Technology Collaboration Programme on Heat Pumping Technologies (HPT)

Annex 57

Flexibility by implementation of heat pump in multi-vector energy systems and thermal networks

Final Report

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme 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 nearly 40 Technology Collaboration Programmes.

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 implementing agreement for a programme of research, development, demonstration, and promotion of heat pumping technologies. 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.

Disclaimer

The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings, and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

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 accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP 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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Foreword

The present report documents the results of HPT Annex 57 “Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks”. The Annex was initiated in the spring of 2019 and started officially in January 2020. The planned work was three years, and the project is finalized within the planned period, despite the Covid-19 pandemic which caused an abnormal startup without physical meetings. The active Annex group consisted of five countries (Austria, Denmark, Germany, the Netherlands, Sweden).

The UNEP’s emissions GAP report from November 2023 shows that the greenhouse gas emissions shall be reduced by 42 % before 2030 to reach the 1.5 °C pathway. The IEA World Energy Outlook 2022 and 2023 show the updated Net Zero Emissions by 2050 (NZE) scenario that the transition away from fossil fuels, mainly in the industry, but also in the transport sector will create an electricity demand which is three times higher than today. The main increase in the production will mainly be renewable energy sources like PV and wind power. This means that the need for short term flexibility will double until 2030, and it will increase more than 400 % until 2050.

In the Net Zero by 2050 scenario, DHC (District Heating and Cooling) is expected to cover 20 % of the global space heating needs by 2030. 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 pump can deliver up to 20 % of the energy to the district heating 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

Abstract

The present report documents the results of HPT Annex 57 “Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks”. The Annex was initiated in the spring of 2019 and started officially in January 2020. The planned work was three years, and the project is finalized within the planned period, despite the Covid-19 pandemic which caused an abnormal startup without physical meetings. The active Annex group consisted of five countries (Austria, Denmark, Germany, the Netherlands, and Sweden).

Annex 57 has focused on solutions where heat pumps can create flexibility to the electrical grid. When the project was initiated, the aim was to focus on flexibility from heat pumps connected to district heating as the project was based on the results from HPT Annex 47 Heat Pumps in District Heating and Cooling Systems. Flexibility from individual heat pumps have also been included in the scope of this annex during the project as some participants and the IEA HPT Executive Committee had a wish to extend the scope to include individual heat pumps as well. The focus has been to describe what is flexibility and what the is potential of flexibility.

The working group has carried out an analysis on a national basis for the participating countries on the potential to create flexibility and the potential for heat pumps in the participating countries.

Templates and detailed descriptions as well as a shorter template have been developed to describe cases. 22 cases have been collected and described. The cases show that it is possible to create flexibility with heat pumps in different ways.

Collecting data from existing plants has been a part of the work and is described in a separate report from Aalborg University.

Identifying barriers and solutions for individual heat pumps as well as large-scale heat pumps in district heating grids has been a part of the work. This was done in a workshop held at the 14th Heat Pump Conference in Chicago in May 2023.

The project shows that heat pumps can create flexibility to the electrical grid and that the demand for flexibility is growing.

Table of content

1. Executive Summary

HPT Annex 57 has focused on solutions where heat pumps can create flexibility to the electrical grid. When the project was initiated, the aim was to focus on district heating as the project was based on the results from HPT Annex 47 Heat Pumps in District Heating and Cooling Systems. However, flexibility individual distributed heat pumps have also been included in the scope of the annex. The focus has been to describe what is flexibility, and what is the potential of flexibility.

As global electricity demand rises, driven by a shift from fossil fuels to electrification, heat pumps are becoming crucial in enhancing grid flexibility. These technologies effectively manage the variability of renewable energy sources, ensuring a resilient energy infrastructure that can adapt to fluctuating demands

- **Creation of flexibility in the electrical grid is possible using both individual heat pumps and heat pumps for district heating.**

Key findings:

Heat pumps significantly enhance grid management and energy efficiency, playing a transformative role in the energy sector.

1: The market for heat pumps in district heating systems is growing
The market for district heating is growing throughout entire Europe, and scenarios show that heat pumps have a potential to cover from 16 % to 38 % of the annual production in most of the markets. Potential Coverage in District Heating: Heat pumps are projected to provide about 25% of Europe's district heating by 2050, underscoring their importance in sustainable heating solutions

2. Flexibility Services: Heat pumps are key in delivering ancillary services, such as frequency regulation, which contributes to the stability of the electrical grid.
It can briefly be shown by the referred demonstration cases that heat pumps are well operated within the energy trading markets of day-ahead and intraday. As large-scale thermal power plants are phasing out, and the implementation of renewable sources like PV-plants and wind-power plants are growing, the market for flexibility services is diversified and growing. Heat pumps might address this and can play a significant key role in the balancing of the market for the electrical grid. It is shown by various analyses that large heat pumps for district heating have a high economical potential to operate accordingly and act into the ancillary service market. Flexibility is also possible to create with individual heat pumps, hybrid heat pumps, and heat pumps in district heating systems.

3. Versatility Across Applications: Whether in individual installations, hybrid systems, or largescale district heating setups, heat pumps show remarkable adaptability to various environments and needs.
Heat pumps can be implemented in combination with other technologies such as gas boilers, wood, pellets and straw boilers. This means that the implementation of heat pumps can be expanded but also that the energy coverage provided by the heat pumps can be increased.
Heat pumps are also showing large versatility in the use of different energy sources from waste heat from sewage clearing stations, to air and exhaust heat from processes including excess heat from data centers.

4. Ancillary Service Market Participation: Heat pumps engage in diverse market segments, including day-ahead, intraday, and ancillary services, meeting the dynamic requirements of the energy market.
Some of the cases show that heat pumps can act in the ancillary service market, especially if they are combined with electrical boilers and weekly storages. However, this is a new way to control heat pumps, and there are still barriers to overcome.

5. Barriers and Business Models: Despite facing technical, regulatory, and economic hurdles, innovative business models that involve aggregating distributed heat pumps for balancing services are proving effective

The annex describes some of the barriers and business models. One of the barriers is that in people's mindset, heat pumps cannot technically create high temperatures for district heating, but the development of the heat pump technology is moving fast now, and the first district heating heat pumps which provides 90°C is starting up in Vienna in 2024.

Regarding business models that involves aggregating distributed heat pumps, has projects from Sweden showed good results. In these projects which provide various balancing services showed promising reductions in overall energy costs. Different types of FCR and aFRR showed the highest cost reduction, while mFRR was slightly less profitable. In Denmark, aFRR showed the best results, followed by FCR and then mFRR. In Austria, aFRR showed significantly higher cost reductions than mFRR

2. Background

Today, there is a wide focus on using energy more efficiently. District Heating (DH) systems are a possible solution to increase the overall energy efficiency if they are well designed. A solution to increase the efficiency and the share of renewable energy in DH systems is to implement heat pumps in the DH system.

This annex is based on the results of HPT Annex 47 “Heat pumps in District Heating and Cooling Systems” which showed that 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, according to that study. The Heat Roadmap Europe 4 scenarios shown in the Annex 47 report shows that with a larger share of district heating implemented in the energy system, can the CO_2 emissions be reduced with more than 70 % compared to the current situation.

Another outcome of HPT Annex 47 “Heat Pumps in District Heating and Cooling Systems” was the necessity 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 implementations 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 be uncovered and experience from existing projects must be identified.

Based on the results of Annex 47, the project group found it necessary to create a follow up project where the focus was to focus on the flexibility heat pumps in DH systems could open, and to analyse the many possibilities to improve the performance of the system and how to implement the use of renewable energy and excess heat in the DH systems. Flexibility created by Heat pumps connected to the district heating grids also make it possible to use them for demand response and, thereby, provide flexibility to the power grid. The main targets of the annex were DH utilities and the heat pump industry. During the project period, the scope has been changed to also include flexibility provided by distributed individual heat pumps.

3. Introduction

District heating systems have a high penetration in some countries and are almost unknown in others. Thus, the potential is great. Even though, DH systems have been used for more than 50 years, there is still a large potential for improvements. The use of heat pumps in DH systems opens many possibilities to improve the performance of the system and to implement the use of renewable energy and excess heat in the DH systems. Heat pumps connected to the district heating grids also make it possible to use them for demand response and, thereby, provide flexibility to the power grid. The main targets of the annex were DH utilities and the heat pump industry. During the project period, the scope has been changed to also include flexibility provided by individual heat pumps.

The project is structured in the following way:

Task 1: Energy market analysis – Future developments and sector coupling

Task 1 gives an overview of the potential in the participating countries and what the need for flexibility will be. A country report is made for each country and a summary report is made.
Aalborg University has made a separate report which describes the potential of heat pumps in district heating, and they have also made a study of the technology and performance of the implemented projects in Europe.

Task 2: Best practice examples – Description of existing projects with flexible solutions with heat pumps in thermal grids

There has been made a collection and analysis of different cases in the participating countries, to give an overview of the possibilities to interested stakeholders. The cases are described and presented at the annex website (https://heatpumpingtechnologies.org/annex57/) with an interactive map. The cases are presented as two-pagers, and as a longer description. The cases cover large-scale heat pumps for district heating and projects with individual heat pumps. 28 projects are described in total.

Task 3: Concepts – Development of representative and promising solutions

Based on the cases in task 2, representative and promising solutions are described in task 3.

Task 4: Flexibility – Assessment and analyses of different options

The definition of flexibility and the ancillary service market are described in Task 4 as well as the technical ability and constraints for heat pumps to operate in a flexible way.

Task 5: Business models – Development and evaluation of innovative concepts

Business models and barriers are analyzed in Task 5.

Coordination of the project with other TCP's:

The project has been coordinated with the DHC TCP in different ways. The project and the progress has been presented for the IEA DHC TCP ExCo during the project. And as some of the project participants are involved in both TCP's there has also been coordination and share of knowledge in that way.

4. Summary of Task 1 - Flexibility by Implementation of Heat Pump in Multi-vector Energy Systems and Thermal Networks

Global Outlook

The IEA World Energy Outlook 2022 and 2023 show an increase in the electrical consumption and productions towards 2030 and 2050. Most of the increase in the demand for electricity is caused by the transition away from fossil fuels, mainly in the industry but also in the transport sector and in the production of PtX fuels. PtX fuels like hydrogen is creating an extra demand which is a factor 3 higher than today.

Renewables capacity expands 2.4-fold in the scenarios by 2030, and almost 95 % of this growth is in the form of solar PV and wind. The share of wind and solar PV in total generation is set to rise from 12 % to about 30 % by 2030.

In the scenario, short-term power system flexibility needs to more than triple globally by 2050 relative to today. Global needs for seasonal flexibility increase less sharply: they rise by nearly 20 % towards 2030 and 45 % towards 2050. The fast-rising share of solar PV emerges as the key factor increases short-term flexibility needs: wind is less variable in the short term but can vary significantly across weeks or seasons, and it becomes an important driver of seasonal flexibility needs as its share increases in power systems across the world. Patterns of wind and solar output can be complementary to variations in electricity demand, but their rising share tends to increase overall system flexibility needs.

District Heating Potential

In the Net Zero by 2050 Scenario, DHC is expected to cover 20 % of global space heating needs by 2030, up from 15 % in 2020. 350 million building units connected to district energy networks by 2030 provide about 20 % of space heating needs, and nearly 90 % of district heating was globally produced from fossil fuels in 2021. To fully play its role in the transition, the DHC system requires significant efforts to improve the energy efficiency of existing networks rapidly, to integrate renewable heat sources (such as bioenergy, solar thermal, heat pumps, and geothermal), to integrate secondary heat sources (such as waste heat from industrial installations and data centres), and to develop high-efficiency infrastructure in areas with dense heat demand.

Today, district heating meets about 12 % of the final energy use for space and water heating for households as well as service and industry sectors. 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 CO_2 emissions can be reduced with more than 70 % compared to the current situation.

Overall Summary – Aalborg University, Denmark

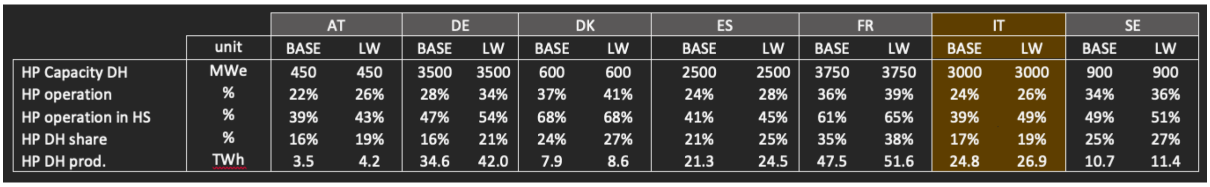
Aalborg University, Denmark, has within the project made an extensive market research for large-scale heat pumps (LHP) to analyse where the trends are heading.

Aalborg University has also made simulations with the EnergyPlan tool of the potential of the future district heating demand for several countries, The simulations show the level of heat pump capacity possible in the system as well as the share and production from heat pumps.

District Heating Demand in the Future

Table 1 summarizes the results of the simulation regarding large-scale heat pumps and district heating. The table shows the thermal capacities of large-scale heat pumps, the annual heat production and share in district heating, and both the annual and average operation times within the heating season from October to April for different countries.

Tabel 1. Simulation results of large-scale heat pumps and district heating.



		AT		DE		DK		ES		FR		IT		SE	
	unit	BASE	LW	BASE	LW	BASE	LW	BASE	LW	BASE	LW	BASE	LW	BASE	LW
HP Capacity DH	MWe	450	450	3500	3500	600	600	2500	2500	3750	3750	3000	3000	900	900
HP operation	%	22%	26%	28%	34%	37%	41%	24%	28%	36%	39%	24%	26%	34%	36%
HP operation in HS	%	39%	43%	47%	54%	68%	68%	41%	45%	61%	65%	39%	49%	49%	51%
HP DH share	%	16%	19%	16%	21%	24%	27%	21%	25%	35%	38%	17%	19%	25%	27%
HP DH prod.	TWh	3.5	4.2	34.6	42.0	7.9	8.6	21.3	24.5	47.5	51.6	24.8	26.9	10.7	11.4

The district heating production is calculated for the 2030 and 2050 scenarios. In the scenario simulations, the sources are simulated. The simulations show that the share of heat pump production has increased from current time to 2030 and 2050. Moreover, fuel boilers and CHP has been phased out.

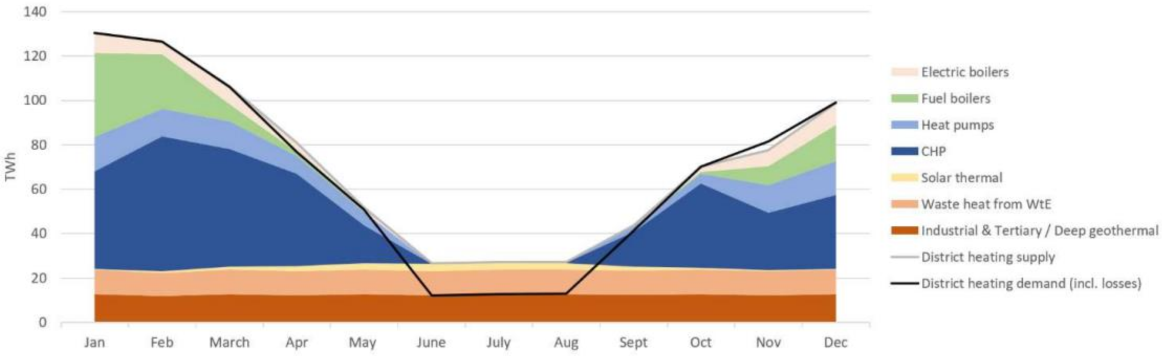


Figure 1 District heating production mix presented monthly, 2030 scenario. (Aalborg University)

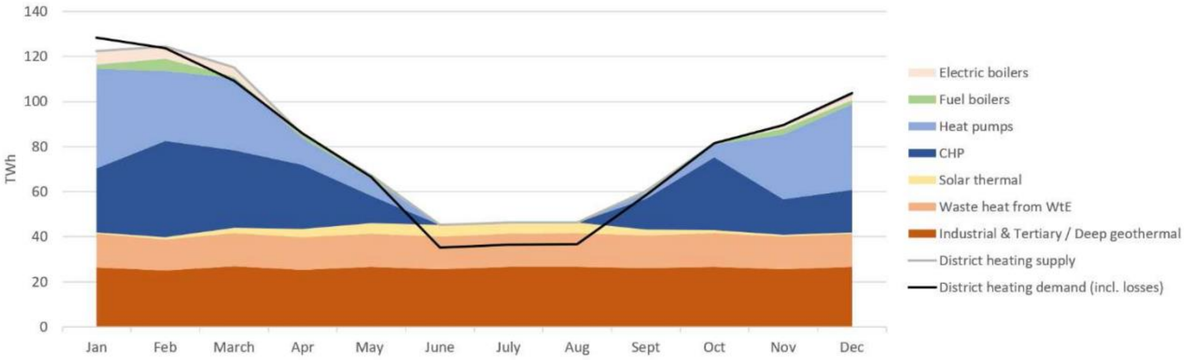


Figure 2 District heating production mix presented monthly, 2050 scenario. (Aalborg University)

The district heating level is assessed for the 27 EU countries towards 2050. The simulation shows that the extent of district heating increases in most countries.

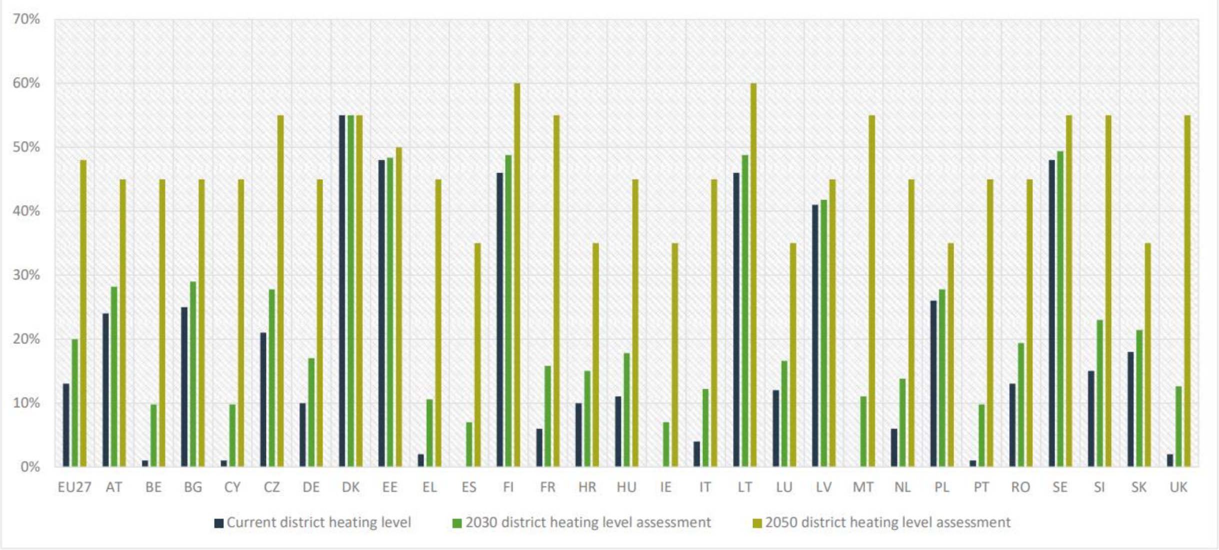


Figure 3 District heating levels towards 2030 and 2050 for heating buildings for EU27, pr. EU country and UK. (Aalborg university)

4.1. Summary Sweden

District Heating Demand Now and in the Future

The Swedish district heating market is mature with a market share of almost 60 % for space heating and domestic hot water (DHW) heating. Today, 285 of the 290 municipalities in Sweden have district heating grids. As shown in figure 4, the delivered district heating in Sweden has been relatively stable during the last 15 years.

