Regeringskansliet

Memorandum

25 February 2021

Ministry of Infrastructure

Sweden’s report under Article 14(1) of Directive 2012/27/EU on energy efficiency – Promotion of efficiency in heating and cooling

Contents

Summary

The aim of this report is to update Sweden's comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling in accordance with Article 14(1) of Directive 2012/27/EU on energy efficiency.

In Sweden, the heating market has to a large extent already switched from fossil fuels to renewable energy. In addition, all cogeneration in Sweden is already highly efficient. Where district heating is not profitable, heating is primarily achieved using heat pumps which use almost completely fossil-free electricity. In the light of this, it is difficult to investigate the potential for more renewable and efficient heating and cooling than what the market is able to provide itself.

As regards district heating generation using fossil fuels (oil, coal and natural gas) this is not something that can be impacted to any great extent by a study with proposals for instruments, as an almost full increase to the carbon tax has already been introduced and the industry is already shifting.

The model calculations in the report show that the last fossil fuel individual heating from oil and natural gas will be unprofitable and completely phased out by 2030 using existing instruments.

A large number of model calculations have been made for the energy system in order to meet the Directive's requirement to investigate the potential of all heating and cooling technologies to reduce CO_2 emissions, increase the renewable shares and primary energy savings, as well as contribute to other benefits such as secure energy supply. By varying the inputs, we have recorded a series of different scenarios with associated sensitivity analyses.

Some overall conclusions can be drawn from the modelling results. Over time, district heating generation will see more production from cogeneration and heat pumps connected to district heating and less production from heat only boilers. In the scenarios with higher CO2 prices, bioenergy with carbon capture and storage (bio-CCS) has a big impact.

District heating supplies do not change much over time, but in the long term there is some increase in most of the scenarios investigated.

The modelling results show an increased utilisation of low-temperature waste heat in the district heating sector, particularly so in the scenario that assumes an increased electrification of 40 TWh in 2050, as this assumes a strong expansion of

data centres.

District cooling supplies increase over time in the modelling results. Free cooling or waste cooling from cogeneration in a heat pump is chosen in the model in the first instance. In addition, compressor cooling is chosen to a greater extent than absorption cooling, with the exception of certain scenario conditions that give a surplus of cheaper district heating capacity during the summer.

In the calculations, a societal perspective is also used (with a lower assumed interest rate) which is compared with an investor's perspective (with market participants' ordinary assumed interest rate) to see whether there are cases where government measures are justified (corresponding to a lower assumed interest rate for investments in heating, cooling and electricity generation) and what this would lead to. In comparison with the investor's perspective, the societal perspective shows a higher degree of energy efficiency at end-user level, more heat pumps (for individual heating) and a slightly lower use of district heating and pellet boilers (for individual heating). This is because the lower assumed interest rate in the socio-economic approach (compared to the investor's perspective) favours capital-intensive investments. Although district heating is a capital-intensive energy type, the proportion of fuel costs and other variable costs constitutes a non-negligible cost item of the total cost. In district heating generation, the societal perspective generally gives a higher proportion of district heating based on waste, waste heat and heating pumps and a lower proportion of biofuel-based production. However, these results do not justify government measures.

In addition to model runs, a review of Sweden's heating and cooling market has also been carried out as well as a review of existing policies and instruments, while maps have been compiled of different types of production facilities, heat demand, waste heat clusters etc.

1. Introduction

The aim of the report is, in accordance with Article 14(1) of Directive 2012/27/EU on energy efficiency1[1], also known as the Energy Efficiency Directive, to update Sweden's comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling.2[2]

The comprehensive assessment that will be made this time is more extensive compared to the previous report, as the data and information requested has increased in scope due to the extended requirements set out in Annex VIII[3] referred to in Article 14.

The report is laid out so that **Chapter 2** gives an overview of Sweden's heating market in order to give a better understanding of how Sweden has chosen to implement the Directive and our specific conditions. This Chapter also begins by responding to the Directive's requirement for an overview of heating and cooling for different sectors broken down by users and producers as well as according to technology and whether they are fossil/renewable. **Chapter 3** goes over the requirements for maps of industrial and production installations for heating and cooling including waste heat and heat demand. **Chapter 4** describes the role played by heating and cooling as regards goals, strategies and political measures as well as how they play into the Energy Union's five dimensions. This Chapter also gives an overview of current instruments for heating and cooling. **Chapter 5** analyses the economic potential for efficiency in heating and cooling. The whole of Sweden is analysed using model runs in the energy system model TIMES-Nordic which develops the solutions with the lowest costs. Costs include investment costs, operating costs, fuel costs, energy taxes etc. This is done to meet the requirement for a cost-benefit analysis set out in Article 14(3) of the Directive. The basis for the model calculations are three basic scenarios that are examined with a financial assumed interest rate, and a lower socio-economic assumed interest rate which have been selected because they are in line with the requirements of the Directive. In addition to various alternative scenarios, sensitivity analyses and assessments are also carried out based on primary energy, CO2 emissions and renewable energy.

2. The heating market in Sweden

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[1] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

[2] The first report was to be submitted on 31 December 2015. The Swedish Energy Agency produced a comprehensive assessment in 2014 which will now be updated to 31 December 2020.

[3] See Annex E for the whole list of requirements from Article 14 EED [and] Annex VIII.

In order to understand the implementation of Article 14 of the Energy Efficiency Directive in Sweden, it is necessary to understand the Swedish context. The original idea behind the assessment of potential to be carried out in accordance with the Energy Efficiency Directive was to first locate a geographic area where fossil fuels, or low-efficiency technologies, are used for heating. This could be a municipality, a residential area or a suburb with oil or gas heating, for example. In order to replace this fossil fuel heating, it must first be determined whether it is technically possible to replace it with a more environmentally friendly and efficient alternative, for example bio-based district heating or heat pumps. A socio-economic cost-benefit analysis must then be performed to find which alternative heating method has the lowest socio-economic cost. Finally, appropriate instruments must be introduced. In the updated Directive (Annex VIII)[4] this approach is less explicit, but the idea is roughly the same. However, in Sweden's case it is not possible to do this type of calculation for all 290 municipalities. It is also not efficient. District heating is already available in 285 of Sweden's 290 municipalities[5] and is, for the most part, fossil-free. Where district heating is not profitable, heating is primarily achieved using heat pumps which use almost completely fossil-free electricity. Conversion to efficient and renewable/fossil-free heating has already been broadly implemented in Sweden.

The remaining fossil fuel boilers in the district heating systems are already being phased out and the individual oil boilers are being converted and disappearing completely as they are no longer cost-effective. The challenge remains to replace natural gas heating in housing and premises which amounts to approximately 0.8 TW as well as to replace or reduce the fossil content of waste in waste cogeneration.

As for increased efficiency in heating, one possibility is to look at increasing the proportion of cogeneration in district heating generation which would also generate increased security in energy supply as regards availability of power and electricity production close to users. However, increasing the proportion of high-efficiency cogeneration of the total cogeneration is not possible as all cogeneration in Sweden is highly efficient. Low-temperature district heating and an increased proportion of waste heat would also mean a more efficient heat supply if it were possible to find socio-economic profitability where the market has not already found it.

In the light of the above, the primary approach to finding the most socio-

[4] Commission Delegated Regulation (EU) 2019/826 of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU of the European Parliament and of the Council on the contents of comprehensive assessments of the potential for efficient heating and cooling.

[5] Swedenergy (2020).

economically profitable heating has been to make model runs in the model Times Nordic[6]. The model expands the most profitable heating option and by varying the input and assumed interest rate we have found various scenarios and made different sensitivity analyses.

1.1 Overview of heating and cooling

This Chapter responds to the requirement set out in Article 14 and Annex VIII, Part 2, points 1 to 2(a)(i)-(iii) and 2(c) and recital 4 of the Directive. For points 2(b)(i)-(v)[7] concerning waste heat potential and points 3(a)-(c) concerning maps for installations, heat demand etc. in Annex VIII see Chapter 3.

Point 1. Heating and cooling demand in terms of assessed useful energy and quantified final energy consumption in GWh per year by sectors (Figure 1)

Point 2. Identifying or, regarding point 2(a)(i), identifying or estimating current heating and cooling supply.

a) Broken down by technology, in GWh per year, in the sectors referred to in point 1 and, if possible, by energy from fossil fuels and renewable sources. (Figure 2)

c) Reported proportion of the district heating and cooling sector's final energy consumption that has come from renewable energy sources, waste heat or waste cooling (4) over the last five years in accordance with Directive (EU) 2018/2001. (Figure 3)

Point 4. A forecast of trends in the demand for heating and cooling to maintain a perspective of the next 30 years in GWh and taking into account in particular projections for the next 10 years, the change in demand in buildings and different sectors of the industry, and the impact of policies and strategies related to demand management, such as long-term building renovation strategies under Directive (EU) 2018/844. (Figure 1, Figure 2, Figure 3)

In addition to the figures referred to in the respective requirements above, it should be added that many figures in the report highlight the heating demand and heating production over time from fuel, technologies, renewable/fossil etc., as well as scenarios with different conditions in Chapter 5. As regards point 4 above, it is complemented not least by the development of the renovation strategies explained in more detail in Chapter 4.

Several assumptions have been made for the data in the figures. On the basis of on the statistics, it is not possible to determine what heating production has been sold to each user. We have therefore chosen to make a proportional breakdown of production among the users. The amount of fuel has been divided proportionally between cogeneration plants and heat plants, based on district heating volume for each production type. The different fuels have also been divided proportionally

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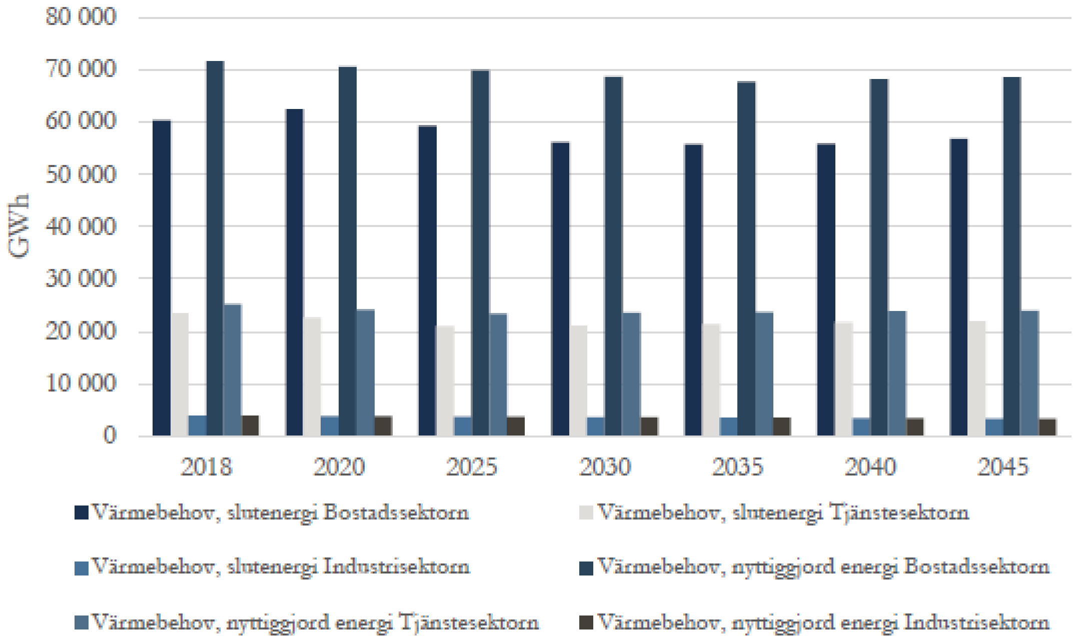
[6] See explanation in Chapter 5.1 and Annex A.

[7] Identification of installations that produce waste heat or waste cooling and their potential heating or cooling supply in GWh per year.

based on received volumes. Other sectors (agriculture etc.) have been excluded as they alone are not deemed to account for more than 5% of the total national demand for useful heat, which is the Directive's prerequisite for being included.

In Figure 1 only district heating is included for the industry. The industry's total fuel use amounts to approximately 90 TWh, but this is mainly process energy.

Figure 1. Current and forecast heating demand by sector and final energy and useful energy



	GWh
	Heating demand, final energy Residential sector
	Heating demand, final energy Services sector
	Heating demand, final energy Industry sector
	Heating demand, useful energy Residential sector
	Heating demand, useful energy Services sector
	Heating demand, useful energy Industry sector

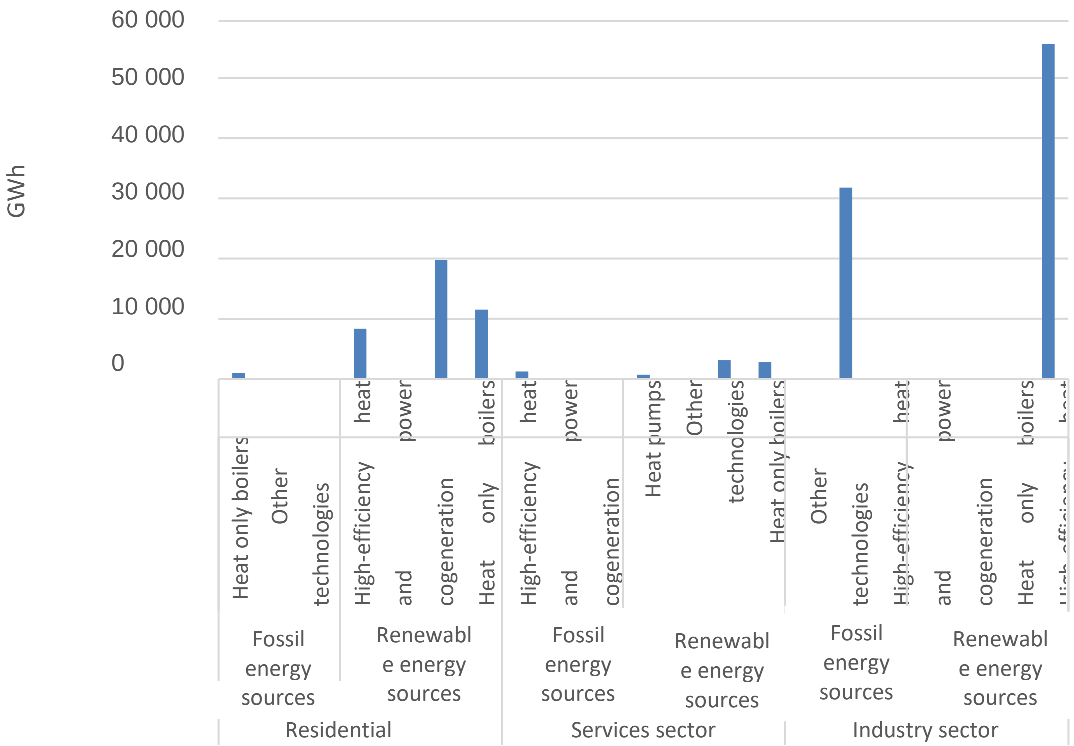
Source: The Swedish Energy Agency (2019c)

As regards the requirement for cooling demand, this amounted to 1 242 GWh in 2018 and is assumed to be in the services sector. The cooling demand for useful energy is difficult to estimate. However, most will fall in the services sector and is estimated in Chapter 5.12 as approximately 2.2 TWh in 2050.

In the case of other technologies in Figure 2 and as regards heating provided off-site this is in practice district heating. Figure 3 therefore shows the use of district heating in 2018 by users.

Figure 3 consists of electric heating (direct and waterborne). All electric heating has been categorised as renewable, despite the fact that the proportion of renewable electricity (according to the definition in the Renewable Energy Directive) is only around 66%, as the fossil fuel proportion is very small (the difference is made up by nuclear power).

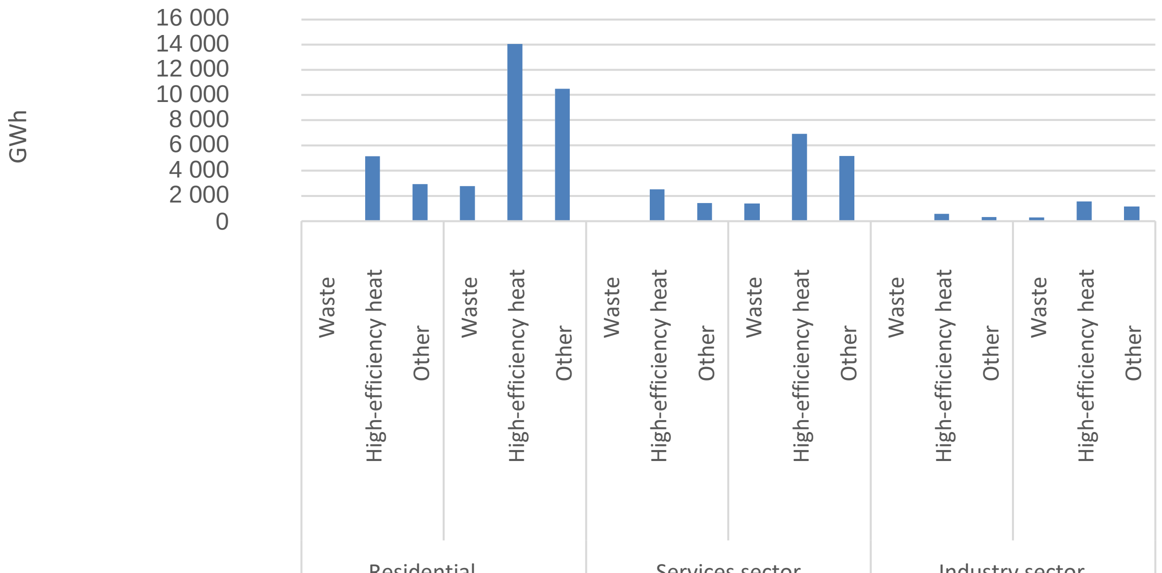
Figure 2 Heat supplied on-site, GWh/year, 2018



Source: The Energy Agency.

As regards heat supplied off-site, in practice this is district heating. Figure 3 therefore shows the use of district heating in 2018 by users.

Figure 3 Heat supplied off-site, GWh/year, 2018



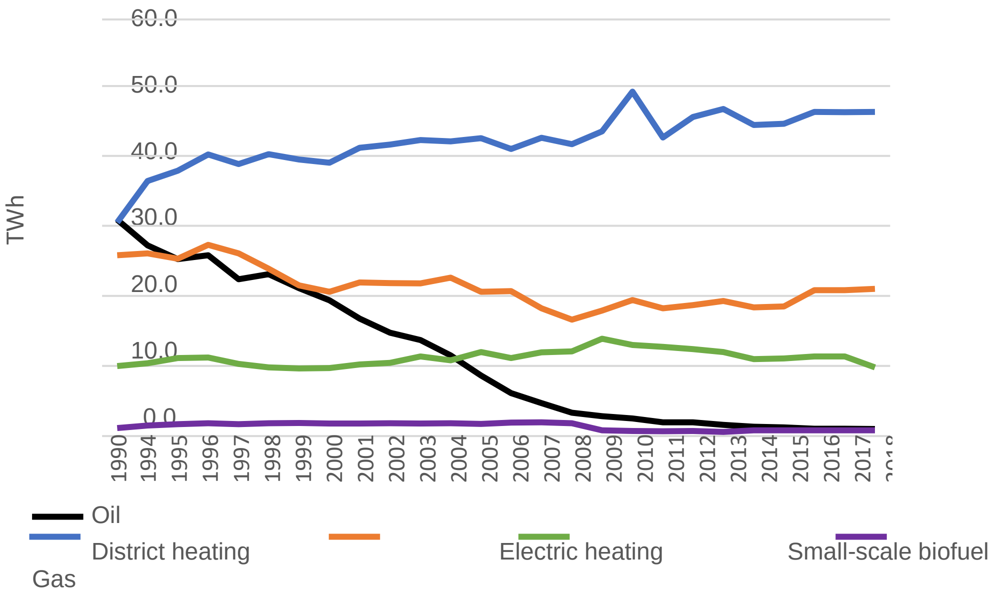
Fossil energy sources | Renewable energy sources | Fossil energy sources | Renewable energy sources | Fossil energy sources | Renewable energy sources

Source: The Energy Agency.

2.2. Conversion to fossil-free heating

Figure 4 shows the conversion to fossil-free heating in small houses, multi-dwelling buildings and premises where oil heating decreased from 31 TWh in 1990 to 1 TWh in 2018. The use of small-scale gas heating has never been high in Sweden and was 0.8 TWh in 2018. Electricity for heating is primarily used to operate heat pumps in small houses but direct-acting electricity and electric boilers are also included. Electrical heat was 21 TWh in 2018. In 2018, district heating was 46.3 TWh and consisted of around 67% renewable energy[8] and 8% waste heat (see Chapter 2.3).

Figure 4 Total energy use for heating and hot water 1990-2018, by energy type, TWh



Source: The Energy Agency (2018a).

2.3. District heating in Sweden – conversion and expansion

District heating has existed in Sweden since the 1950s and was previously produced primarily in heating plants. Until the middle of the 1990s, district heating was mainly municipally owned and operated in municipal energy or district heating companies or in a municipal management form where prices were set according to the principle of cost price. In connection with the electricity market reform in 1996, the district heating market was also liberalised, and requirements were introduced meaning that district heating operations would be run on a commercial basis. This

[8] 62% of biofuel and 5% of the renewable share from large heat pumps calculated based on a COP of 3.

means that around 70 municipal district heating companies were sold to private businesses during the period 1990–2004.[9]

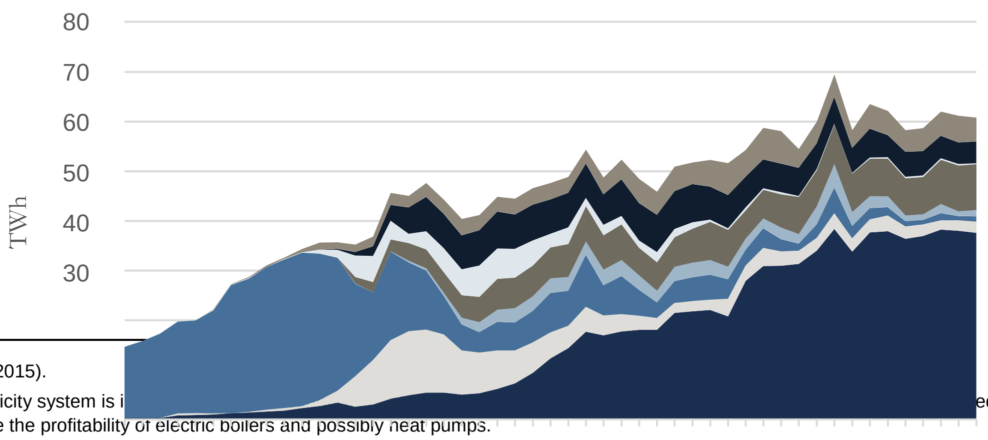
The proportion of district heating from cogeneration has increased successively and is currently around 45% compared to 38% 10 years ago. In 2018, district heating accounted for 71% of the total energy use for heating and hot water in housing and premises. Just over half of district heating is used in multi-dwelling buildings, while premises accounted for 34% and small houses for 10%.

In 2018, biofuel accounted for 62% and waste heat for 8% of the energy supplied in district heating generation (Figure 5). Heat pumps have

gradually decreased in importance and between 2000 and 2009 they accounted for 12% on average while the equivalent figure for 2010-2018 was 8%. The use of electrical boilers has largely disappeared[10]. The greater use of electrical boilers and heat pumps previously was due to lower electricity prices. The use of waste for district heating generation has increased in the last decade. The increase is due to the ban on depositing combustible waste introduced in 2002 and the ban on depositing organic waste from 2005. In several Swedish cities, heat from waste incineration is the basis for district heating. Waste is included both in the item Biofuel (organic waste) and Other fuel (fossil waste). Peat is also included in the item Other waste.

Over the last ten years, the fuel used for district heating has been around 60 TWh (see Figure 5) with minor variations depending on temperature differences[11] which means that the market is relatively saturated although there are certain areas for development. The competition from heat pumps and enhanced efficiency means that district heating supplies will most likely decrease in the future which places a great demand on innovations and new market solutions from the industry.

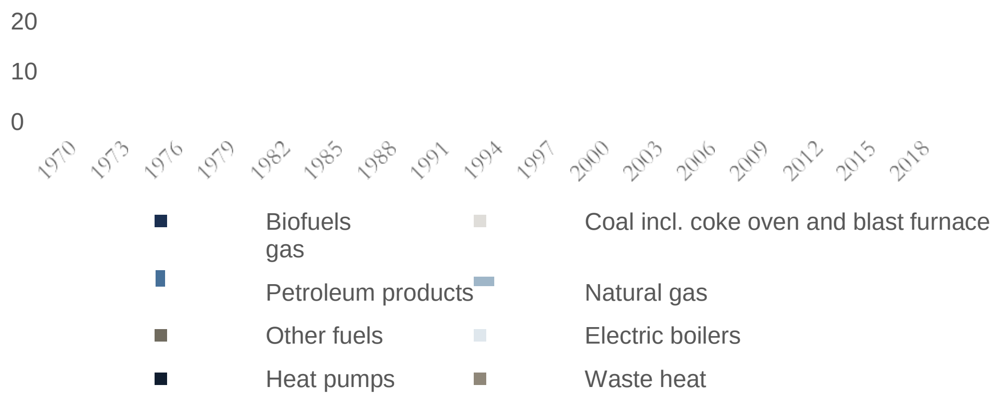
Figure 5 Energy input for district heating generation, TWh.



[9] Energiforsk (2015).

[10] As the electricity system is i… ed which should increase the profitability of electric boilers and possibly heat pumps.

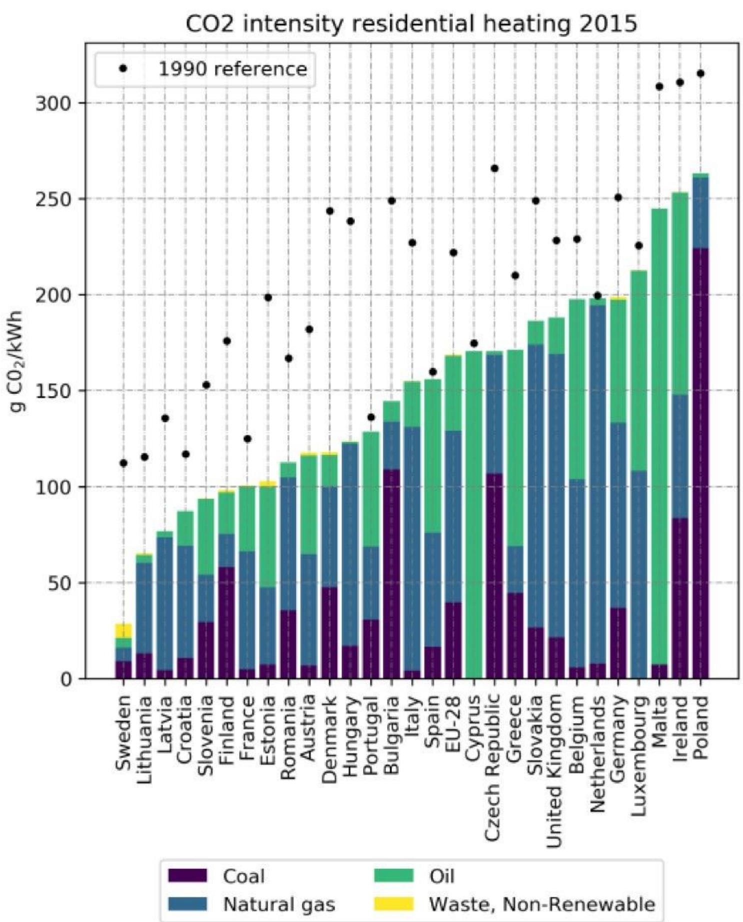
[11] Except 2010 which was an unusually cold year, which resulted in 69 TWh district heating.



Source: The Energy Agency (2020a).

Figure 6 shows Sweden's conversion to fossil-free heating compared to other EU countries. On average, the carbon intensity decreased by 55 g CO_2/kWh among the EU-28 from 1990 to 2015. The results show that in 2015, Sweden had the lowest average carbon intensity with 29 g CO_2/kWh, due to a high concentration of biomass, nuclear power and renewable energy in its heating sector. The decrease from 112 g CO_2/kWh in 1990 is due to a reduction in oil and coal use. It should be noted that in 1990, Sweden already had the lowest carbon intensity in the EU.

Figure 6 Sweden's carbon intensity in residential heating compared to other EU countries, 2015 compared to 1990.

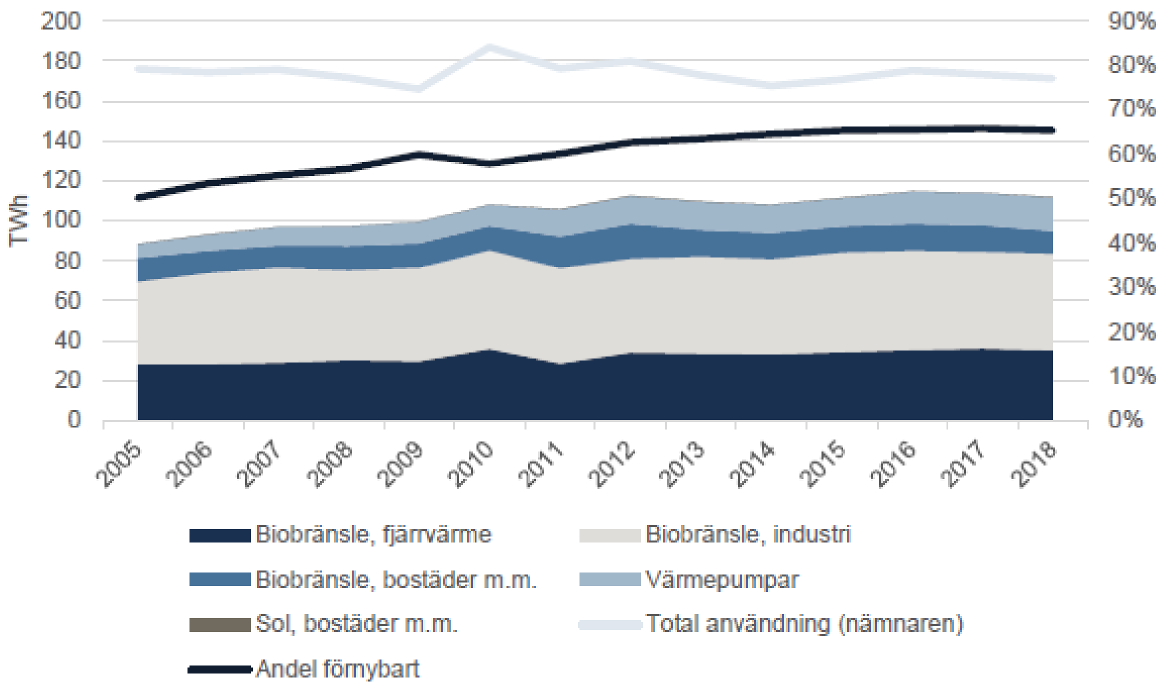


Source: Bertelsen and Mathiesen (2020).

The proportion of renewable energy in the heating and cooling sector[12] in relation to energy use was 66% in 2018 (see Figure 7). In 2005 the equivalent proportion was 51%[13]. The amount of renewable energy in the sector was 112 TWh in 2018 which is an increase compared to 2005, when the amount was 88 TWh. The renewable energy consists primarily of biofuel which accounts for 85% followed by heat pumps which account for 15%.[14]

In the same period, the total energy use has decreased from 176 TWh to 171 TWh, which also contributes to an increased share of renewable energy.

Figure 7 Renewable energy and energy use in the heating and cooling sector, 2005-2018, TWh



	TWh
	Biofuel, district heating
	Biofuel, industry
	Biofuel, residential etc.
	Heat pumps
	Solar, residential etc.
	Total use (denominator)
	Renewable proportion

Source: Eurostat. The Energy Agency’s processing.

[12] The heating and cooling sector includes industry, residential and services etc. as well as district heating, but excludes electricity use in these sectors.
[13] The figure is not completely symmetrical, which is why it is difficult to read exact figures from it.
[14] And a small amount of solar heating.

2.4. The heating industry's commitments – from now on

The heating sector is a large part of the energy market. It comprises nearly 100 TWh of energy annually and has a turnover of SEK 100 billion[15]. In March 2019, the heating industry, consisting of around 50 actors in the sector, submitted the report *Roadmap for fossil-free competitiveness – Fossil-free heating*[16] to the government. The vision for the industry is for the heating sector to be fossil-free by 2030 and a carbon sink by 2045, which will help to reduce Sweden's total greenhouse gas emissions.

Since the actors in the heating sector submitted the roadmap to the government in March 2019, the following has happened:

- Test facility for Bio-CCS began operating, December 2019.
- A facility for sorting plastic from residual waste sent for incineration is under construction in the Stockholm region.
- The country's biggest coal-fired cogeneration plant was decommissioned in 2020 in Stockholm. In 2019, Tekniska Verken i Linköping decommissioned its last coal-fired facility. From 2020, Mälarenergi's production will also completely free from coal and oil. This has been made possible through multi-billion kronor investments in new facilities.
- Intensified phasing out of fossil fuels in district heating companies – only small amounts remain in some peak load facilities where many have already switched to biofuel and many are in the process of converting.
- A large number of twinning projects have been started (for example local market places, residual heat utilisation, negative emissions, plastic in waste etc.)

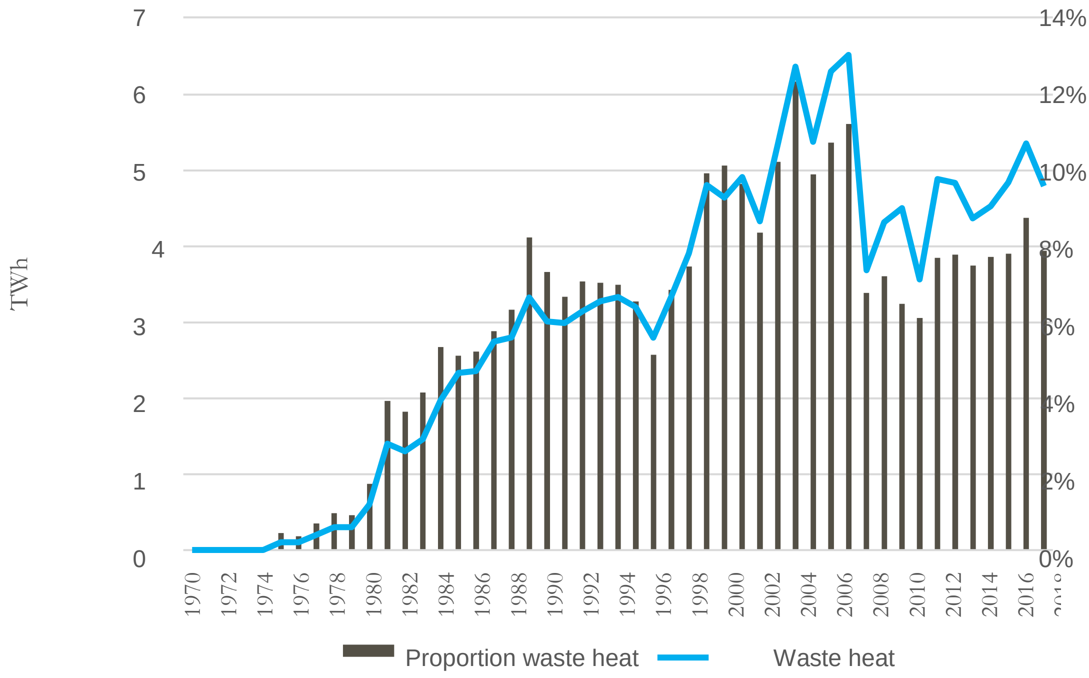
2.5. Development of waste heat in Sweden

In the last 7 years, the waste heat shares of the total district heating supplies have been around 8%, which is equivalent to approximately 5 TWh, see Figure 8. The largest supplies of waste heat were in 2007, when 6.5 TWh of waste heat was added to the district heating network. Until then, the waste heat supplies had shown an upwards trend over around 25 years but since then, the supplies have decreased slightly. However, the number of waste heat partnerships has increased since 2004. In the report *Comprehensive assessment of the potential for using high-efficiency heat and power cogeneration, district heating and cooling*[17] it was found that there were around 90 waste heat partnerships, which can be compared to around 60 in 2004. The received volume of waste heat also varied significantly over the years, depending on economic trends in the industry and varying heating

[15] Sweden's heating market (2020).
[16] Fossil-free Sweden (2019).
[17] ER 2013:09.

demand due to annual temperature changes.[18]

Figure 8 The development of waste heat in TWh (blue line) and proportion of total district heating supplied (black bars). 1970-2018.



Source: The Energy Agency (2020a)

The industry organisation Swedenergy notes that there are waste heat partnerships in 70 places and more than 85 industries supply waste heat to the district heating network each year, with new projects underway in several areas. For example, there is a plan to utilise more industrial waste heat in Köping by bringing regional networks to Arboga instead of building a new boiler in Arboga[19]. Pulp and paper mills and refineries each account for a little over a quarter of the waste heat supplies, while chemical and steel industries supply 10-20% each of the waste heat.

An obstacle for increased waste heat use is that district heating companies see risks in waste heat projects as industries are dependent on economic trends. The

[18] The Energy Agency (2013a).
[19] Swedenergy (2017).

distance to existing district heating networks is another obstacle for profitable investments in transmission lines. Use of waste heat may also be obstructed by cultural differences between municipal district heating companies and private industry as well as the fact that district heating companies may want to have a separate plant and be independent.

There may also be differences in approach where some see waste heat as an energy resource that does not deplete primary energy or result in emissions while others believe that waste heat produced with fossil fuels delays the switch to renewable energy.

2.5.1. Measures to promote waste heat partnerships

Regulated access to the district heating network

In August 2014, provisions were introduced to the District Heating Act (2008:262) which make it possible for those who want to connect to a district heating network to get regulated access to the pipelines, under certain conditions.[20] The justification for giving regulated access to the district heating network is to make it easier for industries and other actors to sell excess heat to the district heating network. Through this, district heating can become more energy efficient, as heat can be used which would otherwise be cooled off as industrial waste heat.

The change in the law obliges district heating companies to grant regulated access to the district heating network, but district heating companies are able to deny regulated access if they can prove that access carries a risk of damage. Damage primarily means economic damage but can also include damage to operational technology. District heating companies are therefore also allowed to deny access to connections that reduce operational safety. Examples of economic damage may be churn rate due to a new actor supplying heat from fossil fuels, which changes the environmental profile of the district heating.[21]

Act on Certain Cost-Benefit Analyses in the Energy Sector

The Act (2014:268) on Certain Cost-Benefit Analyses in the Energy Sector entered into force on 1 June 2014. The Act was introduced as part of the implementation of the EU's Energy Efficiency Directive and sets out requirements for investigations to be carried out on the potential for cogeneration, district heating and cooling as well as industrial waste heat in certain investment decisions. According to the Act, a cost-benefit analysis taking into account the utilisation of industrial waste heat must be carried out:

[20] Prop. 2013/14:187.
[21] Energiforsk (2015).

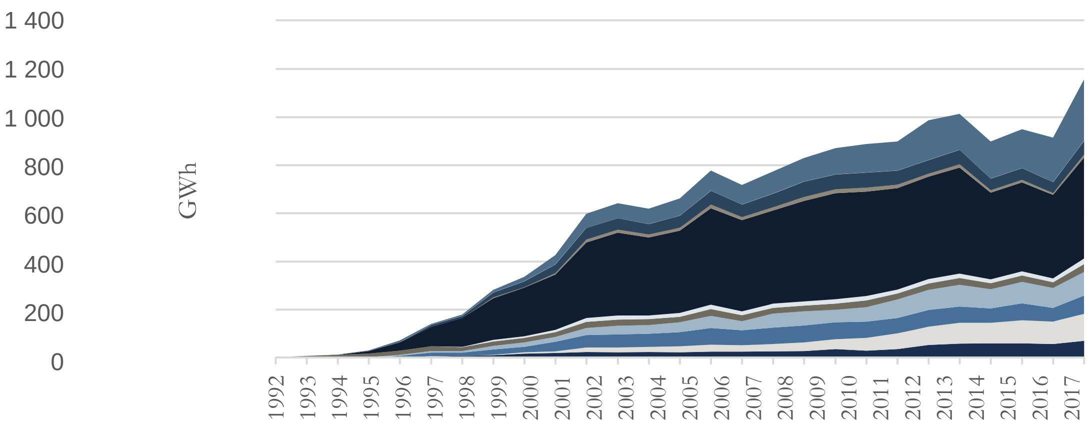
- When planning a new network for district heating or cooling.
- When planning a district heating generation installation with a total thermal input exceeding 20 MW within existing district heating/cooling networks as well as when carrying out comprehensive upgrades of any such existing generation installation.
- When planning a new industrial installation with a thermal input exceeding 20 MW as well as when carrying out comprehensive upgrades of an existing such industrial installation.

