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IEA HPT

Annex 47

Heat Pumps in District Heating and Cooling Systems

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Preface
This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) which is an Implementing agreement within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the Heat Pumping Technologies Programme. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC). Consistent with the overall objective of the HPT TCP the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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IEA Heat Pumping Technologies Annex 47

Heat Pumps in District Heating and Cooling Systems

Summary report:

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Marts 2019

1 Executive Summary

District heating in general and heat pumps connected to the grids in particular are predicted to play a key role in the energy grid and supply for the future. With the implementation of district heating, it is possible to cover up to 50% of the heating demand in Europe, and heat pumps can deliver around 25 % of the energy to the district heating grid. The Heat Roadmap Europe 4 scenarios with a larger share of district heating in the energy system show that the CO_2 emissions can be reduced with more than 70 % compared to today's situation.

Heat pumps can be a key technology in the future district heating grid in different ways:

1: Heat pumps can act as a balancing technology when the electrical production fluctuates.

2: Heat pumps phase out fossil fuels from the energy system.

3: Heat pumps make it possible to use very low (below 60 °C) and ultra-low (below 45°C) temperatures in the district heating grid.

4: Heat pumps make it possible to minimize grid losses in the district heating grid.

Structure of the annex work:

The work of Annex 47 has been divided in the following topics:

Task 1: Market overview: The present status and the possible changes for the future on country level as well as on European level are described.

Task 2: Demonstration projects. Different existing heat pump implementations in district heating grids are described in 39 cases.

Task 3: Reviews of different concepts/solutions: describe different implementation possibilities for heat pumps in the district heating grid.

Task 4: Implementation barriers, possibilities, and solutions: describe barriers for the integration of heat pumps as well as possible solutions.

Task 5: Dissemination.

1.1 Market overview

The Heat Roadmap Europe 4 (HRE4) project showed that for the vast majority of European urban areas district heating (DH) is a cost-efficient solution, which can provide at least half of the total heat demand in the 14 countries included in the study, while efficiently reducing CO_2 emissions and the primary energy demand of the heating and cooling sector. Based on its results, the project also suggests that large-scale heat pumps (HP) should have a big role to play in future DH systems in order to develop flexible and supply safe systems.

According to the HRE4 project, the European share of DH in the heating sector should increase from 12% (current values) to **50% by 2050**. This is an important shift in the European heating sector, and it shows that DH can be cost-effective and essential to significantly reduce CO_2 emissions in the energy sector.

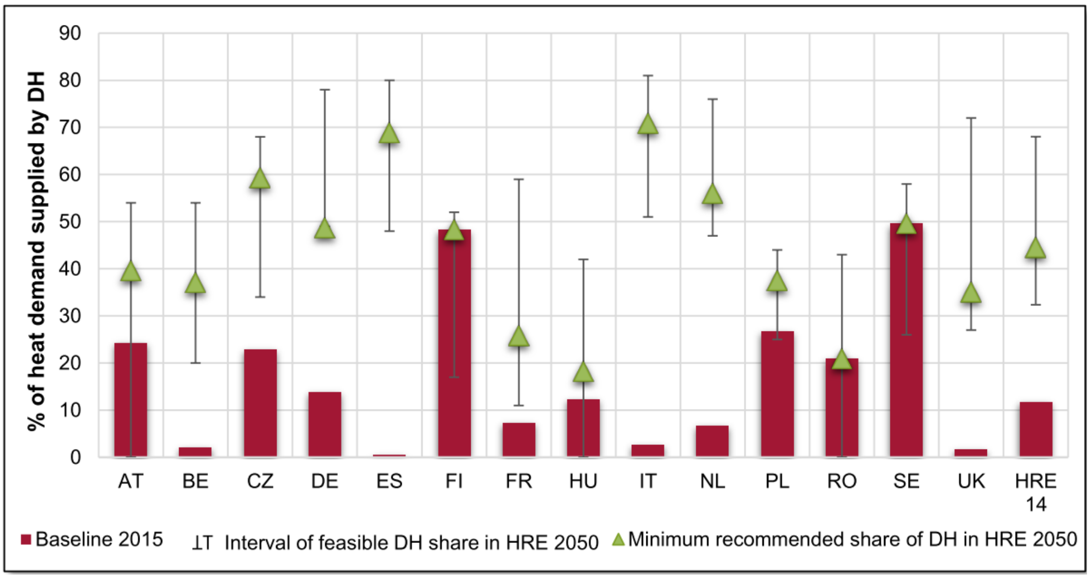

Figure 1: Share of district heating in 2015 (Baseline 2015), recommended level of district heating share in Heat Roadmap Europe 2050 (HRE2050), and the range of economically feasible district heating within a 0.5% total annual energy system cost change sensitivity [1].

In the HRE4 project, three main scenarios were developed:

- **BL 2015** – baseline scenario representing the current situation of the heating and cooling sector, based on data from 2015.
- **BL 2050** – this scenario represents the development of the baseline scenario under the current agreed policies regarding savings and RES, etc., but without any additional measures to improve the decarbonisation of the system.
- **HRE 2050** – scenario representing a highly-decarbonised energy system with redesigned heating and cooling sector that also includes energy savings. This scenario is solely based on proven technologies and does not depend on unsustainable amounts of bioenergy.

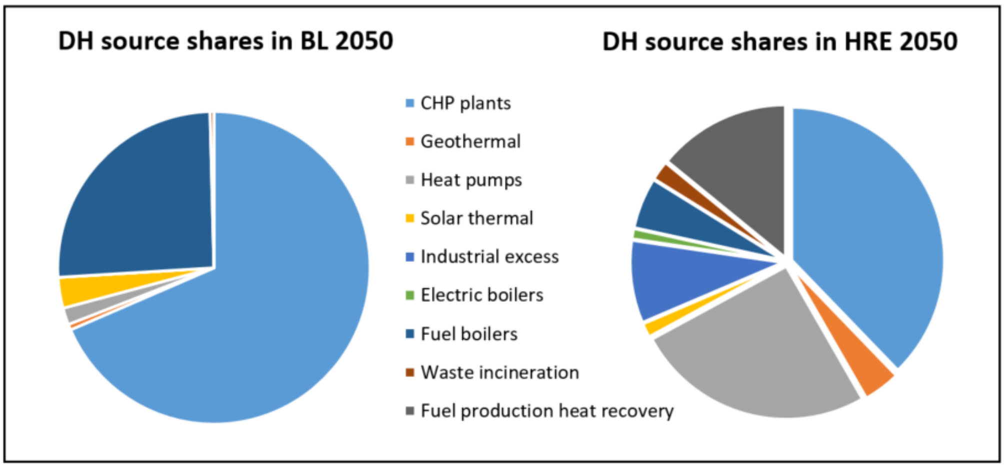

Figure 2: District heating sources share for BL 2050 and HRE 2050 scenarios [1]

In the modelled energy efficiency scenario for 2050 (HRE 2050), DH is supplied mostly by decarbonised energy sources and **25% of the total DH demand is met by large-scale HPs, see** Figure 2. This scenario would bring a higher variety of energy supply to the DH, which will increase the flexibility of the system as well as the security of supply. The HRE 2050 scenario shows that it would be possible to achieve a much more decarbonized DH in 2050 than in the BL 2050 scenario, which **reduces CO_2 emissions with more than 70%**.

1.2 Demonstration projects

One of the main objectives of Annex 47 is to show the possibilities regarding the implementation and integration of heat pumps in district heating grids. It was, therefore, an aim to create an ideas catalogue which shows different implementation cases. It has been possible for the project group to describe 39 different cases where heat pumps are integrated in a district heating grid. All the cases can be found at the [Annex 47 website](https://heatpumpingtechnologies.org/annex47)[1].

Figure 3: Task cases

[1] https://heatpumpingtechnologies.org/annex47

1.3 Review of different concepts/solutions

The research shows that large heat pumps have been integrated in the district heating networks since the 1980’s, especially in the Scandinavian regions. The widespread use of district heating networks as well as the increasing share of fluctuating power sources like photo voltaic (PV) and wind power combined with decreasing electricity prices have been the driving factors. Currently, Sweden is a forerunner using heat pumps in district heating and cooling networks. Approximately 7% of the district heating demand is produced by heat pumps. In other countries, the heat pump market consists mainly of devices for the supply of single and multi-family houses. Because of high system temperatures prevailing in many of the heating networks, adapted concepts are needed in order to be able to guarantee the cost-effectiveness of the systems. The aim of current research projects such as fit4power2heat is, therefore, to establish heat pumps by participating in various energy markets as an attractive alternative. It must be mentioned that especially in the last few years many efforts were initiated all over Europe to foster heat pump integration in district heating and cooling (DHC) networks.

Above all, the basis for economical operation is the correct design and hydraulic integration of the systems. Advantages can be achieved through different modes of operation. Instead of monovalent operation, additional heat generator(s) for peak load times can save a large part of the investment costs and risks.

Furthermore, different circuit options can be used in order to achieve the optimum operation of the system. Depending on which framework conditions exist, it is possible to exploit considerable potentials in terms of efficiency and, therefore, also in terms of costs. The correct design of the heat source system and the heat sink plays as much a role as the dimensioning of the heat pump itself.

As a first clue, the AIT internally developed an Excel based tool which can be used to pre-estimate feasibility and cost-effectiveness. With the help of simple calculations and compare them to already realized plants, first conclusions can be drawn. The more detailed information about the planned project, the more accurate the initial assessment can be. Through the conversion into Excel by means of VBA and the database integrated in the tool as well as the user interface, the calculations can be carried out relatively easily and without prior knowledge of special software. The quick and easy adaptation of the underlying database is, therefore, also guaranteed.

In addition to the electrically driven-compression heat pumps, also thermally operated heat pumps are used. Depending on the field of application, the advantages of the different technologies can be used.

With reference to the results achieved by the mentioned investigations, the importance and contributions of heat pumps in district heating networks were pointed out. In addition, recommendations for "best practice" strategies for the operation of heat pumps in combination with a central storage unit are presented:

- Heat pumps with dynamic pricing and demand-side management (DSM) are more resilient to market risks as dynamic operation counteracts fluctuations in fuel and electricity prices.
- Heat pumps increase the flexibility of district heating systems by expanding the heat generation portfolio, which enables higher reactivity through fast commissioning and low start-up costs as well as takes advantage of the volatility of the electricity market and thermal batteries.
- Heat pumps can be used to increase renewable heat generation. In addition, low-temperature heat sources and alternative heat sources (e.g. waste heat) can be used.

1.4 Implementation barriers, possibilities, and solutions

District heating networks are essential for the future energy system, especially in urban areas. The integration of heat pumps can reduce investment risks in DH networks, increase supply security, reduce CO_2 emissions and thus contribute to the COP 21 objectives agreed in Paris. At present, heat pumps play a minor role in European district heating networks.

Barriers to the large-scale integration of heat pumps are i.a. the lack of heat sources (often only available in small decentralized quantities) or a low temperature level of the sources (low efficiency). Similarly, most operators (still) have a lack of experience regarding the integration and operation of heat pumps in existing district heating systems (compared to well-known biomass or gas-based generation units).

Another barrier is the high temperature of the existing heat networks which reduces the efficiency of the heat pumps. Furthermore, the high temperatures of these networks lead to high heat losses, especially in residential buildings, which make heat networks almost unsustainable in very energy-efficient buildings. Therefore, the low temperature networks implementation would help to increase the use of heat pumps in these networks.

Nevertheless, in recent years there has been greater acceptance of heat pumps among district heating operators. This has led to many innovative heat pump projects as shown in Task 2.

The optimum combination of heat generation plants in DH networks depends on the various parameters and is correspondingly individual for each network. A method for the development of sustainable heat supply concepts for district heating networks is described in Task 3, and it consists of three phases as shown in figure 4.

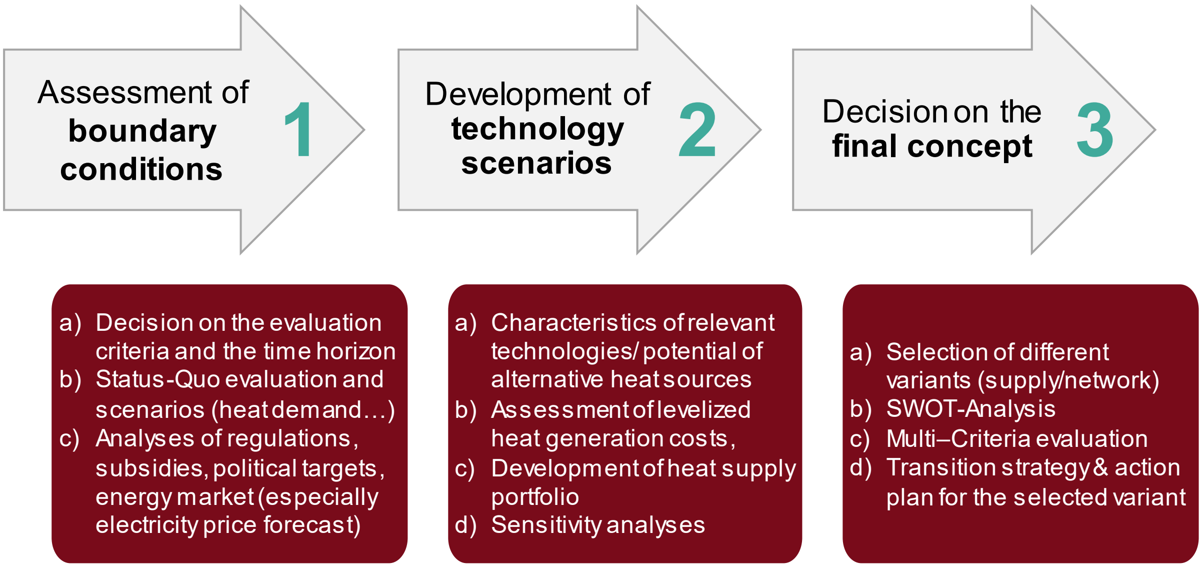

Figure 4: Three phases for the development of a heat supply strategy (Source: AIT) [7]

To achieve a sustainable heat supply, which includes a significant proportion of alternative heat sources, the implementation of more demonstration sites is necessary. **Success factors** are:

- **Strong partners** (companies, institutes, start-ups, etc.)
- **Projects** (demo, best practice, show up experiences and motivation to install HPs)
- **Learning by doing** (requires pioneers who are willing to "pay its dues “)
- **Energy spatial planning** (localizing waste heat, avoiding double infrastructure)
- **Standardized solutions** (R&D, cost degression/ economy of scale)
- **Price signals** (to the use of fossil fuel; reduce the burden from tax and levy on clean energy)

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2 Foreword

The Annex 47 project “Heat Pumps in District Heating and Cooling Systems” has been a long journey, where much has happened since the initialization of the project in 2015. There was resistance against the project before it started, especially from manufacturers of individual heat pumps for households, because they saw district heating as a competing technology to heat pumps, especially in suburban areas.

A huge development has happened since the start of the project. A strong focus has emerged in public among citizens and politicians, and they are aware of the necessity to decrease CO_2 emissions and the use of fossil fuels if the countries want to decrease global warming and keep the increase below the level of 2 °C as agreed in the COP21 climate agreement from Paris 2015. Energy systems, Smart Grid, and balancing between producers and consumers or prosumers as well as smart metering, increasing electrification, gas pipes, and dependency are subjects that fill people’s minds today.

An awareness is also growing around the fact that heat pumps as a technology can be the link to connect different energy systems such as the electrical grid, the gas grid, and the district heating grid. However, it can also be the link between the need for cooling and the need for heating as well as the reuse of waste heat. Studies show that 50 % of the heating demand for buildings in Europe can be covered by excess heat. District heating and heat pumps are the key technologies to open and use this potential.

Before and during the execution of Annex 47, several projects have been started/carried out concerning the implementation of heat pumps in district heating and cooling grids. This implementation has been made in both new and existing grids. Moreover, it has been done at different temperature levels and in different concepts. The Annex 47 project shows that heat pumps can be used in different ways and at several levels in the grid.

A great thanks goes to the project partners and the group for their participation and contribution to the project.

Svend Pedersen

Danish Technological Institute

3 Annex 47 Objective and Scope

3.1 Background

Today, there is a wide focus on using energy more efficiently. District heating and cooling (DHC) systems present a solution to increase the overall energy efficiency. A solution to increase the share of renewable energy in DHC systems is to introduce heat pumps in the system.

