associated emissions that if the air were used as heat source.

Wastewater treatment facilities being universal, data centers becoming extremely popular as digitalization develops, as well as metro and service sectors cooling and ventilation systems is boosting the potential for unconventional waste heat sources associated to 4th Gen DHN. In terms of variability, data centres and wastewater are notable in being largely constant on both daily and annual scales. Other buildings and infrastructure vary by time of day and season to a much greater degree. However, it is important to remind that SO WHAT project is focused on industrial waste heat sources (Conventional waste heat)

Most of this discussion focuses on waste heat because it is much more common than waste cold. **Waste cold** would be a stream that is colder than ambient temperature and that needs to be dissipated or heated. The most significant example is waste cold recovered from gasification of Liquefied Natural Gas (LNG). There is also waste cold related to nitrogen in chemical industries. And a more common example that emits waste cold is heat pumps for heating. However, when it comes to heat pumps, confusion between ambient heat and renewable cooling needs to be avoided.

It is important to remark that the recast RED says that waste heat can be counted towards the increase in the share of renewable energy in the heating and cooling sector, and the renewable share of DHC, but that only waste heat that could not reasonably have been used internally is eligible. Hence, the analysis to identify waste heat has to be done at site level.

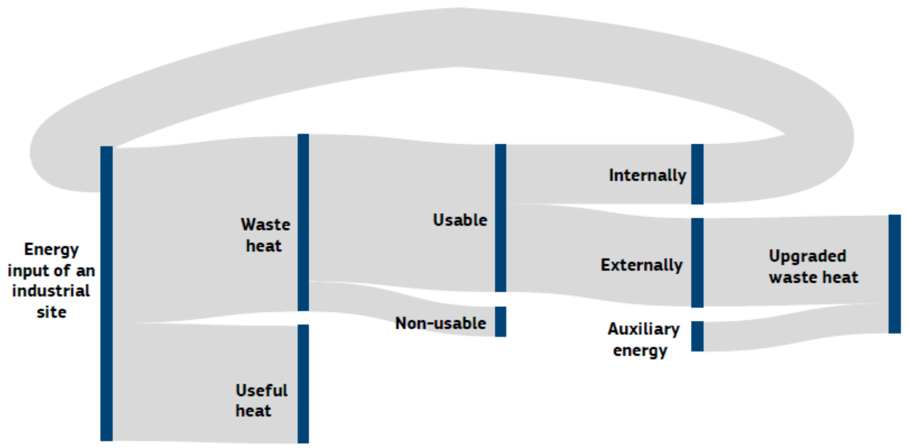


Figure 17: Heat flows at site level [8]

The first step in accounting for waste heat is to identify the internally and externally usable heat. Internally usable heat can be used on site to improve energy efficiency. Externally usable heat can be used off site – either directly, after upgrading using a heat pump (Figure 3), or for cooling using an absorption chiller.

An alternative way of expressing this on-site and off-site application of the heat recovery can be expressed in the next table where 3 possible cases have been considered and how each case is seen by the industrial companies.

Application	Nature of the process

Re-using heat in the industrial process	The transfer of thermal energy that would otherwise be rejected (source) to elsewhere in the same process where the heat is needed (a 'heat sink'). This reduces the overall thermal energy demand of the site. This appears to be equated with energy efficiency
Re-using heat elsewhere on site	Waste heat can be used for space heating or to generate electricity. In this form of heat recovery the overall amount of thermal energy inputted is not reduced, but there is potential to use the generated electricity elsewhere within the process or site – which would reduce a company's overall energy needs. This is seen as similar to energy efficiency.
Exporting heat offsite	Waste heat from industrial processes can be transferred offsite for use in other industrial processes by nearby businesses or within heat networks. Companies may be paid for this heat but their energy needs are not reduced. This is not seen as an energy efficiency measure

Only the third case is suitable for the integration of WH into DHNs, although from the RED regulations and also from the factory owner's perspective, the third case must only be considered after having identified and implemented the possible first and second cases (or checked and discarded due to technical restrictions)

3.2 Challenges and possible solutions to Waste Heat Recovery into DHNs

There are barriers to utilisation of waste heat and cold on both the supply and demand sides. These include several issues with contracts and any other economic aspects. Some technical barriers like temperature requirements and timing. And also, other barriers will also be important to consider in relationship with the recast RED and EED.

As part of the Urban Agenda Energy Transition Partnership, the Austrian Institute of Technology (AIT), with the support of EH&P and stakeholders (waste heat sources, cities, researchers), identified barriers and best practices to boost the off-site use of waste heat and cold. [9] The largest share of this section is based on this AIT paper, although additional contributions from other sources will also be included.

3.2.1 General challenges

3.2.1.1 Identification and quantification of waste heat sources

The first requisite to implement and external waste heat recovery is obviously the existence of such a source. However, the correct identification and later quantification can be a challenge due to several reasons:

- Often very little data is available for unconventional sources or smaller industries, or it can be directly confidential information like the data centres location.
- The location of the waste heat source (industrial facility) doesn't match that of the company (headquarters offices location).
- Businesses may not recognise that they are emitting a valuable heat source that could be used in a heat network.
- The possible correlation factors used for waste heat quantification have an inherent wide spread and thus little accuracy

- Concrete measurements (monitoring campaigns) of waste heat quality, i.e. volumes and temperatures, are often not available. Or when available, this data could reveal information on the production processes to competitors and thus are sometimes kept confidential.

Regarding the possible solutions and good practices to address this challenge they can be summarized in three types of initiatives: European directives, national databases creation and maps and methodologies fostered by European research projects.

- Comprehensive Assessment of the potential for Efficient Heating and Cooling. The obligations that article 14 of Directive 2012/27/EU on Energy Efficiency, in its Annex VIII, establishes for the Member States to carry out an evaluation of the potential use of heating systems and efficient refrigeration, in accordance with Delegated Regulation 2019/826. In the event that this evaluation determines the existence of potential, whose advantages exceed its costs, the States must adopt the necessary measures to carry out efficient heating and cooling infrastructures using residual heat and energy from renewable sources.
- In the last years several national and regional studies have been done in order to create databases for waste heat potential. There are several examples in Germany (District heating usage of industrial waste heat (NENIA) from IFEU), France (Industrial waste heat – ADEME – 2017) or Spain (Heatmap of Spain from IDEA).
- Finally it can be found 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. Among others it can cited: Heat Roadmap Europe project, RepowerMap project, Memphis project, Hotcity project. Tasio project and Reuseheat project.

3.2.1.2 Low interest and know-how of the "waste-heat owner" company for supplying Waste Heat to the District Heating Network

Some exceptions are always possible, but generally the possible utilisation and trading of the waste heat is neither the core business activity or competence of the "waste-heat owner". Human resources, as well as available capital, are concentrated on primary activities This situation can produce the next challenges:

- The benefits from selling waste heat are not considered worth enough to compensate the possible costs. Especially if the company lacks of skilled profiles in energy recovery and therefore additional external personnel costs are foreseen.
- The extraction of waste heat might change the characteristics of the related processes or just be difficult to capture due to the design of the asset. The owner might consider it a possible risk of negatively affecting the core asset of the company. This situation is more likely to happen when the company produces high-price products where the energy costs represent a minor share of the total production costs.

Two possible solutions and good practices have been identified:

- Use of WHR as a sustainability reputation improver. The owner of the waste heat could claim the CO2 savings of the implemented recovery as efficiency measure in the local community sustainability. The brand and their products would be better considered by those possible consumers highly concerned about the environmental impact of their purchases.

- Better communication on waste heat recovery benefits. This is global good practices for policy makers. The possible benefits from waste heat recovery should be better communicated to potential waste heat owners: improve energy efficiency, save CO_2, boost competitiveness (energy efficiency), foster investments in industrial sector (industrial strategy), boost sustainability (circular economy, Sustainable Development Goals)

3.2.2 Technical challenges

Regarding the technical challenges, three possible mismatches have been identified (in time, in place and in quality). It must be said that in general, technical challenges can always be solved, but in turn these solutions will generate additional economic challenges. When possible, references of these new economic costs will be included.

3.2.2.1 Temporal mismatch

Temporal mismatches reduce the amount of useable, recoverable heat, and thus have a negative effect on the feasibility of heat recovery projects. Two possible aspects to be considered:

- Concern about the hourly, daily or seasonal mismatch between the heat demand in the DHN and the waste heat availability. Regarding the hourly/daily aspect, the heat demand changes on a hourly basis depending on the citizens life style. Additionally, weekends, school holidays and other calendar aspects might affect additionally the heat demand curves. Other aspect to be considered is the possible instabilities of the WH supply (due to quick variations in the production circumstances) could negatively affect the control of the district heating networks.
- There also can be considered a possible Summer supply competition between waste heat and other renewable energy sources (like geothermal energy or solar thermal energy but not biomass) as well as waste incineration or waste heat sources. The next figure shows the seasonal mismatch and summer competition between different heat sources. In the winter season, the DHN heat demand is higher and all the heat sources are used, including fossil fuels (economic and environmental cost)

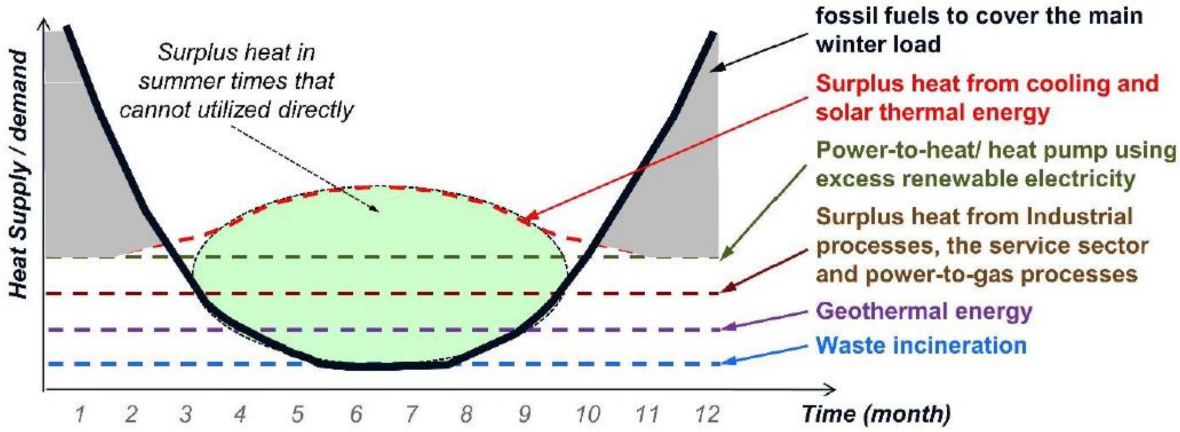


Figure 18: Temporal mismatch and summer competition between the different heat sources in DHN [9]

Three possible solutions are considered to address this challenge in the seasonal aspect: the implementation of district cooling with thermal driven chillers, the use of seasonal storage and finally the consideration of heat to power systems.

Regarding the case of hourly mismatch, generally all the district heating systems are equipped with some kind of minimum thermal storage. Usually making use of water as storing fluid, due to its large heat capacity and low price. In some cases, the size of these storages is limited to a few hundreds of cubic meters. In this case, the storage operates mostly as inertial tank system allowing to absorb and damp the load peaks in the heat demand. As long as the size of these water tanks is increased, its functionality becomes dual: inertial and also heat supplying during these hours when intermittent heat sources are unavailable.

- **District cooling and thermal driven chillers to increase summer heat demand**

For handling the summer surplus heat, sorption chillers (adsorption or absorption chillers) are a smart option to recovery and valorisation of the excess heat that will not be required to cover the reduced summer heat demand.

Mechanical refrigeration cycles are generally based on the use of a refrigerant fluid under two levels of pressure in which latent heat exchanges occur, and therefore at a constant temperature, allowing low temperatures to be obtained while at the same time it is necessary to dissipate a quantity of heat in the environment.

Sorbents are materials that have the ability to attract and hold other gases or liquids. Sorption chillers can be defined as those equipments that through a sorption process (gas on liquid absorption or gas on solid adsorption) are able to establish two levels of pressure through which the refrigerant can condense and evaporate and therefore produce the required heat rejection.

Figure 19 presents the working principle of sorption cooling (SoCo). A SoCo uses waste heat at low/medium temperature typically in the range 65-200°C and a low temperature load (10°C) and it transforms them into a thermal low energy stream. Thus, SoCo valorise waste heat by upgrading a secondary low temperature thermal energy stream which might be used for cooling purposes and the total energy flow to intermedium temperature and thus making it less utilizable. This intermediate temperature outlet usually requires a cooling tower to be dissipated into the ambient.