Furthermore, a cost-benefit analysis must be carried out with respect to the potential for cogeneration when planning a new thermal electricity generation installation. It is not compulsory to make a profitable investment, but it is rational to do so if the cost-benefit analysis shows a positive net present value.

2.6. Development of district cooling

District cooling is used primarily in offices and business premises and for cooling industrial processes. The principle of district cooling is the same as for district heating. It involves the production of cold water in a major installation for distribution via pipes to customers. The most common mode of production is to use waste heat or sea water to produce district cooling with the help of cooling machines. This sometimes happens simultaneously with the production of district heating. Another common mode of production is to use cold water directly from the bottom of the sea or a lake[22], this is called free cooling. The market for district cooling has expanded a great deal since the first installation in 1992. Supplies of district cooling increased by 26% from 2017 to 2018 which was a record year with 1 156 GWh of district cooling supplied, see Figure 9. In 2018, a total of 36 companies supplied district cooling to 40 Swedish cities and the district cooling network's total length amounted to 627 km.

Figure 9 District cooling suppliers in Sweden by municipality



[22] Snow can also be used.

Uppsala
Linköping
Solna/Sundbyberg
Gothenburg
Västerås
Huddinge/Botkyrka/Salem
Stockholm/Nacka
Helsingborg
Lund
other

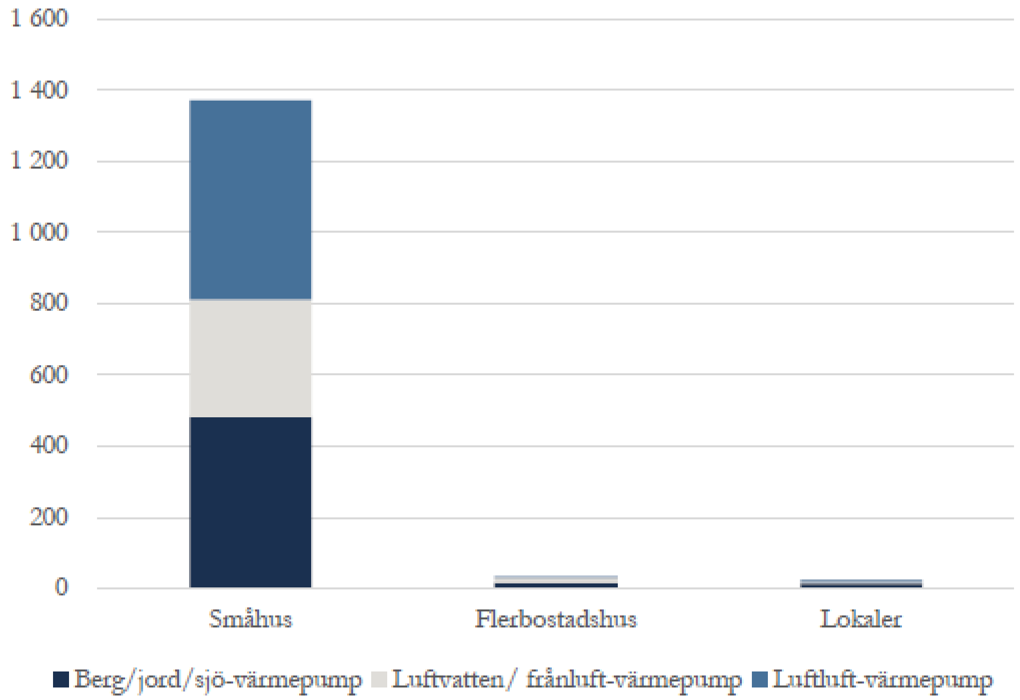
Source: Swedenergy

2.7. Heat pumps where district heating is not accessible

In 2010 the millionth heat pump was installed in Sweden and in 2018 the number of heat pumps installed was estimated at 1.4 million, the majority of which were in small houses, see

Figure 10. The number of small houses was estimated at 2 million at the same time in 2018, which means that around 70% of all small houses have a heat pump (however, a house can have more than one heat pump). The most common type of heat pump is an air-to-air heat pump, but rock/soil/lake heat pumps and air-to-water/exhaust air heat pumps are also present to a fairly large extent.

Figure 10 Estimated number of installed heat pumps in 2018, by building type, [1 000s]

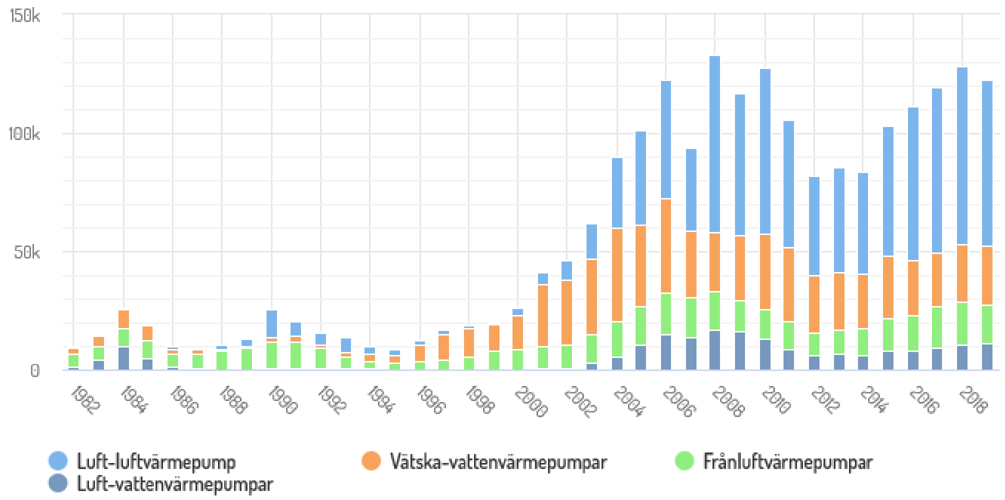


	Small houses
	Multi-dwelling buildings
	Premises
	Rock/soil/lake heat pumps
	Air-to-water / exhaust air heat pumps
	Air-to-air heat pumps

Source: The Energy Agency (2018a).

Figure 11 shows that heat pump sales are still high, and that the replacement market gained momentum after 2014.

Figure 11 Heat pump sales in Sweden 1982-2019



Source: SKVP (2020).
Note: Data for air-to-air heat pumps is estimated.
Note 2: Water-to-water heat pumps are the same as rock/soil/lake heat pumps.

	Air-to-air heat pumps
	Water-to-water heat pumps
	Exhaust air heat pumps
	Air-to-water heat pumps

2.8. Swedish challenges concerning heating and cooling in Article 14 – what remains?

This Chapter highlights the specific challenges in Sweden relating to Article 14 where there is clear potential for improvement. In some cases, no intervention is needed on the market, which is the case with phasing out individual fossil-based heating, for example, but in other cases the problem is more difficult to solve, as is the case with the fossil content of waste. As regards cogeneration, this contributes various benefits which must also be taken into account in accordance with the Directive as a basis for whether measures should be taken or not. Many parts of the Directive have already been implemented in Sweden as we have largely already made the switch to renewable, high-efficiency cogeneration and more broadly towards a fossil-free heating sector. We also have instruments in place to continue such market development. This Chapter attempts to explore specific Swedish challenges/potential improvements further in the context of implementing Article 14 of the Energy Efficiency Directive.

2.8.1. Phasing out fossil fuels in the district heating network.

On 1 August 2019, a carbon tax increase was implemented for cogeneration plants[23] from 11% to 91% of full carbon tax. In the light of this, a consequence analysis was carried out (by consultancy WSP commissioned by the Environmental Protection Agency) on what the tax increase would mean for the last remaining fossil fuel cogeneration plants.[24] The analysis showed that there are a handful of cogeneration plants that account for the majority of fossil fuels used today. Several of these plants have stated that a transition to renewable energy was already underway before the tax was introduced and that the carbon tax increase will not accelerate the transition, a view shared by WSP. In the government's memorandum *Raising energy tax and carbon dioxide tax on fuels for certain applications and raising tax on chemicals in some electronic goods*[25] it is stated that the transition from fossil to renewable energy in district heating generation is already happening and cannot be seen as a consequence of the carbon tax increase:

'The trend is that the use of fossil fuels in district heating generation will continue to decrease. There are already decisions or commitments to phase out a significant proportion of the remaining fossil fuel use.

For example, Stockholm Exergi has stated that the aim is for coal use in the district heating system to be phased out by 2022. Mälarenergi is building a new cogeneration unit for incinerating wood waste in Västerås which means that the company's district heating and electricity generation will be free from coal and oil by 2020. In Norrköping, E.ON are planning to phase out the use of fossil fuels by 2025. Tekniska Verken i Linköping has stated that energy generation using fossil oil and coal will cease as of 2020. E.ON is also planning to shut down Heleneholmsverket (natural gas) by 2025 and replace it with a biofuel-based installation. Uniper has shut down production in the natural-gas-fired Öresundsverket and in 2018 applied for authorisation to permanently close the installation. In Gothenburg there are also plans to phase out the use of oil and natural gas. A significant proportion of the remaining use of fossil fuels for heat production is therefore already being phased out and can thus not be seen as a result of the present rule change.'[26]

In view of the above, district heating generation using fossil fuels (oil, coal and natural gas) is not something that a survey with proposals for instruments can impact to any great extent as an almost full increase to the carbon tax has already

[23] Note that this only concerns heat production in this case as the tax is taken at the production stage. Electricity production is instead taxed at user level.

[24] Environmental Protection Agency (2019).

[25] Fi2019/00431/S2.

[26] Ibid. p. 28.

been introduced and the industry is already changing.

2.8.2. Waste cogeneration

The use of waste for energy recovery increases each year and has done so throughout the 21st century. In 2017, a little over 6.1 million tonnes of waste were incinerated in 35 installations. Imports of waste to Sweden for energy recovery continue to increase and have multiplied over a 10-year period to around 2.4 million tonnes in 2017[27].

The Energy Agency assumes in the report[28] in accordance with Article 22 of the Renewable Energy Directive[29] that the renewable energy share in waste amounted to 52% for 2017 as well as for 2018. The assumption is based on an investigation that the Energy Agency commissioned the energy consultancy Profu to carry out in 2017[30].

However, the composition of the waste changes over time due to increased waste sorting[31].

Greenhouse gas emissions in buildings are also expected to come primarily from district heating in the future, see Chapter 5.8.2. The reason behind this is primarily the incineration of fossil waste as the emissions are recorded in the energy sector and not in the sector where the waste originated which is what happens in most countries. What demarcations are made therefore affects emissions in the heating sector.

Without district heating and electricity production from waste, there would be a problem concerning how waste should be handled. If it is incinerated without the energy being recovered with electricity and/or heat generation, there will be the same emissions but without the benefit of energy generation[32].

2.8.3. Oil boilers for small-scale heating

The Energy Agency’s housing statistics show that 1 TWh oil was used for heating in 2018 of which 0.4 TWh was in small houses, 0.4 TWh in premises and 0.2 TWh in multi-dwelling buildings. The energy statistics for specifically small houses show that 110 000 houses had oil heating in 2009, while the number decreased to 57 000

[27] SCB (2020).

[28] Government Offices (2019).

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

[30] Profu (2017).

[31] Avfall Sverige (2014).

[32] As a result of the market stability reserve becoming operational in 2019 in the EU ETS, national measures have an impact on the total emissions within the EU ETS. However, this only applies in a few years’ time. In the longer term, the EU ETS is expected to function as before which means that national measures result in a redistribution of emissions over time and space, while the amount of total emissions is governed by the level in the EU ETS.

in 2019.[33]

Calculations in the modelling tool Times Nordic show that oil for small-scale heating will be phased out due to unprofitability also from an 'investor's perspective' as early as 2030, see Chapter 5. .

2.8.4. Natural gas for small-scale heating

In the natural gas network in western Sweden there are just under 39 000 natural gas customers, of which approximately 34 000 are household customers and 4 800 are other customers (for example large industries and cogeneration).[34] According to the Energy Agency's energy statistics, gas heating in housing and premises amounts to 0.8 TWh[35].

SOU More biogas! For a sustainable Sweden[36] the following statement is made: 'There are no official statistics on how much biogas is used for heating premises and housing. An estimate made by Energigas Sverige[37] in 2018 as a response to a question from the National Board of Housing, Building and Planning was that the biogas share should be at least 60% of the gas used for heating and that this share was estimated to be at least 60-70% for the period 2020-2025.'[38] This would mean that biogas would account for 0.5-0.6 TWh of gas heating, with fossil fuel at around 0.2-0.3 TWh. The challenge is then to get rid of the last 0.2-0.3 TWh of natural gas.

Based on the modelling in Chapter 5 natural gas will be phased out by 2030 from an investor's perspective as it is not as profitable as other alternatives. This means that no measures need to be taken for the transition to happen. Over time until 2030, biogas will to some extent gradually replace natural gas. The positive development of biogas is the result of government efforts.[39]

2.8.5. Cogeneration and efficiency

The Energy Agency's report *100 per cent renewable electricity*[40] states that it is important to protect the positive properties that cogeneration and hydropower have for the electricity system with specific focus on whether the system services they contribute are correctly priced. It also states that cogeneration is important for Sweden's future electricity system and that it plays an important role for local capacity in cities, for example, while at the same time there is no obvious market

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33 The Energy Agency (2019a).
34 The Swedish Energy Markets Inspectorate (2019), p. 58.
35 The Energy Agency (2019b).
36 SOU 2019:63
37 Energigas Sverige is an industry organisation for actors in biogas, vehicle gas, gas oil, natural gas and hydrogen gas.
38 Energigas Sverige (2018).
39 SOU 2019:63.
40 ER 2019:06

mechanism for this. Lastly, it states that further investigation should be made into how we can make the most of these features in the best way in the future.

The importance of protecting cogeneration is also made clear in an assignment for the County Administrative Boards in Skåne, Stockholm, Uppsala and Västra Götaland which aimed to shed light on the current and future situation for regional electricity supply.[41] The report shows that in Uppsala, Skåne and Stockholm in particular, the capacity ceilings of the electricity network, primarily the transmission network, were reached and exceeded during parts of the year, especially during cold winter days. The County Administrative Boards further state that whether the increased electricity demand will lead to more cases of regional power and capacity shortages in the electricity network in the future depends on a number of different factors, such as expanding network capacity and renewable electricity production, development of flexibility services, energy storage and instruments that increase the incentive to spread the power demand more evenly throughout the day.

The report also states that all counties are highly dependent on electricity supply from other counties (or countries) and that it is a trend in all counties that electricity production with cogeneration plants is unprofitable and is being shut down. Electricity production that could contribute important power and regulating power when the electricity network is increasingly being challenged by an electrified vehicle fleet, new electricity-intensive industry and establishment of data centres.

Cogeneration's benefits in providing local power became clear in connection with the proposal for increasing the tax on fossil fuels in cogeneration from 11% to 91% on 1 August 2019 (see 2.8.1). Then several cogeneration actors[42] announced that the costs for fossil cogeneration would be so high that they would be forced to phase out fossil power earlier than planned and that the local available power would suffer. In a situation with a shortage of local capacity already, the proposal also constituted an increased challenge for new companies to establish themselves or expand in certain regions. The proposal also started a discussion about the value of local power and the benefits of cogeneration in contributing different system services.[43]

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[41] Conditions for a secure electricity supply – final report to the government concerning case I2019/01614/E.

[42] After the tax increase, Göteborg energi expects that Ryaverket will continue to be run with restricted electricity production cut back to approximately half compared to previous years. In Malmö, E.ON has decided to shut down electricity production in Heleneholmsverket, which corresponds to 25% of Malmö's capacity demand (Swedenergy 2019). Reinforcement of the main grid supply to Malmö is expected to be in place in 2026 and will likely be insufficient according to Swedenergy's assessment. Stockholm Exergi in turn will not run its coal-fired power plant KVV 6 for many hours due to lack of profitability, but it will remain until the regular phase-out date of 2022. Several companies have also been prevented from expanding due to lack of available power. Sources: SvD (2019). Dagens industri (2019). Pöyry (2018).

However, in the Stockholm region, the current capacity shortage situation in the main grid has been remedied by cooperation between Stockholm Exergi and Ellevio together with the government, who found an emergency solution to the situation. Source Ellevio (2019).

[43] See for example: Swedenergy (2019), Referral of memorandum High energy tax and carbon tax on fuel in case of certain usage and high tax on chemicals in certain electronics.

A report that consultancy WSP developed for Stockholms Handelskammare states that in the near future the Stockholm region (despite the emergency solution) will suffer from a significant power shortage which will result in very high costs in the form of job losses, housing that cannot be built and failure to grow both regionally and nationally.[44] Svenska kraftnät's investments of around SEK 11 billion in transmission capacity in the Stockholm region are calculated to be completed in 2030 and result in a transmission capacity from the main grid to Ellevio's regional network in Stockholm from the current 1 525 MW to nearly double, but a delay of two years is assessed by WSP to be the most likely scenario in the report.[45]

The report states that: 'In addition to input from the main grid[46] the available power in the Stockholm region is determined by the capacity in the local electricity production. In the short term the insufficient transmission capacity can therefore be compensated, or in any case eased, by increasing the region's own ability to produce electricity. For Stockholm it is essentially about cogeneration, where electricity and heating are produced simultaneously through incinerating waste and other fuel.'[47]

The report *Cogeneration in the future*[48] states that 'Although the profitability of new cogeneration will be relatively weak over the next few years, it should be borne in mind that once the demand for controllable electricity increases significantly in the future, it may be partly too late to count on cogeneration. A number of district heating companies must already decide on investments in new district heating generation primarily in order to replace older installations. If, as a result of the prevailing circumstances, one then decides on a district heating generation other than cogeneration, for example heat only boilers, then the incentive to build cogeneration in 10 years will be limited, as what is chosen today typically has an economic lifespan of two decades and an even longer technical lifespan. The problem is that there is currently no form of incentive to make a decision that from a longer-term perspective might have been preferable in terms of the electricity system.'

Overall, a picture emerges showing major challenges in terms of a lack of available local power, the reasons being partly an insufficiently expanded transmission capacity and partly a loss of cogeneration that may stem from benefits from cogeneration not being priced correctly.

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[44] Stockholms handelskammare (2020).
[45] Ibid.
[46] Now called the transmission network
[47] Ibid
[48] Profu (2019)

In the model calculations for cogeneration potential in Chapter 5 cogeneration increases in the future as electricity prices rise, but in reality, it may be that new investments are not made if incentives for investments in heat only boilers today mean that investments in cogeneration are not made later.

For Sweden it is therefore not about promoting cogeneration to increase the proportion of high-efficiency cogeneration (all cogeneration is already highly efficient, see next chapter) or to reduce primary energy use or increase the renewable proportion. For us it is about safeguarding cogeneration due to benefits in the form of system support services and contributions to a robust energy system with a secure energy supply.

2.8.6. High-efficiency heat and power cogeneration

According to Article 14(1) and Annex VIII, Part III, point 7, the potential for high-efficiency cogeneration must also be analysed.

The values used for calculating the efficiency of cogeneration and primary energy savings must be determined on the basis of the expected or actual operation of the boiler under normal operating conditions. High-efficiency cogeneration will mean primary energy savings of at least 10% compared to the reference values for separate production of heat and electricity.[49]

In Sweden it was already concluded in 2005[50], in view of the Energy Efficiency Directive, that the existing Swedish cogeneration plants are highly efficient and that nearly all Swedish cogeneration plants have an efficiency grade in the order of 90%. Regardless of what reference values are determined by the Commission, the Swedish cogeneration plants will fulfil the criteria for high-efficiency cogeneration plants.

There is therefore no potential in Sweden to increase the share of high-efficiency cogeneration as all cogeneration is already highly efficient. However, there is the potential to replace heat-only production with high-efficiency cogeneration.

3. Maps and installations

This Chapter responds to the requirements set out in the Energy Efficiency Directive Annex VIII 2(b)(i)-(v) and 3(a)-(c). It is stated in brackets where the main requested information can be found and below is an overview of the different figures

[49] For the calculation method, see Annex II to the Energy Efficiency Directive.
[50] SOU 2005:33.

and tables. An introductory chapter also helps to respond to the Directive's requirements.

2(b) Identification of installations that produce waste heat or waste cooling and their potential heating or cooling supply in GWh per year:

i) Installations for thermal power generation that can supply or be equipped to supply waste heat with a total thermal input exceeding 50 MW. (Figure 13, Figure 16, Figure 18, Figure 19, Figure 20)

ii) Cogeneration installations that use the technology referred to in Part II of Annex I with a total thermal input exceeding 20 MW. (Figure 18, Figure 19)

iii) Waste incineration plants. (Figure 18, Figure 19)

iv) Installations for renewable energy with a total thermal input exceeding 20 MW, except the installations referred to in point 2(b)(i) and (ii) which produce heat or cooling using energy from renewable energy sources. (Figure 18, Figure 19)

v) Industrial installations with a total thermal input exceeding 20 MW which can supply waste heat. (Figure 16, Figure 18, Figure 19, Figure 20)

3. A map of the entire national territory which shows, without revealing commercially sensitive information:

a) heating and cooling demand areas following from the analysis of point 1, while using consistent criteria for focusing on energy dense areas in municipalities and conurbations (Figure 12, Table 1, Figure 14, Figure 15, Figure 17)

b) existing heating and cooling supply points identified under point 2(b) and district heating transmission installations (Figure 16, Figure 12, Figure 18, Figure 19)

c) planned heating and cooling supply points of the type described under point 2(b) and district heating transmission installations. (Figure 18)

<u>An overview of the different maps and tables that respond to the questions above.</u>

Figure 12 Potential regional district heating and waste heat partnerships

Table 1 Potential district heating partnerships including waste heat

Figure 13 Potential sources for waste heat use

3.1. Identification of installations that produce waste heat or waste cooling and their potential heating or cooling supply (2(b)(i)-(v)) and maps (3(a)-(c))

In the report 2015:102[51] by Fjärrsyn (the national district heating research programme) (Energiforsk), a number of regional district heating partnerships were studied including the potential for more waste heat partnerships. Identification of potential district heating regions has been based on a number of selection criteria which limit the number of relevant networks. The basis has been that only networks with at least 100 GWh in annual supplies are concerned. This includes a little over 90 district heating networks, which are assumed to be able to be interconnected to nearby networks which have both bigger and smaller district heating supplies than 100 GWh (see Figure 12).

Figure 12 Potential regional district heating and waste heat partnerships

[51] Energiforsk (2015).

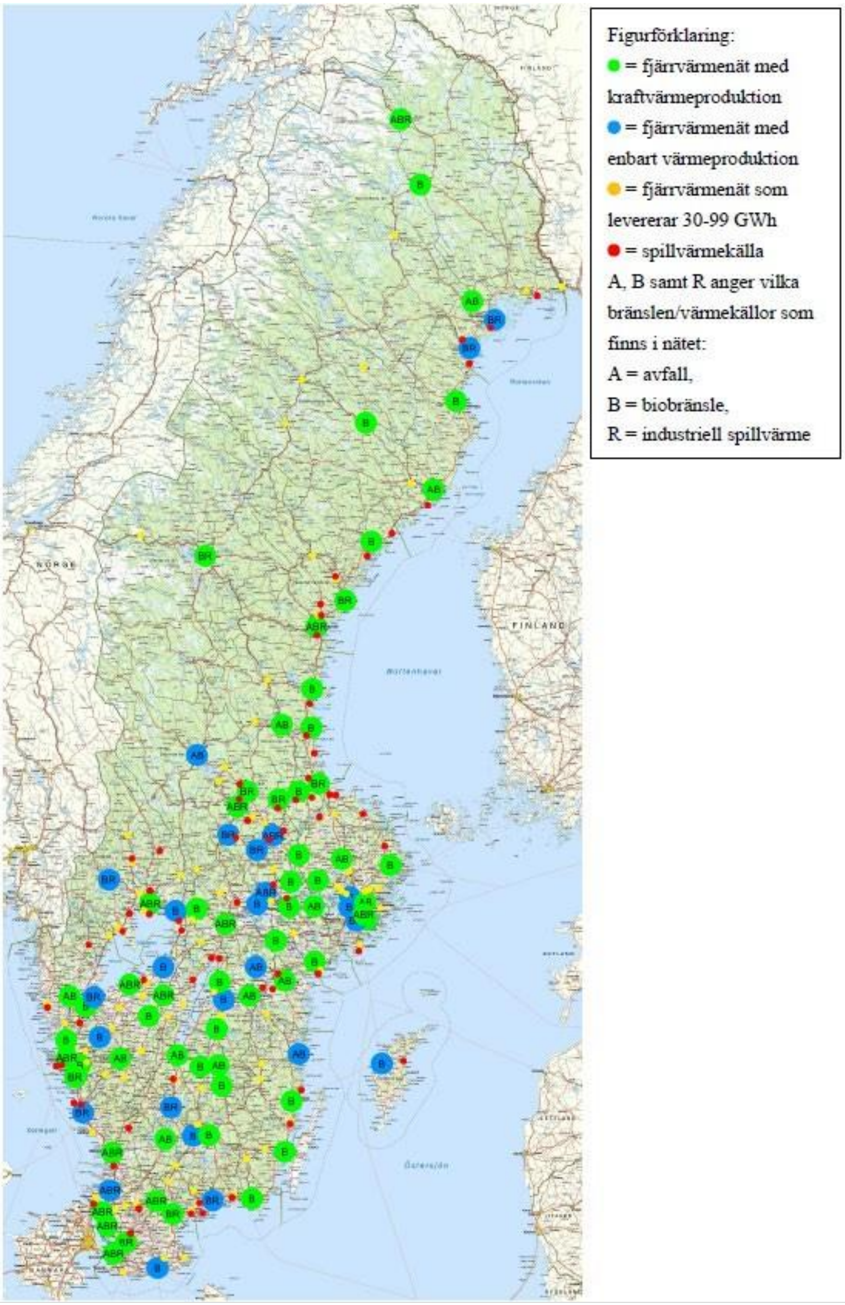


Figure explanation:

- = district heating network with cogeneration
- = district heating network with only heat production
- = district heating network that supplies 30-99 GWh
- = waste heat source

A, B and R indicate which fuels / heat sources are in the network:

A = waste,

B = biofuel,

R = industrial waste heat

Source: Energiforsk (2015).

Figure 12 shows that there are a large number of nearby district heating networks with the possibility of interconnections and utilisation of waste heat. However, the profitability depends on a number of different factors such as distance, heat supply per km, production mix, presence of cogeneration, demand for new investments, etc.[52] When these factors have been taken into account, 10 potential 'clusters' with 19 different district heating actors have been identified which had a GWh/km factor higher than 5, see Table 1. On the basis of these, four clusters which all contain waste heat potential have been studied more closely (Vänersborg–Trollhättan, Gävle–Sandviken, Boden–Luleå and Kristianstad–Hässleholm) In two of these clusters (Boden–Luleå and Kristianstad–Hässleholm) financial calculations have been made which show that profitability is lacking based on the assumptions made in the calculations. The other two clusters (Trollhättan–Vänersborg and Gävle–Sandviken) have themselves made financial calculations which show that it is possible to achieve profitability with an interconnection, but the conditions vary and the profitability is dependent on several factors, where one of the decisive factors is how large the waste heat potential is.

Table 1 Potential district heating partnerships including waste heat

Potential cluster	Actor	Km	Heat supplies 2012 (GWh)	Primary fuel for heat production [1]	GWh/km (30 % of supply)	Comments
Malmö – Lund	E.ON Kraftringen	18.6	2 244 888	ABR BR	47.7	Two big networks relatively close to each other. Kraftringen's network is currently connected to Öresundskraft and Landskrona Energi, which complicates an assessment of the potential. The issue has been investigated more broadly by (Eriksson, 2010) and (Bernstad, 2009), inter alia.
Vänersborg – Trollhättan	Vattenfall Trollhättan Energi	13	145 346	BR B	10.7	The district heating networks consist of different production mixes, at the same time as the distance between the locations is relatively short in relation to the potential amount of heat transferred. However, investigations have been carried out and are ongoing.
Gävle – Sandviken	Gävle Energi Sandviken Energi	24	732 232	BR B	9.7	The district heating networks consist partially of different production mixes, at the same time as the distance between the locations is relatively short in relation to the potential amount of heat transferred. The issue is currently being investigated.
Boden – Luleå	Boden Energi Luleå Energi	37	305 806	AB BR	8.2	The district heating networks consist of different production mixes, at the same time as there is potential to increase the proportion of waste gases fired in Luleå. However, the issue has been investigated before, according to the survey results in the introductory study.
Ängelholm – Helsingborg	Öresundskraft	28	194 1 002	ABR ABR	6.9	The district heating networks consist of different production mixes. However, the issue has been investigated according to

[52] Energiforsk (2015).

						an interview with Öresundskraft, and it is currently not financially profitable to have an interconnection.
Enköping – Västerås	Ena Energi Mälarenergi	35	1 535 211	B B	6.0	Relatively long distance in relation to potential amount of heat transferred, as the production mixes are in principle the same in both networks.
Växjö – Alvesta	Växjö Energi Alvesta Energi	19	557 106	B B	5.6	The district heating networks consist partially of different production mixes, at the same time as the distance between the locations is relatively short. The issue has been partially investigated before, according to the survey results in the introductory study.
Nyköping – Oxelösund	Vattenfall Oxelö Energi	15	284 82	B R	5.5	The district heating networks consist of different production mixes, at the same time as more industrial waste heat can be used. The issue has been investigated previously by Lindow (2009), inter alia. Studies show that profitability is lacking.
Mölnlycke – Mölndal	Solör Mölndal Energi	9	47 389	B B	5.5	The district heating networks consist of different production mixes, at the same time as the distance between the locations is short. However, there are large elevation differences between the locations.
Kristinestad – Hässleholm	C4 Energi Hässleholm Energi	32	353 193	BR ABR	5.1	Relatively long distance in relation to potential amount of heat transferred, as both networks have cogeneration.

[1] A = Waste, B = Biofuel, R = Industrial waste heat

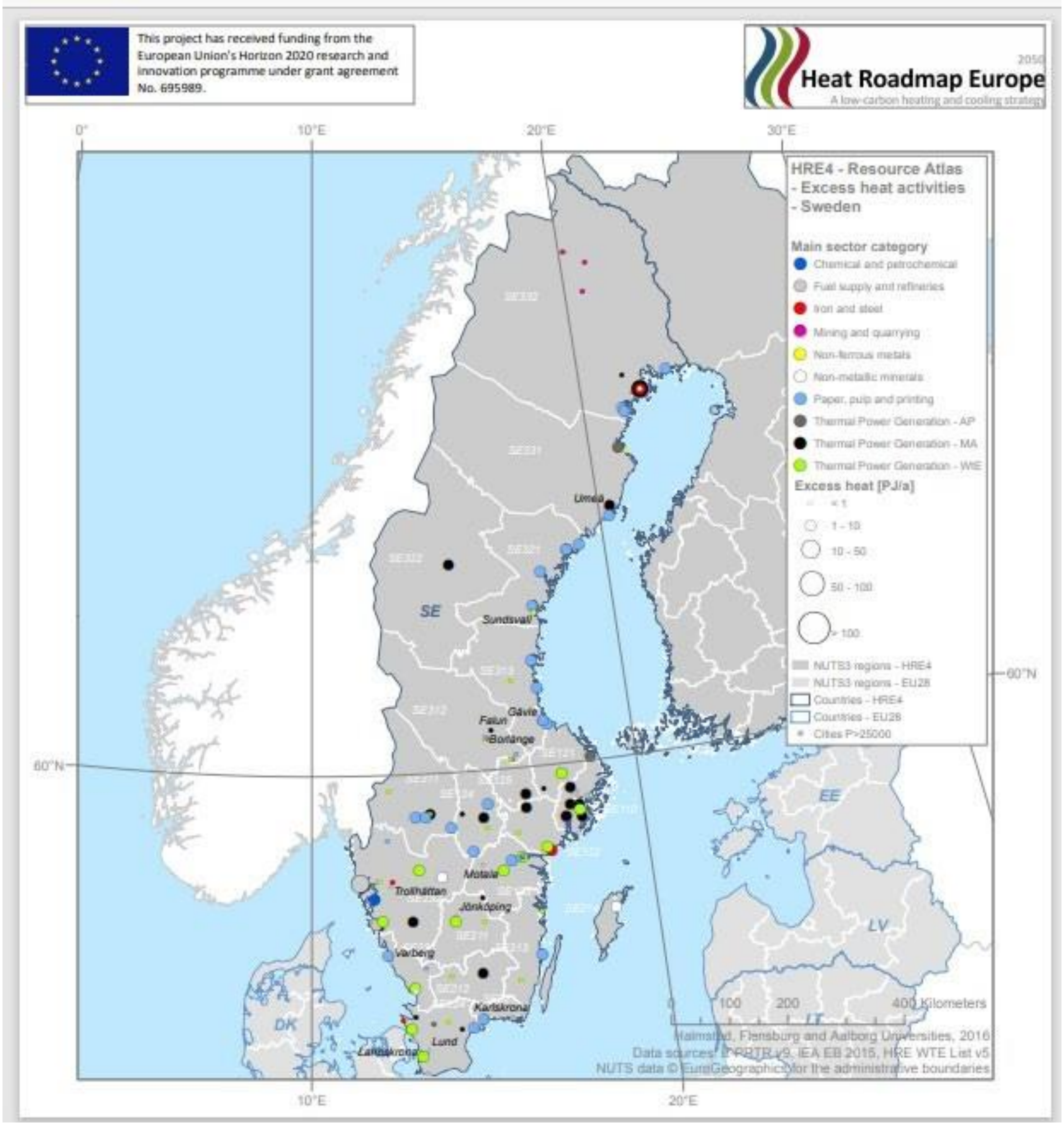
Source: Energiforsk (2015).

The report's overall conclusions are as follows: *'In summary, it can be said that economic viability is a prerequisite for more regional district heating partnerships to take place and if the economic viability exists, time and resources are required to design forms of cooperation and business models that are favourable for all parties involved. Furthermore, it is clear that the regional interconnections that have reasonable potential have been or are currently being investigated by the actors themselves. This shows that the industry is very cost-conscious and open to cooperation with adjoining network owners where this is an economically attractive option.'*

More potential sources for waste heat can be seen in Figure 13 which shows where different types of production installations by sector and fuel are located on the map as well as estimated 'excess heat'[53].

Figure 13 Potential sources for waste heat use

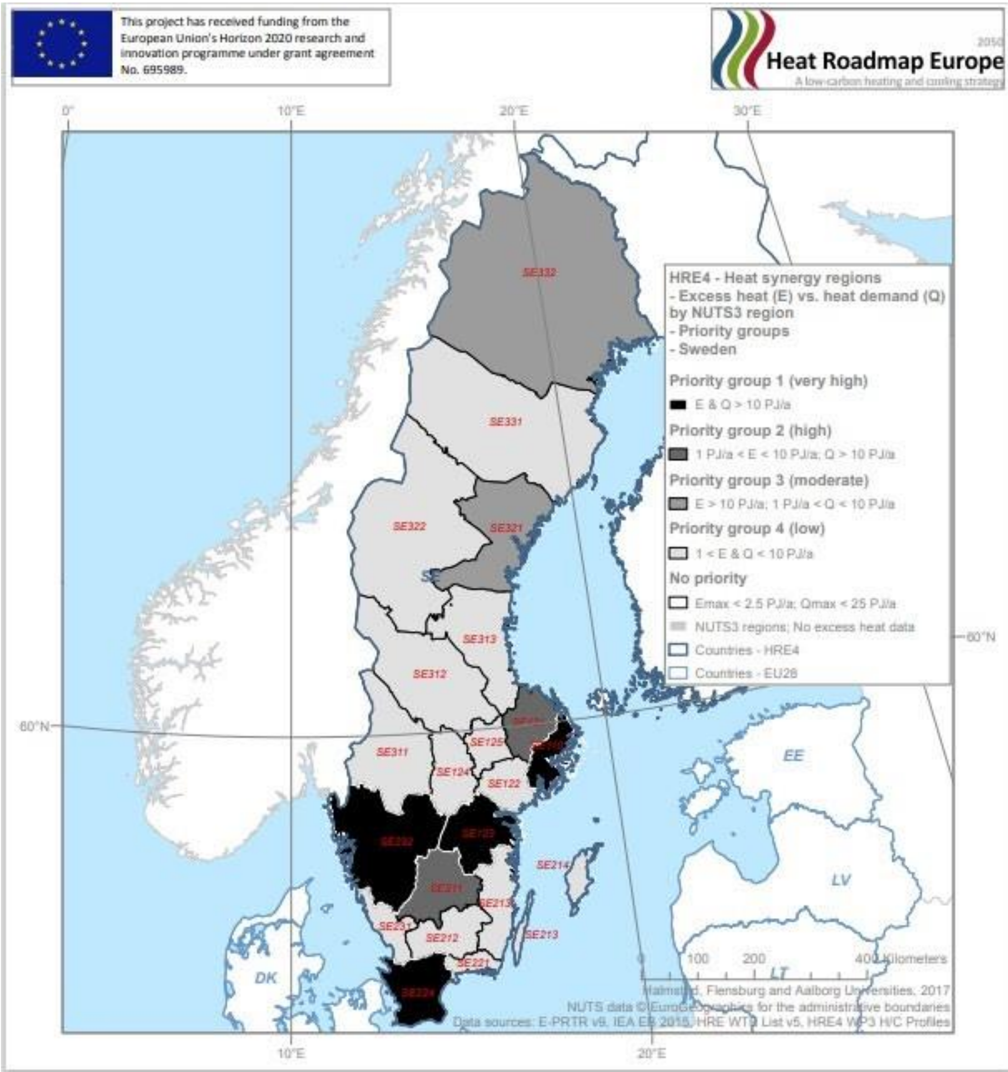
[53] Excess heat is a term that indicates that the waste heat is not necessarily at the right temperature to be used directly on a district heating network.



Source: Heat Roadmap Europe (2020).

