OVERVIEW OF THE POTENTIAL FOR WASTE HEAT AND COST-BENEFIT ANALYSIS OF EFFICIENT HEATING IN ACCORDANCE WITH THE ENERGY EFFICIENCY DIRECTIVE

# OVERVIEW OF THE POTENTIAL FOR WASTE HEAT AND COST-BENEFIT ANALYSIS OF EFFICIENT HEATING IN ACCORDANCE WITH THE ENERGY EFFICIENCY DIRECTIVE

Report for the Ministry of Economic Affairs and Employment

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# EXECUTIVE SUMMARY


Article 14(1) of the EU Energy Efficiency Directive requires Member States to prepare a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling. The assessment includes an analysis of the potential for waste heat used for district heating and a cost-benefit analysis of efficient heating and cooling systems. The aim of this report is to provide information for national reporting, and it has been prepared according to the requirements of the Directive with respect to the assessment of both the application of waste heat and economic efficiency.

In the first part of the overview, the amount of waste heat and its potential for application as district heating was assessed by identifying the typical sources of waste heat for the installation categories specified in the Directive, the total amount of waste heat generation, and the amount of waste heat already being used from these sources and the as yet untapped potential for waste heat. The total estimated waste heat generation is approximately 130 TWh, of which some 3 TWh is used for district heating. The potential for as yet unused waste heat that could be reasonably exploited technically was estimated to amount to some 35 TWh. In many respects, however, this technically usable potential involves challenges relating to economic feasibility or business risks, for example. Furthermore, the full potential cannot necessarily be exploited at the same time or in full, as demand for district heating in the vicinity of waste heat sources is limited and varies by season.

From a technological perspective, the greatest additional potential for the use of waste heat is thought to be found in industry and condensing power plants. In practice, the usable potential for condensing power plants consists of the exploitation potential for the waste heat of the Loviisa nuclear power plant. The Loviisa nuclear power plant generates at most some 16 TWh of waste heat, of which a significant share could be used as district heating, but this would require considerable investment. The technically exploitable waste heat potential of industrial installations was estimated to be approximately 15 TWh. Waste incineration plants condense approximately 0.5 TWh of waste heat into the environment. Of CHP and heating installations producing district heating, the greatest additional potential can be found in the flue gases of plants that burn biomass and peat. The combined, as yet unused waste heat potential of these boilers is estimated at some 1.1 TWh.

In the second part of the study, the efficiency of Finnish heating systems was assessed for the use of primary energy, $CO_2$ emissions, share of renewable energy and costs using four different scenarios: 1) the current type of heat generation structure; 2) the replacement of CHP boilers with thermal boilers using renewable energy; 3) utilisation of geothermal and ground energy, and 4) a substantial increase in the use of waste heat. As Finland is in any case dramatically decreasing the use of fossil fuels and peat, the $CO_2$ emissions from heat generation is the same in all scenarios. Similarly, the shares of renewable energy in the scenarios only vary slightly.

The most significant differences in the impact of the scenarios arise in the use of heating sector electricity and electricity production as well as in the use of fuels (mainly biomass). In the geothermal and waste heat scenario, electricity consumption is higher and fuel consumption lower than in the CHP and thermal boiler scenario.

Economic efficiency was based on a calculation for net present value, taking into account the investment costs of heating technologies, fuel costs including taxes and network charges, heating operating costs and the assumed positive cash flow of the heating system. The positive cash flow is based on the price assumption for heat, considered as a constant, and, depending on the chosen scenario, the trend in the electricity market price for CHP electricity generation. Based on the analysis, the most cost-efficient system was one which maximises the use of waste heat, but there are considerable uncertainties attached to the actual usable potential for waste heat. A sensitivity analysis was conducted for the price of electricity and hurdle rate, which did not change the outcome. Overall, however, the analysis is a very rough generalisation, where there is considerable uncertainty about the assumptions made. For example, the assessment of the use of waste heat must always be made carefully case-specifically, and this analysis does not allow clear conclusions to be drawn that it would always be the most cost-effective alternative.

Other potential for efficient heating systems was also assessed qualitatively. Reducing the temperature of the district heating network and heat storage were identified as the key methods to improve the efficiency of district heating networks, as a lower temperature allows waste heat to be utilised more effectively. A reduction in the outgoing temperature is primarily restricted by the design temperature of existing customer equipment and, to some extent, the transfer capacity of the district heating network. District heating storage, on the other hand, reduces the need for peak boilers, which may reduce the need for using fossil fuels. In addition, electricity-based heating technologies may act as sources of flexibility for electricity systems, which is becoming increasingly important for electricity systems.

# 1. INTRODUCTION

## 1.1 Background and aims of the assignment

The aim of the European Union's Energy Efficiency Directive (2012/27/EU, "EED") is to contribute to the EU's climate objectives by promoting energy efficiency in the generation, transmission, distribution and consumption of energy. Energy efficiency means the ratio of output of performance, service, goods or energy, to input of energy[1]. Improving energy efficiency reduces primary energy consumption.

The EED requires Member States to prepare regular comprehensive assessments of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling systems pursuant to Article 14. The comprehensive assessment in accordance with the Directive includes an overview of the potential for utilising waste heat and a cost-benefit analysis of the application of efficient heating and cooling systems. The comprehensive assessment must be submitted to the Commission every five years.

The Directive defines efficient heating systems as follows:

- Efficient district heating and cooling means a district heating or cooling system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat.
- Efficient individual heating and cooling means a heating supply option that, compared to efficient district heating, reduces the input of non-renewable primary energy or is more cost-effective for the same input of non-renewable primary energy.
- An efficient heating and cooling system means a system covering a defined region that, compared to a baseline scenario, reduces the input of primary energy in a cost-effective way, as assessed in the cost-benefit analysis.

An efficient heating and cooling system therefore balances between cost-effectiveness, energy efficiency and environmental soundness, and an efficient heating and cooling system may comprise both district heating and cooling as well as property-specific solutions. In practice, the most efficient heating solution depends on the specific case.

The cost-benefit analysis pursuant to the Energy Efficiency Directive and the related guidelines are based on a type of heating sector very different from Finland's current heating system. The Directive aims to promote high-efficiency heat and power cogeneration, as many European countries widely use building-specific heating based on natural gas, and electricity has typically been generated in condensing power plants. In Finland, district heating produced from cogeneration has been used on a large scale for years.

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1 Finlex, Energy Efficiency Act (Energiatehokkuuslaki), https://www.finlex.fi/fi/laki/ajantasa/2014/20141429

For this reason, the assumptions and conclusions presented in the overview regarding more efficient systems pursuant to the Directive may differ from the assumptions of the Directive.

This report for the Ministry of Economic Affairs and Employment provides information for the assessment to be submitted to the EU Commission during 2020. The overview has two main goals:

1) To establish the available amount of waste heat that is already being utilised as district heating and the amount of waste heat that is not currently being used but could be utilised in district heating or district cooling.
2) To assess, through a scenario analysis, the potential and cost-effectiveness of more efficient and renewables-based heating and cooling technologies for heating buildings and the impact on society, the climate and the input of primary energy.

The report was mainly carried out as an independent consultants’ report during the summer of 2020. In the assignment, we have used AFRY’s comprehensive database of boilers, AFRY experts’ industry knowledge, available public reports and interviews with selected players where the information was not available otherwise. The scenario analyses were drawn up primarily on the basis of the baseline heating scenarios of the Ministry of Economic Affairs and Employment and the Commission’s fuel price scenarios. Unless otherwise indicated, the source for all tables, figures and diagrams is AFRY Management Consulting.

## 1.2 Structure of the report

The report is structured as follows:

- Chapter 2 describes the current status of Finland’s heating and cooling systems from the perspective of the Energy Efficiency Directive’s definitions and targets. The focus of the report is on heating systems, as considerably more energy is used in Finland for heating than cooling.
- Chapter 3 reviews the generation, utilisation and potential for use of waste heat in district heating by installation category based on the division in Annex VIII of the EED.
- Chapter 4 presents the implementation method and scenarios for the cost-benefit analysis for efficient heating systems and analyses the scenario modelling results from the perspectives of CO2 emissions, use of primary energy, the share of renewable energy and economic efficiency.
- Chapter 5 provides a qualitative assessment of the potential for improving the efficiency of other heating systems.

# 2. HEATING IN FINLAND

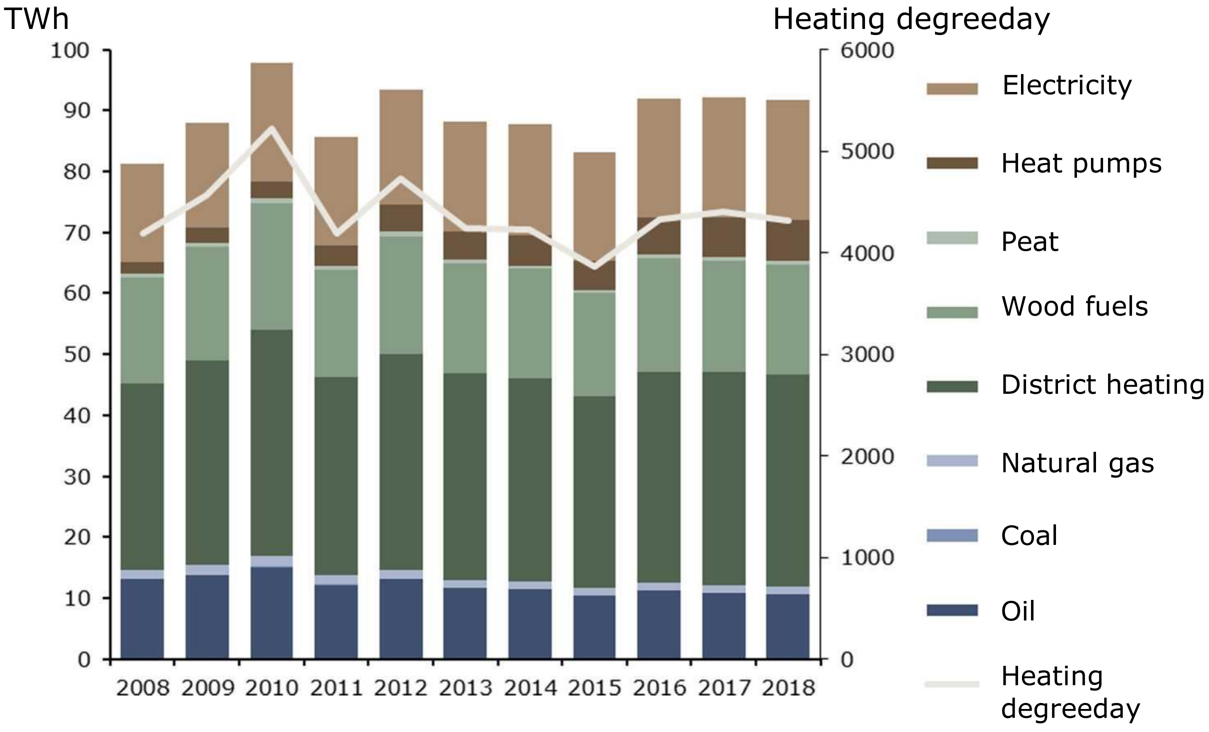
## 2.1 Heating technologies and energy sources

The need for heating covers the heating of premises and water. The consumption of warm water varies little from year to year, but as the energy required for heating premises depends on the outdoor temperature, heating consumption fluctuates yearly. In 2018, the heating of premises and water in Finland consumed 92 TWh of energy. Of the energy consumed, 57% was used in residential properties, 21% in public and commercial buildings, 13% in industrial buildings, 3% in agricultural buildings, and 3% in leisure time buildings such as holiday homes. Figure 1 shows the energy sources used in Finland for heating premises and water between 2008 and 2018. The heating degreeday indicated in the figure represents the need for heating energy in buildings and correlates with the consumption of heating energy.

The heating system can be roughly divided into two parts: district heating and property-specific heating. District heating has long been the most common heating method in Finland, accounting for nearly half of the heating need of buildings, or 37.1 TWh in 2018. The temperature-corrected use of district heating increased on average by 0.8% a year between 2008 and 2018. Together with thermal boilers, combined heat and power generation account for the largest share of district heating production. District heating networks have been built in Finland even in small agglomerations, and therefore no significant potential can be seen in Finland for entirely new district heating networks due to urbanisation, for example.

The most common heating methods for property-specific heating are direct electric heating, the use of wood fuels and oil heating, and, to a growing extent, various heat pumps. The energy produced by heat pumps has increased significantly, on average by 13.9% per year between 2008 and 2018. The use of fossil fuels has decreased by 2.0% per year on average, but approximately 10.5 TWh of oil was still used for heating buildings in 2018.

**Figure 1 – Energy sources for heating premises and water in 2008–2018**

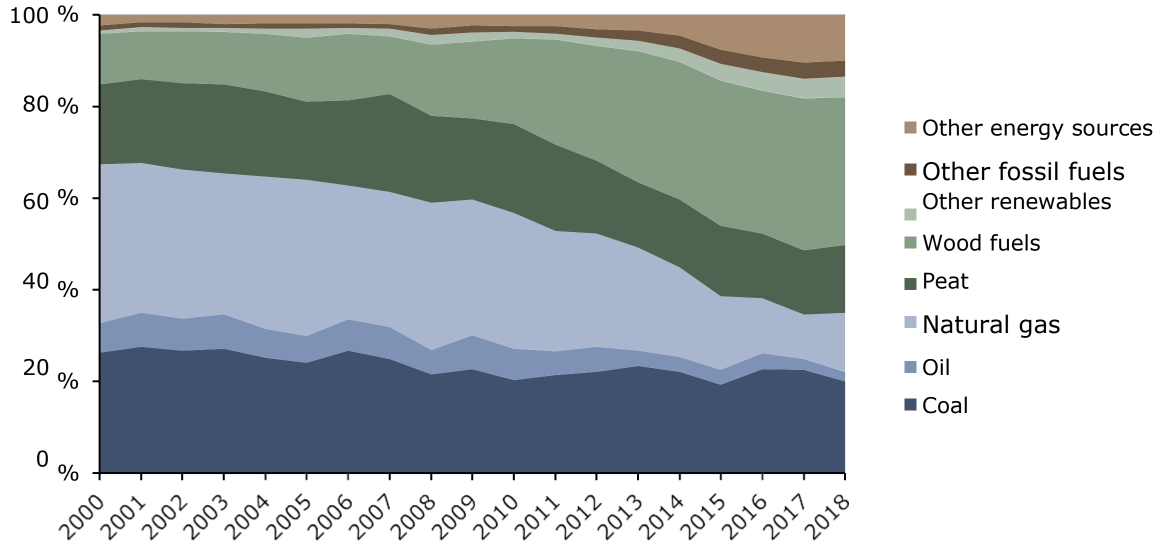



Source: Statistics Finland, Finnish Meteorological Institute

Figure 2 illustrates the share of energy sources used for district heating production between 2000 and 2018. The share of renewable energy in district heating production was approximately 36% in 2018. The share of wood fuels and recovered fuels of the district heating produced has grown substantially in the 2000s, on average by 4.7% per year from 2010 to 2018. Fossil fuels produced some 39% of district heating in 2018. The share of both fossil fuels and peat of the district heating produced has decreased. This trend has been driven by factors such as the increased taxation of fossil fuels and peat and the rise in emission allowance prices. Fossil fuels are taxed according to their energy content and CO2 emissions, whereas renewable fuels used for heat generation have been exempt from tax.

The prohibition on the use of coal as an energy source from 2029 will also increase the need to replace coal with renewable energy sources. Currently, coal is being used mainly in the major cities (Helsinki, Espoo, Vantaa, Turku and Vaasa).

**Figure 2 – Energy sources used for district heating production 2000–2018**




The Other renewables category includes biogas and the bio part of mixed fuels, while the Other fossil fuels category includes blast furnace and coke gas, coke, plastic and hazardous waste as well as the fossil part of mixed fuels. The Other energy sources category includes hydrogen, sulphur, heat generated with electric boilers and heat pumps, and industrial reaction and secondary heat.

Source: Statistics Finland

By calculating the network-specific fuel shares from Finnish Energy's district heating statistics for CHP production and separate heat production in 2018, it can be concluded that over 60% of Finnish district heating networks could, by definition, already be counted as efficient district heating networks in accordance to the Energy Efficiency Directive on the basis of the share of renewable energy alone. However, the statistics are not complete for all data and networks, and fuels do not take into account the production of delivered energy.

In 2018, just over half of district heating was generated through combined heat and power generation. In district heating networks with CHP plants, most heat is typically produced through co-generation. Assessed on the basis of Finnish Energy's statistics, a cogeneration share of at least 75% in an efficient district heating system as defined by the Energy Efficiency Directive was attained in 79% of the 61 district heating networks which had CHP production and on which statistics were available. CHP plants are typically used in larger district heating networks. CHP plants that have reached the end of their technical service life have in recent years been replaced by separate heat generation boilers due to low electricity price expectations, for example, when the profitability of electricity production has been uncertain.

Taking into account the combination alternative included in the definitions of an efficient district heating system in the EED, according to which the district heating system must use at least 50% renewable energy, waste heat or cogenerated heat, the majority of Finland's district heating networks meet the requirement for efficient district heating systems. According to the 2018 district heating statistics of Finnish Energy, at least 92% of district heating networks met the combination option criteria in their own generation mix.  The figure takes into account the production of the sellers of delivered heat.

It must be noted, however, that the statistics used lack information on some district heating networks. The share of district heating networks meeting the definition will likely increase along with the assumed decrease in the use of peat, as many of the networks that did not fulfil the criteria for an efficient district heating system used a significant amount of peat as fuel. The decrease in the use of peat is driven by the rising emission allowance price and the proposed rise in peat tax, which will make renewable fuel a more economical option for many installations.

The efficiency of Finnish heating systems is assessed using alternative scenarios in Chapter 4.

## 2.2 Cooling

The Finnish cooling market can be divided into district cooling and property-specific heat pumps. Heat pumps have become increasingly popular in Finland in the 2000s. According to the Finnish Heat Pump Association, there are more than one million heat pumps in Finland, most of which are air-source heat pumps[2]. Heat pumps are used to heat and cool properties. Air-source heat pumps for cooling are also used in dwellings with district heating.

The Finnish district cooling market is small in size, but it has grown steadily throughout the 2000s. According to the Finnish Energy district cooling statistics, district cooling was offered by 11 energy companies in 2019, with total district cooling sales of 281 GWh that year[3]. According to Finnish Energy, over 90% of district cooling is generated using energy sources that would otherwise go to waste. In 2019, 67% of district cooling energy was generated using heat pumps and 9% using compressors. In numbers, four out of eleven district cooling networks generate the district cooling they supply using at least 50% energy that would otherwise go to waste, hence fulfilling the EED's definition of an efficient cooling system.

Detailed information is not available on the amount of cooling generated by property-specific heat pumps. The need for cooling is expected to increase along with global warming and the improved energy efficiency of buildings.

[2] Sulpu ry, newsletter. https://www.sulpu.fi/-/lampopumpuilla-huippuvuosi-myynti-hipoi-jo-100-000-pumppua- miljoonan-pumpun-rajapyykki-rikottiin-?redirect=https%3A%2F%2Fwww.sulpu.fi%2Fhome%3Fp_p_id%3D101_INSTANCE_WAsJkplJYIg7%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_col_id%3D_118_INSTANCE_F80iMVThU0Yx_column-1%26p_p_col_count%3D1

[3] Finnish Energy, district cooling statistics 2019.

# 3. AMOUNT AND POTENTIAL FOR WASTE HEAT

## 3.1 Scope of the overview

*Legal definitions for waste heat*

Directive (EU) 2018/2001 of the European Parliament and of the Council defines waste heat and cold as follows:

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

The definition of the Renewable Energy Directive highlights usability as district heating or district cooling. Using the heat generated as a by-product of industrial installations within the installation is considered energy efficiency and is not classified as utilisation of waste heat. This overview does not analyse energy efficiency, although it may be difficult to draw the line between the potential for energy efficiency and the potential for the utilisation of waste heat. All fuel used for energy generation at industrial installations is eventually converted into heat, and it is then either conducted or it flows into the environment along with cooling water, flue gases, exhaust ventilation, waste water or mechanical cooling.

The energy that can be defined as waste heat may vary in other contexts as well and depending on the installation, even if the same technology is used for obtaining the heat generated as a by-product of a process. There may be differences between the more energy-efficient design and construction of new installations and the heat recovery systems retrofitted in older installations. Classification practices may also vary between different EU countries. The unclear and inconsistent definitions of waste heat makes it difficult to compile statistics on waste heat. More information on the definitions of waste heat can be found in, among others, the report produced by VTT Technical Research Centre of Finland for Finnish Energy and Ministry of Economic Affairs and Employment[4].

*Installation categories and their restrictions reviewed in the overview*

This overview studies the waste heat of industrial-scale installations as specified in the Annex VIII Part I(2b) of the EED to the extent that it can be used in district heating networks. Waste heat used for district heating can also be used for district cooling with the aid of heat pumps or heat exchangers. Since district cooling networks may exist alongside district heating networks, district cooling has not been analysed separately.