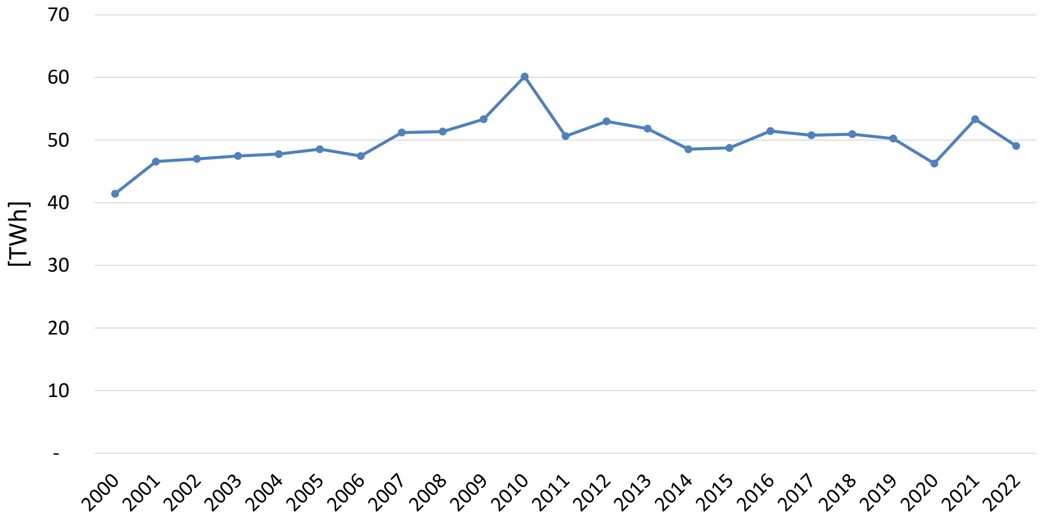


Figure 4 Delivered district heating in Sweden.
(Energiföretagen, 2023)

The Swedish Energy Agency report “Scenarier över Sveriges energisystem 2023” concludes that the production of district heating in Sweden is largely driven by the heating demand in the residential sector as well as the industry. In the short term, the demand for district heating varies in terms of temperature, and in the long term, it varies in terms of population growth and how district heating competes with other heating sources. In the scenarios for 2050, the district heating production is foreseen to slowly increase to approximately 66 TWh in 2050, with only small variations depending on different scenarios.

Electricity Demand Now and Then

The Swedish transmission system operator Svenska kraftnät has analysed and proposed scenarios for the Nordic and northern European electricity systems until 2050. The future scenarios are divided into four different categories, according to figure 5. The common denominators for the given scenarios are an increasing demand of electricity and a supply of electricity to enable the transition towards an energy system which is independent of fossil fuels.

In terms of generation (and dependent on which of the four scenarios is being observed), hydropower and thermal power are assumed to be relatively constant throughout the different analyses. Nuclear power is assumed to remain at current level or to decrease down to zero. Wind power on land and solar power are expected to grow, slightly. The strongest variation in relative as well as absolute terms is assumed to occur in offshore wind power. In this future energy system, one key component is the sector coupling between electricity and gas, specifically hydrogen. It is stated that electricity-based production of hydrogen may play a pivotal role in the energy system, substituting fossil fuels in the transport sector and in the industry sector, as well as enabling expansion of intermittent renewable electricity generation with increased ability to balance the power grid. Furthermore, it is expressed that this infrastructure will be associated with the industry, and with a significant increase in the potential to introduce more flexibility to the energy system.

A few examples of new or increasing electricity demands are, for instance, that the mining and minerals company LKAB together with the steel company SSAB and the energy company Vattenfall have the ambition to manufacture steel using hydrogen instead of coal and coke, using the HYBRIT technology.

Another example is the increasing demands of data centres. This is included as a unique label in figure 5, and according to citing's by Koronen et al. (2020), the share of global electricity demands for data centres is estimated to be about 1 %. Moreover, the electrification of the transport sector is assumed to generate an increased demand as well. This is also specifically estimated in figure 5. Not only electric vehicles are considered in this context but also the option to manufacture liquid fuel, such as methanol in bio-refineries.

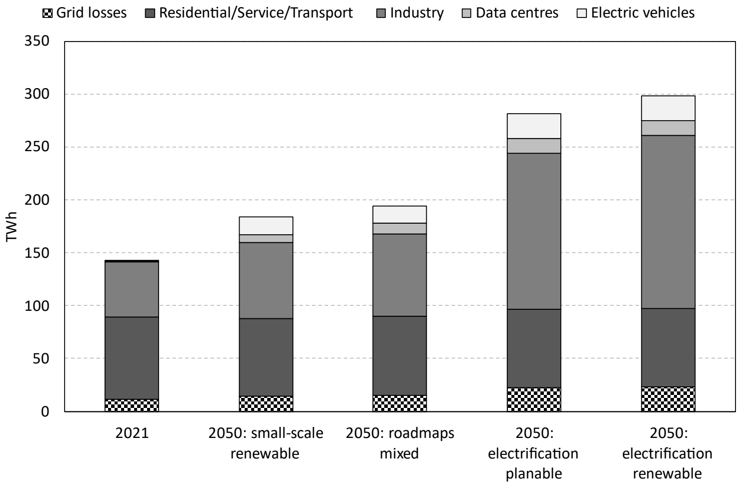


Figure 5 Electricity demand projections for Sweden in four different scenarios (Brunge et al., 2021). Graphical representation based on supplementary spreadsheet file to the cited report.

Perspectives on the Power Grid

While discussing the energy markets in Sweden, it is relevant to mention the Swedish power grid, particularly since it is the power-to-heat sector coupling that is in focus. Often, electricity receives a relatively large focus in the public discourse about energy in general, allocating smaller relative shares to other components of the energy system. Even if a strong emphasis is put on electricity in the energy system discourse, it may not be a large concern since the electricity component of the energy system consists of many interesting layers of complexity. Some of which are discussed a bit further in the following chapters.

The Capacity Situation

The expansion of power grids is associated with a processing time in the size of up to a decade. Hence, a capacity challenge emerges as society is changing quickly. Some examples of changes include (1) the energy transition towards sustainability, (2) changes in composition of electricity demand, for instance, with new electricity demand within the transport and industry sectors, (3) increasing population, (4) greater degree of people living in urban areas, and (5) an aging infrastructure of the existing power grid.

The combined factors have resulted in growing pains for several regions in Sweden in connection with economic growth since a tendency to deny the connection of new demands and the increase from existing demands have occurred due to a lack of capacity. This acts as an inhibitor for economic growth and to some degree the transition into a more sustainable society.

The Swedish Energy Markets Inspectorate was commissioned by the Swedish government to assess the capacity situation. The outcome of this work is documented by Axberg et al. (2020). This section briefly summarises the results of the report. The content of the report focuses among others on the extent of capacity limitations and the demand for changes in regulations. The report suggests a set of actions deemed necessary to alleviate the capacity issues. These actions include:

- Improved planning and coordination in connection with electric grid development
- Improved connection processes
- A more cost-effective operational reliability
- Increased use of flexibility services for more efficient electric grid utilization
- Efficient pricing to counteract large margins in capacity demands of existing consumers in the electric grid.

When reviewing the plans for investments into the transmission grid (220/400 kV), the regional grid (70-130 kV), and the local grids (<20 kV, 400/230 V), an extensive expansion is anticipated during 2020-2040. An expansion should meet the demand, but uncertainties for demand such as technology development, digitalisation, urbanisation, and electrification of society exist. The capacity issue has activated other solutions beyond power grid expansion such as varying options for increased flexibility. It is clarified that the distribution system operators and the transmission system operator are obliged to care for the system responsibility, which means that they have an obligation to expand and ensure that electricity is sufficiently supplied.

In current regulation, it is specified that grid operators may deny access for new and expanded electricity demands with reference to the lack of capacity. However, the regulation is not clear as to how to determine available capacity. The grid operator has an absolute responsibility to supply existing customers since it is not possible to lower capacity to a customer after an agreement has been made. Options to manage the lack of capacity revolve around (1) the potential to limit transmission capacities between countries, (2) the design of flexibility market mechanisms, and (3) the contracting and the use of network capacity reserve.

In an analysis, Axelsson et al. (2018) assess the impact of increased use of heat pumps, related to the capacity scarcity in the electric power grid. It is estimated that the current use of electric heating in Sweden corresponds to 6-9 GW during the coldest periods. It is also estimated that with an increased market share and performance improvements, the electric power demand for heating may decrease by 20 % to 40 % by the year 2030. It is reasoned that the major variation in the total power demand between winter and summer is caused by electric heating.

Currently, there are ongoing discussions about increasing electricity demands in Sweden. Such discussions are combined with different projections of future demand, one of these projections is described in figure 6. For the time series in figure 6, this increased demand is not yet clearly observed. Instead, it seems that a weak tendency for lower electricity demands occurs with time, by observing the average value. The spread of data is quite large, indicating the variation between summer and winter. The cause of the large spread is not known, but it is presumed that electric heating contributes to a large degree during cold periods.

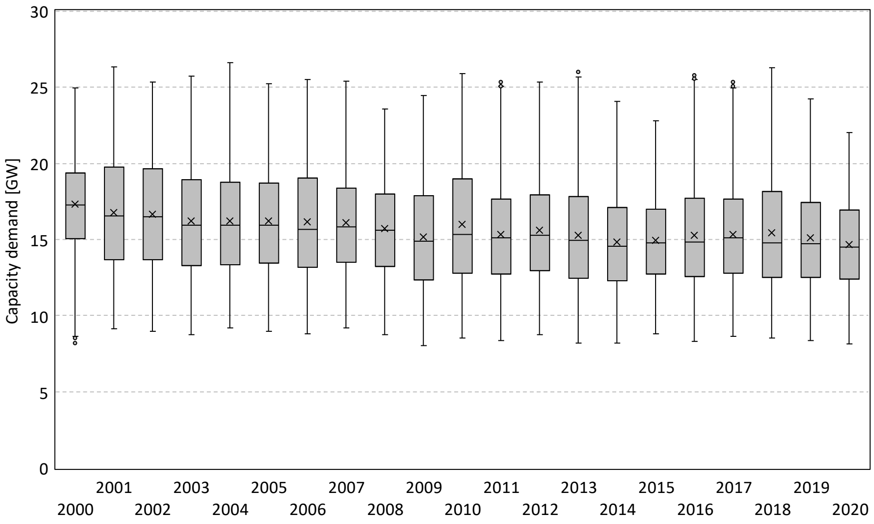


Figure 6 The capacity demand in the Swedish power system between 2000 and 2020. Power as hourly averages. (Statistics from Svenska kraftnät)

The net balance of the electricity grid in Sweden is presented in figure 7, where it is seen that for a large majority of the hours during a year, the total generation exceeds the capacity demand for electric power. This indicates that a surplus situation in terms of energy as a total volume is present during a large part of the year. It is still necessary to differentiate between the total available volume of energy and the potential possibility to transfer capacity to all the nodes of the network without experiencing bottlenecks as could be the case in an expanding urban area.

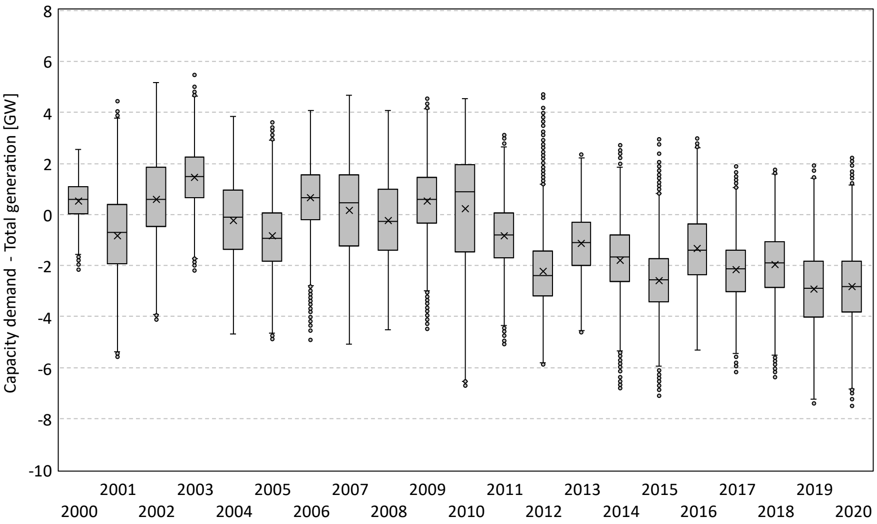


Figure 7 The Swedish power system total balance of import/export. Power as hourly averages. (Statistics from Svenska kraftnät)

Capacity Markets

Capacity markets are employed to assist in grid stability and are currently also part of becoming a component to obtain greater degrees of flexibility within the power grid. Information about the support services for capacity markets provided by Svenska kraftnät is summarised in Table 2.

Table 2. Overview of requirements for support services within the power system. (Svenska kraftnät)

Designation	Minimum bid size [MW]	Activation method	Activation time	Volume requirements [MW]	Minimum time duration
FFR (Fast Frequency Reserve)	0.1	Automatically at frequency changes at low level of rotational energy[1]	Three options for 100 %: -0.7 sec (at 49.5 Hz) -1.0 sec (at 49.6 Hz) -1.3 sec (at 49.7 Hz)	~100	- 30 sec alternatively 5 sec – Repeatability: Ready for activation within 15 minutes
FCR-N (Frequency Containment Reserve-Normal)	0.1	Automatically at frequency deviation within 49.90-50.10 Hz	63 % within 60 sec and 100 % within 3 min	~240	1 hour
FCR-D, up (Frequency Containment Reserve – Disturbance)	0.1	Automatic linear activation in frequency range 49.9-49.50 Hz	50 % within 5 sec and more 100 % within 30 sec	~580	Minimum 20 min
FCR-D, down (downward Frequency Containment Reserve - Disturbance)	0.1	Automatic linear activation in frequency range 50.1-50.5 Hz	50 % within 5 sec and more 100 % within 30 sec	~560	Minimum 20 min
aFRR (automatic Frequency Restoration Reserve)	5	Automatically via frequency deviation from 50.00 Hz	100 % within 120 sec	~140	1 hour
mFRR (manual Frequency Restoration Reserve)	10[2]	Manually at the request of Swedish power grid	100 % within 15 min	None	1 hour

[1] The amount of kinetic energy available in large generators.
[2] In price region SE4, the minimum bid size is lowered to 5 MW.

4.2. Summary Austria

Energy Market Analysis

In this section, the potential for efficient heating and cooling in Austria is discussed under the assumption of reaching climate neutrality 2050 in the building sector. To achieve this goal, extensive efforts in building renovation, decarbonization of electricity generation, and integration of waste heat into district heating systems are crucial.

District heating has been increasing since 1970. As of today, around 25 % of primary residences are supplied by district heating in Austria (around 20 TWh final energy use for heating). Within district heating, the share of biomass has been steadily increasing since 2005, and it is now providing around 50 % of the final energy use in district heating systems. Especially in rural areas, biomass combined with heat and power plants, or biomass boilers are used whereas in larger cities, the district heating is based on fossil fuels, waste incineration plants, and heat pumps.

In Austria, waste heat is in some cases utilized to feed district heating networks (between 0.8 and 1.8 TWh per year). The potential of geothermal energy is limited, and 12 plants (a total of about 70 MW_{th}) using geothermal energy are currently operating, mainly to feed district heating networks. The waste heat potential is differentiated between high (>100°C) and low (<100°C) temperature. In total, Austria has a potential to use waste heat from industrial processes of around 10.3 TWh of which 7.7 TWh are in the temperature range below 100°C. The paper industry has by far the largest potential with a total 5.4 TWh of which 5 TWh are low heat potential. For low heat, the chemical industry has a potential of around 1.4 TWh, the steel mills 0.3 TWh, and the mineral oil processing 0.7 TWh.

To estimate the energy market for the building sector, two scenarios are taken into consideration. The first scenario (WEM) assumes existing measures to stay in place, and no additional efforts for decarbonizing the building sector are taken. This scenario results in a possible reduction of residential heating and hot water demand by around 30 % until 2050. In this scenario, decarbonization of the sector in 2050 is not reached. The second scenario (Transition) enforces a decarbonized building sector by 2050 by enforcing higher building renovation rates and a change in heating systems away from fossil fuels. In this scenario, hot water and heating demands are reduced by around 50 % until 2050. In both scenarios, district heating has a high economic potential in 2050 taking the availability of different sources for district heat generation into account. The scenario results show that district heating would be economical to supply between 20 % and 50 % of all heat demand (figure 8) in 2050.

This result highly depends on the allowed costs for connection, the overall energy prices, and the connection rates of the grid to the buildings within reach and interest rates. Especially high energy prices make district heating a viable option compared to decentralized solutions. The reason for this is that energy prices affect decentralized solutions directly while a relevant share of the costs for district heating is due to the distribution network. A higher connection rate of the heating grid to buildings has a very strong impact on the economic viability of district heating as well which increases the relevance of large-scale heat pumps significantly, while the costs for expanding the heating network seem to have a linear impact.

In all scenarios, heat pumps play a vital role, both for the centralized and the decentralized generation of heat. The results in figure 8 indicate that scenarios with a greater proportion of district heating require an increase in energy input, which is attributable to distribution losses in the district heating systems. Nonetheless, this increased energy requirement does not translate to reduced energy efficiency. In fact, it leads to improved overall heat supply efficiency because it often allows for the utilization of a larger portion of available sources like waste heat, geothermal, or river-based heat pumps.