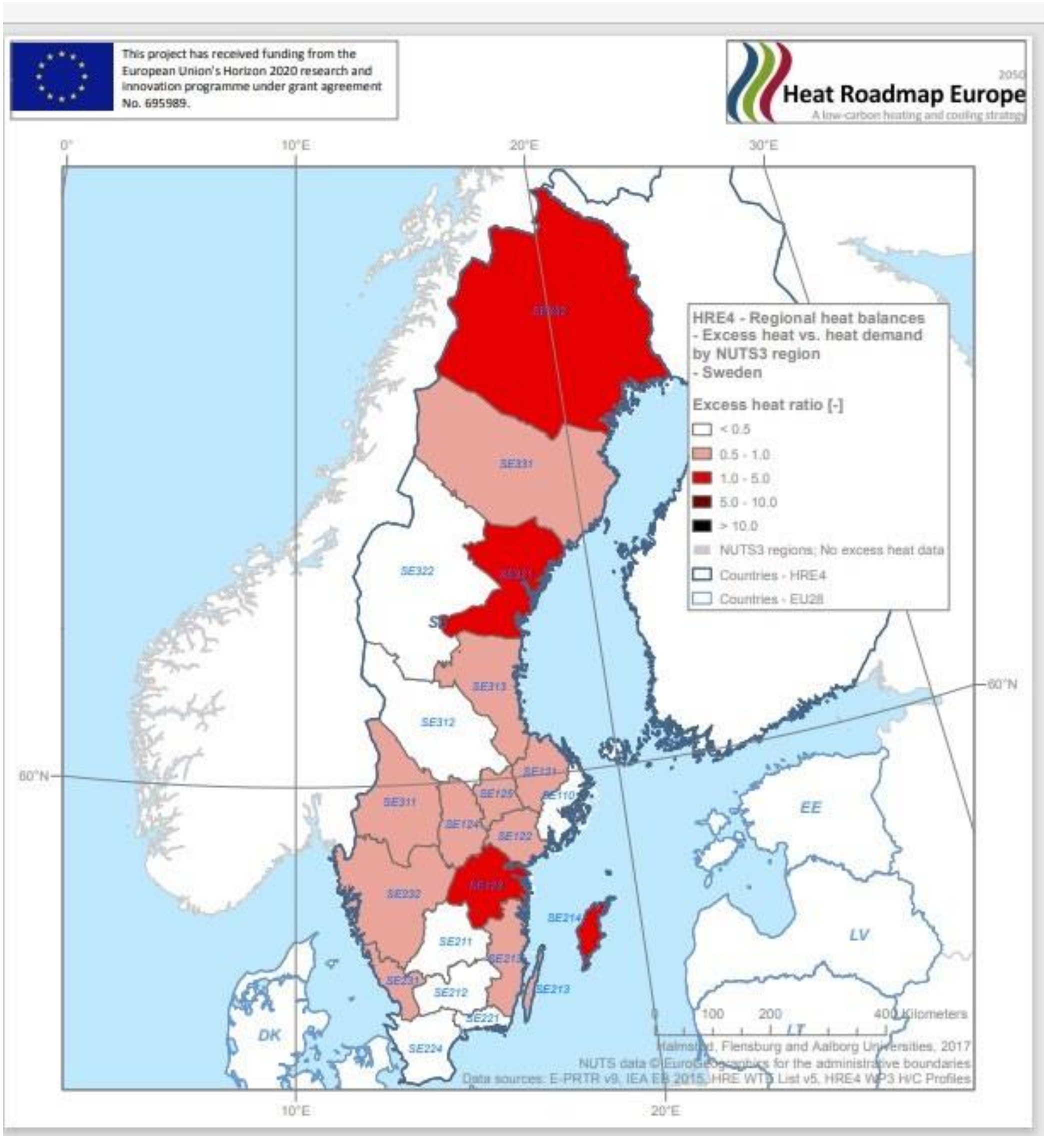
Figure 14 and Figure 15 give an indication of which regions have a greater possibility of being able to use excess heat/waste heat, by also looking at the heating demand.

Figure 14 Regions with greater possibility of being able to use excess heat



Source: Heat Roadmap Europe (2020).

Figure 15 Excess heat vs heating demand



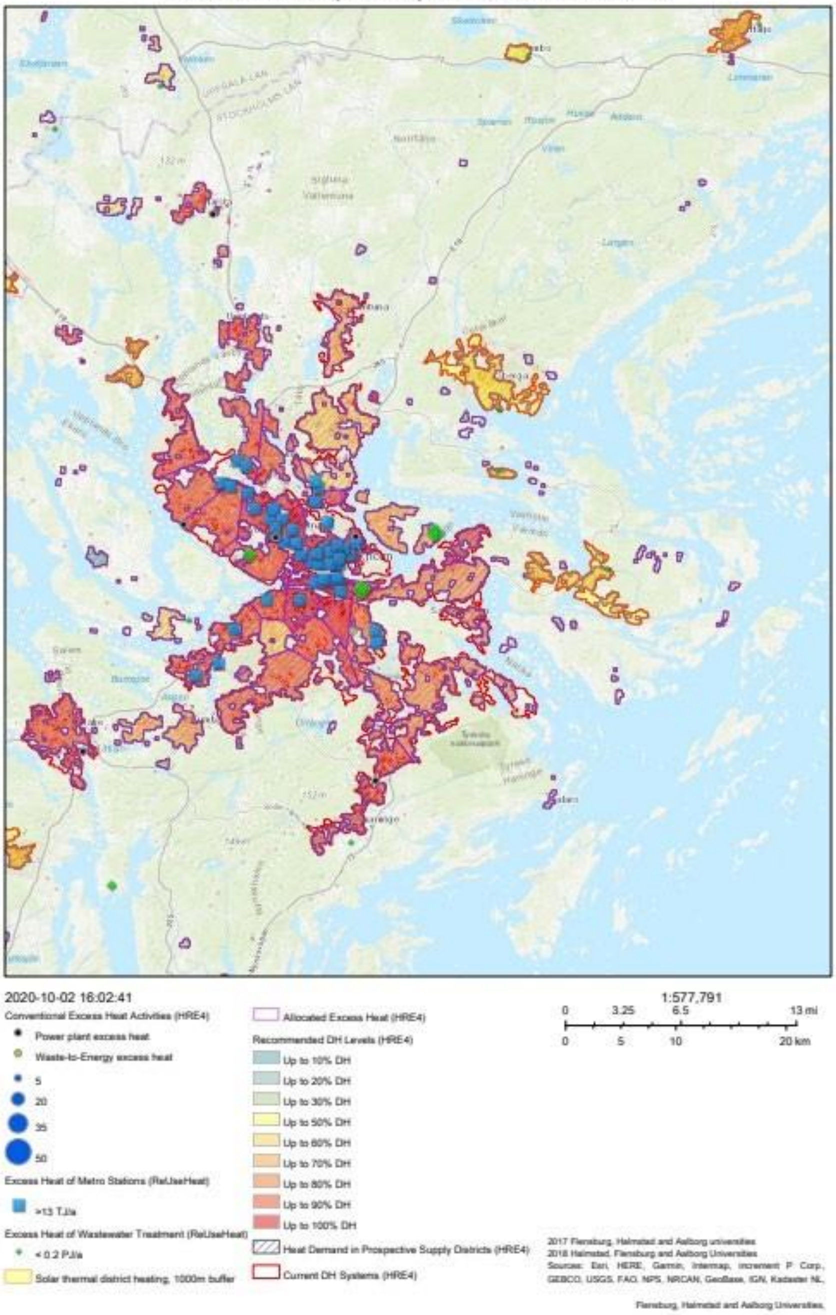
Source: Heat Roadmap Europe (2020).

Figure 16 shows a map of Stockholm which looks at waste heat sources as well as the heating demand, but also the district heating network. The map comes from the project Heat Roadmap Europe[54] where maps for more regions/cities can be developed through an interactive database. Stockholm has been selected in this report. Several of the maps respond to points 2(b)(i)-(v) as well as 3(a)-(c) in Annex VIII. The Heat Roadmap Europe maps include, for example, installations, district heating networks (supply points), demand and the opportunity to see access to biofuel.

Figure 16 Stockholm Heat Roadmap Europe

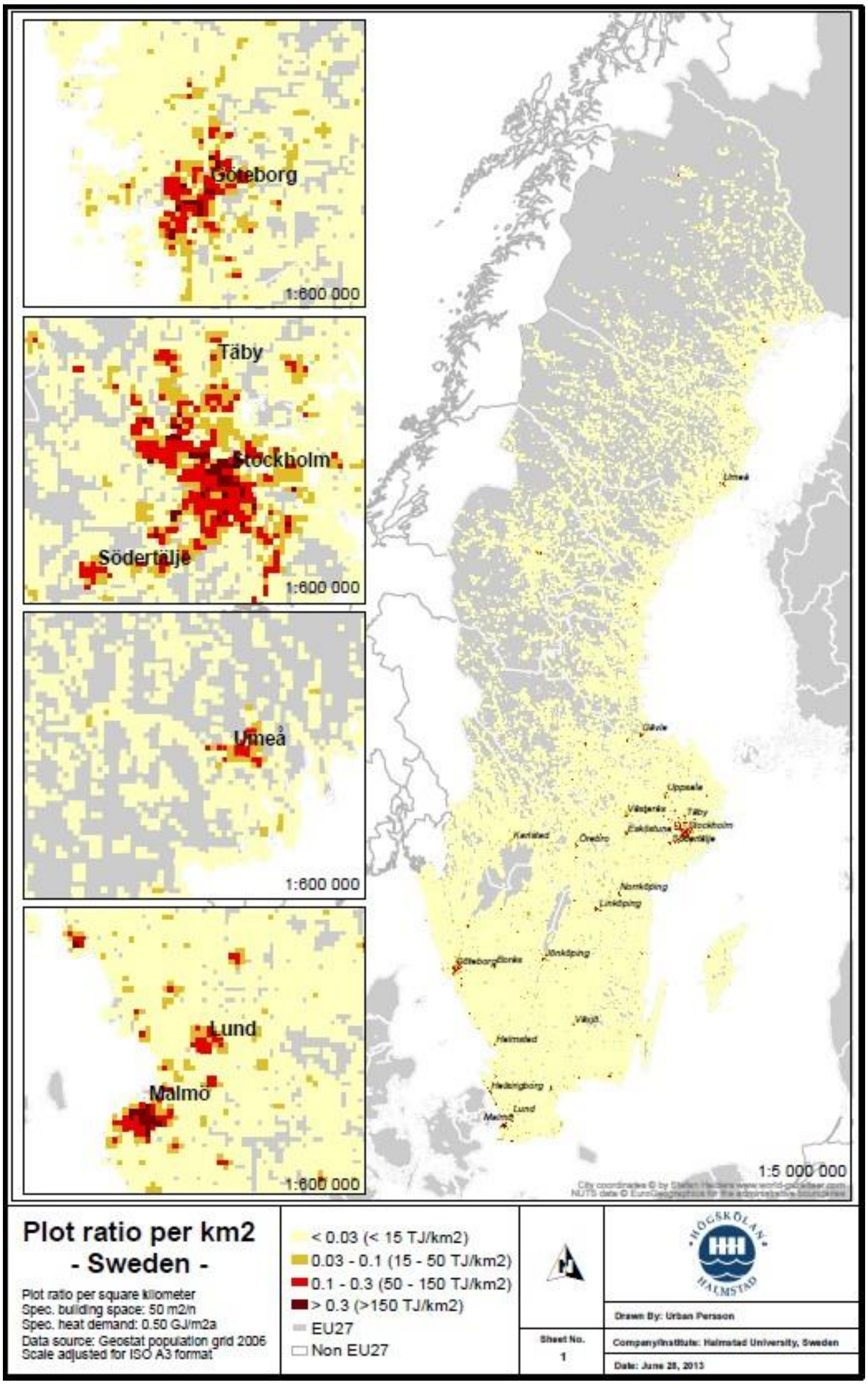
[54] Heat Roadmap Europe (2020).

Heat Roadmap Europe - Peta 4 version 3



Source: Heat Roadmap Europe (2020).

Figure 17 Heat and cooling demand points by plot ratio.



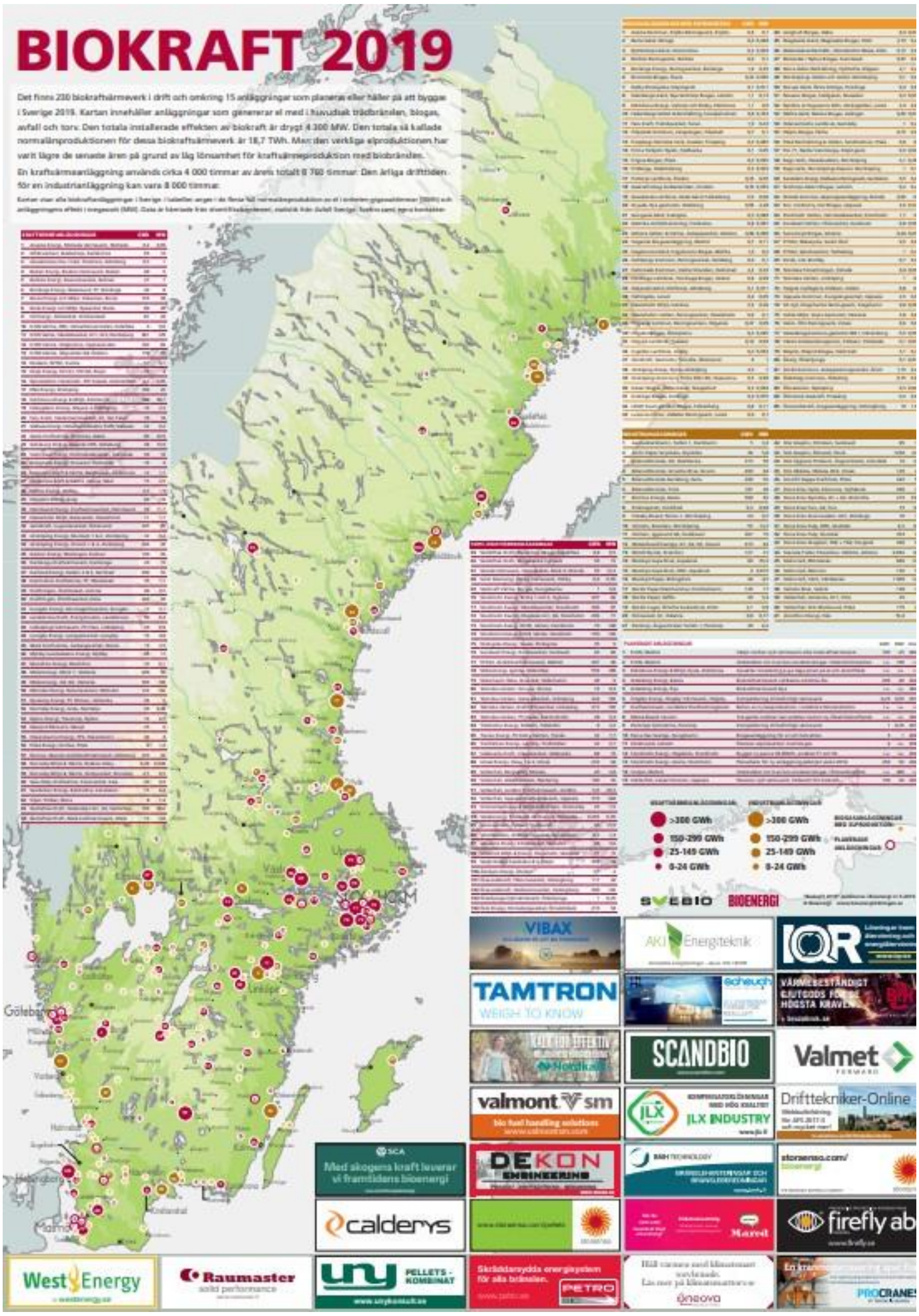
The maps from the industry organisation Svebio[55] include both existing and planned installations in both industry and power production with different types of fuels broken down by network, installed power and annual production (Figure 18 and Figure 19).

Svebio's map 'Biopower in Sweden 2019' contains 230 biomass cogeneration plants in operation and 15 installations that are planned or are being built in Sweden in 2019, see Figure 18. The map includes installations that generate electricity with biofuel, peat and waste as fuel, including industrial installations. For each installation, both GWh/year and the installed power are stated. The total installed power is a little over 4 300 MW. The normal annual production for these biopower plants is around 18.7 TWh, but the real electricity production from biopower was lower in the past year due to the economic conditions. On average, biopower installations are estimated to be used for around 4 000 hours of the annual total of 8 760 hours at normal annual production. The operating time for an industrial installation may be up to 8 000 hours per year.[56]

Figure 18 Biomass cogeneration in Sweden 2019 (including planned installations, and installations in the industry)

[55] Read more about Svebio at https://www.svebio.se/om-oss/.

[56] Svebio (2019a).



Source: Svebio (2019b), https://www.svebio.se/app/uploads/2019/10/Biokraftkartan2019-web.pdf.

BIOPOWER 2019

There are 230 biomass cogeneration plants in operation and around 15 installations that are planned or are currently being built in Sweden in 2019. The map includes installations that generate electricity using mainly wood fuels, biogas, waste and peat. The total installed power of biopower is a little over 4 300 MW. The total 'normal annual production' for these biomass cogeneration plants is 18.7 TWh. However, the actual electricity production has been lower in recent years due to low profitability of cogeneration using biofuel.

A biopower installation is used for around 4 000 hours of the annual total of 8 760 hours. The annual operating time for an industrial installation may be 8 000 hours.

The map shows all biopower installations in Sweden. The table indicates in most cases normal annual production of electricity in the unit gigawatt hours (GWh) and the installation's power in megawatts (MW). Data is taken from the electricity certificate scheme, statistics from Avfall Sverige, Svebio contacts.

	COGENERATION INSTALLATIONS	GWh	MW
1	Alvesta Energi, Moheda Värmeverk, Moheda	0.2	0.05
2	Affärsverken, Bubbetorp, Karlskrona	65	14
3	Akademiska Hus i Väst, Chalmers, Gothenburg	0.5	1
4	Boden Energi, Bodens Värmeverk, Boden	40	9
5	Bollnäs Energi, Säverstaverket, Bollnäs	27	7
6	Borlänge Energi, Bäckelund, P7, Borlänge	42	8
7	Borås Energi och Miljö, Sobacken, Borås	155	44
8	Borås Energi och Miljö, Ryaverket, Borås	80	45
9	C4 Energi, Allöverket, Kristianstad	81	24
10	E.ON Värme, ORC, Hetvattencentralen, Sollefteå	4	0.8
11	E.ON Värme, Händelöverket, G11, G13, Norrköping	461	129
12	E.ON Värme, Högbytorp, Upplands-Bro	165	85
13	E.ON Värme, Åbyverket G4, Örebro	170	25
14	Ekokem, WTE2, Kumla	57	6.1
15	Eksjö Energi, H21G1, H21G2, Eksjö	15	4
16	Elproduktion i Stockholm, ETC Solpark, Katrineholm	0.1	0.05
17	ENA Energi, Enköping	100	23
18	Eskilstuna Energi & Miljö, Eskilstuna	180	38.7

	19	Falbygdens Energi, Majarp 2, Falköping	16	2.3
	20	Falu Kraft, Västermalmsverket, G1, G2, Falun	78	18
	21	Gällivare Energi, Hetvattencentralen, KVP3, Gällivare	32	9.2
	22	Gävle Kraftvärme, Johannes, Gävle	80	23.9
	23	Göteborg Energi, Sävenäs HP3, Gothenburg	38	13.9
	24	Halmstads Energi, Kristinehedsverket, Halmstad	54	10
	25	Halmstads Energi, Oceanen, Halmstad	16	4
	26	Hedemora Kraft & Värme, Bergbacken, Hedemora	12	1.7
	27	Hedemora Kraft & Värme, Hamre, Säter	15	2.5
	28	Hofors Energi, Hofors	2.5	1.5
	29	Härjeåns Energi, Sveg	60	10
	30	Härnösand Energi, Kraftvärmeverket, Härnösand	30	11.7
	31	Hässleholm Miljö, Beleverket, Hässleholm	11	1.7
	32	Jämtkraft, Lugnviksverket, Östersund	225	45
	33	Jönköping Energi, Munksjö 1 & 2, Jönköping	32	9.2
	34	Jönköping Energi, Torsvik 1 & 2, Jönköping	236	49
	35	Kalmar Energi, Moskogen, Kalmar	130	35
	36	Karlskoga Kraftvärmeverk, Karlskoga	24	15
	37	Karlstad Energi, Heden 2 & 3, Karlstad	230	55
	38	Katrinefors Kraftvärme, P7, Mariestad	35	7.7
	39	Kraftringen, Återbruket, Lomma	20	4.5
	40	Kraftringen, Örtoftaverket, Eslöv	220	39
	41	Kungälv Energi, Munkegärdsverket, Kungälv	12	3.1
	42	Landskrona Kraft, Energiknuten, Landskrona	50	8.4
	43	Lidköpings Värmeverk, PC Filen, Lidköping	24	9.8
	44	Ljungby Energi, Ljungsjöverket, Ljungby	15	4.6
	45	Mark Kraftvärme, Assbergsverket, Skene	15	3.5
	46	Mjölby-Svartådalens Energi, Mjölby	45	11
	47	Munkfors Energi, Munkfors	10	2.1
	48	Mälarenergi, Block 7, Västerås	220	50
	49	Mälarenergi, G4, G6, Västerås	500	100
	50	Mölndal Energi, Riskullaverket, Mölndal	132	132

51	Njudung Energi, PC Stickan, Vetlanda	26	7
52	Norrtälje Energi, Arsta, Norrtälje	35	6.36
53	Nybro Energi, Transtorp, Nybro	16	6.5
54	Nässjö Affärsverk, Nässjö	25	9
55	Oskarshamns Energi, FP2, Oskarshamn	20	4
56	Piteå Energi, Hortlax, Piteå	6	1.2
57	Renova, Sävenäs Avfallskraftvärmeverk, Gothenburg	270	42
58	Ronneby Miljö & Teknik, Bräkne-Hoby	0.28	0.049
59	Ronneby Miljö & Teknik, Sörbyverket, Ronneby	2.7	0.5
60	Sala-Heby Kraftvärme, Silververket, Sala	30	9.9
61	Sandviken Energi, Björksätra, Sandviken	15	5.2
62	Siljan Timber, Mora	8	1.4
63	Skellefteå Kraft, Hedensbyn G1, G2, Skellefteå	150	40.6
64	Skellefteå Kraft, Malå kraftvärmeverk, Malå	13	2.8

CONTINUED COGENERATION INSTALLATIONS

65	Skellefteå Kraft, Powerbox, Skega, Skellefteå	0.8	0.5
66	Skellefteå Kraft, Skogsbacka, Lycksele	50	15
67	Skövde Värmeverk, Värmekällan, Block 4, Skövde	59	12.3
68	Solör Bioenergi, Hörby Värmeverk, Hörby	0.4	0.05
69	Statkraft Värme, Borgås, Kungsbacka	1	0.8
70	Stockholm Exergi, Brista 1 & 2, Sigtuna	297	66
71	Stockholm Exergi, Hässelbyverket, Stockholm	300	87
72	Stockholm Exergi, Högdalen G1, G6, Stockholm	296	71
73	Stockholm Exergi, KVV6, Värtan, Stockholm	79	148
74	Stockholm Exergi, KVV8, Värtan, Stockholm	750	130
75	Strängnäs Energi, Sevab, Strängnäs	35	9
76	Sundsvall Energi, Korstaverket, Sundsvall	43	60
77	SYSAV, Avfallskraftvärmeverk, Malmö	267	40
78	Söderenergi, Igelsta, Södertälje	550	108
79	Söderhamn Nära, Granskär, Söderhamn	40	9
80	Tekniska Verken i Kiruna, Kiruna	19	9.4
81	Tekniska Verken, Gärstadverket, Linköping	324	102
82	Tekniska Verken, Kraftvärmeverket, Linköping	215	102
83	Tekniska Verken, PC Väster, Katrineholm	28	5.4

	84	Tidaholms Energi, Eldaren, Tidaholm	8	2.2
	85	Tranås Energi, P6 Södra Vakten, Tranås	32	7.7
	86	Trollhättan Energi, Lextorp, Trollhättan	22	3.7
	87	Uddevalla Kraft, Lillesjöverket, Uddevalla	68	10
	88	Umeå Energi, Dåva 1 & 2, Umeå	233	64
	89	Vattenfall, Bergsätter, Motala	24	3.8
	90	Vattenfall, Idbäcksverket, Nyköping	100	35
	91	Vattenfall, Jordbro Kraftvärmeverk, Jordbro	123	20.3
	92	Vattenfall, Uppsala Kraftvärmeverk, Uppsala	379	204
	93	Vimmerby Energi & Miljö,Tallholmen, Vimmerby	25	7.5
	94	Vänerenergi, Töreboda Värmeverk, Töreboda	0.265	0.05
	95	Värmevärden, Djuped, Hudiksvall	30	13.9
	96	Värmevärden, Kraftvärmeverket, Nynäshamn	6.5	1.4
	97	Värnamo Energi, Sörsjöverket, Värnamo	20	3.6
	98	Västervik Miljö & Energi, Stegeholm, Västervik	21	5
	99	Växjö Energi, Sandvik 2 & 3, Växjö	370	78
	100	Älvsbyns Energi, Älvsbyn	7.7	3
	101	Öresundskraft, Filbornaverket, Helsingborg	117	20
	102	Öresundskraft, Västhamnsverket, Helsingborg	300	126
	103	Örkelljunga Fjärrvärmeverk, Örkelljunga	1	0.25

	104	Övik Energi, Hörneborgsverket, Örnsköldsvik	219	54

BIOGAS INSTALLATIONS WITH ELECTRICITY PRODUCTION		GWh	MW
1	Avesta Municipality, Krylbo Reningsverk, Krylbo	0.4	0.1
2	Berte Gård, Slöinge	0.4	0.044
3	Björketorps Gård, Johannishus	0.2	0.033
4	Bollnäs Reningsverk, Bollnäs	0.4	0.1
5	Borlänge Energi, Reningsverket, Borlänge	1.4	0.25
6	Brunnsbo Biogas, Skara	0.22	0.035
7	Dalby Ekologiska, Köpingsvik	0.1	0.011
8	Edenberga Gård, Nya Skottorp Biogas, Laholm	1.1	0.13
9	Eskilstuna Energi, Viptorp & Ekeby, Eskilstuna	1.1	0.9
10	Falkenbergs Vatten & Renhållning, Smedjeholmen	0.8	0.353
11	Falu Kraft, Främbyverket, Falun	1.9	0.23
12	Filipstad Municipality, Långskogen, Filipstad	0.7	0.1
13	Finspångs Tekniska Verk, Axsäter, Finspång	0.3	0.065
14	Firma Torbjörn Nylén, Fjällbacka	0.1	0.05
15	Frigiva Biogas, Piteå	0.3	0.055
16	Fröberga, Söderköping	0.3	0.033
17	Frötorps Lantbruk, Örebro	0.25	0.05
18	Gaskraftuttag Kulbäcksliden, Vindeln	0.35	0.055
19	Glassbacka Lantbruk, Hede Gård, Falkenberg	0.5	0.06
20	Gryaab, Rya gasmotor, Gothenburg	0.05	2.28
21	Gungvala Gård, Svängsta	0.3	0.044
22	Gästrike Avfallshantering, Forsbacka	0.8	0.097
23	Götene Vatten & Värme, Avloppsverket, Götene	0.84	0.099
24	Hagaviks Biogasanläggning, Malmö	0.7	0.11
25	Hagelsrums Gård, Hagelsrums Biogas, Målilla	1.4	0.2
26	Hallsberg Municipality, Reningsverket, Hallsberg	0.4	0.1
27	Halmstad Municipality, Västra Stranden, Halmstad	2.2	0.33
28	Horshaga Lantbruk, Horshaga Biogas, Vedum	0.6	0.09
29	Häljereds Gård, Olofstorp, Gothenburg	0.1	0.011
30	Hällingsbo, Lerum	0.4	0.05

	31	Hässleholm Miljö, Vankiva	2.5	0.36
	32	Hässleholms Vatten, Reningsverket, Hässleholm	0.6	0.1
	33	Höganäs Municipality, Reningsverken, Höganäs	0.27	0.09
	34	Högebo Biogas, Österplana	0.3	0.045
	35	Högryd Lantbruk, Tvååker	0.72	0.99
	36	Ingelsbo Lantbruk, Aneby	0.2	0.033
	37	Jämtkraft, Gasmotor, Torvalla, Östersund	6	1
	38	Jönköping Energi, Ryhov, Jönköping	3.3	1
	39	Jönköping Municipality, Frichs Mini 90, Huskvarna	0.5	0.09
	40	Kalset Biogas, Östra Kalset, Skeppshult	0.3	0.044
	41	Kvidinge Biogas, Kvidinge	0.4	0.075
	42	LOGP, Kvarngårdens Biogas, Falkenberg	0.8	0.11
	43	Luleå Municipality, Uddebo Reningsverk, Luleå	0.9	0.1
	44	Långhult Biogas, Habo	0.4	0.075
	45	Maglasäte Gård, Maglasäte Biogas, Höör	2.19	0.25
	46	Mellanskånes Renhålln., Rönneholms Mosse, Eslöv	0.15	0.02
	47	Molander i Nyhus Biogas, Svenstavik	0.07	0.03
	48	Norra Åsbro Renhållning, Hyllstofta, Klippan	2.1	0.25
	49	Norrköpings Vatten och Avfall, Norrköping	0.1	0.05
	50	Norups Gård, Östra Göinge, Knislinge	0.4	0.06
	51	Nossans Biogas, Stallgatan, Nossebro	0.3	0.035
	52	Nyhléns & Hugossons Kött, Alviksgården, Luleå	2.4	0.65
	53	Näfsta Gård, Nävsta Biogas, Selånger	0.65	0.075
	54	Odensviholms Lantbruk, Gamleby	1	0.26
	55	Olpers Biogas, Färila	0.15	0.02
	56	Piteå Renhållning & Vatten, Sandholmen, Piteå	0.8	0.1
	57	Pos 71, Nedra Vannborga, Köpingsvik	0.3	0.044
	58	Ragn-Sells, Häradsudden, Norrköping	2.1	0.285
	59	Ragn-Sells, Norrköpings Deponi, Norrköping	1	0.12
	60	Sandviken Energi, Hedåsens Reningsverk, Sandviken	0.5	0.08
	61	Skottorps Säteri Biogas, Laholm	0.2	0.25

62	Skövde Municipality, deponigasanläggning, Skövde	0.65	0.1
63	SLU, misSLUrry, SLU Biogas, Uppsala	3.6	0.527
64	Stockholm Vatten, Henriksdalsverket, Stockholm	1.7	2.8
65	Sundsvall Vatten, Fillanverket, Sundsvall	0.8	0.095
66	Svenstorps Biogas, Götene	0.24	0.037
67	SYSAV, Måsalycke, Sankt Olof	0.5	0.06
68	SYSAV, Sjöviksverket, Trelleborg	1	0.34
69	Sörab, Löt, Brottby	0.7	0.21
70	Tekniska Förvaltningen, Skövde	0.4	0.099
71	Tekniska Verken, Linköping	1	0.5
72	Trägsta mjölkgård, Hölåsen, Hallen	0.8	0.1
73	Uppsala Municipality, Kungsängsverket, Uppsala	2.5	0.66
74	VA Syd, Klagshamns Reningsverk, Klagshamn	0.8	0.095
75	Vafab Miljö, Gryta Gasmotor, Västerås	3.8	0.88
76	Vakin, Öhn Reningsverk, Umeå	0.6	0.66
77	Vänersborg Municipality, gasmotor GM 1, Vänersborg	0.5	0.099
78	Västra Götaland Region, Sötåsen, Töreboda	0.1	0.019
79	Wapnö, Wapnö Biogas, Halmstad	3.1	0.37
80	Åkarp, Örkelljunga	0.1	0.011
81	Åmål Municipality, Avloppsreningsverket, Åmål	1.75	0.25
82	Ödeshög Municipality, Ödeshög	0.75	0.09
83	Öknaskolan, Nyköping	0.3	0.047
84	Ölmetorp Gaskraft, Finspång	0.3	0.05
85	Öresundskraft, biogasanläggning, Helsingborg	10	1.95

	INDUSTRIAL INSTALLATIONS	GWh	MW
1	AarhusKarlshamn, Turbin 1, Karlshamn	5	3.4
2	Arctic Paper Grycksbo, Grycksbo	36	5.8
3	BillerudKorsnäs, G3, Skärblacka	315	50
4	BillerudKorsnäs, Gruvöns Bruk, Grums	450	64
5	BillerudKorsnäs Karlsborg, Kalix	240	52
6	BillerudKorsnäs, Frövi	187	26
7	Bomhus Energi, Gävle	590	92
8	Emåmejeriet, Hultsfred	0.3	0.04

9	Fiskeby Board, Panna 1, Norrköping	24	9.2
10	Holmen, Braviken, Norrköping	55	13.3
11	Holmen, Iggesund G6, Hudiksvall	367	75
12	Metsä Board Sverige, G1, G2, G3, Husum	415	62
13	Mondi Dynäs, Kramfors	127	21
14	Munksjö Aspa Bruk, Aspabruk	60	25.2
15	Munksjö Aspa Bruk, ORC, Aspabruk	4	0.675
16	Munksjö Paper, Billingsfors	28	4.5
17	Nordic Paper Bäckhammar, Kristinehamn	120	17
18	Nordic Paper, Säffle	20	5.4
19	Nordic Sugar, Örtofta Sockerbruk, Eslöv	3.1	9.8
20	Octowood, G1, Kälarne	0.8	0.17
21	Perstorp, Ångcentralen Turbin 1, Perstorp	30	6.2
22	SCA Graphic, Ortviken, Sundsvall	85	19
23	SCA Graphic, Östrand, Timrå	1 250	237
24	SCA Hygiene Products, Ångcentralen, Lilla Edet	10	2.3
25	SCA Obbola, Obbola 20:4, Umeå	120	25
26	Smurfit Kappa Kraftliner, Piteå	342	52
27	Stora Enso Hylte, Eleonora, Hyltebruk	200	38
28	Stora Enso Nymölla, G1 + G2, Bromölla	210	33.5
29	Stora Enso Fors, G2, Fors	75	9.6
30	Stora Enso Kvarnsveden, G21, Borlänge	70	15
31	Stora Enso Pulp, ORC, Skutskär	4.2	0.8
32	Stora Enso Pulp, Skutskär	353	46
33	Stora Enso Skoghall, TG8 + TG9, Skoghall	200	68
34	Svenska Foder, Powerbox, Hällekis, Götene	0.002	0.5
35	Södra Cell, Mönsterås	896	148
36	Södra Cell, Mörrum	150	58
37	Södra Cell, Värö, Väröbacka	1 000	127
38	Vallviks Bruk, Vallvik	138	31
39	Vattenfall, Cementa, G11, Slite	25	6
40	Vattenfall, SCA Munksund, Piteå	175	25
41	Åmotfors Energi, Eda	19.4	3

PLANNED INSTALLATIONS			GWh	MW	Clear
1	E.ON, Malmö	Choosing between new heating plant or biomass cogeneration plant	165	25	2025
2	E.ON, Malmö	Investigating whether biogas can be used in Heleneholmverket.	n.a.	130	n.a.
3	Eskilstuna Energi & Miljö, Kjula, Eskilstuna	Awaiting investment due to low prices of electricity and electricity certificate.	n.a.	n.a.	n.a.
4	Göteborg Energi, Backa	Biomass cogeneration plant at Backa at Göta Älv.	200	40	2022
5	Göteborg Energi, Rya	Biomass cogeneration plant Rya.	n.a.	n.a.	2026
6	Högsby Energi, Högsby Värmeverk, Högsby	Supplement to existing heating plant.	0.25	0.05	2019
7	Cogeneration plant, Northeast Stockholm region	Demand for new basic production in Northeast Stockholm region.	n.a.	n.a.	n.a.
8	Metsä Board, Husum	Two old turbines can be replaced by one new one. Increased	n.a.	n.a.	2022

		biopower production.			
9	Perstorps Fjärrvärme, Perstorp	Supplement to existing heating plant.	1	0.25	2019
10	Rena Hav Sverige, Kungshamn	Biogas installation for electricity and hot water.	5	1	2020
11	Skråmered, Laholm	Planning electricity production with biogas.	6	n.a.	2024
12	Stockholm Exergi, Högdalen, Stockholm	Building new boiler 54 MWth, replaces P1 and P2.	n.a.	n.a.	2021
13	Stockholm Exergi, Lövsta, Stockholm	Planning work for new installation started in spring 2018.	250	50	2022
14	Uniper, Malmö	Investigating whether biogas can be used in Öresundsverket.	n.a.	440	n.a.
15	Vattenfall, Carpe Futurum, Uppsala	Planning new heating plant, prepared for biopower.	150	30	2021

COGENERATION INSTALLATIONS:

INDUSTRIAL INSTALLATIONS:

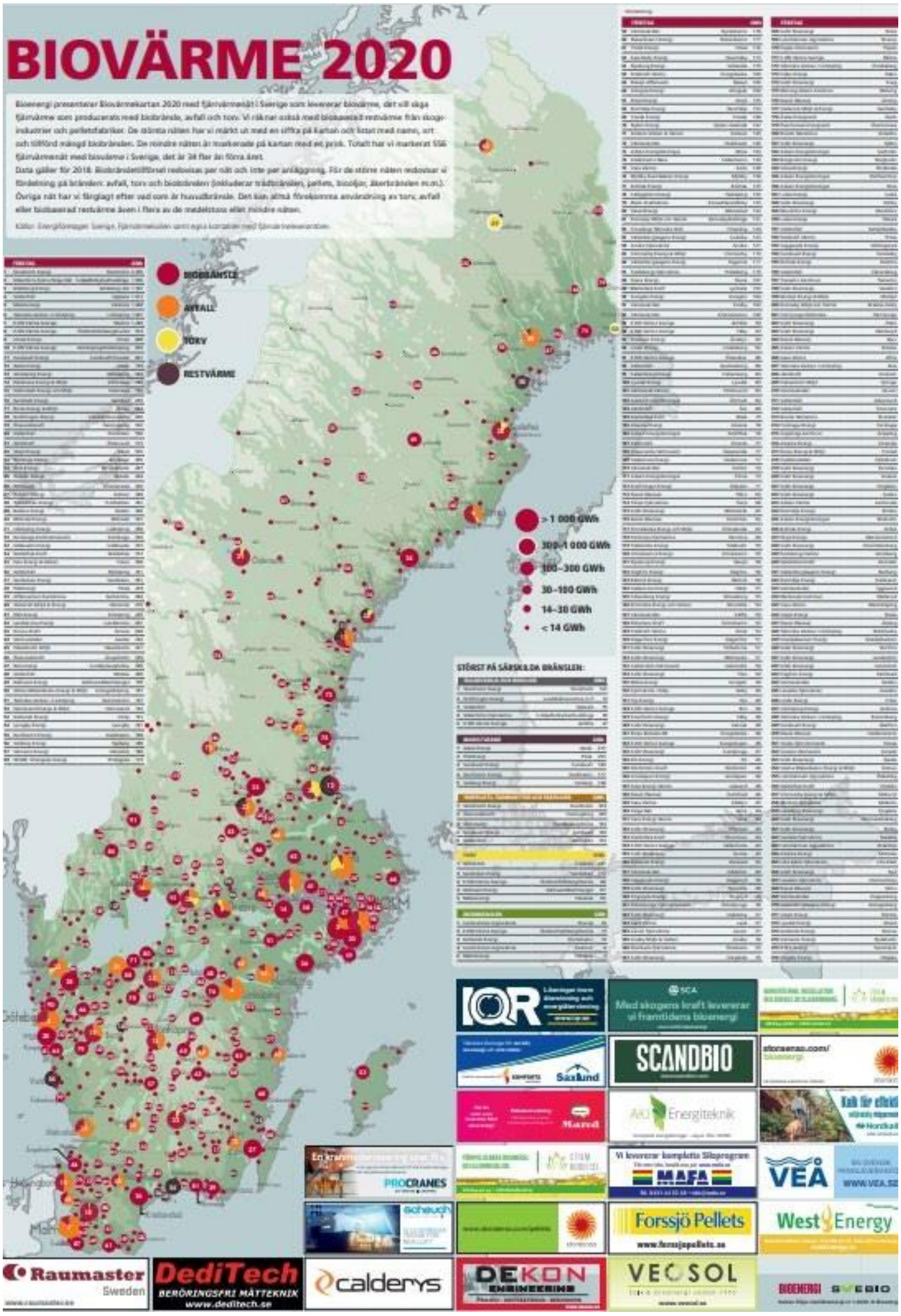
BIOGAS INSTALLATIONS WITH ELECTRICITY PRODUCTION:

PLANNED INSTALLATIONS:

Figure 19 shows the Bioheat Map 2020 of district heating networks in Sweden that supply district heating produced with biofuel, waste and peat. The map also includes bio-based residual heat from forestry industries and wood pellet factories. The largest networks are marked with a figure on the map and listed with name, location and input quantity of biofuel. The smaller networks are marked by a dot on the map. A total of 556 district heating networks with bioheat are marked in Sweden. This applies to 2018. The biofuel input is shown per network and not per installation. For the larger networks, breakdown by fuels is shown: waste, peat and biofuels (including wood fuels, pellets, bio-oils, agricultural fuels etc.). Other networks have been coloured according to their main fuel. The use of peat, waste or bio-based residual heat may therefore also occur in several of the medium-sized or smaller networks.[57]

Figure 19 Bioheat Map 2020, 556 district heating networks with biofuel, waste and peat)

[57] Bioheat Map 2020.