At the working team meeting and the National Team Meeting of the IEA Heat Pump Programme in October 2013 in Nurnberg, Germany, heat pumps in DHC systems were the focal point of discussion. Many subjects were discussed: How to implement heat pumps in thermal grids with multiple energy sources, heat pumps with multiple functions, e.g. domestic heating, heating of hot tap water, and the management of the demand side.

Several projects have been carried out concerning the implementation of heat pumps in DHC systems all over the world.

It is necessary to show how heat pumps can be implemented in DH systems from large cities to urban areas or settlements in a smart and sustainable way so that the CO_2 reduction becomes as large as possible for the entire system. It is also very important to show how the different types of implementation of heat pumps in DH systems can increase the efficiency of the DH system and increase the use of waste heat and renewable energy, both directly in the DH system, but also on the production side. Obstacles to the implementation must to be uncovered and experience from existing projects should be identified.

The objective of this Annex was to gather information and ideas for policy makers, decision makers, and planners of energy systems in urban areas concerning the possibilities and barriers related to the implementation of heat pumps in DHC systems.

One objective has been to suggest how heat pumps can be implemented in both new and older district heating systems in the best way. The different types of integration have been described. The differences and possibilities in integration in both central and local systems have also been described.

The possibilities of increasing a larger share of renewable energy or using excess heat in the different systems by using heat pumps have been a focus area and so has the minimizing of the system losses by using heat pumps.

Existing projects where heat pumps are integrated in district heating systems have been described for each participating country (Austria, Switzerland, Sweden, Denmark, UK).

4 Structure of this document

This document is the final summary of the work, which has been done within the IEA HPT Annex 47 project over the last four years. As such, it presents the perspectives gathered in the project on how to implement heat pumps in district heating and cooling grids. Several documents containing country reports and more detailed analyses are distributed together with this summary (listed in Appendix B). All the reports are available at the IEA HPC website.

This report starts with an introductory part on the principle benefits, which are provided by heat pumps in district heating grids.

Following the introductory part "**Part I**", the following content is presented in the following order:

Part II – Market and energy reduction potential

An assessment of the present market situation and future perspective for heat pumps in district heating is described in this part. Within this document, only the summarising results have been included. Full country reports are available as separate documents.

Part III – Description of different solutions/demonstration projects

This part gives an overview of demonstration projects, which have been carried out in the participating countries. These projects have resulted in a wealth of knowledge about the practical implementation successes and failures of heat pump integration in district heating systems. An introduction to different cases is described in the Task 2 report, and underlying cases are described by the different participating countries.

Part IV – Review of different concept solutions

This part gives an overview of different implementation possibilities and solutions regarding the implementation of heat pumps in district heating grids. It gives an overview of heat pumps in current networks and their sources, and it introduces the design of the systems.

Part V – Implementation barriers, possibilities, and solutions

The last part gives an overview of alternative heat sources in district heating networks, and it describes the barriers for the integration of heat pumps. Possible solutions are described as well as business models.

Part I Introduction to heat pumps in district heating and cooling systems

5 Introduction

The heating demand in EU corresponds to around 50% of its total energy demand [1]. The electricity sector has seen many improvements in the last few decades in terms of savings and energy efficiency measures. However, the heating sector still has a long way to go to become decarbonized, and several studies have shown that the potential to make it more efficient and renewable is very high, especially in countries which already have a high share of district heating systems.

In Europe, a big share of the residential heating is still based on individual systems where water-based radiators supplied by gas-based individual boilers provide heat for each flat. Natural gas is the most imported fuel to the EU, and in total, three quarters of the energy imports for heating and cooling are in the form of fossil fuels, which indicate a strong dependency on non-EU countries.

There are different strategies which can be used to improve decarbonisation of the heating sector. Although much attention has been given to the demand side (by retrofitting the building stock) in the past, the focus has lately changed to the type of heat supply, which would also enable the EU to have more renewable and geo-political independent systems. District heating is an important solution in these regards, since its fundamental idea is to use local fuels and any available sources of heat, which otherwise would be wasted, and to integrate Renewable Energy Sources (RES). DH systems in urban areas allow the wide use of Combined Heat and Power (CHP) and Waste-to-Energy (WTE) solutions as well as the integration of surplus heat sources such as excess industrial heat and renewable heat sources such as geothermal and solar thermal heat.

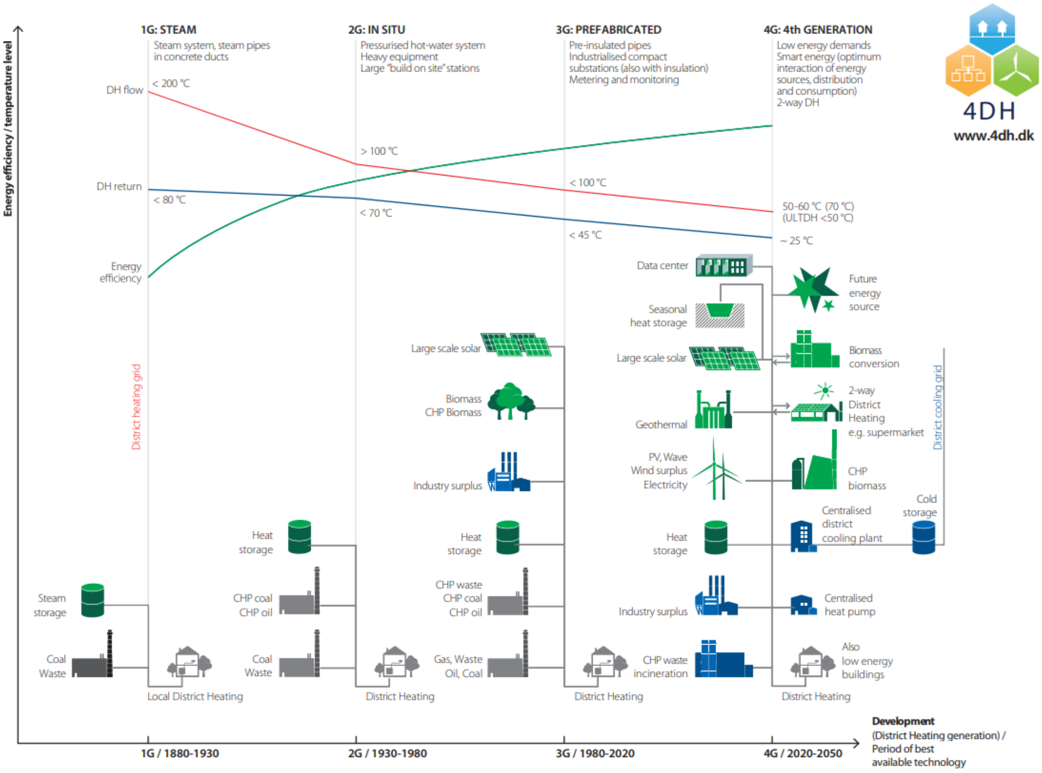


Figure 5: District heating technology evolution (source 4DH research centre, www.4dh.eu)[6]

DH systems have been evolving with a trend towards lowering supply temperatures and introducing different producing units. As shown in figure 5, it is possible to identify three distinct generations of DH until today, while currently moving towards the 4th generation.

The 4th generation of DH is characterised by an integration of both thermal and electrical systems with low supply and return temperatures. When based on CHP, power-to-heat solutions such as large-scale heat pumps (HPs) allow the use of more RES. In this way, DH is becoming more than a system for the distribution of heat; it is becoming increasingly important to integrate intermittent RES as well.

Studies suggest that DH, together with thermal storage and large-scale HPs, is more feasible, fuel-efficient, and cheaper than individual solutions in areas with high urban density. Large-scale electric HPs are an important technology to make DH systems even more efficient and renewable. HPs are essential to developing a 4th generation DH, and they are useful to improve and transform a 3rd generation DH system in case there are low-temperature heat sources available, which need to have their temperatures lifted in order to integrate the DH.

Part II Market and energy reduction potential

6 Market and energy reduction potentials

6.1 Future potentials for large-scale heat pumps

According to a survey from 2016, there are 149 units of large-scale HPs with thermal capacities higher than 1 MW_{th} operating in DH systems in 11 European countries. Figure 6 is a result of this survey, and it shows the year when the HPs were installed in the seven countries with the highest capacities installed. Sweden is the country with most thermal capacity installed, and it is also the one with older large-scale HPs. Other countries, like France and Denmark, have only recently started to install these elements in their DH systems, and the number of installations is still growing.

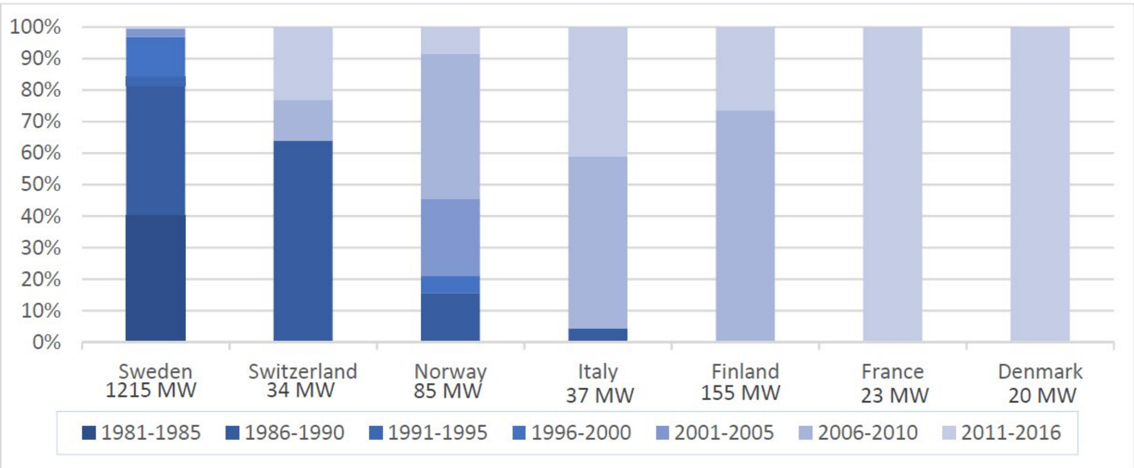


Figure 6: Overview of installed capacity of HPs in Europe and total thermal capacity in each country [1]

Sweden built most of its installed capacity during the 1980's, when there were high levels of excess electricity production from the nuclear power plants and a limited export capacity. During that time, hydrofluorocarbon (HFCs) refrigerants were still in use, which allowed the installation of very large HPs with average capacities of 19 MW_{th} by the end of the decade. Nowadays, approximately 1.000 MW_{th} of these large-scale HPs are still operational.

Table 1 presents the aggregated installed capacity and the number of units for every five years. Moreover, it shows that the average installed capacities have decreased during the years in Europe. This is mainly because there is a competition from other types of heat production, and there is a lack of surplus electricity to enable HPs to operate continuously in full capacity.

Year	Capacity (MW_{th})	Number of Units	Average Capacity (MW_{th})
1981–1985	490	37	13
1986–1990	533	28	19
1991–1995	35	3	12
1996–2000	157	10	16
2001–2005	59	8	7
2006–2010	173	20	9
2010–2016	121	37	3
Total	**1568**	**143**	**11**

Table 1: Overview of installed large-scale HPs in Europe from 1981 to 2016 [1]

In current DH systems, large-scale HPs are used in full capacity most of the time, which means that it would make sense to install them if: a) there is a constant surplus of electricity production in the system; b) the price of electricity makes the use of HPs feasible; or c) the socioeconomical and environmental gains are high enough to compensate the extra costs. In this sense, there is still room for improving the current DH systems by introducing large-scale HPs to lift temperatures from low-temperature heat sources or to reuse excess heat from industries or power production.

6.1.1 Current and future potentials for district heating

The Heat Roadmap Europe 4 (HRE4) project[2] [1] modelled the heating and cooling sectors of the 14 EU countries[3] with higher heat demands, which together represent 90% of the total European heat market. The following figure 7 presents the current share of DH in each of the modelled countries and the recommended shares, which DH should represent in 2050 according to the results from the project.

[2] www.heatroadmap.eu

[3] Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Spain, Sweden and United Kingdom

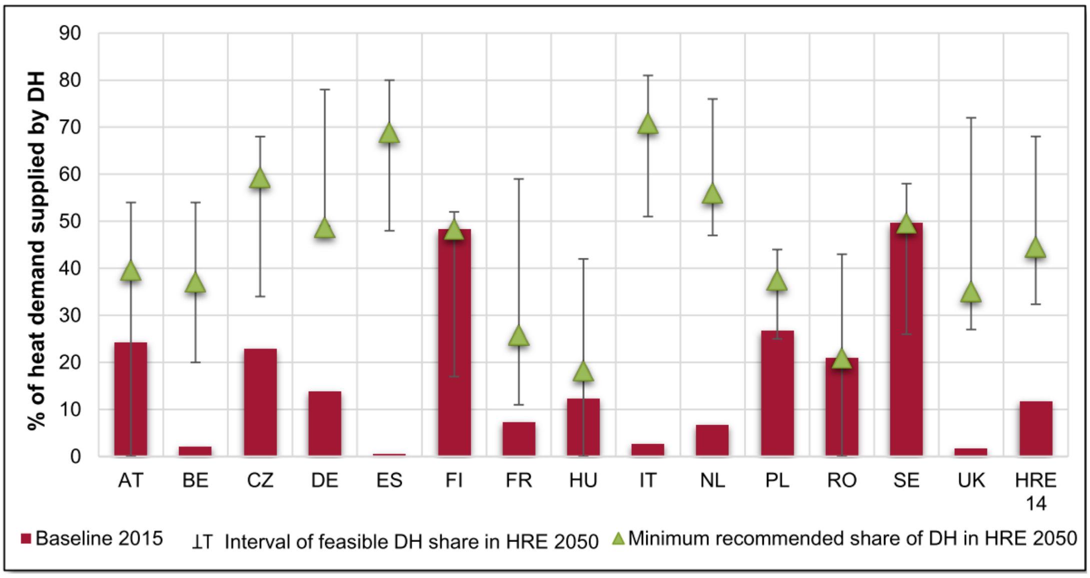


Figure 7: The share of district heating in 2015 (Baseline 2015), the recommended level of district heating share in HRE 2050, and the range of economically feasible district heating within a 0.5% total annual energy system cost change sensitivity [1].

As presented in Figure 7, the current share of DH in the heating market in Europe is 12% (according to the Baseline 2015 scenario). The HRE 2050 scenario recommends a share of DH of about 50% of the heat market, which would enable major savings in primary energy supply and CO_2 emissions in the heating sector. This opens the way for an opportunity for a full-decarbonised energy system. Having around half of the heat demand in Europe covered by DH would be a major shift for the markets in most of the member states, which shows the importance of a new and integrated approach towards supporting DH as a mean of achieving deeply decarbonised energy systems.

Nevertheless, depending on the country, going beyond the recommended values towards the maximum feasible DH levels might bring more benefits such as jobs and industrial development, security of supply, and reduced geopolitics tensions for allowing higher use of domestic fuels. Moreover, a very high share of DH in the heat market is more cost efficient than a full electrified heating system, which would neither enable the recovery of excess heat, nor the creation of a link between the electricity, heating, and thermal storage, which would limit the overall efficiency of the system.

The scenarios developed in the HRE4 project and used in this report are:

BL 2015 – this (BL) scenario represents the current situation of the heating and cooling sector based on data from 2015.

BL 2050 – This scenario represents the development of the baseline scenario under the current agreed policies regarding savings and RES, etc., but without any additional measures to improve the decarbonisation of the system.

HRE 2050 – this scenario represents a decarbonised system with a redesigned heating and cooling sector, which includes energy savings as well. In this sense, this scenario includes a high level of performance from buildings and extensive savings in the industry sector, besides including the reuse of excess heat, use of efficient renewables, and the use of individual HPs (in rural areas) and large-scale HPs (in district energy networks in urban areas). This scenario is also based on only proven technologies and does not depend on unsustainable amounts of bioenergy.

Figure 8 shows the DH shares in the BL 2050 scenario, the range of economically feasible DH shares in the HRE 2050 scenario, and the DH level modelled in the HRE 2050 scenario.