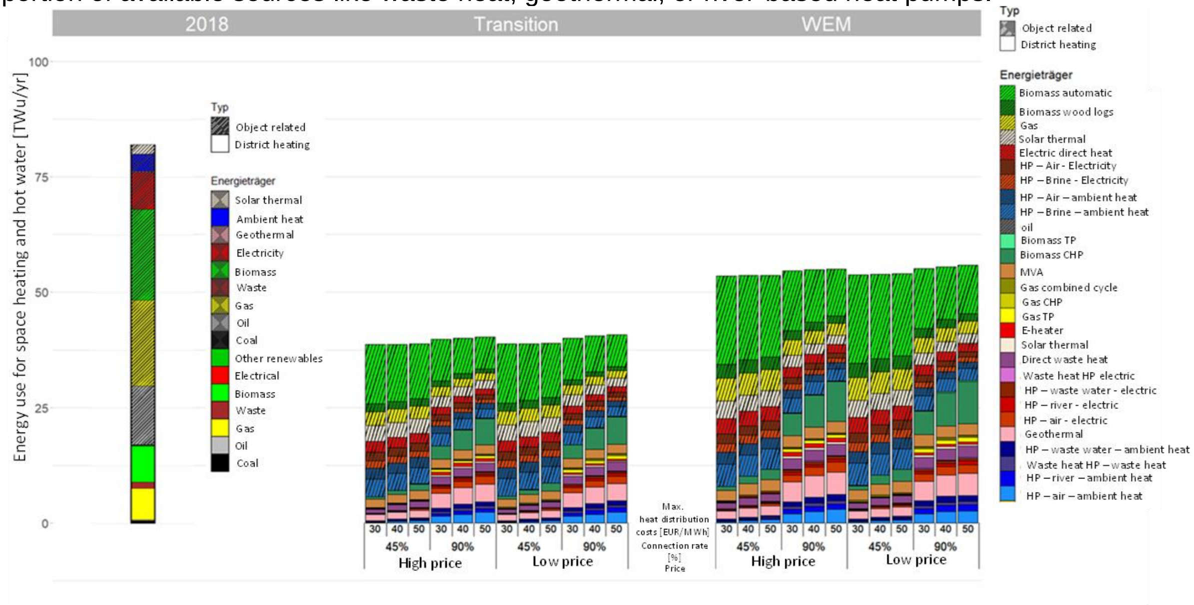


Figure 8 Use of energy sources for space heating and hot water in different scenario in 2050 in Austria from an economic perspective. (AIT)

The scenarios show that renewable gases are not a cost-effective option for decarbonizing the building sector. A high uptake in the electrification of heating systems, centralized (district heating) and decentralized together with the use of biomass will play a major role. The use of large, thermal storage systems contributes significantly to the economical operation of the heating networks. At the same time, there are significant uncertainties regarding the associated costs.

Sources for Waste Heat

The following section discusses on various conventional and unconventional sources for waste heat.

Conventional Sources

Industrial Waste Heat

Marina et al. found the overall waste heat potential from the sectors described above in the EU28 to be close to 1200 PJ per year, with the majority being low temperature waste heat up to 100°C. Figure 9 shows the share of waste heat of each sector and the respective waste heat temperature. The refinery sector has the largest share of waste heat and a great variety of waste heat temperatures.

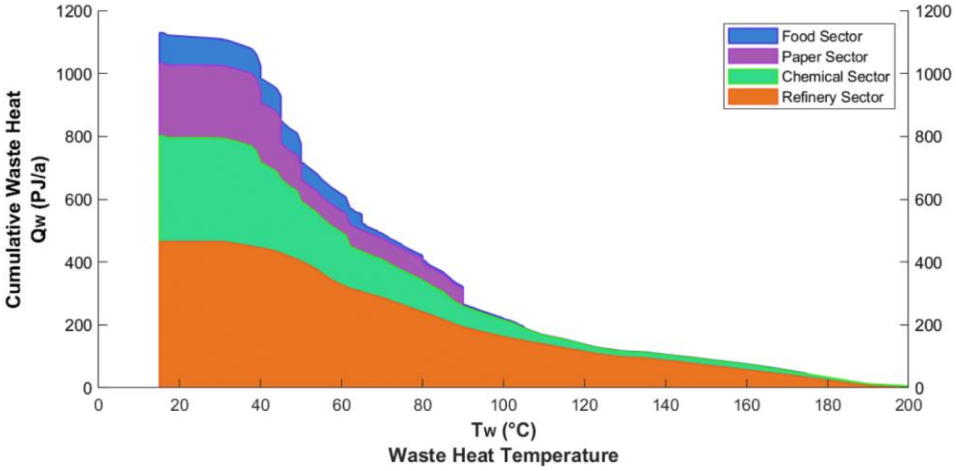


Figure 9 Cumulative waste heat <200 °C in EU28 identified in processes which make up the heat pump market study. (AIT)

Wastewater Heat Recovery

Wastewater heat recovery is a mature technology. The first publications, patents, and implemented projects date back to the mid-1970s. Throughout the year, greywater flows through the wastewater pipes at a temperature of between 10°C and 20°C. The annual performance factor of a heat pump utilizing wastewater as a heat source is around 5 for new buildings and 4 for existing buildings.

Flue Gas Condensation

Flue gas is a mixture of combustion exhaust gases. Often, exhaust gases are identified as waste heat, and they are rejected to the environment whereby valuable heat energy remains unused. However, to utilize the “waste heat”, a flue gas heat recovery system, usually utilizing sensible and latent heat “stored” in the flue gas as a heat source, might be used. Thereby, the cost and consumption of primary energy can be reduced.

Thermal Use of Lakes and Rivers

Heat pumps are used to utilize heat from lakes and rivers as a low temperature heat source. The lake/river water circulates in a primary circuit, and a secondary circuit brings the heat transfer fluid to the user. After the heat is released, the cooled water is returned to the water body.

Waste Heat from Tunnels

The idea of using waste heat from tunnels revolves around the water which drains through the man-made hole in the mountain. Rain penetrates the mountain and seeps downward. With increasing depth, the rock temperature increases. The approximate gradient is 3°C/100m. An example in this field is the Brenner base tunnel, which should be finished by 2030. Above the tunnel are 1800 meters of mountain which lead to water with temperatures around 35°C to 40°C, collected by drainage pipes. Due to a gradient, the water runs towards Innsbruck.

Waste Heat from Converter Stations

Typically, large transformer stations have very high efficiencies, often above 99 %. Nevertheless, losses of as little as 0.5 % can provide a significant amount of waste heat from large systems. A collaboration between a Danish (Energinet) and a Dutch (TenneT) transmission system operator implemented the COBRA cable for energy transmission between the two countries.

The HVDC converter station in the Danish town of Endrup provides excess heat to the local district heating network. The converter station has a voltage of 320 kV and a transmission capacity of 720 MW. The surplus heat generated by the converter station, which has a full load capacity of 3150 kW, will reach around 35°C. Heat pumps are used to reach the temperatures of the district heating network.

Data Centres

The energy consumption associated with data centres was 200-250 TWh in 2020, corresponding to around one percent of the global electricity demand. A different source states a consumption of 350 TWh for the year 2017. Data centres are designed for continuous operation and can, therefore, provide constant heat. Typical specific power densities are in the range of 250 to 1,500 W/m² IT area, resulting in high power requirements for larger data centres. An average European data centre has an area of 2,616 m², which means an electricity demand for the IT hardware of about 17.2 GWh/a when assuming a power density of 750 W/m² and continuous operation. Since the used electricity is completely converted into waste heat, this heat must be cooled away.

Electrolysers

The production of hydrogen from water and renewable electricity with electrolysers is the preferred production path in the future. There is a multitude of different technologies available at varying technology readiness levels. However, three types of electrolysers are the most promising: Alkaline electrolysis (AEL), polymer electrolyte membrane electrolysis (PEM-EL), and solid oxide electrolysis (SOEL). An overview of the key parameters for the technologies is given in Table 3.

Table 3. KPIs of electrolysis technologies

	AEL	PEM-EL	SOEL
TRL	9	8 - 9	6 - 7
Operating temperature [°C]	60 - 90	50 - 80	650 - 900
Electric efficiency (LHV)	50 - 71	50 - 68	75 - 85
Recoverable waste heat (% of electricity input)	16 - 30	20 - 30	-

4.3. Summary the Netherlands

District Heating Networks in the Netherlands

In the Netherlands, the district heating sector does not have a large market share due to an extensive natural gas infrastructure, which is the most common heat source for buildings. Around 490,000 homes are connected to a district heating network, which is equivalent to approximately 6.4 % of homes in the Netherlands. Since 2010, the number of connections has grown by 4.6 %, mainly due to new construction projects. This percentage is relatively low, and some measures must be considered to increase the expansion, also in the existing building stock. Various industrial complexes also make use of a heat grid for steam production, usually from a CHP. In total, this amounted to 35 PJ in 2017, which is more than all district heating combined (22 PJ).

The Netherlands is characterised by two different kinds of networks, the large-scale networks and the small-scale networks. Large networks consist of more than 150 TJ of heat delivery, and the main heat sources are usually power plants, waste incinerators, industry, and refineries. However, there are thousands of small-scale heat distribution networks. According to 2022 figures, there were approximately 41,000 connections connected to a small-scale network (less than 500 connections per network), and 55,000 connected to a network between a small-scale network and a large-scale network. Most of the small-scale networks count less than 50 connected consumers and those networks were owned by small firms, association of homeowners, and other parties. The networks between the large-scale networks and the small-scale networks are mostly owned by energy suppliers, which use cogenerations units, waste heat, heat pumps, or biomass plants as a source.

District Heating in the Future

District heating in the future is aimed at covering around 1/3 of the energy supply. Another 1/3 will be covered by electrical heat pumps, and the last 1/3 will be covered with hybrid heat pumps which runs on renewable gas. Supporting policies will help to achieve the goals below. For example, in 2023, the government opened a new subsidy scheme to reduce the CAPEX investment of new district heading grid projects.

Electricity Demand Now and Then

Heat Pumps

The total number of heat pumps installed in the Netherlands will rise to more than 568,000 units this current year (167,000 units in 2023). The Dutch association of national-regional electricity and gas network operators, Netbeheer Nederland, has introduced a plan to deploy up to 2 million (hybrid) heat pumps by 2030, especially in existing building stock. The plan is supported by a subsidy scheme introduced by the government and enable the installation of at least 100,000 heat pumps per year from 2024. The number has already been reached in 2023. However, the quality of installations must be improved. Manufacturers, installers, and the government have answered by starting the first 200 homes with a hybrid heat pump monitoring pilot program (https://www.demoprojecthybride.nl) and 500 installations a day acceleration program with installers.

To enface the electrification of the energy system, the power grid must be enforced. The acceleration of hybrid heat pumps is seen as a transition technology from gas boilers to electrification in the building environment.

The Capacity Situation

The ever-increasing rate at which additional transmission capacity is required exceeds the speed at which grid operators can expand the electricity grid. Although work on the grid is in full swing in all regions, the billions of invested euros and the additional measures are unfortunately not enough. The grid operators signal that the Netherlands is entering the next phase in which access to the electricity grid will come under further pressure. Without these drastic measures, housing construction, economic growth, and sustainability in the Netherlands will slow down.

In more and more places, a new connection or reinforcement for a company or home is no longer self-evident. This calls for a serious acceleration of the expansion of the electricity grid. In addition, grid operators and the government are taking additional measures to keep the electricity grid accessible and reliable. Examples of this are the mandatory use of smart charging stations, controllable heat pumps, and the mandatory relieving of the power grid at peak times. The changing energy system also requires different behaviour, i.e., using the grid mainly when the supply of energy is large.

The Netherlands is switching en masse to electricity

There are currently more than 105 gigawatts (comparable to more than 150 times the capacity of Amsterdam) in applications for reinforcements or new connections for electricity consumption. These are, for example, applications for large-scale batteries (75 GW) as well as industry, companies, data centres, hydrogen plants, and new residential areas. All these developments add up much faster than grid expansions can be realized. Rising energy prices and increasing climate ambitions are accelerating this considerably. Users are switching to electricity en masse.

Full Nets in all Regions

A study recently published by TenneT for the province Utrecht shows that there is no space available on the electricity grid for entrepreneurs in these regions. This means that they must consider long waiting times. In addition, the maximum capacity of the electricity grid has also been reached in North Holland for companies that want a connection or reinforcement.

Nationally, the trend is that the limits of capacity are coming into focus in more regions. The grid operators also note that the electrification of businesses and households is making the electricity grid in the district busier. Unfortunately, this means that small businesses and consumers will have to wait longer for a connection or an increase.

Changing Energy System Requires Different Behaviour

The joint grid operators indicate that the electricity supply is under pressure, especially at peak times when the maximum limits are reached. This entails risks of slowing down housing construction, economic growth, and making the Netherlands more sustainable. This is an uncomfortable truth that must be deal with in this transition. The energy infrastructure is the foundation of our society. To keep the energy grid as accessible as possible requires not only substantial investments in the energy grid but also a change in behaviour from all users. Electricity is no longer available indefinitely.

Flexibility for Businesses and Households

The new energy system requires a different behaviour from all users, with electricity mainly being used when there is a significant level of sustainable generation of wind or sun and less electricity being used during peak hours. Grid operators are confident that the measures announced by the government today will be implemented quickly, including the accelerated application of grid-aware charging of vehicles, and ensure that smart controllable devices become the norm.

The grid operators also consider it a positive development that the government is making 166 million euros available for an Energy Hubs Incentive Programme. In doing so, companies coordinate their electricity supply and demand locally so that less space is needed on the power grid. In addition, the government and the grid operators want to proactively start flex tenders from next year which allow companies such as a battery operator to offer more than 1 GW of space on the power grid at strategic locations during periods of time.

Smarter Use of the Grid

The main focus of grid operators is to accelerate the realisation of the infrastructure. However, enlargement alone is not enough. The sector is committed to a smarter use of the grid, for example, by making *rush hour avoidance* more financially attractive and less non-committal and by increasing the load on the grid where this is safely possible. To this end, interest groups, governments, ACM and system operators are also working together through the National Action Programme for Network Congestion (LAN). With measures announced by the government, grid operators expect to be able to relieve the electricity grid more and make better use of it so that they can connect more customers in order to limit delays for housing construction as well as the impact on economic growth and the sustainability of the Netherlands.

Actual capacity figures from grid operators (grid lower than 110 kV) can be found on the following website: https://capaciteitskaart.netbeheernederland.nl/

The actual situation in the high-voltage grid (110 kW and higher) can be found below or in the following viewer: www.tennet.eu/nl/de-elektriciteitsmarkt/connecting-dutch-high-voltage-grid/netcapaciteitskaart

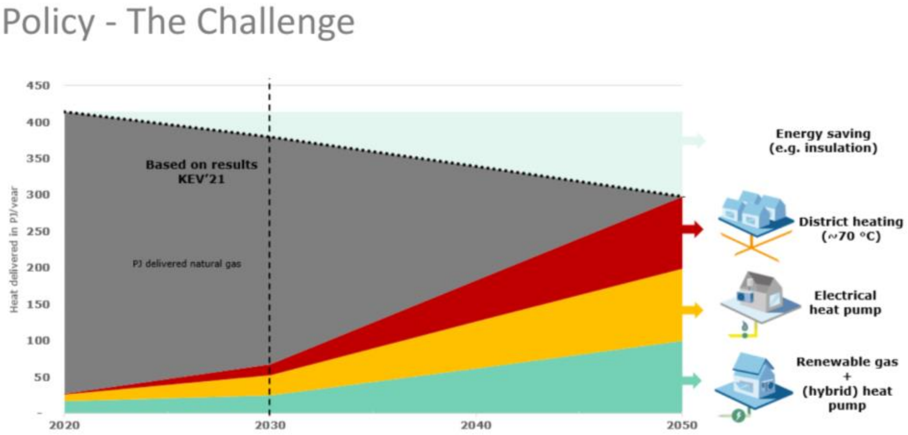


Figure 10 Dutch transition strategy. (IEA HPT)

4.4. Summary Denmark

District Heating Demand Now and in the Future

The opening of the electricity market and the green transition have significantly changed the incentives for establishing and maintaining thermal electricity production capacity in Denmark. Since the opening of the electricity market in 1999 and 2000, a significant part of the thermal electricity production capacity has been taken out of operation.

Danish District Heating Association has made an analysis and forecast of the electrical production and district heating production in the future.

The scenario shows that district heating in the future will be produced mainly by electrical heat pumps and excess heat. Waste incineration and biomass will be phased out as a heating source.

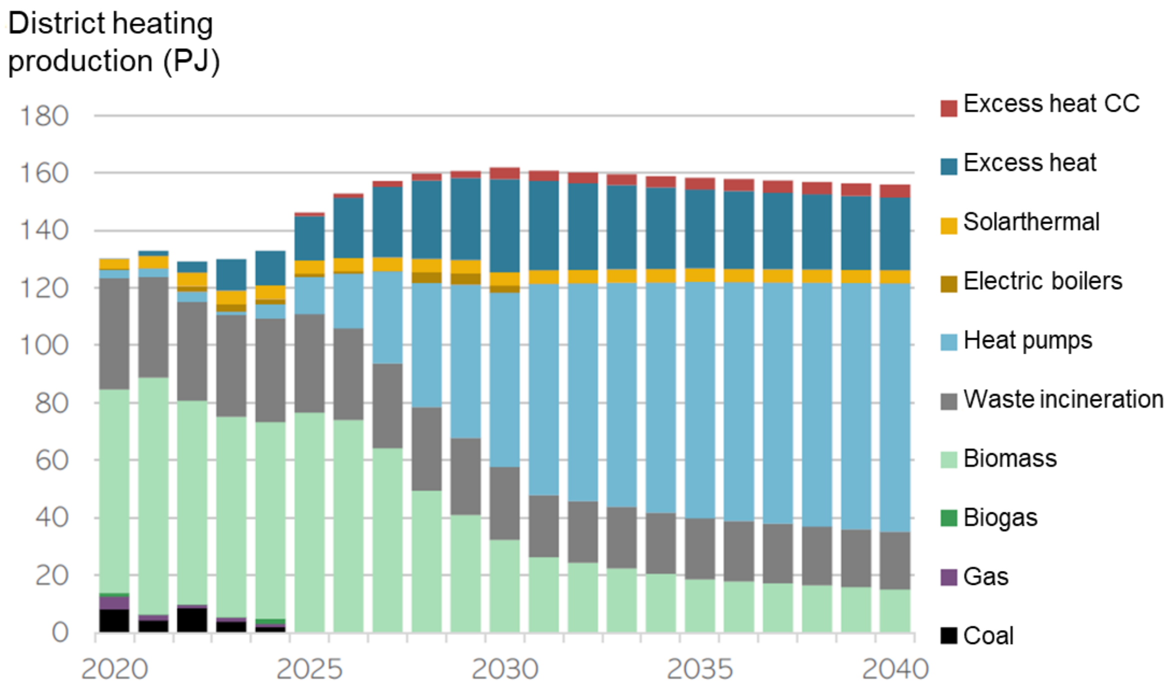


Figure 11 Scenario for the development in district heating production until 2040.
(Danish District Heating Association)

Electricity Demand Now and Then

The primary reason for the decrease in the capacity of the thermal plants is that electricity production will be outcompeted by large amounts of electricity produced in terms of wind and sun. Coal and gas in electricity production will already be phased out in the first half of the 2020s. Lead gas is a mixed product of natural gas and synthetic natural gas. Towards 2040, the proportion of fossil gas in pipeline gas will decrease.