[4] VTT Technical Research Centre of Finland, Hukkalämpö kaukolämpöjärjestelmässä (Waste heat in the district heating system), 2020 https://energia.fi/files/4831/Hukkalampo_kaukolampojarjestelmissa_-_maarittely_ja_luokittelu_VTT_2020.pdf

The reviewed waste heat sources are divided mainly according to Annex VIII Part I(2b) of the EED, though some smaller installations are also considered. The classification used in the overview is presented below in Table 1. Waste heat sources mainly comprise various types of energy generation installations or industrial installations. Hence, the overview does not cover all usable sources of waste heat. For example, the heat potential available from sewage treatment plants is excluded from the scope of assessment in this chapter, as heat derived from sewage water is counted as renewable energy rather than waste heat in the EU Renewable Energy Directive ("REDII"). The guidance provided in the EED Annex covers all industrial installations with a thermal input exceeding a specific threshold value and which generate waste heat, whereas sewage treatment plants do not actually generate waste heat themselves. The return waters of commercial and office buildings and district heating and cooling are also excluded from the overview.

**Table 1 – Classification of waste heat generating installations in the overview**

| Installation type | Capacity | Detailed definition |
|---|---|---|
| Condensing power plants | > 50 MW | All condensing power plants that meet the size requirements, including nuclear power plants. |
| Waste incineration plants | All | All installations that burn municipal waste regardless of what the energy they generate is used for (district heating or process gas). |
| Industrial installations | >20 MW<br>5–20 MW | All installations where the majority of energy generated is utilised in industrial processes. The category also includes CHP plants which supply heat to the district heating network in addition to industry. |
| CHP plants | >20 MW<br>10–20 MW | All CHP plants excluding CHP plants in industries, CHP waste incineration plants and CHP plants that do not meet the size requirements. CHP plants include all plants where the most of the heat production is district heating. |
| Thermal boiler using renewable energy | >20 MW<br>10–20 MW | All thermal boilers using fuel of which at least 90% is renewable and which meet the size category requirement. |
| Data centres | >5 MW<br>0.5–5 MW | Estimated data on large and medium-sized data centres. |
| Other | | Other installations used for heat production, which do not meet the above-mentioned size category or fuel criteria. A more detailed description is provided in Chapter 3.8. |

The estimate for the number of installations is based on AFRY's database of boilers, with the exception of data centres. Most installations could, in principle, be included in several installation type categories, but in this overview, each installation is only included in one category in order to avoid being counted twice. In the overview, waste incineration plants are first put in a separate group. Then, a division is made between installations that produce industrial heat and district heating. Industrial installations encompass all boilers whose main function can be regarded as energy production for industrial installations, even if they also produce district heating. District heating installations are first divided into CHP plants and other installations. Thermal boilers using renewable energy are then separated from the remaining boilers. The chosen criteria for thermal boilers using renewable energy was that renewables should account for at least 90% of the fuel.

The figure of 90% was chosen as the proportions of fuels used in boilers may vary annually, depending on the prices and availability of fuels, for example. If the share of renewables exceeds 90%, the installations can easily use 100% renewable sources without making significant changes in the supply of fuel. The remaining 10% is typically peat, but it is also possible that no peat at all is used in the boilers. The boiler-specific estimates of fuel proportions are based on data gathered by AFRY on emissions, environmental permits, Finnish Energy statistics and other sources. The remaining boilers make up the Other installations category. In Other installations, installations that burn peat and wood as a mix are particularly significant for the utilisation of waste heat.

For each above-mentioned group of installations, the assessment covered

- the number of installations in the category;
- the remaining technical service life of the installations;
- the volume of heat waste production;
- the share of renewable energy in energy generation;
- the amount of waste heat already being used for district heating; and
- the amount of waste heat that is not currently being used but could be utilised in district heating or district cooling.

With regard to CHP plants, renewable energy heat plants and other installations, the assessment covers the amount of energy that can already be recovered from the flue gas scrubbers of existing installations and the amount of energy that could be recovered if a flue gas scrubber was installed in existing installations. Furthermore, the report assesses how much waste heat is and could be recovered in CHP plants, renewable energy heat plants and other installations using heat recovery system heat pumps.

In the case of installations intended for other than district heating production, i.e. industrial installations and data centres, the usability of waste heat is affected by a number of technical and economic factors, since the production of heat generated by the production process is not the main purpose of the installation and the recovery of waste heat has typically not been considered in the design of the installation. The main factors to consider are described in the table below (Table 2).

In many cases, the heat generated as a by-product of the industrial process is easier and more efficient to use locally at the industrial installation, in which case it is an energy efficiency measure, not the utilisation of waste heat as defined in the EED.

**Table 2 – Factors influencing the recoverability of waste heat**

| **Factor influencing recoverability** | **Description** |
|---|---|
| Waste heat temperature | The outgoing temperature of district heating networks is currently around 75–95 °C. The higher the temperature of waste heat, the better its techno-economic recoverability as district heating.<br>Low-temperature waste heat can be recovered with the aid of heat pumps. Heat pumps increase investment costs. |
| Proximity of district heating network | The greater the distance to the district heating network, the more the district heating network must be expanded, which affects the recovery costs of waste heat. |
| Demand for district heating | There must be sufficient demand for district heating to ensure the profitability of the operations, for example. |
| Short-term availability of waste heat | The steady or heat demand-responsive availability of waste heat 24 hours a day throughout the year improves the recoverability of waste heat. |
| Power reserve for waste heat | Waste heat sources require a power reserve, and building the required reserve capacity increases the costs of waste heat recovery. |
| Long-term availability of waste heat | District heating companies plan their heat supply and the required investment on a long-term basis. Uncertainty regarding the availability of waste heat from industrial installations increases the risk of the investments required for is utilisation and requires investments in reserve capacity, thereby impeding the recovery of waste heat. |
| Expertise and requirements | Levels of awareness of the potential for waste heat may not be satisfactory. For industrial operators, the viability of the production process is the first priority, and complicating the process may be seen as a risk for the main process.<br>The investment required for waste heat recovery is not necessarily profitable on the basis of the operator's investment criteria, even though their payment can be agreed to be the responsibility of the recipient of the waste heat. Drawing up the contract may also pose its challenges. |
| Price level and taxation | The price obtained (paid) for waste heat may be too low (high), preventing the conclusion of any contract. Particularly, the high tax on electricity and the calculation of CHP fuel taxes based on energy production rather than fuel consumption may also make waste heat recovery less profitable. It is often more feasible to use the waste heat for the operator's own purposes at the industrial installation, for instance. |

Source: AFRY

The assumptions used in the overview are presented in more detail under the relevant category in the following chapters.

## 3.2 Waste heat potential of condensing power plants

*Number of condensing power plants*

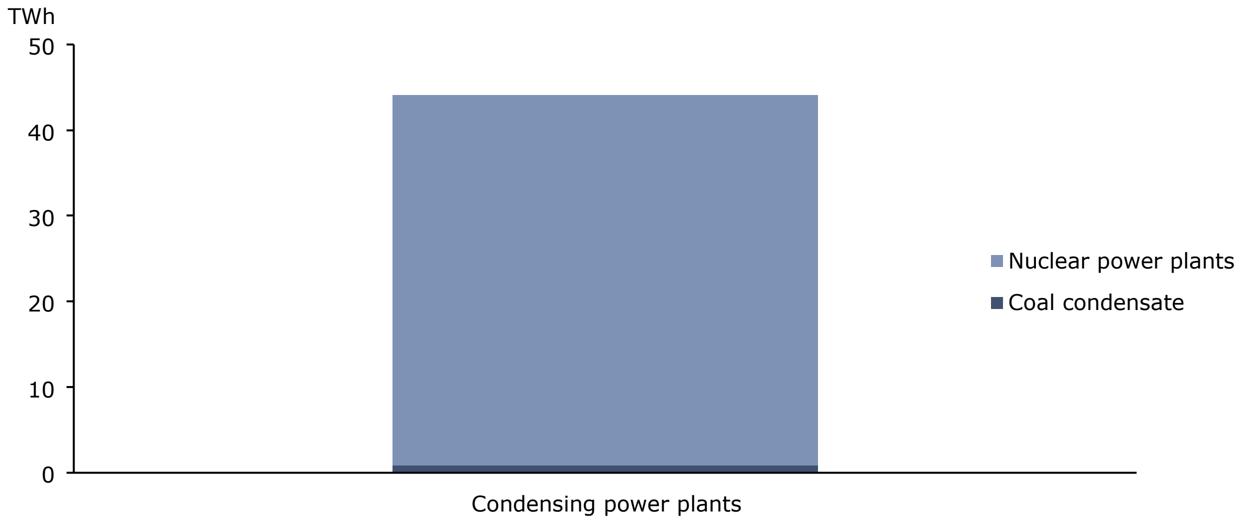
In Finland the only condensing power plants to produce electricity are the Meri-Pori coal-fired power plant and the Loviisa and Olkiluoto nuclear power plants. Part of the Meri-Pori coal-fired power plant (308 MW) was included in the peak-load reserve maintained by Fingrid up to 2020. In 2020, the entire capacity of the plant will be transferred to the peak-load reserve. As a reserve power plant is excluded from

As a reserve power plant is excluded from the electricity market and is only started when needed, the plant is not expected to generate a significant amount of energy in the coming years[5]. For this reason, the Meri-Pori power plant is not counted in the assessment of the potential for waste heat, although it is included in the amount of waste heat generated.

### *Amount of waste heat in condensing power plants and potential for application*

The amount of waste heat in the plants was assessed on the basis of the installations' average efficiency and total fuel consumption. Based on emissions data, coal consumption at the Meri-Pori power plant was about 1.4 TWh in 2018[6]. That figure is expected to decrease considerably when the plant is entirely transferred to the peak-load reserve. The consumption of uranium at the Olkiluoto and Loviisa nuclear power plants was 66.3 TWh. The total amount of waste heat generated by condensed power plants amounts to 44 TWh, of which 43 TWh consists of waste heat from nuclear power plants (Figure 3). The share of renewable energy in the production of condensed power plants is 0%.

**Figure 3 – Amount of waste heat generated by condensed power plants in 2018**




Source: AFRY's database of boilers, AFRY Management Consulting

The waste heat generated by condensing power plants is currently not being used at all for the production of district heating or cooling. In the case of nuclear power plants, the recoverability of waste heat is affected by the location of the installations relative to the users of the heat. The waste heat potential of the Loviisa nuclear power plant has the best location for utilisation. Roughly estimated, the district heating networks of Helsinki, Espoo, Vantaa, Kirkkonummi, Porvoo, Sipoo and Loviisa are within 100 km in the same direction from, or close to, the nuclear power plant.

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[5] Fortum online news, 2019, Fortumin Meri-Porin voimalaitos valittu tehoreservijärjestelmään ajalle 1.7.2020 – 30.6.2022. (Fortum's Meri-Pori power plant selected for peak-load reserve capacity system for the period 1 July 2020 – 30 June 2022) https://www.fortum.fi/media/2019/12/fortumin-meri-porin-voimalaitos-valittu-tehoreservijarjestelmaan-ajalle-172020-3062022

[6] Energy Authority, plant-specific emission data 2018

[7] Statistics Finland, table 3.4.2 Production of electricity and heat, energy sources and CO2 emissions 2000–2018 (energy method)

The total demand for district heating in these areas was about 12.5 TWh in 2018[8]. The Loviisa nuclear power plant generates an estimated 15.8 TWh of waste heat. In a technical sense, the whole share of waste heat could be recovered if there was demand for heat. Therefore, the theoretical maximum potential for the use of waste heat from the nuclear power plant is equal to the demand for heat. The utilisation of waste heat would mean building heat transfer infrastructure between the Helsinki metropolitan area and the Loviisa nuclear power plant, as well as alterations at the plant. Because the demand for heat varies by season, being at its lowest in the summer, not all waste heat could be utilised, as the nuclear power plant is operated steadily around the year, with the exception of a few weeks' service break in the summer. This means that more waste heat is generated during the warm season than there is demand for. On the other hand, it is seldom feasible to design transfer capacity to cover peak demand in winter, which decreases the recoverable amount of waste heat. There is also production capacity in the Helsinki region that would probably be used, despite the existence of nuclear district heating, such as heat pumps and the Vantaa waste incineration plant. Taking into consideration the above-mentioned restrictions, not all waste heat generated at the plant is recoverable. Based on the assessment drawn up by Pöyry in 2010 on the potential of the Loviisa nuclear power plant for district heating production, the amount of recoverable waste heat was estimated to be 6–9 TWh, depending on the heat transfer capacity.[9]

There are no corresponding large heat loads near the Olkiluoto and future Hanhikivi nuclear power plants, which makes the efficient application of waste heat difficult.

As the Meri-Pori power plant is only rarely operated as a peak-load reserve plant, and there is no guarantee as to the profitability of condensing electricity production after the peak-load reserve period due to the emission allowance price, for example, it is not feasible to make investments in the recovery of waste heat. Consequently, the estimated potential for waste heat recoverable from the Meri-Pori power plant is zero.

## 3.3 Waste heat potential of waste incineration plants

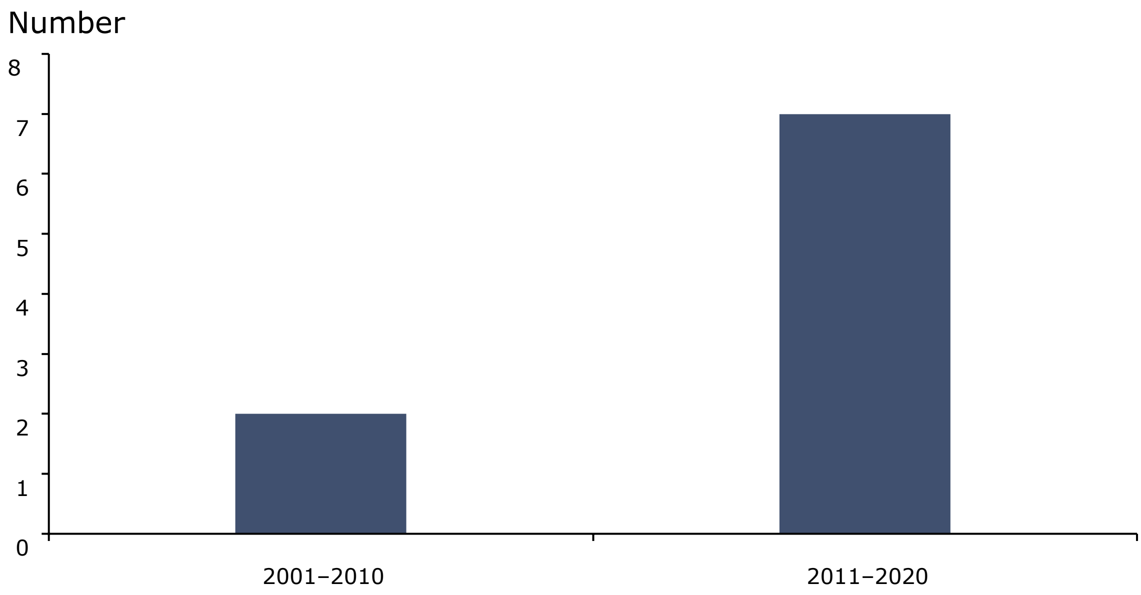
*Number of waste incineration plants*

The waste incineration plant category includes all installations that burn municipal waste regardless of what the energy they generate is used for (district heating or process gas). There are nine waste incineration plants in Finland. Two of Finland's waste incineration plants could also be classified as industrial installations, as they generate most their energy for industrial installations, but in this report, all waste-burning plants are included in the waste incineration plant category. All the waste incineration plants currently in use are relatively new. Most of the waste incineration plants in Finland were built in the 2010s, and they are all electricity and heat co-generation plants. Figure 4 shows the number of waste incineration plants by estimated year of construction.

[8] Finnish Energy, District cooling statistics 2018

[9] Pöyry, Selvitys kaukolämmön johtamisesta Loviisa 3 -ydinvoimalaitosyksiköstä pääkaupunkiseudulle vuosina 2020–2080 (Assessment on conducting district heating from the Loviisa 3 nuclear power plant unit to the Helsinki metropolitan area in 2020–2080), http://mb.cision.com/Public/15253/2212341/95a71499ef895506.pdf

## Figure 4 – Waste incineration plants by year of construction




Source: AFRY database of boilers

### *Amount of waste heat and potential for application at waste incineration plants*

Waste heat at waste incineration plants consists of heat escaping with flue gases into the environment and heat generation that needs to be condensed into the environment. As waste incineration plants burn municipal waste at full capacity practically throughout the year, they may need to condense heat into the environment during the low demand period in the summer.

The amount of waste heat from waste incineration plants has been estimated based on the electricity and heat generated by the plants and the proportion of fuel consumption. The amount of waste heat from waste incineration plants was estimated using annual environmental reports that indicate the energy production amounts and fuel consumption of the plants. These have been used to estimate the efficiency of the plant. The production figures of the heat recovery systems in the waste incineration plants were obtained from the Finnish Energy district heating statistics. In 2018, only two waste incineration plants did not have a heat recovery system for flue gases, and one of these had such a system installed during 2019[10]. This means that most of the easily applied potential has already been used.

Figure 5 shows the amount of waste heat generated in waste incineration plants and the amount of waste heat already utilised. The total estimated amount of waste heat was 1.2 TWh, of which some 0.5 TWh, or 39%, was utilised. Hence, the untapped waste heat potential is 0.7 TWh, of which 0.2 TWh could be recovered by installing heat recovery scrubbers in the plants that do not currently have them. 0.5 TWh of the unused waste heat originates from the condensing required due to the low heat demand.

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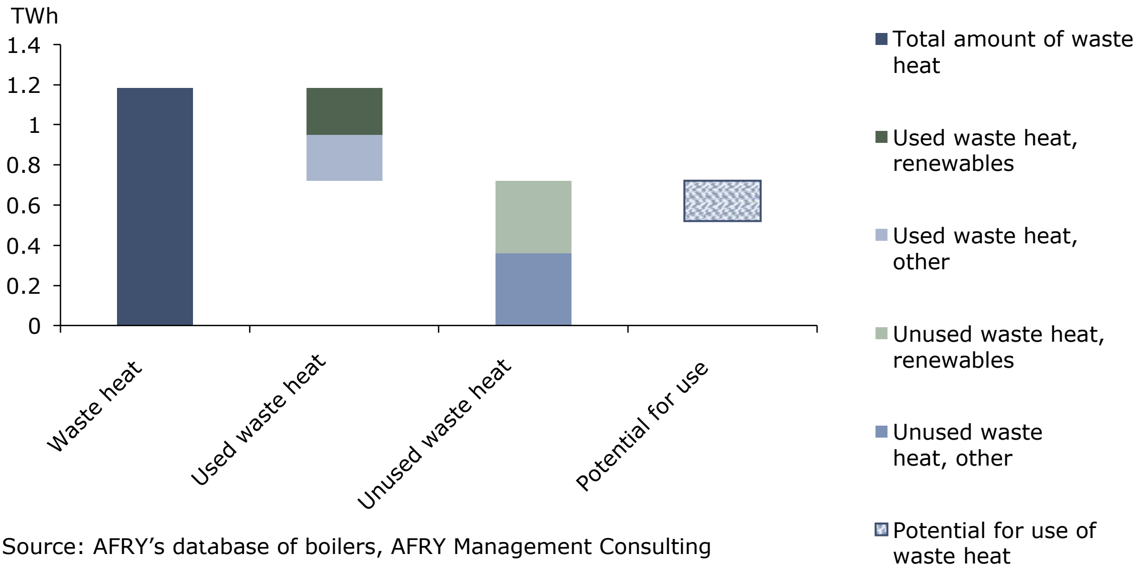
[10] Westenergy, annual report 2019, https://2019.westenergy.fi/tuotanto-ja-kunnossapito/

Approximately half of the waste heat generated by waste incineration plants is produced when renewable fuels are used. The estimate is based on the bio share of municipal waste in Statistics Finland's statistics, which was 50% in 2020[11].

**Figure 5 – Unused and used waste heat at waste incineration plants (2018)**




Source: AFRY's database of boilers, AFRY Management Consulting

The waste heat generated owing to the need for condensing at waste incineration plants could be recovered using seasonal heat storage. Another option would be to improve waste storage so that waste could be incinerated as required by heat demand, but the storage of waste is challenging, and waste incineration plants may not have the capacity to increase waste incineration during periods of peak demand for district heating.