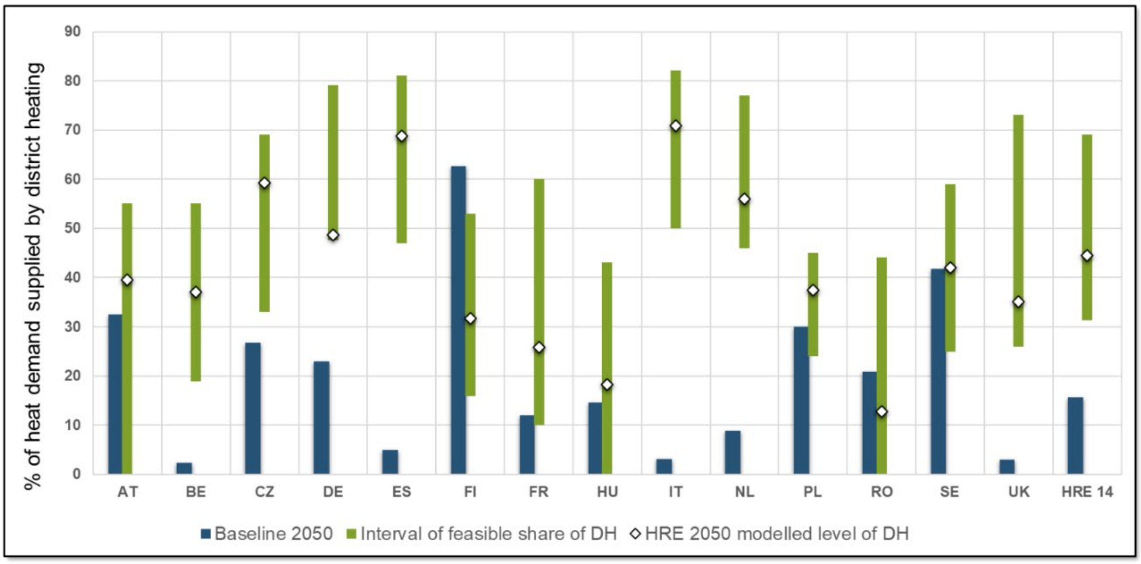


Figure 8: Baseline 2050 share of district heating, modelled share and interval of economically feasible DH in the HRE 2050 scenario [1]

If assumed that the current trends, policies, and goals will not change until 2050, the DH share in the 14 HRE countries will slightly increase, reaching around 16% of the heat market (Baseline 2050 scenario), which represents a very limited development from the current value of 12%. On the other hand, the HRE 2050 scenario is modelled with DH covering about 50% of the heat demand in the 14 countries accounted for in the project. However, this is a conservative approach, which means that the DH share could be expanded up to almost 70% of the total heat demand with additional strategic energy planning measures. Although the costs would increase, the higher the share of DH, the higher some other benefits such as security of supply, jobs creation, and industrial development would be. A very high share of DH in some countries could also mean a decrease of possible geopolitical tensions related to energy supply and the creation of more fuel-efficient systems as it would be possible to recover more excess heat from different sources and to integrate more renewables.

The values of DH modelled for the HRE 2050 scenario are based only on economic metrics. When looking at figure 8, the modelled DH levels for Finland and Romania are below the BL 2050 levels due to a “least-cost approach”. The main reason for the high or low levels of DH in each country is the spatial density of the heat demand in urban areas and the excess heat available nearby.

6.1.2 District heating supply

The DH supply for the HRE 2050 scenario is designed in order to avoid the direct use of fossil fuels. However, although excess heat from industries and cogeneration might be of fossil-fuel origin, the scenario considers the use of existing heat sources and the improvement of the efficiency of the overall system.

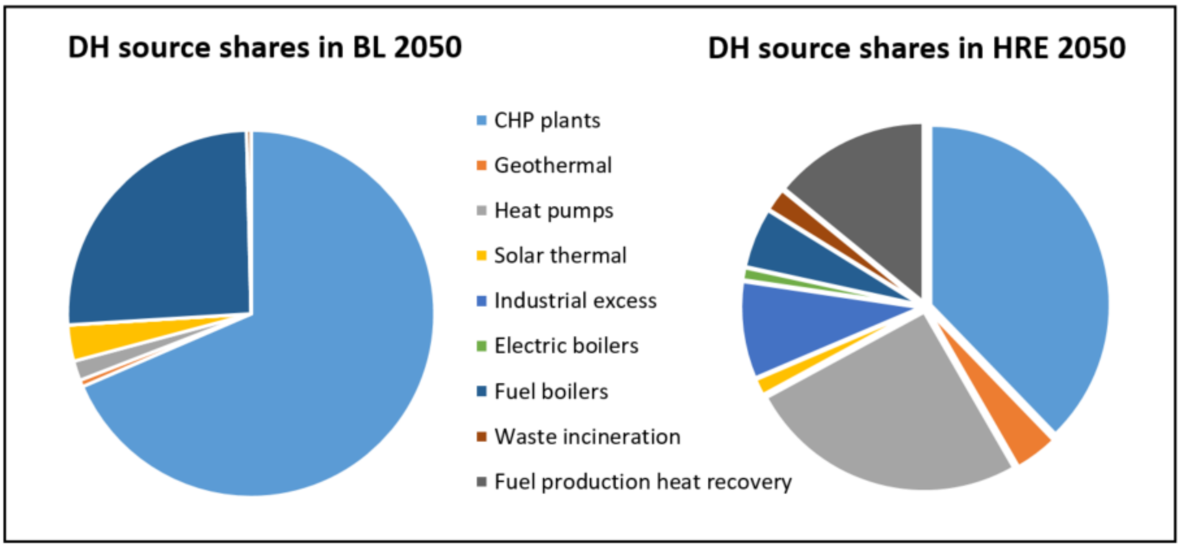


Figure 9: District heating sources share for BL 2050 and HRE 2050 scenarios (Source HRE4 project) [1]

Figure 9 shows the shares of the DH supply for the BL 2050 and HRE 2050 scenarios, respectively. If there would be no changes in the current trends of heating and cooling policies, when considering the **BL 2050** scenario, the **total DH production in the 14 countries would be 550 TWhth/year**. 69% of this amount would be supplied by CHP, 26% would still be supplied by fuel boilers, 17% by solar thermal, and only **2% would be supplied by large-scale HPs**. The BL 2050 scenario would not be a scenario favourable to a decarbonised energy system and neither would it improve the penetration of renewables.

On the other hand, the **HRE 2050** scenario shows that, even with conservative projections, it would be possible to achieve a much more decarbonized DH in 2050. With **a total of 1100 TW$_{th}$h/year of DH production**, 38% would be supplied by CHP, **25% by large-scale HPs**, 14% would have origin in recovered excess heat from fuel production, and 9% from industrial excess heat. Renewables would also be integrated in a higher scale in this scenario; with 4% of geothermal, and 1% of solar thermal and electricity from wind being used to feed in the large-scale HPs. **This scenario would bring a higher variety of energy supply to the DH, which increases the flexibility of the system as well as the security of supply**.

Since HRE4 modelled 90% of the European heat market, the results of this project are actual references to what all European member states should aim for when designing heating and cooling systems for the future. In the following section, the potentials for large-scale HPs in the BL 2015, the BL 2050, and the HRE 2050 will be presented. This provides an indication of what could be the future market share for this technology in Europe.

6.2 Large-scale HPs installed capacities

In order to provide the DH demand for the HRE 2050 scenario, the total installed thermal capacity of DH technologies would have to be around 400,000 MW$_{th}$, where **95,000 MW$_{th}$ correspond to the total installed capacity of large-scale HPs, which represent a share of 23% in the DH network**.

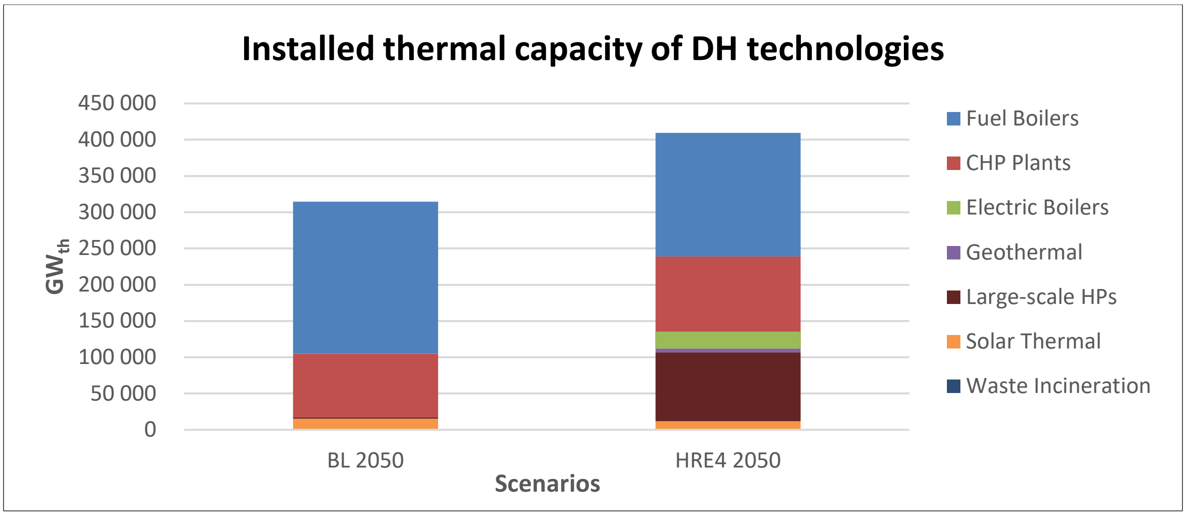


Figure 10: Installed thermal capacities of DH technologies in the BL 2050 and HRE 2050 scenario [1]

When comparing the installed capacity for DH in the BL 2050 scenario and the HRE 2050 scenario, as presented in figure 10, it is possible to see that large-scale HPs have the biggest increase of installed capacity, which shows the importance HPs will have in the future to build decarbonised and efficient DH systems. In fact, in the HRE 2050 scenario, there is an intentional overcapacity of large-scale HPs installed to allow them to function in a flexible way. The following table 2 presents the installed capacity of large-scale HPs in each HRE country as well as the heat, which they produced, and the percentage of full load hours, which they operate per year.

Country	Installed capacity of large-scale HPs (GW_{th})	Share of installed capacity of HPs in the DH	Heat produced by large-scale HPs ($TW_{th}h$/year)	Share of heat produced by HPs in the DH	Percentage of full load hours HPs operate per year	Total DH production ($TW_{th}h$/year)
AT	4,8	37%	10	34%	24%	30
BE	4,0	31%	9	27%	26%	34
CZ	4,0	28%	10	27%	29%	38
DE	22,0	24%	64	24%	33%	265
ES	8,0	29%	21	26%	30%	81
FI	2,8	22%	11	36%	43%	30
FR	6,4	29%	13	16%	24%	85
HU	1,0	19%	3	26%	36%	12
IT	10,4	11%	48	23%	53%	210
NL	5,6	21%	19	28%	38%	66
PL	6,8	26%	16	26%	28%	62
RO	1,6	27%	4	31%	28%	13
SE	4,0	33%	12	34%	33%	34
UK	13,6	29%	38	28%	32%	136
HRE14	**95,0**	**23%**	**279**	**25%**	**33%**	**1,097**

Table 2: Installed capacity and heat produced by large-scale HPs, percentage of full load hours HPs operate per year, and DH production in the HRE 2050 scenario (Source HRE4 project) [1]

From Table 2, according to the HRE 2050 scenario, it is possible to see that in some countries large-scale HPs will cover higher shares of the future heat market, e.g. in Austria, Finland, Romania, and Sweden. It is worth mentioning that the total amount of heat produced by HPs is not directly proportional to the installed capacities because HPs operate on full capacity during different periods. This is how the DH systems in each country were modelled. However, there is a potential to increase these levels. It is recommended that large-scale HPs operate on full load hours for about half of the time during a year. This means that without increasing the installed capacities, large-scale HPs could have a much higher share in the heat market while still being able to operate in a flexible way. In the HRE 2050 scenario, if large-scale HPs would operate at full load capacity half of the time during a year, they would have **a heat market share of 38%** of the DH production (Table 3).

Table 3 shows the heat market for large-scale HPs in each country if they would operate half of the time at full load hours in the HRE 2050 scenario. According to these values, there is a potential to optimize the operation of large-scale HPs in the DH systems modelled in the HRE 2050 scenario. Without increasing the installed capacities of this technology, it would be possible to have higher shares of heat produced by large-scale HPs if they would operate for more hours during the year at high capacities, while still maintaining their flexible way of operation in connection with the operation of CHP.

Country	Total heat produced by large-scale HPs ($TW_{th}h$/year)	Share of heat produced by HPs in the DH system ($TW_{th}h$/year)	Percentage of full load hours large-scale HPs operate per year	Total heat produced by large-scale HPs when operating half of the year at full load hours ($TW_{th}h$/year)	Share of heat produced by large-scale HPs when operating half of the year at full load hours in the DH system ($TW_{th}h$/year)
AT	10	34%	24%	21	70%
BE	9	27%	26%	18	51%
CZ	10	27%	29%	18	46%
DE	64	24%	33%	96	36%
ES	21	26%	30%	35	43%
FI	11	36%	43%	12	41%
FR	13	16%	24%	28	33%
HU	3	26%	36%	4	36%
IT	48	23%	53%	46	22%
NL	19	28%	38%	25	37%
PL	16	26%	28%	30	48%
RO	4	31%	28%	7	55%
SE	12	34%	33%	18	52%
UK	38	28%	32%	60	44%
HRE14	279	25%	33%	416	38%

Table 3: Installed capacity and heat produced by large-scale HPs, percentage of full load hours HPs operate per year and DH production in the HRE 2050 scenario (Source HRE4 project) [1]

The HRE 2050 scenario included conservative estimations also related to the installed capacities. For the DH systems, only electric compressor large-scale HPs were considered in the HRE4 project, with output temperatures of 80-100 °C, and using bodies of water available from nearby urban areas as heat sources. To make the system more efficient, excess heat from industry or power production, which has temperatures high enough to be directly incorporated in the DH grid, were also included, which is the cheapest heat source. However, low-temperature excess heat sources which would require HPs to upgrade the delivered temperature were not included in the analysed scenarios. Although low-temperature heat sources in urban areas are available, they are not considered in the HRE project because this would require further geographical data and analyses. Nevertheless, there is a high potential for the use of large-scale HPs to upgrade low-temperature heat sources in order to increase their share in the DH.

Low-temperature excess heat sources are defined as excess heat from services, industry or specific buildings, and typically they have temperatures between 5°C and 40°C. These excess heat sources need to have their temperatures lifted in order to be integrated in 3rd generation DH systems which, on average, operate with supply temperatures above 80°C. Table 4 presents the potentials for low-temperature excess heat sources in Europe which could be recovered to DH grids, while being upgraded with the use of large-scale compressor HPs with a COP of 3. These low-temperature heat sources were investigated during the project ReUseHeat[4], and they are divided into four indicative unconventional excess heat sources, not representing the total diversity and amount of low-temperature heat sources available.

Country	Data centres 25°C - 35°C (TWthh/year)	Metro stations 5°C - 35°C (TWthh/year)	Service sector buildings 30°C - 40°C (TWthh/year)	Waste-water plants 8°C - 15°C (TWthh/year)	Total 5°C - 40°C (TWthh/year)
AT	2.0	0.3	0.8	6.6	9.8
BE	2.5	0.3	2.3	4.0	9.1
CZ	1.8	0.3	0.5	5.5	8.0
DE	16.3	2.0	7.4	33.7	59.3
ES	4.8	2.9	16.5	6.3	30.5
FI	2.6	0.1	0.6	3.4	6.7
FR	12.7	3.1	13.9	23.8	53.5
HU	1.3	0.3	1.1	4.5	7.2
IT	5.7	1.6	19.1	11.1	37.5
NL	2.3	0.2	0.7	4.3	7.4
PL	4.3	0.2	2.2	18.6	25.2
RO	1.4	0.3	2.2	5.1	9.0
SE	3.7	0.3	1.5	5.6	11.1
UK	7.7	0.8	6.7	25.9	41.1
HRE14	**69.1**	**12.7**	**75.5**	**158.1**	**315.4**

Table 4: Accessible low-temperature excess heat in HRE14 countries, from four types of unconventional sources, within 2 km from urban DH networks [1]

In Table 4, only the unconventional low-temperature heat sources that exist within 2 km from urban areas are accounted for. This extra potential to recover excess heat into the DH systems means that the installed capacities of large-scale HPs might be even higher in the future than estimated by the HRE project if the heat pumps are to be used for recovering heat from unconventional heat sources as well. In fact, the amount of heat, which theoretically could be recovered from these unconventional sources, is so significant that it could replace the need of fuel boilers in the BL 2015 and the HRE 2050 scenarios completely and still reduce the need for other energy demanding heat sources. However, it is not possible to conclude on the financial benefits of, for instance, completely replacing the fuel boiler without further analyses of the whole energy system. In reference, Figure 11 presents the level of accessible low-temperature excess heat in the 14 HRE countries compared with the DH production in the BL 2015 and HRE 2050.