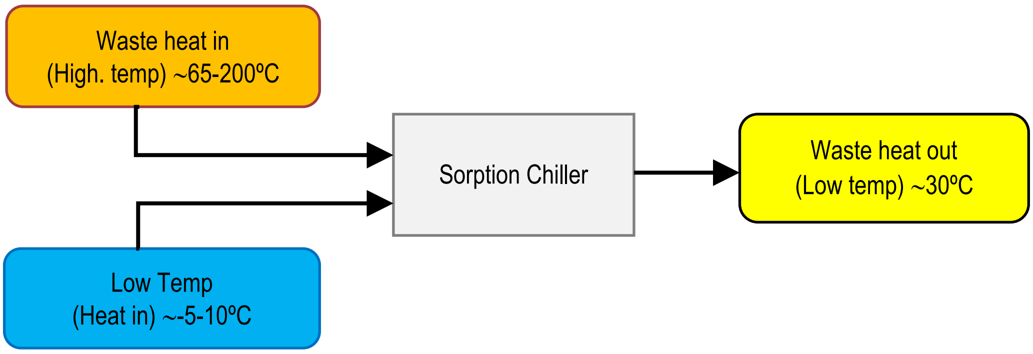


Figure 19: Input and output streams of a sorption chiller [7].

The COP parameter is calculated as the ratio of the cold energy produced by the thermal energy introduced into the chiller from waste heat sources. For waste heat in temperatures around 80°C, the COP ranges from 0.5 to 0.7 for the most common types, also known as simple effect chillers. There are versions (double and triple effect) prepared to operate with higher temperature values between 100 and 200°C and capable to provide COP values between 1.2 and 1.4 [12]

Since there is usually a surplus of heat from various sources in summer and simultaneously the cooling demand is logically increased during the summer season, it is a good match the use of district cooling and sorption chillers to take advantage of the non-used waste heat.

- **Use of functional seasonal storages**

Using seasonal Thermal Energy Storage, (TES) it could be possible to store the surplus heat in summer to be later used for transition or winter times. It could be applied to excess summer waste heat sources and also to solar thermal energy surplus that once stored could replace, at least partially, the fossil fuels required to cover the main winter load.

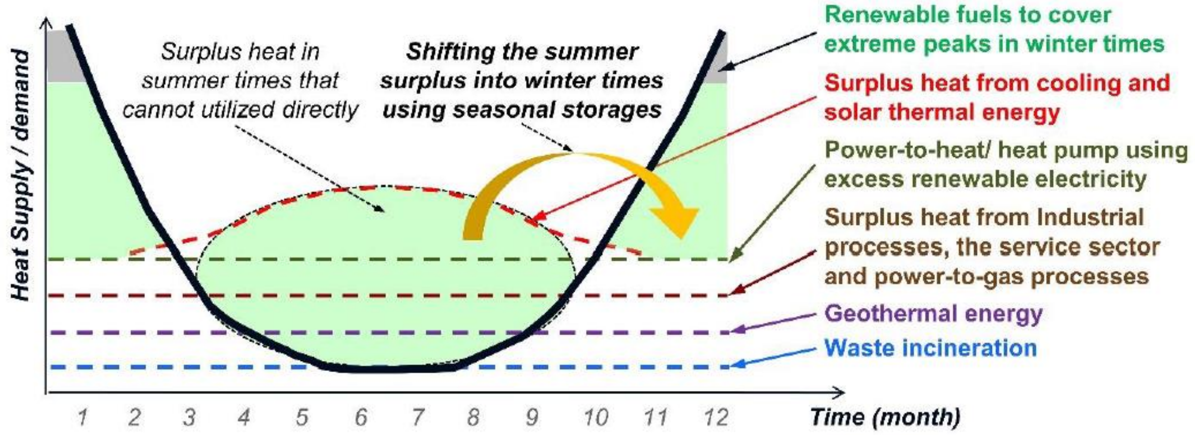


Figure 20: Shifting the summer surplus into winter times using seasonal storages [9]

The previous figure 20, shows the modification of the also previous figure Z (Temporal mismatch and summer competition between the different heat sources in DHN), where thanks to the TES now it could be possible to remove fossil fuels to cover the main winter load. As can be seen, renewable fuels are still considered for the maximum values of the heat demand.

In addition to tank TES typology, large-scale or seasonal storage include Aquifer, Borehole, Pit and Mine TES concepts. In Aquifer Thermal Energy Storage (ATES) heat is stored in an underground water reservoir at temperatures ranging from 20 to 80ºC. In the Borehole Thermal Energy Storage (BTES) heat (up to 90ºC) is stored in the upper 20 to 200 metres layer of the ground. In the Pit Thermal Energy Storage (PTES) large excavated basins with insulated lids store hot water (up to 90ºC). And finally, in the Mine Thermal Energy Storage (MTES), water in abandoned or flooded coal mines is used as a source of low temperature heat. The next figure X [13] shows the concept of the possible Seasonal thermal storage systems.

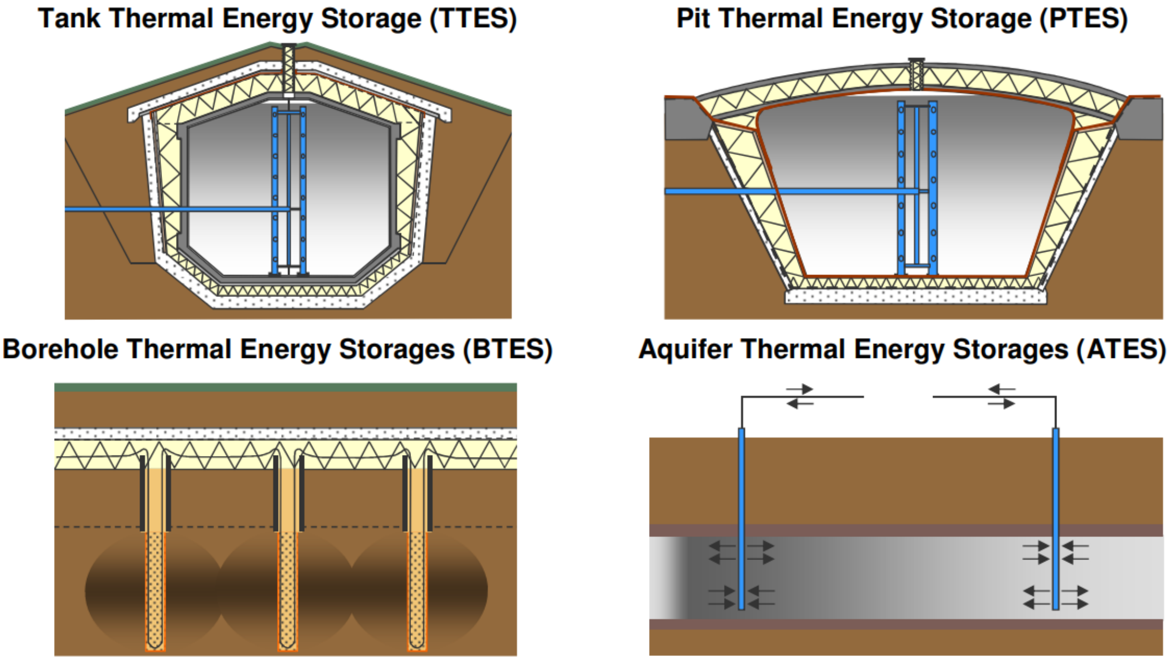


Figure 21: Construction concepts for large-scale or seasonal thermal energy storages [13]

It is important to remark that dislike the hourly/daily TES scenario, where it is possible to consider the use of water tanks specifically built for TES purposes. In the seasonal TES case, this technology presents a clear economic larger cost than other technologies like Pit thermal storage.

Construction cost of the four storage concepts vary significantly. However, there is not one optimum storage concept for all applications and not every storage concept can be built everywhere. The economy of a storage system depends not only on the storage costs, but also on the thermal performance of the storage and the connected system. Therefore, each system has to be examined separately. To determine the economy of a storage, the investment, maintenance and operational costs of the storage have to be related to its thermal performance.

Finally, the next figure [13] presents the cost data of built pilot and demonstration plants. The listed storages are high temperature heat storages (working temperatures up to 95 °C) and are mostly integrated into central solar heating plants with seasonal storage (CSHPSS).

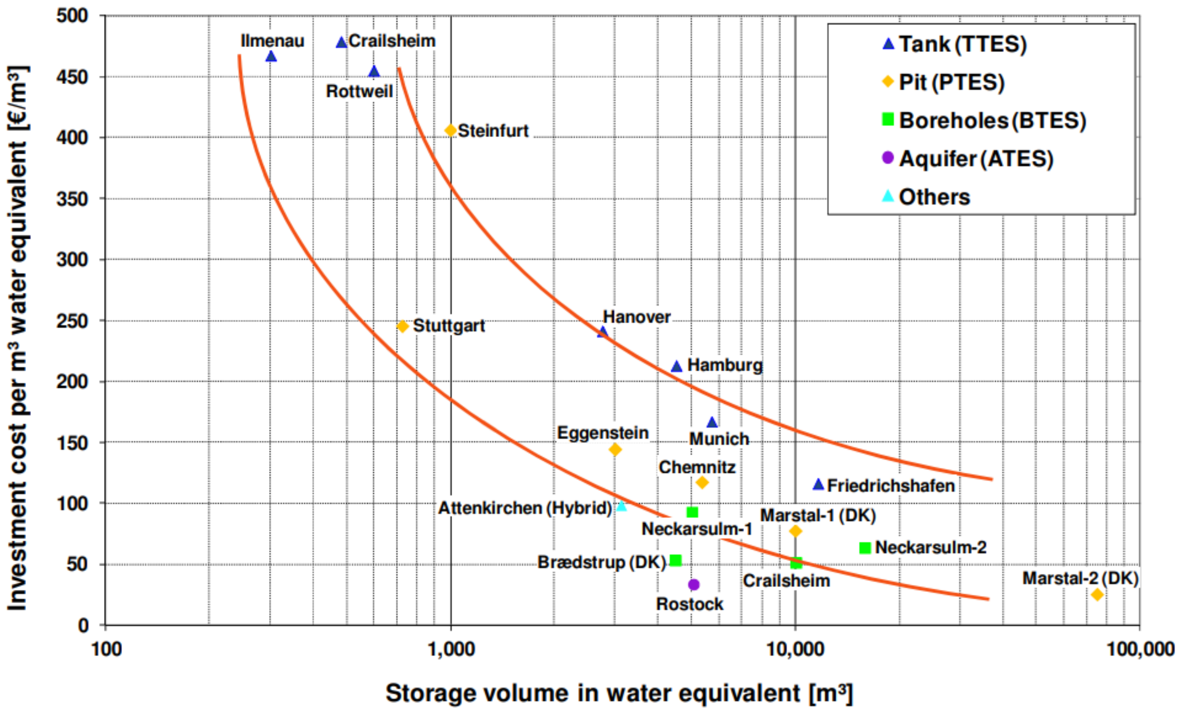


Figure 22: Specific storage costs of demonstration plants (cost figures without VAT, storages without country code are located in Germany). (Source: [13])

The general rule is that cost decrease with an increasing storage volume. Appropriate volumes for seasonal heat storage are larger than 2,000 m³ water equivalent. In this case the investment costs vary between 40 and 250 €/m³. Generally, TTES are the most expensive ones. On the other hand, they have some advantages concerning the thermodynamically behaviour and they can be built almost everywhere. The lowest costs can be reached with ATES and BTES. However, they often need additional equipment for operation like buffer storages or water treatment and they have the highest requirements on the local ground conditions.

As the reader will have already deducted, the seasonal TES is based on the solar District Heating development, but the concept and technologies are directly applicable to waste heat recovery.

- **Use of Heat to Power systems**

Finally, as other alternative use for the summer excess waste heat that could not be transferred to the DHN, it could be considered the use of systems to convert this unused heat into electricity.