## 3.4 Waste heat potential of industrial installations

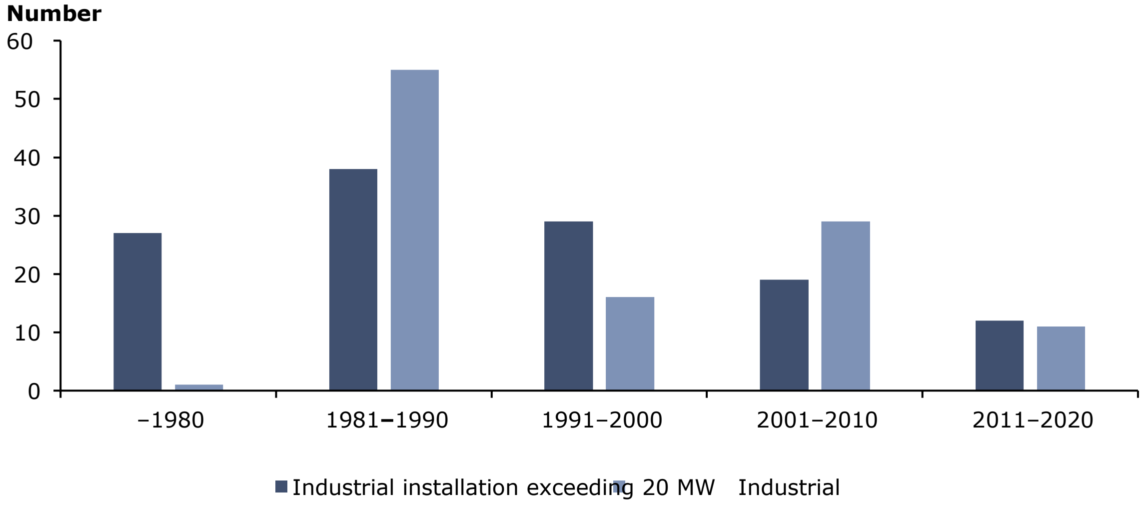
*Number of energy-generating industrial installations*

According to AFRY's database of boilers, there are around 80 industrial installations in Finland with a total thermal input exceeding 20 MW. The figure includes CHP plants where the majority of production is used by industries, even if the same plant also produces district heating. There are also some 80 installations of 5–20 MW, but some installations are presumably missing from this figure. Industrial installations may have several boilers, but an industrial area generally has one main boiler generating heat that could be eventually used as waste heat. For the utilisation of waste heat, it is largely irrelevant as to whether the heat originates from one or several boilers. According to AFRY's database of boilers, large industrial installations have an average of 1.7 boilers and installations of 5–20 MW have an average of 1.4 boilers.

[11] Statistics Finland's fuel classification 2020

Judged on the basis of the database of boilers, the median year of manufacture of the industrial installation boilers was 1991. Figure 6 depicts the age breakdown of the boilers. The actual remaining service life of the installations may often be longer than indicated by their original technical service life due to a range of maintenance and upgrade investments.

**Figure 6 – Number of industrial energy generation installations by construction year and input class**




Source: AFRY database of boilers

*Industrial energy production and waste heat sources*

The combined fuel consumption of the industrial installations included in the database of boilers is 90 TWh. Most (95%) of this consumption occurs in installations of more than 20 MW. According to Statistics Finland, the total energy use of industries in 2018 was 149 TWh, of which fuels accounted for 102 TWh. Fuels are used for the production of both electricity and heat in industry. In AFRY's estimate, the theoretical potential for waste heat is some 70% of fuel consumption (total consumption less the estimated energy used for electricity production and associated with industrial products). This corresponds to approximately 70 TWh. Considering the energy efficiency measures taken by industries, the potential for the use of waste heat in district heating is further reduced. [12]

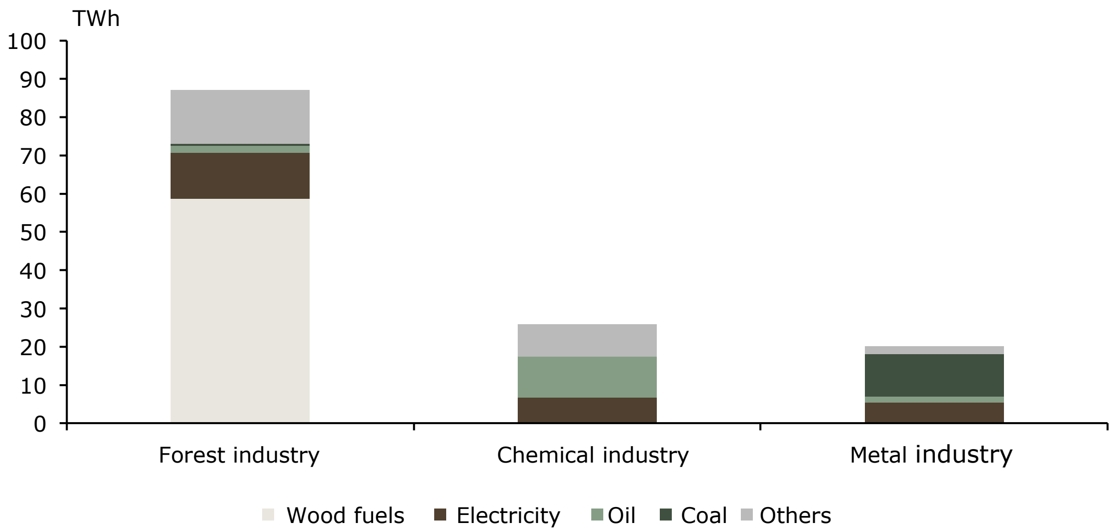
The electricity included in industrial energy use is also ultimately converted into heat that could, in principle, be considered waste heat. The impact of electricity consumption is not taken into account in this analysis, however, as it is not considered to have the same potential for use as the waste heat generated by fuel consumption. In 2018, industrial installations consumed 32 TWh of electricity produced outside the installation.

Based on energy use, the largest three industries in 2018 were the forest industry (87 TWh), chemical industry (26 TWh) and manufacture of basic metals (20 TWh).

[12] Statistics Finland, Energy use in manufacturing by industry, 2020 http://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin_ene__tene/statfin_tene_pxt_001_fi.px/

Combined, these three industries accounted for 89% of industrial energy use, so assessment of waste heat potential should focus on these sectors. Other industrial sectors relevant to the matter of energy use include the food industry, machinery and metal manufacturing, mining, and textile manufacturing, although their combined energy use is less than the energy use of the metal industry alone. In 2018, 60% of industrial fuel consumption was renewable and 40% was fossil fuel-based (including peat). A total of 59 TWh of the forest industry's energy use was wood fuel-based. The chemical industry consumes a considerable amount of oil for energy (11 TWh). The amounts of electricity (7 TWh) and heat (5 TWh) it uses are also proportionately high. Coal (11 TWh) and electricity (5 TWh) play a major role in the energy use of the metal industry. Figure 7 depicts the breakdown of energy use in these industries. [13]

**Figure 7 – Energy use in the forest, chemical and metal industry**




Source: Statistics Finland

Examples of the forest, chemical and metal industry include a pulp mill, oil refinery and steel works respectively. Pulp mills typically feature two boilers using primarily wood-based fuels. The bark boiler is often a circulation or fluidised bed boiler using wood bark as its main fuel. Bark boilers can respond to changes in load, as they are not as tied to the plant processes as a soda recovery boiler. Soda recovery boilers are a part of the chemical pulp production process and use black liquor for fuel, which is also wood-based. The steam generated from the two boilers in the mill are used to generate electricity and process steam and heat for the energy needs of the mill and, in many cases, external users. The largest individual energy consumption factors in a chemical pulp mill are usually the processes related to cooking and drying pulp and the evaporation of black liquor.

[13] Statistics Finland, Energy use in manufacturing by industry, 2020 http://pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin_ene__tene/statfin_tene_pxt_001_fi.px/

They consume process steam. Therefore, the largest heat flows for potential waste heat are related to these processes. Heat from these processes ends up in the plant's waste water, for example, from where it would be possible to recover heat. Sometimes heat even needs to be cooled from the waste water into the atmosphere to ensure the operation of the biological waste water treatment processes and to prevent excess heat from getting into local waters.

In oil refineries, products generated as effluents of oil refining can be used as fuel. For example, the new power plant at the Kilpilahti oil refinery will use asphaltene, which is generated as a by-product of refining[14]. Steel plants, meanwhile, also use the coal required for steel production in their energy production. Steel production also typically consumes a great deal of electricity.

In the other categories in this report, the utilisation of waste heat as district heating is enhanced with the boilers' heat recovery systems, but in industry, waste heat is more likely to be recovered from the heat streams from industrial processes rather than flue gases.

*Utilisation of, and potential for, industrial waste heat*

In the preliminary report drawn up by Pöyry for Motiva in 2019, *Ylijäämälämmön potentiaali teollisuudessa* (Potential of excess heat in industry), the technical waste heat potential of industry in 2017 was estimated to be about 16 TWh. According to the report, previous studies had estimated the technical potential to be 6–23 TWh. The shares of renewable and fossil fuels can be assumed to be the same for waste heat as in fuel consumption. [15]

Large industrial plants are often a long way from major cities and district heating networks, which means that there are no consumers for waste heat. There are also technical challenges in heating solutions based on industrial waste heat. The production of district heating must not endanger industrial processes but, at the same time, district heating needs a steady heat supply during the heating season, whereas industrial production can be intermittent. Other factors limiting the usability of waste heat are described in Table 2 above.

It is estimated that around 1–2 TWh of the heat currently supplied by industry to the district heating network could probably be classified as waste heat. According to Finnish Energy's district heating statistics, the heat supplied by industries to district heating companies in 2018 amounted to ca. 1.2 TWh. Depending on the definition, however, not all of this heat can necessarily be definition as waste heat. On the other hand, the statistics do not include all the district heating sold by industries[16].

There are some district heating networks in Finland that acquire over 70% of their district heating from industry. On the basis of the 2018 statistics, six such towns with a population of around 20,000 were identified: Raahe, Valkeakoski, Jämsä, Heinola, Pietarsaari and Uusikaupunki.

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[14] Enertec, Kilpilahden voimalaitos on kansainvälinen yhteishanke (Kilpilahti power plant is an international joint venture), 2017 https://www.enertec.fi/natiivi/534/kilpilahden-voimalaitos-on-kansainvalinen-yhteishanke

[15] Pöyry, Esiselvitys – Ylijäämälämmön potentiaali teollisuudessa (Preliminary report – Potential of excess heat in industry), 2019 https://www.motiva.fi/ajankohtaista/julkaisut/esiselvitys_-_ylijaamalammon_potentiaali_teollisuudessa.10705.shtml

[16] Finnish Energy, District heating statistics, 2019 https://energia.fi/julkaisut/materiaalipankki/kaukolampotilasto.html#material-view

Since 2018, for example, Siilinjärvi has used industrial waste heat. Siilinjärvi aims to meet up to 96–97% of its district heating need with waste heat[17].

There are also preliminary studies ongoing on using the waste heat of the Kilpilahti industrial area in the Helsinki metropolitan area. In addition to Kilpilahti, three major potential combinations of industrial area and urban area were identified in AFRY's database where a link between industry and district heating has not yet been made: the Naantali oil refinery in the Turku region, the Kantvik industrial area in Kirkkonummi, and the forest and metal industry areas in Imatra. In all these areas, combining waste heat and district heating has presumably been studied, but this has not led to the initiation of heat trading.

Table 3 lists industrial areas where the annual fuel consumption is at least 100 GWh and which are located near potential consumption sites, i.e. towns with a population of at least 20 000 and relatively near an industrial installation. The maximum distance was defined as 100 metres of new district heating network for a waste heat sales potential of 1 GWh per year (100 m/GWh). Industrial installations are often located either in the proximity of a town (a maximum distance of 10 km) or clearly farther from populated areas. The analysis only takes into account industrial installations located near populated areas or with a high potential, resulting in a maximum distance for sales at the level indicated above. There are as yet no references in Finland for supplying waste heat over a longer distance. Most of the sites listed in the table already engage in heat trading, but this trade accounts for no more than 25% of the local heat supply (with an average of 10%).

[17] Adven, 1 July 2020, https://www.adven.fi/fi/uutishuone/uutiset/siilinjarvi-siirtyy-moderniin-kaukolampoon/

## Table 3 – Identified industrial waste heat sources and potential consumers

| Industrial area | Estimate of the industrial area's fuel consumption [GWh/y] | Potential locality for utilising heat | Sales of district heating in the locality 2018 [GWh/v] |
|---|---|---|---|
| Kilpilahti | 4 800 | Helsinki metropolitan area (Porvoo) | 11 000 |
| Tako | 350 | Tampere | 2 100 |
| Nuottasaari and Laanila | 4 400 | Oulu | 1 500 |
| Refinery | 850 | Turku (Naantali) | 1 900 |
| Sorsasalo | 720 | Kuopio | 950 |
| Kuusankoski | 4 200 | Kouvola | 420 |
| Sunila and Kotkansaari | 4 200 | Kotka | 380 |
| Industrial park | 310 | Kokkola | 310 |
| Kirkniemi | 1 200 | Lohja | 120 |
| Kantvik | 150 | Kirkkonummi | 110 |
| Pulp mills and steel mill | 6 200 | Imatra | 160 |
| Pajusaari and Veitsiluoto | 7 000 | Kemi | 160 |
| Päiviönsaari | 2 200 | Varkaus | 180 |

Source: AFRY, Finnish Energy

If 25% of the heat generated from the fuel consumption specified in the table above could be used as waste heat in district heating, and the share of waste heat was no more than 90% of the area's heat supply, the total waste heat potential in the table would amount to ca. 4.2 TWh. It is difficult to accurately estimate a realistic total, as the amount depends very much on large individual sites, such as Kilpilahti. It has been publicly stated that the waste heat generated by Kilpilahti could meet up to a quarter of the heating need in the Helsinki metropolitan area. This would correspond to nearly 3 TWh of heat.

The differences between the technical usability of waste heat between different industries has not been analysed in more detail. Differences affecting the potential for application as district heating in different industries include the waste heat temperature level in the industry. The differences in usability may vary greatly even within an industry. All fuel consumption is eventually converted to heat, but, for now, waste heat is only minimally utilised. Factors such as the tax treatment of the consumption of electricity of heat pumps may affect the profitability of using waste heat.

It should also be noted that industries are continually enhancing their operations, and the use of heat in an industry's internal processes may be more profitable than selling the heat as waste heat to the district heating network. In these cases, the action falls under the notion of energy efficiency rather than the utilisation of waste heat. Where the heat ultimately ends up is affected by tax treatment, for example, and it may be easier to agree on the terms and conditions for using heat internally rather than with an external operator.

On the other hand, the development of heat pump technology will allow a larger share of waste heat to be recovered in the future.

The temperature level of waste heat may also affect the potential for using waste heat as district heating. The possibilities for and impact of lowering the temperature level is described in more detail in Chapter 5.1.

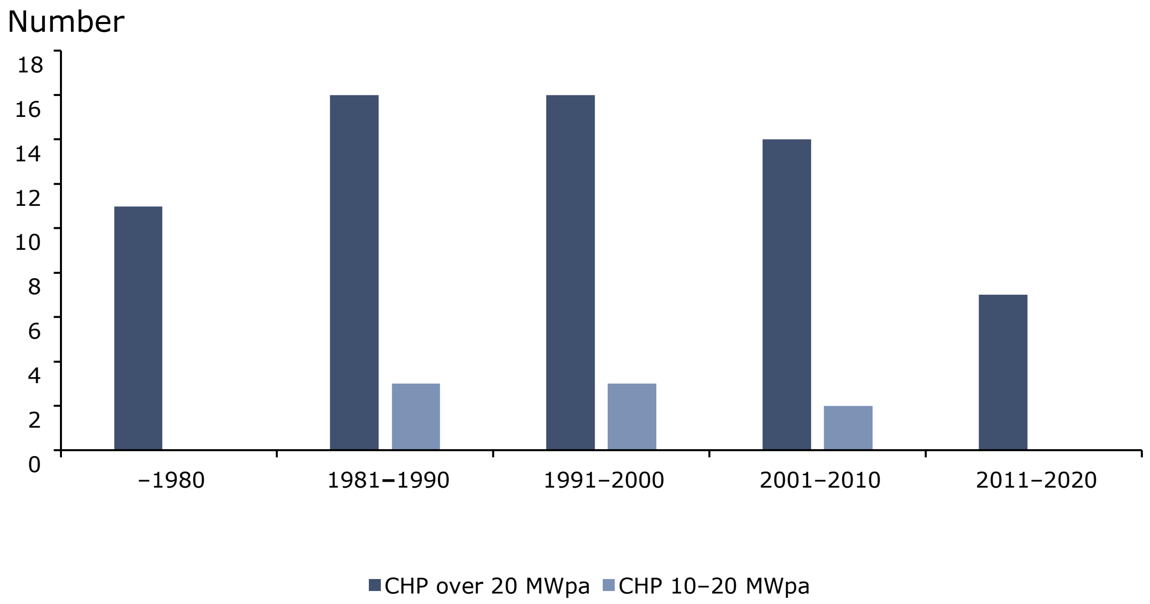
## 3.5 Waste heat potential of CHP plants

*Number of CHP boilers*

This category includes all CHP plants excluding CHP plants in industries, CHP waste incineration plants and CHP plants that do not meet the size requirements. In other words, CHP plants are thought to include all installations which produce mainly district heating and which do not burn municipal waste. CHP boilers that mainly produce energy for industries are not included in this category but in the data on industrial waste heat described in Chapter 3.4. In this report, CHP boilers are divided by thermal input into 10–20 $MW_{pa}$ installations and over 20 $MW_{pa}$ installations.

Figure 8 shows the number of boilers included in the CHP plant category by capacity and year of construction. The year of construction can be used as a rough estimation of when the plants will reach the end of their technical service life and be decommissioned. The average technical service life of plants is approximately 40 years, but it is possible that major renovations are carried out to extend their service life and that the plants are in use for longer periods. Most of the over 20 $MW_{pa}$ plants were built between 1980 and 2000. 66% of the plants in the larger category were built before 2000. CHP plants in the smaller category are clearly less common, with only a total of eight such plants. There is a total of 64 larger plants (Figure 8).

**Figure 8 – Number of CHP boilers by construction year and input class**

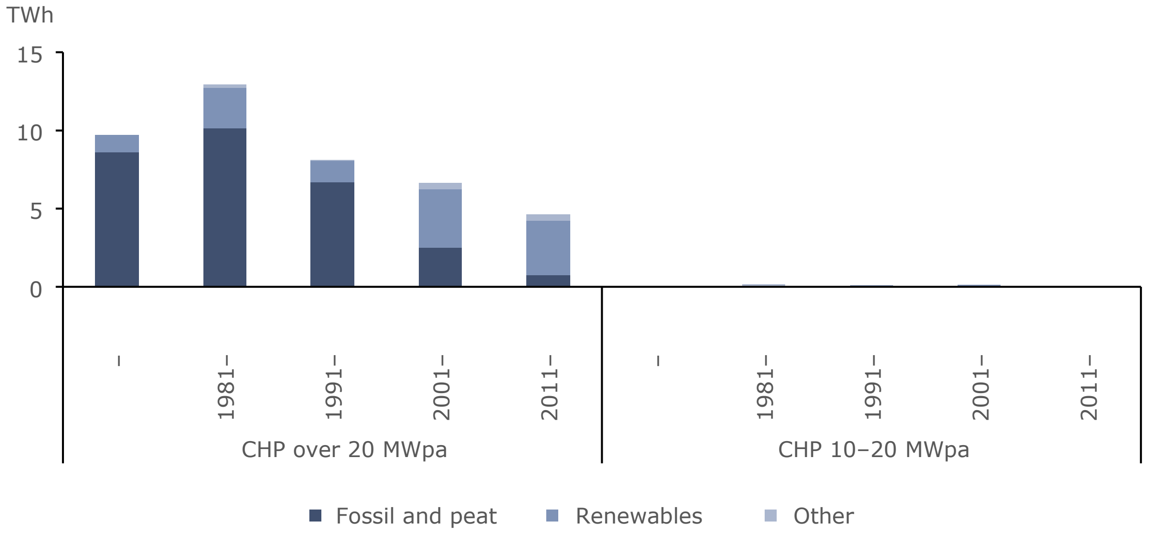



Source: AFRY database of boilers

Currently, most of the fuels used in CHP plants are fossil fuels, but a large number of these fossil fuel-based CHP plants will reach the end of their service life in 2020s.

Figure 9 shows the fuel mix of CHP plants by plant capacity and year of construction.

**Figure 9 – Fuel mix of CHP boilers by construction year and input class**




Source: AFRY database of boilers

## *Amount of waste heat and potential for application at CHP plants*

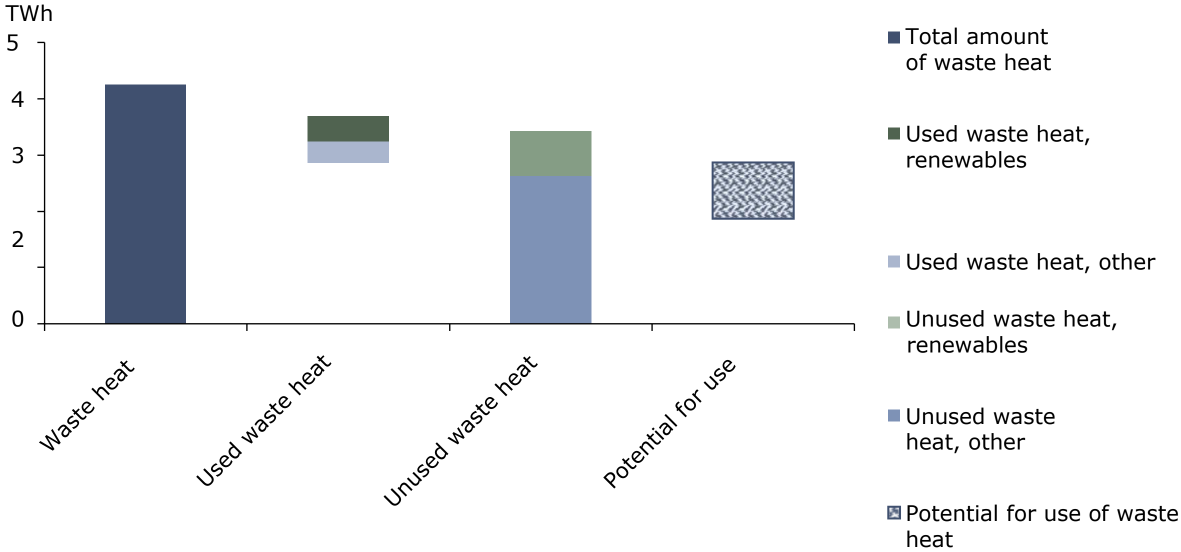
Waste heat in CHP plants consists mainly of heat escaping along with the plant's flue gases, and the recovery of waste heat is based on flue gas heat recovery systems and any heat pumps installed in them. Heat pumps are still uncommon in flue gas heat recovery systems.