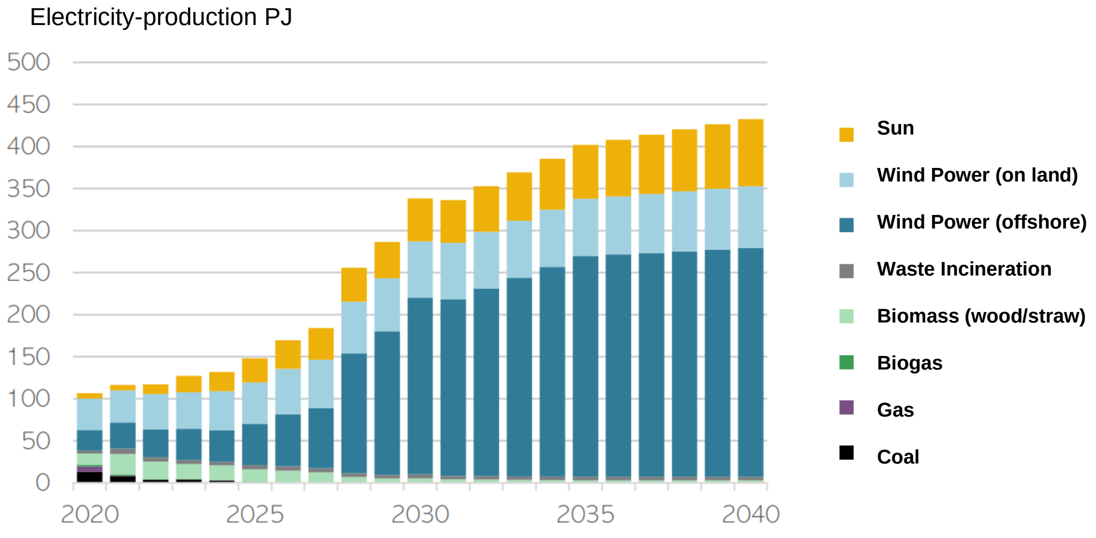


Figure 12 Scenario for the development in electricity production until 2040.
(Danish District Heating Association)

Perspectives on the Power Grid

In order to produce electricity for the growing consumption, a large expansion of renewable energy (RE) technologies is taking place. Electricity production capacity is strongly dominated by wind power, especially offshore wind in 2040 and 2050. Depending on the scenario, 22-26 GW of wind power is seen in 2050. In the ambitious scenario, a greater influx of solar energy is seen with approx. 8 GW capacity from 2030.

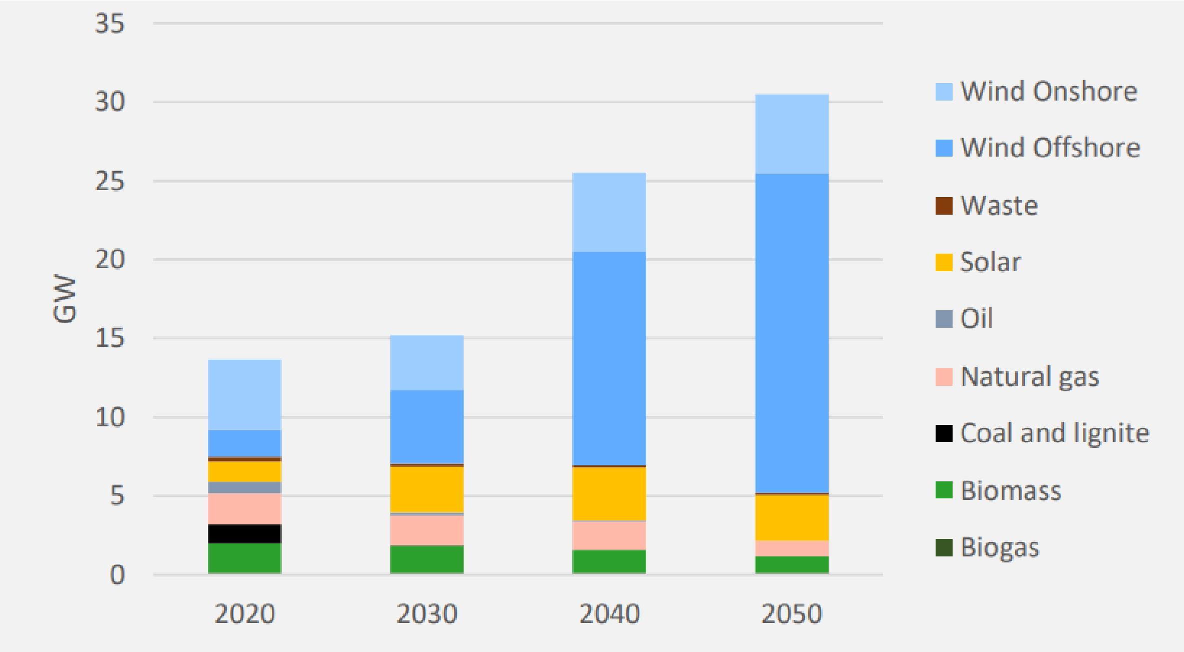


Figure 13 Scenario for the development in electrical production capacity. (Roadmap for elektrificering i Danmark Scenarierapport)

The Capacity Situation

The Danish TSO, Energinet, has made an analysis of the energy system. The purposes of Energinet's system perspective analyses are to analyse possible long-term development processes for the energy system as a unified system and to provide input based on this to the long-term planning of electricity and gas infrastructure as well as the broad system development necessary to handle the significant transformation which the energy system is facing.

The annual balances are shown in the produced scenarios. In the 35 GW scenario, Denmark has enough RE resources to export electricity and hydrogen and for new electricity consuming industry.

In the scenario with 35 GW offshore wind power in the Danish North Sea region, electricity generation from thermal power stations is very limited compared to wind/solar power generation. Demand-side response from PtX, heat pumps, electric vehicles, and batteries represents a significant dispatchable resource most of the time when there is high wind/solar power generation as shown in figure 14.

Capacity Markets

The model calculations show that flexible electricity consumption is increasingly taking over the supply of regulation reserves and ancillary services. The model optimizes both the capacity market, where the necessary regulation capacity is secured, and the activation market, where the up and down regulation itself is delivered.

In the reference scenario, a large share of the capacity market is overtaken by electrically driven heat pumps and boilers as well as PtX while foreign trade and downregulation of wind and solar power also contribute to the activation market. The development is caused by the highly significant growth in flexible electricity consumption primarily from heat pumps and PtX systems. The model establishes a total capacity towards 2040 of approx. 10 GW within these categories.

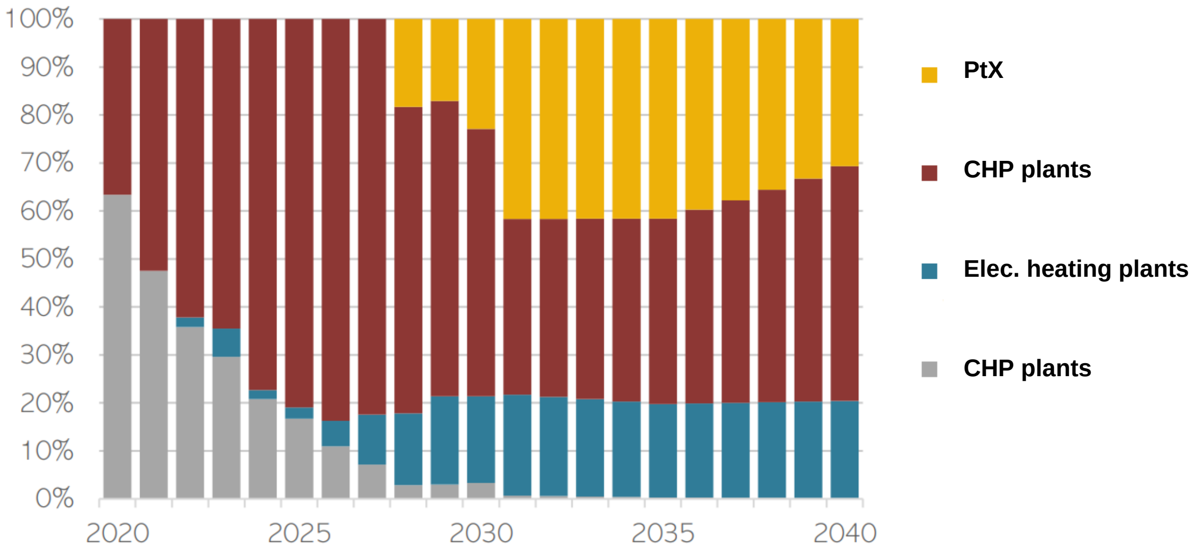


Figure 14 Technology mix which delivers to the capacity market for ancillary services. (Danish District Heating Association)

4.5. Summary Germany

The Federal Climate Change Act (KSG) of Germany has taken effect on 31 August 2021. Thereby, Germany declared its transition and certain targets over time to a greenhouse gas balanced system until 2045. The transition is essentially developed and accompanied by the long-term scenarios of DENA-Leitstudie, Agora - Klimaneutrales Deutschland 2045, the German industry association (BDI) - Klimapfade 2.0, “Langfristszenarien” of Federal Ministry for Economic Affairs and Climate Action (BMWK), and the research of „Ariadne“. The former Federal Ministry of Economics (BMWi) proposed in the “Dialog Klimaneutrale Wärme 2045” the essential parts for the transition of the heating sector. The total sector emissions of greenhouse gas equivalents (GHG) and its designated reduction path are shown in Figure 15.

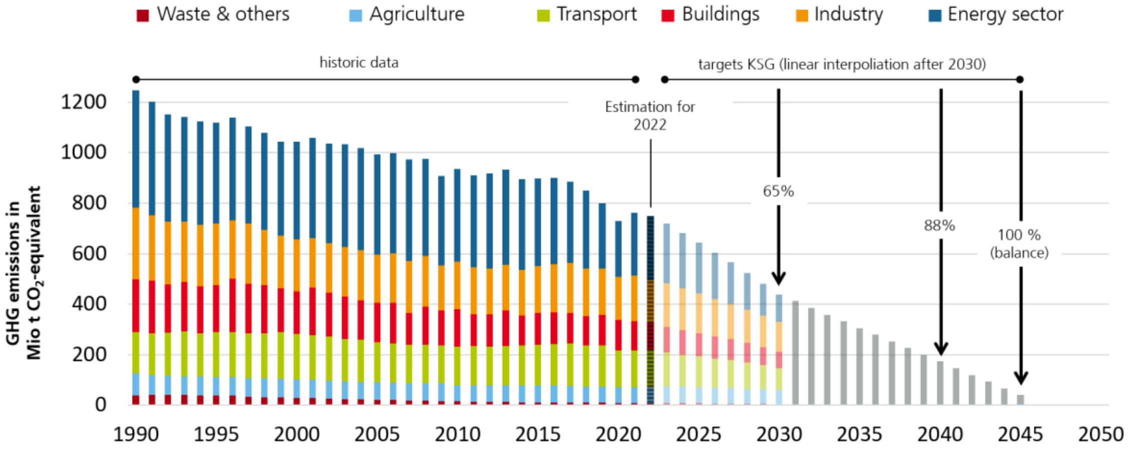


Figure 15 Total green-house-gas (GHG) equivalent emissions since the year of 1990 for Germany and its reduction path until 2045. (Umwelt Bundesamt 2023)

District Heating Demand Now and in the Future

The annual final energy demand supplied by DH systems is estimated based on BMWi energy data to 73 TWh/a for so-called low-temperature heat covering the residential as well as for the trade and commerce sector, including 58 TWh/a for residential household supply. An additional 43 TWh/a account for process heat in the industrial sector in 2021. Heat losses of distribution network need to be considered which might be estimated to additional 17 TWh so that 134 TWh of heat accounting about 10 % of the total heat production in Germany in 2021 might have been generated to be supplied by DHN. The generation is, thereby, based on natural gas (46 %) and coal (20 %) whereas renewables contributed 17 % as almost completely by incineration of biomass.

In connection with a model-based approach accounting a variety of resources, more than 1700 cities and communities were found to incorporate DH systems by an annual demand of 67 TWh for space heating and domestic hot water preparation in the residential sector as well as the industry sector by operating about 26,700 km of DH network. It is, furthermore, shown that DH will annually supply 94 TWh in the residential sector in 2045 by means of an increase in quantities of 60 % compared to 2020. This means additional quantities to be generated of annually about 1.6 TWh.

In connection with energy efficient measures in building physics and its performance, the specific heat demand is simultaneously decreasing so that the number of buildings supplied by DH is to be increased by a factor of about 2 to 3. To realize this annually, about 130,000 to 150,000 new connection units and an addition of 800 km of transmission line are annually to be constructed, which is about twice as much as the amount currently being accomplished. Furthermore, the need of the industrial sector must be taken into account, and the infrastructural impact might be larger when considering on-site constructions.

In another report, an amount of about 200 TWh for DH is estimated in 2050. In this approach, the capacity for DH supply is divided in a fossil free system in about 30 GW to 40 GW of installed centralized large heat pumps and about 13 GW to 27 GW solar-thermal. Peak load is covered by gas-based vessels and CHP in a range of 5 GW to 27 GW.

According to Mellwig et al. (2021) operation of large heat pumps will supply about 70 % of DH related quantities in 2045 which has been developed further in detail in Agora Energiewende, Fraunhofer IEG (2023). This means that about 100 TWh are annually supplied by large heat pumps and additional 10 TWh by electrode boilers in 2045.

Electricity Demand Now and Then

The consumption of electric energy is shown regarding the estimation of different scenarios in Brandes et al. (2021).

It becomes clear that the current electric quantities are approximately doubled from 600 TWh to around 1,200 TWh in 2045 whereas hydrogen is by means of its quantities not supposed to play a significant role in supplying demand in the electricity sector.

Perspectives on the Power Grid

Considering installed capacity, the German Federal Network Agency takes any system connected to the grid into account. A more detailed view regarding the current market development of home storage systems (HSS), large stationary storage systems (LSS), industrial storage systems (ISS), and battery electric vehicle is undertaken in Figgener et al. (2022). The current development and its estimated increase are shown in Brandes et al. (2021) where mobile battery systems are assigned to be used bidirectionally at a share of 10 % of the total battery-based vehicles. Furthermore, a c-factor between power and capacity (GWh to GW) has been assessed to 1. Capacity might vary in 2045 in the considered scenarios in between 400 GWh to 900 GWh.

Energy Markets

Prices of Energy

The composition for the price of electricity is shown for a typical private household. It becomes clear that taxes and cost allocation take about 50 %. Sales take about 24 %, and grid charges including metering cover the remaining 25 %. In the reference, a specific price of 0.32 €/kWh is shown for a costumer of a private household with an annual consumption of 3,500 kWh. In contrast, gas prices are composed regarding to “Die Energieversorgung 2022” as well.

The reference household with an annual consumption of 20 MWh is calculated to a specific fuel price of 0.07 €/kWh. In means of a comparison between gas and electricity prices, please refer to Wolf et al. (2017). Taking the previously stated prices in the private sector for single-family buildings into account, a ratio of electricity to gas fuel of about 4.5 occurs which has been reduced to approximately 3 after the price shock in 2022 whereas robust reference is not possible at the moment.

In the industry sector, final consumer prices are rather difficult to examine. It might be expected to find a ratio of 2 to 2.5 for Germany depending on e.g. local infrastructure and further market criteria. Especially switching to LNG as natural gas source has a certain impact that might affect future price scenarios intensively. Indicating references might be found in recent publications on https://ariadneprojekt.de/ and “Projektionsbericht 2021 für Deutschland”. For a robust scenario evaluation, full cost as levelized cost of heat (LCOH) taking, e.g., CAPEX, OPEX and subsidies over a life cycle into account are necessary when comparing both technologies for heat generation.

DH Prices (LCOH)

The prices have been evaluated in comparison to typical heating technologies in Meyer et al. (2021) for multi-family buildings. It becomes visible that the levelized cost of heat (LCOH) does not vary that much concerning different technologies. It takes around 14 to 15 ct.€/kWh for all considered technologies whereas the share of fuel cost is much lower for gas or electricity-based systems than for DH supply.

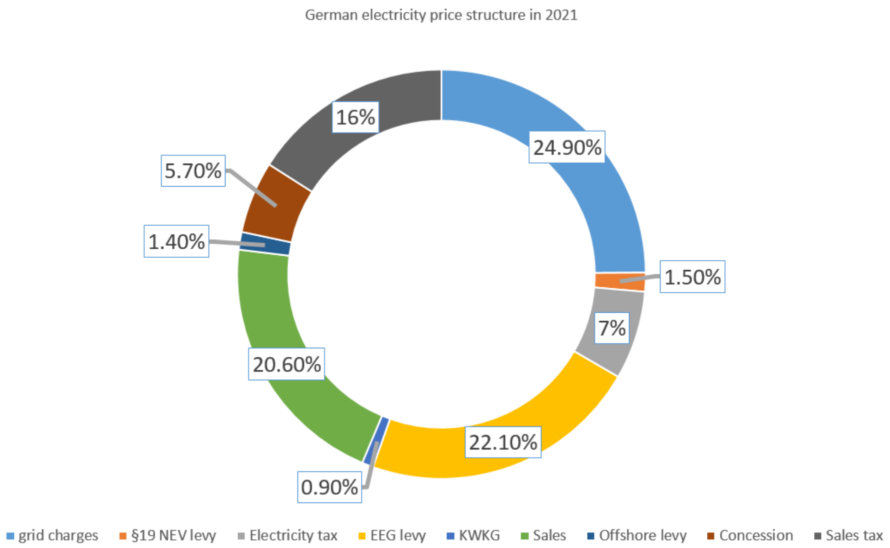


Figure 16 Structure of the German electricity price in 2021. (Verivox, 2021)

According to different sources, the current structure of the electricity price is the reason for different obstacles regarding the expansion of sector coupling technologies. As shown in Figure , the amount of taxes and levies have a high share on the total price. There are currently ongoing discussions if the price structure could be changed to support the consumers.

A smaller electricity price could lead to an expansion of sector coupling technologies like heat pumps or electric vehicles. On the other hand, if part of the taxes and levies are transferred to fossil fuels, it would probably decrease the usage of these. As can be seen from Figure , the share of taxes is much lower compared to electricity. However, there are no concrete plans available yet on how to relieve the consumers.

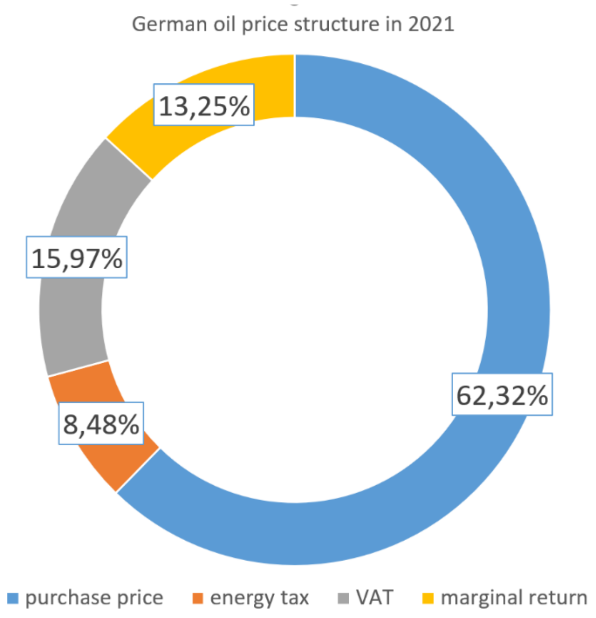


Figure 17 Structure of the German oil price in 2021. (Verivox, 2021)

Policies

Until the BEW Directive came into force, funding for large heat pumps in Germany was according to the KWKG essentially only possible as part of an innovative CHP system (iKWK). Basically, the component for providing renewable heat must be dimensioned so that at least 30 % of the reference heat (total heat provided by the iKWK system) can be generated as innovative renewable heat in a calendar year. The use of waste heat is not part of it.

The BEW guideline came into force on September 15, 2022. It consists of four modules which consider the following:

1) Feasibility studies and transformation plans (max. 50 % or 2 million EUR)

2) Systemic promotion of heating and cooling networks – grid measures (max. 40 % or 100 million EUR; limited by economic efficiency gap to reference technology)

3) Individual measures – generating technology (max. 40 % or 100 million EUR; limited by economic efficiency gap to reference technology)

4) Operating cost support (depending on certain criteria for each technology, e.g., max. 9.2 ct€/kWh for heat pumps and further restrictions)

Aspects on the Flexibility Perspective

First, some considerations of an optimal dispatch in ecological and economic relations are to be pointed out. Depending on the energy market design and cost relation between electricity and gas, it has been investigated that the operation of large-scale heat pumps depends highly on ecological or economic aspects. Considering the operation of a district heating plant consisting of CHP units and a heat pump, the following observations have been done.