The recovery of waste heat for power is a largely untapped type of combined heat and power (CHP), which is the use of a single fuel source to generate both thermal energy and electricity. It is important to remark that CHP and Waste Heat to Power are not strictly the same concept. CHP generally consists of a prime mover, a generator, a heat recovery system, and electrical interconnection. The most common CHP configuration is known as a topping cycle, where fuel is first used in a heat engine to generate power, and the waste heat from the power generation equipment is then recovered to provide useful thermal energy. Waste heat streams can be used to generate power in what is called bottoming cycle CHP. In this configuration, fuel is first used to provide thermal energy, such as using fuel to power a furnace, and the waste heat from that process is then used to generate power. The key advantage of WHP systems is that they utilize heat from existing thermal processes, which would otherwise be wasted, to produce electricity or mechanical power, as opposed to directly consuming additional fuel for this purpose.

The efficiency of generating power from waste heat recovery is heavily dependent on the temperature of the waste heat source. In general, economically feasible power generation from waste heat has been limited primarily to medium- to high-temperature waste heat sources (i.e., greater than 2500 °C). Emerging technologies, such as organic Rankine cycles (ORCs), are beginning to lower this limit, and further advances in alternative power cycles will enable economic feasibility of generation at even lower temperatures over time.

From the DHN perspective, the use of Heat to Power systems must be considered as the last measure to be considered if the first solutions (district cooling and TES) does not enable the possible implementation of a waste heat recovery from an industrial source to be integrated into a DHN. Additionally, only high temperature waste heat sources will present enough economic feasibility for installing waste heat to power solutions.

3.2.2.2 Location mismatch

There are several causes that can produce that the source of waste heat and the end user of the recovered heat do not find themselves closely located to each other:

- District Heating networks does not necessarily extend to the industrial areas since they could be originally designed to serve the residential and tertiary buildings through specific DH boilers
- The existing network has limited capacity for taking up and distributing the waste heat.
- Large-scale industries, which usually are the best waste heat producers (in volume and temperature), are usually located outside of the city due to air pollution considerations
- Larger industrial areas have widely distributed waste heat sources.

All these previous situations usually happen when heating (and cooling) have not traditionally been an object of governance and integral planning. Energy policies are most often found in sectorial policies focussing on electricity and gas on the supply side and buildings efficiency on the demand side.

A significant difference between heat planning and other types of energy planning is the critical importance of the location of the demand and supply. In particular for DHC planners, this knowledge is important to estimate the size of the networks and installed capacities. For investors, as district energy grids are capital intensive investments, it is important to know the potential market size, the supply quantities and potential customers.

In any case, the question to solve is What happens if a long heat transport is required?

Although it is always preferable that owner of the waste heat and the DH are as much close as possible, it is possible to find several examples [14] of long networks. In Helsinki, the Vuosaari power plant is connected to the central city area, by an approximately 30 km long tunnel, which is the longest continuous district heating tunnel in Europe. In Denmark the distance from the CHP to the city centre of Aarhus is 20 km and the length from the CHP to the other end is around 45 km. The total length of the transmission network without considering distribution including a power station in one end, a waste incinerator along the line, and decentralised peak boilers is 130 km. The longest bulk heat transmission distance in Europe is found in Czech Republic, Prague. It is the line from the

Melnik power station to the centre of Prague, whose length is 67 km for a direct distance of 32 km. This transmission pipe is for a large part above ground surface. In Switzerland, a nuclear power plant in Beznau, supplies 81 MW of heat through a 31 km main pipeline to various surrounding cities.

In principle, two types of heat transport networks can be distinguished:

- Single supplier and single consumer network. Since transport pipes requires high investment volumes, this type of one-to-one arrangements are usually possible to long term contracts, limited parties involved and large volumes of heat transferred.
- Multiple suppliers and multiple consumers. In this case, there is a lower risk of stranded investments due to the presence of several heat suppliers and heat demanders. Usually several existing DHNs extend their grids and interconnect between each other allowing to connect to more waste heat sources.

In any case, one-to-one or several-to-several cases, the general rule is that the distance over which heat can be transmitted cost-effectively depends on the amount of energy to be delivered. In other words, the only way to transfer heat to long distances at a reasonable cost is to transfer a big amount of heat. This is indeed what happens also with the transmission of electricity. The main long national distribution lines are high voltage and high capacity lines.

The next figure [15] represents how the heat transmission cost per unit changes with distance and total value of annual energy. For this calculation the cost of transmission includes the construction cost and the cost of pumping. Construction costs for district heating pipes have been taken from 2017 studies and amortised at 30 years with an interest rate of 5%. Pumping cost have been calculated assuming an electricity price of USD 11/MWh. Furthermore, it has been assumed that the energy transported through the pipeline varies sinusoidally through the year.

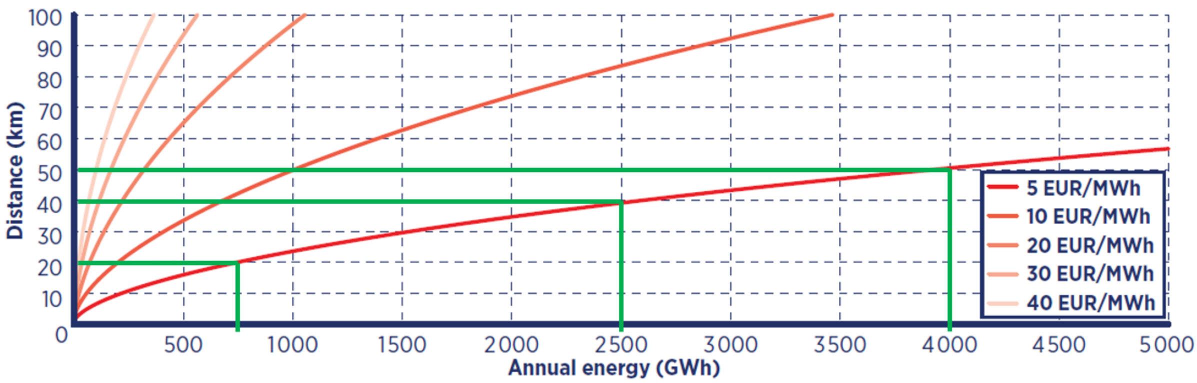


Figure 23: Cost of heat transmission versus distance and annual energy values

As can be seen in the figure green lines, it is considered that transporting annually 2500 GWh to a distance of 40 Km will mean a transmission cost of 5 EUR/MWh. However, to transmit with the same cost 10 km more (up to 50 Km) with the same unit cost, it will be required to annually deliver 4000 GWh. Alternatively reducing the distance in half from 40 Km to 20 Km, allows to reduce the required annual energy from 2500 GWh to 750 GWh (70% reduction).

3.2.2.3 Quality mismatch

The most common quality mismatch is due to the insufficient temperature levels of many waste heat sources compared with the district heating network temperature levels. This issue makes not possible to directly inject into the DHN the recovered heat. The higher the DHN temperature level, the more likely this undesired situation arises. Additionally, the lower temperature level of the waste heat source (typically unconventional waste heat), the more likely to be below the DHN operation temperatures.

There are going to be considered three possible solutions for this challenge:

- Development of low and ultra-low temperature networks

This solution if focused on the development of new district heating networks with lower values of temperature operation in order to be able to directly use of the possible waste heat sources available in the surroundings. This concept has been defined as the "4th generation of DHC networks" and they are designed to work at lower temperatures and enable a more cost-effective transition away from burning fossil fuels toward heat supplied from local renewable and secondary heat sources, such as from waste heat or heat transfer from groundwater.

The first generation of district heating from the 1880s was based on heat distribution by steam. The second generation from the 1930s was based on pressurised hot water with temperatures above 100°C. The third generation from the 1970s was also based on hot water, but with temperatures below 100°C and usually incorporated prefabricated parts in construction. Many suffered from poor temperature control systems. The fourth generation is based on a lower temperature water distribution at around 65°C to limit installation costs and heat losses to the ground, together with a higher contribution from renewable energy and waste heat in order to limit carbon emissions and reduce air pollution.

The clear trend for district heating systems is to move to much lower distribution temperatures and distributed heat transfer instead of combustion.

The logical conclusion is to move toward distributing water circuits at near ambient ground temperature and to use heat pumps in each building to extract heat from the network if the building needs heating – and to reject heat to the network when a building needs cooling: 5th generation district heat networks.

These 5th Gen district heating networks allow for provision of efficient heating and cooling in city centres without emitting any CO_2, and without contributing to urban air pollution. They operate with "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.

It also allows for the collection and reuse of waste heat at any temperature above ambient ground temperature. So clearly focused on unconventional waste heat sources such as data centers

- Efforts for reducing the system temperatures in existing networks

The previously described 4th and 5th Generation DHC are usually designed from scratch with this low (or ultra-low) characteristic. However, the existing DH networks usually have relatively high system temperatures (supply temperatures ranging from 65°C to 120°C, and return temperatures between 50°C and 60°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. Additionally, the temperature reduction would allow a better integration of other alternative and renewable heat sources like solar thermal and geothermal energy. Also, lowering the operation temperatures also reduces the thermal losses in the distribution grids.

So, from a theorical point of view reducing the temperature levels offers multiple advantages. However, there are several reasons why in real life (in real existing DHNs) the considered temperature reduction will not be feasible. The first limitation can appear in the customer of the DHN. The supply temperature must be according to the specifications of the building heating systems. For example, if the apartments or dwellings are using radiators as heating system, reducing the supply temperature might prevent the right operation of the radiators and therefore cause insufficient heating comfort to the building inhabitants. Additionally, there is a minimum temperature level required for the domestic hot water preparation.

The other possible problem could happen with the thermal power to be transferred. If the district heating distribution network is operating at near its maximum capacity, it will not be possible to reduce the temperature levels even if the end users are prepared for operating with these reduced values. The reason is the pumping limitation in the grid. Reducing the temperature levels, for instance in the primary network, will require to increase the flow values. And if distribution pumps are already operating at its maximum speed, or if the system uses fixed speed pumps, it will not be possible.

- Use of new and alternative heat pump technologies

The classical solution to solve the temperature mismatch problem is to use electrically driven (vapor compression) heat pumps to raise the waste heat temperature level to the higher levels required by the district heating.

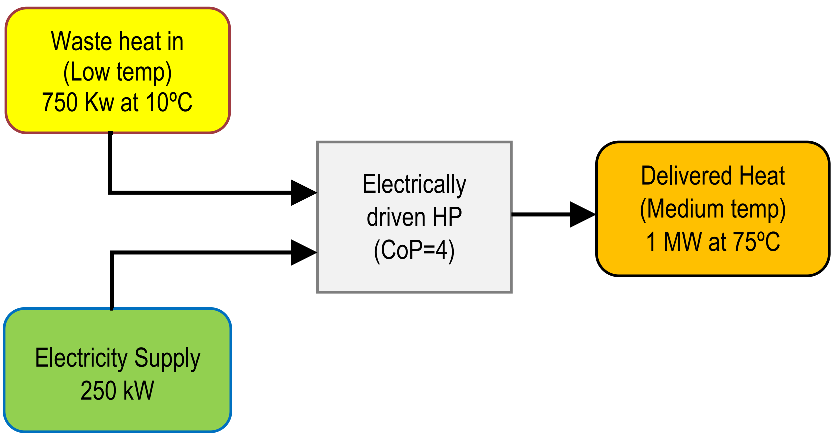


Figure 1: Working Principle of a Compression heat pump

Commercial Heat Pumps (HP) are widely available for low temperature applications (upgrade to levels under 100ºC). This technology enables coupling of heat and electrical systems opening possibilities for new scenarios with diverse business cases. Of particular relevance for industrial waste heat recovery are the new High Temperature Heat Pumps (HTHP) where commercial products exist for upgrade up to about 130ºC, while current near to market developments are targeting upgrade temperatures of up to 150ºC.

Although the main disadvantage is basically that they require electricity to operate that usually is significantly more expensive than fossil fuels, the integration of large-scale heat pumps in future district heating systems are important for multiple reasons:

- Heat pumps combined with storage systems have the potential to become a key technology since it enables for future district heating systems to balance the power grid when the production of electricity from intermittent renewable energy sources fluctuates.

- Heat pumps make it possible to utilize excess heat of low temperatures and therefore consider heat recovery from a wide range of possible unconventional waste heat sources.

- Heat pumps increase the flexibility of district heating systems, by utilizing multiple sources of heat, it enables higher flexibility of the energy system. Fast commissioning and low start-up costs are some of the benefits with heat pumps, as well as taking advantage of the volatility of the electricity market and the possibility to use the thermal grid and storages as thermal batteries.

- Heat pumps play an important role in integrating more renewable energy and phase out fossil fuels from the energy systems.