The amount of waste heat in CHP plants is estimated based on the plants' fuel consumption so that 10% of the energy obtained from the plants' total fuel escapes with flue gases. The remaining useful amount of waste heat has been estimated on the basis of the combined amount of waste heat in CHP boilers that mainly burn moist fuels and which reach the end of their service lives no earlier than 2030. Moist fuels include peat and biomass. The estimate is based on the plants' fuel consumption in 2018. The assumption was that plants to be decommissioned before 2030 would not be fitted with scrubbers, as the remaining service life of the plant would be short.

On the basis of these assumptions and baseline data, CHP plants generate a total of some 4.2 TWh of waste heat that could be utilised. Of this amount, 3 TWh is generated with non-renewable fuels and 1.2 TWh is generated with renewable fuels. A total of 0.8 TWh of the waste heat generated is already being used. Of this amount, about half is generated using renewable fuels. This means that the remaining untapped waste heat potential is approximately 3.4 TWh. The remaining, most readily usable waste heat potential is estimated to be around 1 TWh, taking into account factors such as the plants' remaining service lives.

Renewable fuels account for 29% of all generated waste heat. A total of 54% of the usable waste heat is generated with renewable fuels, accounting for 10% of the entire volume of waste heat. Figure 10 shows the estimated total amount of waste heat, the amount of waste heat already being used, and an estimate of the unused waste heat potential in CHP plants producing district heating.

**Figure 10 – Waste heat from district heating CHP plants and the proportion of currently usable waste heat (based on fuel consumption in 2018)**




Note: Potential for use refers to waste heat as yet unused but which could be used

Source: AFRY's database of boilers, AFRY Management Consulting

## 3.6 Waste heat potential of renewable energy thermal boilers

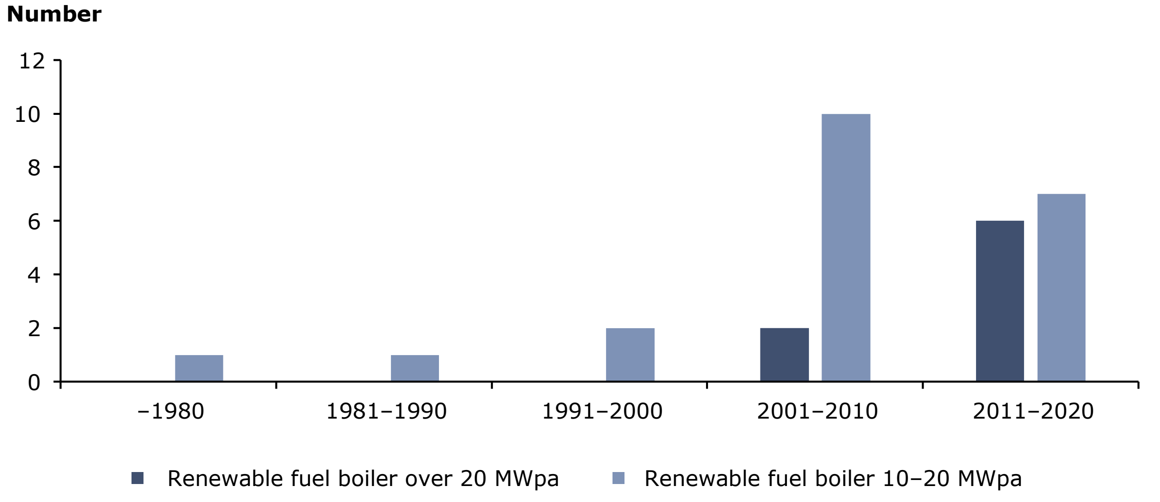
*Number of renewable energy thermal boilers*

In this report, renewable energy thermal boilers are defined as boilers in which the share of renewable energy is at least 90%, the main function is district heating production, the size meets the size class requirements, and the boilers are not CHP boilers. The threshold was set at 90%, as plants with a share of renewables exceeding 90% can typically easily use 100% renewable sources without making significant changes in the supply of fuel. The remaining 10% is typically peat, but it is also possible that no peat at all is used in the boilers. The proportions of fuels may vary annually, depending on the prices and availability of fuels, for example.

The number of renewable energy thermal boilers has increased steadily in recent decades, and their average size has grown as depicted in Figure 11 below.

Boilers with a thermal input of over 20 MWpa have especially been built since the 2010s, but the total number of renewable energy thermal boilers remains relatively low. There are in total 29 boilers meeting the size requirements for the category.

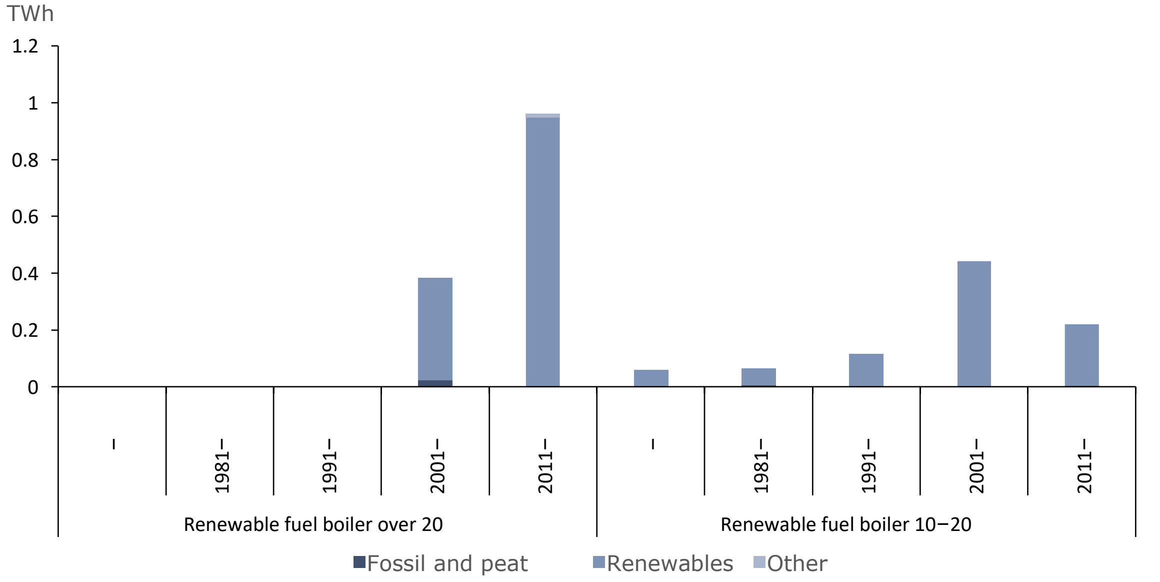
**Figure 11 – Renewable energy thermal boilers by construction year and input class**




Source: AFRY database of boilers

Figure 12 shows the fuel consumption of renewable energy boilers by capacity and construction year. Boilers with a capacity exceeding 20 MWpa account for most of the wood fuel consumption in the category. In addition to wood-based fuels, the boilers can burn small amounts of peat.

**Figure 12 – Fuel consumption of renewable energy thermal boilers by construction year and input**



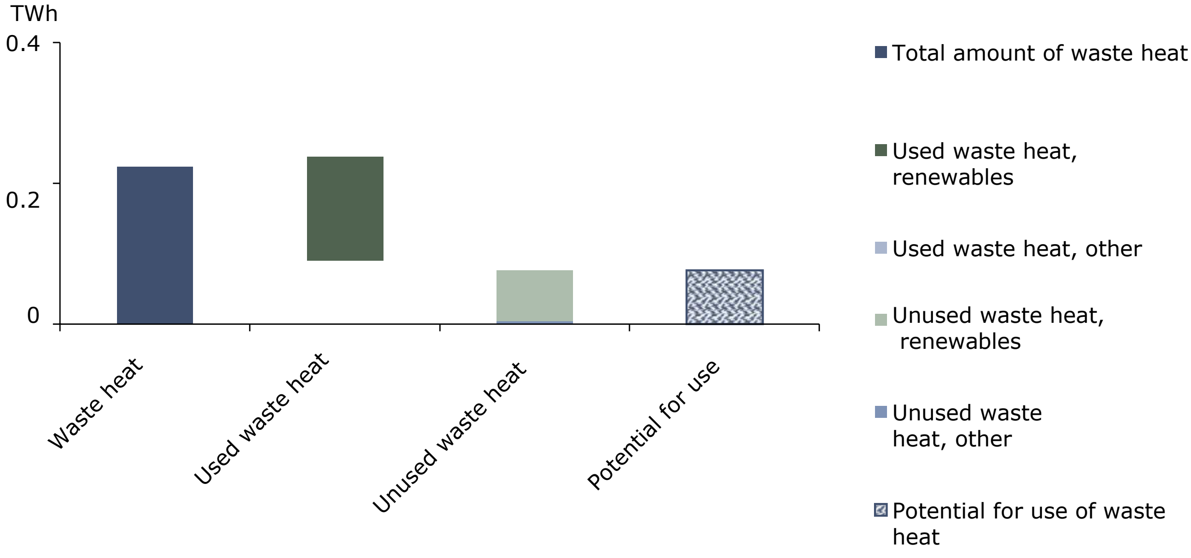

Source: AFRY database of boilers

*Amount of waste heat from renewable energy thermal boilers and potential for use*

The waste heat from renewable energy thermal boilers consists of the heat escaping along with flue gases. The waste heat can be recovered by installing a flue gas scrubber with heat recovery. Figure 13 shows the used and unused amount of waste heat in renewable energy thermal boilers at present. The used portion of waste heat is estimated on the basis of flue gas scrubber production. If a heat pump is installed in addition to flue gas scrubbers, the usable amount is greater.

The total amount of waste heat from renewable energy thermal boilers is 0.22 TWh. Approximately 0.15 TWh of this is being used. The remaining usable proportion is about 0.07 TWh. Boilers that will be decommissioned before 2030 are not included in the usable waste heat potential, as the technical service life of the recovery system would be short. The used share of waste heat in this category is considerable compared to the other categories, as 66% of the waste heat generated is already being used and the remainder could quite easily be used. The share of waste heat generated by burning renewable fuels is 98%. The remaining amount of the waste heat is primarily generated by burning peat. In practice, the used waste heat is generated almost entirely with renewable fuels.

**Figure 13 – Used and unused amount of waste heat in renewable energy thermal boilers**




Source: AFRY's database of boilers, AFRY Management Consulting

## 3.7 Waste heat potential of data centres

*Number of data centres*

There is no comprehensive, publicly available information on data centres, as this information is often kept confidential due to data security and competition. Based on the information compiled by AFRY, there are fewer than ten data centres in Finland exceeding 5 MW. At least the following companies have large, over 5 MW data centres in Finland: Google (Hamina), Equinix (several data centres in the Helsinki area), Telia (Helsinki, Pitäjänmäki), Hetzner (Tuusula, Vantaa), Yandex (Mäntsälä) and Microsoft (secret location in Uusimaa). Experts estimate that there are some 50 mid-size data centres with a capacity of 0.5–5 MW. The number of data centres is expected to increase further in the future.

*Waste heat generation*

Data centres generate waste heat through the operation of their electrically powered equipment. The heat must be removed from the data centres, and the equipment may also require separate cooling. The waste heat potential of data centres is typically significant, and, in most cases, practically all the heat could technically be utilised.

In AFRY's estimate, the total electricity power of data centres suitable for waste heat recovery is about 300 MW. During the peak operating period, 6,000 h/a, this corresponds to approximately 2 TWh of heat generation, most of which could technically be used as district heating. Wahlroos et al (2018) have estimated that the electricity consumption of data centres could in future account for up to 5% of Finland's electricity consumption, i.e. approximately 5 TWh, most of which could technically be used for heat. [18]

The share of renewable energy of data centres' waste heat depends on the origin of the electricity they use. Data centre owners may purchase electricity with a verified origin, in which case the waste heat from a specific data centre is generated entirely through the use of renewable energy. This is the case with Google, for example. If the electricity is not certified, the share based on the residual mix calculated annually by the Energy Authority can be applied to the electricity. In 2019, the share of renewable energy sources in the residual mix was 6.24%, the share of nuclear power was 51.42%, and the remaining 43.34% consisted of fossil energy sources and peat.

*Utilisation of waste heat*

The data centre in Mäntsälä currently supplies about 30 GWh heat to the local district heating network. Waste heat from data centres is also delivered to district heating in the Helsinki area. According to AFRY's estimate, the annual amount of waste heat currently sold by the largest individual data centres can be counted in tens rather than hundreds of GWhs. This means that the untapped potential is significant.

[18] Wahlroos, M. et al, Future views on waste heat utilization – Case of data centres in Northern Europe, 2018 https://www.sciencedirect.com/science/article/pii/S1364032117314314?

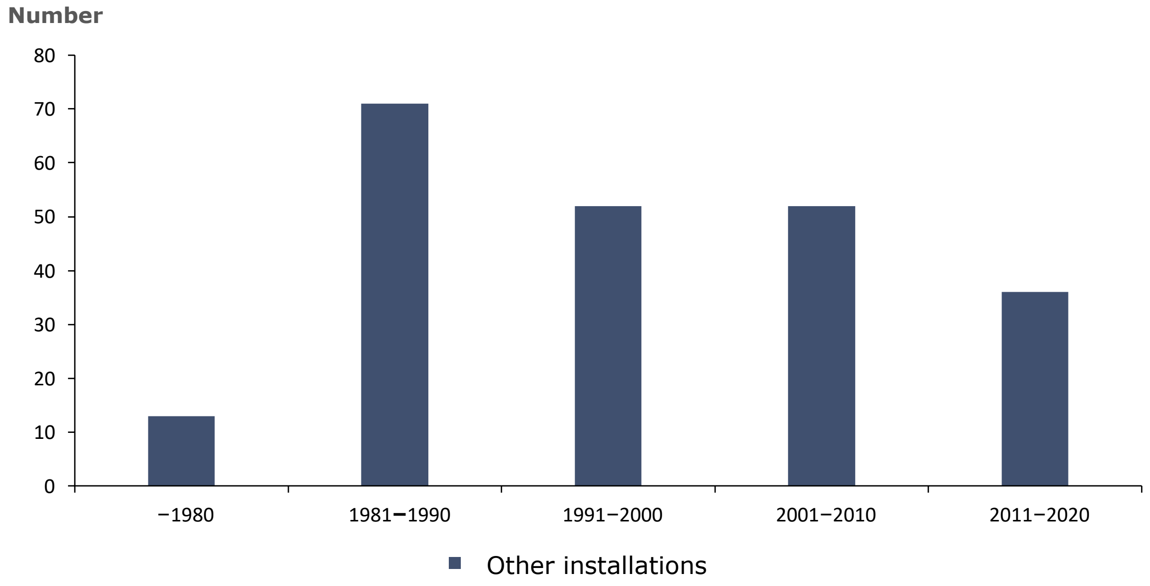
The utilisation of waste heat generated by data centres involves many of the same challenges as the utilisation of industrial waste heat: data centres may be located a long way from heat consumption, and the primary business of the heat producer is not in the energy sector. The required investments may not necessarily meet the yield requirements of the data centre owners.

## 3.8 Other installations

*Number of other installations*

In this report, the category of other installations includes the installations which do not meet the criteria of the other categories with respect to size and/or fuels. Figure 14 presents the number of boilers included in the other installations category by the estimated year of construction. The number of other installations does not include oil-powered auxiliary, backup or peak power boilers due to their minimal operating hours and irregular use. There are some 370 oil-powered boilers in Finland. This category contains a total of 224 boilers, with oil boilers excluded. Boilers reaching the end of their technical service life in 2030–2039 account for the biggest share in this category (oil-powered categories are not included in this figure).

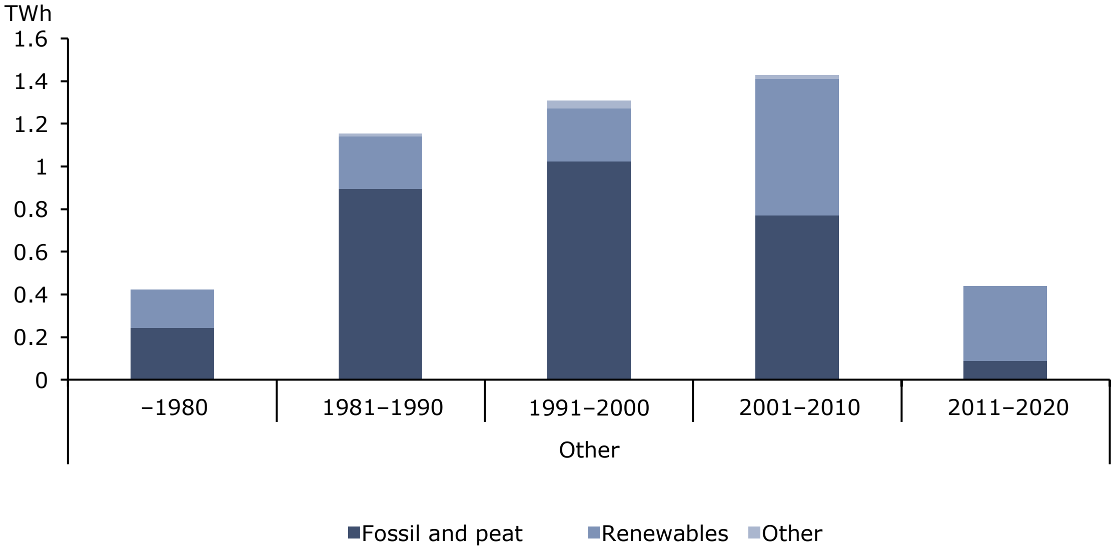
**Figure 14 – Number of other installations by year of construction**




Source: AFRY database of boilers

Figure 15 shows the fuel consumption and fuel mix of boilers included in the other installation category The share of renewable energy is clearly higher in the newest boilers than in older installations. The average fuel consumption per boiler is small, just 21 GWh. This has a significant impact on the potential for the use of waste heat. The fuel mix with boilers built in 1981–2000 consists mainly of fossil fuels. The share of renewable fuels is considerably higher in boilers built after 2000.

**Figure 15 – Fuel consumption and fuel mix of other installations by year of construction**



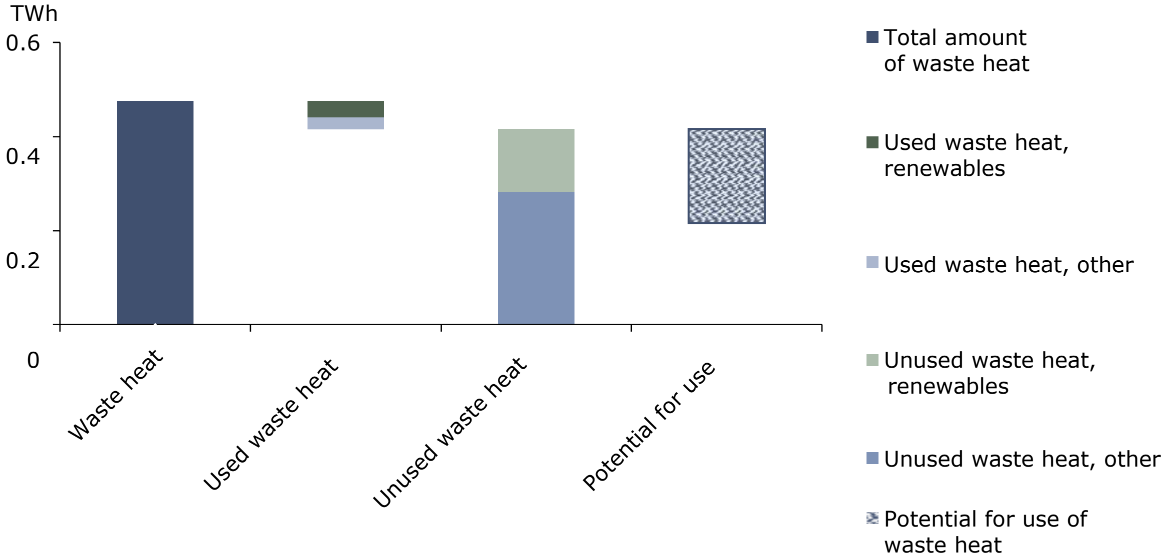

Source: AFRY database of boilers

### *Amount of waste heat and potential for application at other installations*

The waste heat of other installations consists of the heat escaping along with flue gases. The waste heat can be recovered by installing a flue gas scrubber with heat recovery in installations that use moist fuels.

Figure 16 shows the amount of waste heat from installations in the other installations category and its currently usable share. Other installations generated approximately 0.48 TWh of waste heat, of which around 0.06 TWh has been used. Based on the amount of waste heat in installations that burn a mix of peat and wood in this category, the waste heat potential for the category is around 0.2 TWh. The as yet untapped potential does not include boilers that will be decommissioned before 2030. The total share of waste heat generated by using renewable fuels is 35%.