As Hurst et al. (2023) have shown, there are different methods for the allocation of CO_2 emissions in CHP systems for the produced heat and electricity. The most appropriate way is based on the Carnot-method which depends on temperature regime to be considered for each time of operation. The method is not applied in regulatory schemes so far. Instead, quite simple and robust rules are applied which are based on constants, for instance, primary energy factor and a constant share of heat and power. In the current energy system of Germany and its market restrictions, such a consideration leads to a rather different optimal dispatch of heat pumps that are coupled electrically to a CHP system on-site.

Considering the most economic dispatch would lead to an operation of self-consuming electricity of the entire plant as it is favourable to consume the produced energy by the utility itself. In contrast, most ecological dispatch would incorporate renewable-based electricity that might be available through the grid but is too expensive due to network charges. This issue is very sensitive to the considered source of the heat pump, and it is, therefore, assigned COP. On rather high source temperatures resulting on high COP-values, the issue might turn around.

The flexibility contributions of the technologies are presented in this section based on Brandes et al. (2021). Flexibility contributions are the amount of energy which technologies can use when there is a shortage of electricity (electricity generation from renewables is less than the electricity load) or surplus (electricity generation from renewables exceeds electricity load).

Conclusion

It can be stated that electricity is becoming the most important primary energy source and that flexibilization is becoming the new paradigm of grid operation. It might be put to the point that “yesterday supply follows demand”, and it is stated for tomorrow “flexibilization: continuous balancing between power generation from renewable energies (wind, sun), controllable power plants, flexible loads (including electrolysers), and storage”. Furthermore, there is no need for base load power generation. Firstly, on-site energy supply solutions enable a massive reduction in regulatory complexity for integrated energy supply concepts (buildings, districts), and secondly, the creation of a simple legal framework with an interface to the higher-level network (system serving).

5. Summary of Task 2 - Best Practice Examples – Description of Existing Projects

One of the main objectives of Annex 57 is to demonstrate the possibilities for heat pump deployment and integration where they create flexibility as individual, decentralized heat pumps and large heat pumps installed in district heating grids. As a result, the goal was to set up an idea collection displaying several implementation examples. The research group was able to present 28 distinct cases from five different countries where heat pumps are integrated and generating flexibility. All of the cases are available on the Annex 57 website[1].

Figure 18 shows an interactive map with the locations of the gathered case studies marked. The map is freely accessible to all users on the Annex 57 website.

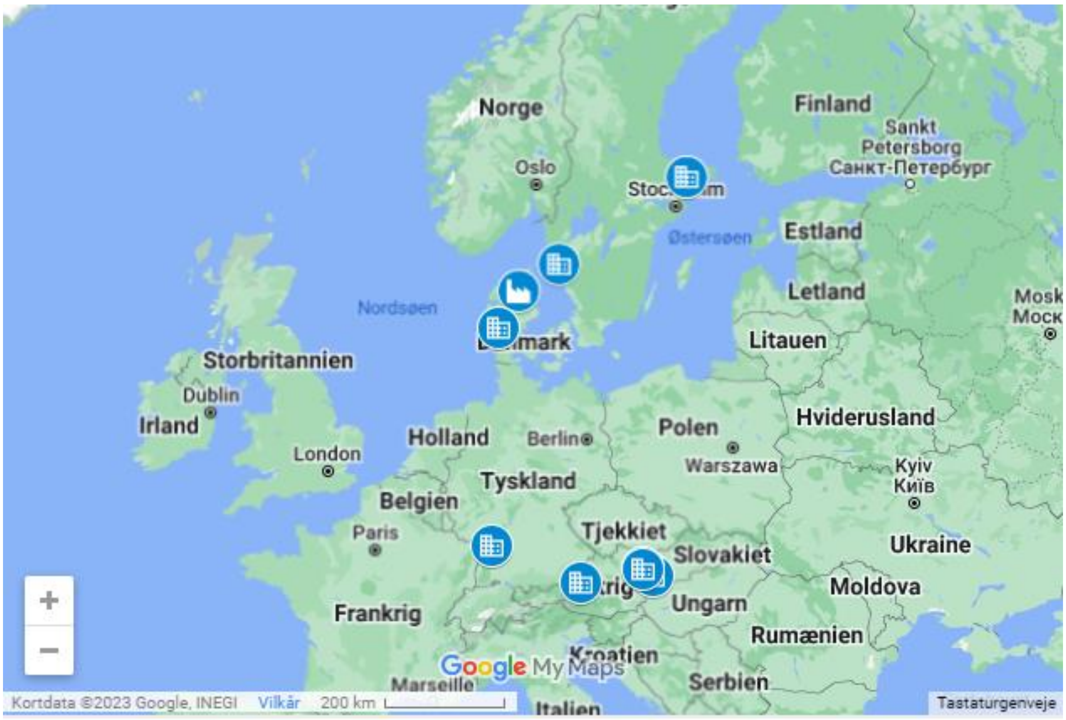


Figure 18 Map with the locations of the descripted cases. (Google Maps)

The following table provides an overview of the various cases; listing and categorizing all selected cases.

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[1] See: https://heatpumpingtechnologies.org/annex57/case-studies/

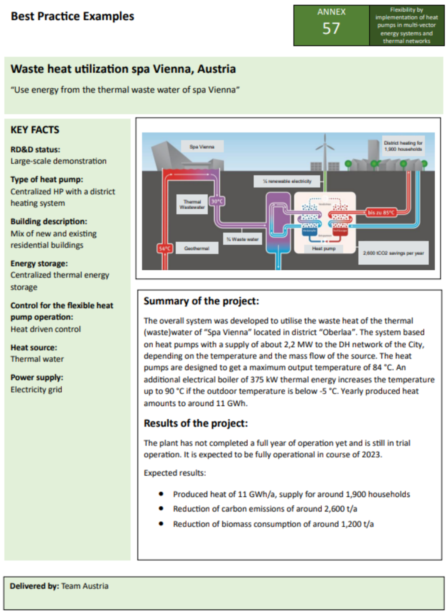
Table 4. Selected and described examples of best practice.

No	***City and Area***	***Country***	***Classification***	***Description***
1	Neusiedl am See	Austria	Central HP & DH In operation	Use excess wind electricity for heat pumps to enable flexible operation of the district heating system
2	Vienna	Austria	Central HP & DH Design study	Exploratory study of heat pump pooling concepts in urban district heating networks
3	Vienna	Austria	Decentral HP In operation	Large-scale deployment of prosumer flexibility in short-term electricity markets considering prosumer interests
4	Hallein / Salzburg	Austria	Central HP & DH In operation	Investigate and demonstrate the integration of an absorption heat in a biomass cogeneration plant for waste heat utilization
5	Vienna	Austria	Central HP & DH In operation	Waste heat utilization spa Vienna, Austria
6	Aalborg	Denmark	Decentral HP In operation	To have a CO_2 neutral cooling production for the warehouse and use of excess heat from the cooling production in the district heating system
7	Sdr. Felding	Denmark	Central HP & DH Under construction	District heating company expands their existing biomass-based production
8	Esbjerg	Denmark	Central HP & DH Under construction	The world's largest seawater heat pump
9	Copenhagen / Nordhavn	Denmark	Central HP & DH In operation	FlexHeat, Energylab Nordhavn
10	Copenhagen	Denmark	Decentral HP In operation	Heat Booster Substation
11	Neuburg an der Donau	Germany	Decentral HP Design study	Transformation and operational optimization
12	Berlin-Köpenick	Germany	Central HP & DH Under construction	Vattenfall Wärme, Berlin-Köpenick, Germany
13	Mannheim-Neckarau	Germany	Central HP & DH Under construction	Large Scale power plant Mannheim
14	Berlin-Neukölln	Germany	Central HP & DH In operation	District Heating Plant Neukölln
15	Rosenheim	Germany	Central HP & DH Under construction	Municipal utility
16	Stuttgart-Münster	Germany	Central HP & DH In operation	Waste-to-energy CHP plant
17	Karlsruhe Durlach	Germany	Decentral HP In operation	Smart District Karlsruhe: smart operation control strategies of various supply technologies under reducing temperature levels
18		Netherlands	Decentral HP In operation	Couperus smart grid. Demonstrates reductions of peak load with help of smart grid technology
19	Utrecht	Netherlands	Decentral HP Design study	Flexibilization of the electricity grid by means of AI optimization
20	Dalen	Netherlands	Decentral HP Design study	DACS-HW Aggeregation and flexible control of hybrid heat pumps in a district
21	Houten	Netherlands	Decentral HP Under construction	Electrification innovation platform building sector
22		Netherlands	Decentral HP In operation	Jouw Energie moment
23	Several locations	Sweden	Decentral HP In operation	Investigate possibilities for demand response of heating and domestic hot water production in homes with electrical heaters and heat pumps.
24	Gothenburg	Sweden	Central HP & DH In operation	The purpose of Smart Heat was to combine district heating and geothermal heat pumps in order to optimize heat consumption and reduce heating costs
25	Eskilstuna	Sweden	Decentral HP In operation	Flexible energy system integration using concept development, demonstration and replication. The project Flexi-Sync aims to optimize the flexibility in the district energy sector, a sector with untapped potential to balance the energy system
26	Uppsala	Sweden	Decentral HP In operation	New forms of cooperation in the energy market: We are convinced that demand-flexibility through aggregators will be a very important issue in our future energy
27	Stockholm	Sweden	Central HP & DH In operation	Stockholm Exergi has some large heat pumps in the district heating system. The operation of the heat pumps is optimised together with other heat generation resources depending on heat demand, electricity and other fuel prices.
28	Stockholm	Sweden	Central HP & DH Under construction	Sthlmflex is a research project aimed to create and test a flexibility market in ”Storstockholm” (Greater Stockholm)

Stories of Successful Implementation

So far, the case examples have been included and explained in accordance with standard procedure. In all, 13 case examples describe decentralized heat pump integration in buildings and 15 cases describe large heat pump integration in district heating grids. 17 of the 28 case examples are operational, seven cases are under construction, and four cases have been documented as design studies.

If feasible, the case examples are offered in a two-page version as well as a longer version. Each case study marked on the map includes a specific link to a longer and more comprehensive explanation of the case as well as a brief summary in the form of a free to download pdf file. The overview documents are two pages long. The first page summarizes the key points of the project and includes images of the given item. More details on the technological idea may be found on the second page.



Best Practice Examples

Waste heat utilization spa Vienna, Austria

"Use energy from the thermal waste water of spa Vienna"

KEY FACTS

RD&D status:
Large-scale demonstration

Type of heat pump:
Centralized HP with a district heating system

Building description:
Mix of new and existing residential buildings

Energy storage:
Centralized thermal energy storage

Control for the flexible heat pump operation:
Heat driven control

Heat source:
Thermal water

Power supply:
Electricity grid

Summary of the project:

The overall system was developed to utilise the waste heat of the thermal (waste)water of "Spa Vienna" located in district "Oberlaa". The system based on heat pumps with a supply of about 2,2 MW to the DH network of the City, depending on the temperature and the mass flow of the source. The heat pumps are designed to get a maximum output temperature of 84 °C. An additional electrical boiler of 375 kW thermal energy increases the temperature up to 90 °C if the outdoor temperature is below -5 °C. Yearly produced heat amounts to around 11 GWh.

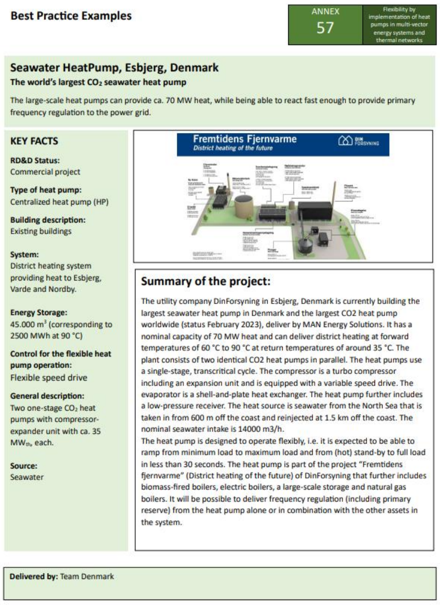
Results of the project:

The plant has not completed a full year of operation yet and is still in trial operation. It is expected to be fully operational in course of 2023.

Expected results:

- Produced heat of 11 GWh/a, supply for around 1,900 households
- Reduction of carbon emissions of around 2,600 t/a
- Reduction of biomass consumption of around 1,200 t/a

Delivered by: Team Austria



Best Practice Examples

Seawater HeatPump, Esbjerg, Denmark

The world's largest CO_2 seawater heat pump

The large-scale heat pumps can provide ca. 70 MW heat, while being able to react fast enough to provide primary frequency regulation to the power grid.

KEY FACTS

RD&D Status:
Commercial project

Type of heat pump:
Centralized heat pump (HP)

Building description:
Existing buildings

System:
District heating system providing heat to Esbjerg, Varde and Nordby.

Energy Storage:
45.000 m^3 (corresponding to 2500 MWh at 90 °C)

Control for the flexible heat pump operation:
Flexible speed drive

General description:
Two one-stage CO_2 heat pumps with compressor-expander unit with ca. 35 MW_{th}, each.

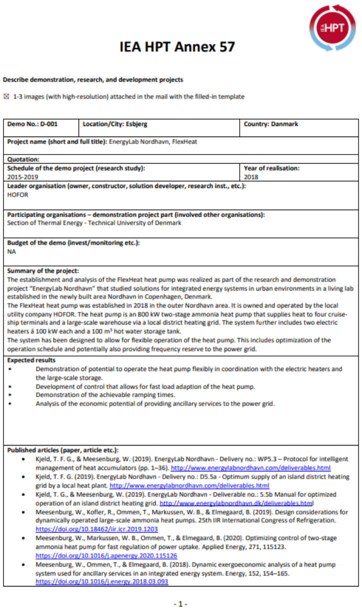
Source:
Seawater

Summary of the project:

The utility company DinForsyning in Esbjerg, Denmark is currently building the largest seawater heat pump in Denmark and the largest CO2 heat pump worldwide (status February 2023), deliver by MAN Energy Solutions. It has a nominal capacity of 70 MW heat and can deliver district heating at forward temperatures of 60 °C to 90 °C at return temperatures of around 35 °C. The plant consists of two identical CO2 heat pumps in parallel. The heat pumps use a single-stage, transcritical cycle. The compressor is a turbo compressor including an expansion unit and is equipped with a variable speed drive. The evaporator is a shell-and-plate heat exchanger. The heat pump further includes a low-pressure receiver. The heat source is seawater from the North Sea that is taken in from 600 m off the coast and reinjected at 1.5 km off the coast. The nominal seawater intake is 14000 m3/h.
The heat pump is designed to operate flexibly, i.e. it is expected to be able to ramp from minimum load to maximum load and from (hot) stand-by to full load in less than 30 seconds. The heat pump is part of the project "Fremtidens fjernvarme" (District heating of the future) of DinForsyning that further includes biomass-fired boilers, electric boilers, a large-scale storage and natural gas boilers. It will be possible to deliver frequency regulation (including primary reserve) from the heat pump alone or in combination with the other assets in the system.

Delivered by: Team Denmark

Figure 19 Example of the 2-pager case study descriptions.



IEA HPT Annex 57

Describe demonstration, research, and development projects

☒ 1-3 images (with high-resolution) attached in the mail with the filled-in template

Demo No.: D-001	**Location/City: Esbjerg**	**Country: Danmark**
Project name (short and full title): EnergyLab Nordhavn, FlexHeat		
Quotation:		
Schedule of the demo project (research study): 2015-2019		**Year of realisation:** 2018
Leader organisation (owner, constructor, solution developer, research inst., etc.): HOFOR		
Participating organisations – demonstration project part (involved other organisations): Section of Thermal Energy - Technical University of Denmark		
Budget of the demo (invest/monitoring etc.): NA		
Summary of the project: The establishment and analysis of the FlexHeat heat pump was realized as part of the research and demonstration project "EnergyLab Nordhavn" that studied solutions for integrated energy systems in urban environments in a living lab established in the newly built area Nordhavn in Copenhagen, Denmark. The FlexHeat heat pump was established in 2018 in the outer Nordhavn area. It is owned and operated by the local utility company HOFOR. The heat pump is an 800 kW two-stage ammonia heat pump that supplies heat to four cruise-ship terminals and a large-scale warehouse via a local district heating grid. The system further includes two electric heaters á 100 kW each and a 100 m^3 hot water storage tank. The system has been designed to allow for flexible operation of the heat pump. This includes optimization of the operation schedule and potentially also providing frequency reserve to the power grid.		
Expected results • Demonstration of potential to operate the heat pump flexibly in coordination with the electric heaters and the large-scale storage. • Development of control that allows for fast load adaption of the heat pump. • Demonstration of the achievable ramping times. • Analysis of the economic potential of providing ancillary services to the power grid.		
Published articles (paper, article etc.): • Kjeld, T. F. G., & Meesenburg, W. (2019). EnergyLab Nordhavn - Delivery no.: WP5.3 – Protocol for intelligent management of heat accumulators (pp. 1–36). http://www.energylabnordhavn.com/deliverables.html • Kjeld, T. F. G. (2019). EnergyLab Nordhavn - Delivery no.: D5.5a - Optimum supply of an island district heating grid by a local heat plant. http://www.energylabnordhavn.com/deliverables.html • Kjeld, T. G., & Meesenburg, W. (2019). EnergyLab Nordhavn - Deliverable no.: 5.5b Manual for optimized operation of an island district heating grid. http://www.energylabnordhavn.dk/deliverables.html • Meesenburg, W., Kofler, R., Ommen, T., Markussen, W. B., & Elmegaard, B. (2019). Design considerations for dynamically operated large-scale ammonia heat pumps. 25th IIR International Congress of Refrigeration. https://doi.org/10.18462/iir.icr.2019.1203 • Meesenburg, W., Markussen, W. B., Ommen, T., & Elmegaard, B. (2020). Optimizing control of two-stage ammonia heat pump for fast regulation of power uptake. Applied Energy, 271, 115123. https://doi.org/10.1016/j.apenergy.2020.115126 • Meesenburg, W., Ommen, T., & Elmegaard, B. (2018). Dynamic exergoeconomic analysis of a heat pump system used for ancillary services in an integrated energy system. Energy, 152, 154–165. https://doi.org/10.1016/j.energy.2018.03.093		

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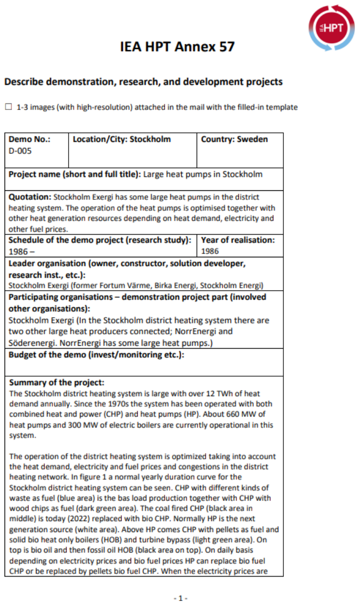


IEA HPT Annex 57

Describe demonstration, research, and development projects

☐ 1-3 images (with high-resolution) attached in the mail with the filled-in template

Demo No.: D-005	**Location/City: Stockholm**	**Country: Sweden**
Project name (short and full title): Large heat pumps in Stockholm		
Quotation: Stockholm Exergi has some large heat pumps in the district heating system. The operation of the heat pumps is optimised together with other heat generation resources depending on heat demand, electricity and other fuel prices.		
Schedule of the demo project (research study): 1986 –		**Year of realisation:** 1986
Leader organisation (owner, constructor, solution developer, research inst., etc.): Stockholm Exergi (former Fortum Värme, Birka Energi, Stockholm Energi)		
Participating organisations – demonstration project part (involved other organisations): Stockholm Exergi (In the Stockholm district heating system there are two other large heat producers connected; NorrEnergi and Söderenergi. NorrEnergi has some large heat pumps.)		
Budget of the demo (invest/monitoring etc.):		
Summary of the project: The Stockholm district heating system is large with over 12 TWh of heat demand annually. Since the 1970s the system has been operated with both combined heat and power (CHP) and heat pumps (HP). About 660 MW of heat pumps and 300 MW of electric boilers are currently operational in this system. The operation of the district heating system is optimized taking into account the heat demand, electricity and fuel prices and congestions in the district heating network. In figure 1 a normal yearly duration curve for the Stockholm district heating system can be seen. CHP with different kinds of waste as fuel (blue area) is the bas load production together with CHP with wood chips as fuel (dark green area). The coal fired CHP (black area in middle) is today (2022) replaced with bio CHP. Normally HP is the next generation source (white area). Above HP comes CHP with pellets as fuel and solid bio heat only boilers (HOB) and turbine bypass (light green area). On top is bio oil and then fossil oil HOB (black area on top). On daily basis depending on electricity prices and bio fuel prices HP can replace bio fuel CHP or be replaced by pellets bio fuel CHP. When the electricity prices are		

- 1 -

Figure 20 Example of the extended case study descriptions.