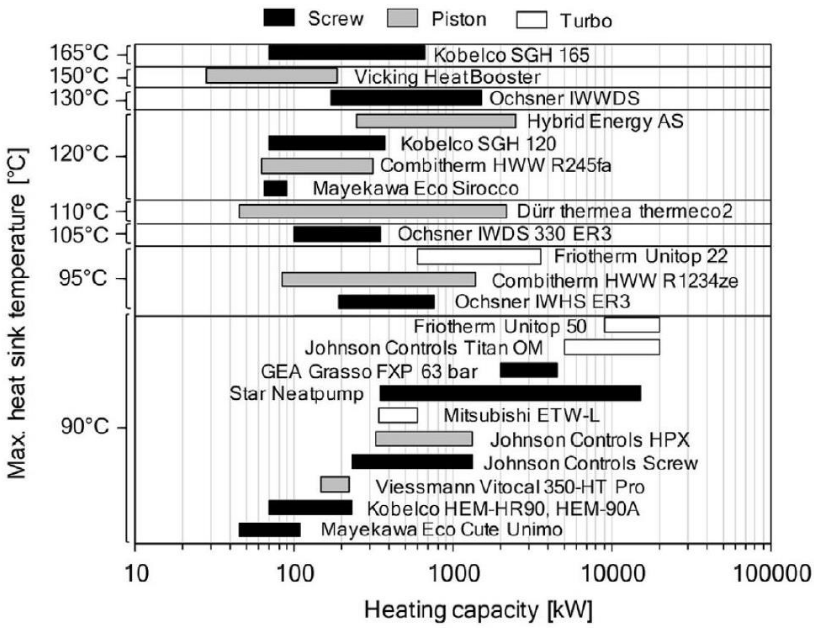


Figure 25: Industrial HTHP commercially available (Source: [16])

There is a near-to-market alternative technology to HPs that could be interesting. The Absorption Heat Transformers operate as an inverse absorption heat pump to simultaneously produce high grade heat (around 150ºC) and low grade heat (around 30ºC) from a middle temperature WH source (between 60 and 90ºC). Thus, AHTs valorise WH by upgrading part of it to higher temperature, hence making it more utilizable, but also producing a secondary low temperature thermal energy stream which might be used for cooling purposes. If such cooling is not available (temperatures around 30ºC), then this technology requires a cooling tower to dissipate the low temperature heat out. Coefficient of performance of these devices rarely reaches 0.5, which means that only up to 50% of the WH input can be upgraded to the high temperature heat out. Similarly to absorption chillers, since this is a purely thermal driven technology the main advantage is their minimal electricity consumption.

AHTs have been fully demonstrated at MW scale in industrial environment although they have not been commercialized after the demonstration stage. The reasons for might be several like the lack of awareness of this technology by industrial stakeholders and the fact that it is required a highly speialised knowledge to design, install and operate this technology. Unlike the HPs, these systems are not a buy off the self products. Still more technical development and public dissemination is required.

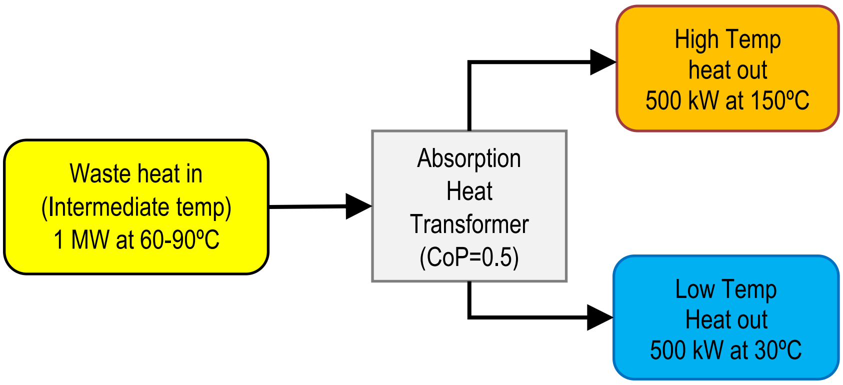


Figure 2: Working principle of an Absorption Heat Transformer

3.2.3 Economic and financial challenges

Economic and financial challenges are usually deeply interrelated among them. For instance, high investments costs produce long payback periods. This long-term consideration introduces the need for long-term guarantees. But energy prices can change quite a lot in the long term and therefore changing the economic evaluation of the waste heat. Additionally, every specific use case can introduce its own economic particularities caused by the specific technical requirements in both actors: the waste heat owner and the DHN end user.

3.2.3.1 Long payback periods

There is a high investment cost in the equipment for waste heat recovery, transportation and utilisation. We are referring to heat exchangers, monitoring and control hardware, piping costs and in a smaller or larger size some kind of thermal storage.

The possible revenues for selling the energy are usually rather low, specially in summer when heat demand is lower and other heat sources like solar thermal can compete with lower costs versus recovered waste heat.

This scenario creates a non-attractive situation of low profitability in the investments and high risk due to possible changes in the medium-long future.

3.2.3.2 Limited standardisation of the waste heat utilisation

Each project has its own individual and site-specific boundary conditions. So, it is almost impossible to fully replicate in an "automatic way" any previous waste heat recovery and external integration project. It increases the efforts required for planning, designing and finally operating the system

In addition to the waste heat owner and the DHN end user, usually a high number of stakeholders needs to be involved. For example, contractors of WHR machinery, city authorities, road operators or environmental agencies. This additional complexity, again means additional costs.

Finally, there is a lack of standardised contracts that increases the time required for the contract negotiation. And additionally, it represents a risk of omitting important clauses.

There are several references [17] proposing what main information should be included in the heat supply contracts. Among others:

- Shared Incentive for both parties: split incentives for both.
- Details of Supply: heat values, temperatures, hours; payments; quality control; maintenance activities; cost of the waste heat.
- Resources: resources (machinery and material or energy flows) needed for heat recovery and who is responsible for their supply.
- Communication Channels: details and frequency of communication.
- Renegotiation: Clauses to allow for flexibility in the long-term nature of heat supply contract, thus reducing the risk.
- Mitigation: Actions to be taken, and by which party, when difficulties arise should be written carefully and unambiguously into the contract

More detailed information about contractual aspects to support collaboration in exploiting industrial waste heat and cold resources can be found in Deliverable 3.3 Report on current contractual arrangements for WH/C exploitation

3.2.3.3 Missing long-term guarantees

DH operators prefer long-term contracts for waste heat delivery since their customers (citizens) do not change usually in a quick way. However industrial companies are exposed to market changes and therefore they are not usually able to agree on providing strict long-term guarantees.

There are risks that might affect the quality and quantity of the waste heat supply from the company like the industry company changing its process to both utilizing the heat internally or removing or altering the process that was generating the waste heat. And finally, the industrial activity could be terminated because the company decides to shut down or relocate. Or in the worst scenario, the company might go bankrupt.

Strictly talking, there could be also considered a risk for the partner supplying the heat. It could happen that the receiver of the waste heat decided to invest on a new larger own production plant to substitute the waste heat source. In other words, the DH company builds a new boiler and no longer demands waste heat supply.

Again, more detailed information about these possible risks can be found in Deliverable 3.4 Business and risks models for industrial WH/C recovery and exploitation towards replication.

3.2.3.4 Requirements to install back-up facilities

In the case of integrating a new WHR source into an existing DHN, several cases can be considered:

a) The share of DHN heat demand covered by the WHR is not critical versus the total self-heat generation (boilers) of the DH company. This situation happens when the existing DH was able to cover its maximum demand (winter peak load) with its own resources before the WHR integration and the total DH demand has not increased (no new customers connected to the district) since that moment.

b) The biggest majority of the DHN demand is covered by the WHR. For example, this situation typically happens when the DHN was originally designed to be feed up with recovered heat from a CHP power plant. Power plants that are designed to operate 24x7 and it is not consider that this plant stops more than a few hours per year.

c) The share of DHN heat demand covered by the WHR is at least 50% of the WH demand and the remaining self-heat generation (boilers) of the DH company might be able to cover the DH demand during the summer and transition periods, but not during the winter peak loads. This situation typically happens when after the integration of the WHR, the DHN increased its number of clients (increased its heat demand), but since there was availability of waste heat, it was not decided to purchase additional boilers but to cover these new clients heat demand with the excess heat available from the industrial company. Indeed, the source of WH is not a critical CHP facility but a conventional private industrial facility.

The case a) represents a safe situation since in case of disconnection of the WHR, the DHN company could still cover its clients heat demand even during the winter peak load.

On the other hand, case b) is strictly not a safe case, but since we are considering a critical power plant, probably the possible problems of stopping the CHP plant would be much more critical in the electricity lack rather than on the lack of heat demand. In any case, it can be considered that although the consequence of the risk is maximum, the likelihood is minimum.

And finally, the case c) represents a situation where the consequences are maximum but in this case the likelihood is medium or high (if the factory is suffering any kind of production difficulties). In this case, the operator of the DHN will be required to install additional heat production facilities as back-up to cover the risk of unplanned interruptions in the waste heat supply. And this represents an additional economic cost. Sometimes, the contract specifies that the industrial company should be in charge of implementing such buck-up mechanism (for instance using the factory boilers). But in this case, the factory will try to compensate this additional investment increasing the price of the waste heat delivery.

3.2.3.5 Diverging views on the value of the waste heat and the amortisation time

DHN companies try to minimise the expenditures for waste heat supply. Obviously, the possible cost has to be lower than the cost of self-producing the required heat. On the other hand, private companies (owners of the factories producing the waste heat) want to exploit their waste heat potential in monetary terms. Although in some cases, industrial facilities could provide their waste heat with very reduced price (just to cover production costs) as a way of improving their institutional reputation within the community. Additionally, regional and national governments might take advantage of WHR to reduce carbon emissions and therefore place some kind of tax reduction or subsidies for the delivered and sold waste heat.

One important point to consider is the fact that domestic heat demand tends to be significantly higher in the winter months than in the summer. It could be argued that the cost of heat should also be dependent on demand and, therefore on outside temperature. Everything is possible if agreed by both actors. Even in some cases, delivering the waste heat for free during the summer period, since this recovered heat means less electricity consumption in the alternative factory cooling systems that would have to operate if the waste heat recovery mechanism were disabled.

Regarding requirements about amortisation time, industrial companies are usually exposed to the market fluctuations and the owners´ expectations. For investments related with the core business of the factory like the main ovens or similar, financial managers usually allow amortisation periods over 10 and up to 20 years. However, for all the peripherical business or issues, like any kind of auxiliary energy systems, maximum amortisation accepted period rarely exceeds 5 years with 2-3 years as the most frequently decision threshold. However, DH companies are long-term oriented companies, basically because they have assured the capital reflux from their clients (usually a monopoly on the end customer side). Additionally, most of the DH companies are owned by municipalities so no large profit is expected. For all of this, amortisation periods over 10 years are always considered and, in some cases, up to 20 years can be accepted.

3.2.4 Legislative and Regulatory challenges

There are no regulatory restrictions for the supply of WH into DH networks. Regulation is based on one-to-one contracts between the DH owner/operator and the owner (factory/utility) of the waste heat

3.2.4.1 Energy Efficiency Directive (DIRECTIVE 2012/27/EU)

The EED mentions waste heat and cold several times (Article 2: Definitions, Article 7: Energy savings obligations and Article 14: Promotion of efficiency in heating and cooling) but gives no clear definition of the concept itself. It mentions waste heat from power generation, which could be recovered through cogeneration, and waste heat from industry. The terms "useful temperature level of waste heat" and "useful waste heat" are also used but without additional explanation. More specifically:

Article 2 -Definition 41 states that **'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 7a and 7b indicates the **Energy savings obligations and alternative measures** (referencing to additional guidance documents and annex). It recognises waste heat recovery as a valid type of alternative measure to achieve the MS energy saving obligations.