BIOVÄRME 2020
Bioenergi presenterar Biovärmekartan 2020 med fjärrvärmenät i Sverige som levererar biovärme, det vill säga fjärrvärme som producerats med biobränsle, avfall och torv. Vi räknar också med biobaserad restvärme från skogsindustrier och pelletsfabriker. De största näten har vi märkt ut med en siffra på kartan och listat med namn, ort och tillförd mängd biobränslen. De mindre näten är markerade på kartan med en prick. Totalt har vi markerat 556 fjärrvärmenät med biovärme i Sverige, det är 34 fler än förra året.
Data gäller för 2018. Biobränsletillförsel redovisas per nät och inte per anläggning. För de större näten redovisar vi fördelning på bränslen: avfall, torv och biobränslen (inkluderar trädbränslen, pellets, biooljor, återbränslen m.m.). Övriga nät har vi färglagt efter vad som är huvudbränsle. Det kan alltså förekomma användning av torv, avfall eller biobaserad restvärme även i flera av de medelstora eller mindre näten.
BIOBRÄNSLE
AVFALL
TORV
RESTVÄRME
> 1 000 GWh
300–1 000 GWh
100–300 GWh
30–100 GWh
14–30 GWh
< 14 GWh
STÖRST PÅ SÄRSKILDA BRÄNSLEN:
Med skogens kraft levererar vi framtidens bioenergi
SCANDBIO
Energiteknik
Vi levererar kompletta Siloprogram
MAFA
VEÅ
PROCRANES
Forssjö Pellets
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DediTech
BERÖRINGSFRI MÄTTEKNIK
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calderys
DEKON ENGINEERING
VECOSOL
BIOENERGI
SVEBIO

Source: Bioheat Map 2020,
https://bioenergitidningen.se/app/uploads/sites/2/2020/02/Biova%CC%88rmekartan_2020-web.pdf

	BIOHEAT 2020
	Bioenergi presents the Bioheat Map 2020 of district heating networks in Sweden which supply bioheat, i.e. district heating produced with biofuel, waste and peat. We also include bio-based residual heat from forestry industries and wood pellet factories. We have marked the largest networks with a figure on the map and listed their names, locations and input quantity of biofuel. The smaller networks are marked by a dot on the map. We have marked a total of 556 district heating networks with bioheat in Sweden, which is 34 more than last year. This applies to 2018. The biofuel input is shown per network and not per installation. For the larger networks we show the breakdown by fuel: waste, peat and biofuel (including wood fuels, pellets, bio-oils, agricultural fuels etc.). We have coloured other networks according to their main fuel. The use of peat, waste or bio-based residual heat may therefore also occur in several of the medium-sized or smaller networks. Sources: Swedenergy, District heating auditing as well as separate contacts with district heating

	suppliers.
	BIOFUEL
	WASTE
	PEAT
	RESIDUAL HEAT
	LEADER IN SPECIFIC FUELS:
	COMPANY GWh
	Stockholm Exergi Stockholm 5 369 Södertörns Fjärrv./Telge Nät S-tälje/Botkyrka/Huddinge 1 946 Göteborg Energi Göteborg Ale 1 787 Vattenfall Uppsala 1 612 Mälarenergi Västerås 1 448 Tekniska Verken i Linköping Linköping 1 401 E.ON Värme Sverige Malmö 1 268 E.ON Värme Sverige Örebro/Hallsberg/Kumla 974 Umeå Energi Umeå 848 E.ON Värme Sverige Norrköping/Söderköping 839 Sundsvall Energi Sundsvall/Tunadal 801 Gävle Energi Gävle 739 Jönköping Energi Jönköping 704 Eskilstuna Energi & Miljö Eskilstuna 702 Halmstads Energi & Miljö Halmstad 700 Karlstads Energi Karlstad 649 Borås Energi & Miljö Borås 644 Kraftringen Energi Lund/Eslöv/Lomma 606 Öresundskraft Helsingborg 593 Vattenfall Drefviken 560 Jämtkraft Östersund 519

Växjö Energi	Växjö	505
Borlänge Energi	Borlänge	495
Övik Energi	Örnsköldsvik	467
Skövde Energi	Skövde	444
C4 Energi	Kristianstad	392
Kalmar Energi	Kalmar	368
28 Trollhättan Energi	Trollhättan	367
Bodens Energi	Boden	360
Mölndal Energi	Mölndal	357
Lidköping Energi	Lidköping	346
Karlskoga Kraftvärmeverk	Karlskoga	343
Uddevalla Energi	Uddevalla	333
Skellefteå Kraft	Skellefteå	319
Falu Energi & Vatten	Falun	309
Vattenfall	Nyköping	301
Sandviken Energi	Sandviken	301
PiteEnergi	Piteå	293
Affärsverken Karlskrona	Karlskrona	284
Västervik Miljö & Energi	Västervik	276
ENA Energi	Enköping	24
Landskrona Energi	Landskrona	241
Kiruna Kraft	Kiruna	238
Värmevärden	Avesta	232
Hässleholm Miljö	Hässleholm	231
Öresundskraft	Ängelholm	225
47 Norrenergi	Sundbyberg/Solna	200
Vattenfall	Motala	200
Gällivare Energi	Gällivare/Malmberget	199
Västra Mälardalens Energi & Miljö	Arboga/Köping	197
Tekniska Verken i Linköping	Katrineholm	197
Härnösand Energi & Miljö	Härnösand	192
Gotlands Energi	Visby	191

Ljungby Energi	Ljungby	191
Karlshamn Energi	Karlshamn	188
Varberg Energi	Varberg	188
Värnamo Energi	Värnamo	180
SEVAB Strängnäs Energi	Strängnäs	179

TALL OIL AND BIO OILS
GWh

1	Stockholm Exergi	Stockholm	521
2	Kraftringen Energi	Lund/Eslöv/Lomma etc.	73
3	Vattenfall	Uppsala	55
4	Södertörns Fjärrvärme	S-tälje/Botkyrka/Huddinge	49
5	E.ON Värme Sverige	Järfälla	47

BIO RESIDUAL HEAT **GWh**

1	Gävle Energi	Gävle	375
2	PiteEnergi	Piteå	293
3	Sundsvall Energi	Sundsvall	180
4	Karlshamn Energi	Karlshamn	177
5	Varberg Energi	Varberg	148

WOOD PELLETS, WOOD BRIQUETTES AND WOOD FLOUR GWh

1	Stockholm Exergi	Stockholm	474
2	Öresundskraft	Helsingborg	230
3	Norrenergi	Sundbyberg/Solna	193
4	Sundsvall Energi	Sundsvall	169
5	Vattenfall	Drefviken	152

PEAT **GWh**

1	Vattenfall	Uppsala	367
2	Sandviken Energi	Sandviken	112
3	E.ON Värme Sverige	Örebro/Hallsberg/Kumla	88
4	Gällivare Energi	Gällivare/Malmberget	87
5	Mälarenergi	Västerås	85

	AGRICULTURAL FUELS **GWh** **1** Lantmännen Agrovärme Skurup 23 **2** E.ON Värme Sverige Örebro/Hallsberg/Kumla 13 **3** Gotlands Energi Klintehamn 10 **4** Lantmännen Agrovärme Kvänum 8 **5** Mälarenergi Västerås 5
	Continued.
	Värmevärden Nynäshamn 178 Oskarshamn Energi Oskarshamn 177 Ystad Energi Ystad 176 Sala-Heby Energi Sala-Heby 172 Njudung Energi Vetlanda 170 Statkraft Värme Kungsbacka 160 Nässjö Affärsverk Nässjö 160 Alingsås Energi Alingsås 160 Eksjö Energi Eksjö 155 Norrtälje Energi Norrtälje 153 Tranås Energi Tranås 148 Nybro Energi Nybro stadsnät 147 Götene Vatten & Värme Götene 145 Värmevärden Hudiksvall 145 Adven Energilösningar Mora 143 Söderhamn Nära Söderhamn 139 Vasa Värme Kalix 138 Mjölby-Svartådalen Energi Mjölby 138 Bollnäs Energi Bollnäs 135 Falbygdens Energi Falköping 135

	Mark Kraftvärme Kinna/Skene/Örby 133
	VänerEnergi Mariestad 132
	Ronneby Miljö & Teknik Ronneby/Kallinge 131
	Finspångs Tekniska Verk Finspång 124
	Västerbergslagens Energi Ludvika 123
	Arvika Fjärrvärme Arvika 121
	Vimmerby Energi & Miljö Vimmerby 119
	Västerbergslagens Energi Fagersta 111
	Trelleborgs Fjärrvärme Trelleborg 110
	Skara Energi Skara 107
	Skellefteå Kraft Lycksele 105
	Kungälv Energi Kungälv 104
	Värmevärden Torsby 103
	Värmevärden Kristinehamn 100
	E.ON Värme Sverige Järfälla 94
	E.ON Värme Sverige Täby 93
	Älvsbyns Energi Älvsbyn 92
	Linde Energi Lindesberg 92
	E.ON Värme Sverige Österåker 86
	Vattenfall Gustavsberg 86
	Falkenberg Energi Falkenberg 84
	Ljusdal Energi Ljusdal 84
	Jämtlands Värme Strömsund 83
	Adven Energilösningar Älmhult 82
	Jämtkraft Åre 80
	Skellefteå Kraft Malå 79

	105 Alvesta Energi Alvesta 78 106 Adven Energilösningar Sollefteå 78 107 Vattenfall Knivsta 77 108 Haparanda Värmeverk Haparanda 77 109 Hedemora Energi Hedemora 77 Värmevärden Hofors 74 Adven Energilösningar Timrå 73 Kraftringen Energi Klippan 71 Nevel (Neova) Tibro 69 Tierps Fjärrvärme Tierp 68 Solör Bioenergi Mönsterås 65 Nevel (Neova) Kramfors 62 Emmaboda Energi & Miljö Emmaboda 62 Perstorps Fjärrvärme Perstorp 60 Tidaholms Energi Tidaholm 59 Ulricehamns Energi Ulricehamn 59 Njudung Energi Sävsjö 58 Hagfors Energi Hagfors 58 Rättvik Energi Rättvik 58 Hedemora Energi Säter 57 Sölvesborg Energi Sölvesborg 55 Bromölla Energi & Vatten Bromölla 54 Värmevärden Säffle 54 Österlens Kraft Simrishamn 53 Statkraft Värme Åmål 53 Degerfors Energi Degerfors 51

	Solör Bioenergi Vilhelmina 51 Solör Bioenergi Mölnlycke 51 Jokkmokks Värmeverk Jokkmokk 50 Solör Bioenergi Flen 50 Mälarenergi Kungsör 50 Fjärrvärme i Osby 49 Hjo Energi Hjo 49 E.ON Värme Sverige Bro 48 Stockholm Exergi Täby 48 Solör Bioenergi Vännäs 48 Eksta Bostads AB Kungsbacka 48 E.ON Värme Sverige Kungsängen 48 Solör Bioenergi Svenljunga 47 Kils Energi Kil 46 Olofströms Kraft Olofström 46 Arvidsjaurs Energi Arvidsjaur 46 Dala Energi Värme Leksand 46 Nevel (Neova) Hultsfred 46 Vasa Värme Edsbyn 45 Telge Nät Järna 44 Vara Energi Värme Vara 44 Solör Bioenergi Filipstad 44 Skellefteå Kraft Storuman 44 E.ON Värme Sverige Vallentuna 43 Solör Bioenergi Sunne 43 Gislaved Energi Gislaved 42

	Värmevärden Hällefors 40 Vaggeryds Energi Vaggeryd 39 Solör Bioenergi Tomelilla 38 Tingsryds Energi Tingsryd 38 Örkelljunga Fjärrvärmeverk Örkelljunga 38 Solör Bioenergi Vadstena 37 Laxå Värme Laxå 37 Lerum Fjärrvärme Lerum 37 Aneby Miljö & Vatten Aneby 36 Överkalix Fjärrvärme Överkalix 35 Solör Bioenergi Vårgårda 35 Solör Bioenergi Nora 35 Lantmännen Agrovärme Skurup 34 Pajala Värmeverk Pajala 34 E.ON Värme Sverige Bålsta 34 Tekniska Verken i Linköping Åtvidaberg 34 Habo Energi Habo 33 Solör Bioenergi Sveg 33 Malung-Sälen Municipality Malung 33 Nevel (Neova) Åstorp 33 Västervik Miljö & Energi Gamleby 32 Åsele Energiverk Åsele 32 Övertorneå Energiverk Övertorneå 32 Bionär Närvärme Ockelbo 32 Solör Bioenergi Sjöbo 32 Adven Energilösningar Vaxholm 32

	Borgholm Energi Borgholm 32 VänerEnergi Töreboda 32 Adven Energilösningar Staffanstorp 31 Adven Energilösningar Orsa 31 Luleå Energi Luleå 31 Solör Bioenergi Hörby 30 Munkfors Energi Munkfors 30 Luleå Energi Råneå 30 Vattenfall Saltsjöbaden 30 Statkraft Värme Trosa 29 Vaggeryds Energi Skillingaryd 29 Sundsvall Energi Kvissleby 29 Bollnäs Energi Kilafors 29 Vattenfall Vänersborg 29 Tranemo Municipality Tranemo 28 Solör Bioenergi Vansbro 27 Mullsjö Energi & Miljö Mullsjö 26 Ronneby Miljö & Teknik Bräkne-Hoby 26 Herrljunga Elektriska Herrljunga 26 Solör Bioenergi Höör 26 Solör Bioenergi Markaryd 26 Nevel (Neova) Bjuv 26 Adven Värme Bräcke 26 Vasa Värme Alfta 25 Tekniska Verken i Linköping Kisa 25 Jämtkraft Krokom 24

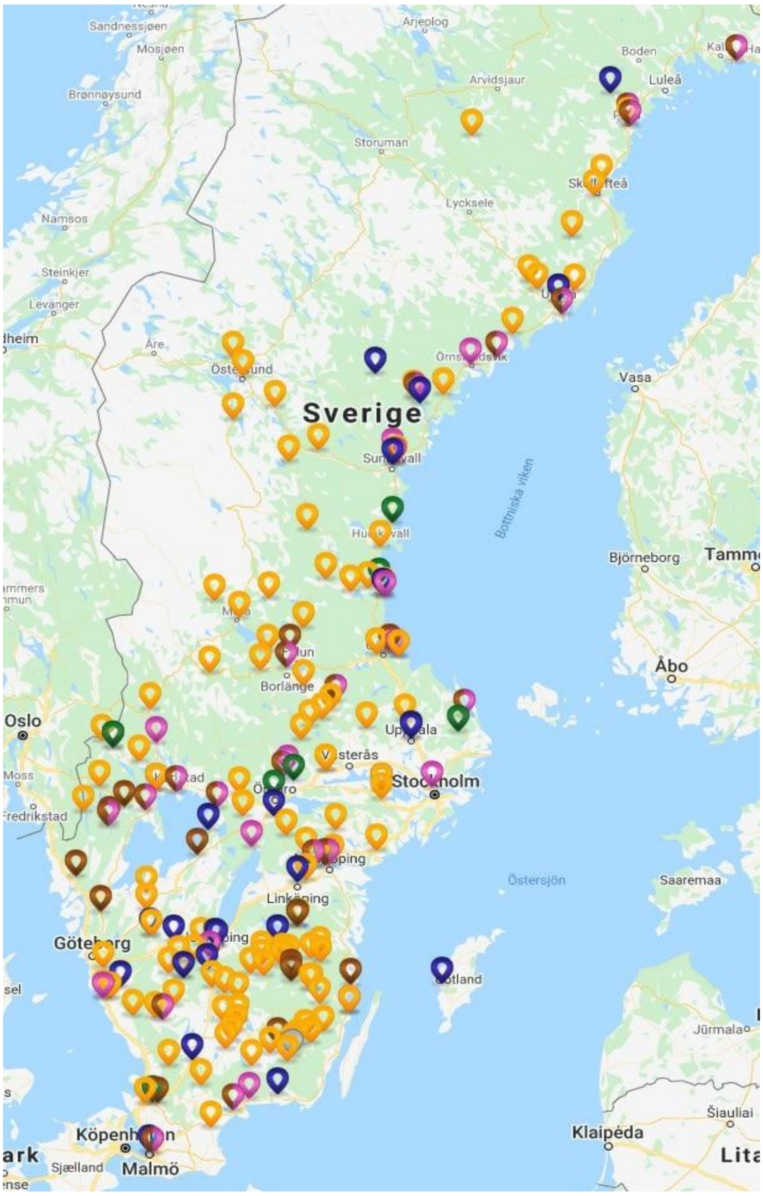
	Hässleholm Miljö Tyringe 24 Värmevärden Grums 24 Vattenfall Askersund 24 Vattenfall Storvreta 24 Bionär Närvärme Skutskär 23 Forshaga Energi Forshaga 23 Arjeplog Municipality Arjeplog 23 Alvesta Energi Vislanda 23 Borås Energi & Miljö Fristad 22 Hyltebostäder Hyltebruk 22 Solör Bioenergi Dorotea 22 Solör Bioenergi Gnesta 22 Solör Bioenergi Vingåker 22 Solör Bioenergi Svalöv 22 Adven Värme Lenhovda 22 Norrtälje Energi Rimbo 22 Adven Energilösningar Boxholm 22 Bollnäs Energi Arbrå 22 Eksjö Energi Mariannelund 21 Solör Bioenergi Charlottenberg 21 Karlsborgs Värme Karlsborg 21 Skellefteå Kraft Burträsk 21 Västerbergslagens Energi Norberg 21 Norrtälje Energi Hallstavik 20 Värmevärden Iggesund 20 Mellerud Municipality Mellerud 20

	Vasa Värme Malmköping 20 Växjö Energi Braås 20 Nevel (Neova) Årjäng 20 Tekniska Verken i Linköping Skärblacka 20 Smedjebacken Energi Smedjebacken 19 Solör Bioenergi Storfors 19 Solör Bioenergi Landvetter 19 Solör Bioenergi Lammhult 19 Hagfors Energi Ekshärad 19 Värmevärden Delsbo 18 Lessebo Fjärrvärme Lessebo 18 Linde Energi Frövi 18 Jönköping Energi Gränna 18 Tekniska Verken i Linköping Borensberg 18 Sundsvall Energi Matfors 18 Nevel (Neova) Valdemarsvik 17 Torsås fjärrvärmenät Torsås 17 Sorsele Värmeverk Sorsele 17 Solör Bioenergi Åseda 17 Västra Mälardalens Energi & Miljö Kolsva 17 Lantmännen Agrovärme Ödeshög 17 Skellefteå Kraft Vindeln 16 Vimmerby Energi & Miljö Södra Vi 16 Molkom Biovärme Molkom 16 Lekeberg Bioenergi Fjugesta 16 Solör Bioenergi Skinnskatteberg 16

	Solör Bioenergi Broby 16 Svedala Fjärrvärme Svedala 16 Lantmännen Agrovärme Grästorp 16 Alvesta Energi Moheda 16 Lilla Edets Fjärrvärme Lilla Edet 16 Solör Bioenergi Ryd 15 Lessebo Fjärrvärme Hovmantorp 15 Nevel (Neova) Gimo 15 Värmevärden Kopparberg 15 Västerbergslagens Energi Grängesberg 15 Växjö Energi Rottne 14 Ljusdal Energi Järvsö 14 Gotlands Energi Hemse 14 Värnamo Energi Rydaholm 14 BTEA Energi Svenstavik 14 Högsby Energi Högsby 14

Figure 20 is a supplementary map showing where paper pulp and sawmills/timber industries are located (i.e. the actors that account for most of the waste heat supplied).

Figure 20 Paper/Pulp, Sawmill/Timber industry and related industry



Source: The Swedish Forest Industries Federation (2020), https://www.skogsindustrierna.se/om-skogsindustrin/vara-medlemmar/karta/

4. Overview of current objectives, strategies and policy measures

This Chapter responds to Part IV, point 9 and Part II of Annex VIII concerning objectives, strategies and policy measures:

5. planned contribution of the Member State to its national objectives, targets and contributions for the five dimensions of the energy union, as laid out in Article 3(2)(b) of Regulation (EU) 2018/1999, delivered through efficiency in heating and cooling, in particular related to points 1 to 4 of Article 4(b) and to paragraph (4)(b) of Article 15, identifying which of these elements is additional compared to integrated national energy and climate plans;

6. general overview of the existing policies and measures as described in the most recent report submitted in accordance with Articles 3, 20, 21 and 27(a) of Regulation (EU) 2018/1999.

4.1. Current energy and climate policy targets

More can be read about planned contributions to national objectives, targets and contributions to the Energy Union's five dimensions in Sweden's integrated energy and climate plan[58]. This section briefly outlines important objectives for energy and climate policies with a focus on the energy policy's promotion of a fossil-free and efficient heating and cooling sector.

The national climate and energy policy targets can be found in table 2. Overall, the Swedish energy and climate policy fits well with the ambitions in the Energy Union's five dimensions.

Table 2. Overview of climate and energy policy objectives

Target	Target year	Base year
Sweden will not have any net emissions of greenhouse gases into the atmosphere, in order to subsequently achieve negative emissions. A maximum of 15% of the emission reductions may take place through accompanying measures.	2045	1990
75% reduction in emissions from sectors outside the EU ETS. A maximum of 2% through accompanying measures.	2040	1990
63% reduction in emissions from sectors outside the EU ETS. A maximum of 8% through accompanying measures.	2030	1990

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40% reduction in emissions from sectors outside the EU ETS. A maximum of 13% through accompanying measures	2030	1990
70% reduction in emissions in the transport sector	2030	2010
100% renewable energy production (this is a target not a cut-off date for nuclear power)	2040	
50% more efficient energy use	2030	2005

Sweden's overall targets for the energy policy are based on the same three foundations as EU cooperation in the energy sector and aim to combine security of supply, competitiveness and environmental sustainability. The energy policy will thus create the conditions for efficient and sustainable energy consumption and a cost-efficient Swedish energy supply with a low negative impact on health, the environment and the climate that also facilitates the conversion to an environmentally sustainable society (Bill 2017/18:228, report 2017/18:NU22, Riksdag Communication 2018/19:411). In the bill concerning the focus of the energy policy, the Government also states that a competitive district heating sector and efficient electricity use in heating are prerequisites for managing the future electricity and heating supply on cold winter days and also that is it important that the possibility for high-efficiency electricity production is used in fuel-based district heating generation.

The Government's climate action plan (REF) also states that although Sweden has a low proportion of fossil fuels in electricity and heat production, the net zero target means that greenhouse gas emissions from several sectors including the electricity and heating sectors will in principle need to be at zero no later than 2045, and that the electricity and heating sectors also have the potential to contribute to negative emissions in some parts. There are currently already instruments in place that promote the continued market development of the fossil-free heating and cooling sector.

4.2. Overview of current policies and strategies

4.2.1 Operating aid for bio-CCS

To further drive the reduction of greenhouse gas emissions and make negative emissions possible, the Swedish Energy Agency will submit a proposal in 2021 to design a system for operating aid in the form of reverse auctioning or fixed storage fees for carbon capture and storage from renewable sources (bio-CCS). The Agency will also review the possibility of including negative emissions with the help of biochar in the system.

4.2.2. National strategy for electrification

Increased electrification will be an important element in the transition to net zero emissions primarily in the transport sector and industry. Electrification is highlighted as a key issue in the Government's climate policy action plan and in several of the roadmaps produced by businesses, including the energy industry in the context of the Fossil-Free Sweden initiative. The Government is therefore developing a national electrification strategy. In the strategy, the Government takes a holistic approach to the conditions in the energy sector in order to enable increased electrification. A plan for tackling any obstacles to increased electrification will also be included. The starting point for the task force's work is to help create the conditions for a quick, smart and socioeconomically efficient electrification that will help achieve the climate goals for 2030, 2040 and 2045. Using a holistic approach, the strategy will analyse technical, economic and political conditions in the energy sector in order to enable increased electrification and present a plan for tackling any obstacles. The analysis will also involve analysing how electricity production and district heating can make increased electrification possible.

4.2.3. Sweden's Third National Strategy for Energy Efficient Renovation[59]

Sweden's Third National Strategy for Energy Efficient Renovation describes Sweden's building stock and gives an estimate of what the renovation rate and renovation demand look like. In the renovation strategy, three scenarios have been developed to give an idea of the expected degree of energy efficiency up to 2050. This is based on the extent of renovation currently taking place, with existing instruments and based on how property owners act and are likely to act in the coming years. See Table 3 below. For a more detailed review of the scenarios and methods for development see the renovation strategy[60].

Table 3 Expected energy consumption in GWh for the years 2030, 2040, 2050 for the building categories apartment buildings, schools, offices and houses according to the baseline scenario

Building category	**Heating/electricity**	**2020**	**2030**	**2040**	**2050**	**Total saving 2020–2050**	**Change from 2020 to 2050 (per cent)**
Apartment buildings	Purchased	24 917	22 249	21 343	20 509	4 408	-17.7%

[59] The Government (2020b).

[60] Ibid, p. 68.

	heat						
	Purchased electricity	10 039	10 093	10 115	10 130	+ 91	+ 0.9%
Schools	Purch ased heat	5 690	5 216	5 032	4 915	775	-13.6%
	Purchased electricity	2 910	2 812	2 775	2 750	160	-5.5%
Offices	Purch ased heat	3 854	3 775	3 743	3 723	131	-3.4%
	Purchased electricity	3 138	2 884	2 766	2 728	410	-13.1%

According to the scenarios, it is estimated that purchased heat (i.e. energy purchased for heating and hot water including electricity for heat pumps but excluding property energy) may decrease by a total of 3 221 GWh between 2020 and 2030 in apartment buildings, schools and offices. This corresponds to a decrease of just over 9% over this period.

The three scenarios show that the potential for improving energy efficiency in connection with renovation is significant, but that the possibilities for promoting energy efficiency improvements in conjunction with renovation are being relatively little used. The buildings that have already undergone renovation will not do so again in the near future and therefore all future renovations need to take place in accordance with the higher energy efficiency levels if the full energy efficiency potential is to be realised. The estimated energy efficiency for each building type and scenario is shown in Table 4.

Table 4 Different building categories' total energy consumption in 2016 and 2050 and proportion of energy savings for the three scenarios.

		Reference scenario	**Energy efficient renovation**	**Major renovation**
	Total energy consumption 2016 (kWh/m2)	Total energy consumption 2050 (kWh/m2)	Total energy consumption 2050 (kWh/m2)	Total energy consumption 2050 (kWh/m2)
Apartment	162	137 (15%)	119 (26%)	100 (38%)

buildings				
Offices	225	202 (10%)	177 (21%)	163 (27%)
Schools	216	187 (13%)	164 (24%)	135 (37%)

The table above shows total energy consumption, i.e. not divided into purchased heat and electricity. For apartment buildings, the reference scenario shows that energy purchased for heating and hot water will decrease by just over 17% by 2050 due to renovation measures; for schools a reduction of just over 13% by 2050 can be seen, while for offices the reference scenario shows that energy purchased for heating and hot water is expected to decrease by just over 3% by 2050.

4.2.4. Energy savings in public sector buildings

In accordance with Article 5 of the Energy Efficiency Directive, Sweden has reported total energy savings in public buildings of 31 251 MWh for the period 2021–2030[61].

Assuming that the public authorities' total energy use in 2020 is 305 769 MWh/year, that gives an energy-saving obligation for the period 2021–2030 in accordance with Table 5.

Table 5 Energy-saving obligation 2021–2030 in buildings owned by public authorities based on the information in the Energy Declaration Register.

Year	**Accumulated saving [MWh]**
2021	3 571
2022	7 034
2023	10 394
2024	13 652
2025	16 813
2026	19 879
2027	22 854
2028	25 739
2029	28, 537
2030	31 251

[61] National Board of Housing, Building and Planning (2019).

The Swedish Fortifications Agency and the National Property Board Sweden are subject to this energy-saving obligation.

4.2.5. Energy audits[62]

On 1 June 2014, the Act (2014:266) on energy audits of large companies entered into force. In accordance with the Act, major companies are obliged to carry out quality-assured energy audits at least every four years. An energy audit must provide answers as to how much energy is supplied and consumed annually to operate the activity and give proposals for cost-efficient measures that the company can implement to reduce their costs and energy consumption and increase their energy efficiency.

972 companies have applied to the programme for aid for energy auditing. Of these, 833 companies have been granted aid, 177 of them in 2019. Together the savings potential is estimated to be 208 GWh. There is no estimate of how large a part of this potential can be attributed to measures for more efficient heating/cooling.

4.2.6. The Climate Leap

All types of organisation except activities that are part of the EU ETS have been able to apply for grants for local climate investments since 2015. Examples of investments in the heating sector that are entitled to aid are the conversion from fossil oil to biofuel or district heating, expansion of smaller district heating networks or recycling waste heat.

During 2020, several companies invested in projects that utilise waste heat for district heating with aid from The Climate Leap. Some examples are[63]:

- Turnlight AB will reuse waste heat from server farms that feed into district heating networks in Uppsala. This measure will contribute to a reduction in emissions of around 8 000 tonnes of carbon dioxide per year.
- Gävle Energi AB is building and establishing an inter-municipal district heating pipeline between Gävle and Sandviken. This interconnection provides a direct opportunity to decommission the fossil fuel installation for peat in Sandviken in favour of a district heating supply in Gävle. Through the project, waste heat that would otherwise have been cooled off will be able to be safeguarded. This measure contributes to carbon dioxide reductions of around 46 000 tonnes per year.

[62] The Swedish Energy Agency (2018b).
[63] The Environmental Protection Agency (2020).

- Volvo Personvagnar AB is focusing on using waste heat from their operations by decommissioning liquefied petroleum boilers and instead reusing waste heat from the manufacturing process. An interconnection with Olofströms Kraft’s district heating network will simultaneously enable both the use of Volvo’s waste heat in Olofströms Kraft’s district heating network in the summer as well as environmentally friendly supplementary heating in the winter for Volvo. The measures will reduce emissions by just under 2 600 tonnes of carbon dioxide per year.

4.2.7. The Industrial Leap

Sweden’s parliament has adopted the climate goal for Sweden to have no net greenhouse gas emissions into the atmosphere by 2045 and to subsequently achieve negative emissions. In order to support the transition, the Government has decided on the long-term initiative The Industrial Leap. The Industrial Leap is the Government’s long-term initiative to reduce industrial process-related emissions as well as achieve negative greenhouse gas emissions. Large and complex technological advances are required in several industries and companies in order to achieve the climate goal. There are grants available for measures that help reduce industrial process-related emissions of greenhouse gases or negative emissions through separation, transport and geological storage of greenhouse gases of biogenic origin or which have been removed from the atmosphere.

The Industrial Leap comprises SEK 600 million per year until 2022 and then SEK 300 million per year until 2027. Through the 2018 letter of allocation, the Swedish Energy Agency was assigned as responsible for The Industrial Leap. As a result of the amendment to the 2019 spring budget, The Industrial Leap was expanded to include aid to investments in technologies that can lead to negative emissions through separation, transport and geological storage of greenhouse gases of biogenic origin or which have been removed from the atmosphere.[64] In the draft State Budget for 2021[65], The Industrial Leap was extended and broadened to include reductions in industrial process-related greenhouse gases, including other greenhouse gas emissions closely linked to these, negative emissions and strategically important initiatives in industry which contribute to the climate transition. The budget item has also been extended to SEK 750 million for 2021, SEK 750 million for 2022 and SEK 800 million for 2023.

4.2.8. The contribution of more efficient heating technology to reduced emissions

The implementation of ecodesign requirements is something that can contribute to reduced emissions. The Ecodesign Directive sets minimum requirements for, inter

[64] The Swedish Energy Agency (2020b).

[65] Bill 2020/21:1.

alia, energy performance of heat pumps, and as there are a large number of heat pumps installed in Sweden, more efficient heat pumps could help further reduce emissions and increase primary energy savings. There are currently no estimates of how large these savings might be.

4.3. Overview of existing policies for heating and cooling

The existing public measures are limited to horizontal instruments. To avoid repetitions, new measures are only briefly described in this section. More information on these instruments and more horizontal instruments concerning the heating sector can be found in Sweden's integrated energy and climate plan[66].

4.3.1. Carbon tax and energy tax for cogeneration and heat production[67]

For heat production, both energy and carbon tax apply. Biofuel and peat for heat production are exempt from energy and carbon tax. Other fuels used for heat production in cogeneration plants and other heat plants within the EU ETS are subject to a 91% carbon tax and full energy tax. For cogeneration plants, this is a sharp increase that entered into force on 1 August 2019, as these fuels were previously only subject to 11% carbon tax and 30% energy tax. Cogeneration plants that are not included in the EU ETS pay full energy tax and full carbon tax on fuels used for producing heat. This is also an increase, as these fuels were subject to a tax reduction before 1 August 2019 and only paid 30% energy tax.

4.3.2. Tax on waste incineration[68]

Acting on a proposal from the Government, the parliament has decided on a new excise duty on incinerated waste[69]. The duty is expected to lead to a reduction in waste incineration capacity in Sweden after 2030. However, the duty does not have to be paid on hazardous waste, biofuel, animal by-products or waste sent to a co-incineration plant that primarily produces materials where waste incineration is part of the production of the materials. The proposal entered into force on 1 April 2020.

4.3.3. The establishment of a centre for carbon capture and storage and operating aid

The Swedish Energy Agency is to become a national centre for carbon capture and storage, known as CCS, and funds will also be provided to set up a system with reverse auctions or fixed storage fees for carbon capture and storage from renewable sources (bio-CCS). The ambition will be to introduce the system for

[66] The Government (2020a).
[67] Ibid.
[68] The Government (2020a).
[69] Bill 2019/20:32, report 2019/20:SkU12.

operating aid in 2022 to accelerate the implementation of bio-CCS.[70]

4.3.4. Aid for heating and cooling through research and innovation[71]

The Swedish Energy Agency provides aid to research and innovation in the energy field as an instrument for developing technologies and creating market demand. Aid is given to academia, institutes, and businesses as well as the public sector and can cover studies from basic research to market research. The following initiatives exist in the heating and cooling sector:

Termo – heating and cooling for the energy system of the future

This programme covers the heating and cooling sector at large and will contribute to the following outcome targets:

- Energy for heating and cooling consists of recovered and renewable energy. Excess heat from different sectors is utilised for the benefit of society.
- The interaction between heating and cooling and other energy carriers contributes to a resource- and cost-efficient energy system as well as a secure energy supply.
- Heating and cooling are used in a resource-efficient manner with minimal environmental impact. The users benefit from competitive prices on local markets.
- Businesses, public entities and research operators in Sweden are world leaders in innovation for climate-smart heating and cooling. Products, system solutions and services are competitive on the global market.

The programme is intended to contribute to reduced primary energy consumption through, for example, utilising low-value heat while contributing to reduced CO2 emissions through resource-efficient use and development of new solutions to avoid fossil-based alternatives.

Energy policy goals:

- 50% more efficient energy consumption by 2030
- 100% renewable electricity by 2040
- Net zero emissions by 2045, then negative emissions

Programme period: 2018–2024
Budget: approximately SEK 40 million/year.

[70] Bill 2020/21:1 Expenditure heading 21.
[71] Sofia Andersson, The Swedish Energy Agency (2020).

Biopower – electricity and heating from thermal conversion of biofuel and waste

This programme develops cost-efficient and environmentally sustainable solutions. It covers heat and cogeneration installations of all sizes, from household boilers and stoves to full-size cogeneration installations. The programme also includes studies of materials and elements in boilers and installations as well as the functioning of existing and future installations, bioenergy combined with other industrial processes and cogeneration's role in the future energy system.

The programme is intended to contribute to reduced primary energy consumption by enabling electricity and heat production from residual products and waste that would not otherwise benefit society. The programme also contributes to reduced CO_2 emissions by developing solutions for avoiding fossil fuels as well as achieving negative emissions.

Energy policy goals:

- 100% renewable electricity by 2040
- Net zero emissions by 2045, then negative emissions

Programme period: 2018–2021
Budget: approximately SEK 21 million

Biomass for energy and materials

This programme's goal is to reduce knowledge barriers in order to increase the availability of characterised biomass to the bio-based industry and develop efficient and innovative processes where the residual flows of primary production are used for energy purposes.

The programme contributes to reduced CO_2 emissions by developing processes for manufacturing biofuel, which can replace fossil raw materials in industry as well as for electricity and heat production.

Energy policy goals:

- Net zero emissions by 2045, then negative emissions

Programme period: 2018–2021
Budget: approximately SEK 18 million/year

5. Analysis of the economic potential for efficiency in heating and cooling

5.1. Introduction

This Chapter responds to Article 14(3) and Annex VIII to the Energy Efficiency Directive and analyses the economic potential of the technologies for heating and cooling specified under point 7 according to the criteria and considerations set out under point 8 (see below).[72]

Point 7. An analysis of the economic potential of different technologies for heating and cooling shall be carried out for the entire national territory by using the cost-benefit analysis referred to in Article 14(3) and shall identify alternative scenarios for more efficient and renewable heating and cooling technologies, distinguishing between energy derived from fossil and renewable sources where applicable. The following technologies should be considered:

a) industrial waste heat and cold;

b) waste incineration;

c) high-efficiency cogeneration;

d) renewable energy sources (such as geothermal, solar thermal and biomass), other than those used for high-efficiency cogeneration;

e) heat pumps;

f) reducing heat and cold losses from existing district networks;

Point 8. This analysis of economic potential shall include the following steps and considerations:

a) Considerations

i) the cost-benefit analysis for the purposes of Article 14(3) shall include an economic analysis that takes into consideration socioeconomic and environmental factors, and a financial analysis performed to assess projects from the investors' point of view. Both economic and financial analyses shall use the net present value as criterion for the assessment;

ii) the baseline scenario should serve as a reference point and take into account existing policies at the time when this comprehensive assessment was compiled, and be linked to data collected under

[72] For point 8 in full, see Annex E; only points (a)(i)-(iii) have been included here, as these are deemed to be the most important points for understanding the approach.

Part I and point 6 of Part II of this Annex;

iii) alternative scenarios to the baseline shall take into account energy efficiency and renewable energy objectives of Regulation (EU) 2018/1999. Each scenario shall present the following elements compared to the baseline scenario:

- *economic potential of technologies examined using the net present value as a criterion;*
- *greenhouse gas emission reductions;*
- *primary energy savings in GWh per year;*
- *impact on the share of renewables in the national energy mix.*

Scenarios that are not feasible due to technical reasons, financial reasons or national regulation may be excluded at an early stage of the cost-benefit analysis, if this is justified on the basis of careful, explicit and well-documented considerations. The assessment and decision-making should take into account costs and energy savings from the increased flexibility in energy supply and from a more optimal operation of the electricity networks, including avoided costs and savings from reduced infrastructure investment, in the analysed scenarios.

b) Costs and benefits
c) Relevant scenarios to the baseline
d) Boundaries and integrated approach
e) Assumptions
f) Sensitivity analysis

The whole of Sweden is analysed using model runs in the energy system model TIMES Nordic which, given input data[73], develops the solutions with the lowest costs. However, it is important to note that it is the electricity and heating sectors that are modelled and that the transport sector is not included. The model is operated in order to minimise the total system costs and uses the net present value of all costs that arise in the model throughout the modelled period. The costs include, for example, investment costs, operating costs, fuel costs, energy taxes, etc.[74] as required by point 8 of Annex VIII to the Energy Efficiency Directive. This is done in order to fulfil the requirement of carrying out a cost-benefit analysis as set out in Article 14(3) of the Directive, which states, *'The cost-benefit analysis shall be capable of facilitating the identification of the most resource-and cost-efficient solutions to meeting heating and cooling needs.'* In addition to different alternative

[73] See Annex A for input data and calculation assumptions.
[74] See Annex A.

scenarios, sensitivity analyses and assessments based on primary energy, carbon dioxide emissions and renewables are also carried out (in accordance with the requirements set out in point 8 of Annex VIII). As regards any socioeconomic or environmental factors, the different scenarios analysed are not deemed to differ to such an extent that there is a need for a comparative analysis of these factors.

The purpose of the model runs is to provide data for assessing the future economic potential of different heating and cooling technologies. The calculation results focus on district heating and cooling input as well as technologies for heating housing and non-residential premises.

The model calculations are based on three baseline scenarios. All scenarios are then examined with two different calculated interest rates. One calculated interest rate that reflects the financial analysis and assesses projects from the investors' point of view and a lower calculated interest rate that assesses projects from a socioeconomic perspective.[75] If a lower (socioeconomic) calculated interest rate is shown to provide benefits that the market cannot provide itself (with a financial rate) it may be justified to introduce some form of State aid or support provided that the benefits (for example more renewables, fewer emissions etc.) are assessed to outweigh the costs of the aid measures.