Conclusions from the Case Studies

The main objective of the case study descriptions was to generate and gather new demonstration concepts as success stories for the integration of flexibility with heat pumps. Flexibility can be realized on a single building scale with decentralized heat pumps and on a larger scale with larger heat pumps and district heating grids. Based on these experiences, ideas and insights gained in developing these systems are provided. Demonstrated systems include the utilization of modern technologies and interaction between diverse components within the systems. As demonstrated by the many case studies, there are several opportunities to incorporate heat pumps in the flexibility market, both technically and commercially.

Within the considered realized systems, an economically optimal dispatch is widely rolled out and scientifically monitored. As the electricity grid system forms operation as part of balancing, the ancillary service markets as the mFRR and aFRR are expected to have a high potential which has been examined by simulation approaches but not implemented in the considered real-live running systems so far.

On the Annex 57 website, there is a short explanation of each analysed case as well as an expanded and more extensive version of each case example. Table 4 provides an overview of the key aspects of the projects.

6. Summary of Task 3 – Concepts for Heat Pump Flexibility and Promising Solutions

Task 3 gives an overview of promising concepts and solutions which can create flexibility. The concepts and solutions consist of solutions for individual homes, and district heating systems.

Heat Pump Flexibility in Single-Family Houses (SFH)

In general, heat pumps can provide flexibility services. It is important to understand that the flexibility potential can be distinguished in 'capacity' and 'time length'. First, the outdoor temperature is a major determinant for the capacity that can be provided since the outdoor temperature determines the operational level of the heat pump. Second, it is also important to consider outdoor and indoor temperatures as they constrain the operational flexibility with respect to the time length for which flexibility services can be provided. A lower outdoor temperature gives a shorter period of time before the heat pump needs to start again to avoid low indoor temperatures.

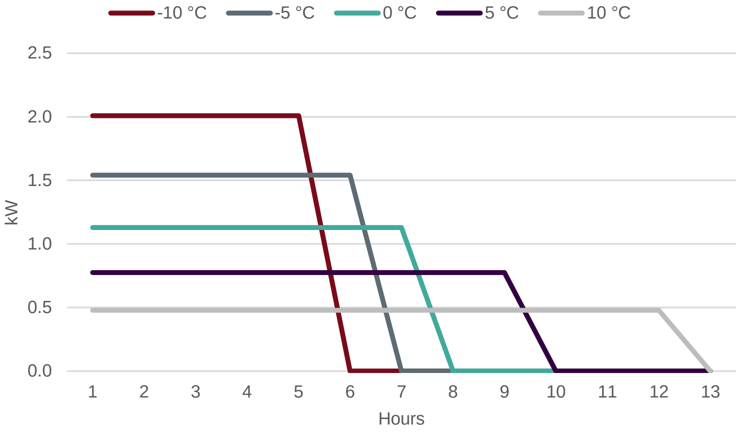


Figure 21 Flexibility potential depends on outside temperature. (Task 3)

The positive flexibility potential increases with lower outside temperature since the electric heat pump demand can be reduced, at least for a certain period of time. However, one must keep in mind that the electric load of the heat pumps is only moved in time. Sooner or later, the heat pumps have to run harder to catch up with the missed heat production.

Flexibility from SFH-HP on the DA Market: Simple Approach on Historic Data

In the course of the Annex 57 project, another approximation of the revenue potential was undertaken by deploying a linear optimization model, which models the thermal behaviour of a representative single-family house (SFH) in a simplified way.

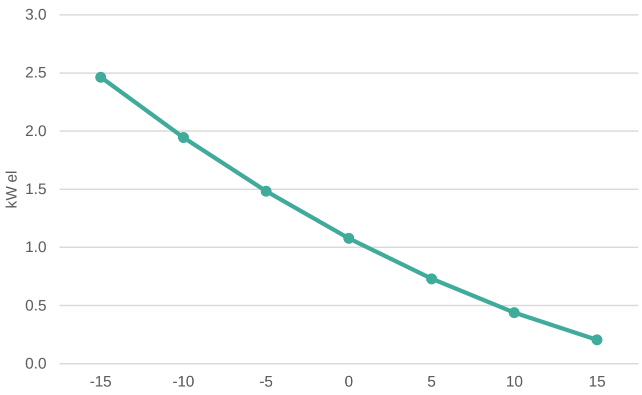


Figure 22 Electric demand as a function of outside air temperature for a single-family house. (AIT)

Figure 23 illustrates the costs of the baseline scenario as well as the benefits from flexible heat pump operation across multiple historical years. The figure shows that in historical years before 2021, electricity costs of (inflexible) heat pump operation range around 600 €/year. It is worth noting that these costs represent only a fraction of the total costs of electricity as network charges, taxes, and levies are not considered herewith. However, grid fees and taxes are fixed over time and, therefore, not relevant for the results regarding the flexibility potential of heat pumps.

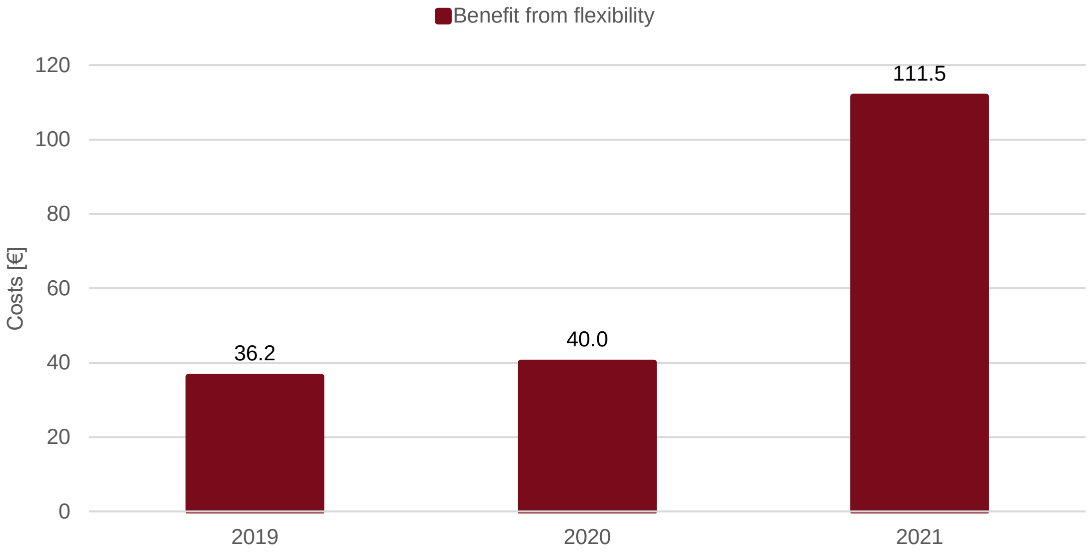


Figure 23 Electricity benefits from flexible heat pump operation. (AIT)

Flexibility from SFH-HP on the DA Market: Sophisticated Approach on Scenario Data

Field Tests of Remote Control of Individual Heat Pumps for Flexibility Services

In the Swedish SLAV project, a field test was carried out by using three inverter-controlled ground source heat pumps which were installed in three different single-family buildings. The main scope of the tests was to evaluate the possibilities to fulfil the demands of Svenska kraftnäts ancillary services through remote control of heat pumps via the cloud and API of the manufacturer.

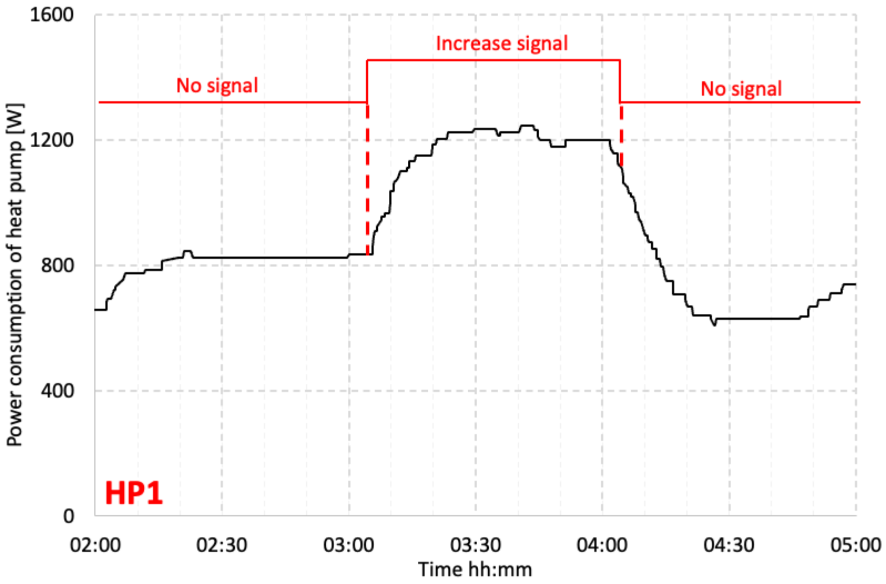


Figure 24 Increase of power consumption on the first heat pump (HP1). (Svenska kraftnäts)

Conclusions from Field Tests

Field tests carried out on three inverter-controlled ground source heat pumps in three single-family buildings showed that:

- The response to a control signal to increase the power consumption of the heat pumps is slow when the compressor is already running.
- The heat pumps stop quickly when they get an off signal. The heat pumps stop within five to eight seconds if the compressors run at a low frequency when the stop signal is sent. However, the time to stop the compressor increases with the frequency of the heat pump compressor.
- With the used control strategy, it was not possible to control the domestic hot water production. If the heat pump makes domestic hot water, the stop signal will be ignored. This shows the need for improved demand response signals for heat pumps.
- Tests within the project have shown that during the heating season, it is possible to keep the heat pump turned off as long as wanted and to start it on demand.

NL Heat Pump Hybrid Input from Monitoring Projects

Installation Monitor 1.0: Hybrid Heat Pump is an Excellent Transition Technology

Due to the grid constraints, the Dutch government started a hybrid heat pump program. Part of this program is funded to monitor projects to provide real performance data. A hybrid heat pump provides significant savings in natural gas consumption and, thus, contributes directly to reducing CO_2 emissions. This is evident from the final results of the monitoring process of the “Installation Monitor”. With the current gas and electricity prices, the purchase of a hybrid heat pump leads directly to savings on energy bills for almost all types of homes.

According to the final results of the Installation Monitor, a hybrid heat pump provides 60 % of the average annual heat demand for space heating. The remaining 40 % as well as the tap water demand are met by the gas boiler. For every cubic meter of natural gas saved in this way, the heat pump uses 2.35 kWh of electricity, i.e., a SCOP of 3.8 on average.

Ongoing: Demo Project Hybrid Heat Pumps

To get a good picture of the applicability, performance, savings, and comfort of the hybrid heat pump, the operation of 200 hybrid heat pumps in homes is monitored. The installations are monitored for at least one heating season, and the resulting data are recorded and interpreted.

At the moment, the results of 120 homes with appliances from various brands have been analysed. With this, enough data has been collected to draw the first conclusions. Extensive measurements show a reduction in the energy consumption achieved by the hybrid system. For example, it is now possible to determine the consequences for gas consumption, CO_2 emissions, and energy costs without assumptions or fictitious calculations.

The ongoing project has already yielded some important conclusions:

- The participating homes had an average gas consumption of 1850 m^3 over the two years prior to the project.
- By installing the hybrid system, the average gas consumption has been reduced by 75 % to 475 m^3.
- To achieve these savings, the homes used an average of 2360 kWh of extra electricity per home.
- This results in annual savings of almost 1000 euros per home. The energy tariffs were applied according to the price cap: 1.45 euros for 1 m^3 of gas and 0.40 euros for 1 kWh. Calculated with the current (May 2023) market average rates. With the expectation that energy prices will rise in the future, the savings for the residents will increase and the payback period will decrease further.

Potential Backup Systems (Electrical Heater, Biomass, Gas / Oil Burner)

In Denmark, the implementation of heat pumps in smaller district heating grids has accelerated over the last years. A promising solution is to combine heat pumps with an electrical boiler and a storage tank and with biomass/gas or oil as backup solutions. A plant that operates with such a solution is Sdr. Felding District Heating.

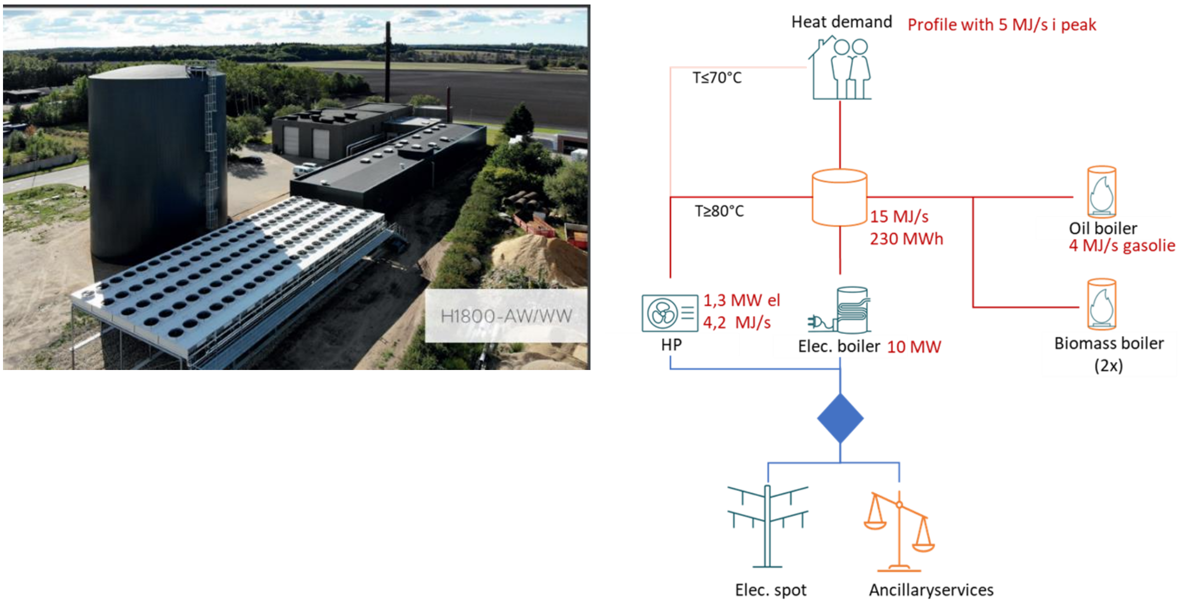


Figure 25 System plant and layout. (EnergiNet)

Flexibility Shown

The heat pump and the electrical boiler supplement each other. When it comes to delivering ancillary services, the boiler can react very fast and adjust the electric load up and down, and it can supplement the heat pump to reach the bid limit when the plant operator is putting offers into the market.

The heat pump has been tested in terms of its reaction time. It has a start-up time within seven minutes and a turn down time within four minutes, as shown in the graphs below. This means that it is able to act in the aFRR regime.

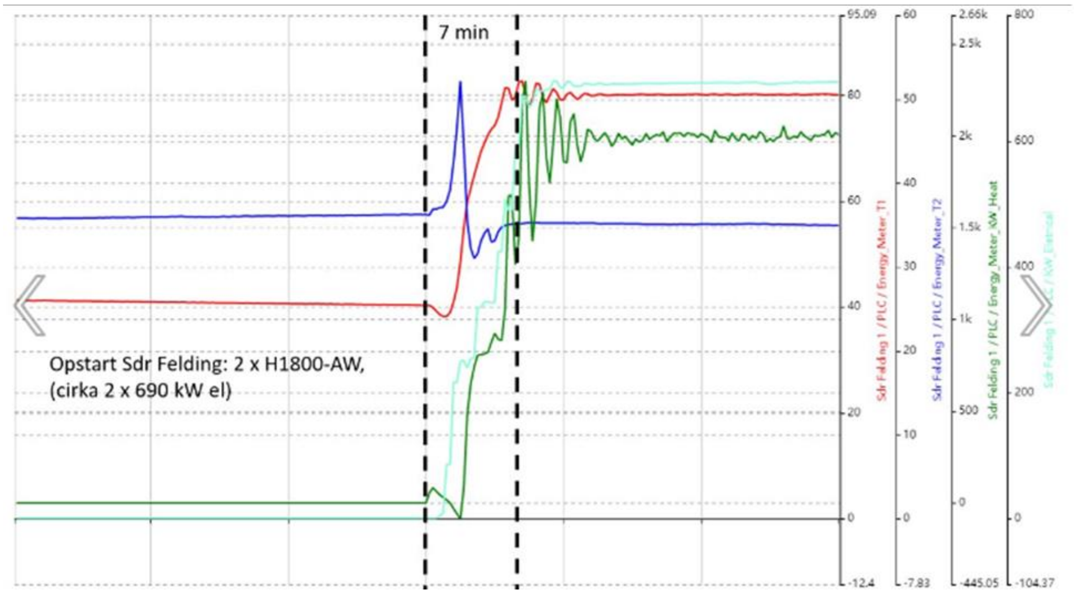


Figure 26 Startup Sdr. Felding. (Fenagy)

The heat pump and the electrical boiler supplement each other. When it comes to delivering ancillary services, the boiler can react very fast up and down, and it can, thereby, supplement the heat pump to reach the bid limit of 1 MW when the plant operator is putting offers into the market.