Article 14 states that by 31 December 2015, Member States shall carry out and notify to the Commission a **comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling**, containing the information set out in Annex VIII. The comprehensive assessment shall take full account of the analysis of the national potentials for high-efficiency cogeneration carried out under Directive 2004/8/EC. Among other parameters, the mentioned Annex VIII requires to provide:

(b) **identification of installations that generate waste heat or cold and their potential heating or cooling supply**, in GWh per year:

(i) thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MW;

(ii) heat and power cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW;

(iii) waste incineration plants;

(iv) renewable energy installations with a total thermal input exceeding 20 MW other than the installations specified under point 2(b)(i) and (ii) generating heating or cooling using the energy from renewable sources;

(v) industrial installations with a total thermal input exceeding 20 MW which can provide waste heat;

Article 14-5 also states that Member States shall ensure that a **cost-benefit analysis** in accordance with Part 2 of Annex IX is carried out when, after 5 June 2014:

(a) a new thermal electricity generation installation with a total thermal input exceeding 20 MW is planned, in order to assess the cost and benefits of providing for the operation of the installation as a high-efficiency cogeneration installation;

(b) an existing thermal electricity generation installation with a total thermal input exceeding 20 MW is substantially refurbished, in order to assess the cost and benefits of converting it to high-efficiency cogeneration;

(c) an industrial installation with a total thermal input exceeding 20 MW generating waste heat at a useful temperature level is planned or substantially refurbished, in order to assess the cost and benefits of utilising the waste heat to satisfy economically justified demand, including through cogeneration, and of the connection of that installation to a district heating and cooling network;

(d) a new district heating and cooling network is planned or in an existing district heating or cooling network a new energy production installation with a total thermal input exceeding 20 MW is planned or an existing such installation is to be substantially refurbished, in order to assess the cost and benefits of utilising the waste heat from nearby industrial installations.

3.2.4.2 Renewable Energy Directive (DIRECTIVE EU 2018/2001)

As mentioned in the previous contextualization section, this directive provides **the official definition of waste heat and cold (Article 2-9).** Specifically *defines waste heat and cold as "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 DHC network, where a cogeneration process has been used or will be used or where cogeneration is not feasible".*

As also explained in the previous contextualisation section, this new definition introduces several restrictions about can be or can not be considered waste heat. First, only unavoidable losses are counted as waste heat. Second, waste heat and cold should be a by-product. And third, waste heat and cold must be used via DHC. This third requirement also implies the next 3 requirements: a) The consumption must be off site, i.e. by a different economic entity, b) Waste heat must be sold, c) Waste heat must go to a heat network of some kind.

It is also important to remark that the RED also includes a definition of DH and DC in the Article 2 (definition 19*). 'district heating' or 'district cooling' means the distribution of thermal energy in the form of steam, hot water or chilled liquids, from central or decentralised sources of production through a network to multiple buildings or sites, for the use of space or process heating or cooling.*

It is important to remark that these new criteria refer to requirements to be counted as waste heat eligible for the heating and cooling target as well as the district heating and cooling targets. Next figure [14] summarizes which waste heat streams can be considered for the purposes of the recast RED heating and cooling targets. Theoretically, the residential and transport sectors could have been included in the RED definition of waste heat but from a practical point of view sources in those sectors are very diffuse and it would be hard to meet the criteria of "by-product", "unavoidable" and use via DHC. DHC networks serve the residential sector, but return water should not be double-counted.

Sector		By-product		Energy efficiency		Use
Power generation		Waste		Unavoidable waste		Sale to a DHC network
Cogeneration						
WtE						
Industry	+	Intended production	+	Avoidable waste	+	On-site use
						Industrial symbiosis
Services						Any off-site use other than DHC
Residential						
Transport						

Notes: Green = Meets the eligibility condition; Light red = Does not meet the eligibility condition. All four conditions must be met. WtE = Waste-to-energy. DHC = District heating and cooling.

Figure 3: Eligibility of waste heat and cold for the RED heating and cooling targets (Source: [18])

Under the recast RED, waste heat that cannot be avoided or used on site, which is then sent for use off site, can be counted towards the targets for renewable heating and cooling (Article 23) and renewable DHC (Article 24).

Article 23(1). In order to promote the use of renewable energy in the heating and cooling sector, **each Member State shall endeavour to increase the share of renewable energy in that sector by an indicative 1,3 percentage points as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030**, starting from the share of renewable energy in the heating and cooling sector in 2020, expressed in terms of national share of final energy consumption and calculated in accordance with the methodology set out in Article 7, without prejudice to paragraph 2 of this Article. **That increase shall be limited to an indicative 1,1 percentage points for Member States where waste heat and cold is not used.** Member States shall, where appropriate, prioritise the best available technologies.

Article 23(2). For the purposes of paragraph 1, when calculating its share of renewable energy in the heating and cooling sector and its average annual increase in accordance with that paragraph, each Member State:

(a) may count waste heat and cold, subject to a limit of 40 % of the average annual increase;

(b) where its share of renewable energy in the heating and cooling sector is above 60 %, may count any such share as fulfilling the average annual increase; and

(c) where its share of renewable energy in the heating and cooling sector is above 50 % and up to 60 %, may count any such share as fulfilling half of the average annual increase.

When deciding which measures to adopt for the purposes of deploying energy from renewable sources in the heating and cooling sector, Member States may take into account cost-effectiveness reflecting structural barriers arising from the high share of natural gas or cooling, or from a dispersed settlement structure with low population density.

Article 24(4) Member States shall lay down the necessary measures to ensure that district heating and cooling systems contribute to the increase referred to in Article 23(1) of this Directive by implementing at least one of the two following options:

(a) Endeavour to **increase the share of energy from renewable sources and from waste heat and cold in district heating and cooling by at least one percentage point as an annual average calculated for the period 2021 to 2025 and for the period 2026 to 2030**, starting from the share of energy from renewable sources and from waste heat and cold in district heating and cooling in 2020, expressed in terms of share of final energy consumption in district heating and cooling, by implementing measures that can be expected to trigger that average annual increase in years with normal climatic conditions.
Member States with a share of energy from renewable sources and from waste heat and cold in district heating and cooling above 60 % may count any such share as fulfilling the average annual increase referred to in the first subparagraph of this point.
Member States shall lay down the necessary measures to implement the average annual increase referred to in the first subparagraph of this point in their integrated national energy and climate plans pursuant to Annex I to Regulation (EU) 2018/1999.

(b) **Ensure that operators of district heating or cooling systems are obliged to connect suppliers of energy from renewable sources and from waste heat and cold or are obliged to offer to connect and purchase heat or cold from renewable sources and from waste heat and cold from third-party suppliers** based on non-discriminatory criteria set by the competent authority of the Member State concerned, where they need to do one or more of the following: (i) meet demand from new customers; (ii) replace existing heat or cold generation capacity; (iii) expand existing heat or cold generation capacity.

3.2.4.3 Energy Performance of Buildings Directive (EPBD) (DIRECTIVE EU 2018/844)

Article 4 Setting of minimum energy performance requirements

Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels. The energy performance shall be calculated in accordance with the methodology referred to in Article 3 (that refers to ANNEX 1).

ANNEX 1- Point 2

The energy needs for space heating, space cooling, domestic hot water, ventilation, lighting and other technical building systems shall be calculated in order to optimise health, indoor air quality and comfort levels defined by Member States at national or regional level.

The calculation of primary energy shall be based on primary energy factors or weighting factors per energy carrier, which may be based on national, regional or local annual, and possibly also seasonal or monthly, weighted averages or on more specific information made available for individual district system.

Primary energy factors or weighting factors shall be defined by Member States. In the application of those factors to the calculation of energy performance, Member States shall ensure that the optimal energy performance of the building envelope is pursued.

In the calculation of the primary energy factors for the purpose of calculating the energy performance of buildings, Member States may take into account renewable energy sources supplied through the energy carrier and renewable energy sources that are generated and used on-site, provided that it applies on a non-discriminatory basis.';

3.2.4.4 WHR regulatory conclusions

Although the 2012 Energy Efficiency Directive (EED) mentions waste heat and cold several times it does not give a definition of the waste heat concept. This directive also includes the definition of efficient district heating and cooling where renewable energy and waste heat are considered in a complete symmetrical way (a minimum 50% contribution of any of these sources is required to be considered efficient)

However, 2018 Renewable Energy Directive introduces a much more restrictive definition of waste heat introducing the term "unavoidable" that is difficult to define since it could relate to technical or economic feasibility. It could also be source of difficulties looking into the medium- and long-term future of the waste heat owner. For example, future new technologies might change the process and what was initially unavoidable might be avoidable with new technologies.

In this directive Article 23 it is stated that in order to promote the use of renewable energy in the heating and cooling sector, each Member State shall endeavour to increase the share of renewable energy in that sector by an indicative 1,3 percentage points as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030, starting from the share of renewable energy in the heating and cooling sector in 2020.

However, it also creates a discrimination of waste heat versus renewable energies. That increase shall be limited to an indicative 1,1 percentage points for Member States where waste heat and cold is not used. (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).

So, those Member states who do not foster waste heat recovery will be required to have a lower value of increase of the share of renewable energy. This article remains unchanged in the 2022 RED update. 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 calculation of the share of renewable energy in heating and cooling could deter some Member States from including it.

And finally, regarding the Energy Performance of Buildings Directive (EPBD) it could create some difficulties with the use of waste heat due to the PEF values. Specifically in those countries where the electricity used to upgrade the temperature of waste heat is not always renewable and can consequently have a high PEF value. Under these circumstances the use of waste heat may then appear unfavourable for the energy performance of a building.

Other possible problematic issue would appear when 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. In this scenario, connecting industrial waste heat becomes meaningless in some cases, as a building will need additional on-site renewables and thus additional investments to meet EPBD performance requirements.

4 Simplified Use cases of WHR into DHNs

For drafting this paragraph, the project consortium members have been invited to submit a synthetic viewgraph about some very relevant sites from their countries for the purpose of integration of Waste Heat/Cold in DHNs.

The submitted graphs have been reproduced in the followings.

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

GENERAL ASPECTS

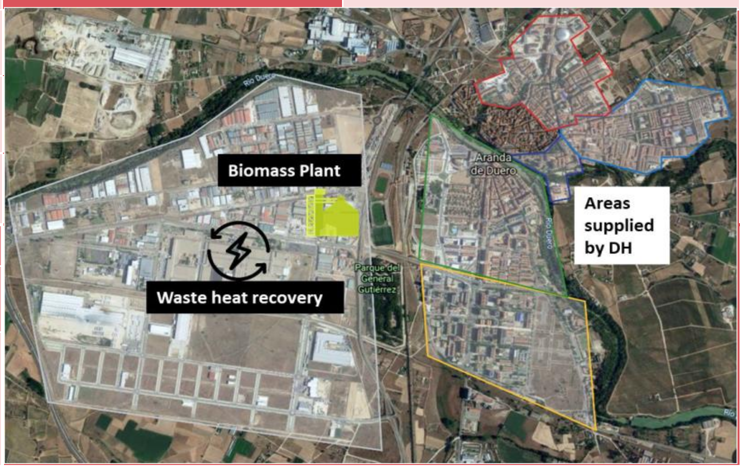
Location	Aranda de Duero (Spain)					
Start of the project	2016					
Year of first supply	2019 (after 1st phase construction)					
Supply	District Heating					
Network generation	2nd generation	**Temperature**	Medium temperature			
Construction phases	2	1st phase	2nd phase	3rd phase	4th phase	5th or more phases
Phases duration		3 years	1 year	-	-	-

GRID ASPECTS

km network	15 km		**Energy production (GWh/year)**		54 (2020)	
Installed capacity (MW)	24 MW		**Waste heat share**		50,00%	
Installed capacity per fuel (MW)	Fossil fuels	0 MW	RES	12 MW	Waste heat	12 MW
DH share in the city	9,5% (of compatible buildings in the city connected)		**CO_2 emissions avoided**		14.700 tn CO_2/ year	

Residential buildings	8
Tertiary buildings	2
Industrial buildings	0

MAIN CLIENTS		
Residential	**Tertiary**	**Industrial**
80%	**20%**	**0%**



TECHNOLOGIES DETAILS (CURRENT SITUATION)

Fuel(s)	Biomass	tn biomass/year	13.500
	Waste heat	Origin	Industrial (tyre factory)
Heat production	2 boilers (wood chips)	MW total	12 (6 MW per boiler)
		Efficiency	85%
DH network	Grid equipped with optic fibre for control	DH Temperature supply (ºC)	75-85 (winter) 65 (summer)
Storage	Inertial Thermal Storage Tank	Store (MWh)	100 (8 h with 12 MW boilers production)
		Volume (m^3)	4,000
Waste heat recovery	CHP unit (waste heat)	MWe total MWth total	33 75.5
	Heat exchanger steam/water (12MW)	Efficiency	90%
		Heat recovery (GWh/year)	15-40