Reference scenario

The first scenario **Ref_Inv** is a reference scenario and describes trends until 2050 if development continues as it is today with existing prices and instruments. **Ref_Inv** is based on a business-economic calculated interest rate used by market actors. The scenario is then examined with a socioeconomic calculated interest rate **Ref_Sam** which means that some technologies then become more/less prominent and that changes occur in input (primary energy) and carbon dioxide emissions as well as renewable shares. If this development is assessed to have benefits that outweigh the costs, adequate measures must also be taken to achieve this new scenario (in accordance with Part IV of Annex VIII to the Energy Efficiency Directive). Where possible, other aspects are also considered in the cost-benefit analysis, for example the benefit of a larger share of cogeneration for the power balance. The quantifiable costs and benefits are judged to be included in the input data for the model runs while qualitative assessments may need to be made in conjunction with these.

Climate scenario

[75] In accordance with the requirements in point 8 of Annex VIII to the EED.

In order to take into account the targets concerning energy efficiency and renewable energy in Regulation (EU) 2018/1999 (see Annex VIII point 8(iii)), a climate scenario with significantly higher emission prices is also examined. This scenario is also compared with two different calculated interest rates **Klimat_Inv** and **Klimat_Sam**. In view of the more ambitious climate policy announced by the EU this scenario is largely realistic.[76] As in the comparative reference scenarios, the climate scenarios are analysed on the basis of which technologies have an impact as well as changes in primary energy, renewables and emissions.

Climate scenario with high electrification

In addition to increased climate ambitions (see climate scenario), this baseline scenario assumes a sharp increase in electrification. This assumption is made as it is likely that the electrification of the transport sector and industry will lead to a significant increase in electricity demand. The scenario therefore assumes an additional 40 TWh of electricity demand in 2050. This scenario is called **KlimatEl_Inv,** and is then compared with a case with a socioeconomic calculated interest rate known as **KlimatEl_Sam**. This is deemed to be a relevant scenario based on demand in accordance with point 8(c) of Annex VIII to the Energy Efficiency Directive.

The question of how much importance should be attached to the various scenarios to assess which relevant measures should be taken is not straightforward. If a similar development can be found in the comparison between the business-economic/financial investor case and the case with a socioeconomic calculated interest rate in the three different baseline scenarios, this creates a certain robustness that indicates what the overall most cost-efficient heating solutions are and what the potential looks like (given different assumptions and environmental factors). Promoting these solutions is then the socioeconomically desirable goal.

In order to further identify socioeconomically efficient heating/cooling technologies, individual technologies such as extra cogeneration or heat pumps have also been ‘forced’ into the model runs to see what effect this would have. The reason for this is to provide an even better basis for what is requested in Annex VIII under both point 7 *(‘…and shall identify alternative scenarios for more efficient and renewable heating and cooling technologies…’)* and point 8(c) *(‘All relevant scenarios to the*

[76] On 17 September 2020, the EU Commission presented its plan for reducing greenhouse gas emissions in the EU by at least 55% by 2030 compared with levels in 1990, which is a sharp increase compared with the current target of 40%. The idea behind the more ambitious reduction is to achieve a climate neutral EU by 2050. Source: The European Commission (2020) https://ec.europa.eu/commission/presscorner/detail/sv/IP_20_1599 (accessed: 30 October 2020).

baseline shall be considered, including the role of efficient individual heating and cooling.').

These scenarios are described in more detail in Chapter 5.2.

5.2. On the scenarios

Assumptions for baseline scenarios, technology scenarios and sensitivity analysis have been developed by the consultancy Profu in collaboration with the Swedish Energy Agency and taking into account comments from the project's focus group[77]. Scenarios and model cases are broken down into baseline scenarios, technology scenarios and sensitivity analyses[78]. A total of 22 different model cases with different combinations of assumptions have been modelled. The relevant energy-related taxes are included in each case. Image 1 gives an overview of the different scenarios and what requirements in Article 14 they correspond to. The different scenario assumptions are also contrasted in table format in Annex C. However, not all model cases have been deemed effective in responding to the Directive's requirements, which is why the report does not show all 22 different cases[79].

Image 1 Overview of scenarios and model cases in relation to requirements in Article 14 of the Energy Efficiency Directive

Baseline scenario	Required rate of return	Scenario type	Model case	Article 14
Reference case	Investor's perspective	Baseline	Ref_Inv (RI)	7(a)-(e), 8(a) (i) (financial) and (ii)
		Technology	Less cogeneration (RI-KVV minus)	7(c)
		Technology	More cogeneration capacity (RI-KVV plus)	7(c)
		Technology	More heat pumps (RI-CP plus)	7(e), 8(c)
		Technology	More efficiency (RI-Eff plus)	8(a)(iii)
		Technology	Less efficiency (RI-Eff minus)	8(a)(iii)
		Sensitivity	Less waste incineration (RI-Avfall minus)	7(b)
		Sensitivity	Increased competition for biofuel resources (RI-Bio minus)	7(d)
		Sensitivity	Lifetime extension existing nuclear power (RI-Kärnkraft plus)	General analysis
	Socioeconomic perspective	Baseline	Ref_Sam	7(a)-(e), 8(a)(i) (socioeconomic) and (ii)
Climate scenario	Investor's perspective	Baseline	Klimat_Inv	7(a)-(e), 8(a)(i) (financial) and (iii) (RES and ENEF)
	Socioeconomic perspective	Baseline	Klimat_Sam	7(a)-(e), 8(a)(i) (socioeconomic) and (iii)

[77] Representatives from Swedenergy, Svebio, NIBE and the Swedish Forest Industries Federation.

[78] Note that the baseline scenarios *Climate scenario* and *Climate scenario with high electrification* can also be said to be sensitivity scenarios that respond to the Directive's requirements for changing circumstances and consideration of the targets for renewables and efficiency improvements.

[79] This scenario modelling is outside the scenario modelling that the Swedish Energy Agency does within the context of climate reporting, as it was not possible to synchronise the modelling due to different reporting dates. This means that the assumptions made may differ.

				(RES AND ENEF)
Climate scenario electricity	Investor's perspective	Baseline	KlimatEl_Inv (KIE)	7(a)-(e), 8(a)(i) (financial) and (iii) (RES and ENEF)
		Technology	Less cogeneration (KIE-KVV minus)	7(c)
		Technology	More cogeneration capacity (KIE-KVV plus)	7(c)
		Technology	More heat pumps (KIE-CP plus)	7(e), 8(c)
		Technology	More efficiency (KIE-Eff plus)	8(a)(iii)
		Technology	Less efficiency (KIE-Eff minus)	8(a)(iii)
		Sensitivity	Less waste incineration (KIE-Avfall minus)	7(b)
		Sensitivity	Increased competition for biofuel resources (KIE-Bio minus)	7(d)
		Sensitivity	Nuclear phase-out (KIE-Kärnkraft minus)	General analysis
	Socioeconomic perspective	Baseline	KlimatEl_Sam	7(a)-(e), 8(a)(i) (socioeconomic) and (iii) (RES AND ENEF)

5.2.1 Baseline scenarios

The baseline scenarios constitute the project's main scenarios. In line with the requirements in Article 14 of [and] Annex VIII to the Energy Efficiency Directive the baseline scenarios are made partly from an 'investors' perspective' and partly from a 'societal perspective'. These two perspectives are differentiated by different input data assumptions concerning the calculated interest rate for investments. The investors' perspective ('Inv') has calculated interest rates between 3-10% for investments depending on the type of technology and sector in question. The societal perspective ('Sam') has a calculated interest rate of 3.5% on all investments. The investors' perspective is the perspective that has normally been used in previous TIMES Nordic studies.

The baseline scenarios consist of the following cases (short scenario name given in brackets):

- **Reference scenario** (Ref_Inv, Ref_Sam)
  The reference scenario is based on the reference scenario from the Swedish Energy Agency's report *Scenarios for Sweden's energy system 2018*[80] (however, model updates made after this report are included). The scenario has a 'medium' EU ETC CO2 price, and this price is, like fossil fuel prices, based on the IEA's WEO 2019 Stated Policy Scenario[81].
- **Climate scenario** (Klimat_Inv, Klimat_Sam)
  The climate scenario has a higher EU ETS CO2 price and lower fossil fuel

[80] The Swedish Energy Agency (2019c).

[81] Read more at https://www.iea.org/reports/world-energy-model/stated-policies-scenario.

prices[82] than the reference scenario, based on the IEA's WEO 2019 Sustainable Development Scenario[83]. Otherwise, the same conditions apply as in the reference scenario.

- **Climate scenario with high electrification** (KlimatEl_Inv, KlimatEl_Sam)
The climate scenario with high electrification has the same CO2 and fossil fuel prices as the climate scenario but assumes a higher degree of electrification in the transport, industrial and service sectors. This scenario assumes, inter alia, a transition to hydrogen-based reduction[84] in the iron and steel industry and a relatively large expansion of data centres. At the end of the modelled period (2050) the electricity demand in this case is around 40 TWh higher than in the reference scenario and the climate scenario.

5.2.2 Technology scenarios

The technology scenarios intend to test the effects of a greater or smaller impact of specific technologies on the energy system (with a focus on the heating sector) in comparison with the baseline scenarios Ref_Inv (RI) and KlimatEl_Inv (KIE). These baseline scenarios have been chosen as a starting point for obtaining a range that covers the baseline scenarios that are furthest apart.

The technology scenarios include the following cases:

- **Less cogeneration** (RI-KVV minus, KIE-KVV minus)
In this case, the effects of energy companies refraining from investing in new cogeneration plants are studied.
- **More cogeneration capacity** (RI-KVV plus, KIE-KVV plus)
In this case, additional cogeneration capacity is added to the system. In the model, this means that more cogeneration capacity is 'forced in' above what is optimal from a cost-minimising perspective. The level for the introduction of cogeneration is based on the high case in the 'Cogeneration in the future' study[85] and amounts to around 6 GW electricity in 2050.
- **More heat pumps** (RI-VP plus, KIE-VP plus)
In this case, a higher possible market share for heat pumps for individual heating in housing and non-residential premises is assumed than in the baseline scenarios. The different levels for the possible expansion of heat pumps (in the baseline scenarios and in this case respectively) are based on scenarios from The Heating Market in Sweden project[86].
- **More efficiency improvements** (RI-Eff plus, KIE-Eff plus)
In this case, a higher degree of energy efficiency is assumed (with a focus on measures that reduce heating demand) in housing and non-residential premises than is the case in the baseline scenarios. In the model, this means that more efficiency measures are 'forced in' than what is optimal from a cost-minimising

[82] The price of fossil fuels is lower, but the higher carbon dioxide price makes the cost of carbon dioxide significantly higher than in the reference scenario.
[83] Read more at https://www.iea.org/reports/world-energy-model/sustainable-development-scenario.
[84] Hydrogen-based reduction is being developed in the HYBRIT project (Hydrogen Breakthrough Ironmaking Technology). If the initiative is successful, large amounts of coal, coke oven and process gases will disappear, and electricity use will increase considerably.
[85] Profu (2019).
[86] The Heating Market in Sweden (2014).

perspective.

- **Fewer efficiency improvements** (RI-Eff minus, KIE-Eff minus)
  In this case, a lower degree of energy efficiency improvements is assumed in housing and non-residential premises than is the case in the baseline scenarios. In the model, this means that the possibilities for efficiency improvements are limited in comparison with the baseline scenarios.

In total, the technology scenarios consist of ten model cases. The technology cases for heat pumps and energy efficiency improvements can be found in Annex F.

5.2.3 Sensitivity analysis

In the sensitivity analysis, alternative assumptions are tested for parameters that are largely external from a heating and cooling system perspective. As with the technology scenarios, changes are made to the model assumptions based on the baseline scenarios Ref_Inv (RI) and KlimatEl_Inv (KIE).

The sensitivity analysis comprises the following cases:

- **Less waste incineration** (RI-Avfall minus, KIE-Avfall minus)
  In this case, it is assumed that less waste is available for incineration in cogeneration plants and heat only boilers in comparison with the situation in the baseline scenarios. Potential reasons for this may be reduced imports and/or an increased degree of recycling. Around 20% less waste for incineration is assumed in relation to the baseline scenarios.

- **Increased competition for biofuel resources** (RI-Bio minus, KIE-Bio minus)
  In this case, an increased competition for biofuel is assumed in comparison with the baseline scenarios. This may represent, for example, a demand arising for biofuel production based on forestry resources. The model includes a new demand for wood chips from forestry which will increase from 20 TWh in 3040 to 50 TWh in 2045.

- **Nuclear phase-out** (KIE-Kärnkraft minus)
  As described in Annex A, nuclear power is included as an investment option in the baseline scenarios. In this case, we assume that new nuclear energy will not be expanded. This may be a result of political decisions or higher costs of nuclear power expansion than what is assumed in the baseline scenarios.[87]

- **Lifetime extension existing nuclear power** (RI-Kärnkraft plus)
  This case includes the possibility of extending the lifetime of existing nuclear power from 60 to 80 years at a certain investment cost.[88]

In total, the sensitivity analysis consists of six model cases but not all of them have

[87] This case is implemented only as a variant of KlimatEl-Inv (KIE) and not for Ref_Inv (RI). This is because no new nuclear power is seen in the results for Ref_Inv and this sensitivity analysis thus becomes redundant.

[88] This case is only implemented as a variant of Ref_Inv (RI) and not for KlimatEl-Inv (KIE). This is because there are already investments in new nuclear power in KlimatEl_Inv (at a higher cost than the lifetime extension alternative) and this sensitivity analysis thus becomes redundant.

a direct bearing on the implementation of Article 14 which is why only a selection of the calculations has been included.

5.2.4 Calculation results

The calculation results focus on district heating and cooling and heating of housing and non-residential premises with regard to the following parameters:

- Economic potential
- Energy input / primary energy
- CO_2 emissions
- Renewable shares

'Economic potential' means the cost-efficient development calculated by the model for each energy type in question. The economic potential depends on external conditions and may therefore differ between different calculations. The baseline scenarios are used as a starting point, but with additions where relevant, also for the results of the other scenarios. In some of the cases, a shorter reasoning of a more qualitative and discussional nature is also used.

In the model calculations, 'normal' conditions are assumed with regard to temperature, water inflow, economic situation and accessibility to installations in the energy system, for example. This means that there may be deviations from the actual outcome for the base year 2015.

5.3. An overview of the economic potential for heating and cooling

This Chapter provides an overview of the cost-efficient calculation result or the economic potential for some key energy types in the modelling. In-depth results are given in later chapters of the report.

Table 6 shows the cost-efficient development calculated by the model for some key energy types for the baseline scenarios Reference and Climate scenario with high electrification. These have been chosen to give as large a range as possible as they are furthest apart in terms of results. For both of these, results are shown both from an investors' perspective and a societal perspective. The table also shows the range of results in brackets which will be the outcome for the alternative conditions in the technology scenarios and the sensitivity analysis for the baseline scenario in question.

Regarding the range of results presented (based on technology scenarios and sensitivity analysis), it should be noted that in some cases these are the result of 'critical' assumptions that are designed to clearly highlight the system effects of a very high or low impact for a certain technology category, for example. In the KVV-minus case, for example, no new investment in cogeneration is permitted, which is reflected in Table 6 by an exceptionally low value in the KVV range.

Table 6 Model result for district heating, cogeneration, heat pumps (individual heating), waste heat for district heating and district cooling for the most important baseline scenarios and, in brackets, ranges of model results for all model cases including technology scenarios and sensitivity cases.

	Baseline scenario	**2015**	**2030**	**2040**	**2050**	**Number of model cases**
District heating, supplies [TWh]	Ref_Inv	53	51 (47–54)	54 (47–55)	55 (46–56)	9
	Ref_Sam	53	47	52	53	1
	KlimatEl_Inv	53	54 (51–55)	55 (49–57)	56 (52–57)	9
	KlimatEl_Sam	53	48	51	54	1
KVV, produced heat [TWh]	Ref_Inv	30	35 (15–37)	39 (1–41)	41 (1–43)	9
	Ref_Sam	30	32	39	40	1
	KlimatEl_Inv	30	36 (15–38)	41 (1–43)	43 (1–45)	9
	KlimatEl_Sam	30	33	39	41	1
Waste heat, low and high temp.[a] [TWh]	Ref_Inv	6.6	8.1 (7.8–8.2)	8.4 (8.3–8.7)	9.1 (9.0–10)	9
	Ref_Sam	6.6	8.2	8.3	9.1	1
	KlimatEl_Inv	6.6	9.1 (8.5–9.1)	10 (10–10)	12 (11–13)	9
	KlimatEl_Sam	6.6	8.7	10	12	1
Heat pumps (individual), prod. heat [b] [TWh]	Ref_Inv	17	28 (25–29)	26 (23–30)	25 (22–31)	9
	Ref_Sam	17	29	29	29	1
	KlimatEl_Inv	17	25 (24–29)	24 (22–30)	24 (20–31)	9
	KlimatEl_Sam	17	28	29	27	1
District cooling, supplies [TWh]	Ref_Inv	1.0	1.4 (1.4–1.5)	1.9 (1.7–1.9)	2.3 (2.2–2.3)	9
	Ref_Sam	1.0	1.4	1.9	2.3	1
	KlimatEl_Inv	1.0	1.4 (1.3–1.5)	1.8 (1.7–2.0)	2.3 (2.3–2.5)	9
	KlimatEl_Sam	1.0	1.5	1.9	2.3	1

a) Refers to industrial waste heat (high temperature) for direct use in district heating and low-temperature waste heat from, for example, water treatment plants and data centres, for upgrading in heat pumps before being used in district heating (low-temperature heat for heat pumps from surrounding sources, water bodies etc. is excluded).

b) This also includes a small amount of direct electric heating when this is used in combination with a heat pump.

Some overall conclusions can be drawn from the model results. Over time, in district heating production, more production is generally seen from cogeneration and heat pumps connected to district heating and less production from heat only boilers. In climate scenarios (with high CO2 prices) bioenergy with carbon capture and storage (bio-CCS) has a major impact[89].

The district heating supplies do not change much over time, but in the long term, there is some increase in most cases. Exceptions are cases where conditions are tested that adversely affect district heating in various ways, including scenarios where new investments in cogeneration are absent (KVV minus), individual heat pumps have a greater impact (VP plus), a significant amount of energy efficiency improvements are implemented (Eff plus), or the competition for biomass increases significantly (Bio minus).

The model results show an increased use of low and high-temperature waste heat from industry and services in the district heating sector (low-temperature waste heat is assumed here to be upgraded using heat pumps). Particularly in electrification scenarios (KlimatEl), a significant increase in low-temperature waste heat can be seen, as a considerable expansion of data centres is assumed in these cases.

District heating supplies increase over time in the model results. Free cooling or waste cooling from simultaneous heat production in a heat pump is selected in the model at first instance. Furthermore, compression cooling is selected to a greater extent than absorption cooling[90], with the exception of some scenario assumptions that give a surplus of cheaper district heating capacity in the summer, see Chapter 5.12. Absorption cooling has a significantly lower energy yield (heat to cooling) than compression cooling (electricity to cooling) and needs heat at low or very low costs to be competitive.

At the end-user level, climate scenarios (with higher CO2 prices) show a slightly higher consumption of district heating and pellets for individual heating but a slightly lower consumption of heat pumps for individual heating than corresponding reference cases. This is explained by the higher electricity price in the climate scenarios.

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[89] Read more about bio-CCS in the electricity and heating sector in Sweden in Annex D.

[90] Absorption cooling involves using waste heat or district heating to operate a cooling machine that generates district cooling. The benefit of absorption cooling compared to conventional, electricity-driven refrigeration units is that heat-based cooling uses excess heat instead of electricity.

At the end-user level, the societal perspective (a generally lower calculated interest rate for investments) shows, in comparison with the investors' perspective, a higher degree of energy efficiency, more heat pumps (for individual heating) and a slightly lower use of district heating and pellet boilers (for individual heating). This is because the lower calculated interest rate in the socioeconomic approach (compared to the investors' perspective) favours capital-intensive investments. Although district heating is a capital-intensive energy type, the share of fuel costs and other variable costs constitutes a non-negligible cost item of the total cost. In district heating production, the societal perspective generally gives a higher proportion of district heating based on waste, waste heat and heat pumps and a lower proportion of biofuel-based production.

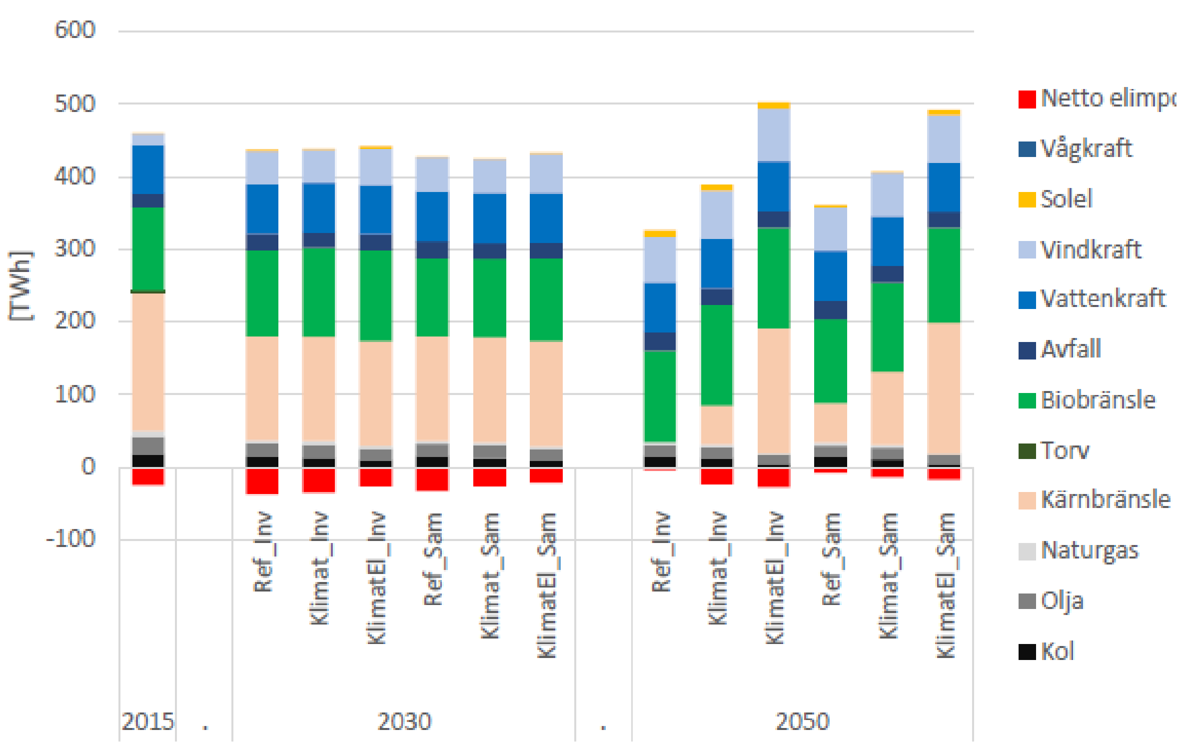
5.4. Energy input/primary energy

This Chapter looks at the overall picture of all the baseline scenarios as regards primary energy savings. In other words, how much less primary energy (energy input) would be needed if more efficient technologies were used. Although Article 14 of and Annex VIII to the Energy Efficiency Directive focus on heating and cooling, the whole energy system must be taken into account in the cost-benefit analysis that is to be carried out.

As regards calculations of primary energy savings in cogeneration, according to Annex II to the Energy Efficiency Directive, a method must be applied based on the assumption that the heat and electricity produced in a cogeneration plant would otherwise have been produced in separate boilers which produce heat and electricity with the same fuel, regardless of how this replacement would have taken place in reality. The primary energy savings of biomass cogeneration, for example, is then a calculation of how much biofuel would have been consumed if the same amount of heat and electricity had been produced partially in a heat only boiler and partially in a condensing power plant. In Sweden, this is often not what replaces cogeneration, which is why both methods for calculating the primary energy savings of cogeneration have been carried out in the chapter on cogeneration including a comparison from a Northern European perspective (see Chapter 5.9.).

Figure 21 presents the energy input to the Swedish energy system from energy carriers. Nuclear power is represented in the figure by nuclear fuel. Energy input at the Swedish level is lower for the reference scenarios (Ref_Inv, Ref_Sam) than the climate scenarios (for example KlimatEl_Inv and KlimatEl_Sam), mainly due to the larger component of nuclear fuel in the latter. The societal perspective with a generally lower calculated interest rate for investments favours capital-intensive technologies. In these cases, a slightly higher consumption of nuclear power is noted in relation to the corresponding scenario with an investment perspective in the results.

Figure 21 Sweden's energy input (primary energy) for baseline scenarios



	[TWh]
	Net electricity import
	Wave energy
	Solar electricity
	Wind power
	Hydropower
	Waste
	Biofuel
	Peat
	Nuclear fuel
	Natural gas
	Oil
	Coal

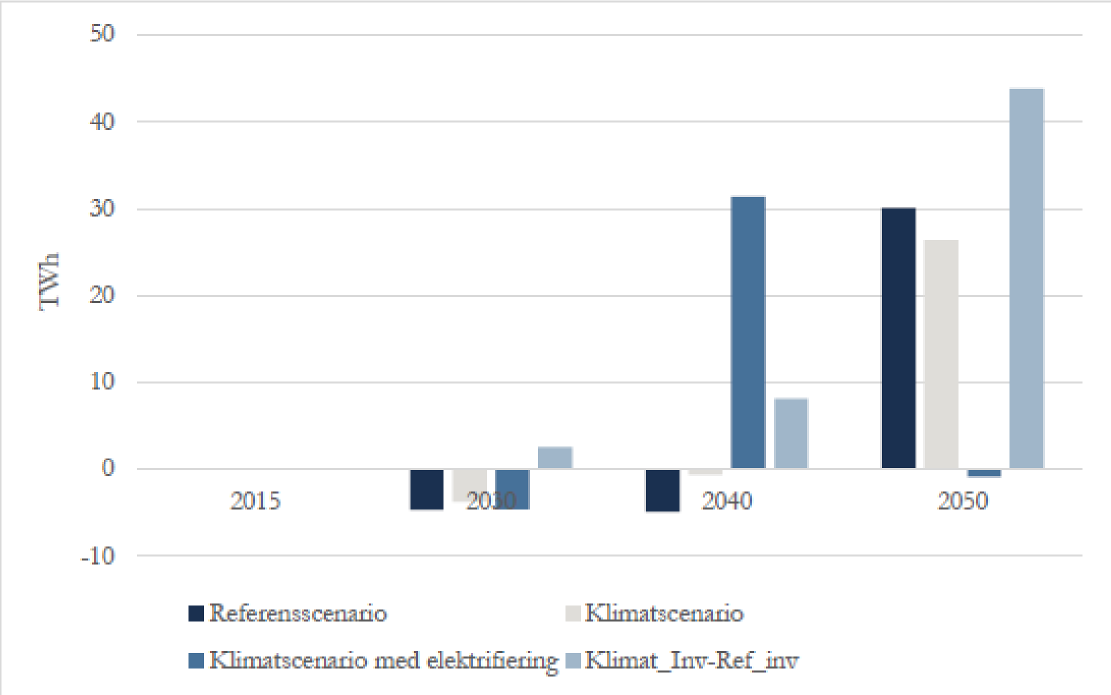
Note: Negative columns for 'Net electricity import' mean a net export of electricity

Figure 22 shows the difference in primary energy consumption in TWh between the different baseline scenarios from a socioeconomic perspective (lower calculated interest rate) and from an investors' perspective (higher calculated interest rate).

The reference scenario (blue columns) thus shows how Ref_Sam minus Ref_Inv would impact the primary energy savings. By 2030, primary energy consumption would decrease by 3.7 TWh but by 2050 this would increase by 30.1 TWh. Positive columns therefore show that more primary energy is used to meet the demand in each scenario. The reason for the result is primarily the development of nuclear power that is expanded more with a socioeconomic calculated interest rate compared with a business-economic one. The exception is the climate scenario with electrification (KlimatEl) as the electricity demand in this scenario increases by 40 TWh and drives prices up, so that it becomes profitable to expand nuclear power, but also to a greater extent biomass cogeneration, also from an investors' perspective. The only scenario that would lead to a primary energy saving with the help of a socioeconomic calculated interest rate in 2050 is the climate scenario with higher electrification, but this is a very modest saving of 0.8 TWh by 2050 (see negative green column).

The yellow column has a different approach from the above and instead compares two different scenarios from an investors' perspective, Klimat_Inv minus Ref-Inv, which shows that the primary energy consumption would increase significantly with a higher price of carbon dioxide compared with 'business as usual'. The reason for this is that nuclear power would become profitable due to higher electricity prices and require more primary energy.

Figure 22 Primary energy consumption, difference between the baseline scenarios with regard to the use of a socioeconomic rate and a market-based rate.



	TWh
	Reference scenario
	Climate scenario
	Climate scenario with electrification
	Klimat_Inv-Ref_inv

Conclusion

- Overall, for all baseline scenarios, a socioeconomic calculated interest rate would not mean lower primary energy consumption by 2050 (with the exception of marginally lower consumption in one of the cases). This therefore means that the market's investments (in the long term) generally consume less primary energy than if state investments with a lower calculated interest rate for investments in electricity and heat production were to be made.

5.5. CO2 emissions

This Chapter looks at the overall picture of all the baseline scenarios as regards carbon dioxide emissions. It is important to note that the emissions do not include the whole of Sweden's energy system; they cover the heating and electricity sectors but exclude the transport sector. Although Article 14 of and Annex VIII to the Energy Efficiency Directive focus on heating and cooling, the whole energy system must be taken into account in the cost-benefit analysis that is to be carried out.

Figure 23 shows carbon dioxide emissions for the baseline scenarios for Sweden for 2030 and 2050 while Figure 24 shows the difference in emissions between the reference scenario Ref_Inv and other scenarios.

Figure 25 shows the trend of CO2 emissions by sector for the scenario KlimatEl_Inv retrospectively to 1990.

Figure 23. CO2 emissions for the electricity and heating sector in Sweden for the baseline scenarios (net)

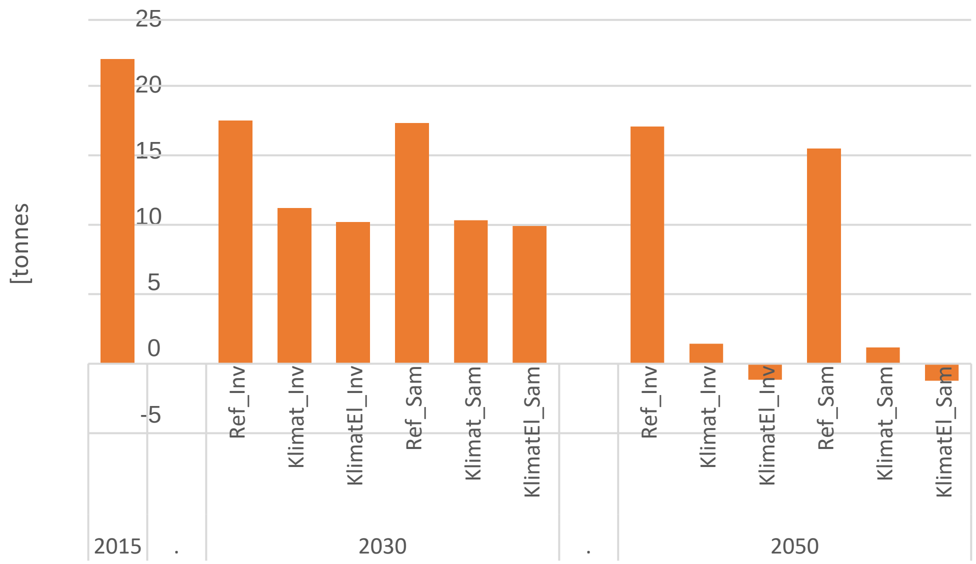


Figure 24. CO2 emissions for the electricity and heating sector in Sweden, in contrast with Ref_Inv

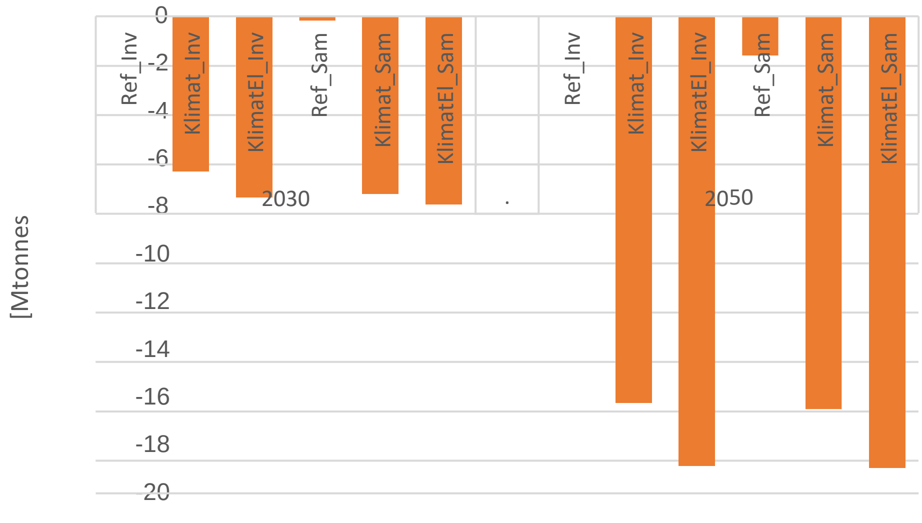
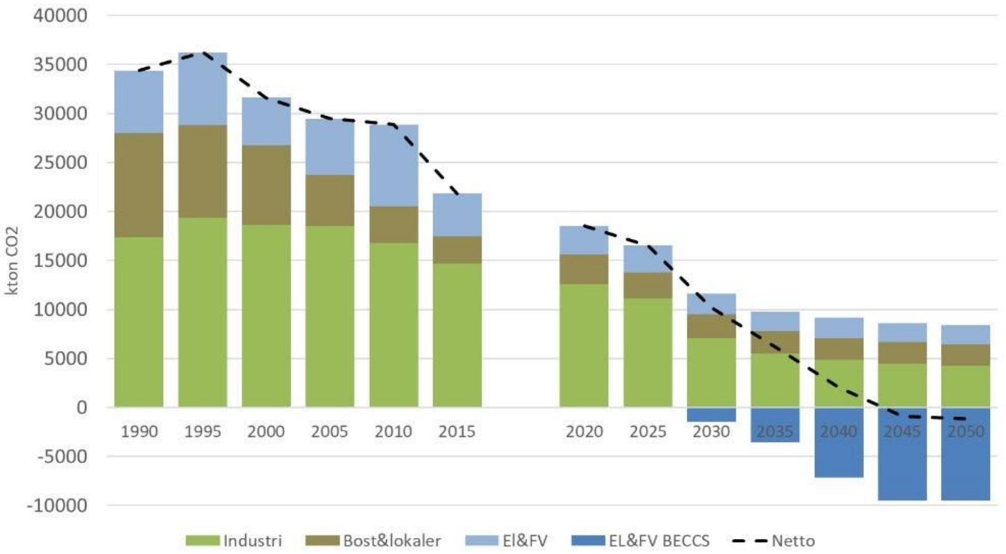


Figure 25. CO2 emissions for the electricity and heating sector in Sweden for the scenario KlimatEl_Inv and historical values 1990-2015



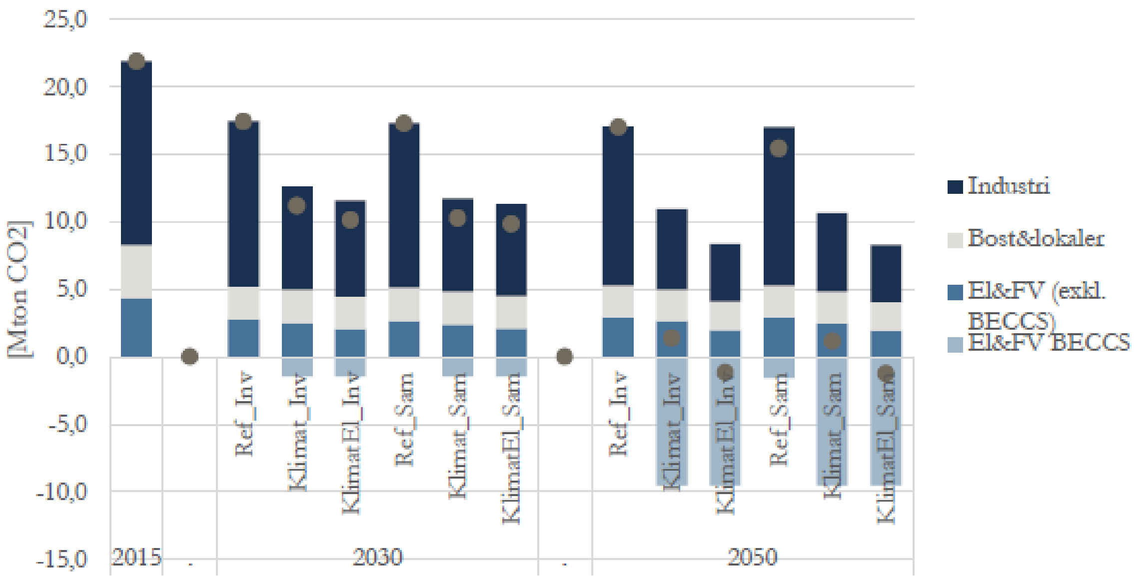
	ktonnes CO2
	Industry
	Housing & non-residential premises
	Electricity & Heating
	Electricity & District heating
	Net

Carbon dioxide emissions decrease over time in all scenarios. As expected, there is a more significant reduction in emissions in the climate scenarios that have a higher carbon dioxide price than in the reference scenarios. The societal perspective shows slightly lower accumulated emissions for the modelled time period than the investors' perspective. This indicates that capital-intensive technologies, particularly nuclear power but also heat pumps and energy efficiency improvements, benefit from lower calculated interest rates and that the emissions from these technologies are slightly lower overall than district heating. District heating is also a capital-intensive technology but does not benefit as much from a lower calculated interest rate as the investments in district heating also have a lower calculated interest rate from an investment perspective. Industrial emissions also play a role to some extent in this case.

In the climate scenarios, negative emissions linked to the use of bio-CCS[91] are very significant. As a result of using bio-CCS, negative net emissions are achieved by the end of the modelled period for the sectors included at the Swedish level for climate scenarios with high electrification (KlimatEl). The lower emissions in KlimatEl in comparison with Klimat are largely explained by the electrification of the iron and steel industry that takes place in the former case. See Figure 26.

[91] Carbon storage of biomass.

Figure 26. CO2 emissions for electricity and heating in Sweden by sector in the different scenarios



	[tonnes CO2]
	Industry
	Housing & non-residential premises
	Electricity & District heating (excl. BECCS
	Electricity & District heating BECCS
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam

Conclusions

- Given the market assumptions (including assumed investment costs for bio-CCS) in the climate scenarios, the high CO2 price results in it becoming profitable to invest in bio-CCS, which contributes greatly to reduced emissions. In the case with increased electrification, industrial emissions also decrease, which, together with the impact of bio-CCS make it possible to achieve negative emissions by 2050. Consequently, no further promotion with a lower calculated interest rate is necessary.
- A condition for reaching Sweden's target of achieving negative emissions by 2045 is for it to be profitable to invest

in bio-CCS and for price levels to develop approximately as assumed in the model in both the climate scenarios (which are deemed to be realistic scenarios). Technological progress towards bio-CCS is needed if the target is to be reached, as negative emissions require carbon dioxide to be removed from the atmosphere[92]. Investments have already been made in bio-CCS in the research programme The Industrial Leap[93] of SEK 100 million per year until 2022 and subsequently SEK 50 million per year until 2027.[94] The Swedish Energy Agency is proposed to become a national centre for carbon capture and storage, known as CCS, and funds will also be provided to set up a system with reverse auctions or fixed storage fees for carbon capture and storage from renewable sources (bio-CCS). The aim must be to introduce the system for operating aid in 2022, in order to accelerate the implementation of bio-CCS (see Chapter 4.3.3). These funds and investments together with the industry's commitment (see Chapter 2.4), may be entirely sufficient, but the development should be followed in order to see whether bio-CCS needs to be promoted further for the goal of negative emissions to be met.