[4] https://www.reuseheat.eu/

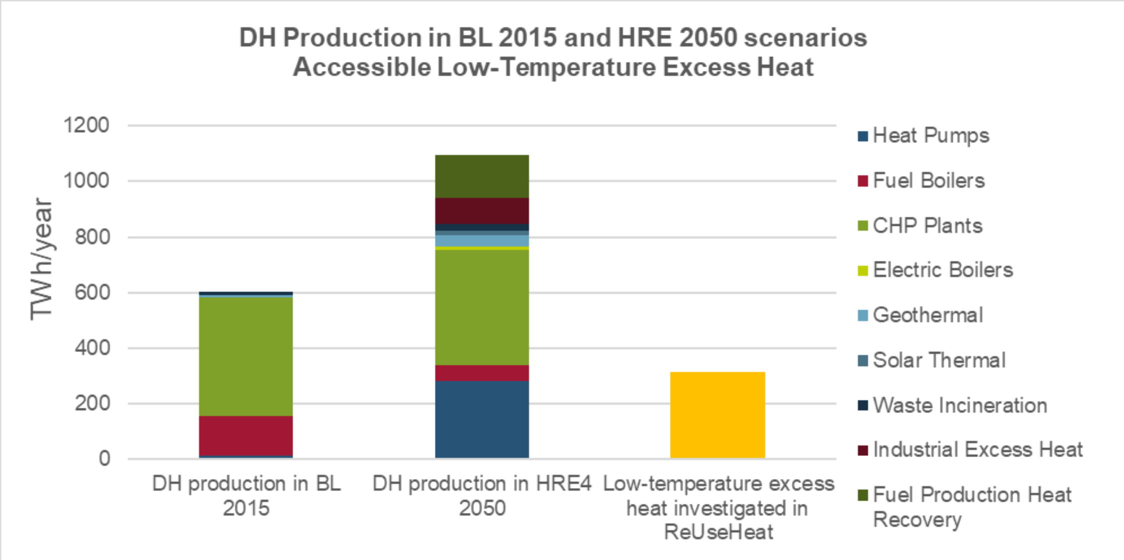


Figure 11: Comparison between the DH production in the BL 2050 and the HRE 2050 scenarios, and the accessible low-temperature excess heat in the 14 HRE countries (Source HRE4 project and [1]).

Figure 11 shows that the results for the large-scale HPs potential in the HRE 2050 scenario (where only water bodies, rivers, and sewage water are used as low-temperature heat sources) are likely to be very conservative compared with the real potential. The amount of accessible low-temperature excess heat from unconventional sources in Figure 11 is merely indicative of the fact that the potential of large-scale HPs in future energy systems might be much higher than the one predicted in the HRE project. Besides, further technology improvements are possible, especially when aiming for low-temperature DH and a 4th generation DH. If the required temperature for DH would be lower, between 50°C and 60°C, it would be possible to recover a higher amount of heat from unconventional low-temperature heat sources, while still using large-scale HPs with a COP of 3 to uplift the temperatures.

6.3 Higher integration of renewables and CO_2 reductions

In the HRE 2050 scenario, the electricity production is much higher than the one in the baseline scenarios because a very high level of electrification of the industry and transport sectors is assumed. Moreover, there is a high demand of electricity to produce e-fuels. This broader diversity of electricity sources is what gives the system a high level of flexibility, and it is only possible due to the synergy between the electricity and heating sectors, which is created with the use of large-scale HPs.

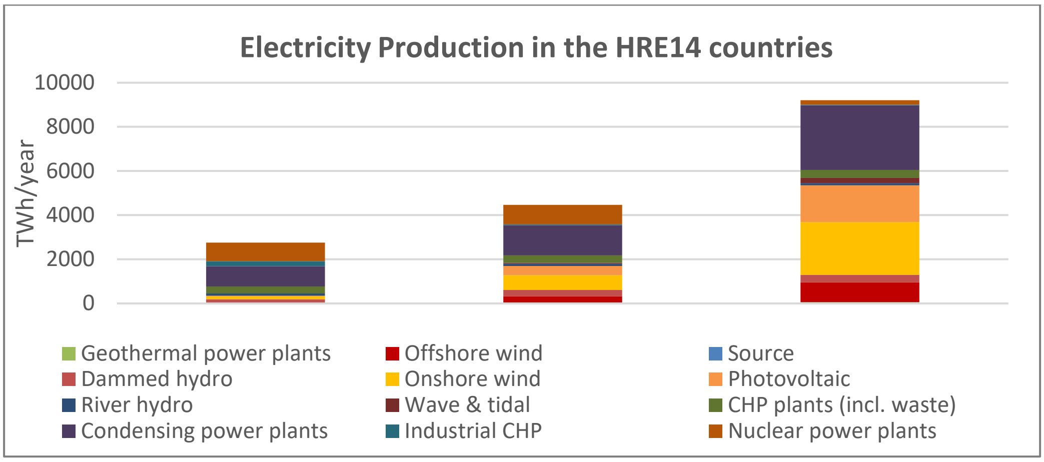


Figure 12: Electricity production in the BL 2015, BL2050, and HRE 2050 scenarios (Source HRE4 project) [1]

As presented in Figure 12, renewables account for a higher share in the HRE 2050, representing 64% of the electricity production, while in the BL 2050, the renewables only account for 42%. Onshore wind is the RES with the higher share in the HRE 2050 scenario.

The higher share of renewables being integrated in the energy system will lead to lower CO_2 emission levels. As can be seen in Figure 13, the HRE 2050 scenario represents a deeply decarbonised system with much lower emissions compared with the baseline scenarios.

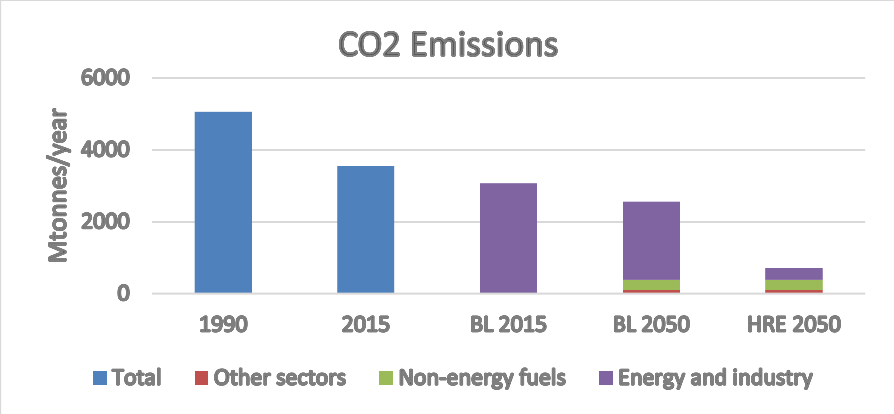


Figure 13: CO_2 emissions for the HRE14 countries (Source HRE project) [1]

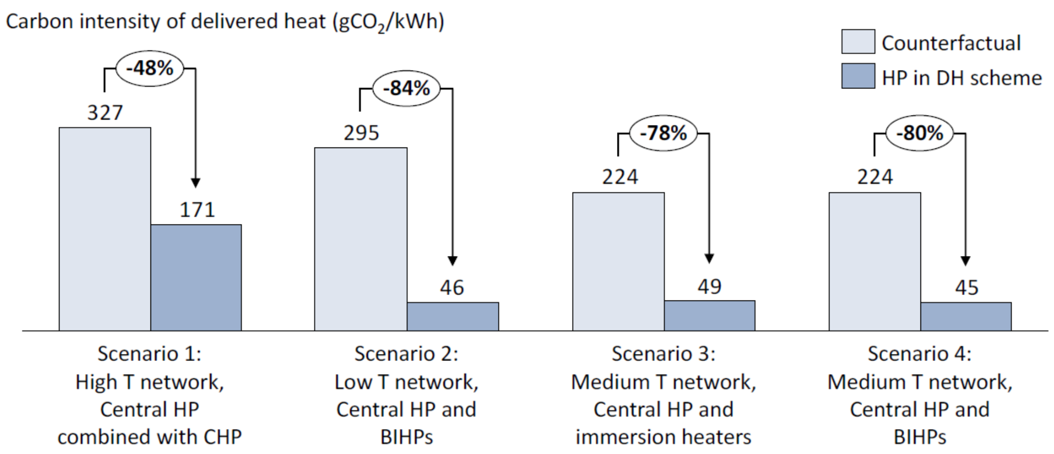
In the DECC Heat Pumps in District Heating Final Report [10], one of the key findings was that alongside a decarbonizing grid, the integration of heat pumps into district heating offers a large potential for CO_2 emission reduction.

The applied scenario analysis, which uses the model, showed that incorporating heat pumps into district heating schemes have the potential, in the context of a rapidly decarbonising electricity grid, to offer large CO_2 savings relative to a counterfactual of district heating based on either gas-CHP (for large schemes) or gas boilers (for small schemes). Assuming the current trajectory towards a low carbon electricity generation, it was found that CO_2 savings versus the counterfactual scheme in the range of 48-84% across the four core scenarios, as shown in Figure 14.

As may be expected from simple thermodynamic arguments, the report showed that CO_2 savings are greater in cases where the following scheme characteristics are combined:

- Heat pumps provide a larger fraction of the heating
- Heat pumps operate with a lower source-sink temperature difference, leading to increased efficiency
- Network thermal losses are lower, typical for lower temperature networks

As a result of the various configurations studied, it has been found that low or medium-temperature networks based entirely on heat pumps offer the greatest CO_2 savings potential.



[1] The four core Scenarios describe district heating schemes serving a range of different areas/buildings, from a large-scale area of existing mixed-use buildings to a small-scale, new residential development. Therefore, the counterfactual scheme is in general different in each case.

[2] The counterfactual is based on gas CHP for Scenarios 1 and 2, and gas boilers in Scenarios 3 and 4.

Figure 14: Comparison of the carbon intensity of delivered heat for counterfactual and the HP in DH scheme for each of the four Scenarios studied. [10]

6.4 DH implementation costs

The HRE 2050 scenario has a high degree of decarbonisation, and its high level of energy efficiency measures makes it the scenario with the most investments needed to be made in the DH networks. Expanding the DH grids and achieving the installed capacity modelled in the HRE 2050 scenario require some significant investments. However, these investments would only represent 14% of the total investments necessary in the heating and cooling sector (which include a very high level of investments in savings). The annualized costs of the investments for all the components needed to expand the DH grid can be found in Figure15.

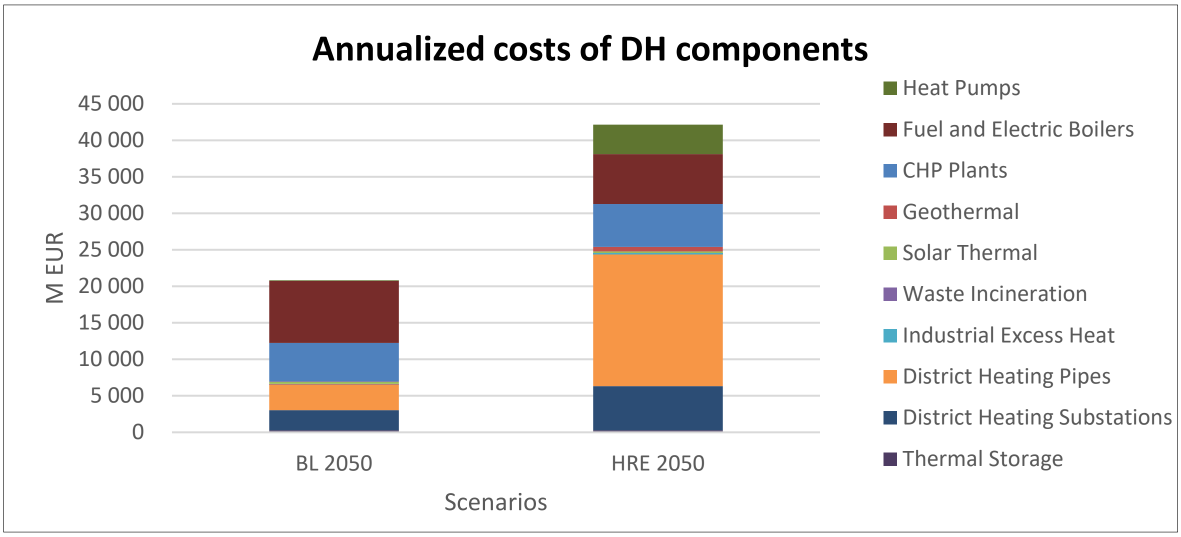


Figure 15: Annualized costs of DH components in both BL 2050 and HRE 2050 scenario (Source HRE4 project) [1]

Although HPs are predicted to play an important role in future DH systems, and their installed capacity has to increase significantly, the largest investments will be allocated to DH pipes (more than 40% of the total investment) for the grid expansions. The investment in increasing the installed capacity of HPs in DH will represent 10% of the total annualized costs.

It is important to mention that, compared with other traditional technologies in the heating sector, large-scale HPs can be considerably expensive. However, in the end it might enable considerable savings in the operation costs.

Policy limitations and cost of fuels also affect the market share of HPs and might have a larger impact on their market development than technological limitations. When fossil fuels are cheap, or while biomass, although being a limited resource, still have higher financial incentives, it might be more difficult for HPs to penetrate the market. Because of the lack of incentives, large-scale HPs end up with higher investment costs than their competitors. If fuel prices are high or there are more subsidies to encourage the use of HPs, these would be more profitable even with a low COP. In the end, it is a matter of making large-scale HPs more known and making policy-makers aware of their high socio-economic benefits in order for them to be considered for tax exemptions or other promoting schemes to help expand this technology.

6.5 District cooling

In the HRE 2050 scenario, district cooling (DC) accounts for less than 5% of the cooling market, and it is mainly used for the industry and service sectors. However, this result is based on estimations, which besides being based on a conservative approach lack the rigorousness used to analyse the heat market. This means that this result is an underestimation of the share, which district cooling could have in the future, leaving space for further research. Cooling is growing rapidly and faster than any other thermal sector. Nevertheless, the relatively smaller demands compared to the demands of the heat sector will keep impact of the thermal sector on the whole energy market very limited.

Nevertheless, the greater number of district cooling networks being installed, the higher the demand would be for large-scale HPs, and if the energy systems are designed with a Smart Energy System (SES) approach, there would be a potential to have those HPs operating simultaneously to supply the DH and the district cooling grids in order to optimize the system performance.

Part III Description of different concepts/solutions

7 Description of different concepts/solutions

Heat pump projects relating to district heating can be complex and very different from each other. There are many different types and possibilities both in relation to heat sources, but also in relation to temperature levels and in which part of the district heating grid the heat sources are implemented.

Task 2 describes different case studies, where heat pumps are integrated in the district heating grid. The intention is that this collection of cases inspires new considerations regarding how heat pumps can be a part of the district heating production in a future district heating system, but also in which ways heat pumps can be implemented.

The project group intended to describe the projects in a short and equally structured format, in which the different projects can provide inspiration and a short overview. If detailed and further information is needed, it is possible to contact the project organization.

	High temp. (HT)	**Low temp. (LT)**	**Very low temp. (VLT)**	**Ultra-low temp. (ULT)**	**Thermal grids (TG)**
Typical temperature supply/return	100 °C/50°C	80 °C/40°C	60 °C/30°C	45 °C/30°C	28 °C/8°C
Task 2 cases	16	12	5	0	5
Domestic hot water production type	Tank/ Instantaneous heat exchanger unit	Tank/ Instantaneous heat exchanger unit	Tank/ Instantaneous heat exchanger unit	Micro booster heat pump/electrical heater/gas or oil	Micro booster heat pump/ Decentral heat pump
Heating system usable	Radiator/floor heating	Radiator/floor heating	Radiator/floor heating	Radiator/floor heating/ Air coils	Floor heating
Heat pump integration	Central	Central	Central/decentral	Central/decentral	Decentral

Table 5: Task 2 case overview [6]

Part IV Review of different concepts and solutions

8.1 District heating temperatures:

Heat pumps are operated most economically if the temperature difference between the heat source and the heat sink is as low as possible. In order to achieve optimum operating conditions and to reduce grid losses, the supplied heat network should be operated with the lowest possible flow temperatures.