GOVERNANCE AND BUSINESS MODEL

Ownership		Biomass heating plants in Castilla y León (CCBCYL)		
Operator		REBI		
Business model patterns		Target market	Small to medium cities with a heating market dominated by centralised fossil-fuelled boilers	
		Supply contracts with clients of at least 5-year duration		
Prices and tariffs	Tariffs options	A fixed 10% discount with respect previous fossil-fuel supply	Connection fee	No
		A variable tariff throughout the year, updated annually	Average price	76,65 €/MWh
Investment cost		Total Investment cost	15 M€	
		Heat recovery	1 M€	
Impacts		Economical	25-30% reduction electrical bills	
		Social	40 new job positions	
		Environmental	Avoidance of 14,7 tn Co2/year emitted	
		Other		

MORE INFORMATION https://reddecalordearandadeduero.es/datos-tecnicos

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

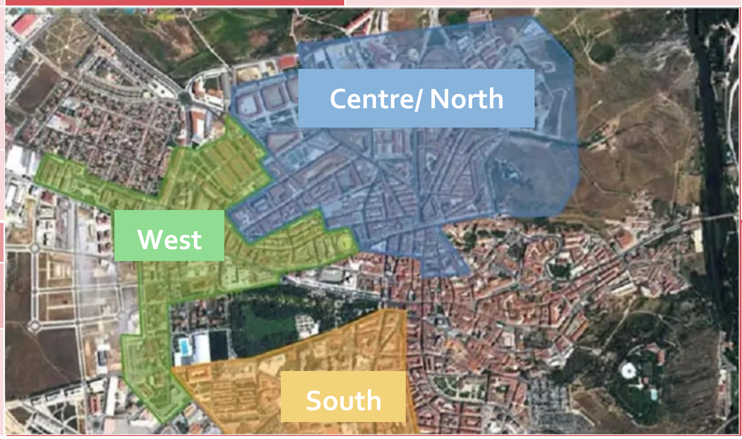
GENERAL ASPECTS

Location	Soria (Spain)					
Start of the project	2014					
Year of first supply	2015					
Supply	District Heating					
Network generation	2nd generation	**Temperature**	Medium temperature			
Construction phases	4	1st phase	2nd phase	3rd phase	4th phase	5th or more phases
Phases duration		2 years	2 years	1 year	1 year	-

GRID ASPECTS

km network	28 km		**Energy production (GWh/year)**		120	
Installed capacity (MW)	38 MW		**Waste heat share**		80,00%	
Installed capacity per fuel (MW)	Fossil fuels	0 MW	RES	24 MW	Waste heat	14 MW
DH share in the city	66% (of compatible buildings in the city connected)		**CO_2 emissions avoided**		28.000 tn CO_2/ year	

Residential buildings		170
Tertiary buildings		30
Industrial buildings		0
MAIN CLIENTS		
Residential	**Tertiary**	**Industrial**
85%	**15%**	**0%**



TECHNOLOGIES DETAILS (CURRENT SITUATION)

Fuel(s)	Biomass	tn biomass/year	16,000
	Waste heat	Origin	Industrial (wood factory)
Heat production	4 boilers (wood chips)	Power installed (MW)	24
		Efficiency (%)	85
DH network	Grid equipped with optic fibre for control	DH Temperature supply (ºC)	85
Storage	Inertial Thermal Storage Tank	Volume (m^3)	5,000
Waste heat recovery	CHP unit	Total Waste Heat recovery (MW)	13-14
	Thermal oil circuit		
	Steam Turbine		
	Biomass boilers fumes		

GOVERNANCE AND BUSINESS MODEL

Ownership		Red De Calor De Soria S.L.		
Operator		REBI		
Business model patterns		**Target market**	Small to medium cities with a heating market dominated by centralised fossil-fuelled boilers	
		Duration of supply contracts with clients around 10-15 years		
Prices and tariffs	**Tariffs options**	A fixed 10-15% discount with respect previous fossil-fuel supply	**Connection fee**	No
		A variable tariff throughout the year, updated annually	**Average price**	76 €/MWh
Investment cost		**Total Investment cost**	30 M€	
		Heat recovery	6 M€	
Impacts		**Economical**	10-15% reduction electrical bills	
		Social	180-200 new job positions	
		Environmental	Avoidance of 28.000 tn Co2/year emitted	
		Other		

MORE INFORMATION https://reddecalordesoria.es/datos-tecnicos

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

LOCATION	Aartselaar, Antwerp Belgium			
YEAR OF CONSTRUCTION	**2023**			
SUPPLY	(●) DH	( ) DC	( ) DH&C	
NETWORK GENERATION	2nd Generation	**TEMPERATURE**	Medium Temperature	
CONTRUCTION PHASES	2	**1st Phase**	**2nd Phase**	
PHASES DURATION		**2 year**	**1 year**	

GRID ASPECTS

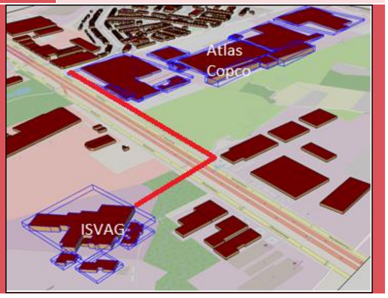
km network	2		**Energy production (MWh/year)**	10,023	
Installed capacity (MW)	8		**Waste heat share**	100.00%	
Installed capacity per fuel (MW)	Fossil fuels	0	RES	Waste heat	8
DH market share	Less than 1%		**CO2 emissions**	3950 Ton/year	

Buildings connected	6
Residential buidlings	0
Terciary buildings	0
Industrial buildings	6

MAIN CLIENTS

Residential	Tertiary	Industrial
0%	0%	100%

Visual



DETAILED TECH (LAST PHASE)

PRODUCTION MIX	**Fuel(s)**	Residential waste	**tn biomass/year**	140,000
		Waste heat		
	Heat production	1 steam drum	**MW total**	8MW
			Efficiency	90%
	DH network	Grid equipped with optic fibre for control	**DH Tª supply (ºC)**	55-95 (winter) 65 (summer)
	Storage	Inertial Thermal Storage Tank	**Store (MWh)**	0
			Volume m^3	0
	Waste heat recovery	CHP unit (waste heat)	**MWe total** **MWth total**	16 16
		Heat exchanger steam/water	**Efficiency**	90%
			Heat recovery (GWh/year)	10

GOVERNANCE AND BUSINESS MODEL

OWNERSHIP		ISVAG Waste incinerator (Inter municipality)		
OPERATOR		ISVAG		
BUSINESS MODEL PATTERNS		**Target market**	Small to medium cities with a jeating market dominated by decentralised fossil-fuelled boilers	
		Supply contracts with clients of at least 5-year duration		
PRICES AND TARIFFS	**Tariffs opcions**	Not more than otherwise (individual gas boilers as reference)	**Connection fee**	Yes
		A fixed tariff throughout the year, updated annually	**Average price**	118€/MWh
INVESTMENT COST		**Total Investment cost**	8 M€	
		Heat recovery	1,5 M€	
IMPACTS		**Economical**		
		Social	business anchoring	
		Environmental	Avoidance of 1660 ton C02/year emitted	
		Other		

Web and more information https://reddecalordearandadeduero.es/datos-tecnicos

RED DE CALOR DE ARANDA DE DUERO

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

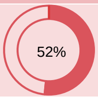
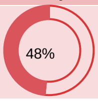
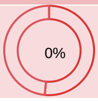
LOCATION	Parque das Nações, Lisbon, Portugal					
YEAR OF CONSTRUCTION	**1998**					
SUPPLY	○ DH	○ DC	◉ DH&C			
NETWORK GENERATION	4th Generation	**TEMPERATURE**	Medium Temperature			
CONTRUCTION PHASES	3	**1st Phase**	**2nd Phase**	**3rd Phase**		
PHASES DURATION		**3 years (1996 - 1998)**		**2011**		

GRID ASPECTS

km network	4 pipe network with a total extension of 80 km (20 km coverage)		**Energy production (MWh/year)**	65 000 MWh (heat) + 40 000 MWh (cold)	
Installed capacity (MW)	29 MW (heat) + 35 MW (cold)		**Waste heat share**	?	
Installed capacity per fuel (MW)	Fossil fuels	37.2	RES		Waste heat	
DH market share	100.00%		**CO2 emissions**	30 000 tCO2	

Buildings connected	128
Residential buidlings	66
Terciary buildings	62
Industrial buildings	0

MAIN CLIENTS

Residential	Tertiary	Industrial
		

Visual

DETAILED TECH (LAST PHASE)

PRODUCTION MIX	**Fuel(s)**	Natural Gás	**tn biomass/year**	
	Heat production		**MW total**	
			Efficiency	
	DH network	Mainly steel pipes, but over the recent years HDPE (High Density polyethylene) pipes are being used for cooling.	**DH Tª supply (ºC)**	90 ºC
	Storage	Inertial Thermal Storage Tank (cold water 4ºC)	**Store (MWh)**	20 MW/6 hours
			Volume m^3	15,000
	Waste heat recovery	CHP unit (waste heat)	**MWe total** **MWth total**	5 16.2
		Heat exchanger steam/water	**Efficiency**	Overall: 85%; Eletrical: 30%; Thermal: 55%)
			Heat recovery (GWh/year)	

GOVERNANCE AND BUSINESS MODEL

OWNERSHIP		ENGIE		
OPERATOR		Climaespaço		
BUSINESS MODEL PATTERNS		**Target market**	Specific area of Lisbon (called PARque das Nações) that was completely remodeled to host the world exposition (EXPO 98). In the renovation process, the thermal energy network was immediately included and, in the same way, the new buildings built already have technical	
		Supply contracts with clients of a 2-year duration		
PRICES AND TARIFFS	**Tariffs opcions**	**Variable component** – proportional to the energy consumption measured in the enthalpy counter to be installed by CLIMAESPAÇO **Fixed component** - proportional to the contracted power **Fixed component** – which reflects the cost of collecting and processing readings, as well as issuing and sending invoices.	**Connection fee**	Monthly fee: 1,82 €/kW (Heat); 10,23 €/kW (Cool)
			Average price (2022)	0,05599 €/kWh (Heat) - 0,0641 €/kWh (Cool)
INVESTMENT COST		**Total Investment cost**	85 M€	
		Heat recovery		
IMPACTS		**Economical**	20% to 50% reduction enery bill for heating and cooling	
		Social		
		Environmental	Avoidance of 20 000 tC02/year emitted	
		Other	40% Reduction in the GHG emission factor associated with final energy use for heating, cooling and eletricity	

Web and more information http://www.climaespaco.pt/index.html

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

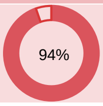
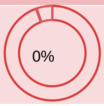
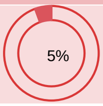
LOCATION	**Cernavoda, Romania**				
YEAR OF CONSTRUCTION	**2010**				
SUPPLY	◉ DH	○ DC	○ DH&C		
NETWORK GENERATION	2nd Generation	**TEMPERATURE**	Medium Temperature		
CONTRUCTION PHASES	2	**1st Phase**	**2nd Phase**		
PHASES DURATION					

GRID ASPECTS

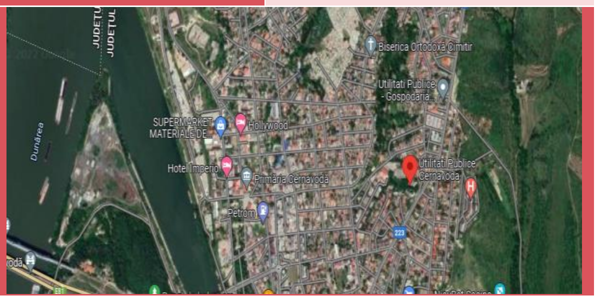
km network	31	**Energy production (MWh/year)**	77,765.40
Installed capacity (MW)	46.5	**Waste heat share**	100.00%
Installed capacity per fuel (MW)	Fossil fuels: 0	RES:	Waste heat:
DH market share		**CO2 emissions**	

Buildings connected	5518
Residential	5210
Public institutions	14
Economic operators	294

MAIN CLIENTS

Residential	**Public institutions**	**Economic operators**
		

Visual



DETAILED TECH (LAST PHASE)

PRODUCTION MIX	**Fuel(s)**	Residual heat from Cernavoda Nuclear Powerplant, unit 1		
		Waste heat	**MWh/year**	77765.4
	Heat production	Distribution point (unit 1) with 2 heat exchangers	**MW total**	46,5 MW
			Efficiency	98%
	DH network	Grid equipped with optic fibre for control	**DH Tª supply (ºC)**	65-110 (winter) 65-75 (summer)