**Figure 16 – Waste heat from other installations and the share of currently usable waste heat by fuel class**




Source: AFRY database of boilers

## 3.9 Summary of waste heat production and use

This chapter analysed the generation of waste heat and the use of waste heat following the categorisation of installations in Annex VIII of the EU Energy Efficiency Directive. First, the number of installations in each category was established by capacity and year of construction. The results are summarised in the table below (Table 4).

**Table 4 – Summary of the number of boilers and data centres generating waste heat**

| Installation type | Capacity | Total number | Built prior to 1980 | 1981–1990 | 1991–2000 | 2001–2010 | 2011–2020 |
|---|---|---|---|---|---|---|---|
| Condensing power plants | >50 MW | 5 | 2 | 2 | 1 | 0 | 0 |
| Waste incineration plants | All | 9 | 0 | 0 | 0 | 2 | 7 |
| Industrial installations | >20 MW | 125 | 27 | 38 | 29 | 19 | 12 |
| | 5–20 MW | 112 | 1 | 55 | 16 | 29 | 11 |
| CHP plants | >20 MW | 64 | 11 | 16 | 16 | 14 | 7 |
| | 10–20 MW | 8 | 0 | 3 | 3 | 2 | 0 |
| Renewable energy heat installations | >20 MW | 8 | 0 | 0 | 0 | 2 | 6 |
| | 10–20 MW | 21 | 1 | 1 | 2 | 10 | 7 |
| Data centres | >5 MW | <10 | | | | | |
| | 0.5–5 MW | 50 | | | | | |
| Other installations | All | 224 | 13 | 71 | 52 | 52 | 36 |

Source: AFRY

Next, total waste heat generation, the share of renewables in waste heat generation, and the amount already being used or which could technically reasonably be used as district heating was estimated for each installation category. The results of the waste heat analysis are summarised in the following table (Table 5).

## Table 5 – Summary of waste heat generation and potential for use

| Installation type | Capacity | Waste heat generation | Share of renewable energy of waste heat generation | Waste heat currently used as district heating | Estimate of remaining waste heat potential |
|---|---|---|---|---|---|
| Condensing power plants | >50 MW | 44 TWh | 0% | 0 TWh | 16 TWh |
| Waste incinerators | All | 1.2 TWh | 50 % | 0.5 TWh | 0.2 TWh |
| Industrial installations | >20 MW | 70 TWh | 60% | 1 TWh | 15 TWh |
| | 5–20 MW | 4 TWh | | <<1 TWh | 1 TWh |
| CHP plants | >20 MW | 4.2 TWh | 29% | 0.8 TWh | 0.8 TWh |
| | 10–20 MW | <<1 TWh | 39% | <<1 TWh | <<1 TWh |
| Renewable energy heat installations | >20 MW | 0.1 TWh | 97% | 0.1 TWh | 0.1 TWh |
| | 10–20 MW | 0.1 TWh | 99% | 0.1 TWh | 0.1 TWh |
| Data centres | >5 MW | 2 TWh | 80% | 0.2 TWh | 2 TWh |
| | 0.5–5 MW | 1 TWh | 60% | - | |
| Other installations | All | 0.5 TWh | 34% | <<1 TWh | 0.2 TWh |
| **Total** | | **ca. 127 TWh** | **36%** | **ca. 3 TWh** | **ca. 35 TWh** |

Note: Not all waste heat sources may be usable at the same time or in full, as demand for district heating in the vicinity is limited and varies by season. These constraints are not taken into account in the figures above.

Source: AFRY

The greatest additional potential for the use of waste heat is to be found in industry and condensing power plants. Industrial waste heat may be more feasible to use locally at the industrial installation than as district heating, which poses a challenge for estimating the potential for use as waste heat. Although the use of waste heat from nuclear power plants could in some cases be financially viable, there are other challenges involved, such as social and political acceptance and the design and investment needs for backup production capacity. Consequently, the cost-benefit analysis in Chapter 4 does not assume that the waste heat of condensing power plants would be used despite its potential. It is technically possible to use an amount of waste heat from the Loviisa nuclear power plant equivalent to the demand for heat. The potential heat load was estimated to be ca. 12.5 TWh. Due to the practical constraints (Chapter 3.2), the potential for use was estimated to be 6-9 TWh.

The waste heat potential for CHP, renewable energy and other boilers was seen as consisting of the heat from flue gases. The flue gas loss was estimated to amount to 10% of the boiler fuel consumption. At CHP plants, uncertainty is caused by the share of the operation in condensing-only mode, which means that extra waste heat is generated in energy production.

This waste heat share is not taken into account in the assessments. In addition, all installations have smaller sources of waste heat, but these are assumed to be small relative to the flue gas losses and difficult to utilise. Not using the waste heat potential of CHP plants may be influenced by the timing of the need for heat and the moisture content of the flue gases, for example, which depends on the fuels used.

The amount of waste heat already being used as district heating is ca. 3 TWh of a total of some 130 TWh of waste heat produced by the installation groups assessed. The potential amount that could technically be used as district heating was estimated to be ca. 35 TWh, but using the potential poses various challenges. In terms of the next ten years, the greatest waste heat potential could likely be obtained by increasing the efficiency of the existing large cogeneration bioboilers with heat recovery systems and by increasingly using the waste heat from industry for district heating. The use of waste heat could be promoted by measures such as lowering the tax on electricity consumed by heat pumps and the development of heat pump technologies.

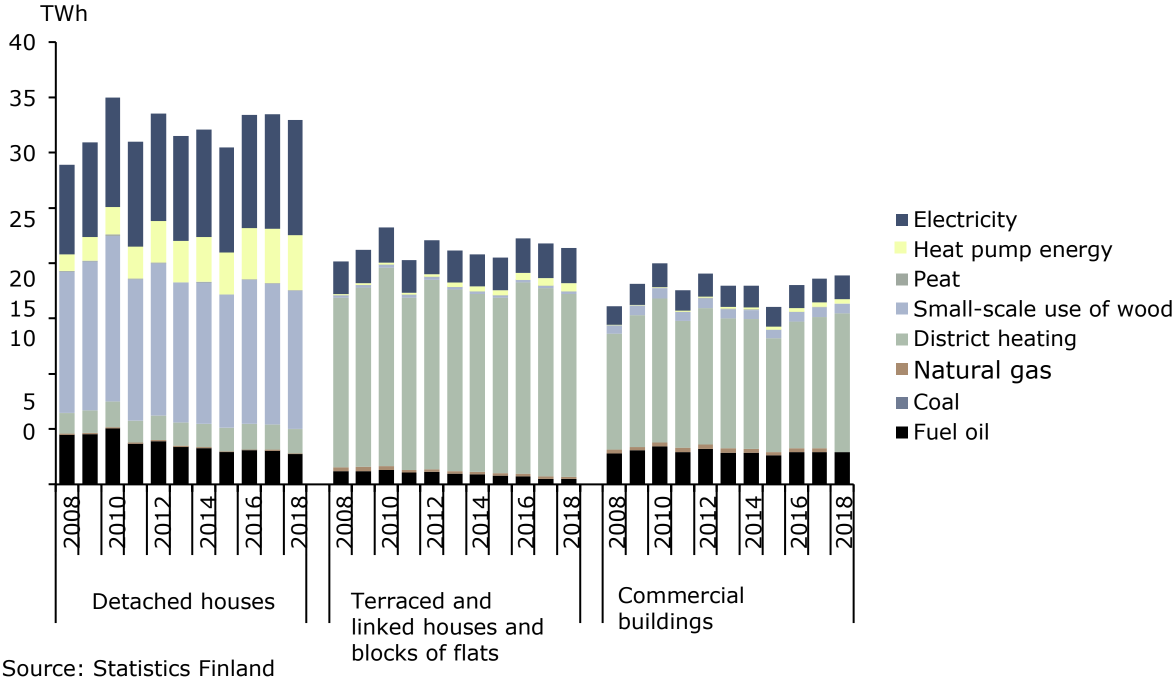
# 4. COST-BENEFIT ANALYSIS OF THE ECONOMIC POTENTIAL FOR EFFICIENT HEATING

## 4.1 Economic viability of different heating methods today

In Finland, the energy sources for heating buildings vary by building type. Figure 17 illustrates the change in energy sources used by building type from 2008 to 2018. In 2018, district heating was the most common heating energy source for terraced or linked houses, blocks of flats, service buildings and industrial properties. The most common heating energy source for detached houses, leisure-time buildings and agricultural buildings was the small-scale use of wood and electricity (including heat pumps). These building types are less commonly connected to district heating networks than, for example, service buildings and blocks of flats, which are located in built-up areas.

In detached houses, the use of heat pump energy and electricity for heating has increased since 2008, whereas the share of district heating has remained at the same annual level of ca. 2 TWh. The shares of energy sources for terraced and linked houses and blocks of flats have stayed at the same level, with district heating as the main energy source. District heating is also the most common form of energy in commercial buildings, such as service, industrial and agricultural buildings, and the shares of the energy sources have remained at the same levels. In 2018, the most common heating method in detached houses was the small-scale use of wood, followed by electricity and heat pumps. In terraced and linked houses and blocks of flats, the most common heating method is district heating, followed by electricity and heat pumps. In commercial buildings, the most common heating method is district heating, followed by fuel oil and electricity. In 2018, the most common energy source for heating was district heating, and the second most common energy source was electricity.

**Figure 17 – Energy sources for heating buildings by building type 2008–2018**




Source: Statistics Finland

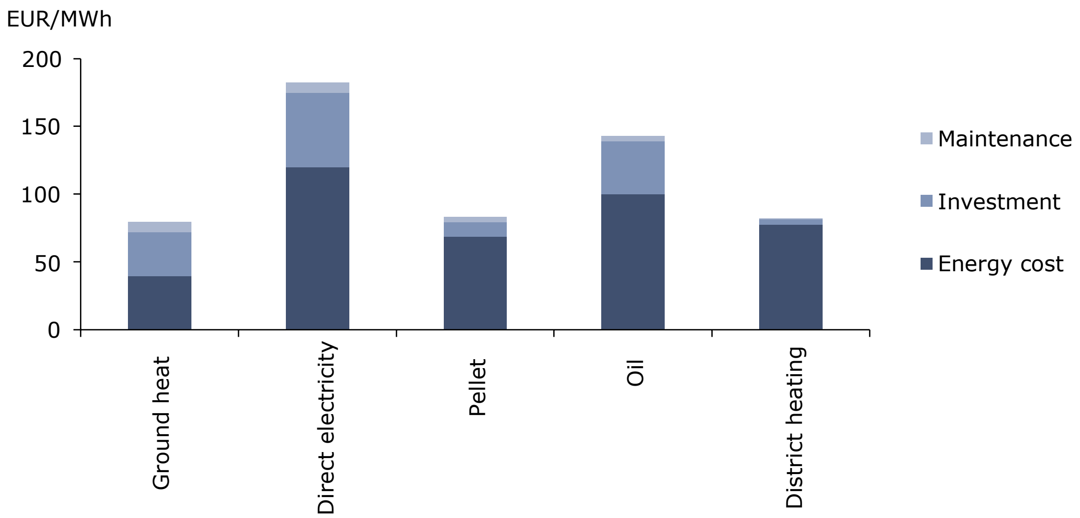
The Finnish heating market is competitive, and users of heat can freely choose between different heating methods and change their heating method at will. Factors affecting the heating solutions for buildings include:

- location of the property, distance from the existing district heating network and population density of the area (centralised heating generation is a more expensive solution in sparsely populated areas), local restrictions regarding ground energy, for example (underground structures, groundwater area etc.);
- the local price of district heating, which is strongly influenced by the price of fuels used for the production of district heating and the required emission allowances, and the level of energy taxes on the fuels;
- the end-customer price of electricity, including energy, tax and network charges, which affects the costs of building-specific ground-source heat pumps, other heat pumps and electric heating, for example;
- investment costs in property-specific heating solutions or district heating connection charges and the financing options for these investments, and
- the residents' preferences regarding factors such as technological ease of use and the use of renewable energy.

In general, the choice of heating method seems mainly to be influenced by price and the technical scope for implementing different options in a specific area. If the property requires cooling, the cost-efficiency of heat pumps may be better than that of a district heating solution. Centralised and property-specific heating systems can also be used in parallel.

A comparison of the costs of different heating methods typically employs LCOE (levelised cost of energy) calculation, where different heating methods are assigned mutually comparable production prices (EUR/MWh), including variable costs (such as fuel or electricity costs and the associated taxes) and investment costs. Figure 18 provides an example of the costs of different heating methods for a block of flats. As can be seen from the figure, a ground-source heat pump is the most cost-efficient heating solution for this example property, as the LCOE for this technology is the lowest. The cost of pellet heating and district heating is almost the same as that for a ground-source heat pump. The results cannot be generalised across Finland and for all customer types, however, as the costs used in the calculation depend on the area and building type, and costs such as network charges and district heating costs may vary a great deal.

**Figure 18 – Cost comparison of heating methods for a block of flats, EUR/MWh**




The example building in the LCOE calculation is a block of flats with an annual heating need of 469 MWh. The LCOE calculations include investment costs, operating costs and energy costs, i.e. fuel costs and electricity costs. The interest rate used is 3%.

Source: AFRY, Finnish Energy, technology suppliers

## 4.2 Basis for scenario modelling

A cost-benefit analysis was used to assess the economic potential for efficiency in heating and cooling in accordance with the guidelines of Annex VIII EED. The guidelines call for an assessment of the economic potential of heating systems, with efficiency assessed for primary energy consumption, CO2 emissions and costs by means of scenario analysis. In preparing the scenarios, the following technologies were considered:

- industrial waste heat and cold, including data centres;
- waste incineration;
- high-efficiency cogeneration;

- renewable energy sources (such as geothermal energy, solar thermal energy and biomass) other than those used for high-efficiency cogeneration:
- heat pumps;
- reducing heat and cold losses from existing district networks.

Four scenarios were established for the heating sector using technologies with the potential for increased use and considered to be relevant in Finland. The alternative scenarios vary the use of industrial waste heat, CHP plants, separate heat production, geothermal energy and property-specific heating solutions. The demand for district heating is kept the same in all the scenarios, however. Nevertheless, the increase in waste heat that can be obtained with heat storage in waste incineration has not been taken into account in the scenarios, as it was not considered feasible to do so. Nor do the scenarios assume the utilisation of the waste heat potential of condensing power plants (nuclear power). Due to the uncertainty attached to the immaturity of the technology, nuclear power with small modular reactors (SMR) is also excluded from the analysis. The overview of district heating and cooling losses is described as a separate exercise from the scenario analysis in Chapter 5.1.

### 4.2.1 Baseline scenarios for heating demand

The baseline data used for the analysis were the baseline scenarios compiled by the Ministry of Economic Affairs and Employment on heating in residential and service buildings and district heating consumption. The district heating consumption and residential and service building scenarios compiled by the Ministry of Economic Affairs and Employment include time series up to 2040, after which the development in demand was extrapolated up to 2050. The scenarios for industrial buildings and agricultural buildings were created using the demand scenarios assigned to other building types, assuming the same sort of trend. The transmission losses from the district heating network were assumed to remain constant (10%) and were added to the demand for district heating. Table 6 lists the demand scenarios, which are the same for each heating scenario.

**Table 6 – Heating scenarios for district heating and total heating demand, TWh**

| | 2018 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| **Demand for district heating** | 34.8* | 36.6* | 35.6* | 34.8* | 34.0* | 33.1* | 32.2 | 31.4 |
| Transmission loss in district heating | 3.5 | 3.7 | 3.6 | 3.5 | 3.4 | 3.3 | 3.2 | 3.1 |
| District heating production | 38.3 | 40.3 | 39.2 | 38.3 | 37.4 | 36.4 | 35.4 | 34.5 |
| **Heating demand, useful energy** | | | | | | | | |
| Residential buildings | 50.1* | 49.8* | 48.9* | 48.3* | 47.7* | 46.9* | 46.2 | 45.5 |
| Service buildings | 18.3* | 19.1* | 17.9* | 16.8* | 15.7* | 14.6* | 13.5 | 12.4 |
| Industrial properties | 10.8 | 10.8 | 10.6 | 10.5 | 10.3 | 10.2 | 10.0 | 0.9 |
| Agricultural buildings | 1.9* | 1.9 | 1.9 | 1.9 | 1.8 | 1.8 | 1.8 | 1.7 |
| **Total heating demand** | **81.2** | **81.6** | **79.3** | **77.4** | **75.6** | **73.4** | **71.4** | **69.4** |

*Data provided by the Ministry of Economic Affairs and Employment

Sources: Statistics Finland 2018, Ministry of Economic Affairs and Employment, AFRY

### 4.2.2 General assumptions regarding technologies and costs in the scenarios

In addition to the common demand scenarios, all four scenarios apply certain common assumptions related to production technology, which are described in more detail in this chapter. The differing production assumptions are described in Chapter 4.2.3.

The main changes with respect to separate heating concern oil heating and electric heating. The current Government Programme set the goal of gradually phasing out oil heating in the early 2030s[19]. It is also assumed that direct electric heating will decrease in the building stock with property-specific heating. Most of the buildings with electric heating were built after the 1970s, and they are mostly between 10 and 35 years old[20]. This means that most of the building stock with electric heating also requires or will soon require renovation, and renovation projects often involve switching the heating method from electric heating-only to methods such as heat pumps. The main differences in property-specific heating in the scenarios are the use of wood fuels, electricity and heat pumps. The use of fossil fuels in property-specific heating is the same in all the scenarios.

In district heating, the main difference is in the use of fuels. The use of coal for energy production is prohibited as from May 2029.

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[19] Government, NCEP 2019 https://ec.europa.eu/energy/sites/ener/files/documents/fi_final_necp_main_en.pdf

[20] Pöyry Management Consulting Oy, Hajautetun uusiutuvan energiantuotannon potentiaali, kannattavuus ja tulevaisuuden näkymät Suomessa (The potential, profitability and future outlook of distributed energy production in Finland), 2017

According to the current Government Programme, the use of peat as the primary energy source will end during the 2030s due to rising emission allowances, and the use of peat in energy production will be reduced by at least half by 2030[21].

Furthermore, in four heating scenarios, the following general assumptions were applied regarding production technologies:

- The trend in the price of electricity was assumed to be in accordance with the baseline scenario for the price of electricity provided by SKM to the Ministry of Economic Affairs and Employment[22]. In this scenario, the price of electricity will be around EUR 41 per MWh in the 2020s, EUR 38 per MWh in the 2030s, and EUR 42 per MWh in the 2040s. The sensitivity analysis is conducted using the high and low price scenarios in the report.
- The trend in the price of fossil fuels and emission allowances was based on the recommended scenarios published by the EU Commission in June. The price of the emission allowance is expected to rise from the level of approximately EUR 26 per CO2t to EUR 55 per $CO_2$t between 2020 and 2040. The price of coal will increase from a level of around EUR 41 per MWh to EUR 51 per MWh in the same period. The price of gas will increase from a level of around EUR 38 per MWh to EUR 56 per MWh. The relevance of the above prices for district heating production will decrease as fossil fuels are phased out.
- Based on AFRY's own estimate, the price of biomass is expected to rise to a level of EUR 25 per MWh by 2030. The analysis did not take into account the varying demand for biomass in different scenarios, which would, in fact, affect the price of biomass so that, especially in the CHP scenario, it might be higher than in the other scenarios.
- The taxation of fuels and electricity is assumed to remain at the current level[23] throughout the review period. The electricity tax on heat pumps that generate district heating is EUR 0.5 per MWh, as specified in the Government Programme [24].
- The fuel emission factors (kg $CO_2$/MWh_e and kg $CO_2$/MWh_pa) are based on Statistics Finland's figures.
- The assumed default efficiency of heat generation installations are based on Statistics Finland's published figures and AFRY's expert estimates.
- The investment and O&M costs for heat production technologies are based on AFRY's expert estimate using the average MW or MWh costs. The assumptions are presented in Annex A.

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[21] Finnish Government, Government Programme, https://valtioneuvosto.fi/marinin-hallitus/hallitusohjelma/hiilineutraali- ja-luonnon-monimuotoisuuden-turvaava-suomi

[22] SKM, Sähköntuotannon skenaariolaskelmat vuoteen 2050 (Scenario calculations for electricity production up to 2050), 22 February 2019. https://tem.fi/documents/1410877/2132100/S%C3%A4hk%C3%B6ntuotannon+skenaariolaskelmat+vuoteen+2050+%E2%80%93+selvitys+22.2.2019/8d83651e-9f66-07e5-4755-a2cb70585262/S%C3%A4hk%C3%B6ntuotannon+skenaariolaskelmat+vuoteen+2050+%E2%80%93+selvi tys+22.2.2019.pdf

[23] Tax Administration, Tax rates on electricity and certain fuels as of 1 January 2019. https://www.vero.fi/yritykset-ja-yhteisot/tietoa-yritysverotuksesta/valmisteverotus/sahko_ja_eraat_polttoaineet/sahkon_ja_eraiden_polttoaineiden_verota/

[24] Finnish Government, Government Programme, https://valtioneuvosto.fi/marinin-hallitus/hallitusohjelma/hiilineutraali- ja-luonnon-monimuotoisuuden-turvaava-suomi

### 4.2.3 Heat production scenarios

The reference point for heat production scenarios is the current situation and currently operational heat generation installations. The changes in heat production technology are made through the investments to replace outgoing capacity so that the demand for heating is fulfilled. The technology to replace the outgoing capacity varies in the four scenarios. The scenarios also take into account CHP electricity generation.