The supply and return temperatures in the different district heating grids vary greatly. For instance, in Sweden, the network temperatures are significantly lower than in Austria, which enables a high proportion of heat pumps and other renewable sources.

If the required network temperatures exceed the application limit of the heat pump or if efficient operation due to an increased temperature difference between heat source and heat sink cannot be guaranteed, heat should be provided by additional heat generators. Networks with low system temperatures such as secondary networks may be preferred for the installation of a heat pump.

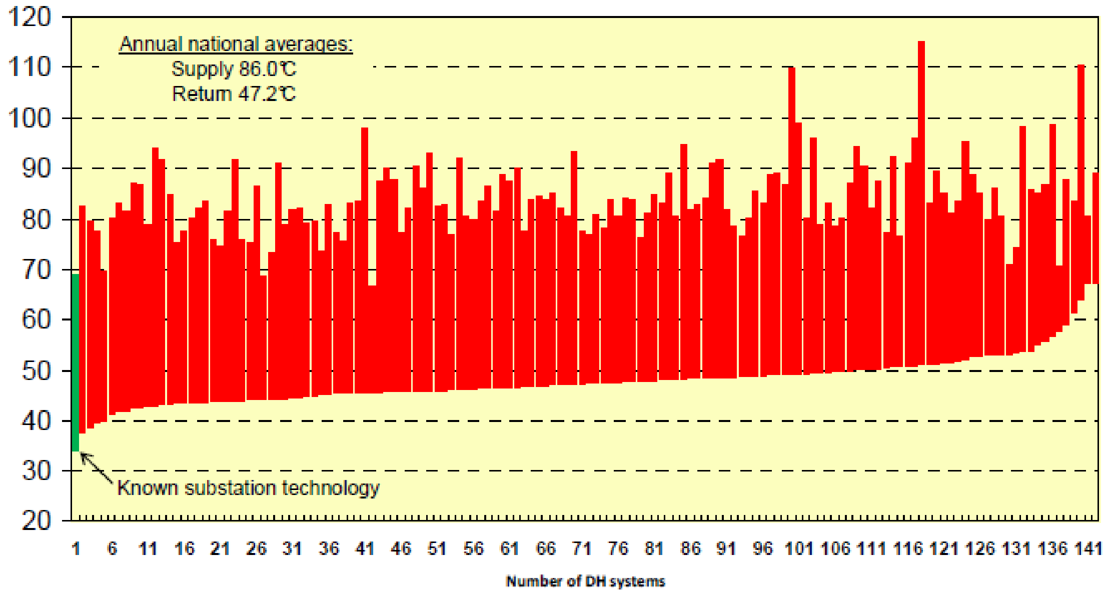


Figure16: Flow and return temperatures of various district heating networks in Sweden [7]

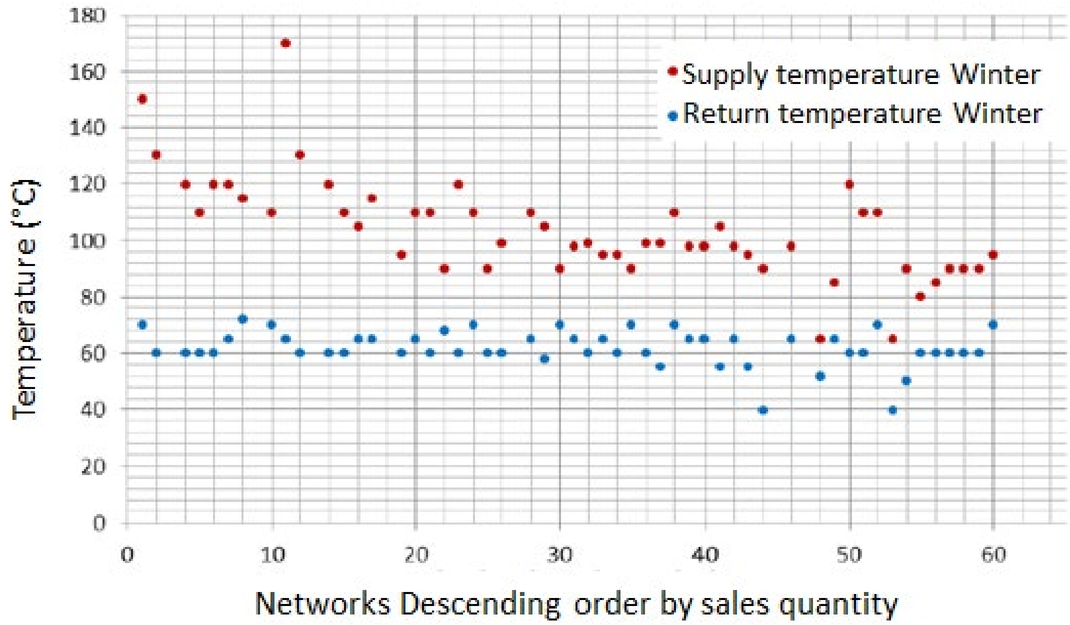


Figure 17: Flow and return temperatures of various district heating networks in Austria [7]

8.2 Current fields of heat pump application in thermal networks

A study by the DHC and technology platform (see [9]) confirms that, especially in the Scandinavian region (and particularly in Sweden), large heat pumps are already heavily integrated in district heating systems, and sometimes they take over a significant part of the heat supply. Table 6 lists the results of the market analysis in 13 European countries, including the installed capacity and number of systems as well as heat pump units.

Country	***Total Thermal Output (MW_{th})***	***Number of plants***	***Number of HP units***
Norway	84.5	8	15
Sweden	1,022.3	13	43
Denmark	45	9	11
Finland	154.6	4	9
Italy	36.6	5	9
Switzerland	35.4	9	13
Austria	10.1	2	3
Lithuania	15	1	1
Slovakia	1.8	1	1
Czech Republic	6.4	1	1
Poland	3.7	1	2
France	5.5	2	3
Netherlands	1.2	1	1

Table 6 - Large heat pumps in thermal networks [7]

When looking at the heat sources of heat pumps in DH in Europe, around 30% of the plants use various urban wastewater (sewage). Around 25% of the wastewater is accounted for in terms of industrial waste heat and flue gas condensation and another 25% of the facilities use sea, river, or lake water. Geothermal sources or storage systems (such as seasonal storage) are also used as heat sources, but they only represent a small part. The sink temperature or heat output temperature of the heat pump depends on the integration of the heat pump into the respective district heating network, and thus varies widely. According to the above study, the supply flow temperature varies between 61 and 90 °C in most systems, see table 8.

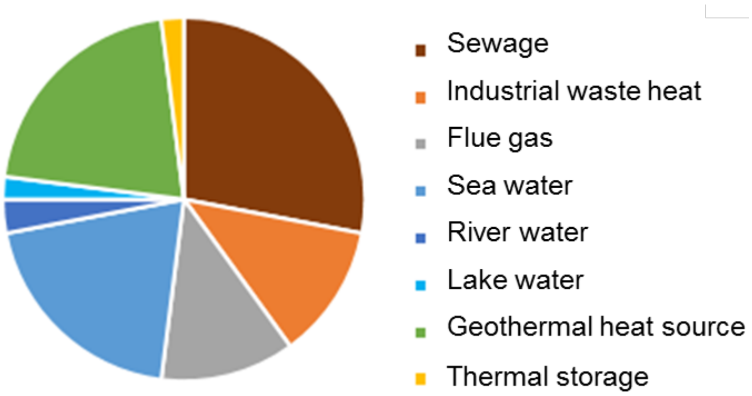


Figure 18 - Distribution of heat sources [1]

Temperature range	2-9 °C	10-20 °C	11-40 °C	14-46 °C	10-40 °C	15-75 °C
Heat source	See, River, Lake water	Wastewater	Flue gas	Industrial waste heat	Thermal storage	Geothermal heat source

Table 7 - Temperature ranges of different heat sources [7]

Supply temperature	41-50 °C	51-60 °C	61-70 °C	71-80 °C	81-90°C	91-100 °C
Number of HP units	1	2	22	36	35	1

Table 8 - Number of heat pumps per temperature range [7]

8.3 Hydraulic integration options for heat pumps in DH networks

Heat pumps can be integrated in different ways depending on the needs and possibilities in thermal networks. In principle, a distinction can be made between decentralized and centralized integration. If there is only one or a few main feed-in points with a large capacity of the existing facilities, usually it is a case of central integration. If a separate location for smaller generation technologies is realized or producers are distributed over many locations in the network, it is possible to talk about decentralized integration. For hydraulic integration, whether a heat pump is regarded as a central or a decentralized feed-in usually plays a subordinate role. In the case of the central option (for example to an already existing power plant location), the required infrastructure, such as electricity connections, pipelines, pumps, etc., is often already available or needs only to be adjusted. Furthermore, it can be differentiated when integrating heat pumps, whether external or internal heat sources are used. External sources refer to heat sources, which bring energy into the system from the outside. In contrast, internal sources do not bring additional renewable energy directly into the system. Here, the district heating network is used as a heat source, e.g. to carry out a temperature increase at the premises of the consumer (for example for the preparation of hot water) or to further cool the return flow, and thus to increase the transport capacity or for a deeper discharge of a storage unit. Due to the greater degree of cooling, other renewable energy sources such as solar thermal energy, waste heat, etc. can easier or increasingly be integrated into the system. The next figures show different possible integration concepts.

Figure 19 shows the integration of heat pumps with an external heat source in the DH supply. Through this option, additional energy is brought into the DH system from the outside. By integrating into the flow, the heat pump provides the highest temperatures, which reduces efficiency. In addition, special refrigerants must be used with very high condensation temperatures. The advantage of this option is that it does not affect existing generation plants.

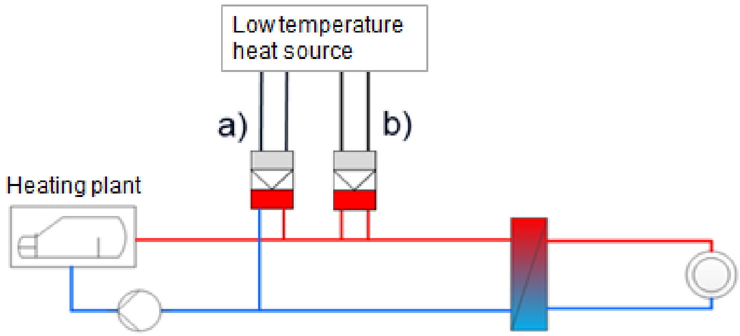


Figure 19 - Integration of heat pumps with external heat source in the DH supply line; a) parallel b) serial [7]

Figure 20 shows the integration of heat pumps with an external heat source into the DH return pipe. As a result, energy can be introduced from the outside as described above. The lower return temperature has a positive effect on the efficiency of the system. When connecting to the return line, care must be taken to ensure that existing heating plants work with higher return temperatures.

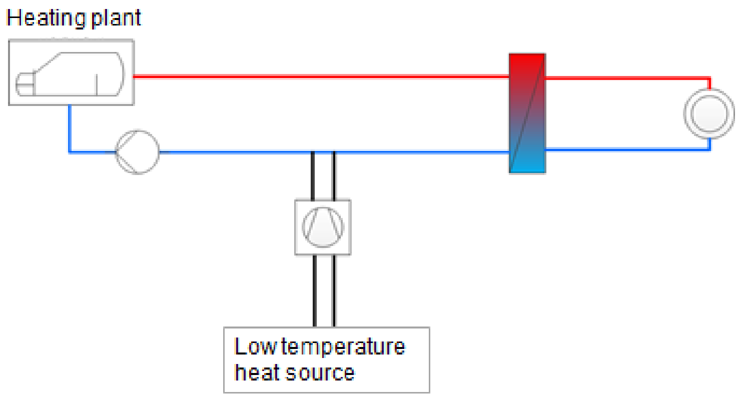


Figure 20 - Integration of heat pumps with external heat source in the DH return [7]

The diagram for integrating heat pumps with internal heat sources into the DH flow is shown in Figure 21. The heat pump uses the DH return as a heat source and supplies heat to the flow. As a result, no additional renewable energy is brought into the system directly (except when using renewable electricity to drive the heat pump). However, the cooled return flow makes it possible to integrate additional energy carriers such as solar thermal energy or waste heat from flue gas condensation plants. Thus, additional renewable energy is brought into the system.

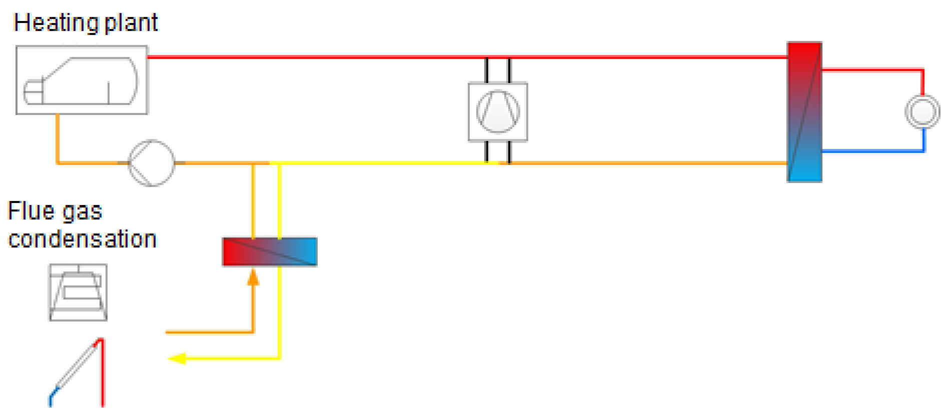


Figure 21 - Integration of heat pumps with internal heat source in the DH supply line; additional possibility for (renewable) energy sources due to reduced temperatures, e. g. flue gas condensation or solar thermal energy [7]

To increase transport capacities, heat pumps can be integrated as shown in figure 22. The graphic shows two options for increasing the temperature in certain network sections, here for secondary networks. As an example, remote areas are, thereby, supplied with DH without having to increase the temperature throughout the network. This decentralized temperature increase allows additional consumers to be connected to the grid. Thus, possible network bottlenecks can be bypassed or prevented. Figure 23 shows a similar concept for the integration of heat pumps for the supply of secondary networks. Here, the supply of the secondary network is entirely covered by the heat pump, which uses the DH return as heat source.

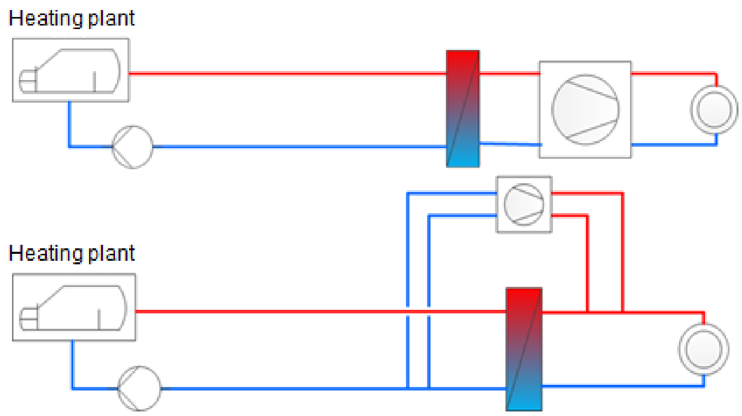


Figure 22 - Integration of heat pumps with internal heat source to increase transport capacity; e.g. temperature increase in secondary networks [7]

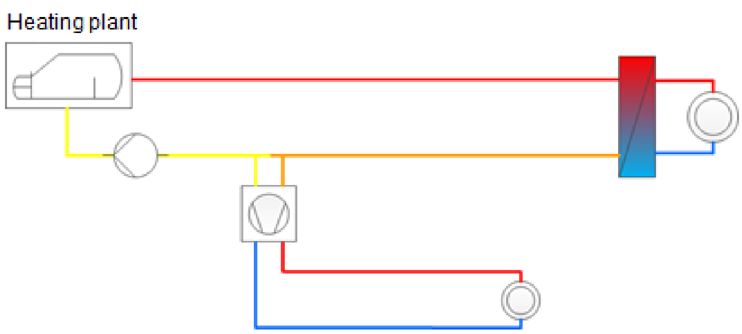


Figure 23 - Integration of heat pumps with internal heat source to increase transport capacity; e.g. supply of secondary networks [7]

8.3.1 Micro booster heat pumps:

In large buildings or buildings with DHW circulation, it is necessary to keep the circulation temperature at 50 °C, which requires a district heating supply temperature of more than 55 °C. This problem can be avoided by using a micro-booster heat pump to heat the circulation loop to 50 °C. The booster heat pump is relevant in combination with ULT district heating and in VLT district heating grids or in combination with the return flow. Studies show that supply temperatures at 45-40 ° are sufficient to ensure heating 80 % of the year. This means that the grid losses can be reduced with 25% on a yearly basis.