5.6. Renewables

This Chapter begins by looking at the overall picture of all the baseline scenarios as regards renewables. This is in order to meet the requirement concerning the impact of different scenarios on the national energy mix (Annex VIII point 8(a)(iii)[95]. The proportion of renewable energy used for heating housing and non-residential premises is then shown. Figure 27 shows the proportion of renewable energy input for electricity and heat generation for all baseline scenarios without taking into account exports/imports of electricity[96]. The result shows that the socioeconomic calculated interest rate leads to a reduced proportion of renewable energy input (compare the dotted lines with the solid lines of the same colour at the same point in time). In other words, the market trend results in a larger share of renewables than if the government were to promote heat and electricity generation by providing a lower calculated interest rate. The main reason for the lower renewable shares with a socioeconomic calculated interest rate is that nuclear power, which is especially capital-intensive, is expanded to a greater extent, which leads to larger shares of nuclear power in the energy mix.

Figure 27 Proportion of renewable energy input for electricity and heat generation, all baseline scenarios

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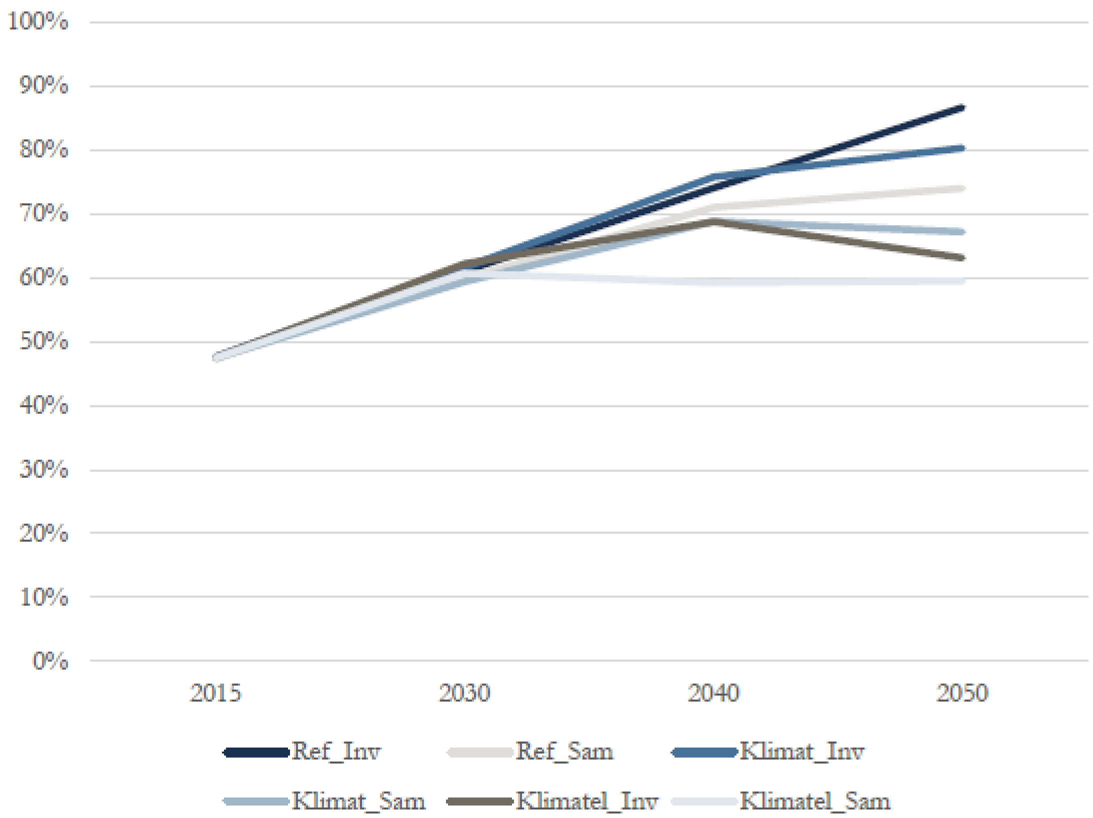
92 The Swedish Energy Agency (2020c).

93 Read more in Annex D.

94 The Swedish Energy Agency (2020d).

95 Energy input national level (for industry, electricity and district heating, housing and non-residential premises), TWh.

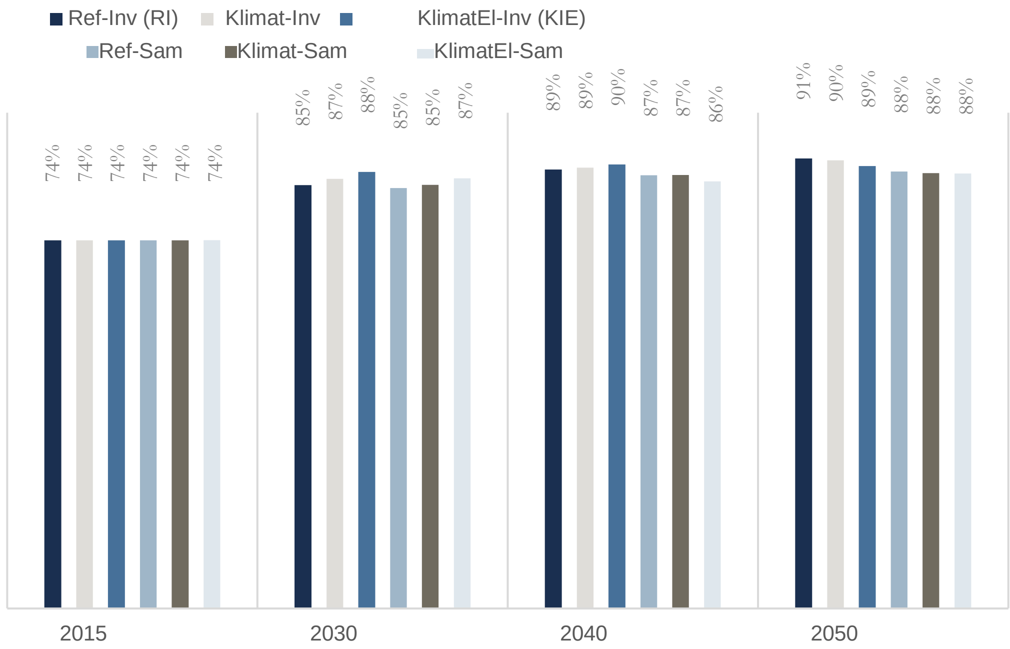
96 Note that this is not strictly speaking the calculation made in accordance with the Renewable Energy Directive, but it reflects Figure 21.



	Ref_Inv
	Ref_Sam
	Klimat_Inv
	Klimat_Sam
	KlimatEl_Inv
	KlimatEl_Sam

For the heating sector, the differences are significantly smaller, as nuclear power does not have as much of an impact there. As can be seen in Figure 28, the differences between the various scenarios are minor. It should be noted that a socioeconomic calculated interest rate would not increase the share of renewables in comparison with the investors' perspective for any scenario there either. In fact, a socioeconomic calculated interest rate leads to a slight decrease in the renewable shares for heating, which can be explained by the fact that the societal perspective gives a higher share of district heating based on waste, waste heat and heat pumps and a lower share of biofuel-based production.

Figure 28 Share of purchased renewable energy (including waste heat) for heating housing and non-residential premises for all baseline scenarios



To calculate the renewable share of electricity, domestic production is used as a basis (electricity trading has been excluded here), and the share includes technologies such as wind power, solar electricity, hydropower, biofuel and biogenic waste. Biofuel, biogenic waste and solar are similarly counted in the renewable share of district heating. Waste heat has also been included in the figure and it should be noted that according to the Renewable Energy Directive[97], some waste heat may be included in the renewable energy target.

The fossil proportion of the waste for waste incineration is the largest contributing factor to the renewable share not being even higher, but nuclear power's share in electricity production also has an impact. For a sensitivity analysis of the impact of waste on the renewable share of district heating, see Figure 39.

Conclusion

- The market itself is able to invest in renewable energy for electricity and heat with high renewable shares and would not benefit from a socioeconomic perspective

[97] (EU) 2018/2001.

with a lower calculated interest rate.

5.7. Heating housing and non-residential premises

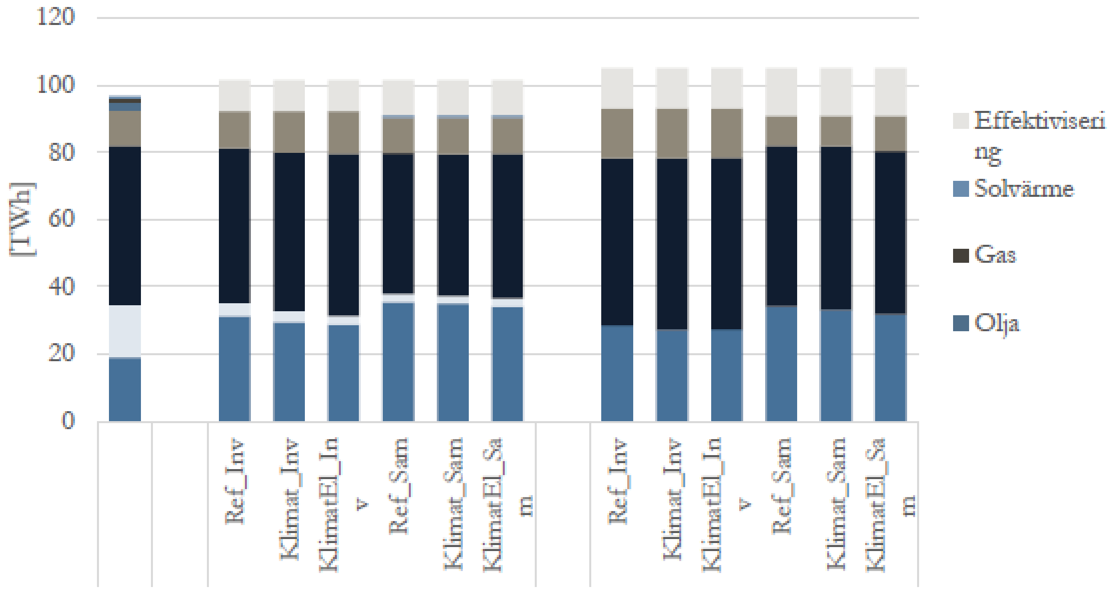
5.7.1 Heating technologies

Figure 29 shows the result for heating housing and non-residential premises for the baseline scenarios. The figure shows useful energy, i.e. heat from each technology (heat production from heat pumps, heat from district heat exchangers, etc.). The figure also shows the degree of efficiency. As a result of new construction, heating demand is assumed to increase slowly over time in housing and non-residential premises. However, the final useful energy for heating decreases in comparison with the base year 2015 as a result of more energy efficient buildings, more efficient heating technologies and the implementation of efficiency measures.

Concerning the technology choice for heating, over time, a decreased use of direct electric heating and an increased use of heat pumps can be seen. By 2050, the contribution from direct electric heating is in principle zero. However, this is not entirely true, as a small share of direct electric heating is used to supplement air-to-air heat pumps and exhaust air heat pumps, for example, which come under the item ‘heat pumps’ in the figure. The result must instead be interpreted as meaning that the number of buildings using only direct electric heating will be virtually zero by 2050.

Small scale heating using oil and gas for houses, apartment buildings and non-residential premises disappears completely by 2030 in all scenarios. At the end of the modelled period (2050), an increase in district heating can be seen for all baseline scenarios in comparison with the start of the modelled period (2015), although in some cases this is marginal (see Chapter 5.8.1 for a review of the trend). The trend until 2050 for biofuel (small-scale heating solutions such as pellets and firewood) differs between the cases, with a decrease for baseline scenarios with a societal perspective and an increase for baseline scenarios with an investment perspective, in comparison with 2015.

Figure 29. Heating of housing and non-residential premises in baseline scenarios

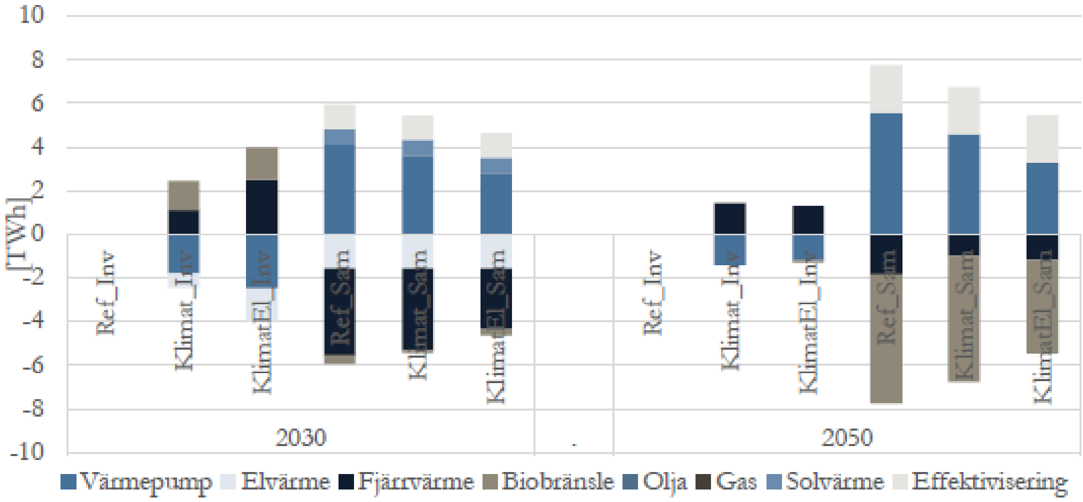


	TWh
	Efficiency improvements
	Solar heat
	Gas
	Oil
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam

Figure 30 clarifies the difference in outcome between the climate scenarios and the reference scenario, as well as between the investment perspective and the societal perspective. Compared to the reference scenario, the climate scenarios with higher carbon dioxide prices show a slightly higher use of district heating and pellets and a slightly lower use of heat pumps, as electricity is more expensive.[98] Compared to the investment perspective, the societal perspective shows an increased use of heat pumps and efficiency improvements and a slightly decreased use of district heating and pellets, as heat pumps and efficiency improvements are more capital-intensive and therefore become relatively more competitive with a lower calculated interest rate.

Figure 30 Useful energy for heating in housing and non-residential premises compared to the reference scenario Ref_Inv

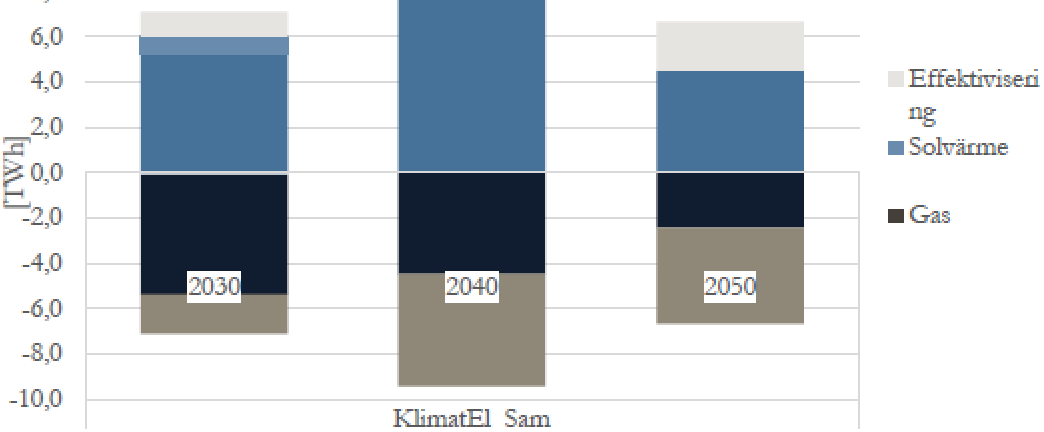
[98] However, this assumes that there is still fossil electricity production somewhere in Europe on the margin that is price-setting



	TWh
	Efficiency improvements
	Solar heat
	Gas
	Oil
	Biofuel
	District heating
	Electric heating
	Heat pumps
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam

Figure 31 shows the difference in the increase of useful energy for heating in housing and non-residential premises for KlimatEl_Sam in comparison with KlimatEl_Inv for all time periods 2030, 2040 and 2050. Heat pumps and energy efficiency improvements also benefit here from a socioeconomic perspective, while district heating and small-scale biofuel are reduced.

Figure 31 Useful energy for heating in housing and non-residential premises, KlimatEl_Sam in contrast with KlimatEl_Inv



	TWh
	KlimatEl_Sam
	Efficiency improvements
	Solar heat
	Gas

Conclusion:

- By 2030, the last oil and gas used for heating in housing and non-residential premises will be phased out due to unprofitability.
- In the long term, the last direct electric heating will also be more or less phased out in all cases.
- Heating for housing and non-residential premises will be provided by heat pumps, district heating, small-scale biofuel or a reduction in heat demand through energy efficiency improvements. All these technologies compete in a free market given existing instruments and they all contribute to an efficient consumption of primary energy and renewable energy. A socioeconomic perspective with a lower calculated interest rate is therefore assessed to be effective.

5.8. District heating

This chapter goes more in-depth into specific technologies as requested in Annex VIII, Part III, point 7:

a) industrial waste heat and cold;

b) waste incineration;

c) high efficiency cogeneration;[99]

d) renewable energy sources (such as geothermal, solar thermal and

[99] All cogeneration plants in Sweden are highly efficient (See the Swedish Energy Agency (2013b)).

biomass) other than those used for high efficiency cogeneration;

e) heat pumps;

f) reducing heat and cold losses from existing district networks.

The development of industrial waste heat (7a), waste incineration (7b), high-efficiency cogeneration (7c), renewable energy sources (7d) and heat pumps in the district heating network (7e) is shown for all baseline scenarios in Chapter 5.8.2. In accordance with the requirements in the Directive, breakdowns according to fossil and renewable energy are also shown.

As regards the reduction of heat losses in existing networks 7(f), there are almost no new data but what is available is shown in Chapter 5.10.

A more in-depth analysis of cogeneration is carried out in Chapter 5.9 where primary energy savings are also calculated according to the Directive’s method.

A more in-depth analysis of low-temperature waste heat is also carried out in Chapter 5.11 as well as of district cooling/waste cooling in 5.12.

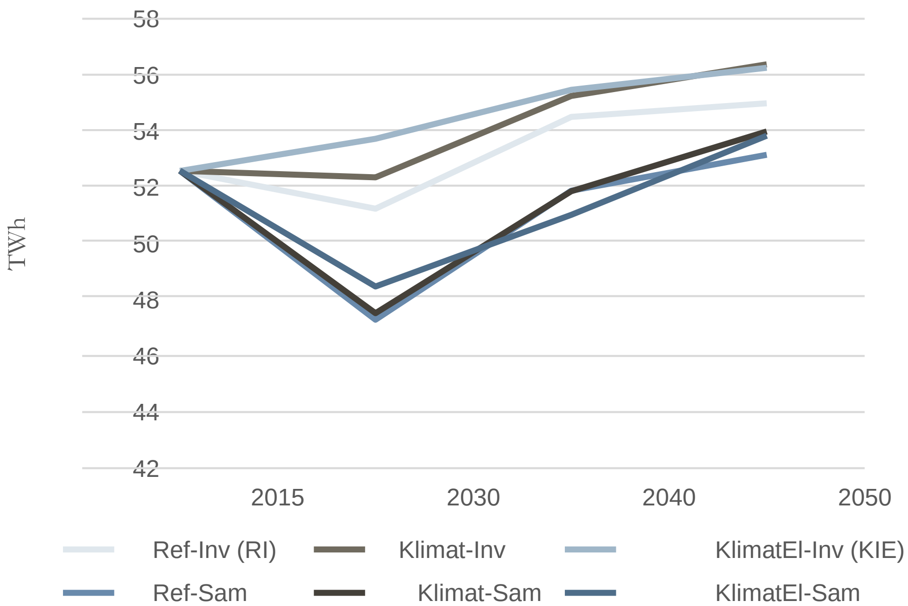
5.8.1 District heating supplies

As a result of increased competition from heat pumps and efficiency measures on the heating market, the district heating supplies are relatively constant and stay at approximately the same level as they are today until 2030 according to the model calculations, see Figure 32. Towards 2030, the model results point to a slight decline in the overall district heating base for all but one of the reported calculation outcomes, KlimatEl_Inv. This particularly applies to the scenarios with a socioeconomic calculated interest rate. The lower calculated interest rate favours the most capital-intensive investments, which benefits energy efficiency measures which are usually characterised only by a cost of capital. Although the district heating option is relatively capital intensive, a significant proportion of fuel costs and other variable costs are included in the total cost. It is also assumed that the cost of capital for the district heating network itself does not in principle change when switching from an investors’ perspective to a socioeconomic perspective as the calculated interest rate for investments in district heating transmission is low even from an investors’ perspective. This is because that type of infrastructure typically has long-term investments with low required rates of return. The geothermal heat pump option also benefits from a socioeconomic perspective, for the same reasons as the efficiency measures, which then strengthens its competitiveness slightly against district heating.

After 2030, the cheapest efficiency measures are estimated to be exhausted at the same time as electricity prices are assumed to rise as a result of stricter climate policies, inter alia. The total heating demand is also assumed to increase as a result of population growth and economic growth which will result in the district heating demand accelerating again in the long term, not least due to new housing construction. The model calculations also highlight the housing sector as a potential growth market in the longer term. Overall, however, there are no significant changes regarding the district heating demand over the entire analysis period.

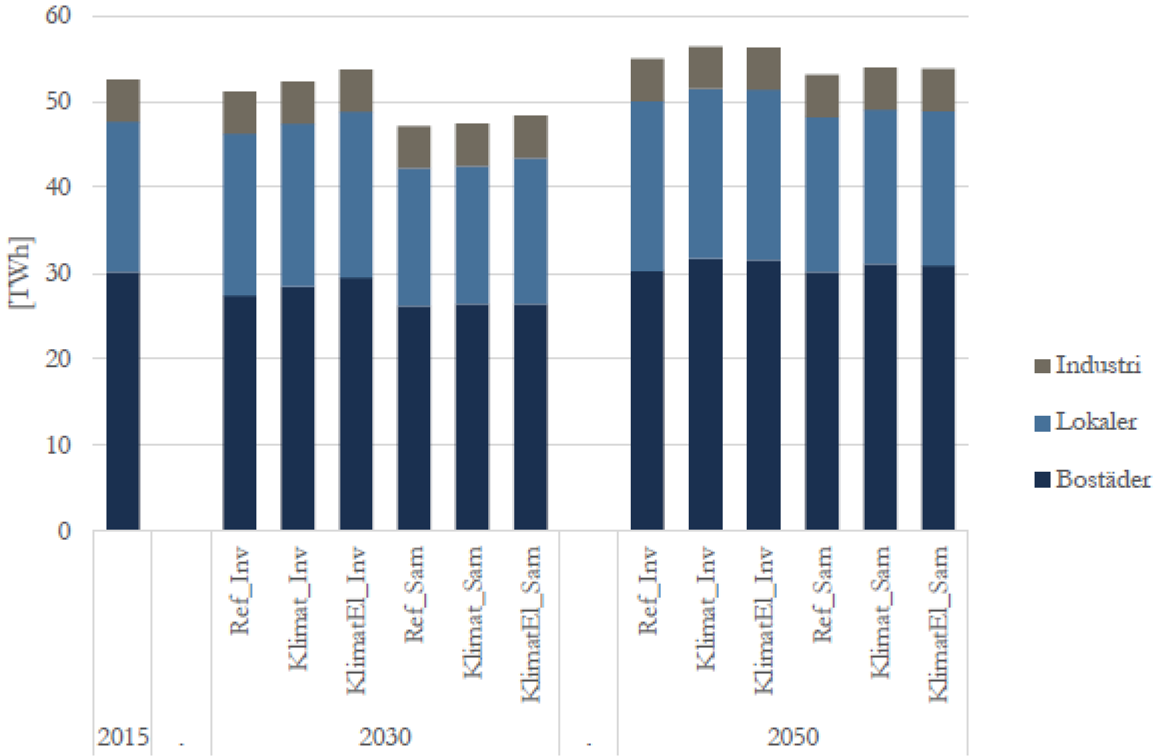
The assessments of potential for district heating supplies in total amount to 47-54 TWh in 2030 depending on the scenario, while in 2040 the range is 51-55 TWh and in 2050 it is 53-56 TWh (see Figure 32). It should be noted that in the cases with a socioeconomic calculated interest rate, the supplies are assumed to be smaller. This means that the market expands more district heating than would be the case if the expansion of the energy system were to take place with a socioeconomic calculated interest rate. This is again the result of heat pumps and energy efficiency improvements benefiting more from a lower interest rate.

Figure 32 Assessment of potential for district heating supplies



The modelling tool presents the district heating market as an aggregated Swedish district heating system. The model results must therefore be considered an overall picture of the Swedish district heating market's long-term development until 2050. In reality, the district heating market is largely local, which means that trends may differ between different systems, for example growth regions versus regions with a higher degree of relocation, as well as in the case of local differences in the composition of production and thus its competitiveness. Developments for the next decade's district heating consumption are also relatively sensitive to various energy price trends. Figure 33 shows the breakdown of district heating development by sector for the different calculations. The figure also shows that growth is greatest in housing and then in non-residential premises.

Figure 33 Development of district heating consumption by sector in the baseline scenarios



	[TWh]
	Industry
	Non-residential premises
	Housing
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam

5.8.2 District heating production

District heating production from cogeneration plants today (2015) is around 53%

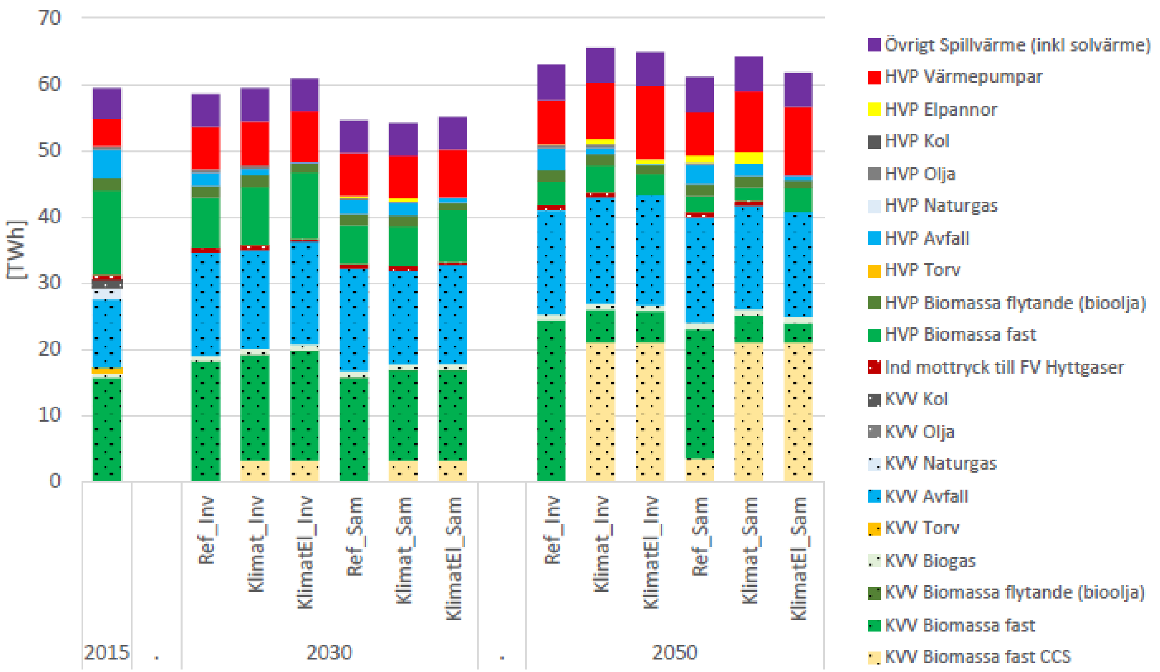
and increases in the model calculations to around 66% in 2050 with marginal differences between the different scenarios. The fuel composition of district heating production is shown in Figure 34 and in more detail in Figure 35, Figure 36, Figure 37 and Figure 38. Fossil energy types will already be phased out by 2030, except for the fossil share of combustible waste, blast furnace gas and a very small share of fuel oil for peak load production[100]. However, it should be noted that bio-oil can replace fossil peak load oil and that the industry has adopted a fossil-free roadmap (see Chapter 2.2) to act as a driving force for this. Blast furnace gases and fuel oils disappear completely in the climate scenarios. Biofuel of different types and waste are the two dominant energy types, but heat pumps also take up a bigger share of the market than they do today. An important explanation for this is the increasing availability of low-grade heat sources such as excess heat from data centres, especially in the climate scenario with increased electrification. The high electricity prices in the climate scenarios motivate a shift from heat only boilers to cogeneration, which is especially clear for waste-based fuels. In the climate scenarios, bio-CCS[101] has an extensive impact as of the model year 2040. This is because the high carbon dioxide prices clearly exceed the costs of bio-CCS, according to the assumptions made in the model. However, in the reference scenario the carbon dioxide prices are not sufficient to justify such investments. Nevertheless, there are major uncertainties concerning the bio-CCS technology as it still lacks commercial experience, even though the district heating industry as well as the policy makers have taken some initiatives[102].

Figure 34: District heating production's development and composition in the baseline scenarios, (KVV=Cogeneration plants, HVP=Heat only boilers).

[100] As the resolution in Times on an annual basis is only 12 or 13 steps, the model does not capture price volatility particularly well. This may mean that the profitability for electric boilers is underestimated. For example, it might be interesting to invest in electric boilers in a scenario with volatile electricity prices and where these particular hours are zero.

[101] Bio Energy Carbon Capture and Storage.

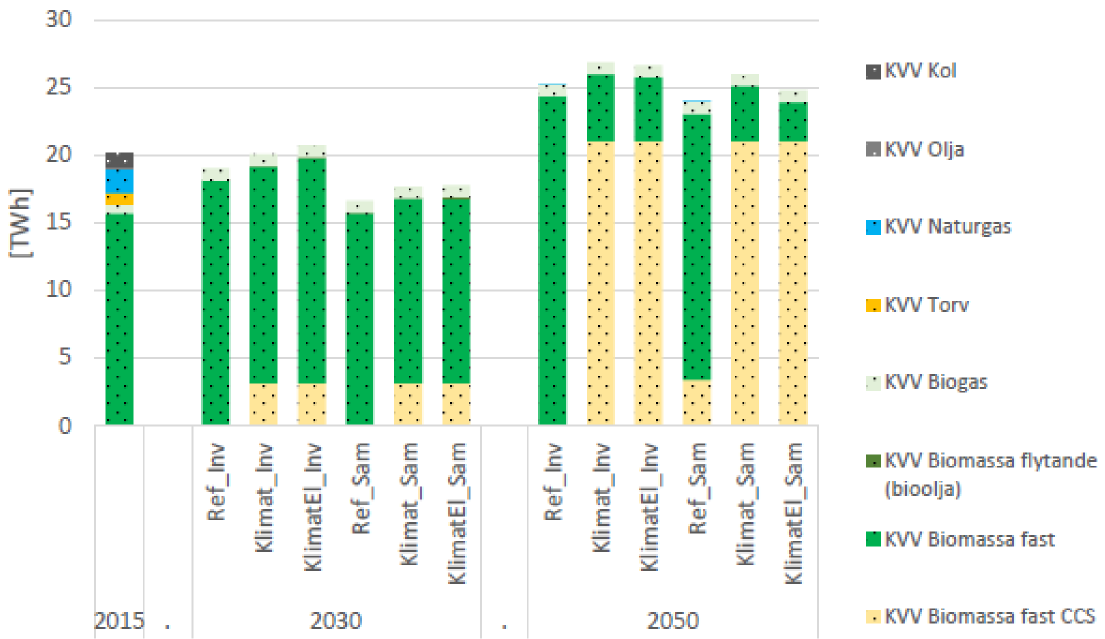
[102] See Chapter 2.4 and 4.3.3 and Annex D.



	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	Other Waste heat (incl. solar heat)
	HVP Heat pumps
	HVP Electric boilers
	HVP Coal
	HVP Oil
	HVP Natural gas
	HVP Waste
	HVP Peat
	HVP Biomass liquid (bio-oil)
	HVP Biomass solid
	Individual back pressure to district heating blast furnace gases
	KVV Coal
	KVV Oil
	KVV Natural gas
	KVV Waste
	KVV Peat
	KVV Biogas
	KVV Biomass liquid (bio-oil)
	KVV Biomass solid
	KVV Biomass solid CCS

Figure 35 shows that the contribution from biofuel-based cogeneration increases in all baseline scenarios in 2050 compared to 2030.

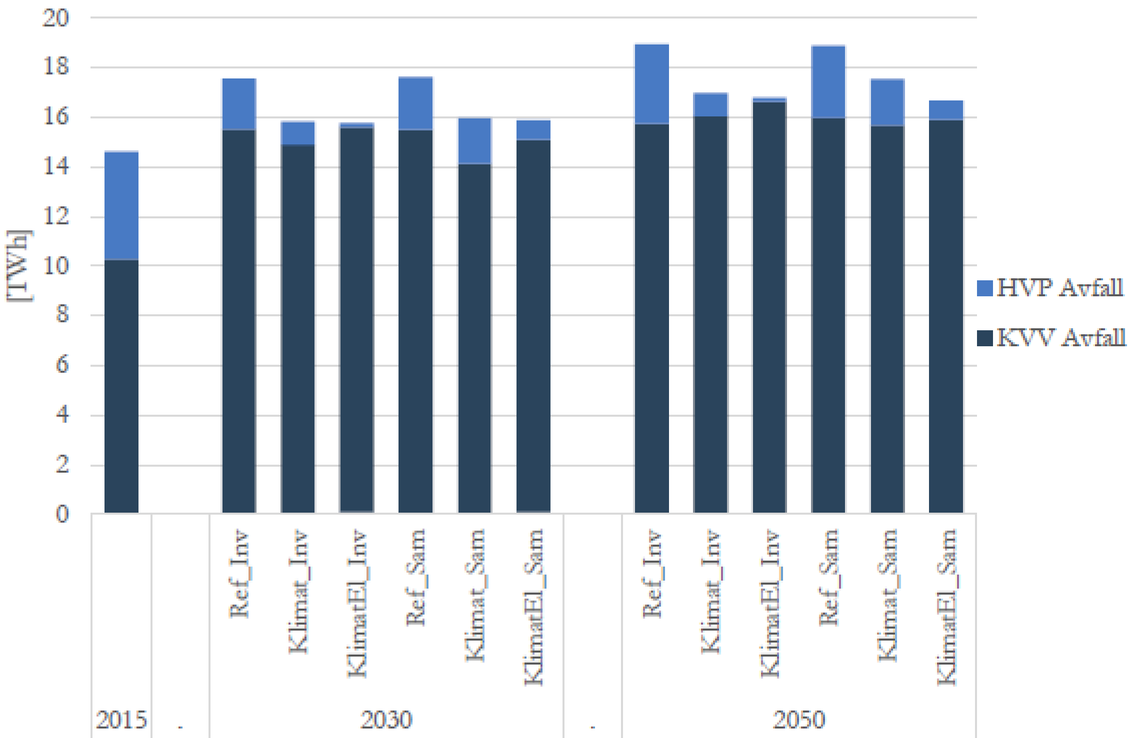
Figure 35 District heating produced from cogeneration (excl. waste)



	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	KVV Coal
	KVV Oil
	KVV Natural gas
	KVV Peat
	KVV Biogas
	KVV Biomass liquid (bio-oil)
	KVV Biomass solid
	KVV Biomass solid CCS

Figure 36 shows that the contribution from waste cogeneration increases in all baseline scenarios in 2050 compared to 2030 but that high carbon dioxide prices restrict the fossil content in the climate scenarios, which means that those scenarios have slightly less waste cogeneration than the reference scenarios[103].

Figure 36 District heating from waste incineration divided into heat-only boilers (HVP) and cogeneration (KVV)

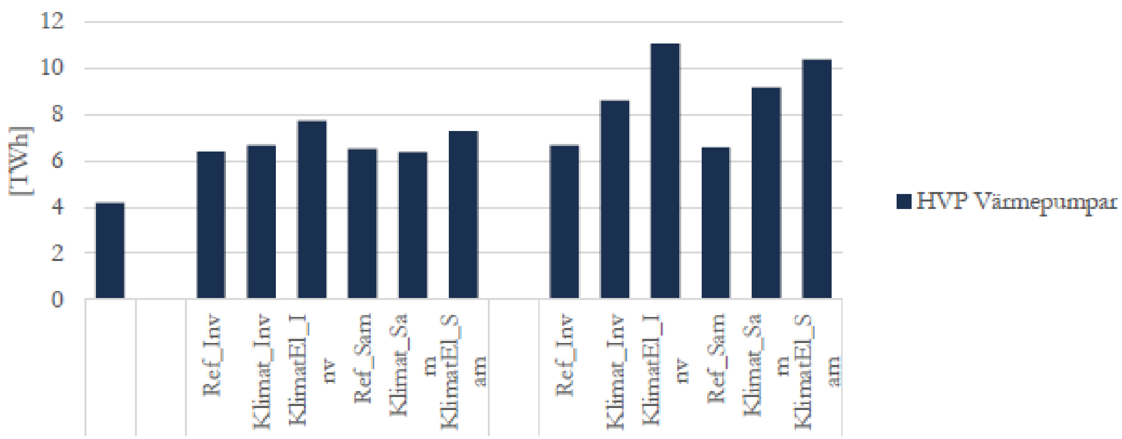


	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	HVP Waste
	HVP Peat
	KVV Waste

Figure 37 shows that heat pumps in district heating production will be more important in 2050 than 2030, especially in the climate scenarios and particularly in the climate scenario with increased electrification. However, the total district heating demand decreases in the case with a socioeconomic calculated interest rate. This also affects heat pump production in the district heating network, however to a lesser extent than (bio)fuel-based production.

Figure 37 District heating from heat pumps

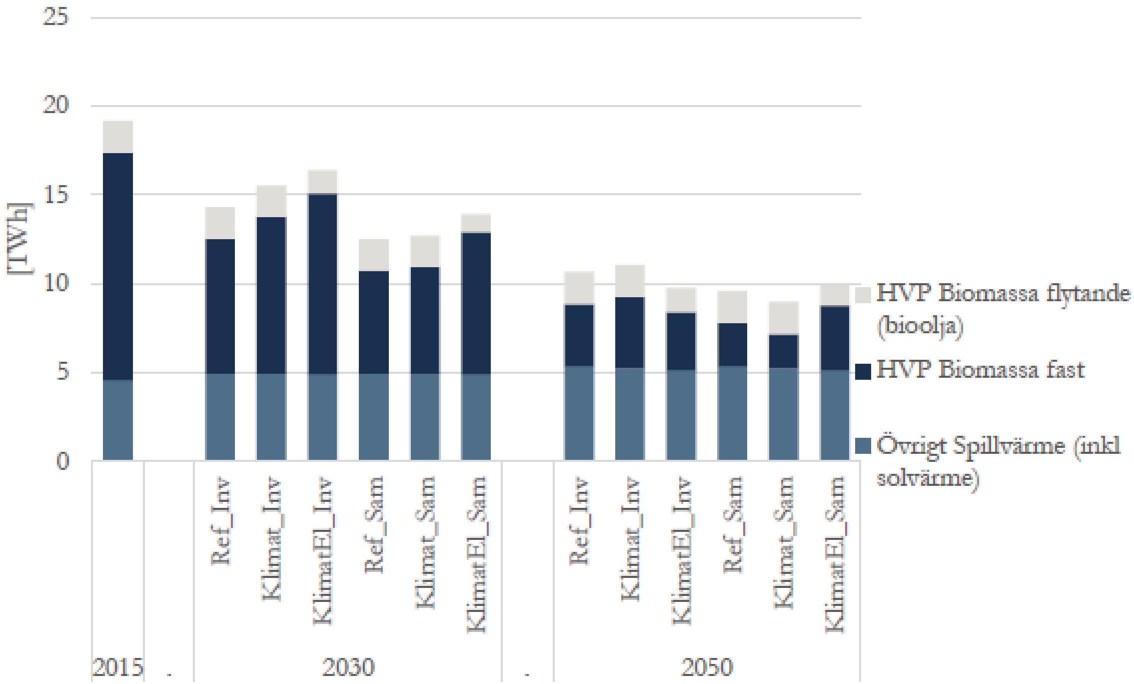
[103] In Sweden, the district heating sector is included in the EU ETS and waste incineration installations for energy production pay emission allowances.