Results

The project has shown that it is possible for heat pumps to react into the ancillary service market, the mFRR as well as the aFRR market.

The combination of a heat pump and an electrical boiler gives certain advantages regarding reaction time and capacity. Biomass boilers are great when long periods with high electricity prices occur, for example, in periods of two weeks with no wind. Storage with a weekly capacity increases the flexibility of the plant.

Heat Pump in Combination with Biomass

In Austria, there is a large number of small biomass-based district heating networks, which were built about 20 years ago. They are reaching the end of their technical lifetime and are operating with lower efficiency compared to modern plants. Installing additional heat pumps in those grids can improve the overall efficiency of the heat plants by utilizing flue gas as a source.

In the Austrian research project fit4power2heat, this concept was analysed with simulations, using a techno-economical optimization model of the heating systems and the interaction with the electricity markets. Various scenarios were calculated, comparing different types of heating grids, different heat sources as well as different electricity markets.

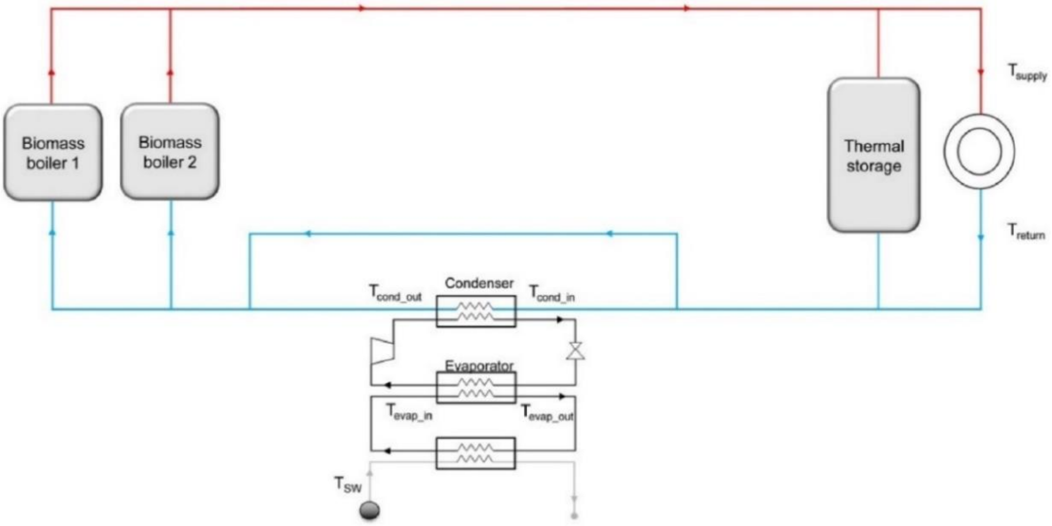
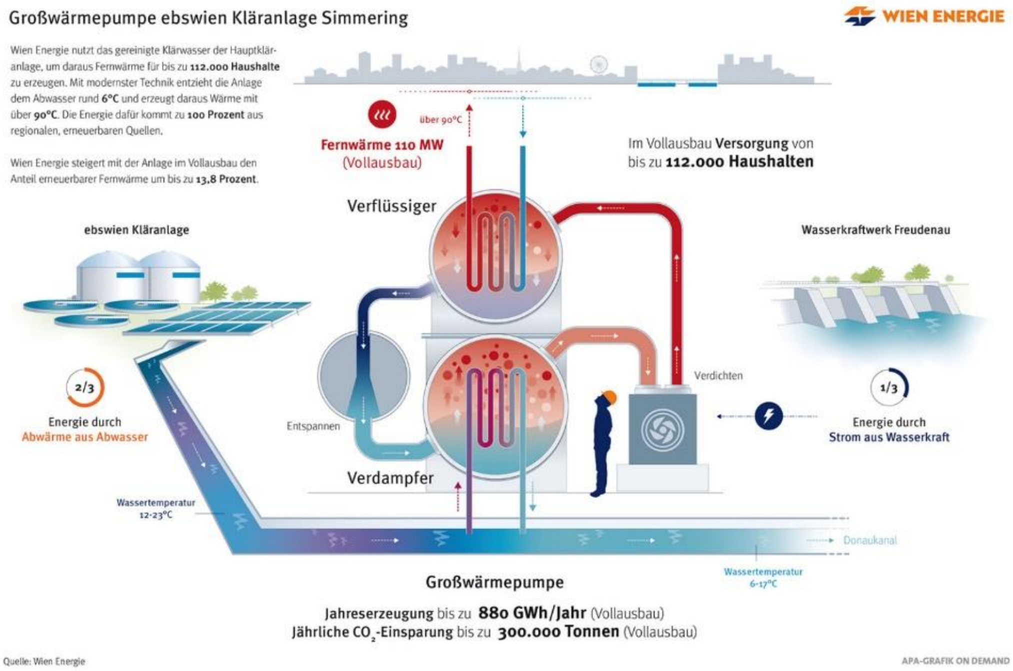


Figure 27 Scheme of the heat pump integration using sewage water as a source. (Task 3)

Heat Pump in High-Temperature District Heating

The Austrian energy supplier “Wien Energie” is currently constructing a large heat pump in Vienna which uses the access heat from a water treatment plant. The heat pump will feed into the Viennese district heating grid. The first part of the plant should start operating in early 2024. Figure gives an overview of the total system. According to “Wien Energie, the heat is supplied at temperatures between 12°C and 23°C by the nearby water treatment plant. After the heat is utilized in the evaporator of the heat pump, the water leaves the system at 6°C to 17°C and enters the Danube channel. The electricity needed for the heat pump is supplied through a cable directly from a nearby hydropower plant.


Großwärmepumpe ebswien Kläranlage Simmering

Wien Energie nutzt das gereinigte Klärwasser der Hauptkläranlage, um daraus Fernwärme für bis zu **112.000 Haushalte** zu erzeugen. Mit modernster Technik entzieht die Anlage dem Abwasser rund **6°C** und erzeugt daraus Wärme mit über **90°C**. Die Energie dafür kommt zu **100 Prozent** aus regionalen, erneuerbaren Quellen.

Wien Energie steigert mit der Anlage im Vollausbau den Anteil erneuerbarer Fernwärme um bis zu **13,8 Prozent**.

Im Vollausbau **Versorgung** von bis zu **112.000 Haushalten**

Jahreserzeugung bis zu **880 GWh/Jahr** (Vollausbau)
Jährliche CO_2-Einsparung bis zu **300.000 Tonnen** (Vollausbau)

Quelle: Wien Energie

APA-GRAFIK ON DEMAND

Figure 28 Scheme of the large-scale heat pump for high temperature district heating (>90°C), currently under construction in Vienna. (Wien energi)

In the final construction stage (planned for 2027), the plant should supply 110 MWth at heat sink temperatures >90°C using seven heat pumps. Some of this heat is used for a local gardening network. The rest is re-heated using a CHP to enter the district heating grid at up to 150°C. In the first construction stage, three heat pumps with a nominal thermal capacity of 18 MWth at a nominal electric power of 7.1 MWel are used. The heat pumps are each using 18t of R1234 zE and have four stage turbo compressors.

7. Summary of Task 4 – Flexibility Assessment and Analyses of Different Options

The Task 4 report includes flexibility assessment and analyses of different options, and it focuses on flexibility delivered from heat pumps to support the power grid. Both heat pumps for single-family buildings and larger heat pumps connected to thermal grids are included in the scope of the study. The increasing production of electricity from renewable, intermittent sources as well the ongoing electrification of society increase the demand for electricity and put pressure on the existing grid infrastructure. Here, the need for flexibility to balance variations in electricity production and consumption will increase to achieve a resilient and efficient power system. Flexibility can also help to reduce problems with bottle necks and shortage of capacity in the electricity grids. A sector coupling unit like heat pumps can support by connecting the electricity sector with the heating sector. Thereby, heat pumps can provide flexibility to the electric power system by exploiting the thermal inertia and storage capacities available in the heating sector.

Available flexibility services can be divided into implicit and explicit flexibility. Implicit flexibility includes a voluntary adjustment of the power use to save costs related to variations in electricity price or to lower costs for power tariffs. Explicit flexibility means that the flexibility provider has an agreement, or is active on a flexibility market, to deliver a flexible power use as a service.

Flexibility Services to the Power Grid

There are several identified markets where a heat pump controlled in a flexible way can be active. Heat pumps are already active in some markets like the Day-ahead market and for others there are still barriers to overcome.

The **Day-ahead market** enables trading of electricity with a lead time of around one day before physical delivery. The market participants can submit their bids and offers based on the most recent generation and demand forecasts for their units. Heat pumps can be operated flexibly in response to day-ahead market prices, which can help reduce operational costs. For heat pumps in thermal grids, it is common to operate them based on the hourly variations in electricity price. The startup time for heat pumps is shorter than that of other heat production units for district heating like boilers with wood chips. Technically, it is possible to start or stop heat pumps almost immediately, but a least in Sweden, the district heating companies look at the longer trends for the electricity price, and in practice, the minimum running time for heat pumps lasts from at least 3 or 4 hours to 12 hours in most grids. The reason given by the companies is that frequent start and stop increase the risk of higher maintenance costs, especially for older heat pumps.

The **Intraday market** is conducted after the Day-Ahead market. It allows the market participants to react to schedule deviations or to manage unforeseen changes, for example, power plant outages. Active consumers can bid directly on this market (directly or via aggregators). This allows them to gain more short-term flexibility and additional revenue. To our knowledge, heat pumps do not regularly operate on the Intraday market today. However, it could be an interesting alternative in addition to other market options like the day-ahead market or ancillary services.

For customers with larger power demands, a price component based on the maximum power peaks might be added, and in recent years, some grid owners have started with **power tariffs** also for end-users in single-family buildings. This is slowly growing into a trend. The introduction of power tariffs makes the control of the large electricity consumers in the home like the heat pump or EV charger more complex in order to keep the electricity cost down. The homeowner should not only focus on using electricity when the electricity price is low based on the Day-ahead market, but he or she should also keep the buildings power peaks down.

The transmission system operator (TSO) is responsible for operating the transmission system and to ensure that the electricity generation and demand are balanced at any time. This ensures that the grid frequency is kept constant at 50 Hz within the synchronous area. The TSO is responsible for outbalancing any unforeseen variations by activating different **ancillary services**. Ancillary services comprise different measures to contain the frequency deviation and restore the frequency to the nominal frequency. The various services primarily in the required response time and duration of activation, i.e., how fast a unit should be able to adapt its load and for how long the unit is able to run at the adapted load. The TSO has six different markets for ancillary services:

- FCR
- aFFR
- mFFR
- FFR
- FCR-D
- FCR-N

Figure 29 Overview activation time for ancillary services. (EnergiNet)

There are international examples of heat pumps in thermal grids participating in TSOs ancillary markets. One example is the CO_2 heat pump in Sdr. Felding, which is the first site in Denmark to obtain the official qualification to deliver aFRR regulation. In Denmark, this requires a start-up time of maximum five minutes and a minimum bid size of 1 MW.

Local flexibility markets are under development with the aim of supporting the local grids or reducing problems with bottlenecks. Since several of the local markets are still in the pilot phase, the requirements to fulfil are still under development.

Renewable Energy Communities (REC) also work on a local level, where they give heat pumps the possibility to use their flexibility on a community level, which provides different benefits. In Austria, RECs will, for example, get a reduction of grid tariffs for electricity transferred between participants. Energy communities also allow for more of the generated photovoltaic (PV) electricity to be used on a local level. The energy community can also help to reduce greenhouse gas emissions by sharing renewable energy within the community.

There are also **bilateral agreements** where the flexibility provider has an agreement with a specific partner, e.g., the grid owner, to adjust the power consumption or production according to the terms of the agreement. “**Conditional agreements**” refer to agreements between network owners and customers that condition the customer’s use of electricity in specific situations.

The **imbalance settlement** is a financial settlement mechanism for balance groups to be charged or paid for their deviations from their schedule (= imbalances). Imbalance settlement is designed to reflect the real-time value of energy by considering both balancing, and wholesale market prices in imbalance settlement prices. The administrative control of the Balancing Groups is carried out by Balancing Responsible Parties (BRP). The BRP is financially liable for its imbalances and is required to submit the resulting internal and external schedules of the Balancing Group to the Control Area Operator or TSO.

Technical Possibilities and Constraints

It can be expected that a demand driven operation will result in a larger number of part-load hours, while the operation according to electricity prices will favour an on-off operation to exploit the hours with lowest electricity prices. Supplying ancillary services using heat pumps requires the ability to adapt the load quickly and to operate efficiently in part-load. It also requires an exact control of the power uptake. In general, the capacity of heat pumps is adapted by changing the load on the compressors. Depending on the compressor set-up, there are two common ways for capacity control in large-scale heat pump systems – variable speed drive and on/off compressors. The former is applicable to all systems, while the latter is typically used in systems with many compressors in parallel or in older systems. Variable speed drives enable precise and step-less control of the compressor speed. For low part loads, the efficiency does, however, drop considerably. This is caused by a drop in the efficiency of the electric motor and increased compression losses.

Depending on the type of flexible service, it may be a requirement of the time which it takes to adapt the load of the heat pump and of how exact the power uptake needs to be controlled. Some frequency regulation services require the ability to continuously adapt the power uptake, while others only have a requirement of the ramping rate, the minimum duration of the service, and the maximum waiting time before the system needs to be able to react again. This operation requires a dedicated control design of the heat pump plant to ensure safe operation of the thermodynamic cycle as quick load changes may lead to sudden changes in evaporation and condensation pressure and thereby increased wear.

To be able to control the power uptake of heat pumps, it is necessary to be able to measure the power uptake and to actively control it. Normally, heat pump controls are set up to be able to control the heating capacity (directly or indirectly by controlling the source capacity and outlet temperature) and the supply temperature. In this case, the power uptake will result from the heat pump operating conditions and heat demand. However, many flexibility applications like balancing services require high resolution measurements and guaranteed values of the electric power uptake.

Large Heat Pumps in Thermal Grids

There are several factors limiting the ramp-up times of large-scale heat pumps:

- Pressure and temperature fluctuations: Starting a compressor at full speed can cause sudden pressure and temperature fluctuations in the system. These fluctuations may put stress on various components like the compressor, heat exchangers, and others.

- Component stress and wear: The pressure and temperature fluctuations during rapid start-ups can result in increased stress and wear on the components of the Vapor Compression Heat Pump (VCHP). Over time, this can lead to premature failure of the components.

- Heat pump configuration: The aim is to ensure a stable built-up of the thermodynamic cycle. The cycle design influences the achievable ramping times.

- Refrigerant: The refrigerant may influence both the thermal capacity of the system compared to the energy flow rate as well as the required cycle complexity to a certain extend and, thereby, poses a natural limit of the achievable ramping times.

- Compressor type: Different compressor types behave differently during ramp up, resulting in differences in the required ramping times.

- Turbo-compressors can adapt their load within a few seconds. The limiting factors are the time constants implemented in the compressor control.

- Piston compressors: During start-up the pistons are coupled in after each other and the speed needs to be ramped up to full load. This process may be limited by dead times between coupling-in of pistons.

- Load fluctuations: Rapid starting can lead to load fluctuations in the system, including the secondary streams.

- Peaks in electric load: Fast start-ups can lead to high start-up currents, which stress the electrical infrastructure.

- Initial conditions: Many of the factors limiting the allowable ramp-up times may be reduced if warm start-up can be ensured.

- Absorption heat pumps have longer ramp-up times compared to conventional vapour compression heat pumps due to larger thermal masses and inherent heat and mass transfer processes.

The flexible operation of heat pumps may lead to increased numbers of start-stop cycles. Before starting up again after a shut-down, a minimum waiting time is typically required. The reason for this is:

- To allow the refrigerant to settle in the foreseen receivers/vessels in the system and to stabilize the conditions within the cycle. This is mainly to ensure that no liquid is compressed in the compressor and that the valve is fed with liquid to ensure a safe and stable start-up.

- To prevent overheating and/or increased wear on the electric motor of the compressor. Typically, large-scale motors have a limited number of consecutive starts as well as maximum starts per year.

Heat Pumps for Buildings

In the Swedish research project SLAV, technical experts from four heat pump manufacturers were interviewed about technical possibilities and constraints when it comes to using heat pumps for flexible operation, focusing on heat pumps for single-family buildings. The manufacturers have a common ground in how fast their heat pumps can be controlled to decrease or increase the heat pumps power consumption. The auxiliary heater can change power in a second, but it may need new software adapted for flexibility. On/off compressors can also be turned off in a second, but they need some time to restart. Variable speed heat pumps are much slower to change power. It can take minutes to start or stop them or control their speed when they are already running.

There is also a market requirement for the balancing service provider to measure their flexibility resources in real-time. This can be costly and difficult for an aggregator because heat pumps are usually not measured individually today. This obstacle can be hard to circumvent. Either real-time measurement needs to be added to each participating heat pump, or the aggregator needs to get an exception from the TSO to instead measure or calculate the delivered flexibility in another way. As the current heat pumps lack electricity meters, alternative ways to measure or estimate the power consumption was discussed with the heat pump manufacturers focusing on the measurement uncertainty. Variable speed drive (VSD) heat pumps may have the possibility to measure the power consumption within the inverter controlling the speed of the compressor. On/off compressors have no technical possibility to measure the power consumption, instead it needs to be calculated based on operating temperatures of the compressor and known compressor equations. Based on discussions with the experts, the estimated measurement uncertainty of the power consumption for VSD heat pumps is 2-10 %, while on/off heat pumps have an uncertainty of 10-20 %. The auxiliar heater has an uncertainty of 0.5-5 % if the voltage is known, otherwise the uncertainty is higher.

Communication Protocols

There are different ways to communicate between an aggregator and a heat pumps. In the SLAV project, seven different communication standards were evaluated, mainly higher-level protocols, also referred to as communication middleware. OpenADR and IEEE 2030.5 are two US-based standards that have great potential for enabling demand response from heat pumps. A potential drawback is that they are not that common in Europe today. Interesting European alternatives are EEBus and EFI/S2. All these four standards are free to use or can be bought at limited costs. They are not ranked as further work is needed to recommend any of them before the others. There are also several building automation protocols, and solutions which are built upon these, that are evolving and can potentially be used for demand response from heat pumps.

8. Summary of Task 5 – Business Models – Development and Evaluation of Innovative Concepts

Heat pumps allow for flexible operation to a certain degree. However, certain barriers exist for the implementation and exploitation of this flexibility. The Task 5 report provides answers to the following key questions:

- What kind of barriers prevent flexibility of heat pumps to be used by the market or grid support?
- What kind of innovative business models can emerge around the flexibility of heat pumps?
- What kind of business models are already in use across different countries?

Barriers for Flexibility-Provision of Heat Pumps

In this chapter, barriers hindering flexibility of heat pumps are discussed. The barriers can be divided into four groups: technical barriers, economic barriers, regulatory barriers, and other barriers. The dimension [S, L] indicates whether the barrier mainly applies to small-scale (S) or large-scale (L) heat pumps in terms of (cooling or heating) capacity (S < 15 kW < L).

Technical Barriers

In the following, key technical barriers of vapour compression heat pumps (VCHP) and absorption heat pumps (AHP), including cooling as well as heating applications, are described along the following dimensions: time, capacity, temperature, and location.