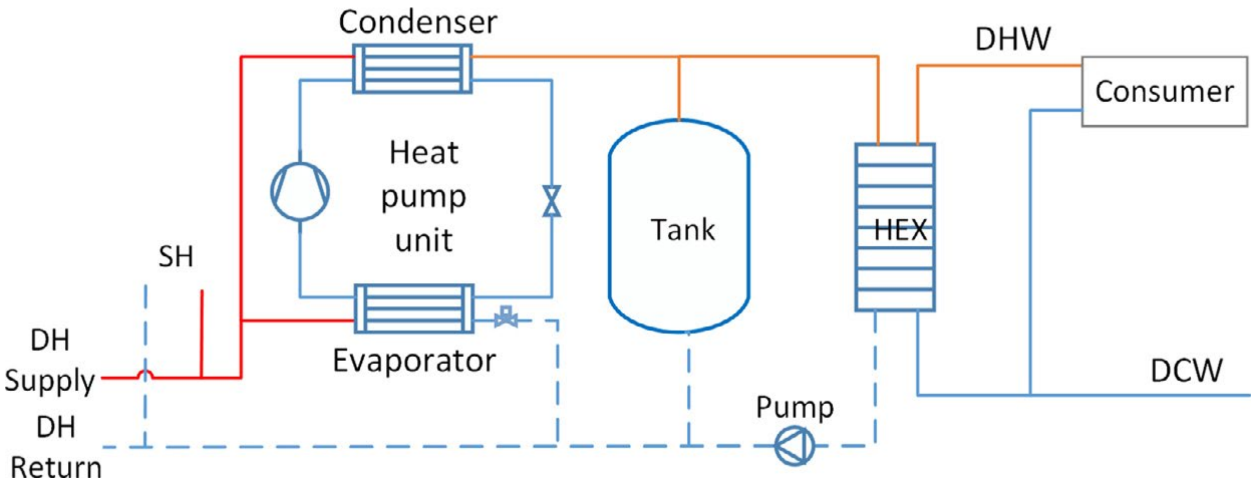


Fig 24: DHW system installing a central heat exchanger combined with a heat pump. [7]

Nevertheless, a circulation loop temperature of 45°C still has about 50% heat losses. A scheme with an ambient temperature loop was made to further reduce the loop temperature and thus to solve this problem. This scheme consists of a 25°C loop linked to a heat pump in each dwelling which provides domestic hot water and space heating (Figure 25). In this scheme, the heat sources can be multiple (from waste heat to heat pump or gas), which give a great flexibility. Furthermore, the dwelling heat pump can be reversible and, therefore, also provide space cooling. This system has many advantages:

- It minimizes heat losses
- It can use multiple heat sources
- It works with different types of emitters (radiators, fan coil, underfloor heating)
- It provides individual zone control
- It can apply simultaneous heating and cooling
- It generates hot water as a by-product of the cooling process which makes it more efficient

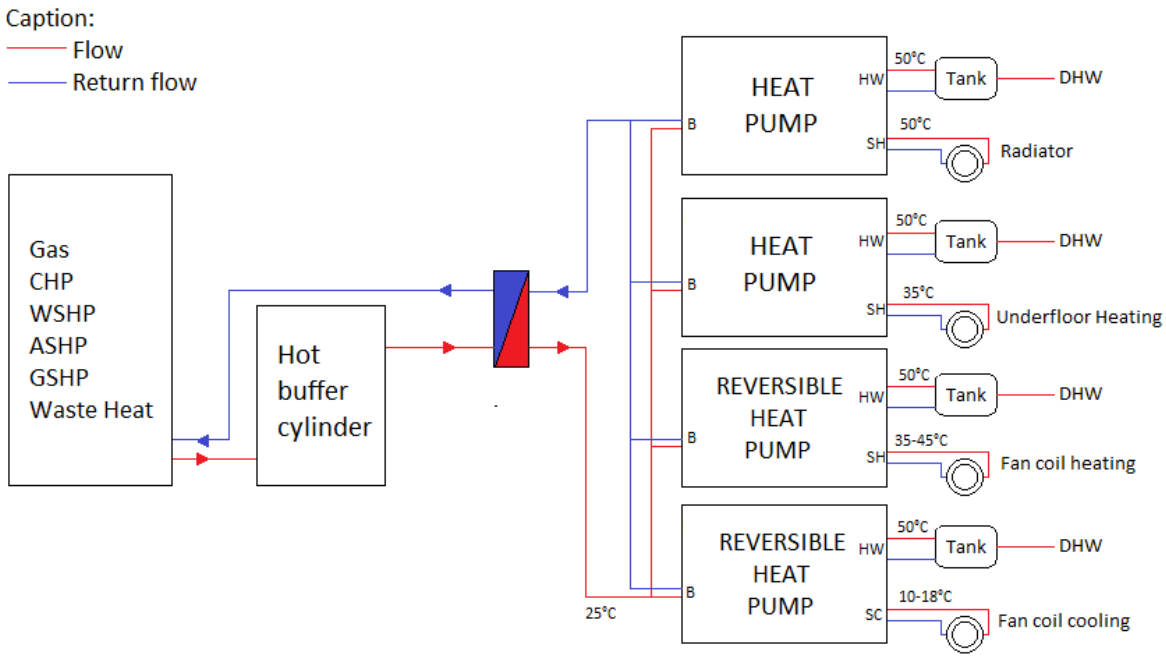


Figure 25: Ambient temperature loop system

8.4 Commercially available heat pumps

In task 3, a study regarding commercially available heat pumps is made, and the size and limits of a heat pump are dependent on the type of compressor in combination with the refrigerant and the refrigerant circuit. A list is made with some of the different heat pumps, their sizes, and the types of used refrigerants. The list is included in the Task 3 report. Today, heat pumps are available up to the MW range.

8.5 Design of the heat pump

The design of heat pumps for thermal networks is mainly dependent on the heat source. Depending on the possible extraction capacity, the heat pump can be dimensioned. The heat exchangers and the unit itself are designed for the respective frame conditions. Other decisive parameters are site-specific restrictions and legal issues. Furthermore, the properties of the heat distribution system (here the thermal network) such as temperature and volume flow must be suitable for the operation of the heat pump. Since heat pumps for district heating applications in most cases are not standard or series products, the devices are designed by the respective manufacturer in cooperation with the network operator for the specific application.

As a basic rule for the design of heat pumps in thermal networks with unlimited heat sources, it can be assumed that the basic load should be covered by heat pumps. This ensures that the heat pumps have a high number of full load hours. In addition, the required installed capacity can be kept small (including lower investment costs) and still cover a significant part of the heat load. Figure 26 shows the annual duration line with base load coverage.

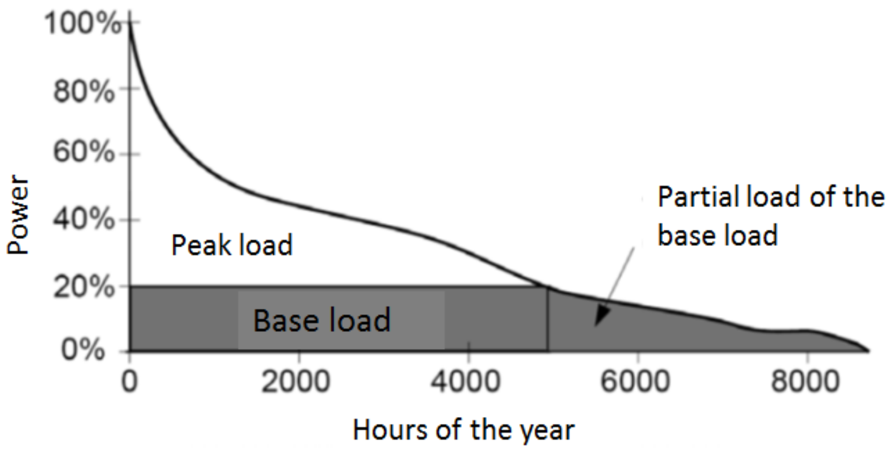


Figure 26 - Annual duration line with base load coverage [7]

Depending on the connection option, heat pumps can also be integrated into the return line to ensure high efficiency at lower temperatures. The maximum flow temperature required for some district heating networks can be reached by post-heating, e.g. with combustion processes or e-boilers.

Otherwise, the design of heat pumps may be similar to that of other producers of district heating networks, taking parameters such as heat load, simultaneity factor, etc. into account.

8.6 Storage systems

A storage system can decouple heat production from heat consumption. This is important in order to increase flexibility as the electricity peaks do not occur at the same time as the heat demand peaks. In a large district heating network, load balancing is demanding. The daily response in the district heating network is strongly fluctuating. These capacity changes in the network can easily be balanced by storage systems. With a daily amount of storage, the maximum daily capacity can be reduced by approximately 30 %.

Storage systems can increase the power of the network when placed decentrally, i.e. at the location of the user. Furthermore, decentralized storage systems fed by renewable energies can enable the network to connect more houses with the same capacity.

8.6.1 Long-term (seasonal) storage systems

The economy of seasonal storage systems depends not only on the storage costs, but also on the thermal performance of the storage system and the connected system. Therefore, each system must be examined separately. In this context, important parameters are the maximum and the minimum operation temperatures of the storage system and the district heating system. Obviously, heat from the storage system can only be used without a heat pump as long as the storage temperature is higher than the return temperature of the district heating system. To determine the economy of a storage system, the investment and maintenance costs of the storage must be related to its thermal performance. This quantity is equivalent to the cost of the usable stored energy.

The following long-term storages are considered:

ATES: aquifer thermal energy storage

Aquifers, i.e. naturally occurring self-contained layers of ground water, are used for heat storage. Heat is fed into the storage system through wells and taken out by reversing the flow direction. Aquifers cannot be found everywhere. Thus, an extensive exploration program must be passed for the building site, before one can be sure that an aquifer thermal energy storage is suitable.

BTES: borehole thermal energy storage

In this kind of storage system, heat is directly stored in the water-saturated soil. U-pipes, the so-called ducts, are inserted into vertical boreholes to build a huge heat exchanger. While water is running in the U-pipes, heat can be fed in or out of the ground. The heated ground volume comprises the volume of the storage system. The upper surface of the storage system is heat insulated.

TTES: tank thermal energy storage

A tank thermal energy storage is built as a steel or reinforced pre-stressed concrete tank, and as a rule, partially built into the ground. The storage volume is filled with water as storage medium.

PTES: pit thermal energy storage

The usually naturally tilted walls of a pit are thermally insulated and then lined with watertight plastic foils. The storage is filled with water, and a heat insulated roof closes the pit.

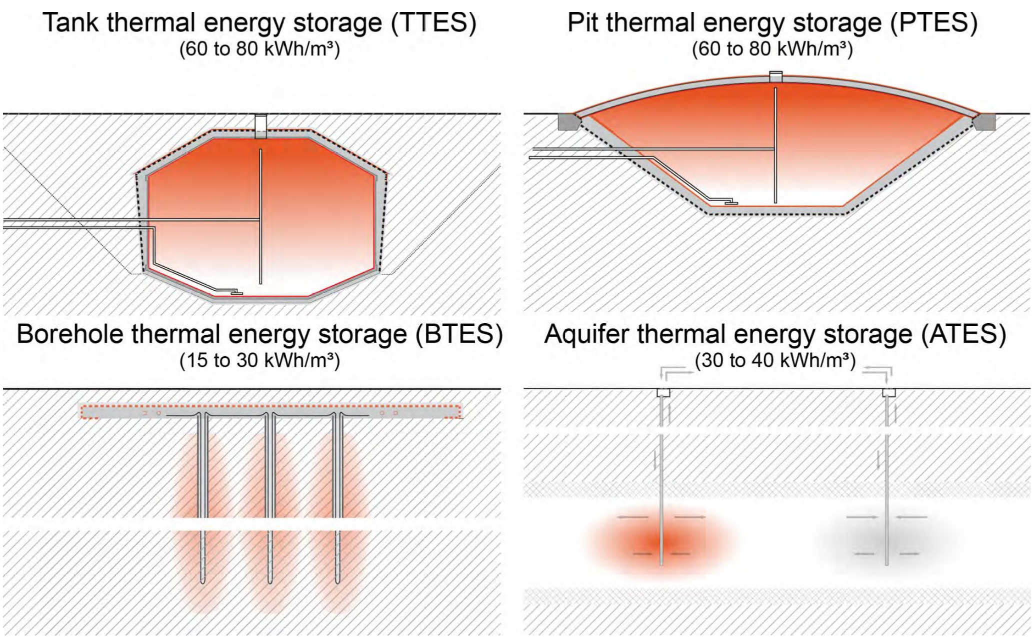


Figure 27 - Types of seasonal storages [7]

8.7 Decision support tool for selection and integration of heat pumps

In the project, a decision support tool for selection and integration of heat pumps has been developed. By using the tool, it is possible to evaluate the process, and the type of compressor and refrigerant. Based on these inputs, it is possible to calculate the CO_2 and primary energy savings as well as the heat generation costs.

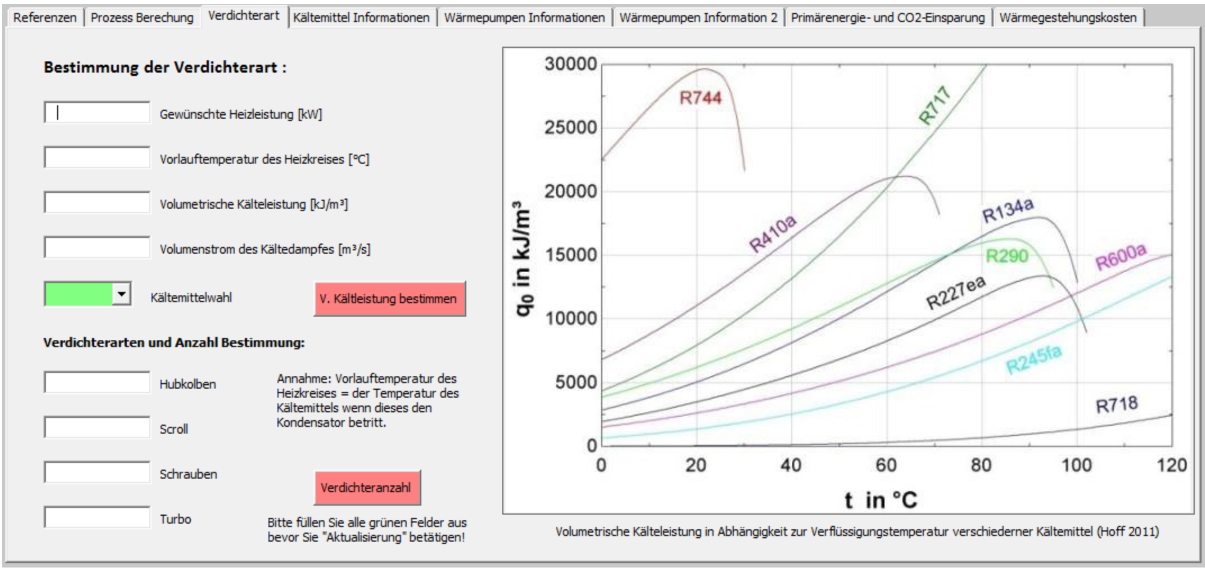


Figure 28 - Third register of the tool (compressor type)[7]

8.8 Modeling and dynamic assessments for the evaluation of operational strategies

The work for the Demand Side Management (DSM) part pursued the following research question: "Does demand side management increase the efficiency of heat pumps in a district heating network?" A representative district heating network for Austria, consisting of a biomass boiler for base load and an oil boiler for peak loads, was considered as an example. The existing heat generators can then be replaced by a heat pump in combination with a heat storage.