	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	HVP Heat pumps

Figure 38 shows that district heating production from biomass in heat only boilers decreases over time for all cases, but that bio-oil increases slightly.

Figure 38 Renewable district heating from heat only boilers (HVP) and industrial waste heat

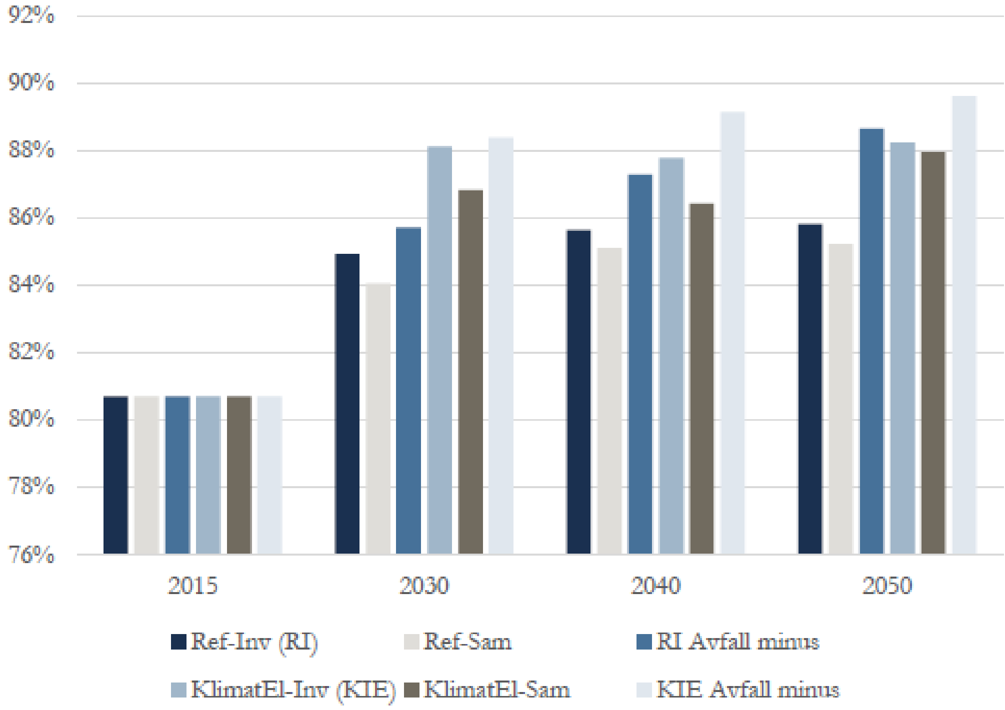


	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	Other Waste heat (incl. solar heat)
	HVP Biomass liquid (bio-oil)
	HVP Biomass solid

It is the fossil content in the waste that makes it difficult for district heating to increase its renewable shares. Figure 39 shows that a socioeconomic interest rate would give lower renewable shares than what the market itself would give. This is because investments in biofuel heat only boilers, but also to a certain extent in biomass cogeneration, decrease in cases with a socioeconomic calculated interest rate, as investments go to a greater extent to heat pumps and energy efficiency improvements, while waste cogeneration remains the same (the interest rate applies to the entire heating and electricity sector and the calculation model optimises according to the options that can heat a certain area at the lowest cost). The proportion of waste therefore increases, which decreases the renewable shares in the case with a socioeconomic calculated interest rate.

The case ‘Avfall minus’ shows what would happen if Sweden imported 20% less waste (waste that has more fossil content than domestic Swedish waste). In the reference scenario (blue columns), decreased imports of waste would lead to a 3-percentage-point increase in renewables by 2050. In the Klimat-El scenario (green columns), the increase would be 2 percentage points by 2050.

Figure 39 Renewable district heating compared to reduced waste incineration in two of the baseline scenarios



	Ref-Inv (RI)
	Ref-Sam
	RI Avfall minus
	KlimatEl-Inv (KIE)
	KlimatEl-Sam
	KIE Avfall minus

Conclusions

- Bio-CCS has great opportunities to reduce carbon dioxide emissions from district heating production and, according to the model runs the technology will have an impact in 2040 in both climate scenarios. For bio-CCS to have the impact that the model results show, the technology needs to be profitable (i.e. cheaper to invest in than the cost of releasing carbon dioxide[104]). Investments are already being made through research grants and in The Industrial Leap while the draft State Budget proposes that the Swedish Energy Agency becomes a national centre for carbon capture and storage, known as CCS, and is also awarded the funds to establish a system with reverse auctions or fixed storage fees for carbon capture and storage from renewable sources[105] (see Chapter 4.3.3 and conclusions in Chapter 5.5). If the goal of reaching net

[104] This in turn assumes an instrument that provides revenue for collecting CO2 from the atmosphere.

[105] Bill 2020/21:1, Expenditure heading 21.

zero emissions by 2045 and subsequently negative emissions is to be achieved, the development of the commercialisation of bio-CCS should be followed in order to assess whether existing actions are sufficient.

- The only fossil component in district heating generation in the long term is the fossil content of waste (except any peak load boilers that use oil, but these can be replaced with bio-oil). In order to increase the renewable shares further, some form of instrument for reducing the fossil content of waste is required. One possibility could be to introduce an instrument that results in reduced imports, as fossil content is higher in imported waste than in domestic waste. However, Swedish waste cogeneration is relatively dependent on imports of waste, which is why an instrument that reduces waste imports could lead to other negative effects. To be able to rectify the problem of fossil waste, the composition of the waste used for incineration needs to change. This is not a problem that is solved primarily through measures taken in the energy sector; the control instead needs to be directed at the actors who have access to waste generation (see also Chapter 2.8.2).

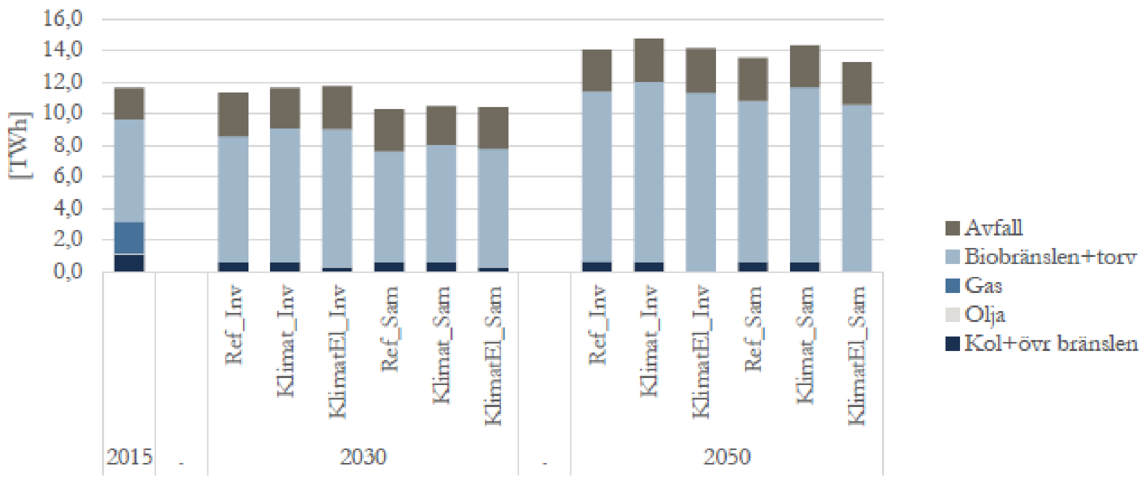
5.9. Cogeneration

5.9.1 Electricity production

Figure 40 and Figure 41 show that cogeneration plants' contribution to electricity production in the model calculations will increase slowly, or stagnate, until 2030 compared with the base year 2015. By 2030, fossil cogeneration plants will be phased out and replaced with biofuel and waste cogeneration plants. This means that electricity production decreases slightly, as the fossil cogeneration plants that are phased out generally have a higher electricity yield than the installations that increase their production, see

Figure 40. In addition, the investment incentives for new cogeneration are limited by, inter alia, electricity price development, which is expected to be relatively modest until 2030, not least as a result of a continued strong expansion of wind power. Increased competition from heating options other than district heating also plays a role.

Figure 40: Electricity production from cogeneration plants in the Swedish district heating networks (i.e. non-industrial).



	[TWh]
	Ref_Inv
	Klimat_Inv
	KlimatEl_Inv
	Ref_Sam
	Klimat_Sam
	KlimatEl_Sam
	Waste
	Biofuel + peat
	Gas
	Oil
	Coal + other fuels

The electric power in Swedish cogeneration plants currently (2018) amounts to around 3 000 MW electricity and the electricity production from cogeneration plants has been just under 10 TWh in recent years[106]. The model calculations indicate that electricity production in Swedish cogeneration plants will stay approximately at current levels until 2030 or, as in the cases with a socioeconomic approach, even decrease slightly, see Figure 40.[107] This is partly due to the fact that district heating is a lot less competitive compared to efficiency improvements and heat pumps, under the external conditions that apply to the climate scenario, with a consistently lower calculated interest rate.

In the longer term, after 2030, the model calculations show that electricity production and the electricity contribution from biomass cogeneration increase as a result of rising electricity prices especially during the winter.

In the model results, some coal also remains in 2050, but in reality, it is not particularly likely that this would remain even if it were profitable[108]. However, in the

[106] This does not include the industrial back pressure, i.e. cogeneration from industry.

[107] The result for 2015 is an estimated value and assumes a normal year with normal operating times for the cogeneration plants. In reality, production has been slightly lower for various reasons.

[108] Considering, inter alia, the heating industry's roadmap for fossil-free heating.

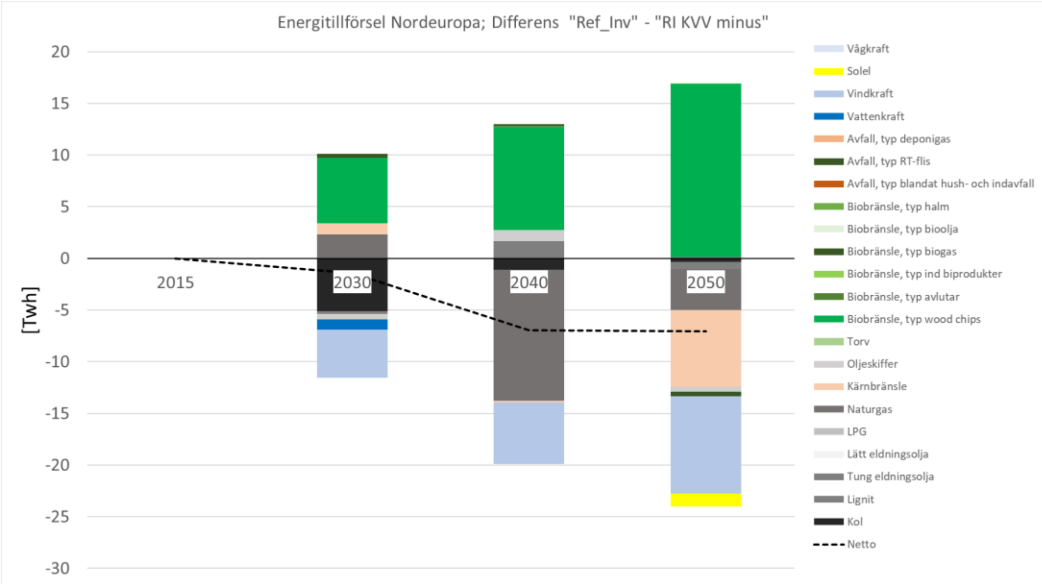
climate scenario with higher electricity prices, the last fossil content in cogeneration also disappears in the model.

5.9.2 Effects of cogeneration on primary energy

In the technology scenario RI KVV minus, the effect of a lack of investment in cogeneration in Sweden is analysed compared with the reference scenario Ref_Inv. The reason for such a development may be that investors for various reasons judge the uncertainties to be too great to risk committing to cogeneration and instead choose to invest in heat only boilers or something else when it comes to replacing ageing installations with new ones. How such a development would affect primary energy consumption is shown in Figure 41. The figure shows the difference in primary energy consumption in the whole of Northern Europe[109] between a case where new investments in Swedish cogeneration (Ref_Inv) are permitted provided they are profitable and a case where new investments in cogeneration are not permitted (RI-KVV minus), i.e. a fictional case where it is assumed that new investments in cogeneration are not profitable. The latter implies that the last cogeneration plant will be phased out some time around 2045. As the system boundary is set around Northern Europe, the primary energy consumption is also encompassed as a result of changes in electricity trade between Sweden and the rest of the world. The figure also shows that the net effect is an increased primary energy consumption, if new investments in Swedish cogeneration do not take place. According to this view, Swedish cogeneration thus entails a primary energy saving. That this is not larger than what can be seen in the figure is due to the fact that cogeneration involves an extensive use of biofuels. If we only look at effects within Sweden's borders, we can see that a lack of investment in new cogeneration means less biofuel consumption (which would be used in cogeneration plants) but more investments in wind power. At the same time, electricity trade between Sweden and the rest of the world changes and Swedish import dependency increases, particularly during the winter when the electricity balance may be more strained.

Figure 41: Difference in primary energy input at the northern European level between a case where new investments in Swedish cogeneration are permitted (Ref_Inv) and a case where such investments are not permitted (RI KVV minus).

[109] The countries in question are specified in Annex A.



	[TWh]
	Energy input northern Europe; Difference between ‘Ref_Inv’ – ‘RI KVV minus’
	Wave energy
	Solar electricity
	Wind power
	Hydropower
	Waste, landfill gas
	Waste, RT chips
	Waste, mixed household and individual waste
	Biofuel, straw
	Biofuel, bio-oil
	Biofuel, biogas
	Biofuel, by-products
	Biofuel,
	Biofuel, wood chips
	Peat
	Oil shale
	Nuclear fuel
	Natural gas
	LPG
	Light fuel oil

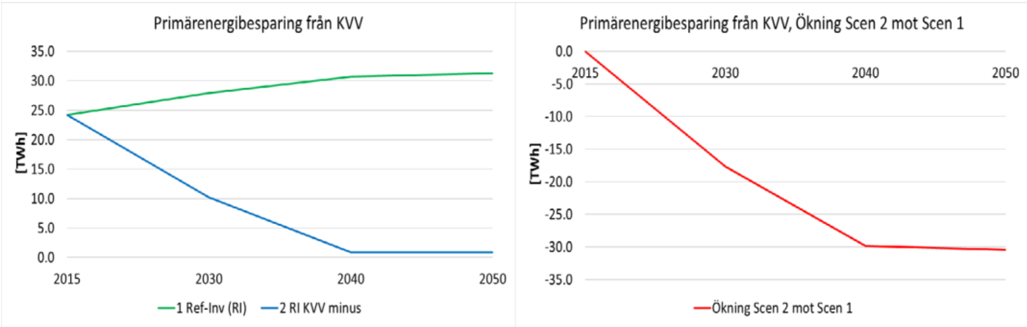
	Lignite
	Coal
	Net

However, the Energy Efficiency Directive (Annex II) requires primary energy savings from cogeneration to calculate the fuel usage in the separate production of electricity (condensing power plant) and district heating (heat only boilers) and compare it with the equivalent production of electricity and district heating in cogeneration plants (alternative production methods), see Figure 42. Such a calculation method means that the primary energy savings from cogeneration become significantly greater than what is shown in Figure 41 which is due to the fact that there are two completely different ways of calculating this. The red line in the right-hand diagram in Figure 42 shows that when using the method in the Energy Efficiency Directive (Annex II), the primary energy savings amount to 30 TWh. However, the dotted line in Figure 41 shows that the primary energy savings ‘in reality’ would only amount to 7 TWh if cogeneration were assumed to replace the technologies under the 0 line.

The red line in Figure 42 is the difference in primary energy savings between a case where cogeneration is expanded (corresponds to the green line in the diagram on the left) and a case where no new investments are made in cogeneration (corresponds to the blue line in the diagram on the left, Figure 42). Both the blue and the green line are therefore the result of the primary energy savings, given the alternative production method in the Energy Efficiency Directive. It can be seen that the primary energy savings in the case without new investments in cogeneration will go down to zero around 2040 as it is assumed that the lifetime of the cogeneration plants has been reached and that they are then completely phased out. In the calculation for Figure 41 it is instead the difference between two scenarios (with and without cogeneration) that determines the primary energy savings. This means in turn that cogeneration is replaced by a mix of primarily wind power, biofuel and nuclear fuel. As regards, for example, electricity production from wind power that replaces electricity production from cogeneration, the primary energy savings are zero. But if the starting point is that a certain electricity production in a biofuel cogeneration plant instead takes place in a biofuel condensing power plant with a significantly lower degree of efficiency, the savings will then be significantly greater. As regards district heating production, the difference is very small, as the degree of efficiency for the alternative production, a heat only boiler, is very high.

Figure 42: On the left: Primary energy savings for cogeneration compared with separate production of electricity and heat for Ref_Inv and RI KVV

minus. On the right: difference between Ref_Inv and RI KVV minus.



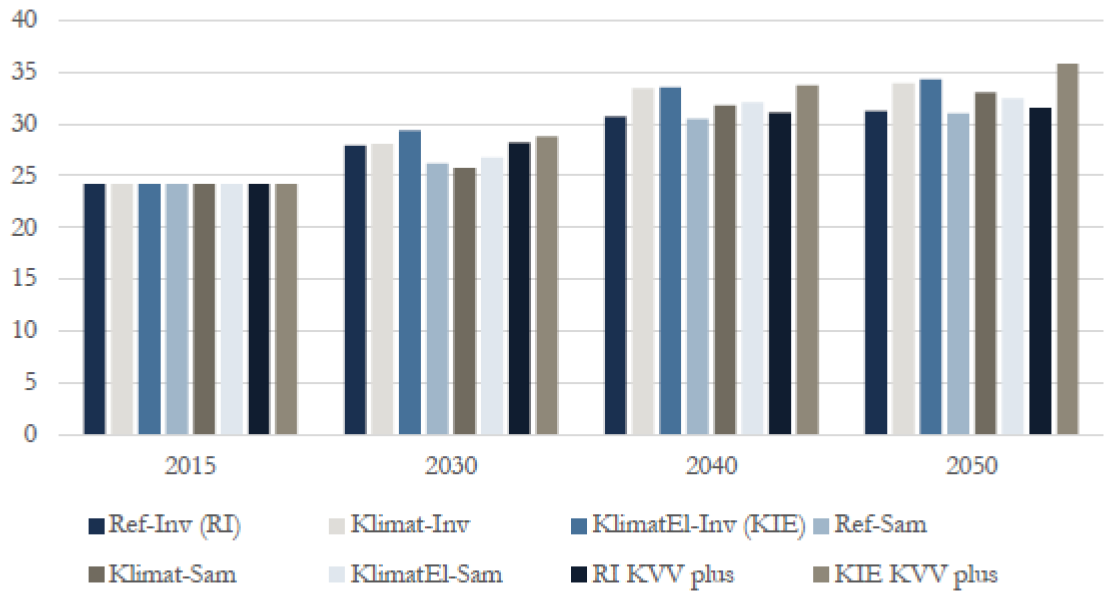
Note: Scen 2 against Scen 1 means Scenario 2 (Ref-Inv) minus Scenario 1 (RI KVV minus).

	Primary energy saving from KVV
	Primary energy saving from KVV, Increase Scen 2 against Scen 1
	TWh
	1 Ref-Inv (RI)
	2 RI KVV minus
	Increase Scen 2 against Scen 1

Figure 43 shows that even with a socioeconomic calculated interest rate, the primary energy savings would not increase compared to the same scenario using a business-economic rate (striped columns compared to solid columns of the same colour). There is instead a slight decrease. The reason is that the total district heating production (including cogeneration) decreases as investments are attracted to other (relatively) more capital-intensive technologies (such as heat pumps and energy efficiency improvements). The only way to increase the primary energy savings is to force in more cogeneration than is profitable (see the columns RI KVV plus and KIE KVV plus) but even in those cases, there are no significant additional primary energy savings[110].

Figure 43 Primary energy savings from baseline scenarios and scenarios with more cogeneration, EU calculation method

[110] The level for cogeneration is based on the high case in the 'Cogeneration in the future' study and amounts to around 6 GW electricity in 2050. See Profu (2019).



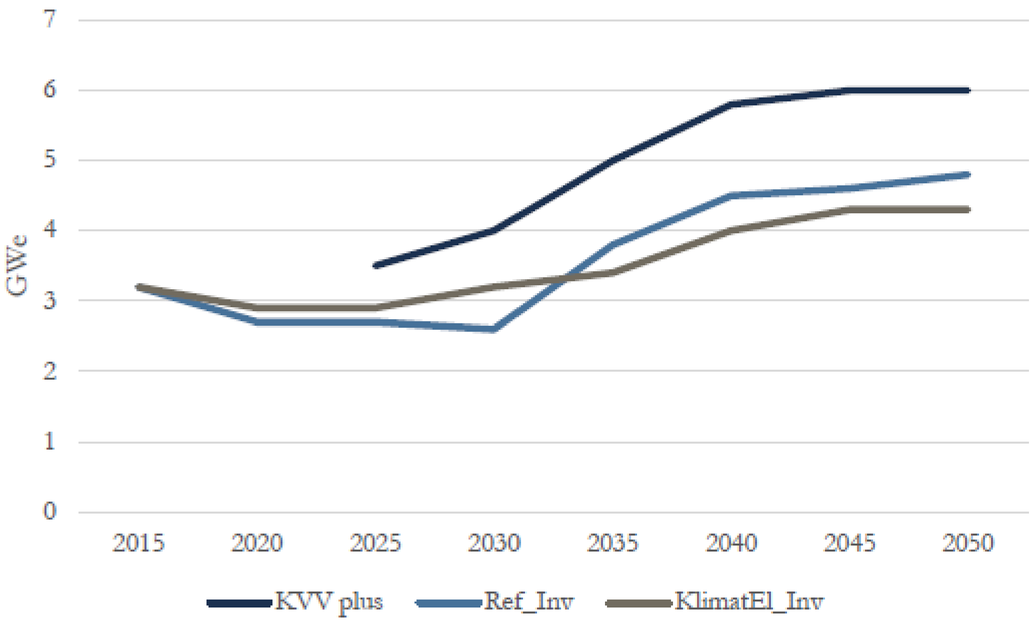
	Ref-Inv (RI)
	Klimat-Inv
	KlimatEl-Inv (KIE)
	Ref-Sam
	Klimat-Sam
	KlimatEl-Sam
	RI KVV plus
	KIE KVV plus

5.9.3 More cogeneration capacity and effects on system costs

Figure 44 shows the installed capacity from cogeneration in the reference scenario (Ref-Inv) and the climate scenario with increased electrification (KlimatEl_Inv) compared with the KVV plus case where extra cogeneration is forced into the model, i.e. more than what the model builds out in a cost-optimal manner. Depending on the scenario, this would then mean an increase in installed electricity in 2050 of 1.7 GW and 1.2 GW, respectively. However, as can be seen in Figure 43, the KVV plus case would not affect the primary energy savings as much. This is because the higher proportion of installed power is simply not as profitable to run, which in other words means that the useful life of the additional capacity in the KVV plus case is not very high.

If the cost of the extra installed power is low, however, it may still be the case that the benefits of providing extra power to address local power shortages may exceed the costs of forcing in more cogeneration (than what the model expands), see Chapter 2.8.5.

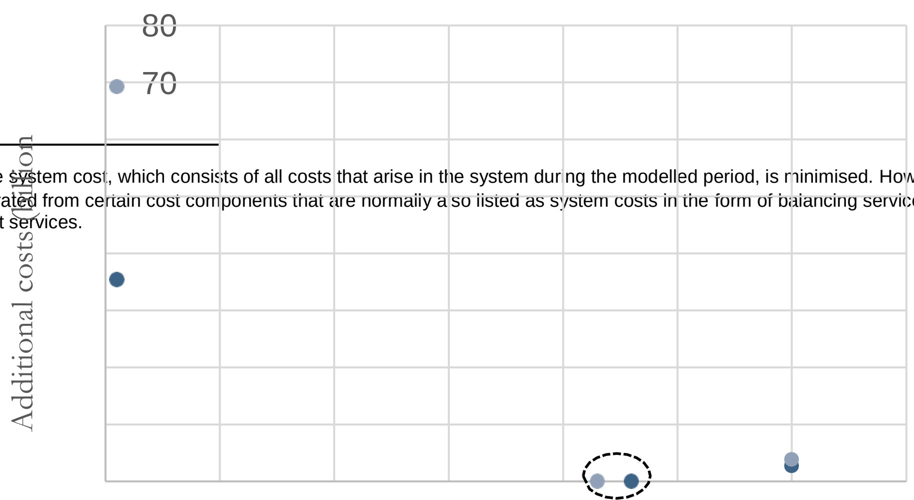
Figure 44 Installed cogeneration capacity KVV plus compared with baseline scenarios Ref_Inv and KlimatEl_Inv



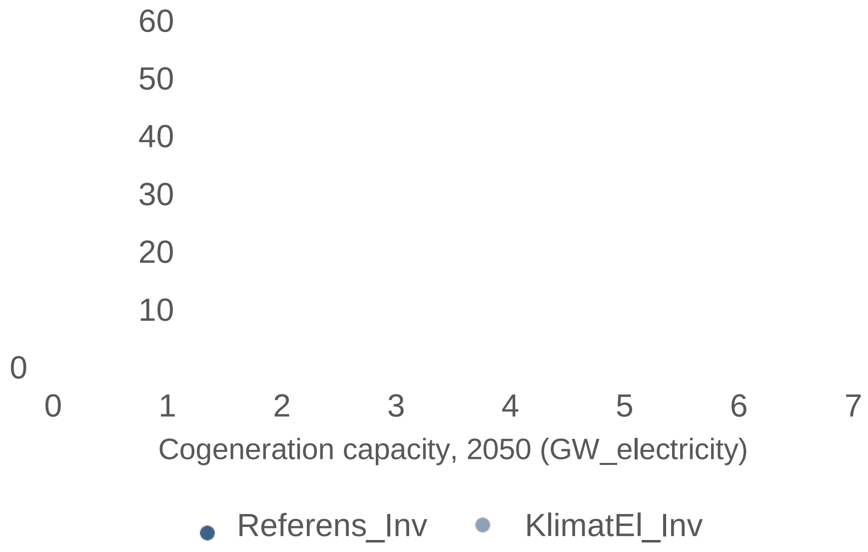
	GW electricity
	KVV Plus
	Ref_Inv
	KlimatEl_Inv

Figure 45 shows the effect on the model's system cost of the technology scenarios in which alternative assumptions concerning cogeneration capacity are tested. The model's system cost is all costs that arise in the system over the entire modelled period (2005 to 2050) and is expressed as a net present value to the model's base year 2005 (a discount rate of 3.5% is used in the analysis)[111]. The green and blue dots on the far left of the figure show the additional costs of no new investments in cogeneration for the cases Ref-Inv and KlimatEl_Inv. The circled dots in the middle show the normal situation for each scenario, i.e. no additional costs for the installed power. The dots on the far right show the additional costs for further capacity in the KVV plus case compared with the Ref-Inv and KlimatEl_Inv cases (compare Figure 44).

Figure 45: Effect on system cost for different levels of cogeneration capacity (GW electricity), expressed as additional costs for technology scenarios compared to baseline scenarios (which are circled). KVV minus to the left of the image, KVV plus to the right of the image compared with circled baseline scenarios.



[111] In the model, the system cost, which consists of all costs that arise in the system during the modelled period, is minimised. However, these costs must be separated from certain cost components that are normally also listed as system costs in the form of balancing services/reserve markets and support services.



The results show additional system costs of around SEK 35 and SEK 70 billion for Referens and KlimatEl conditions respectively for non-investment in cogeneration (KVV minus). The high cost efficiency for bio-CCS in the scenario KlimatEl_Inv means that a missed opportunity to invest in this technology has further negative consequences on the system cost in relation to the conditions in the reference case with lower carbon dioxide prices. For the KVV plus cases an increased system cost of around SEK 3-4 billion can be seen. The model calculations show that the additional costs of forcing in more cogeneration compared with the optimal outcome in each baseline scenario are very small compared to the additional costs that arise when new investments in cogeneration are not permitted in the model.

Conclusions

- A socioeconomic calculated interest rate would not contribute to more primary energy savings than what the market contributes as district heating production including cogeneration would decrease slightly due to increased competition from heat pumps and energy efficiency improvements, which would earn more at a lower calculated interest rate.
- Low profitability now risks leading to underinvestment in cogeneration if it is not correctly priced based on its usefulness in being able to contribute various system support services. According to the Energy Efficiency Directive, cogeneration also leads to benefits in the form of primary energy savings, which is a criterion that must be taken into account in the assessment to be done in the cost-benefit analysis.[112]

[112] Annex VIII Part III point 8(iii) EED. 'The assessment and decision-making should take into account costs and energy savings from the increased flexibility in energy supply…'. It should be noted that primary energy savings are not a benefit in themselves and that the scarcity of a resource has an impact on the price signal, which according to the Swedish Energy Agency is what should be the determining factor.

- An analysis of the system costs of a lack of investment in cogeneration shows that they are quite high, at 35-70 billion, while the system costs for forcing an extra 1.2-1.7 GW electric power from cogeneration into the system are comparatively low, at 3-4 billion.
- Cogeneration plays an important role in the power balance especially as regards increasing electrification and more variable power in the electricity system.
- An appropriate action would be to look at existing instruments and whether cogeneration is priced correctly so that it can continue to contribute not only different system support services but also *efficient heating and cooling* as defined in the Energy Efficiency Directive[113] as well as contributing to an *efficient system for district heating and cooling.*[114]

5.10. Efficiency improvements in the district heating and cooling networks

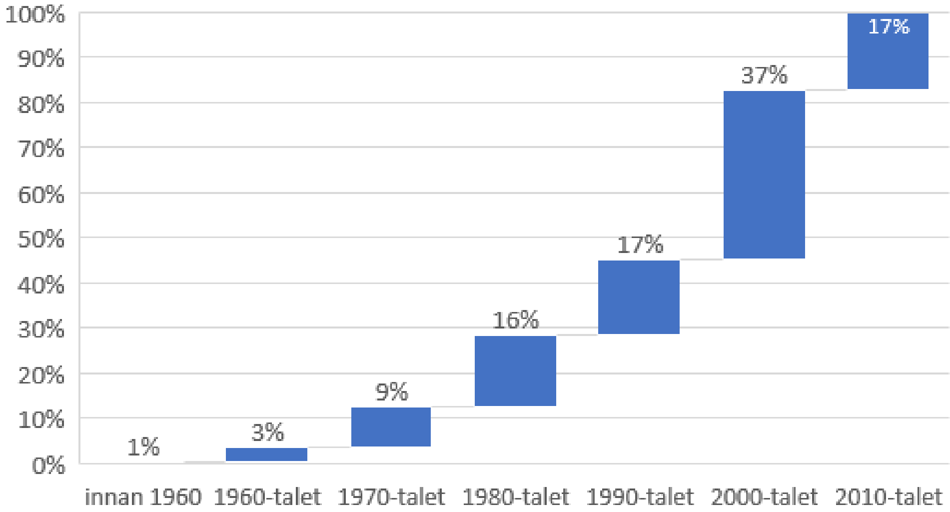
Annex VIII point 7(f) demands a potential for reducing of heat and cold losses from existing district heating networks. There are no new research projects or new estimates that show the potential for reducing losses in the district heating and cooling networks. The most recent estimates can be found in the report *Comprehensive assessment of the potential for exploiting high-efficiency cogeneration, district heating.*[115] Sweden's district heating network is relatively new (Figure 46). It is a modern network with continuous investments which means that we consequently have relatively low losses.

Figure 46 Expansion of the district heating network

[113] Article 2 (42) EED efficient heating and cooling: a heating and cooling option which, compared with a reference scenario that reflects a scenario where one continues as before, measurably reduces the primary energy input needed to supply a unit of supplied energy within a relevant system boundary in a cost efficient manner, in accordance with the assessment in the cost-benefit analysis referred to in this Directive, taking into account the energy required for extraction, conversion, transport and distribution.

[114] Article 2 (41) EED efficient system for district heating and district cooling: system for district heating or district cooling which uses at least 50% renewable energy, 50% waste heat, 75% heat produced by cogeneration or 50% of a combination of such energy and heat

[115] ER2013:24



Source: Swedenergy

	before 1960
	1960s
	1970s
	1980s
	1990s
	2000s
	2010s

Current district heating, also called third-generation district heating (3GDH), uses hot water that is transported in pipes usually underground at a temperature of 80-100°C depending on the outdoor temperature, with lower temperatures on the district heating network in summer and higher temperatures during the winter. For traditional district heating, prefabricated insulated steel pipes are used to transport the district heating water.
Fourth-generation district heating (4GDH) in principle works in the same way as traditional district heating (3GDH) but uses a lower temperature level, new material and an equipment shelter. In the equipment shelter, there is a large substation used to decrease the temperature on the primary district heating network from around 80-100°C down to around 60°C. Reducing the temperature level enables PEX pipes to be used which are a type of plastic pipe that are flexible and cost-efficient compared to steel pipes.[116]

There are currently no 4GDH installations in Sweden, but there are several similar systems with low-temperature district heating (LTDH) in Västerås, Linköping and an area in Kiruna, for example. LTDH resembles 4GDH as both systems are

[116] Fourth generation district heating and collocation at Kiruna urban regeneration, Wirsenius, M.

designed for lower temperatures, around 60-70°C in the supply line and 30-40°C in the return line. The current LTDHs use a mixture of PEX and steel pipes. Simulations have shown that, under the right conditions, 4GDH is more cost-efficient than third-generation district heating and also has significantly fewer losses. In a simulation for an area in Kiruna, the thermal losses from a normal district heating network would amount to SEK 3.74 million over 50 years, while these would be more than halved for 4GDH.[117]

In the study *Economic benefits of fourth generation district heating*[118], the authors use another simulation to show that, given certain conditions, the losses may decrease from 8.4% in a normal district heating network to 3.3% for a low-temperature district heating network.

However, the potential for low-temperature district heating networks 4GDH/LTDH is difficult to estimate more precisely.

5.11. Low-temperature waste heat for district heating production[119]

Waste heat is divided here into high-temperature industrial waste heat that can be used directly on the district heating network ('industrial waste heat') and waste heat/residual heat at a lower temperature which is increased by heat pumps. As regards industrial waste heat, the potential is not particularly large (see Chapter 2.5 and Chapter 3.1) which is reflected in the model calculations which show a potential for future industrial waste heat of 0.6-0.8 TWh between 2015-2050 for the different scenarios (see Table 7).

Table 7 Potential industrial waste heat all baseline scenarios

Baseline scenario	Increase 2015 to 2050, TWh
Ref-Inv (RI)	0.8
Klimat-Inv	0.6
KlimatEl-Inv (KIE)	0.6
Ref-Sam	0.8
Klimat-Sam	0.6
KlimatEl-Sam	0.6

The major potential can instead be found in low-temperature waste heat, for example from data centres, which may grow significantly more with estimates between 1.7-4.8 TWh additional waste heat depending on the baseline scenario, see Table 8. It is worth noting that a socioeconomic calculated interest rate would

[117] Fourth-generation district heating and collocation at Kiruna urban regeneration, Wirsenius, M.
[118] Averfalk, H. and Werner, S. Energy 193 (2020) 116727
[119] See Annex B for conditions and assumptions.

not contribute more waste heat, as the competition with other technologies (for example energy efficiency improvements and heat pumps) would also increase with a lower rate. The potential for low-temperature waste heat is particularly large in the climate scenario with increased electrification. In this scenario, it is assumed that the potential for waste heat from data centres is larger than in the reference scenario as data centres are assumed to expand in Sweden and therefore affect both electricity consumption and access to low-temperature waste or residual heat.

Table 8 Low-temperature waste heat before temperature increase with heat pumps for all baseline scenarios

	2015	2030	2040	2050	Increase 2015-2050
Ref-Sam	2.0	3.2	3.3	3.7	**1.7**
Ref-Inv (RI)	2.0	3.1	3.3	3.8	**1.8**
Klimat-Sam	2.0	3.1	3.6	5.1	**3.1**
Klimat-Inv	2.0	3.3	3.3	5.1	**3.1**
KlimatEl-Sam	2.0	3.8	4.9	6.3	**4.4**
KlimatEl-Inv (KIE)	2.0	4.1	4.9	6.8	**4.8**

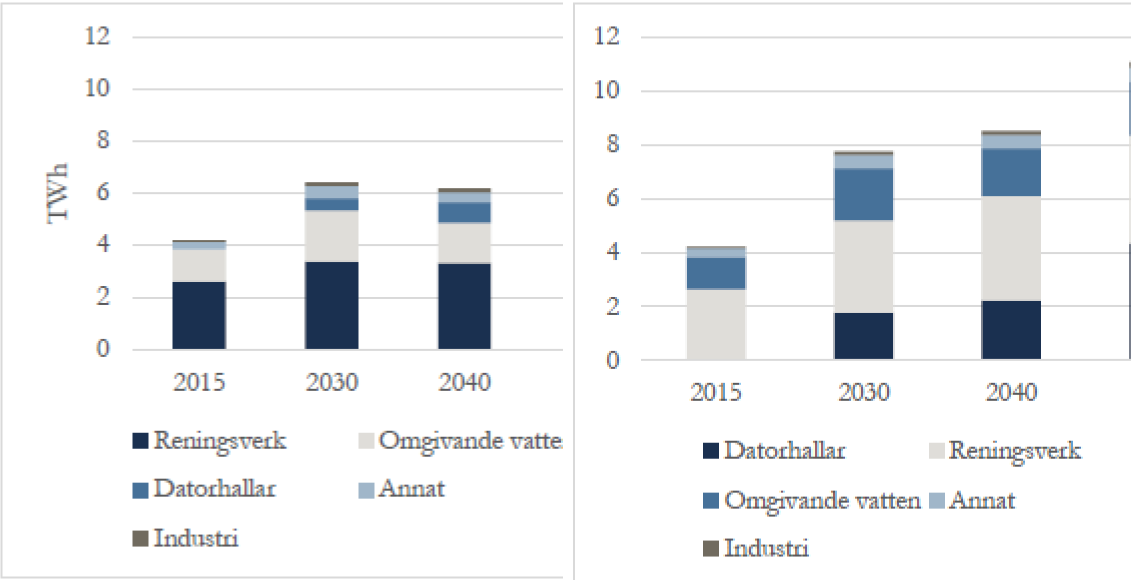
However, in order to use the low-temperature waste heat in the district heating network, the temperature must be increased using heat pumps. The potential for increased district heating production with heat pumps that use low-temperature waste heat is between 2 and 6.1 TWh between 2015 and 2050, depending on the baseline scenario (see Table 9).

Table 9 Low-temperature waste heat including temperature increase with heat pumps

	2015	2030	2040	2050	Increase 2015-2050
Ref-Sam	3.0	4.6	4.6	5.0	**2.0**
Ref-Inv (RI)	3.0	4.5	4.7	5.1	**2.1**
Klimat-Inv	3.0	4.7	4.5	7.0	**4.1**
Klimat-Sam	3.0	4.4	5.0	7.0	**4.0**
KlimatEl-Sam	3.0	5.3	6.8	8.5	**5.5**
KlimatEl-Inv (KIE)	3.0	5.8	6.8	9.1	**6.1**

A closer look at the distribution of the origin of the low-temperature waste heat for district heating production is shown for two of the scenarios (with most and least waste heat) in Figure 47. The figure shows that waste heat from treatment plants is an important resource in both cases but that waste heat from data centres is assumed to increase a lot in the climate scenario with high electrification by 2050.

Figure 47 District heating production from heat pumps that use waste heat with lower temperatures, Ref_Inv (on the left) KlimatEl_Inv (on the right)



	TWh
	Treatment plants
	Data centres
	Industry
	Surrounding water
	Surrounding water
	Other

Note: Surrounding water is included in the figure but is not counted as low-temperature waste heat.

Conclusions

- The potential for industrial waste heat (waste heat with temperatures that mean that it can be used directly on a district heating network) is not deemed to be particularly large. Overall, the potential is an increase of between 0.6-0.8 TWh from 2015-2050.
- The potential for low-temperature waste heat (residual heat) in combination with heat pumps to increase the temperature so that it can be used on a district heating network is assessed to be a further 2-6.1 TWh in 2050 compared with 2015, depending on the scenario. There is a large potential for procuring heat from data centres in the climate scenario with high electrification, which assumes a large number of data centres being built. There is also some potential in the reference scenario.