GOVERNANCE AND BUSINESS MODEL

OWNERSHIP	**Cernavodă Local Council**			
OPERATOR	**Utilități Publice Cernavodă Ltd.**			
BUSINESS MODEL PATTERNS	**Target market**	Small to medium cities		
PRICES AND TARIFFS	**Tariffs opcions**	A fixed tariff throughout the year, updated annually	**Connection fee**	No
			Average price	14,81 €/MWh
INVESTMENT COST	**Total Investment cost**			
	Heat recovery			
IMPACTS	**Economical**	100% reduction natural gas fuel		
	Social	133 new job positions		
	Environmental	Avoidance of 17652,75 tn C02/year emitted		
	Other	The lowest price of thermal energy from Romania paid by customers (2021)		

Web and more information

https://www.anre.ro/ro/energie-electrica/legislatie/serviciul-public-de-alimentare-cu-energie-termica/raport-privind-starea-serviciului-public-de-alimentare-cu-energie-termica-in-sistem-centralizat-pentru-anul-2021-en
https://primaria-cernavoda.ro/consiliu-local/institutii-subordonate-consiliului-local/utilitati-publice-cernavoda-srl/

DISTRICT HEATING WITH HEAT RECOVERY FACTSHEET

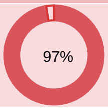
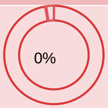
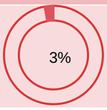
LOCATION	**Constanța, Romania**					
YEAR OF CONSTRUCTION	**1970**					
SUPPLY						
NETWORK GENERATION	2nd Generation	**TEMPERATURE**	Medium Temperature			
CONTRUCTION PHASES	2	**1st Phase**	**2nd Phase**			
PHASES DURATION						

GRID ASPECTS

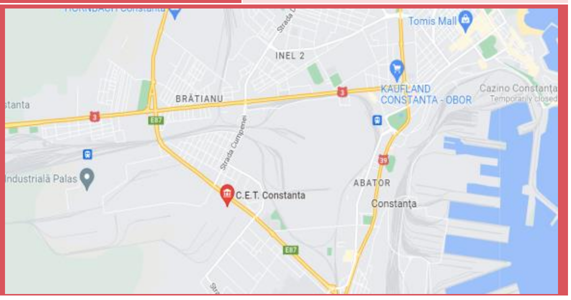
km network	300.6		**Energy production (MWh/year)**	572,076.00	
Installed capacity (MW)	350		**Waste heat share**	0.00%	
Installed capacity per fuel (MW)	Fossil fuels	350	RES	0	Waste heat 0
DH market share	100.00%		**CO2 emissions**	129,861.25	

Buildings connected	36326
Residential	35299
Public institutions	117
Economic operators	910

MAIN CLIENTS

Residential	Public institutions	Economic operators
		

Visual



DETAILED TECH (LAST PHASE)

PRODUCTION MIX	**Fuel(s)**	Natural gas		
		Waste heat		
	Heat production	PT (unitatea 1) cu 2 schimbătoare de căldură	**MW total**	572076
			Efficiency	50%
	DH network	Grid equipped with optic fibre for control	**DH Tª supply (ºC)**	65-110 (winter) 65-75 (summer)
		Heat exchanger steam/water	**Efficiency m³**	
			Heat recovery (GWh/year)	

GOVERNANCE AND BUSINESS MODEL

OWNERSHIP		**Ministry of Energy - source Constanta Local Council - distribution**		
OPERATOR		**Electrocentrale Constanta - source Termoficare Constanta - distribution**		
BUSINESS MODEL PATTERNS		**Target market**	Large cities	
PRICES AND TARIFFS	**Tariffs options**		**Connection fee**	No
		A fixed tariff throughout the year, updated annually	**Average price**	235 €/MWh
INVESTMENT COST		**Total Investment cost**		
		Heat recovery	0	
IMPACTS		**Economical**		
		Social	Subsidy for the final price of thermal energy during the winter, granted by the Public Authority, for 80,000 inhabitants	
		Environmental	The reduction of carbon footprint, compared to the individual heating systems	
		Other		

Web and more information

5 Detailed description of Romanian successful cases.

Based on a partnership between DH utility company Thermoficare and Ovidius University of Constanta it has been demonstrated the possibility to convert the classical re-heating station is local RES Power plants.

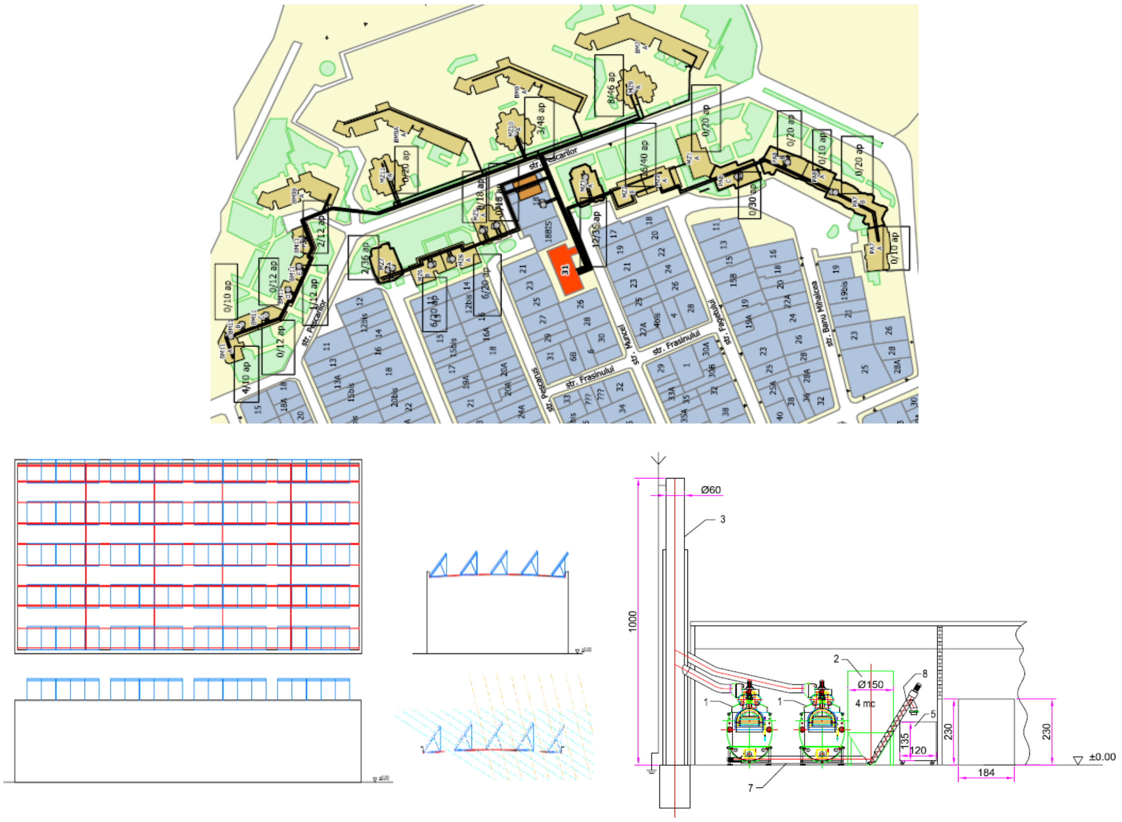


Figure 28. Renewable Energy DH Plant

One of the re-heating stations located in the district "Faleza Nord", that is suppling hot water for heating and warm water for daily use for an impressive secondary network of dwellings in apartments blocks has been selected for a pilot project.

The aim of the project was to define a concept of pilot plant using solar energy by installing solar-thermal panel on the roof-top of the building without additional structural changes as an alternative thermal energy source, sustainable but, at the same time assuring the quantity and quality thermal energy for the end-user customers in the frame of the legal provisions for thermal energy distribution in Romania.

To develop the concept of the pilot plant, between 2016 and 2018 there were carried out studies of evaluation of demand side characteristics by drafting the energy consumption plots for the existing customer structure as the daily statistical demand side curve for summer and winter season. There were taken into consideration also the yearly variations due to weather conditions.

The solar thermal installation has been dimensioned by correlating the thermal energy demand and the available surface on the roof top of the PT31 building. The solar thermal installation is composed of 100 solar thermal panels, serial connected in groups of 5 panels, and the series are connected in parallel for a section of 25 panels. The sections of panels are operated by 4 recirculation stations of the working fluid. The thermal energy is stored in storage tanks with a total capacity of 10 m3.

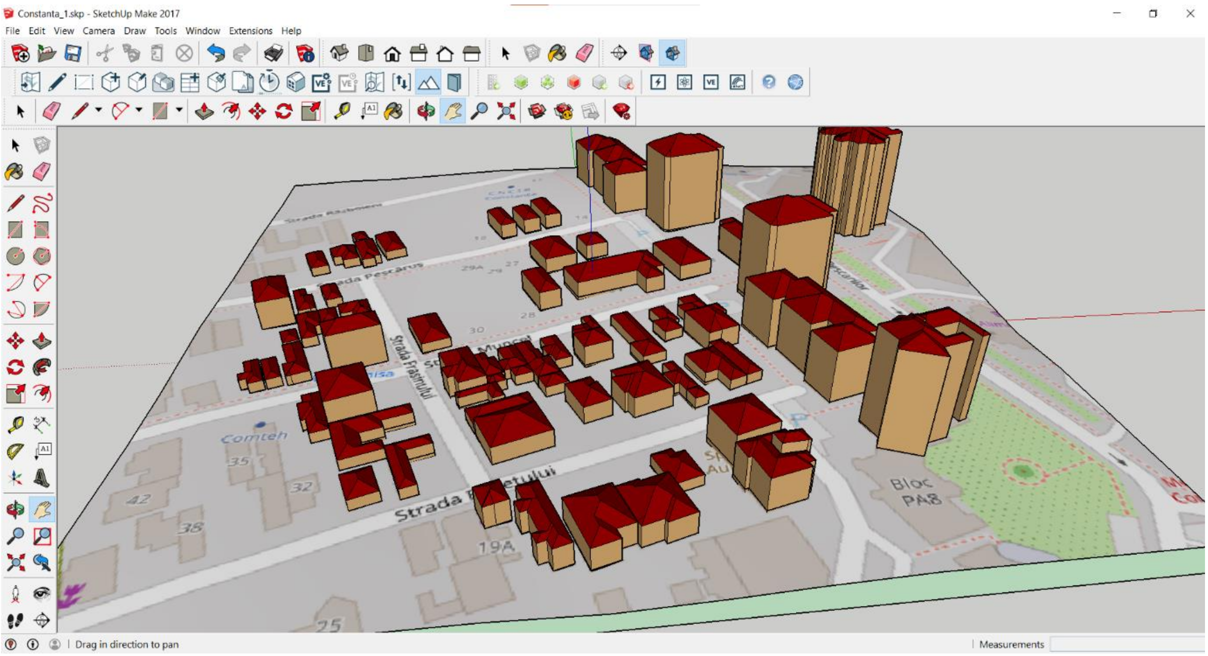


Figure 29. Site modelling for the Constanta RES Pilot Plant

The station is preparing the hot and warm water streams based on the primary thermal energy stream from the cogeneration plant. Due to the very high costs of the thermal energy, many dwellings shifted to individual gas fired boilers. In October 2018, about 100 end-user dwellings were still connected to the secondary distribution network.

The concept of the pilot plant has been conceived as during the summer season, the solar-thermal panels to be able to cover the entire energy demand and working together with the energy accumulation system to be able to cover the morning and evening daily picks.

The pellet boilers are manufactured by Ecohornet Ltd that is a Romanian manufacturer of highly performant boilers working with pelletized waste biomass. The boilers are fully automatic, integrating up-to-date digital technologies for monitoring the parameters and dynamic adjustment to the operating conditions.

The modelling and simulation activities offered the possibility of dimensioning and adjusting the components of the pilot plant for a continuous operation based only on solar and biomass that allows the spectacular reduction of the CO_2 emissions. The remaining GHG emissions are only related to the electricity consumption in the pumping process.

In terms of energy efficiency, the overall efficiency of the pilot plant after the conversion to renewable energy sources is 92% and was possible using high performance solar-thermal panels and pellet boilers.

Based on the results obtained, the partners have conceived a concept of Renewable Energy Islands for the district of Faleza North of the city coupling 6 converted re-heating stations coupled in a common distribution loop.