With reference to the results achieved by the mentioned investigations, the importance and contribution of heat pumps in district heating networks were pointed out. In addition, recommendations for "best practice" strategies for the operation of heat pumps in combination with a central storage unit are presented:

- Heat pumps with dynamic pricing and demand side management are more resilient to market risks as dynamic operation counteracts fluctuations in fuel and electricity prices.
- Savings in heat generation costs of up to 9 % with the "dynamic pricing" application and 11 % to 15 % is possible with DSM in residential blocks or in the overall network.
- Heat pumps increase the flexibility of district heating systems by expanding the heat generation portfolio, which enables higher reactivity through fast commissioning and low start-up costs as well as takes advantage of the volatility of the electricity market and thermal batteries.
- Heat pumps can be used to increase renewable heat generation. In addition, low-temperature heat sources and alternative heat sources can be used.

8.9 Outlook: Participation in the balancing energy market

A new field of application for heat pumps in district heating networks could be the support of the power grids. The rapid development of renewable electricity generation capacities has led to high capacities of wind and PV systems. These generate massive challenges in the power grids due to the stochastic production characteristics. Accordingly, flexibility options will increasingly be needed in the electricity markets such as the day-ahead or spot market, but also in the balancing energy market. On the other hand, the district heating market is confronted with many small and medium sized plants. Many of these systems have reached the end of their technical life. Additional challenges are changing market conditions, which results in a reduced profitability of investments and an uncertain outlook. Heat pumps can create a connection between the electricity and heat sectors, thus counteracting high costs for the expansion of electricity grids, and at the same time increasing the efficiency of existing heating grids. Although technical solutions are available on the market and have already been successfully demonstrated, only very few examples have been realized. The aim of the project fit4power2heat[5] is to develop and evaluate innovative business models for the economic integration of heat pumps in small and medium-sized urban heating networks, regarding synergies from the heat and electricity market. The project includes the analysis of technical integration concepts, including the identification of suitable business models based on the coupling of heat and power markets, e.g. by pooling several systems to participate in the balancing energy market, in the foreground. If applied successfully, this represents an essential component for significantly increasing the system efficiency and the share of renewable energies in heat networks.

[5] https://projekte.ffg.at/projekt/2808472

Part V Implementation barrier possibilities and solutions

9.1 Barriers for the integration of heat pumps

At present, heat pumps are used throughout Europe, primarily for the production of domestic hot water (DHW) and space heating for individual heating systems in residential buildings. Heat pumps in district heating networks are emerging in most European countries[6]. For instance, in Sweden about 7% of district heating is provided by heat pumps. In Swedish district heating networks, wastewater, sea and river water as well as industrial waste heat are the main sources for heat pumps. At present, the seasonal performance factor (SFP) is around 4.1. The motivation to use heat pumps in district heating can be divided into the following areas:

1) usage of low temperature alternative heat sources (e.g. too low temperature level for direct feed-in)
2) enabling other alternative energy sources (e.g. waste heat)
3) link to the power system (e.g. participation in the electricity market, balance of energy domains, reduction of grid bottlenecks through demand side management)
4) reduction of network temperatures through the (decentralized) use of heat pumps
5) increasing transport capacities (e.g. using the return line as a source, install decentralized units at hydraulic bad connections)

Although heat pumps can be beneficial to DH networks, they are still underrepresented. Implementation barriers were identified and discussed based on stakeholder workshops and literature research. Figure 29 gives an overview of aspects and challenges, which were considered in order to address the barriers. The outcomes are summarized into three categories (social, economic, and technical barriers) and displayed in Figure **30**.

[6] The Task 2 (Description of existing DHC systems and demonstration and R&D projects with heat pumps) report summarizes national demo sites. Available under: https://heatpumpingtechnologies.org/annex47/publications/

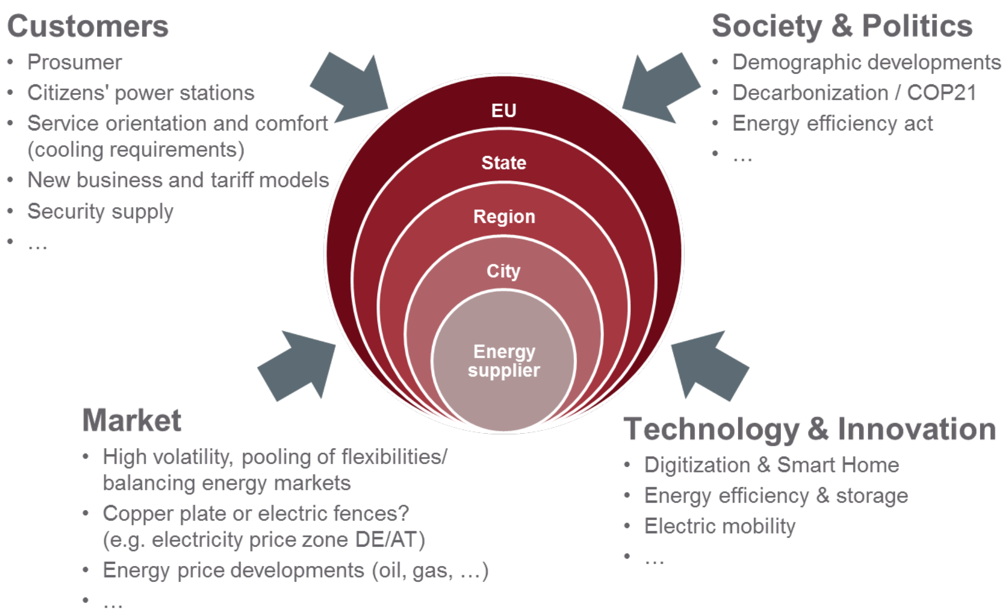


Figure 29: Aspects and challenges for district heating network operators / energy suppliers [8]

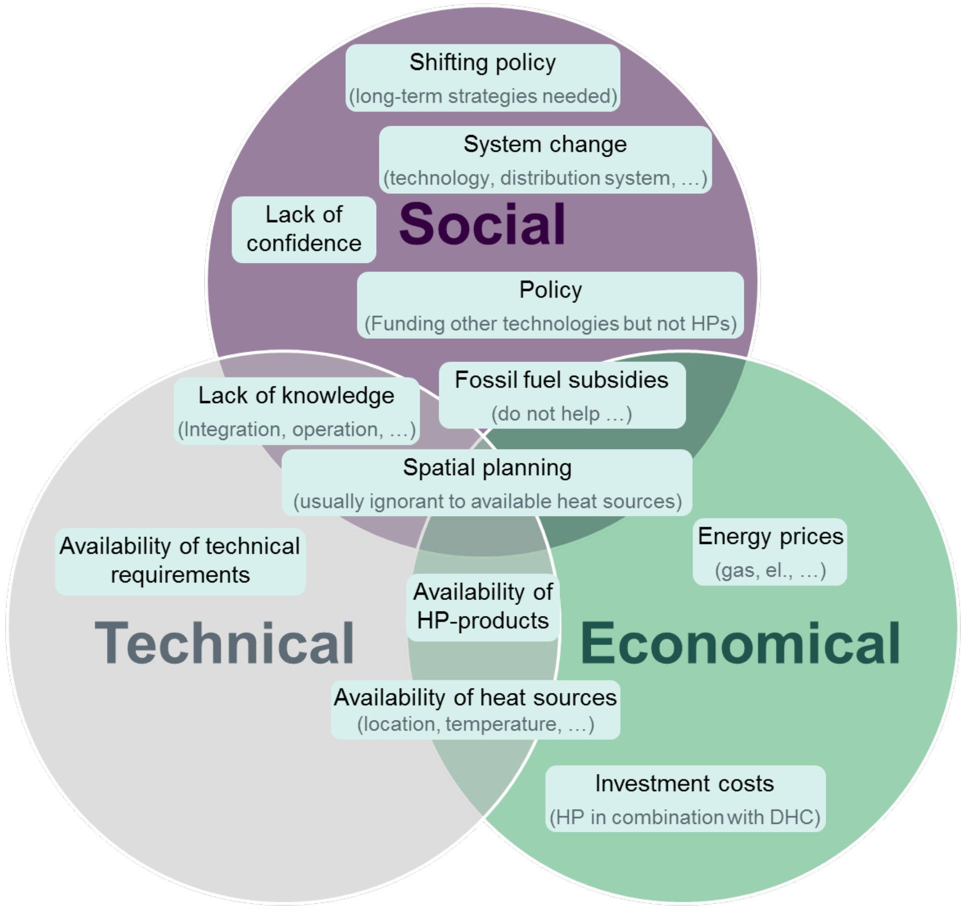


Figure 30: Social, economic, and technical barriers for heat pump integration into district heating networks [8]

Shifting policy *(long-term strategies needed)*

The current legal framework conditions are not suitable for a significant share increase of heat pumps in DH networks. Changing governments mostly develop their own climate and energy strategies with changing funding schemes, which results in low planning reliability for cost-intensive projects for the long-term.

System change *(i.a. technology, distribution system)*

Heat pumps represent a competitive situation to biomass. While biomass boilers focus on heat generation, heat pumps are increasingly focusing on electricity (high connected loads, etc.). Services such as participation in the energy balancing market could generate additional income, but from the point of view of small biomass operators, this is too expensive or the knowledge about this "new business" too low, and thus the risk too great.

Comparison with biomass boilers. It is often more economical to use a biomass boiler in connection with new heating networks. If the capacity within a heating network is increased, retrofitting with a heat pump can be economically interesting, especially in combination with flue gas condensation. Another positive factor is the greater flexibility / diversification in generation (optimization according to biomass and electricity prices).

Risk for standard business. "Standard technologies" such as gas-fired boilers, biomass boilers, and CHP plants characterize the generation of DH. "Novel" technologies such as heat pumps are still regarded as innovations in the DH sector in many countries. Since the generation concept is of a different value, it is a risk for conventional business. Above all because changes in the value-added/production chain are imminent (established and functioning processes such as fuel procurement/logistics are changing).

Lack of confidence

No standard heat generation unit in DH systems

The technology has existed for decades (keyword refrigerator) and in many Scandinavian countries there is also some experience with the technology. However, heat pumps are not yet established as a standard technology in European heating networks. This gives rise to a certain amount of skepticism regarding integration, operating characteristics, and long-term experience.

Competitive concepts (including solutions) are missing

From the point of view of the workshop participants, competitive concepts for the heat pump integration are still missing or there is not yet sufficient standardization. Each integration or large heat pump is still a "special design" with special requirements. As a result, there is currently still a lack of confidence, especially in the operating mode after commissioning.

Sensibility - especially in winter regarding exergy

From the thermodynamic aspect, the sense of heat pumps is questioned. The use of electricity for heating purposes is criticized, especially in winter, when the COP is lower (higher network temperature and a lower source temperature depending on the heat source).

Policy *(funding other technologies, but not heat pumps)*

The lack of coordination of subsidies at federal and state level, example for green electricity (heat pumps), results in non-utilization of synergies (e.g. storage). The lack of financing incentives for large-volume infrastructure investments such as long-term storage or large-scale heat pumps. While subsidies exist for other renewables, incentives for heat pumps are still missing. Legal requirements for the prevention of legionella are in some countries more restrictive (e.g. Austria) than in other countries (e.g. Sweden), which makes the standardization of technical concepts more difficult.

Fossil fuel subsidies *(do not help …)*

As long as there are subsidies for fossil energy sources, there will be high entry barriers for alternative energy sources. Fossil subsidies should be gradually reduced and replaced by renewable sources.

Lack of knowledge *(integration and operation)*

Heat pumps are not yet an established technology in the DH networks. There is a lack of both internal and external know-how (planners, suppliers, etc.). Furthermore, integration into existing networks, including producers, is not yet state-of-the-art. While large network operators can use external companies (national, international), it is difficult to integrate heat pumps into existing networks (lack of personnel, capital, etc.), especially for the large number of small biomass networks. In addition, biomass technology is widespread (e.g. Austria) and there is a history of many years of reliable partners and manufacturers. The operators are familiar with the technology and can make smaller repairs by themselves.

New domain (heat and electricity)

The addition of a new domain (electricity in addition to heat) brings along additional requirements/regulations or it requires new/further know-how (technical, organizational, regulatory, etc.). This creates additional hurdles, especially for rural heating network operators (corresponding resources required).

Spatial planning *(usually ignorant to available heat sources)*

Intelligent energy planning should avoid the emergence or continued existence of double infrastructures (e.g. DH and gas network at one site). These could also be DH preferential areas. For example, no holistic tools exist, which provide an overview of development areas and possible heat sources.

Availability of technical requirements *(high-temperature applications)*

Above all, demand is seen for high-temperature heat pumps. From certain points of view, the current heat pump cannot yet fully meet technical requirements. Market readiness is viewed critically.

Availability of heat pump products *(missing overall database)*

There are no satisfactory databases available, which provide an overview of product/technology as well as market overview of established manufacturers, their offers, and implemented projects[7]. There are some suppliers of large heat pumps, but only a handful of manufacturers are producing these specific types of systems. In addition, large heat pumps in the MW-range have several months of production/delivery times. Regarding product, technology, and market assessment, independent institutions are regarded as trustworthy and necessary.

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[7] An overview of manufacturers and products (no guarantee of completeness) is given in Task 3 of the Annex. Task 2 extracts some best practice examples on a country base.

Availability of heat sources *(i.a. location, temperature, temporal)*

(Waste) heat source(s)

A high availability of the heat source is required to achieve many operational hours, and thus low heat generation costs. However, the availability of the heat source does not always match the demands (e.g. certain sources are smaller, especially in winter, when they are most needed). The availability of waste heat from industries depends very much on the process and on the economic situation. A major barrier is the uncertainty of the economic situation of companies. The time horizon for economic considerations and budget plans is usually 2-3 years, whereas heat suppliers plan with periods of 10-20 years. The different time periods are mentioned as the main barrier for the implementation of waste heat feed-in in DH networks (e.g. even if the economic efficiency can be proven, this can be a no-go criterion).

It should be noted that an increasing feed-in of waste heat and decentralized heat sources as well as a higher interaction with the electricity grid via heat pumps and possible new market players, such as storage providers, require an increased need for coordination in the planning, design, implementation, operation, and renovation of networks.

Temperature levels

Often the ratio between the heat source (especially at ambient heat) and the heat sink (DH network temperature) does not match in order to achieve sufficient COPs, and thus corresponding economic efficiency. The usage of two-stage heat pumps helps to achieve higher COPs, but the investment costs are quite high compared to the efficiency gain.

Energy prices *(electricity and fuel prices)*

The economic decision for the integration of heat pumps is very dependent on energy prices. When gas is cheap and electricity expensive, heat pumps do not pay off.

Investment costs (*costs and geographical proximity for the development of heat sources)*

The investment costs (CAPEX) of heat pumps are significantly higher compared to conventional heat generators. On the other hand, the operational costs (OPEX) are much lower. Due to low COPs, air is hardly considered as a heat source, and deep drillings have high costs. The development of waste heat sources is seen most favorably (however, other points are to be considered here as described above). Water bodies or cooling water from power plants are another option. For all sources goes that the closer a connection is to the grid, and the cheaper it is, the better the economy will be.

9.2 Possible solutions

For the integration of heat pumps in district heating networks, general solution options were developed within the project and described in the below subchapters. These possible solutions could also necessitate innovative business models. Within stakeholder workshops, possible solutions were discussed. The outcomes are summarized into the same categories as the barriers and displayed in Figure 30.

Figure 31: Possible solutions and aspects that could promote heat pump integration into district heating networks [8]

According to the previous chapter, two main barriers are the availability of heat sources (temperature, location) and the energy prices. The ambient temperature scheme (previously described) could help to overcome these barriers. Indeed, this scheme allows the use of multiple heat sources which give a real flexibility (the heat source can change as a function of the demand and the period). Moreover, as the temperature decreases, it allows the exploitation of more types of heat source (environmental sources, waste heat) and thus increases the number of heat possibilities.

In the economical point of view, low temperature networks could be more cost-effective:

- As heat losses are minimized, less energy is needed, and energy consumption costs are reduced.
- It allows heat pumps to be used efficiently and, therefore, further reduce the energy consumption and cost.
- It provides heating and cooling at the same time.