Vapour Compression Heat Pumps (VCHP)

<u>Ramp-up times [L]</u>: Vapour compression heat pumps (VCHP) are usually started using start-up ramps. The reason for this is that a too fast start-up may lead to following impacts on VCHP: Pressure and temperature fluctuations**,** component stress and wear**,** load fluctuations**,** inefficiency, amplifying effects**,** peaks in electric load**.**

<u>Stand-still / idle times [S & L]</u>: Properly determined stand-still times, e.g., for “external” defrosting, reduce the frequency of start-up and shut-down cycles, minimizing energy consumption and, therefore, lowering operational costs.

<u>Part load behaviour [S & L]</u>: Typically, heat pumps are designed for specific capacities in a temperature range at a predefined compressor speed. If the VCHP uses a frequency control (FC), the compressor speed can be set limited by the compressor and FC specifications. The source and sink temperatures can be varied limited by the properties of the working fluid used by the VCHP as well as associated operating limits of the components (e.g., maximum and minimum pressures and temperatures).

<u>Measurement / control of electric load [S]</u>: In very small VCHP (e.g., used in household-applications), compressors are usually operated using on/off-mode only. Here, temperatures and mass flows are typically “fixed” and an “uncontrolled” expansion valve (e.g., a capillary tube) is used. Moreover, small-scale heat pumps are sometimes not able to provide exact measurements of their electricity consumption. In addition, heat pumps are usually operated heat driven. Thus, the electric load is rather a consequence than a controllable output. However, many flexibility applications like balancing services require high resolution measurements and guaranteed values of the electric power.

<u>Measurement of flexibility [S]</u>: Another aspect, which needs to be considered, is where the flexibility, i.e., the change in electrical load is being measured. Possible options include the measurement directly at the component, at the energy management system (if this is additionally available), or at the grid connection point. To prove that the flexibility is actually delivered, probably measurement on both, i.e., the grid connection point and the component needs to be conducted.

Temperature flexibility: The temperature flexibility of heat pumps is confined by the inherent constraints of the utilized working fluids (such as saturation pressures) and the operational limits of the utilized components (like the compressor). For compressors, these limits occur, e.g., due to a maximum of discharge temperatures.

Fast change of the source temperature [S & L]: A fast change in source temperature results in inefficiency or may cause the refrigerant to remain partially liquid after the evaporation process, which in turn can cause serious problems for the compressor.

Absorption Heat Pumps (AHP)

Ramp-up times / transient operation [S & L]: Absorption heat pumps (AHP) have longer ramp-up times compared to conventional vapour compression heat pumps (e.g., due to larger thermal masses and inherent heat and mass transfer processes).

Capacity – part load [S & L]: AHP and absorption chillers are usually designed for specific operating conditions (e.g., temperatures and volume flows in a district heating system). During operation, the operating conditions might differ from design criteria, e.g., when varying pump speed (using a frequency control (FC)) source and sink temperatures as well as mass flow rates.

Temperatures [L & S]: AHP enable high temperature “lifts” between low-temperature heat source and heat sink, but “suffer” from limitations due to “high” saturation pressures.

Regulatory Barriers

Unforeseeable changes in regulation (S/L): As in many other fields, unforeseeable regulation can be identified as a hurdle to flexibility provision of heat pumps as it creates uncertainties for investors. However, market conditions for flexibility have generally been improving in recent years.

Local flex markets still under development (S/L): Local flexibility markets are under development in many countries, but the fact that they still are under development creates an uncertainty to the business case.

Different regulations in different regions / countries (S/L): Different regulations in different regions / countries counteract the development of business models for companies acting internationally and focusing on heat pump flexibility. Common EU regulations should be further enhanced, and existing directives should be implemented into national law as soon as possible.

Minimum bid size (S): For the provision of balancing services, a minimum bid size (e.g., 1 MW) is required. Therefore, small-scale applications were excluded in the past. By aggregating multiple heat pumps into a pool, smaller units are still able to provide balancing services.

Market entry requirements(S): To participate in balancing markets, flexible components need to be pooled (to achieve minimum bid size), be prequalified by the TSO and provide a baseline concept.

Aggregation of small assets creates coordination problem (S): Aggregation of small flexible components (e.g., heat pumps in single-family houses) requires a substantial effort with a high number of stakeholders. For example, components could be supplied by different suppliers and be located in different balancing groups.

Economic Barriers

Low revenues from day-ahead prices: Operation of the heat pump oriented to the day-ahead electricity price only provides limited revenues. This typically does not justify any investments, risk of reduced comfort, or change in behaviour.

Grid fees make up the large part of electricity bill (S): Linked to the above point, this is particularly true for small-scale applications. The variable electricity price consists of only a fraction of the costs for electricity for heat pump operation (with grid fees and taxes making up for the other part). Therefore, the overall potential for cost-reduction based on variable day-ahead prices is generally limited.

Risk of end user intervention in case of aggregation (S): Depending on the business case definition, the end user is allowed to overrule the flexibility system, e.g., by manually increasing the set-points or by switching the heat pump on/off. This, however, may create a risk for the aggregator since they cannot completely rely on the flexibility of the heat pump.

Maintenance costs (S/L): Maintenance costs can be a significant economic burden for VCHPs. Regular maintenance is essential to ensure the optimal performance and longevity of VCHP systems. This includes activities like cleaning, lubrication, refrigerant checks, and addressing wear and tear on various components. These maintenance procedures can be both time-consuming and costly, particularly for larger or complex VCHP systems.

Reduced efficiency & lifetime (S/L): Reduced efficiency and diminished longevity pose substantial economic challenges for heat pump systems. Corrosion, particularly prevalent in harsh environments or with corrosive heat transfer fluids, affects components like coils, pipes, and heat exchangers.

Accumulated debris, including environmental contaminants like leaves, compounds the problem by reducing heat exchange efficiency. This increased workload heightens energy consumption and decrease the overall system efficiency. Overworking the heat pump can accelerate the degradation of internal parts such as compressors and fan motors, leading to costly replacements.

Addressing these issues requires a focus on systematic maintenance, high-quality installation, corrosion-resistant measures, and energy efficiency enhancements to ensure the economic viability and sustainability of heat pump applications.

Other Barriers

Education of operators and installers: New types of flexibility services require additional knowledge and education of both heat plant operators (in case of district heating) and installers (in case of smaller buildings). If these actors do not understand the benefits of installing a flexible heat pump instead of a regular one, and they are not able to configure everything properly, the flexibility potential of buildings and grids cannot be unlocked.

Cyber security / data protection (S/L): Heat pumps for single-family houses need to be remotely controlled over the Internet to effectively contribute to flexibility. This can as with all Internet-connected devices make them vulnerable to cyberattacks.

Acceptance of end users (S): One of the most important stakeholders to achieve the wide-spread appliance of flexible heat pumps are the end users. Without their consent, the theoretically available flexibility potential cannot be utilized. They need to be properly informed and incentivized to create acceptance for the potentially reduced comfort or loss of control of the heat pump.

Different situations of electricity/heat supply mix in each country (S/L): European countries are quite heterogenous in terms of their electricity / heat supply capacities. This creates an additional hurdle to implement flexibility measures and business models which can be used across different countries.

More clear information from manufacturers (S/L): To successfully implement business models based on flexible heat pumps, more detailed information about certain technical specifications (like ramping times, etc.) is needed from heat pump manufacturers.

Wider digitalization measures (S): For heat pumps to be able to provide flexibility to the market and grid, some digitalization measures are needed at first. The heat pumps need to be able to communicate with an aggregator or supplier, e.g., via the internet.

Innovative Business Models

This section describes innovative business models for flexible heat pumps. The lean canvas approach was used to enable a graphical visualization of the business models.

Provision of balancing services: Heat pumps can be aggregated (in case of small-scale applications) to provided balancing services to the transmission grid. Depending on their reaction speeds, they can offer different types of balancing services. In the Austrian project Flex+, heat pumps were able to provide both manual and automatic frequency restoration reserve.

Support of the distribution grid: The flexibility of heat pumps can be used to support the electric distribution grid operator (DSO). This is currently most commonly done via interruptible tariffs, where the DSO can interrupt the electricity supply of the heat pump during certain times of the day. In return, the customers receive cheaper grid tariffs.

Exploit variable spot-market prices (day-ahead, intraday): Day-ahead prices can easily be exploited by heat pumps as estimating heat demand into the near future (a few hours) is possible with little effort when using weather forecasts. Thus, heat pump operation can be continuously scheduled for the following hours taking advantage of low tariffs to charge thermal storages or pre-heat the building mass.

Purchase / increasing size of storage (for plant operator): The optimal storage size depends on whether or not flexibility is offered.

Demand side response for heat demand: Some electricity suppliers offer time dependent variable electricity prices to consumers, examples are ‘Tibber’ from Norway and ‘aWATTar’ from Austria. Can a similar concept be applied to heat? At present time, such a concept has not been put into practice to the knowledge of the consortium.

Provide advice for flexible plant operation: Developing a blueprint of flexible plant operation / district heating and optimize operation. In case of an integrated system with on-site electricity generation (e.g., wind, solar), large-scale heat pumps, thermal storages, and conventional sources (e.g., gas or biomass), operation can be optimized.

Existing business models per country: The following provides an exemplary list of business models which have been identified in different countries.

Sweden: Variation of heat source and provision of balancing services for property owners with a hybrid heating system including a decentralized heat pump system combined with district heating.

Corresponding business models:
Provision of balancing services
Exploit variable spot market prices (day-ahead, intraday)

Denmark: Sdr. Felding District Heating

Corresponding business models:
Provision of balancing services
Exploit variable spot market prices (day-ahead, intraday)
Purchase / increasing size of storage (for plant operator)

The Netherlands: Jouw Energie Moment 2.0 (JEM2.0) (2019)

Corresponding business models:
Support of the distribution grid
Demand side response for heat pumps
House owners and/or grid operator

Austria: Pooling of small-scale heat pumps for participation in various short-term electricity markets

Corresponding business models:
Provision of balancing services
Exploit variable spot-market prices (day-ahead, intraday)

Germany: Economical and ecological optimal dispatch for large-scale heat pumps in combination with CHP systems.

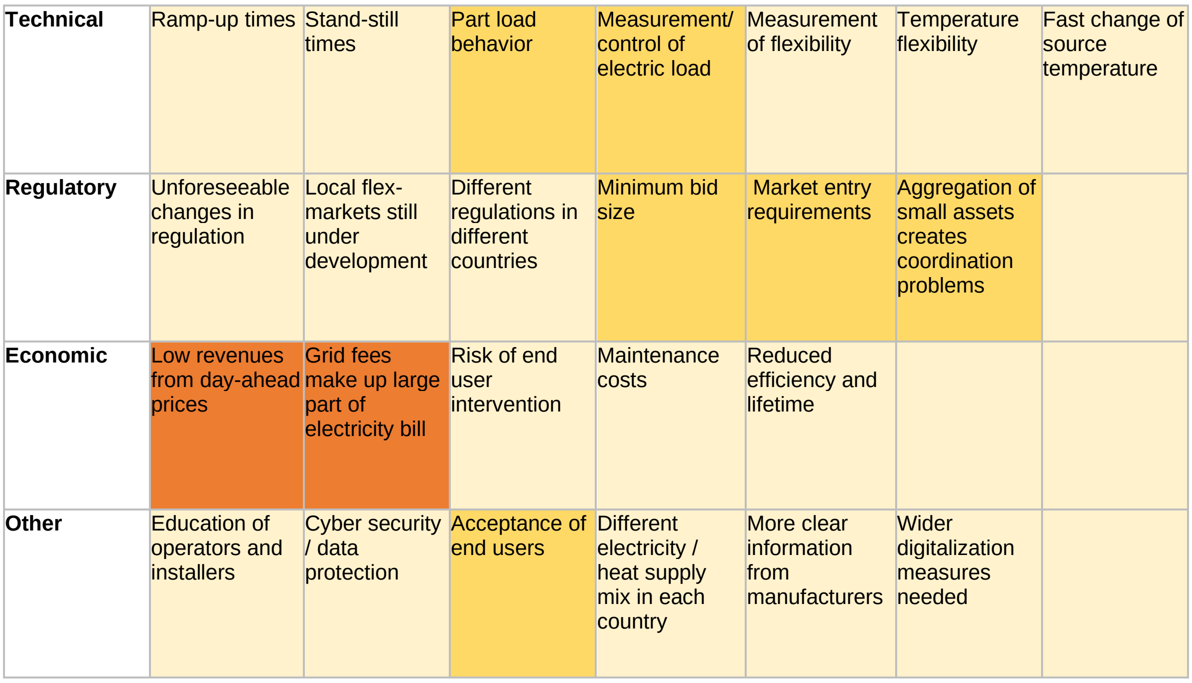
Conclusions

At the moment, flexibility provision with heat pumps is a very relevant topic across Europe. Many different types of flexibility services are currently being researched. Some of them are already at a high market readiness level and can form the basis of successful business models in the near future.

The most commonly applied business model in the analysed case studies was a combination of spot market participation and the provision of balancing services. This business model was already used in various research projects in Sweden, Denmark, Austria, and Germany.

Especially the provision of various balancing services showed promising reductions in the overall energy costs. In Sweden, different types of FCR and aFRR showed the highest cost reduction, while mFRR was slightly less profitable. In Denmark, aFRR showed the best results, followed by FCR and then mFRR. In Austria, aFRR showed significantly higher cost reductions than mFRR. The colours in Table 5 indicates the estimated extent to which the barrier hinders the business model development.

Table 5: Overview of barriers for business models.



Technical	Ramp-up times	Stand-still times	Part load behavior	Measurement/ control of electric load	Measurement of flexibility	Temperature flexibility	Fast change of source temperature
Regulatory	Unforeseeable changes in regulation	Local flex-markets still under development	Different regulations in different countries	Minimum bid size	Market entry requirements	Aggregation of small assets creates coordination problems	
Economic	Low revenues from day-ahead prices	Grid fees make up large part of electricity bill	Risk of end user intervention	Maintenance costs	Reduced efficiency and lifetime		
Other	Education of operators and installers	Cyber security / data protection	Acceptance of end users	Different electricity / heat supply mix in each country	More clear information from manufacturers	Wider digitalization measures needed	

⬜	Low barrier for business model formation
🟨	Medium barrier for business model formation
🟧	High barrier for business model formation

9. Results

Task 1: Energy market analysis – Future developments and sector coupling

Aalborg University, Denmark, has made a simulation of the district heating potential in the European countries, EU 27 towards 2030 and 2050. The scenarios show a district heating potential in 2050 above 30 % in all of the countries. The scenarios also show that the heat pumps will cover around 25 % of the district heating production.

Other scenarios have been made which show the monthly district heating production during the years 2030 and 2050.

Aalborg University has also made an analysis of the heat pumps which are installed in DH grids in Europe, and their performance. The update is made based on the best available data. The analysis shows that the implementation rate is growing, and that air is the main used source in the newly installed heat pumps. There is also a trend towards the use of natural refrigerants in the heat pumps.

National market reports for the participating countries have been made, and the reports show that the need for flexibility in the electrical production is growing and will grow in the coming years. The reason is that more renewables like PV panels and wind power are implemented in a wide scale in the electrical production.

The report gives an overview of the ancillary service markets and the energy production in the countries.

Task 2: Best practice examples – Description of existing projects with flexible solutions with heat pumps in thermal grids

The main objectives of Annex 57 were to show the possibilities regarding the implementation and integration of heat pumps where they are creating flexibility, both as individual heat pumps and in DH grids. It was, therefore, an aim to create an idea catalogue which shows different implementation cases. It was possible for the project group to describe 28 different cases where heat pumps are integrated and create flexibility.

A great amount of work was done to create and collect the data in a structured way. All the cases are presented on the Annex website as two-pagers and as a more detailed description.

Task 3: Concepts – Development of representative and promising solutions

The task gives an overview of promising solutions for creating flexibility, both in single-family houses and by remote control. It also shows the potential for the flexibility dependent on temperature. Creation of flexibility by implementation of heat pumps in district heating is described.

The report includes implementation of hybrid heat pumps, and the potential is also described.
For heat pumps in district heating systems, it is shown that heat pumps can act in the ancillary service market and with a positive result seen from a flexibility perspective as well as from an economical perspective.

It is also shown that the technology to implement heat pumps in district heating grids where a temperature of 90°C is needed is available and in the implementation stage. This is one of the barriers in many of the countries.

Task 4: Flexibility – Assessment and analyses of different options

Gives an overview of the TSO ancillary service markets as well as other potential flexibility markets of interest for heat pumps. It also describes different types of flexibility as well as technical abilities and constraints for heat pumps to operate in a flexible way.

Regarding individual heat pumps, the task describes that there is a need to standardize the communication protocols.

Task 5: Business models – Development and evaluation of innovative concepts

Task 5 shows that flexibility provision with heat pumps is currently a very relevant topic across Europe, and many different types of flexibility services are being researched. Some of them are already at a high market readiness level and can form the basis of successful business models in the near future.

The most commonly applied business model in the analysed case studies was a combination of spot market participation and the provision of balancing services. This business model was already used in various research projects in Sweden, Denmark, Austria, and Germany.

Especially the provision of various balancing services, which are described in the task 4 report, showed promising reductions in overall energy costs. In Sweden, different types of FCR and aFRR showed the highest cost reduction, while mFRR was slightly less profitable. In Denmark, aFRR showed the best results, followed by FCR and then mFRR. In Austria, aFRR showed significantly higher cost reductions than mFRR.

10. Conclusions

The implementation of heat pumps in residential buildings, district heating systems, and in the industry increases, and the growth is very important as the heat pump technology plays a key role in the transition away from fossil fuels towards climate neutrality in 2050.

The reason why the implementation of heat pumps is crucial is the expansion of other renewable energy sources like wind power and photovoltaic plants. The capacity and production from these plants are foreseen to increase with 3-4 times from the level of 2023. The growth in production from these renewable energy sources means that the need for flexibility in the electrical grid will grow by 25 % from the current level towards 2030.

From this perspective, the work performed in the frame of Annex 57 together with the achieved results are very relevant and useful.

The main message from Annex 57 is that the need for flexibility will grow towards 2050, and heat pumps can provide flexibility and act in the ancillary service market as well as help with the stabilization of the electrical grid. Heat pumps can also provide flexibility when it comes to the use of energy sources during the year.

Produced scenarios show a district heating potential in 2050 above 30 % in all of the European countries. The scenarios show that heat pumps will cover around 25 % of the district heating production.

Annex 57 also includes a study and a description of what flexibility is and the different ancillary services in the market.

Furthermore, Annex 57 shows that flexibility is created by the implementation of heat pumps in the 28 cases collected during the project period. The flexibility can be subject to the electrical grid but also in terms of the way in which sources are used during the year and used in the district heating system.

The cases show that flexibility is possible to create with individual heat pumps, hybrid heat pumps, and heat pumps in district heating systems.

Annex 57 describes some of the barriers for implementation of heat pumps in district heating and possible business models. One of the barriers is that heat pumps in people's mindset cannot create high temperatures for district heating, but the development of the heat pump technology is going fast at the moment, and the first district heating heat pumps which provide 150°C are starting up in 2024.

11. References

This report does not include a list of references.

For an overview of references relevant to a specific section, please refer to the different task reports, which can be found on the annex website: https://heatpumpingtechnologies.org/annex57/.

In the various task reports, you will find reference list entries which contain specific information on the applied publications.

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