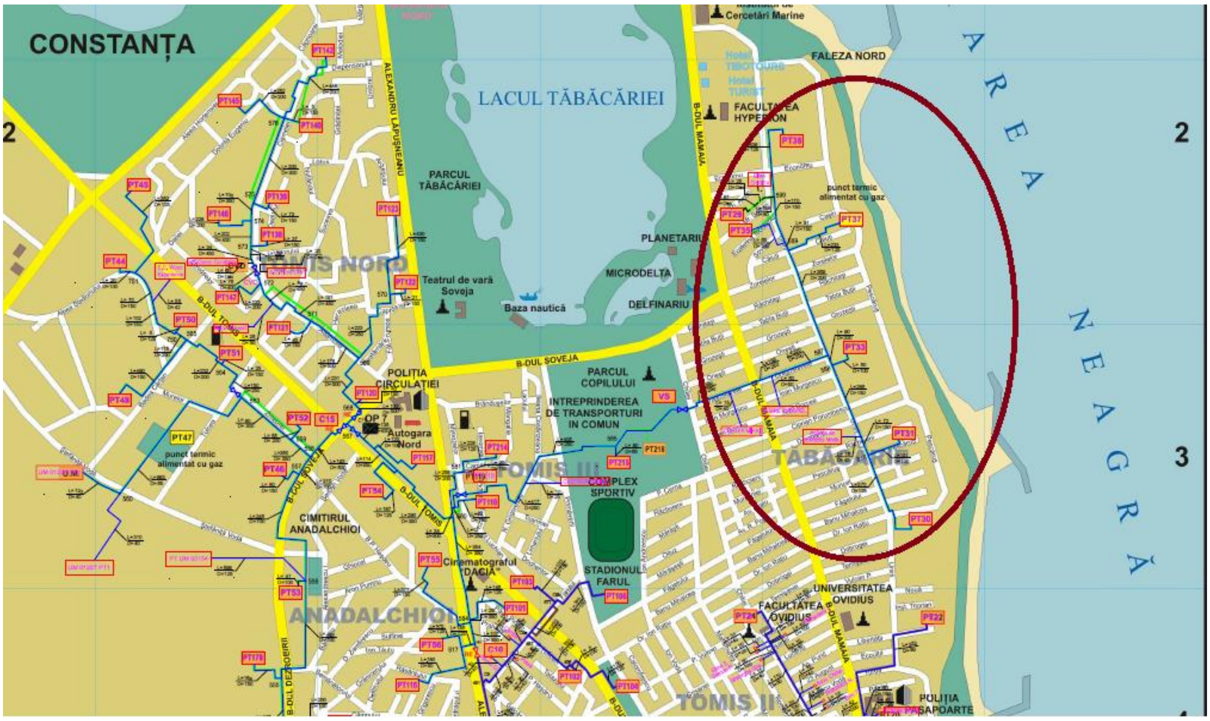


Figure 30. Concept development for Renewable Energy Islands

For attracting possible investors, the were identified the following models of business:

- The owner of the thermal energy is investing into necessary equipment and is directly managing the transfer of thermal energy to the distribution company;
- After investing into necessary equipment, the owner transfers the investment to the District Heating operator for administration;
- An ESCO takes over the investment implementation activity and becomes the interface between the producer and the distributor of thermal energy;
- The District Heating operator ensures the connection of the residual thermal energy producer to the distribution network, under certain conditions;
- The possibility to develop thermal energy production systems from renewable sources / transformation of thermal distribution points for the distribution of heat in residential areas or districts, so that private investors can develop thermal energy production systems based on renewable energy sources, which will subsequently be transferred to the District Heating operator for administration.

Cernavodă DH system connected to the Nuclear Power Plant

In 1996, the Cernavodă Power Plant started the operation of the first Nuclear Reactor of 700 Mwe and in 2007 it has been commissioned the second reactor of 700 MWe.

In 2008, with the support of the CNE Prod company it has been developed the DH system of the city having a population of 15 000 inhabitants.

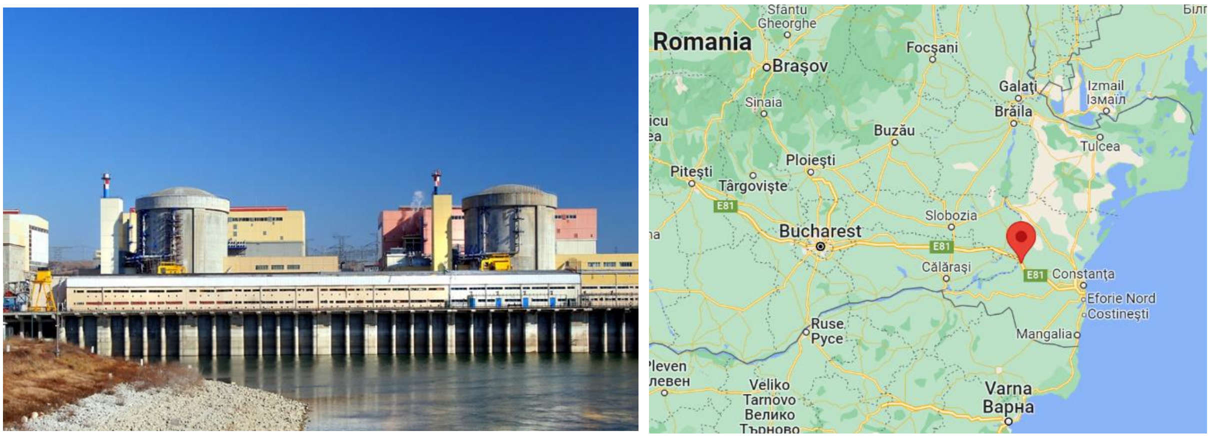


Figure 31. The Cernavoda DHN

At present, the total number of households connected to the DH network is 5518. The price of thermal energy at the end-user is 14,81 Euro/MWh that is the lowest price in Romania.

6 Lessons learnt from Romanian failed case studies

The Case of the City of Galați

During the 1970-1980 period, the thermal power plant (CET Galați) was located in the industrial area within the steel manufacturing complex. In that period, it has been developing also the national strategy for the implementation of DH systems by production of electricity and thermal energy in cogeneration and integrating also industrial waste heat. The integrated system was using industrial steam (temperature higher than 100 °C at a pressure of 12-16 bars) for industry and respectively hot water (65-120 °C) and for the use of the population. The concept of this developed by ISPE Bucharest and it has been applied in several big cities in that period.

Since 1990, during the shift from centralized economy towards market economy, the large industrial companies have been divided, or effectively disappeared from the market, and these situations caused to the Power Plant operators that were connected to the former large industrial companies to become oversized compared to the needs of their previous customers for thermal and electrical energy. Therefore, the production costs for the remaining customers (in most of the cases, the already existing old DH systems) have increased to unsustainable levels. The low level of natural gas distributed by public utilities offered an alternative for the citizens in peril and the installation of individual boilers in apartment dwellings became a phenomenon. The local authorities have been very weak to control the process by imposing minimal requirements for the evacuation of stack gases, safety requirements or health protection. Very soon, due to the massif decoupling of customers, the DH system of the city reached the point to be not possible to be managed and the municipality offered to subsidies for the remaining customers that were captive in the DH system, to install individual boilers or to connect to small DH islands served by natural gas fired thermal plants.

The case of the Brăila Municipality

A similar case with the one in Galați was developed in the neighbouring city of Brăila. The DH system of the city was integrated with the waste heat recovery facility of the industrial platform for pulp and paper from Chișcani.

The colaps of the pulp and paper company after 1990, left without heat source the DH system of the city and the shift towards a heat source based on natural gas was not possible due to the required investment costs for a new power plant and reconfiguration of the distribution and transport piping system.

As a consequence, the citizens have been put in the situation to find by themselves solutions to heat their apartments.

The Case of the City of Brașov

The city of Brașov has a long industrial tradition that started from middle ages when the city know as Kronstad was supplying with manufactured goods the whole SE Europe and Otoman Empire. The tradition continued in the 20th Century when the city became the industrial pole of Romania. Obviously, several industries where supplying waste heat to the DH system of the city and the system was operated very well assuring the satisfaction of the connected citizens.

The colaps of the industries from the region after 1990, brought the DH system to a very difficult situation and most of the citizens have decoupled from the system by installing individual boilers.

Figure 33. A new facility of cogeneration plant in Brasov city

By a public-private partnership, it has been developed a new approach by using 4 units of cogeneration internal combustion engines as heat sources. Part of the produced electricity is sold on the GRID balancing market for higher revenues and the DH operator – BEPCO is developing in the last years.

7 Conclusions

The document includes some of the results of the study of the paradigm change from a public and industrial perspective regarding WH/C and surplus RES recovery. Particular focus has been put to explore those opportunities associated to the level of environmental commitment which act as economic drivers of the industrial activity, affecting investments and business decisions.

The presented results underline the existence of two major trends within the EU. From one side, in Western European countries there is a trend of increasing emphasis on the development of DHNs that is supported by the commitment of the EC for energy efficiency, mitigation of CO_2 emissions, security and accessibility of energy to all citizens. But, there is also another trend mostly in Eastern European Countries with a history in centralized planning where the DH systems have been developed since 1960's and after 1990's it has been a process of restructuring and re-engineering for adaptation to the new conditions of market economy.

In the document, there is presented the case of Romania where in 1989 there were operational 315 DH systems and at present there are less than 50, creating a very big impact regarding the complexity and lack of viable solutions to manage large scale systems.

It looks like there is a big opportunity to concentrate on developing such solutions under the frame of the Horizon Europe Mission: Climate-neutral and smart cities that could have a huge impact at a very large geographical scale.

The activities within this project have demonstrated that there are many examples of innovative solutions like the case in Constanta, where the restructuring of the DHNs can be dome by integrating RES but, still there are barriers in the mentalities and practices of local authorities that are adopting classical conventional solutions that assure simple solutions for funding the required investments.

References

[1] : Tilia, Overview of District Heating and Cooling Markets and Regulatory Frameworks under the Revised Renewable Energy Directive, TU Wien, IREES, Öko-Institut, Fraunhofer ISI, October 2021, ISBN 978-92-76-52343-7, doi:10.2833/962525, MJ-07-22-263-EN-N, 2022

[2] E. Mamut, Thermal Energy Engineering, Lecture notes, Ovidius University of Constanta, 2022

[3] Euro Heat & Power Country by Country 2019 Study

https://www.euroheat.org/resource/the-2019-country-by-country-is-here-.html

[4] ADHAC Asociación de Empresas de Redes de Calor y Frío; Censo de Redes

https://www.adhac.es/portalsSrvcs/publicaciones/archivos/10_Presentacion_Censo_Javier_S_Ignacio_A.pdf

[5] R. A. Dunlap, "Heat Engines and Heat Pumps," in Sustainable Energy, 1st ed. Stamford, CT: Cengage Learning, 2015

[6] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[7] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)

[8] JRC European Commission JRC Technical Report Defining and accounting for waste heat and cold; Lyons, L., Kavvadias, K., Carlsson, J; 2021

[9] Schmidt, R.R., R. Geyer and P. Lucas (2020), The barriers to waste heat recovery and how to overcome them?
https://ec.europa.eu/futurium/en/system/files/ged/20200625_discussion_paper_v2_final.pdf

[10] Unconventional Excess Heat Sources for District Heating in a National Energy System Context; by Steffen Nielsen *ORCID, Kenneth Hansen ORCID, Rasmus Lund ORCID and Diana Moreno (2020)

[11] Herold, K.E., Radermacher, R., Klein, S.A., 1996. Absorption Chillers and Heat Pumps. CRC Press, ISBN 0-8493-9427-9.

[12] U.S. Department of Energy. Combined Heat and Power Technology. Fact Sheet Series

[13] Schmidt, T. and O. Miedaner (2012), Solar district heating guidelines - Fact sheet 7.2 - Storage,

[14] 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

[15] Integrating low-temperature renewables in district energy systems - Guidelines for policy makers IRENA 2021 (ISBN 978-92-9260-316-8)

[16] Arpagaus, C., Bless, F., Uhlmann, M., Schiffmann, J., & Bertsch, S. S. (2018). High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy. https://doi.org/10.1016/j.energy.2018.03.166

[17] 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

[18] JRC Technical Report - Defining and accounting for waste heat and cold; Lyons, L., Kavvadias, K., Carlsson, J (2021) ISBN 978-92-76-42588-5

[