*Scenario 1: CHP*

In the first scenario, the outgoing capacity reaching the end of its technical service life is replaced mainly with equivalent capacity; for example, CHP capacity is replaced with new CHP capacity. The new CHP and separate heat generation capacity uses biomass for fuel. In this scenario, the total CHP capacity will not fall as sharply as in the other scenarios, but CHP capacity will nevertheless decrease due to factors such as decreasing demand for heating. In this scenario, the amount of CHP electricity generation is also the largest.

*Scenario 2: HOB*

In the second scenario, CHP plants reaching the end of their technical service lives, including CHP plants using renewable fuels, are replaced with separate heat generation, mainly with boilers using biomass (HOB = heat only boilers). In this scenario, CHP production decreases more than in the CHP scenario. The reduction in CHP capacity is modelled to take into account the decommissioning of installations based on their service lives and existing political goals, such as the phasing out of coal, which may lead to CHP plants being decommissioned before the end of their technical service lives.

*Scenario 3: Geothermal heat*

In the third scenario, the use of geothermal energy is maximised by increasing geothermal heat generation in district heating and increasing property-specific heat pump generation. The capacity level of district heating CHP plants is similar to that in the HOB scenario. There are still uncertainties attached to the techno-economical potential of geothermal heat generation in Finland, but the scenario assumes that it will be ripe for the market by 2035.

*Scenario 4: Waste heat*

In the fourth scenario, the use of waste heat is increased significantly with reference to the potential described in Chapter 3 above. The capacity level of CHP plants is similar to that in the HOB scenario. The increase in the use of waste heat will take place particularly through the utilisation of industrial waste heat and, in district heating, by means of heat pumps.

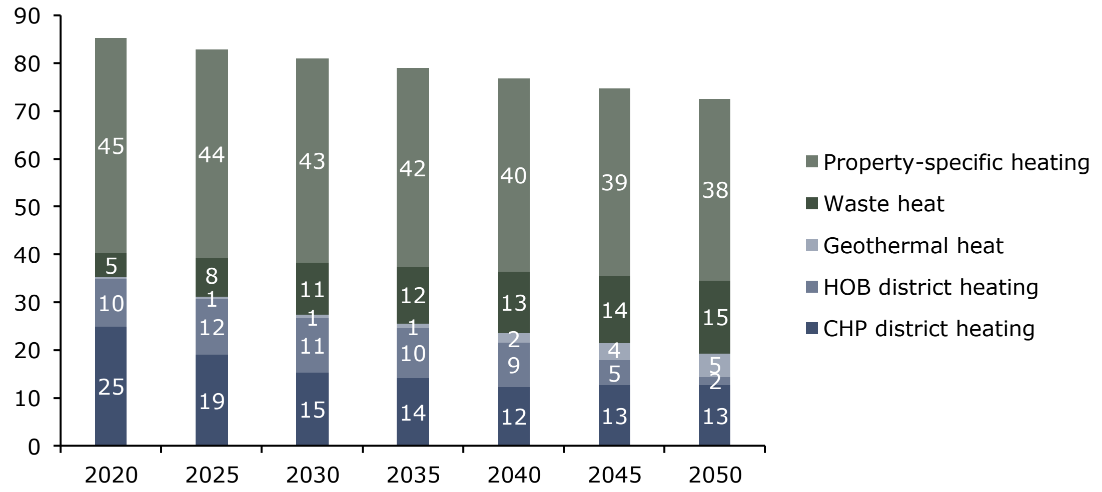
## 4.3 Results of the scenario modelling

### *4.3.1 Heat generation*

*Scenario 1: CHP*

Figure 19 shows the heat generation distribution between district heating generation and property-specific heating in the CHP scenario. Table 7 illustrates the heat and electricity generation in the CHP scenario in more detail.

**Figure 19 – Heat generation in the CHP scenario, TWh**




Source: AFRY

**Table 7 – Breakdown of energy generation in the CHP scenario, TWh**

| **Heat generation (TWh)** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|
| **District heating production*** | **40.3** | **39.2** | **38.2** | **37.4** | **36.4** | **35.4** | **34.5** |
| **CHP district heating** | **24.9** | **19.0** | **15.2** | **14.2** | **12.3** | **12.8** | **12.7** |
| Coal | 7.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 3.3 | 2.7 | 2.1 | 1.8 | 0.4 | 0.4 | 0.0 |
| Peat | 4.5 | 3.4 | 2.2 | 1.1 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 0.9 |
| Wood fuels and other renewable fuels | 8.5 | 9.0 | 9.6 | 10.1 | 10.6 | 11.1 | 11.7 |
| Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Separate heat and power generation** | **10.3** | **11.1** | **12.2** | **11.4** | **11.4** | **8.7** | **6.6** |
| Coal | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.3 | 0.0 |
| Natural gas | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0.8 | 0.0 |
| Peat | 1.2 | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Wood fuels and other renewable fuels | 5.7 | 7.8 | 8.0 | 7.3 | 6.5 | 3.5 | 1.1 |
| Other | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Geothermal heat | 0.2 | 0.5 | 0.8 | 1.0 | 2.0 | 3.5 | 5.0 |
| **Waste heat** | **5.1** | **8.0** | **10.8** | **11.8** | **12.8** | **14.0** | **15.2** |
| **CHP electricity generation** | **14.7** | **10.9** | **8.4** | **7.6** | **6.0** | **6.2** | **6.0** |
| **Property-specific heating**** | **45.0** | **43.7** | **42.6** | **41.6** | **40.3** | **39.2** | **38.0** |
| Coal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 6.3 | 4.2 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Peat | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wood fuels and other renewable fuels | 9.5 | 9.0 | 8.6 | 8.2 | 7.8 | 7.3 | 6.9 |
| Other | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Heat pumps | 14.0 | 16.2 | 18.7 | 21.2 | 21.0 | 20.9 | 20.8 |
| Electricity | 14.1 | 13.5 | 12.8 | 12.2 | 11.6 | 10.9 | 10.3 |

*District heating generation includes district heating transmission losses

**Property-specific heating does not include transmission losses

Source: Statistics Finland, AFRY

The baseline data for Other fossil fuels and Other are based on Statistics Finland's definitions. Other fossil fuels include blast furnace and coke gas, coke, plastic and hazardous waste as well as the fossil part of mixed fuels. Other energy sources include hydrogen, sulphur, the electricity used in electric boilers and heat pumps, and industrial reaction and secondary heat. The use of these energy sources for heat generation is thought to be unchanging, except that it is assumed that the use of fossil fuels will be phased out in district heating generation as the installations reach the end of their maximum service life.

Waste heat was modelled in every scenario according to its sources. Table 8 describes the waste heat sources in the cost-benefit analysis. The estimates for industry and data centres are based on the amounts and potential for future use estimated in previous sections in this report. The number of flue gas scrubbers takes into account the number of flue gas scrubbers in existing installations and the future decommissioning of installations. The decommissioning of installations is based on their estimated average service life, which is 40 years.

The growth potential estimate is based on Finnish Energy's statistics and AFRY's own database of boilers for assessing the installations where flue gas scrubbers could be installed. All scenarios used the same estimate for developments in the use of flue gas scrubbers up to 2050. The usable heat from the flue gas heat recovery systems is calculated separately for district heating production, and is thus not included in the CHP or separate heat generation figures.

**Table 8 – Waste heat sources in the cost-benefit analysis**

| | |
|---|---|
| Industry | Unused waste heat of industrial installations. The maximum technical potential of unused industrial waste heat is estimated to be 16 TWh by 2050, of which 6 TWh can be relatively easily achieved. In a maximum scenario, the potential is estimated to be 10 TWh. This category covers industrial areas such as Kilpilahti. |
| Flue gas scrubbers | Waste heat in the flue gases of installations. The estimated potential for flue gas scrubbers is 1.9 TWh in 2020, increasing to a level of 2.8 TWh by 2030. By 2050, the usable amount is expected to fall back to a level of 1.4 TWh. The heat recovery systems of new energy generation installations and industrial installations can in other contexts be classified as improved energy efficiency in the installations, but in this report, they are classified as waste heat. |
| Heat pumps | Heat pumps not included in other waste heat categories, such as heat pumps for utilising sewage waters. The use of heat obtained from sewage waters is classified as a source of waste heat, although the Renewable Energy Directive defines it is a renewable heat source. |
| Data centres | Includes estimates for large and medium-sized data centres. The potential for waste heat generation from data centres is estimated to be around 5 TWh, most of which could technically be used for heat. |

Source: AFRY

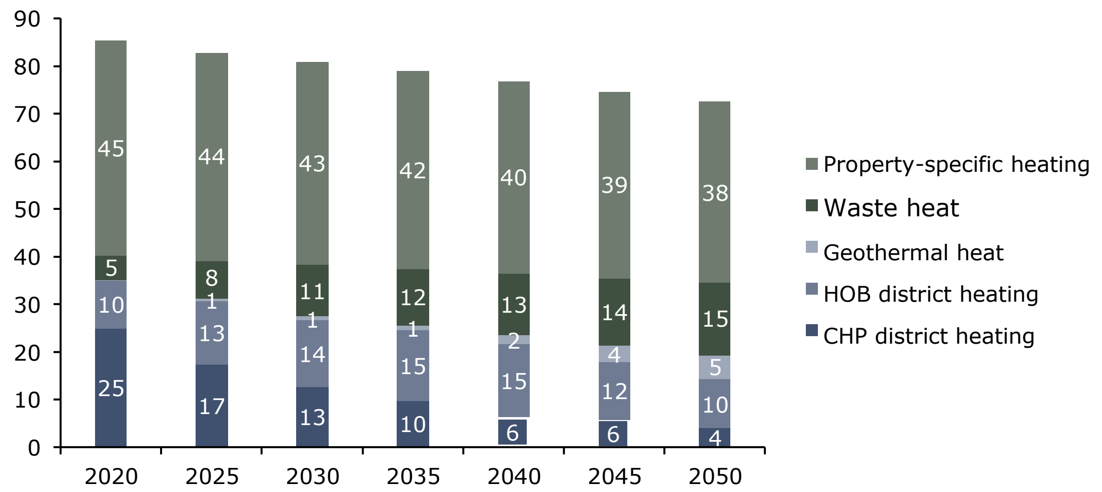
In the CHP scenarios, as in the other scenarios, the use of fossil fuels in heat generation is predicted to decrease in both CHP production and property-specific heating. Correspondingly, the use of wood fuels and other renewables for district heating production will increase, but in property-specific heating, it is predicted that the small-scale use of wood will decrease[25]. The small-scale use of wood for heating buildings has already decreased during the last ten years. For property-specific heating, the prediction is that the use of heat pumps will increase significantly and the use of electricity for heating will decrease by 2050.

### *Scenario 2: HOB*

Figure 20 depicts an HOB-scenario, with the most wood fuel-based separate heat generation compared to the other scenarios. Table 9 illustrates the heat and electricity generation in the HOB scenario in more detail.

[25] Statistics Finland, Rakennusten lämmityksen energialähteet rakennustyypeittäin (Energy sources for heating buildings by building type) https://pxhopea2.stat.fi/sahkoiset_julkaisut/energia2019/html/suom0006.htm

## Figure 20 – Heat generation in the HOB scenario, TWh




Source: AFRY

## Table 9 – Breakdown of energy generation in the HOB scenario, TWh

| **Heat generation (TWh)** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|
| **District heating production*** | **40.3** | **39.2** | **38.2** | **37.4** | **36.4** | **35.4** | **34.5** |
| **CHP district heating** | **24.9** | **17.4** | **12.7** | **9.7** | **6.4** | **5.8** | **4.1** |
| Coal | 7.1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 3.3 | 2.7 | 2.1 | 1.8 | 0.4 | 0.4 | 0.0 |
| Peat | 4.5 | 3.4 | 2.2 | 1.1 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 0.9 |
| Wood fuels and other renewable fuels | 8.5 | 7.5 | 7.0 | 5.6 | 4.8 | 4.1 | 3.0 |
| Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Separate heat and power generation** | **10.3** | **13.8** | **14.8** | **15.9** | **17.2** | **15.7** | **15.2** |
| Coal | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.3 | 0.0 |
| Natural gas | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0.8 | 0.0 |
| Peat | 1.2 | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Wood fuels and other renewable fuels | 5.7 | 9.4 | 10.6 | 11.8 | 12.4 | 10.5 | 9.7 |
| Other | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Geothermal heat | 0.2 | 0.5 | 0.8 | 1.0 | 2.0 | 3.5 | 5.0 |
| **Waste heat** | **5.1** | **8.0** | **10.8** | **11.8** | **12.8** | **14.0** | **15.2** |
| | | | | | | | |
| **CHP electricity generation** | **14.7** | **10.1** | **7.2** | **5.5** | **3.2** | **2.9** | **2.0** |
| | | | | | | | |
| **Property-specific heating**** | **45.0** | **43.7** | **42.6** | **41.6** | **40.3** | **39.2** | **38.0** |
| Coal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 6.3 | 4.2 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Peat | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wood fuels and other renewable fuels | 9.5 | 9.0 | 8.6 | 8.2 | 7.8 | 7.3 | 6.9 |
| Other | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Heat pumps | 14.0 | 16.2 | 18.7 | 21.2 | 21.0 | 20.9 | 20.8 |
| Electricity | 14.1 | 13.5 | 12.8 | 12.2 | 11.6 | 10.9 | 10.3 |

*District heating generation includes district heating transmission losses

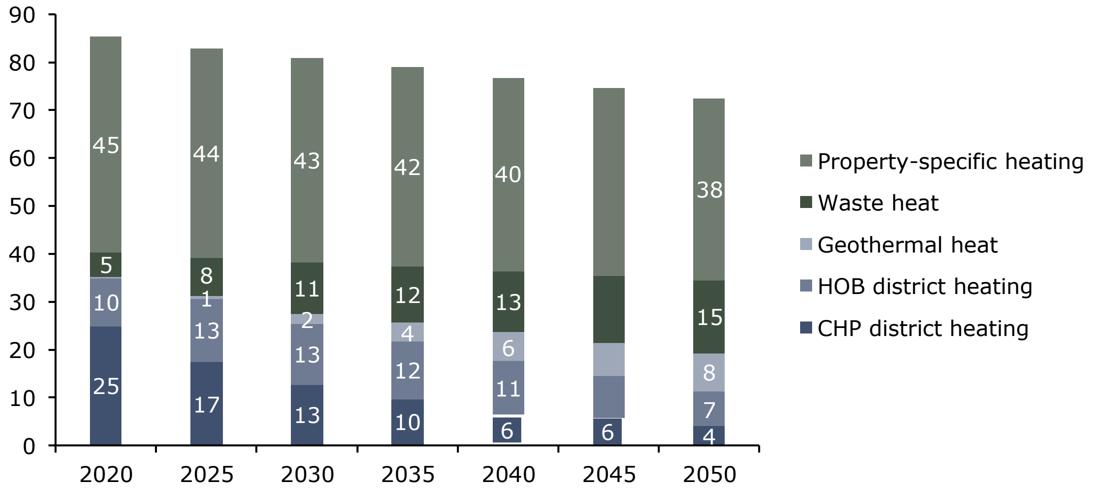
**Property-specific heating does not include transmission losses

Source: Statistics Finland, AFRY

## *Scenario 3: Geothermal heat*

Figure 21 illustrates a geothermal heat scenario where an increase in geothermal heat and property-specific ground heat reduces the fuel need for separate generation. Table 10 illustrates the heat and electricity generation in the geothermal scenario in more detail.

**Figure 21 – Heat generation in the geothermal heat scenario, TWh**




Source: AFRY

**Table 10 - Breakdown of energy generation in geothermal heating scenario, TWh**

| **Heat generation (TWh)** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
|---|---|---|---|---|---|---|---|
| **District heating production*** | **40.3** | **39.2** | **38.2** | **37.4** | **36.4** | **35.4** | **34.5** |
| **CHP district heating** | **24.9** | **18.5** | **12.7** | **9.7** | **6.4** | **5.8** | **4.1** |
| Coal | 7.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 3.3 | 2.7 | 2.1 | 1.8 | 0.4 | 0.4 | 0.0 |
| Peat | 4.5 | 3.4 | 2.2 | 1.1 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 0.9 |
| Wood fuels and other renewable fuels | 8.5 | 7.5 | 7.0 | 5.6 | 4.8 | 4.1 | 3.0 |
| Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Separate heat and power generation** | **10.3** | **13.8** | **14.8** | **15.9** | **17.2** | **15.7** | **15.2** |
| Coal | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.3 | 0.0 |
| Natural gas | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0.8 | 0.0 |
| Peat | 1.2 | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Wood fuels and other renewable fuels | 5.7 | 9.4 | 9.4 | 8.8 | 8.4 | 7.0 | 6.7 |
| Other | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Geothermal heat | 0.2 | 0.5 | 2.0 | 4.0 | 6.0 | 7.0 | 8.0 |
| **Waste heat** | **5.1** | **8.0** | **10.8** | **11.8** | **12.8** | **14.0** | **15.2** |
| **CHP electricity generation** | **14.7** | **10.1** | **7.2** | **5.5** | **3.2** | **2.9** | **2.0** |
| **Property-specific heating**** | **45.0** | **43.7** | **42.6** | **41.6** | **40.3** | **39.2** | **38.0** |
| Coal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 6.3 | 4.2 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Peat | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wood fuels and other renewable fuels | 9.2 | 8.5 | 7.8 | 7.1 | 6.3 | 5.6 | 4.9 |
| Other | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Heat pumps | 14.2 | 16.7 | 19.5 | 22.3 | 22.4 | 22.6 | 22.8 |
| Electricity | 14.1 | 13.5 | 12.8 | 12.2 | 11.6 | 10.9 | 10.3 |

*District heating generation includes district heating transmission losses

**Property-specific heating does not include transmission losses

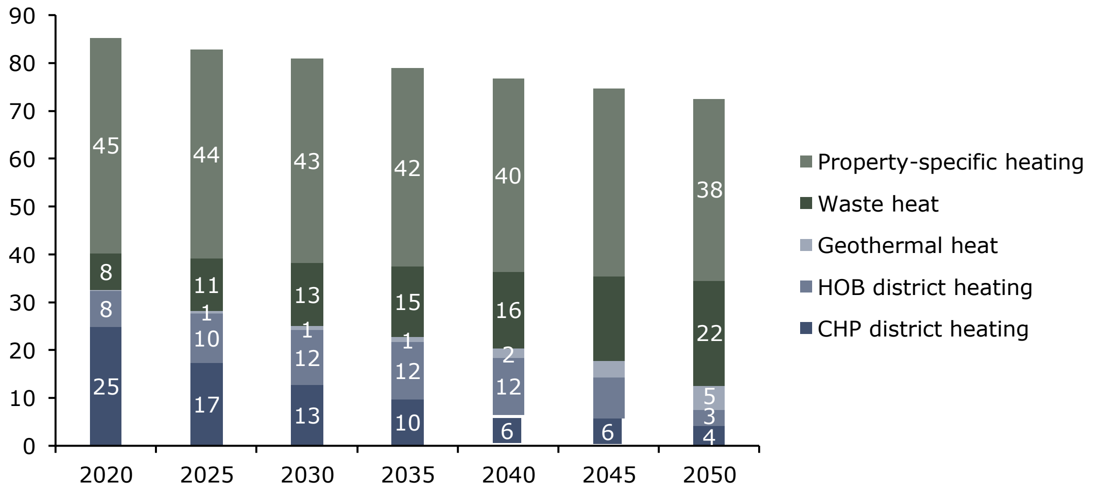
Source: Statistics Finland, AFRY

In the geothermal scenario, the production of geothermal heat has been increased compared to the other scenarios. The scenario takes into account the potential of both medium-depth and deep geothermal wells. Medium-depth geothermal wells are 1–4 kilometres deep, and deep wells are 6–8 kilometres deep. Geothermal energy can be used in district heating networks, but the total potential for geothermal energy and the technology costs are uncertain. In the geothermal heat scenario, it is assumed that the amount of geothermal energy in district heating production will rise to a level of 4 TWh by 2035 and a level of 8 TWh by 2050. In the other scenarios, the generation potential is expected to be lower, reaching a level of 5 TWh by 2050. Half of the geothermal heat is expected to be obtained from deep wells with a higher COP heat coefficient and half from medium-depth wells. In this scenario, the use of heat pumps in property-specific heating has also been increased more than in the other scenarios.

### *Scenario 4: Waste heat*

Figure 22 depicts a waste heat scenario in which the use of waste heat will grow the most compared to the other scenarios, with a simultaneous reduction in the amount of separate production based on fuels. Table 11 illustrates the heat and electricity generation in the waste heat scenario in more detail.