9.2.1 Holistic heat supply strategies

The optimum combination of heat generation plants in DH network depends on the most varied parameters, and the combination is correspondingly individual for each network. In the following, a method for the development of sustainable heat supply concepts for district heating networks integrated in the overall energy system in the target triangle of supply security, sustainability, and economic efficiency is presented, and the respective tools are explained. One focus is on the integration of alternative heat sources (e.g. heat pumps). The following approach is divided into three phases:

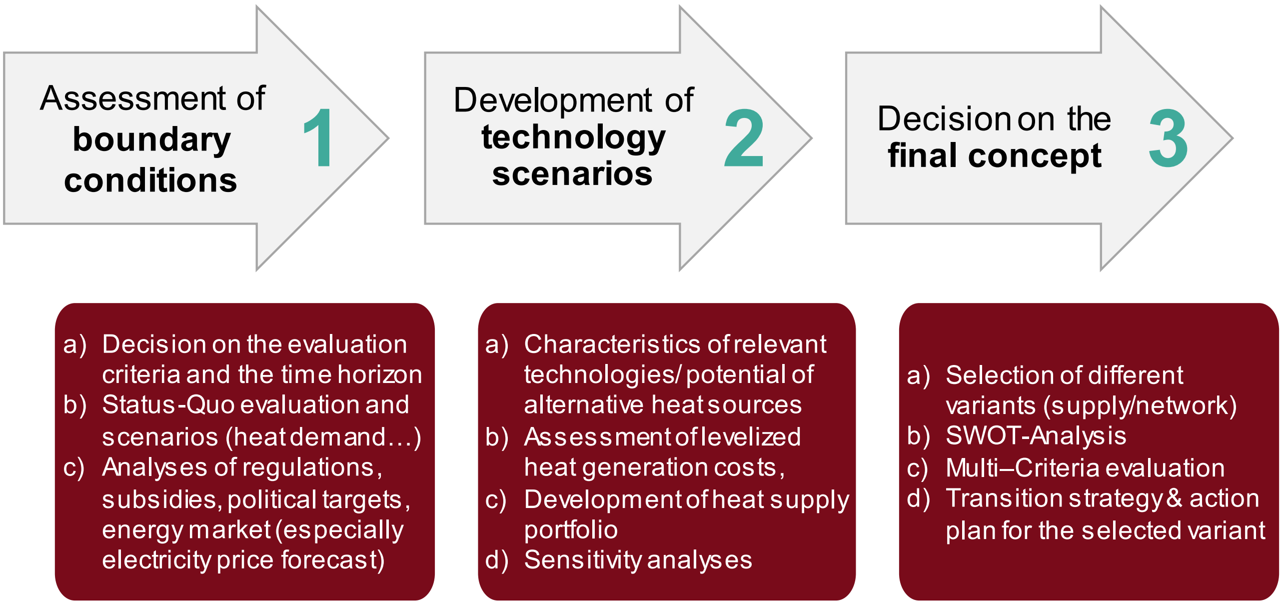

Figure 32: Three phases for the development of a heat supply strategy [8]

9.2.2 Assessment of boundary conditions

The first phase creates basic principles for the further considerations in phases 2 and 3, and it includes the following aspects:

a) Coordination of the **evaluation criteria** (including the calculation methodology and parameters; e.g. share of renewables) and the time horizon to be considered (e.g. 2030/50) with the stakeholders involved to achieve a high degree of acceptance of the heat supply concept.
b) **Status quo evaluation** and **scenarios**: Evaluation of existing generation plants of the network infrastructure and the consumers regarding the status quo according to the above-mentioned evaluation criteria and elaboration of perspectives in the required time horizon. Creation of scenarios for the development of heat demand and network temperatures as well as analysis of hydraulic restrictions in the network is important.
c) **Analysis** of **energy** and **climate policy framework conditions**: Focus on forecasting electricity and fuel prices. This also includes the consideration of current or foreseeable developments or (binding) objectives on the part of the city/community, the (federal) government and the EU as well as socio-political objectives, including relevant taxes and subsidies.

9.2.3 Development of technology scenarios

In the second phase, different technology scenarios and generation portfolios are developed and evaluated as the basis for the decision-making in phase 3:

d) **Characteristics** of generating plants/potentials of alternative heat sources: Research and consolidation of the techno-economic characteristics of relevant new plants, in particular (partial load) efficiencies as well as investment (CAPEX) and operating costs (OPEX). Estimation of the available or technical potentials of the relevant heat sources (heat pumps, biomass and waste, solar thermal energy, deep geothermal energy, waste heat, etc.)
e) Calculation of **heat generation costs** based on full-load hours of the relevant generation technologies. This allows a rough overview with the help of simple assumptions for economic efficiency calculation and efficiency of the technologies.
f) **Development** of **generation portfolios** for different years based on the respective heat demand curves and assessment of heat generation costs and, where applicable, existing plants.
g) **Sensitivity analysis** with the aid of application and operational optimization for different external boundary conditions from phase 1 (electricity and fuel prices, heat demand and investment costs). In this way, the robustness of the individual scenarios against future changes is tested.

9.2.4 Decision on the final heat supply concept

The final concept development in phase 3 summarizes the results from phase 2 and compares all the different scenarios:

a) **Selection** of **different scenarios** (generation/grid): Consideration of the compatibility of generation and, if applicable, heat grid options and testing of grid hydraulics.
b) **SWOT analysis** of the individual production technologies considering qualitative criteria from phase 1.
c) **Multi-criteria evaluation** using a standardized, weighted decision matrix for all meaningful generation portfolios. Where possible, individual portfolios are valued based on quantitative data (economic and ecological parameters) and the results of the SWOT analysis (technical and other criteria). Weighting criteria as well as the respective sub criteria with each other.
d) **Transition scenarios** and **action plan** for the selected variant: derivation of necessary implementation measures and a reasonable time schedule for transformation of existing plants and installation of new plants.

9.3 Business models

To establish alternative heat sources in heating networks, new players will emerge (or old ones will be replaced) and innovative business models will be necessary. In addition to stakeholder discussions, the findings from coaching sessions of the EU project "STRATEGO" and the project "heat_portfolio" were used as a basis for outlining possible innovative approaches for new business models. The experiences from these two projects are described using the nine elements of the "Business Model Canvas" in Figure 33. The evaluation should provide an ability to generalize how "typical" business models of heating networks can look like. Innovative elements of the business model are underlined in red.

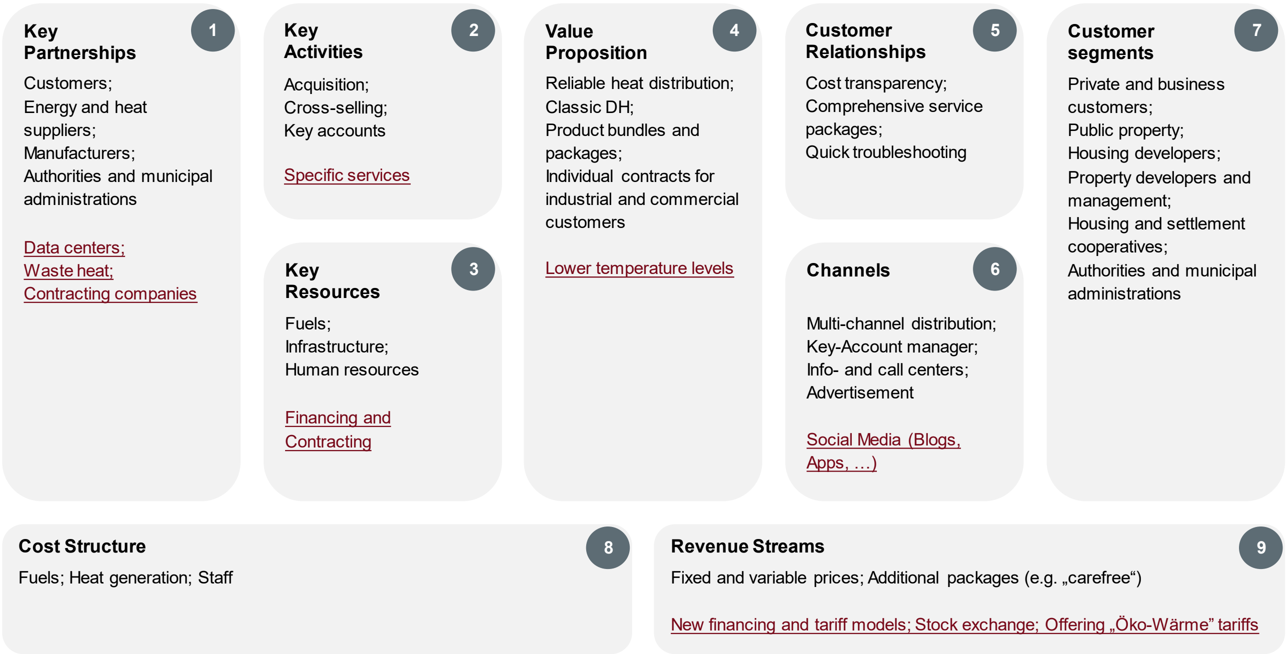

Figure 33: Exemplary business model of a district heating network operator (according to: Business Model Canvas); new elements of the business model are underlined in red [8]

The following innovative elements can be mentioned:

Regionality: Highlighting socio-economic indicators such as value (added) creation, jobs, avoided CO_2 emissions, "regional factor", etc.

Fuel substitution (replacing scarce resources): Increasing the renewable share in DH networks. Heat production through "environmentally friendly" electricity from renewable sources (PV, wind, geothermal energy, etc.) and substitution of fossil fuels. Offer an eco-heating tariff (like the eco-electricity tariff).

Holistic system concept: Application of sector coupling and offering of several services, e.g. providing electricity additional to heat, telecommunications (fiber optics), and mobility. Addressing "green" overall concepts to customers and the establishment as a regional and "visible" local supplier.

Usage of **waste heat/cooling energy** (three positive effects can result from the use of heat pumps): Offering heat, cooling and electricity (energy balancing market). An example would be the provision of cooling for data centers and production of heat feeding into DH networks. Obtaining additional energy savings by replacing cooling towers. Decentralized contractor solutions would also be possible. This means additional sources of income, which can have a positive effect on investment decisions and economic considerations. This results in additional usable applications for new urban development areas, which are unfavorably distant from existing heating networks. These could be supplied by micro-networks with utilization of local waste heat sources. This requires intelligent urban/city planning to make the best possible use of synergies. Contracting companies could play a key role here.

Specific services: For the largest or most energy-intensive customers, special services such as analysis of heat consumption (load profile), energy saving measures, reducing return/system temperatures, shading/shifting peak loads for smoothing the load profile, etc. could be offered. Especially for larger heat consumers such as industrial customers, hotels, swimming pools, etc., the potential for load shifting is huge. Demand Side Management (DSM) would enable intelligent network operation by remote control of loads. Customers, who actively contribute to load management, could benefit from financial incentives. With additional capacities created, additional customers could be connected in a cost-effective manner.

Financing and contracting: The conversion or upgrading of an energy supply system involves high investment costs. New financing models such as contracting, external financing (crowdfunding, crowd investing, crowdlending), leasing, factoring, but also customer and supplier participations should be considered to avoid risks. Best practice examples can be found in Denmark. Many of the solar heating networks are operated or financed by the customers themselves, whereby the focus is on minimizing heat generation costs. Another form of financing could be investment participation by key component manufacturers. Using "Big Solar Graz" as an example, this could be equipment providers. On the one hand, this would reduce the investment risk for heat suppliers, which has a positive effect on investment decisions, and on the other hand, manufacturers can benefit from product sale and further long-term business relationships (warranty, maintenance, insurance, etc.).

Reducing system temperatures: The structure of the current heat supply contracts or technical connection conditions with long-term orientation hardly permits a reduction of system temperatures, since high supply temperatures (barrier for heat pumps) - for historical reasons - have been contractually agreed, and this is difficult to change retrospectively. In order to reduce system temperatures in renovated buildings, heat supply contracts must be renegotiated. For properties with many customers, this means an enormous administrative effort. Optimization often fails because heat suppliers are not even informed about renovation measures. Therefore, appropriate communication interfaces and adapted rules and regulations are required. In addition, the consumer is one of the most important instruments for achieving low return temperatures. This requires consumer information, and the conscious observance of the prescribed return flow temperatures or the achievement of these must be monitored more closely.

Corporate appearances: Strategic communication and presence in the most important channels and platforms are necessary to strengthen customer relationships: Social media, communities, blogs, apps, etc. provide the opportunity to interact with customers. These communication channels should be used for a holistic corporate strategy regarding various interests such as sales, product placement, market observations, but also opinion polls, customer feedback, and entertainment.

System optimization: High system temperatures result in inefficient operation and pose a major problem for heating networks, especially in combination with decentralized generation units (heat pumps, etc.). The causes are usually due to errors at the customer substations as well as unsuitable heating systems and operating modes. Planners and installers are often not aware of the requirements for customer installations or the effects of non-compliance. Therefore, workshops and training should be offered to various stakeholders to get them on board right from the start and to show them the importance of customer installations for overall efficiency. In addition, cooperation between the individual heat network operators should be expanded. Knowledge transfer of best practice examples and solutions should promote the multiplication and implementation of efficiency and optimization potentials on other networks. Additional revenues could be generated by offering additional services such as system assessments, system analyses, and optimization of customer heating systems.

Digitalization (new opportunities, more cooling capacity, smart heat meters, etc.): Digitization is generally seen as an enabler for alternative heat sources. On the one hand, new opportunities arise for generation, network, and customers with the potential of global optimum (smart heat meters send real-time data whereby continuous optimization regarding pricing, flexibility, DSM etc.). On the other hand, more digitization also means more computing power, and thus more cooling capacity. This also results in new lines of business such as the simultaneous supply of heat and cooling mentioned above.

The introduction of new tariff systems can be another way of promoting the integration of heat pumps: **Low return temperatures** are an important feature of future district heating networks. Wherever users have the possibility of adapting their heating system (especially in single-family homes), suitable tariff systems can be an incentive for users to take measures to reduce system temperatures.

A possible structure of such an incentive system could be as follows: Customers, who achieve an average spread between supply and return temperature of over 35 K ($\Delta T = T_S - T_R$), receive a discount (bonus). However, in the case of an average spread below 30 K, a fee (penalty) must be paid. The billing (of the energy price in whole or in part) via the volume flow rate has a comparable effect. However, it should be noted that (most) currently installed heat meters do not permit such tariffs, since they are calibrated only to the energy quantity[8] and accordingly no billing may take place. It should also be noted that many users do not have access to the heating system to make necessary changes themselves.

Flexible tariff models or "**district heating exchange**" can become relevant in district heating as soon as the share of volatile generation units become dominant. Furthermore, it is possible to design district heating tariffs in such a way that high working prices are charged during peak load periods. This means that loads such as space heating or storage charging can be shifted to times with low prices. In Sweden for example, there are already heat suppliers (e.g. Göteborg Energi AB, Öresundskraft AB) who offer their customers flexible tariffs. These are subject to seasonal or daily fluctuations and are partly offered on an hourly basis at different prices. This type of "district heating exchange" is intended to offer customers financial incentives so that they can actively participate in load shifts towards times of cheaper heat. This pricing model can be attractive to all consumers, not only to private households, which have little or no opportunity to structure their demand for space heating over time. This depends on the regulated daily routine (with demand peaks mainly in the morning and late afternoon times) and above all on the outside temperature, building age and type as well as the location of the buildings. However, such incentive systems may lead to reduced user comfort and financial burdens, especially for low-income households, where energy costs are a relevant factor.

[8] That means to the product ($\dot{Q} = \dot{m} \cdot c_p \cdot \Delta T$) and not to the temperatures or volume/mass flow itself.

Part VI Reference material

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Appendix A: List of participants

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SE	RISE	Research Institute	Markus Lindahl
UK	Dept. for Business, Energy & Industrial Strategy	Government	Oliver Sutton
UK	Glen Dimplex	Manufacturer	Martin Betz

Appendix B: Additional documents

[1] Task 1 report: Heat Road Map Europe: Potentials for Large-Scale Heat Pumps in District Heating; Joana Neves, Brian Vad Mathiesen

[2] Task 1 report Sweden

[3] Task 1 report Switzerland

[4] Task 1 report Austria

[5] Task 1 report Denmark

[6] Task 2 Case Introduction

[7] Task 3 report. Review of different concepts and solutions

[8] Task 4 report. Implementation barriers, possibilities and solutions

[9] Task 4 report – Denmark

[10] DECC Heat Pumps in District Heating Final Report

[11] Task 1 report UK Heat Pumps in District Heating and Cooling Systems

Appendix C: Glossary

Abbreviations	Definition
DH	District Heating
DHC	District Heating and cooling
HP	Heat Pump
SES	Smart Energy System
DSM	Demand Side Management

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