**Figure 22 – Heat generation in the waste heat scenario, TWh**




Source: AFRY

**Table 11 - Breakdown of energy generation in the waste heat scenario, TWh**

| Heat generation (TWh) | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| **District heating production*** | **40.3** | **39.2** | **38.2** | **37.4** | **36.4** | **35.4** | **34.5** |
| **CHP district heating** | **24.9** | **17.4** | **12.7** | **9.7** | **6.4** | **5.8** | **4.1** |
| Coal | 7.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 3.3 | 2.7 | 2.1 | 1.8 | 0.4 | 0.4 | 0.0 |
| Peat | 4.5 | 3.4 | 2.2 | 1.1 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 0.9 |
| Wood fuels and other renewable fuels | 8.5 | 7.5 | 7.0 | 5.6 | 4.8 | 4.1 | 3.0 |
| Other | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Separate heat and power generation** | **7.7** | **10.8** | **12.3** | **13.1** | **14.0** | **12.0** | **8.4** |
| Coal | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.3 | 0.0 |
| Natural gas | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0.8 | 0.0 |
| Peat | 1.2 | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Wood fuels and other renewable fuels | 3.1 | 6.4 | 8.2 | 8.9 | 9.1 | 6.8 | 2.9 |
| Other | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Geothermal heat | 0.2 | 0.5 | 0.8 | 1.0 | 2.0 | 3.5 | 5.0 |
| **Waste heat** | **7.7** | **11.0** | **13.3** | **14.6** | **16.0** | **17.7** | **22.0** |
| **CHP electricity generation** | **14.7** | **10.1** | **7.2** | **5.5** | **3.2** | **2.9** | **2.0** |
| **Property-specific heating**** | **45.0** | **43.7** | **42.6** | **41.6** | **40.3** | **39.2** | **38.0** |
| Coal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oil | 6.3 | 4.2 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Natural gas | 0.9 | 0.6 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Peat | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other fossil fuels | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wood fuels and other renewable fuels | 9.5 | 9.0 | 8.6 | 8.2 | 7.8 | 7.3 | 6.9 |
| Other | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Heat pumps | 14.0 | 16.2 | 18.7 | 21.2 | 21.0 | 20.9 | 20.8 |
| Electricity | 14.1 | 13.5 | 12.8 | 12.2 | 11.6 | 10.9 | 10.3 |

*District heating generation includes district heating transmission losses

**Property-specific heating does not include transmission

losses Source: Statistics Finland, AFRY

In the CHP, HOB and geothermal heat scenarios, the use of waste heat increases clearly, but in the waste heat scenario, the use of waste heat was further increased for industry, data centres and heat pumps.

### *4.3.2 The impact of the scenarios on emissions*

The energy production emissions in the scenarios were calculated using emission factors, and the analysis only takes into account CO2 emission factors. The differences between the scenarios in the use of fuels arise from the differences between wood fuels and other renewable CHP plants and separate generation installations, as well as differences in waste heat, electric heating and heat pumps. The emission factors of wood fuels and other renewables, as well as the emission factor of electricity, are assumed to be zero. Emissions decrease in all scenarios by 2050, as the consumption of fossil fuels will decrease in heat generation. Therefore, there are no differences between the CO2 emissions in the scenarios. Table 12 shows the total emissions for all scenarios.

**Table 12 – $CO_2$ emissions for total heat generation in the scenarios**

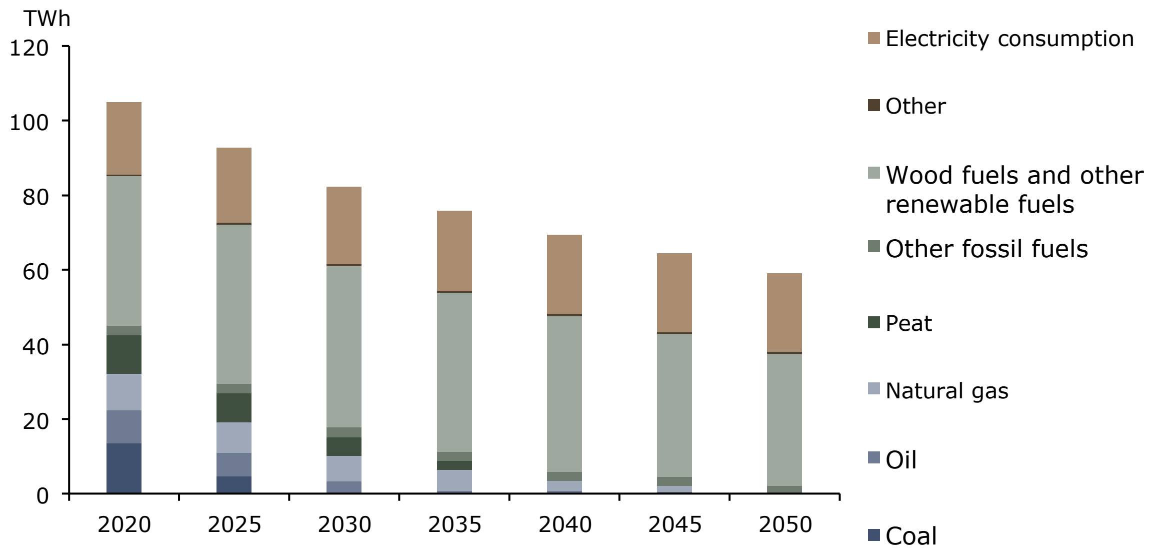
| Total annual heating emissions (million kg $CO_2$) | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| Scenarios 1-4 | 13 400 | 8 400 | 4 800 | 2 800 | 1 300 | 1 000 | 500 |

Source: AFRY

### 4.3.3 *Impact on the use of primary energy*

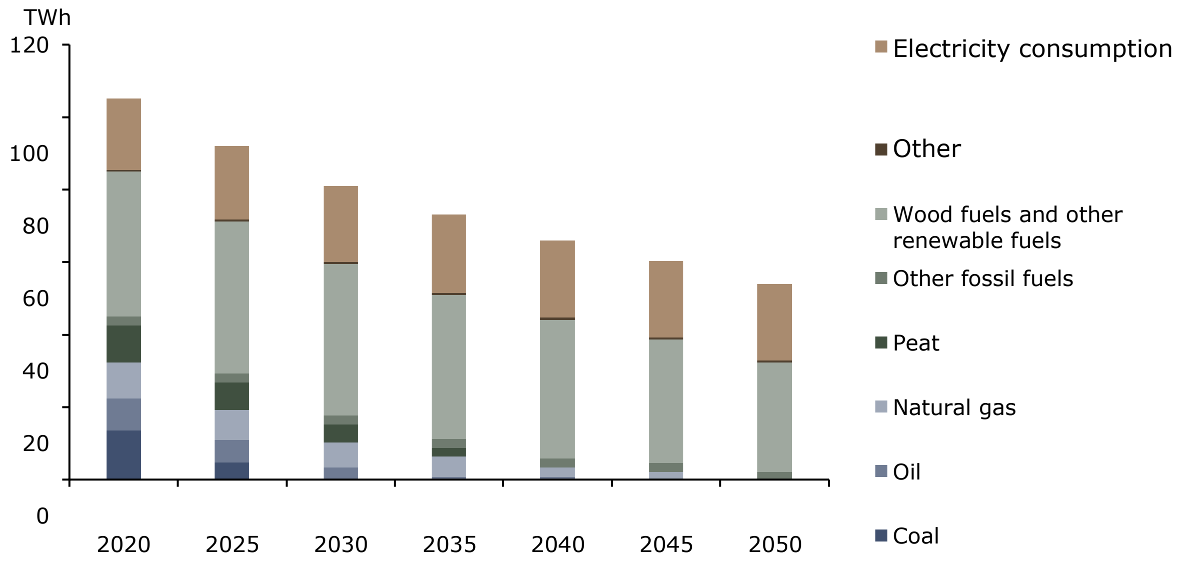
The use of primary energy is divided into fuel consumption and electricity consumption. CHP production, separate production and property-specific heating use fuels. Electricity is used in geothermal heat pumps and waste heat generation as well as in property-specific heat pumps and electric heating. However, the results of the cost-benefit analysis do not provide an overall picture of the use of primary energy in electricity production. The results do not take into account how much primary energy is used for other electricity production that is not in connection with CHP plants. The fuel consumption of CHP production in electricity generation is taken into account in total fuel consumption. Figure 23, Figure 24, Figure 25 and Figure 26 present the fuel consumption in the scenarios for different fuels and electricity consumption.

**Figure 23 – Fuel and electricity consumption in the CHP scenario, TWh**



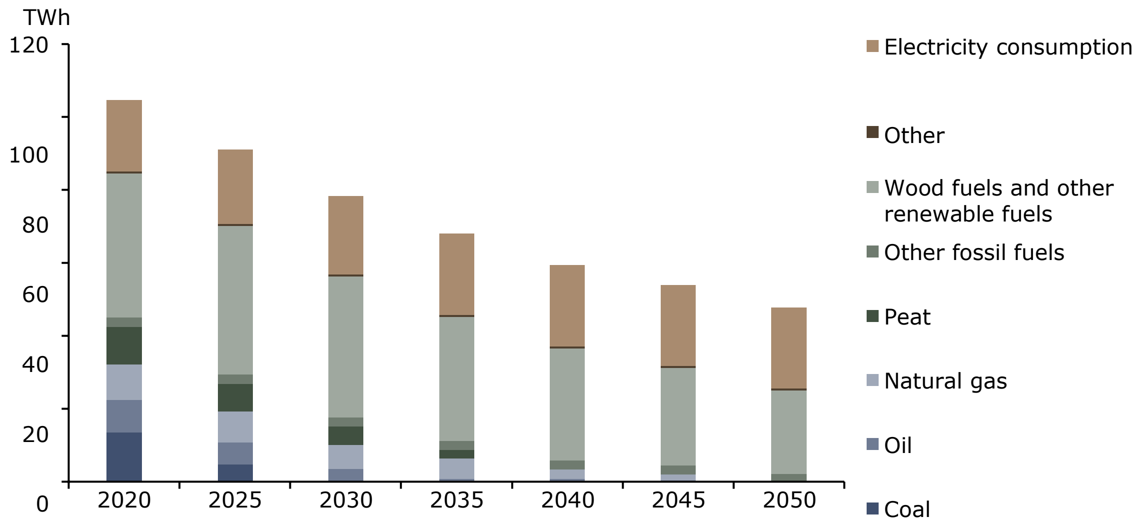

Source: AFRY

## Figure 24 – Fuel and electricity consumption in the HOB scenario, TWh



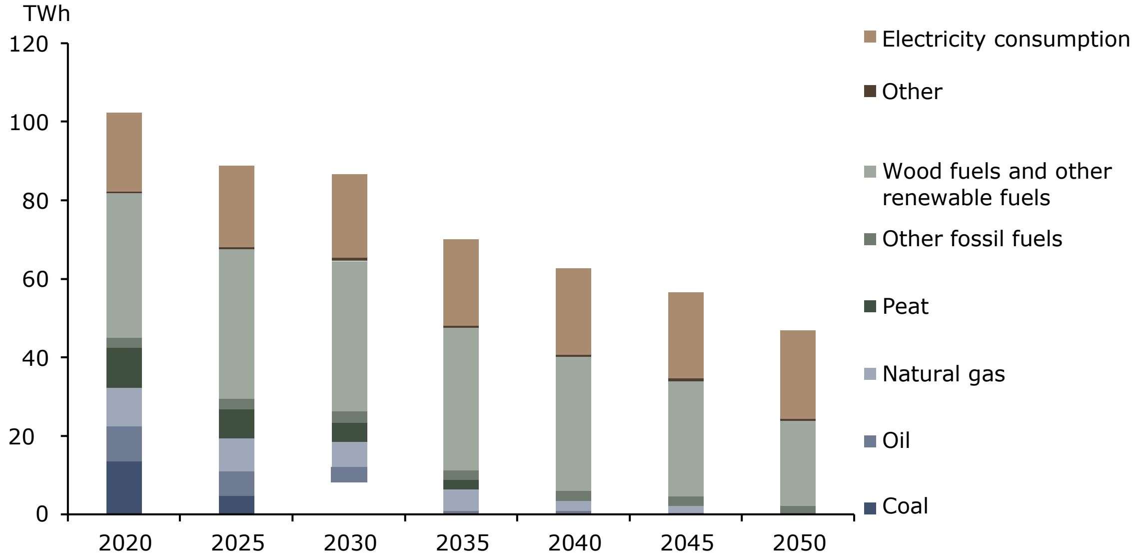

Source: AFRY

## Figure 25 – Fuel and electricity consumption in the geothermal heat scenario, TWh




Source: AFRY

**Figure 26 – Fuel and electricity consumption in the waste heat scenario, TWh**




Source: AFRY

The waste heat scenario indicates the lowest total energy consumption while the CHP scenario indicates the highest. The total energy consumption of waste heat is the lowest because the large-scale use of waste heat reduces the production of district heating and separate heat, resulting in the lowest fuel consumption compared to the other scenarios. The CHP scenario indicated the greatest fuel consumption due to the higher fuel consumption required for CHP heat generation and electricity generation compared to the other scenarios.

Table 13 shows the electricity generation and consumption in the scenarios. The electricity is generated by CHP plants. Electricity generation is the highest in the CHP scenario, as the CHP capacity is the largest. In other scenarios, electricity generation is the same, as CHP capacity decreases equally in these three scenarios. By 2050, electricity generation is the greatest in the waste heat scenario, which is explained by the exploitation of the maximum potential of waste heat. As regards total electricity consumption, the geothermal scenario comes very close to the waste heat scenario.

**Table 13 – Electricity generation and consumption in the scenarios, TWh**

| Electricity generation and consumption (TWh) | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| **CHP electricity generation** | | | | | | | |
| CHP | 14.7 | 10.9 | 8.4 | 7.6 | 6.0 | 6.2 | 6.0 |
| HOB | 14.7 | 10.1 | 7.2 | 5.5 | 3.2 | 2.9 | 2.0 |
| Geothermal heat | 14.7 | 10.1 | 7.2 | 5.5 | 3.2 | 2.9 | 2.0 |
| Waste heat | 14.7 | 10.1 | 7.2 | 5.5 | 3.2 | 2.9 | 2.0 |
| **Electricity consumption** | | | | | | | |
| CHP | 19.5 | 20.1 | 20.8 | 21.4 | 21.2 | 21.1 | 20.9 |
| HOB | 19.5 | 20.1 | 20.8 | 21.4 | 21.2 | 21.1 | 20.9 |
| Geothermal heat | 19.6 | 20.3 | 21.3 | 22.3 | 22.3 | 22.2 | 22.1 |
| Waste heat | 20.0 | 20.7 | 21.4 | 22.0 | 21.9 | 21.9 | 22.4 |

Source: AFRY

### *4.3.4 Impact on the share of renewable energy*

The share of renewable energy was calculated from the consumption of fuels used for heating in this scenario. The share of renewable energy is not defined for electricity consumption. Table 14 depicts the annual renewable energy shares. According to the weighted average in total fuel consumption, the share of renewable energy is the highest in scenarios 1 and 2. The % shares in the table cannot be directly used to calculate the average for the renewable energy share in the scenario, as the consumption of primary energy varies by scenario and year.

**Table 14 – Share of renewable energy of heating in the different scenarios**

| Annual renewable energy share of heating | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| CHP | 59% | 69% | 78% | 83% | 87% | 88% | 93% |
| HOB | 59% | 69% | 78% | 82% | 86% | 87% | 92% |
| Geothermal heat | 58% | 69% | 77% | 80% | 83% | 84% | 90% |
| Waste heat | 57% | 67% | 77% | 81% | 84% | 85% | 89% |

Source: AFRY

## 4.4 Cost-effectiveness of, and economic potential for, heating systems

This section reviews the economic potential for the scenarios. Annex VIII EED states that a cost-benefit analysis must be carried out to assess the welfare change attributable to an investment decision relating to efficient heating and cooling technology.

The cost-benefit analysis is an analytical tool for assessing the costs and benefits of an investment to support decision-making[26].

### 4.4.1 Approach

According to Annex VIII EED, the cost-benefit analysis must include an economic analysis that takes into consideration socio-economic and environmental factors, and a financial analysis performed to assess projects from the investors' point of view. Both economic and financial analyses must use the net present value as a criterion for the assessment. The analysis must also include a sensitivity analysis to assess the impact of variable factors on the economic potential.

*Economic analysis*

The economic analysis takes more account of the impact of the investment on national welfare than the financial analysis. National impacts are often difficult to value, as the impacts may not necessarily be associated with a price or monetary value. For this reason, the economic analysis often uses shadow prices or calculation prices that differ from financial values. The most significant external impact on society in the scenarios is CO2 emissions; these, however, are the same in every scenario, making any comparison between the scenarios with respect to emissions unnecessary. In a cost-benefit analysis, therefore, it is reasonable to carry out the economic analysis by comparing the impact on the national economy in each scenario qualitatively. An assessment of aspects such as health and safety considerations as well as labour market effects in accordance with Anne VIII EED were excluded from the scope of this overview.

*Financial analysis*

In line with the Commission recommendation, the financial analysis included in the cost-benefit analysis of heating scenarios takes into account the following benefits and costs:

Benefits

- revenues from selling heating and electricity / value of the output to the consumer, which is calculated using average district heating prices and electricity price forecasts

Costs

- capital costs of plants
- fuel costs
- electricity and electricity transmission costs
- variable and fixed operating costs
- taxes
- emission allowances

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[26] Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014–2020. European Commission, Directorate-General for Regional and Urban policy, 2014. ISBN 978-92-79-34796-2. https://ec.europa.eu/inea/sites/inea/files/cba_guide_cohesion_policy

The financial analysis is carried out for each heating scenario as a system-level cash flow calculation, which is used to calculate the net present value for the scenarios. Net present value calculation is typically used to assess the profitability of investments and involves discounting current and future costs and revenue streams to their present value. If the net present value of an investment is positive, the investment is profitable. Net present value calculation is not the most suitable method to examine a nation-wide heating system, as it is challenging to determine the revenue stream or monetary value of heating. Therefore, an artificial positive cash flow has been set for heating in all of Finland in the analysis. This cash flow is standardised in all scenarios, as the benefit or value of heating is likely to be the same in all scenarios. Because the benefit of the heating system is artificially determined, the absolute net present value is not relevant for the analysis, but it can be used to compare the scenarios.

The starting point for the net present value calculation is the heating demand and production in the scenarios described above using different generation technologies. The baseline for the capacity required for heat generation is the current situation, and additional investments will be made after the end of the installations' technical service lives. The installation losses are based on the construction year data in AFRY's database of boilers, and the assumed service life of the installations is 40 years. The prohibition on the use of coal by 2029, halving the use of peat by 2030, and phasing out the use of peat after 2035 are implemented through conversion investments (10%) and renewal investments (90%). The distribution is based on the assumption that it is not worthwhile to carry out conversions of old installations, but in newer installations, conversion will be less expensive than investing in replacements.

The required replacement investment capacity is derived from the production energy in the scenarios based on peak operating times. Production methods that occasionally need backup capacity are expected to receive investment in backup capacity in the calculations. With respect to waste heat, it is expected that the need for backup capacity will grow with the production methods due to the fluctuation of availability or dependence on industrial production, for example. Flexible electricity generation is needed in the geothermal heat scenario, as the power coefficient of ground-source heat pumps decreases in cold weather, when the need for heating is the greatest. In such situations, ground-source heat pumps switch to using electric resistors. The investments made in the electricity system were excluded from the calculation.

The costs of the scenarios are divided into two types: capital costs and operating costs. Capital costs were calculated using replacement investment capacity by production technology based on AFRY's cost estimates. Operating costs include the price of fuels used for heating and fuel taxes, the network charge of natural gas based on the estimated network charge of an installation connected to the main grid, the total price of electricity, including the market price, the average network charge and electricity taxes in tax brackets I and II, the emission allowance price, and the average installation operating costs. The fuel costs and tax values applied are listed in section 4.2.2. The cost assumptions related to investments and operation are listed in Annex A.

In the net present value calculation, investment costs are modelled to incur every five years for computational reasons, although, in reality, investments may not follow the modelled schedules. The negative and positive cash flows reflecting operating costs and the benefit of heating are calculated on a yearly basis. Net present value is calculated for each scenario using a real interest rate of 3% in accordance with the EED guidelines.

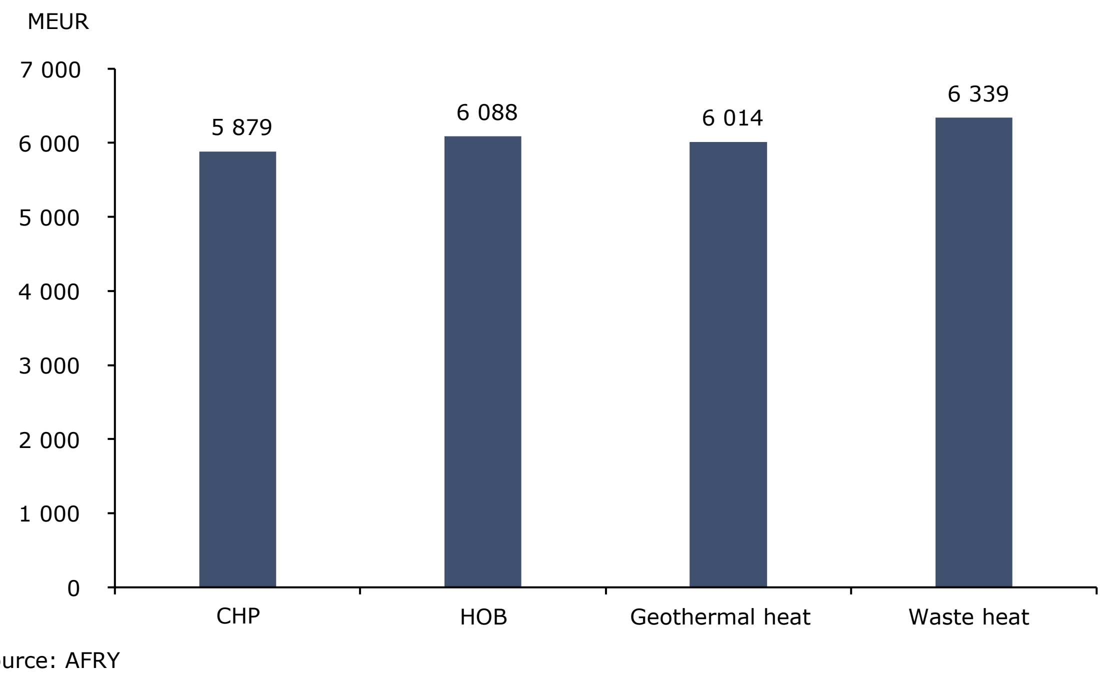
The positive cash flow required in the net present value calculation should reflect the overall national benefit gained from the heating system. In this analysis, the revenue flow from heating includes revenue from heating and the value of electricity from district heating CHP plant production. The revenue from heating is calculated from the demand for district heating using average prices. The chosen revenue flow from the heating system does not reflect the actual positive cash flows relating to Finland's heating system or the value of heating; in reality, different customers pay different charges depending on the location, heating technology and the time of year. The value of electricity from CHP production is calculated as the product of the total production volume and the electricity price scenario.

### 4.4.2 Results of the cost-benefit analysis

*Net present values and total investments*

Figure 27 shows the net present values for the scenarios. The highest net present value occurs in the waste heat scenario, where the use of waste heat is maximised. The CHP scenario has the lowest net present value, which means that it is the least profitable based on the assumptions used. The HOB scenario has the second-highest net present value, with a net present value higher than the CHP and geothermal heat scenario.

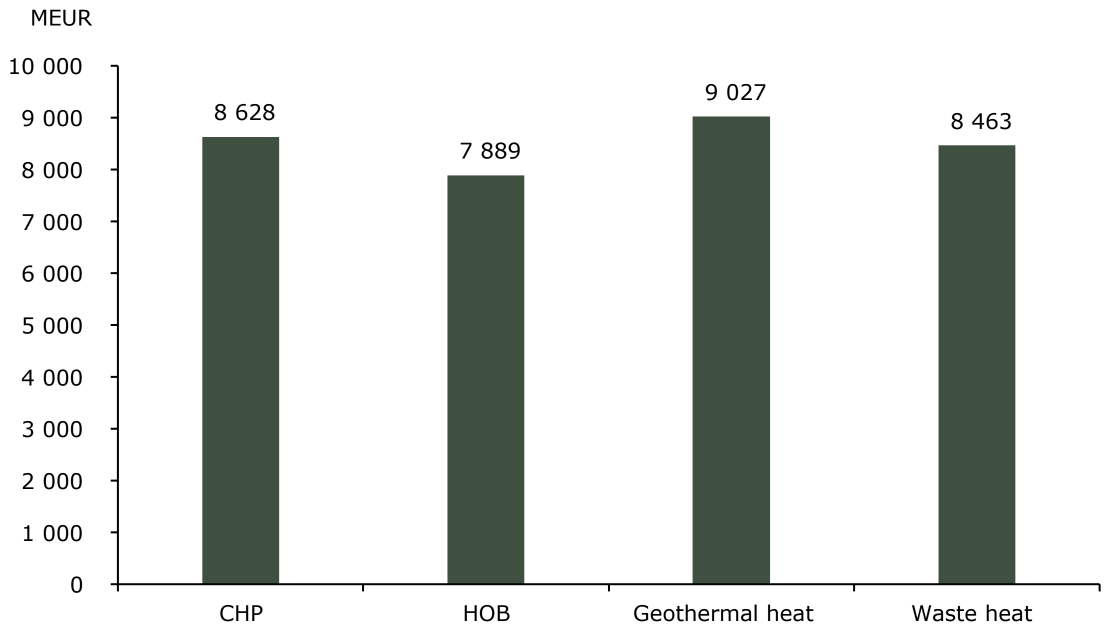
**Figure 27 – Net present values of heating systems applying an interest rate of 3%**




Source: AFRY

The differences in the net present values in the various scenarios arise mainly from differences in investment costs, fuel consumption and electricity consumption and generation. Figure 28 gives the estimated total investments in the different scenarios. Total investment costs are the highest in the geothermal heat scenario. Although the investment costs of the CHP scenario are lower than in the geothermal heat scenario, the net present value of the CHP scenario is lower than of the geothermal heat scenario, as there are more variable costs in the CHP scenario due to higher fuel consumption. Investments are lower in the waste heat scenario than in the geothermal heat and CHP scenarios, but higher than in the HOB scenario.

**Figure 28 – Total investments in the scenarios**



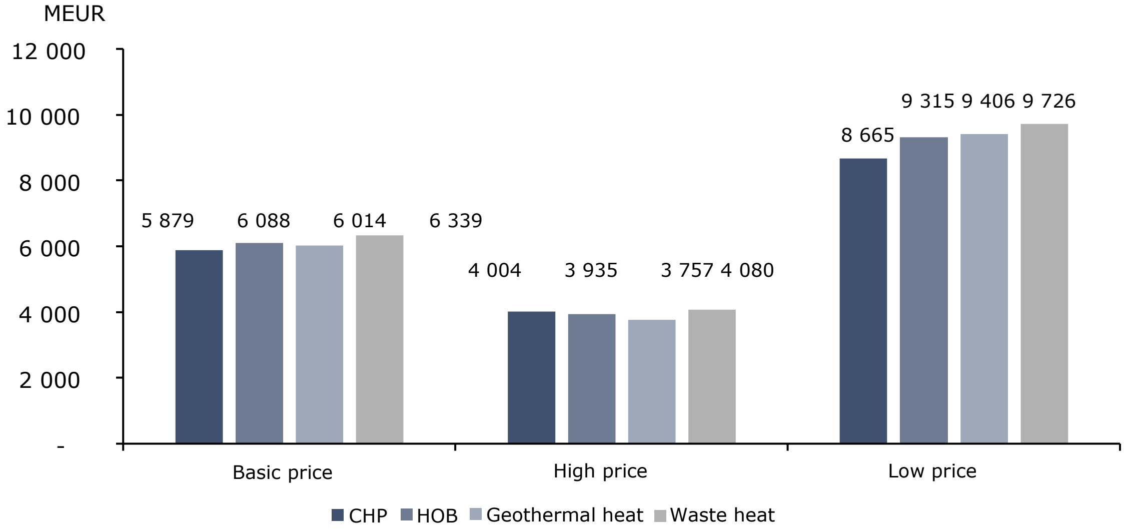

Source: AFRY

There are considerable differences in the fuel and electricity consumption in the scenarios. In the CHP and HOB scenarios, fuel consumption is higher than in the geothermal heat and waste heat scenarios, where heat is more often generated with technologies that consume electricity. The geothermal heat scenario has the lowest total operating costs.

### *Sensitivity analyses*

There are major differences between the scenarios in the consumption of fuel and electricity, and their costs have a considerable impact on net present value. Electricity costs, in particular, are highly relevant, as they also affect the profitability of CHP production. Therefore, a sensitivity analysis was carried out on net present values using three different electricity price scenarios. Figure 29 – Net present values for heating systems analysed for sensitivity with the price of electricity using an interest rate of 3% shows the net present values in different electricity price scenarios.

**Figure 29 – Net present values of heating systems analysed for sensitivity with the price of electricity using an interest rate of 3%**



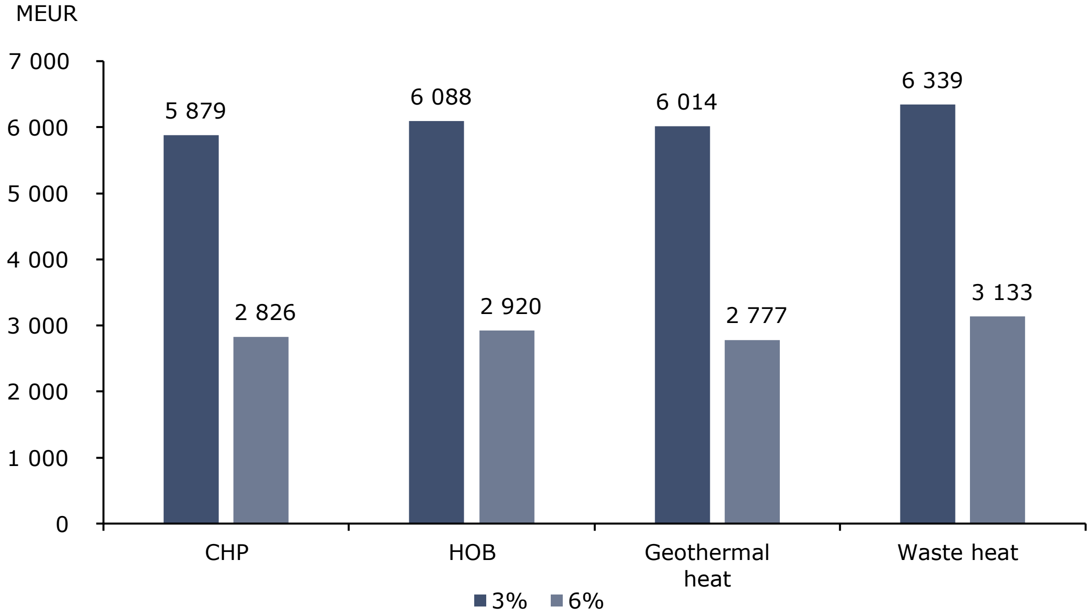

Source: AFRY

In the high electricity price scenario, the costs of the electricity required for heating rise, which decreases the net present values of all scenarios. The cost increase is particularly marked in the geothermal heat scenario, where the net present value falls to the lowest level due to its high electricity consumption. The net present value of geothermal heat is lower than that of waste heat, as the investments continue to be larger than in the waste heat scenario. The net present value of the CHP scenario exceeds that of the HOB scenario because the revenue from electricity production in CHP considerably increases the positive revenue flow in the high electricity price scenario.

Correspondingly, net present values rise in the low electricity price scenario due to decreasing costs. In this electricity price scenario, the lowest net present value is in the CHP scenario, where relatively higher fuel costs combined with low revenue decrease the profitability of electricity production.

A sensitivity analysis for the net present value was also performed by changing the interest rate applied. The interest rate of 3% specified in the EED is typically lower than the interest rate required of investments by companies operating in the energy market. The values 3% and 6% were used in the sensitivity analysis. Figure 30 illustrates the net present values with different interest rates. The net present value of the geothermal heat scenario is lowest with a higher interest rate, highlighting the impact of high total investments on net present value, as a higher discount rate reduces the net present value of future positive cash flows.

**Figure 30 – Net present values of heating systems applying an interest rate of 3% and 6%**




Source: AFRY

## 4.5 Summary of the cost-benefit analysis and conclusions

The efficiency of Finnish heating systems was assessed for the use of primary energy, CO2 emissions, share of renewable energy and costs using four different scenarios: CHP, HOB, geothermal and waste heat. In all scenarios, the CO2 emissions from heat generation are the same, when fuels used for other than CHP electricity generation are not taken into account. The differences in the shares of renewable energy are also minor, as the use of fossil fuels is expected to decrease dramatically in all scenarios. In the geothermal heat and waste heat scenario, electricity consumption is higher and fuel consumption lower than in the CHP and thermal boiler scenario.

The cost-efficiency of different heating systems was calculated using net present value calculation, taking into account the investment costs of heating technologies, fuel costs and electricity costs including taxes and network charges, heating operating costs and the assumed positive cash flows of the heating system. The positive cash flow is based on a single price assumption for the heat consumed and the market price of electricity for CHP electricity production. The sensitivity analysis was carried out for the price of electricity and the interest rate required for investment.

Given the assumptions of the analysis, the most cost-efficient system was one which maximises the use of waste heat. The scenario representing the use of waste heat was also the most cost-efficient in all sensitivity analyses. The price of electricity had a major effect on the relative profitability of heating systems.

A low electricity price made the geothermal heat scenario the second most profitable scenario, but a high electricity price made it the least lucrative. With a high electricity price, the CHP scenario became more profitable than the HOB scenario. A higher interest rate lowered the relative profitability of the geothermal heat scenario to a level below that in the CHP scenario in the baseline electricity price scenario.

However, there are uncertainties attached to any evaluation of the results. Particularly investment in the use of geothermal heat generation and waste heat remains an uncertain area, which may affect the results of the analysis as a result of the cost estimates used. Furthermore, the analysis does not take into account all the investments in a scenario, such as investment needs for the electricity grid and electricity generation arising from changes in heating systems. The positive cash flow in the analysis is based on a fictive value for heating for all customers and heating methods, although, in reality, this may vary depending on the heating method and location. In addition, it was not possible to include any detailed modelling of the operation of every district heating network in the analysis; instead, the review is based on a rough examination of production based on the current situation.

In Finland, decommissioned CHP production has in recent years been replaced with separate electricity generation due to the low price expectations regarding electricity. This is line with the conclusions of the analysis and the current price level of electricity. If the price of electricity is assumed to remain low, more electrification of heating may be more worthwhile than heat generation with biomass in thermal boilers. The required return on investment and the use of financing may have a considerable impact, particularly on the use of geothermal and waste heat, as geothermal heat requires major initial investment, and industries generating waste heat may require a higher return. Technological development may, however, advance the use of new technologies and increase the rate of electrification in heating on market terms. The challenge in electrification may be the flexible heat generation capacity required for heating in cold winter weather.

# 5. OTHER POSSIBLE MEASURES TO IMPROVE THE EFFICIENCY OF HEATING SYSTEMS

## 5.1 Lowering the temperature level of district heating networks

During the heating season, water with a temperature of at least 75–95 °C is typically fed into the district heating network. The temperature level of waste heat sources is often lower than this, which means that a heat pump, for example, is needed to raise the temperature to the required level, which increases the costs of district heating. By lowering the temperature level of district heating, district heating would become more compatible with waste heat and other low-temperature heat sources. In particular, the return temperature is of major importance to heat generation. The lower the return temperature, the more efficiently heat can be produced. In combustive production, for example, flue gases can be cooled by ensuring that the return temperature is low. The return temperature is particularly affected by the cooling caused by the customer's equipment.

The temperature level also affects heat losses in the district heating network. Heat losses typically represent around 10% of the heat generated. If the outgoing temperature was lowered from 10 °C, the heat losses would decline by nearly 10%, which would reduce the amount of heat loss relative to the heat generated by approximately 1%. The network's return temperature also affects the network's heat losses, but, due to the lower temperature level, not as significantly as the outgoing temperature. It is possible to optimise district heating networks so that both the outgoing and return temperatures can be lowered. If both temperatures can be lowered from around 3–5 °C by optimisation, the heat losses associated with the network will decrease by about 7%.

Lowering the temperature level may be limited by the transmission capacity of the district heating network, preventing an increase in the district heating water flow if the outgoing temperature was lowered. In most cases, however, lowering the temperature level is limited by the design and cooling of the customer's equipment. The customers' current design inlet temperature is 115 °C, which has been used since 1978. This design temperature should be lowered to allow the temperatures of district heating networks to be lowered in the future. The network temperature and the customers' design must correspond to each other to allow customers to obtain sufficient heat. The cooling of a new building, for example, is very much a larger-scale process than that for existing buildings, so the renewal of the building stock will also lead to gradually improved cooling.

Lowering the design temperature would increase the purchase price of district heating equipment for customers. According to AFRY's estimate, the purchase costs of heat distribution centres would increase by about 5% if the design temperature was lowered to less than 100 °C. The lower limit for design is just above 80 °C due to the high temperature of radiator systems in older properties. Some radiator-heated buildings designed for temperatures over 80 °C may be found in the oldest district heating networks, but customised solutions can be developed for them. Accordingly, it is not feasible to design entire networks for higher temperatures. Examined in the longer term, purchase costs only account for a small share of total heating costs. This cost increase can also be compensated by the better cooling of a new heat distribution centre, which will reduce the customer's water flow based capacity charge (basic charge) during the transition phase.

Transition phase refers to the period from the implementation of new designs up to the time when all heat distribution centres in the district heating network are designed for a lower outgoing temperature, or at least their functionality has been verified using a lower outgoing temperature. [27]

In the context an entire city, however, it would take several years to deploy a lower temperature level, even if design temperatures were lowered quickly. With a natural equipment replacement cycle, the transition phase can last over 20 years, as the service life of a heat distribution centre is long. Smaller regional heating networks can be designed and operated at lower temperatures at a faster rate. These may include new residential areas. In the Skanssi district of Turku, for example, the local regional heating network is operated year round at an outgoing temperature of 65 °C. New buildings and buildings being renovated can be designed to operate at lower inlet temperatures than previously. Old buildings are the most challenging due to the high temperatures of their radiator networks.

District heating networks are continually being reconditioned. These works decrease heat loss, and that for the district heating pipelines currently used is the equivalent of about one third of the losses of old pipelines. The current and by far most common pipe type 2Mpuk/Mpuk (preinsulated single/twin) was introduced in the 1980s. The technical service life of this type of pipe is estimated to be at least 60 years, which means that district heating networks can be expected to last for at least the next 30 years without major network investments. The reconditioning rate for the network is currently about 0.5% per year. If the old pipe types accounted for half of this,
heat losses would decrease by some 5% during the next 30 years merely as a result of network maintenance. However, the reconditioning rate can be expected to slightly increase over the next 30 years, resulting in a decline in heat losses which is actually greater than indicated above. On the other hand, the actual service life of the pipe types can be considerably longer than their technical service life.

## 5.2 Increasing the flexibility of the heating system

The heating system can be enhanced by optimising heat consumption and heat production mainly at the hourly and daily level. The potential and prerequisites for heat flexibility are different for separate heating and district heating. In separate heating, the fluctuating price of electrical energy and distribution network charges in particular encourages a reduction in the use of direct electric heating or heat pumps, when electricity is expensive. Longer-term flexibility can be achieved by switching to wood-burning, for example.

The hourly-based district heating consumption metering system commonly used in Finland enables dynamic and power-based pricing that encourages customers to even out their heat consumption. More even heat consumption may reduce the need for peak power in heat generation, although the number of price-sensitive or active customers must be very large.

[27] AFRY, Kaukolämpöasiakkaiden mitoituslämpötilan laskeminen (Lowering the design temperature of district heating customers), 2020

In addition to various dynamic and incentive tariff structures, different types of condition services may help optimise heat consumption and improve the efficiency of the heating system. District heating suppliers have also started to offer condition services to their customers, with the related technology allowing the supplier to adjust heat consumption within the framework agreed with the customer.

With respect to the district heating system, the realistic potential for consumer flexibility and the most effective means to promote it have hardly been studied at national level. Reduced operation of peak-power plants reduces the emissions required for heating, as peak plants often use oil for fuel. If the heat consumption peak is sufficiently likely to decrease, the capacity and number of peak boilers can, at least in theory, be reduced, which would cut the investments required for heat generation. There may be network-specific constraints regarding any assessment of the realistic potential due to the local nature of heat consumption and production, as the need for heat may vary in different parts of the network.

Flexibility in the production of district heating systems can be achieved with heat accumulators. Heat accumulators are a faster and more efficient method of increasing flexibility in the district heating system compared to heat consumption flexibility. Some district heating companies already use heat accumulators to optimise production (cogeneration power plants are optimised according to the price of electricity) or as a backup system in case of unplanned interruptions in the installation, as it is easy and inexpensive to store heat. Heat accumulators can also replace the use of peak boilers.

The investment costs of heat accumulators are around EUR 300 per $m^3$, which equals about EUR 7 per kWh with a network temperature difference of 35 °C[28]. Heat accumulators are typically designed to withstand unexpected interruptions lasting several hours. The design process usually takes account of the capacity of the main boiler, which means that their size typically varies between 0.1 and 1 GWh, depending on the size of the network. With the advances in low-carbon goals, the use of longer-term heat storage is also now being examined. The largest projects are Helen's 11.6 GWh storage in Mustikkamaa and the 4.5 GWh storage in Kruununvuorenranta.

[28] AFRY; E. Guelpa, V. Verda, Thermal energy storage in district heating and cooling systems: A review, 2019. https://www.sciencedirect.com/science/article/abs/pii/S0306261919311481

# ANNEX A – COST ASSUMPTIONS

Table 15 lists the cost assumptions used in the cost-benefit analysis of heating systems.

**Table 15 – Assumptions in the cost-benefit analysis**

| **Investment costs** | **Value** |
|---|---|
| Bio CHP plants | EUR 1 100 per kW |
| Bio HOB plants | EUR 750 per kW |
| Industrial waste heat | EUR 1 000 per kW |
| Flue gas scrubbers | EUR 400 per kW |
| Heat pumps in the utilisation of waste heat | EUR 1 100 per kW |
| Waste heat from data centres | EUR 1 340 per kW |
| Geothermal heat | EUR 1 675 per kW |
| Property-specific heat pumps | EUR 1 200 per kW |
| **Variable costs** | **Value** |
| Operating costs | EUR 3.5 per MWh |
| Electricity network charge | EUR 70 per MWh |

Source: AFRY

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