5.12. District cooling

District cooling supplies increase significantly over the modelled period, from around 1 TWh in 2015 to around 2.3 TWh in 2050 for all baseline scenarios, see Figure 48. A socioeconomic calculated interest rate has no great impact on the expansion. The trend in the model is driven by a generally increased cooling demand due to new construction, an assumed development with a larger share of cooled areas as well as an assumption of a warmer climate in the future (see Annex B for further information).

The market share for district cooling for comfort cooling in non-residential premises shows a moderate increase from around 23% in 2015 to around 26% in 2050. The increasing cost of distribution, as district cooling expands to areas with a less concentrated demand for cooling, is the factor in the model that prevents a further, cost-efficient increase in the district cooling share.

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Annex A Calculation assumptions

This Annex shows a number of important calculation assumptions that form the basis of the results for the economic potential of heating and cooling in Chapter 5. . In general, these apply to all scenarios with some exceptions which are then indicated. Some of the calculations and exceptions differ from the Swedish Energy Agency's long-term scenarios 2020. The reason for this is that the Article 14 analysis is based on energy demand projections from what were at the time the most recent available 'Long-term scenarios' from the Swedish Energy Agency which were compiled around 2 years ago. On the other hand, the fuel price and CO2 price assumptions are from a more recent average and are based on what was published by the IEA in WEO in 2019. By contrast, the current phase of 'Long-term scenarios' (2020), which began after the completion of the Article 14 work, is based on completely updated energy demand projections and completely new fuel price projections, which were provided to Profu by the Swedish Energy Agency prior to this assignment. Some model development and other technology-specific input data updates have also been added. However, in the ongoing phase of 'Long-term scenarios', Profu has used the model development that was done in the context the of Article 14 work, i.e. low-temperature waste heat, district cooling and bio-CCS. The reason why Profu has not been able to synchronise input data in the Article 14 analysis with what is assumed in the ongoing phase of 'Long-term scenarios' is simply that the Article 14 analysis was completed before the analysis in 'Long-term scenarios 2020' was started.

Energy demand

Profu has based its calculations on the scenario projections used in the Swedish Energy Agency's latest 'Long-term scenarios' from 2019 for the reference scenario and the climate scenario. However, some updates have come, inter alia, under the work within NEPP[120]. This primarily concerns electricity consumption which is slightly higher here than in the Swedish Energy Agency's reference scenario from 2019. By contrast, in the 'climate scenario with high electrification', projections are used for the energy demand which were produced in connection with the background work for the electricity industry's 'Roadmap electricity' from 2019[121].

This mainly concerns electricity consumption, which is consequently significantly higher in the long term in this scenario than in the reference scenario and climate scenario.

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[120] Read more at https://www.nepp.se/.

[121] Swedenergy (2019), Swedenergy is working for a fossil-free Sweden.https://www.energiforetagen.se/vara-positioner/energiforetagen-arbetar-for-ett-fossilfritt-sverige/fardplan-el-- for-ett-fossilfritt-samhalle/ (accessed 18.11.2020).

In the model, the energy demand is stated partly as input data (non-substitutable energy consumption, for example for household and operational electricity, industrial process electricity and net heat demand for housing and services) and partly as a calculation result (substitutable energy such as electricity for heating and process heating). Input data supplied by the Swedish Energy Agency therefore covers the former category of energy demand. This in turn means that the calculated values for electricity consumption, for example, may deviate from the Swedish Energy Agency's overall assumptions.

The energy consumption in housing and services is divided into heat and household electricity/operational electricity within the following sub-areas:

1. Net heat demand (i.e. useful heat for heating and hot tap water; after conversion losses) in existing and new houses.
2. Net heat demand for existing and new apartment buildings.
3. Net heat demand for existing and new non-residential premises.
4. Household electricity (including operational electricity for apartment buildings, for example lighting, lifts, etc.).
5. Operational electricity and equipment electricity in non-residential premises.
6. Other final oil consumption in households and services, i.e. not related to heating. This could be, for example, kerosene and petrol, which are part of this sector (but are not used for heating or transport purposes).
7. Other final energy consumption in the construction, agriculture, forestry and fishing sectors. This includes energy used for business. This means, for example, that the heating demand for living areas in the agriculture sector is not included (this is instead counted as heating demand in houses) but rather things that, for example, are needed for heating in properties used for the business, such as barns.

The heat demand is a projection, while the energy carriers to meet the heat demand are a result from the model. Heat can be generated by oil, natural gas, electricity, heat pumps, district heating and pellets, for example. The demand for household electricity/operational electricity can naturally only be covered by the energy carrier electricity. The final energy consumption for heating can be reduced in the modelling tool partly through conversion to a more efficient heating option and partly through efficiency measures such as additional insulation, window replacement, improved regulation etc. As mentioned earlier, the heat demand for the residential and services sector is shared between 6 different categories: existing and new houses, existing and new apartment buildings and existing and new non-residential premises. The net heat demand for existing buildings is estimated to stay at the current level for the whole model period (we assume that no existing buildings are demolished during the model period) except for the scenario ‘Klimat’ where it is instead assumed to fall over time. However, the final energy consumption to meet this demand is a model result and changes (decreases) as a result of conversions and efficiency improvements that are chosen endogenously in the model. The demand for cooling is also included in the modelling tool but this is described in more detail in Annex B.

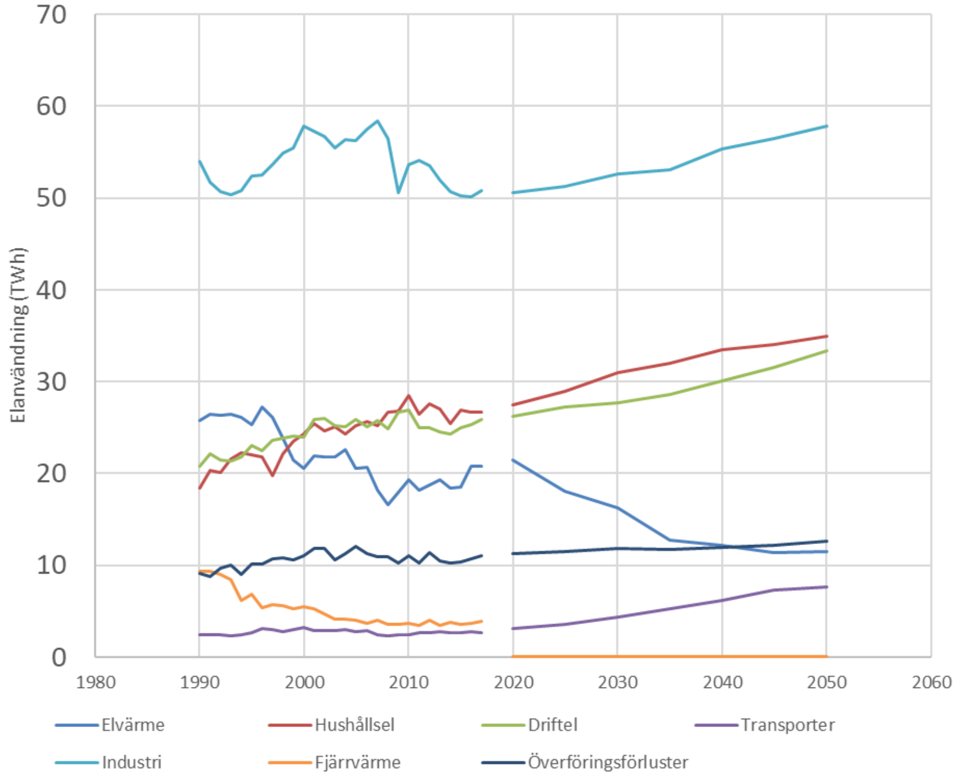
As with the heating demand in the construction sector, the energy demand is divided within the industry into substitutable energy and non-substitutable energy.[122] Coke, light fuel oil, gasoline, process heat and district heat are represented as non-substitutable energy carriers whose demand is stated exogenously, while natural gas, heavy fuel oil and biofuels, for example, are mainly substitutable fuels that are used to generate process heat (including steam). The consumption of the substitutable fuels in industry is, in other words, a model result. Electricity is both a substitutable energy carrier (in electric boilers to generate process heat) and a non-substitutable energy carrier (for example for process electricity for motors, pumps and the like). Industry is expressed as five different sectors: paper and pulp, iron and steel, mining, chemical and other industries. A number of industrial processes are explicitly included in the modelling (albeit somewhat simplified and aggregated) such as recovery boilers, blast furnaces and coking plants. A number of other processes that can produce both electricity and process heat are also included.

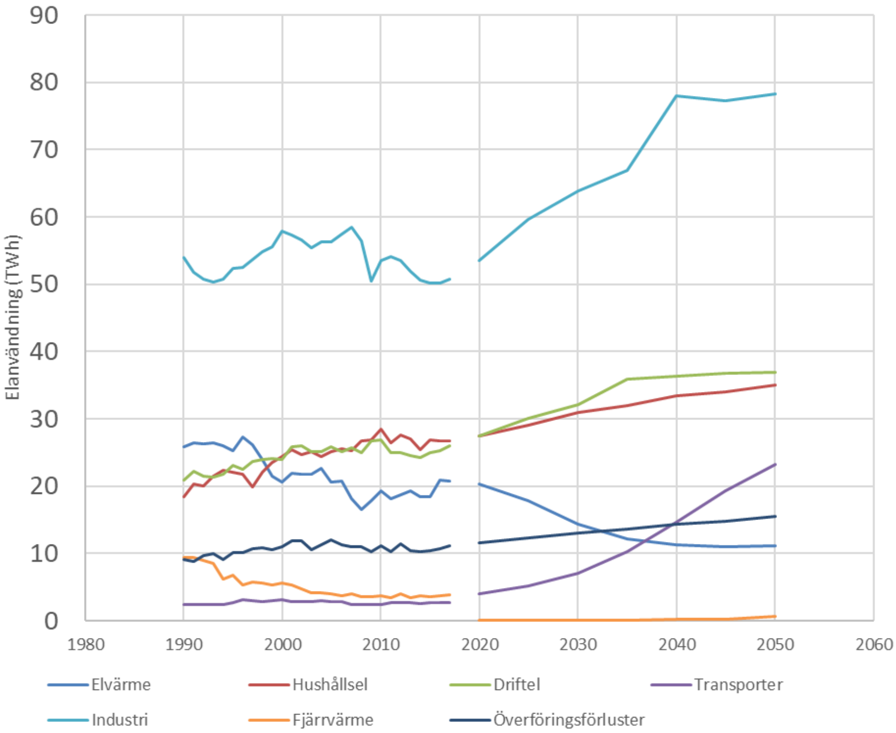
The process heat demand is calculated based on the demand forecasts provided by the Swedish Energy Agency for coal, process gases, heavy fuel oil, biofuel and electricity for electric boilers, as well as separate assumptions on degrees of efficiency for generating process heat.

Some examples of input data for energy demand trends are shown in Figure 48 which presents the final electricity consumption in Sweden, by sector, for the reference scenario and the climate scenario with a high degree of electrification. The result in the figure consists partly of the calculation result (when the electricity is substitutable), and partly of input data (when the electricity is non-substitutable). The result in the figure may therefore differ slightly between the different calculations.

Figure 48: Electricity consumption in Sweden, by sector, in the reference scenario (top image) and in the climate scenario with high electrification (bottom image).

[122] Primarily only fuel (or electricity) that is used for energy purposes is included. However, the model includes some fuel consumption for both industrial processes and energy purposes (e.g. coke).


70
60
50
40
30
20
10
0
Elanvändning (TWh)
1980
1990
2000
2010
2020
2030
2040
2050
2060
Elvärme
Hushållsel
Driftel
Transporter
Industri
Fjärrvärme
Överföringsförluster


90
80
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Elanvändning (TWh)
1980
1990
2000
2010
2020
2030
2040
2050
2060
Elvärme
Hushållsel
Driftel
Transporter
Industri
Fjärrvärme
Överföringsförluster

	Electricity use (TWh)
	Electric heating
	Household electricity
	Operational electricity
	Transport
	Industry
	District heating
	Transmission losses

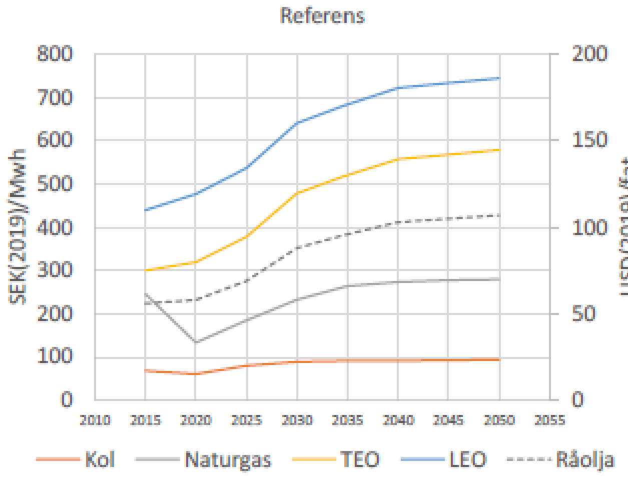
Fuel prices

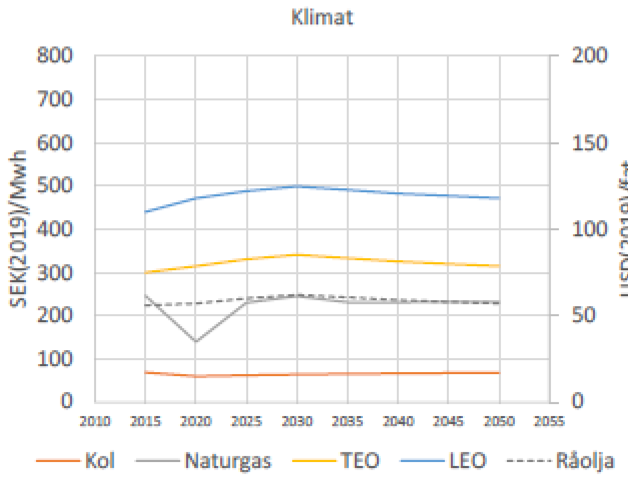
Fossil fuels

The price assumptions for fossil fuels are shown in Figure 49 for the reference scenario and the climate scenario (with and without extensive electrification). Other calculations use one of these two price projections. The long-term price projections are based on the IEA's WEO (2019)[123], specifically on the scenarios 'Stated Policies' ('Reference') and 'Sustainable Development' ('Climate'). In addition, Profu has made its own assumptions and used forward prices for the shorter timeframe (from the year end 2019/2020). Crude oil is not explicitly included in the modelling but is shown here only as an indicator of the general trend in energy prices. The link between the price of light/heavy fuel oil and crude oil is based on historical price coupling.

Figure 49 Fossil fuel prices (SEK_{2016}/MWh, free national limit and excluding tax). Source: WEO (2019) and own assumptions. TEO=heavy fuel oil, LEO=light fuel oil.

[123] WEO (2019), World Energy Outlook 2019, (accessed 18.11.2020).





	SEK(2019)/MWh
	USD(2019)/fat
	Reference
	Climate
	Coal
	Natural gas
	TEO
	LEO
	Crude oil

A number of distribution surcharges will be added to the import prices (excluding taxes) of the fossil fuel types depending on user. For natural gas, for example, around SEK 20/MWh is added in transmission costs for new gas pipes (slightly less for existing Swedish gas pipes and then counted as a variable transport cost). For industrial consumption and consumption in housing and services, additional distribution costs are added. One assumption is also that there are differences between the countries. For example, we assume that the ex-works coal price is slightly lower in Germany and Poland, mainly due to economies of scale in power plants. Another assumption is that natural gas consumption in Nordic gas-fired power plants in Western Norway can occur with no transport costs due to proximity to gas terminals. Such assumptions affect the comparative advantages of power generation seen in the countries included in the modelling (in addition to fossil fuel costs, there are a number of other factors included in the modelling that vary between countries in terms of comparative advantages and disadvantages).

Biofuels

Biofuels are represented in the model by supply curves, i.e. the biofuels are divided into different cost categories with different available potentials. The same type of biofuel can be used by different sectors in the energy system. For example, wood chips from forestry are available for both district heating generation and in industry. The final consumption of a certain type of biofuel, and the price of this, is consequently a model result.

Typical costs for wood chips from forestry (normally BATT) are between SEK 170-200 per MWh (ex-works) depending on cost category (which in turn depends on transport distance and quality) around 2020 (the calculated price for 2020 is therefore a result depending on how much of this is demanded and how much of each category is available) and between SEK 200 and 260 per MWh ex-works depending on cost category around 2030. For processed forest fuels such as briquettes and pellets, we typically assume costs of SEK 330-350/MWh (free installation) depending on year (only one category). Other biofuels included in the modelling are straw, energy forests and peat. Some forest fuels which are limited to use in the forestry industry, such as bark and some bio-oils, are also included. Biogas production in the model is based on substrates such as sewage sludge and waste but also via anaerobic digestion of some field crops. Landfill gas is also included in the group biogas. In total we assume a potential of around 3 TWh of biogas, of which less than half is assumed to consist of biogas based on field crops.

The calculation assumptions concerning the cost of, and access to, different biofuels were agreed with the Swedish Energy Agency before the work on ‘Long-term scenarios’ from 2018/2019.

Taxes

The most important existing energy- and climate-policy instruments in Sweden have been included in all calculations (from 1 January 2020 inclusive). This includes carbon dioxide and energy taxes on fossil fuels as well as electricity tax. Sulphur taxes and NOx charges are not included in the modelling.[124] The sectoral energy and carbon dioxide taxes are modelled in TIMES Nordic in accordance with Table 10. Electricity production is exempt from carbon dioxide and energy taxes.

The general level of the carbon dioxide tax is equivalent to approximately 110 öre/kg CO2 and is assumed to remain at that level throughout the calculation period. Different sectors have different rules for reductions based on the general level (the different levels in per cent that different sectors pay is shown in Table 10).

Table 10 Carbon dioxide and energy tax levels (in per cent of the general level) for fossil fuels and for various sectors (1 January 2020). Source: The Swedish Tax Agency[125]

	CO2 tax (öre/kg)	Energy tax (öre/kWh)
Residential and services	100%	100%
Heat only boilers (within ETS)	91%	100%
Cogeneration (on heat production, within ETS)	91%	100%
Industry (ETS)	0%	30%
Industry (non-ETS)	**100%**	**30%**

1) 100% if the installation is outside the EU ETS

Table 11 shows the fuel-specific tax rates (general level) for the energy taxes.

Table 11 Assumed taxes on fuels for heat production and electricity (general level; 1 January, 2020). Source: The Swedish Tax Agency.

	Energy tax1) (SEK/MWh)
Fossil fuels	91
Electricity for households, services and district heating production (southern Sweden)	353
Electricity for industry	**5**

1) As the energy and carbon dioxide taxes are originally defined by weight or volume, the tax rate expressed per unit of energy depends on the assumed calorific values for each fuel.

Emission allowances for CO2

The EU's emission allowance system for carbon dioxide is included in all calculations, see Table 12. Here, too, the price projections are based on the IEA's

[124] Most of the installations in electricity and district heating production are currently estimated to be equipped with sufficiently advanced desulphurisation systems. The sulphur tax should therefore not be a relevant economic factor, at least in electricity and district heating production. This assumption has some significance, particularly for peat, which in Sweden is not subject to any fuel taxes apart from sulphur tax.

[125] See https://skatteverket.se/foretagochorganisationer/skatter/punktskatter/energiskatter.4.18e1b10334ebe8bc8000 843.html.

WEO (2019) in combination with separate assumptions and readings on the futures market for quantifications in the shorter term (reading from the turn of the year 2019/2020). In the model the trading system is represented consistently as a system based on an auction of emission allowances.

Table 12 Price of CO2

EUR(2019)/tonnes CO2	2015	2020	2030	2040	2050
'Reference'	8	24	40	44	50
'Climate'	**8**	**25**	**80**	**125**	**140**

The different fossil fuels' emission factors (for CO2) are shown in Table 13.

Table 13 Emission factors for fossil fuels (Source: The Environmental Protection Agency[126])

	Hard coal	Coke	Natural gas	Heavy fuel oil	Light fuel oil	Combustible waste	Peat
kg CO2/MWh	**326**	**371**	**203**	**274**	**267**	**90**	**386**

Aid and electricity certificate

The common Swedish-Norwegian electricity certificate scheme (from 1 January 2012 inclusive) is included as a production target in TWh where the amount of renewable electricity in Sweden and Norway together will increase by 28.4 TWh by 2020 compared with the start of 2012. The starting point is that 6.5 TWh were eligible for electricity certificates in Sweden at the time of the introduction of the Swedish scheme in May 2003. For Norway, the assumption is that it entered with around 1.3 TWh at the beginning of 2012, which mainly consisted of hydropower (personal communication with NVE and own assessments). After 2020, the expansion within the electricity certificate scheme will only continue with a Swedish commitment to increase renewable electricity production by a further 18 TWh between 2020 and 2030.

In the model we do not differentiate between technical lifetime and the installation's lifetime in the electricity certificate scheme (max 15 years). Installations are therefore not phased out of the electricity certification scheme either but rather they are phased out due to age. For this reason we are working with a production target that represents an annual accumulated production of electricity certificates (renewable electricity production) and whose trend over time differs from the real ratio curve. In reality, installations are phased out of the system after 15 years. However, in the

[126] See Naturvårdsverket – Emissionsfaktorer och värmevärden 2020.

modelling we do not take this into account but rather the installations are allowed to generate electricity certificates over their entire technical lifetimes which may be twice as long (although by 2035 this will be over). But since we do not, at the same time scale, back the ratio curve to reflect the fact that installations leave the scheme, we do in some sense have the same supply/demand balance as in reality, which means that the calculated price on the electricity certificate market is a reasonable reflection of reality. However, the most important thing is that the electricity certificate has no real impact on the calculations (after 2020) as more than is demanded is built within the electricity certificate scheme. This concerns partly the ongoing construction and partly investments that are made exclusively on the basis of the revenue streams of the electricity market. This is also something that we see on the real electricity certificate market, i.e. it has almost completely lost its governing ability. The electricity certificate price may be underestimated slightly (in fact, the marginal cost of producing electricity certificates is calculated, the actual price involves additional parameters such as uncertainties and surplus size) as the actual investments are based on a revenue stream of only 15 years while the installations in the model receive electricity certificates for slightly longer.

The technologies in the modelling tool that are assumed to be eligible for an electricity certificate include biofuel cogeneration (including peat), industrial bio back pressure, wind (offshore and onshore), solar electricity, wave power and new hydropower.[127]

In addition to the electricity certification scheme, targeted aid for solar cells in Sweden is also included. This includes investment aid (which is phased out during 2020) and tax reductions for electricity sold, 60 öre/kWh. As, at the time of writing, a decision has not been made on a green ROT (Repairs, Conversions and Extensions) tax deduction (as compensation for the abolished investment aid) for solar cells, no such aid is included.

Heating technologies in housing and services

The heating demand in TIMES Nordic is divided into six building types: existing and new houses, existing and new apartment buildings, and existing and new non-residential premises. In the model there are a number of heating technologies for each building type represented. As the existing building stock has the most significance as regards energy consumption until 2050, particular importance has been given to having a good degree of detail for heating technologies (and conversion measures) for this segment. There are fewer heating technologies for

[127] In Norway, the renewable share of combustible waste is also included in cogeneration plants. However, we have not currently taken this into account in the modelling.

new buildings in the modelling.

Heating with district heating, together with geothermal heat, is currently the most important form of heating. For this reason, particular importance has been given to the degree of detail for these heating options, which are both represented by a number of different cost categories for each building type. These categories mainly represent the current spread in investment cost on the market for geothermal heat and the spread in production cost, and therefore customer price, depending on production systems currently available in district heating (more on district heating later on). For example, for geothermal heat in the existing housing stock, a cost interval of 125 000-150 000 excluding tax is assumed, broken down into three cost categories, given a heat demand of 25 MWh/year. For new buildings, only one cost category is used per technology. Table 14 shows the heating technologies included in the model.

Table 14 Heating technologies in housing and non-residential premises represented in the model

Building type	Heating technology	
Houses	Geothermal heat pumps, 3 categories	Various investment costs
	Air-to-water heat pumps	
	Air-to-air heat pumps	
	Exhaust air heat pumps	
	District heating, 5 categories	Various production costs for district heating
	Waterborne electric heat	
	Direct electricity	
	Pellet boiler	
	Wood burning stove	
	Solar heat	
	Oil boiler	
	Gas boiler	
Apartment buildings	Geothermal heat	Various investment costs
	pumps, 3 categories	
	Air-to-water heat	
	pumps	Various production costs for district heating
	Exhaust air heat pumps	

	District heating, 5 categories	
	Waterborne electric heat	
	Direct electricity	
	Pellet boiler	
	Solar heat	
	Oil boiler	
	Gas boiler	
Non-residential premises	Geothermal heat pumps, 3 categories	Various investment costs
	Air-to-water heat pumps	
	Exhaust air heat pumps	
	District heating, 5 categories	Various production costs for district heating
	Waterborne electric heat	
	Direct electricity	
	Pellet boiler	
	Solar heat	
	Oil boiler	
	Gas boiler	

In reality, the assumptions for each investment are unique, such as conversion with regard to heating. In TIMES Nordic, as in energy system models in general, it is of course a limited number of technologies that are handled in the modelling. Often a number of cost and performance categories are used for each technology which are assumed to be representative of the whole range and in many cases a certain upper limit is also assumed ('market potential') for the size of the market share (in this case, of the heating market) that a technology can occupy. The upper limit enables the exclusion of the most expensive investments that in reality probably 'penalise' themselves. There are also other reasons for a technology type not achieving 100% of the market, for example personal preferences. The upper limit ensures that a certain technology cannot take an unreasonably large share of the market if in the model calculations it turns out that the technology is cheaper than the competing technologies, and can be said to represent factors which are not otherwise captured by the model. The more technology types and the more cost and performance categories for the different technology types, the bigger the resemblance to reality. The significance of the choice of upper limit for market potential therefore also decreases.

As regards heat pumps, as a group these can in principle gain very high market shares in the model – for existing houses, all households can install some type of heat pump solution and for existing apartment buildings, the upper limit for heat pumps as a group amounts to 80%. However, this applies to all heat pump technologies (air-to-air, air-to-water, exhaust air and geothermal heat) and mutual cost categories combined. Each option thus has a lower potential in the model (for example 'geothermal heat, cost category 1' etc.). For typical model scenarios, the model results will not show market shares close to the total maximum potential, as the most expensive heat pump options must then be used. Instead, other more competitive heating options are used. Assumed market potential values for heat pumps in the model are produced during development work in several different projects, for example linked to the Swedish Energy Agency's long-term scenarios, and are based, inter alia, on input from the Heating Market in Sweden project.

Heat pump scenario

In this current study a technology scenario is run where the intention is to test the system effects of a higher share of heating from individual heat pumps than what is the case in the baseline scenarios (RI-VP plus and KIE-VP plus). To achieve this, the permitted market shares for heat pump options of different technology types and cost categories have been adjusted upwards. The adjustment has been made so that the share of individual heat pump heating in the model results ends up at similar levels as the corresponding share in the Heating Market in Sweden scenario[128] 'More individual' (for the building stock as a whole). The Heating Market in Sweden scenario models societal trends which give more individual and small-scale solutions, with, inter alia, a high proportion of heat pumps.

Electricity production

The modelling tool includes a number of different technologies for electricity production (and for other energy supply), both existing technologies and a comprehensive catalogue of new technologies which can be chosen through investments. Each technology is represented by a number of performance and cost parameters such as investment costs (for new installations), operating and maintenance costs, lifetime, degree of efficiency, fuel costs (governed by fuel selection and degree of efficiency), accessibility etc. The data set is largely derived

[128] The Heating Market in Sweden (2014), *The Heating Market in Sweden* – a comprehensive overview.

from the periodical publication ‘Electricity from new installations’[129] (by Energiforsk), other public sources (for example ‘Energy Technology Perspectives’ by IEA)[130] and Profu’s own assumptions. In addition to data related to cost and technology, the different technologies are linked, as necessary, to limits in potential as a result of limits in pace of expansion, degree of commercialisation and political objectives and limits.

Hydropower

We assume that around 1 TWh of new hydropower can be added until 2030 at a cost of around 40–50 öre/kWh depending on the type of investment. The vast majority of this is assumed to be comprised of energy increases in existing large-scale hydropower, while the potential for new small-scale hydropower is assumed to be very limited in the modelling.

In Norway, new hydropower of just over 10 TWh may be added in the long term (around 2030), provided that the model finds these investments to be profitable.

Nuclear power

As of the model year 2025, only six reactors are expected to be in operation in Sweden (R3–4, F1–3 and O3).[131] The technical lifetime for these reactors is assumed to amount to 60 years from the start of operation. This means that existing nuclear power will be available up until 2045 (see Table 15). New investments in Swedish nuclear power, i.e. completely new reactors, are permitted in the modelling as of 2030 if it turns out to be profitable, given the cost assumptions. However, the total amount of nuclear power (existing and new) is expected to be limited to approx. 8 GW from 2030 until the end of the model period (2050).

Estimated costs for new nuclear power can be found in Table 16 (with the calculated interest rates, lifetimes and utilisation times used here, the total production costs for new nuclear power will be around 60 öre/kWh electricity, excluding any production taxes). The thermal power tax is expected to be phased out as of 2020 and the production tax consequently only consists of a relatively small part (which finances the future repository, around SEK 40 per MWh electricity).

Table 15 Installed power for the existing Swedish nuclear power plants. Their lifetime is expected to be 60 years in total. The utilisation time for the existing Swedish nuclear power plants is expected to be typically 80-85% during large parts of the calculation period.

[129] Energiforsk (2014), Electricity from new and future installations. https://energiforskmedia.blob.core.windows.net/media/19919/el-fran-nya-och-framtida-anlaggningar-2014- elforskrapport-2014-40.pdf (accessed 18.11.2020).

[130] IEA (2020), Energy technology perspectives 2020. https://www.iea.org/reports/energy-technology- perspectives-2020 (accessed 18.11.2020).

[131] During the 2020 model year, R1 is also available.

Model year	2015	2020	2030	2035	2040	2045	2050
Available power (GW)	**8.8**	**7.5**	**6.6**	**6.6**	**3.7**	**2.5**	**0**

Table 16 Assumed costs for new nuclear power

Investment cost (SEK/kW electricity)	Fixed operations and maintenance (SEK/kW electricity)	Variable operations and maintenance and fuel cost (SEK/MWh electricity)	Lifetime (years)
50 000	**550**	**100**	**50**

It is assumed that new nuclear power plants can be built in Finland, Poland and in the three Baltic States if this is profitable (in these countries any production taxes or fees for the disposal of nuclear fuel are not included). The potential for new investments in these countries is, however, limited to typically one or two large reactors.

Biofuel-based electricity production

In the model, new biofuel-based power production can take place in a number of different technologies and on different scales including, inter alia, conventional cogeneration, IGCC installations (Integrated Gasification Combined Cycles), recovery boilers (with and without gasification), biogas motors and co-incineration plants which can be co-fired with peat and coal. The main limitations for biofuel-based power are related to fuel resources and fuel prices, as well as the district heating base (condensing production is also included in the model but is generally considerably more expensive than cogeneration). Typical data for a conventional biofuel cogeneration plant can be found in Table 17. With flue gas condensing, which is assumed for these installations, the overall degree of efficiency is around 105-110% calculated from the lower calorific value.

Table 17 Typical data for a conventional biofuel cogeneration plant with flue gas condensing on three scales (some parameters, for example degree of efficiency and alpha value, are assumed to evolve over time)

	Investment (SEK/kW electricity)	Fixed operations and maintenance (SEK/kW electricity)	Variable operations and maintenance (SEK/MWh electricity)	Efficiency level (%)	Alpha value	Lifetime (years)
Large plant (approximately 80 MW electricity)	25 500	380	80	30–32 (electricity)	0.38–0.41	30

Medium-sized plant (ca 30 MW electricity)	34 500	580	85	28–30 (electricity)	0.35–0.39	30
Small plant (approximately 10 MW electricity)	**45 000**	**920**	**85**	**25–27 (electricity)**	**0.32–0.34**	**30**

For biofuel-based technologies, in general no reduction of investment costs is assumed over time as a result of technical development, except for IGCC installations.

Waste-based cogeneration and heat generation are also included in the modelling. Despite high investment costs, this is generally a profitable alternative due to the negative fuel costs (thanks to the gate fees).

In the modelling for Denmark and countries outside the Nordic countries, the representation of the biofuel market and electricity and district heat production based on biofuel is described in a lower level of detail than in Sweden and Finland in particular. In Norway, the potential for biofuel-based electricity and district heating production is assumed to be relatively limited, due to the limited district heating base. In the calculations it is assumed that biofuel can be used in co-firing in both existing modern and new hard coal-fired power stations with a maximum interference of between 10 and 20% calculated in energy units.

Gas power

After 2020, it is assumed that only one large gas-fired power plant will remain in operation in Sweden, namely Ryaverket in Gothenburg at just under 0.3 GW. New gas power can be expanded in Sweden (and in other included countries) through new investments, if the model finds these to be profitable. Typical input data for gas-based power production and cogeneration is presented in Table 18.

Table 18 Typical data for gas-based power production and cogeneration

	Investment (SEK/kW electricity)	Fixed operations and maintenance (SEK/kW electricity)	Variable operations and maintenance (SEK/MWh electricity)	Efficiency level (%)	Alpha value	Lifetime (year)
Condensing power	7 000	40	15	55-62	-	30
Cogeneration, large	9 500	70	20	45-50 (electricity)	1.1	30

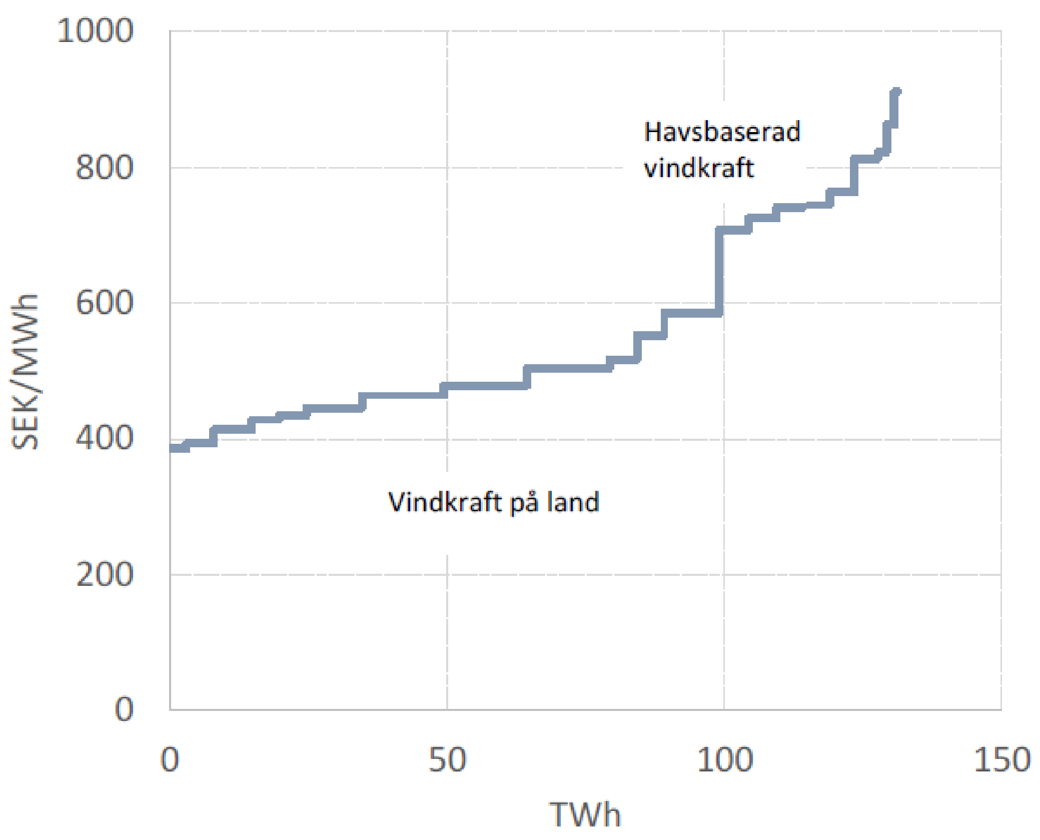
Cogeneration, small	**12 500**	**120**	**25**	**45-50 (electricity)**	**1**	**30**

1) Evolves over time

Wind power

The model includes 12 different onshore categories and 9 different offshore categories in Sweden. The cost assumptions for new wind power in Sweden are based on data from the Swedish Energy Agency (2016)[132] and a slightly less extensive update by the Swedish Energy Agency from 2018[133]. Nearly 100 TWh of onshore wind power is assumed to be available for expansion (Figure 50) The model adds system integration costs (for example regarding reserve capacity and some network expansion), especially for very large volumes of wind power. The model also takes some account of the fact that the earning capacity decreases when the proportion of wind power reaches a certain limit (the more wind power in the system the more the electricity price that the wind farms receive is reduced).

Figure 20 Production costs for new wind power in Sweden, given a 25-year lifetime and 7% calculated interest rate (real).



[132] The Swedish Energy Agency (2016), Production costs for wind power in Sweden, ER 2016:17.
[133] The Swedish Energy Agency (2019), Scenarios for Sweden's energy system 2018, ER 2019:7.

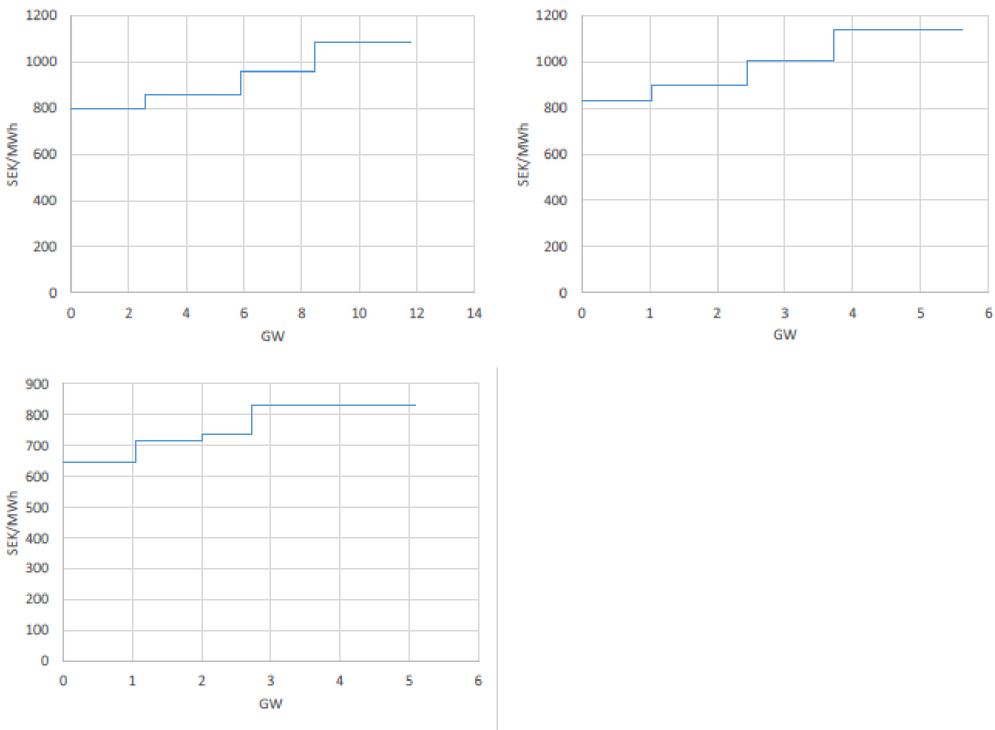
	SEK/MWh
	Offshore wind power
	Onshore wind power
	TWh

Wind power in countries outside Sweden is represented in a similar way in the modelling tool, i.e. with a number of different cost categories with different potentials. However, in general, the level of detail is lower than in the modelling for new wind power in Sweden.

Solar electricity

As with wind power, investments in new solar electricity are represented by a relatively large number of cost categories. The data is based on a study carried out by Profu for the Swedish Energy Agency in 2018.[134] The different cost categories cover solar electricity on rooftops (houses, apartment buildings and non-residential premises) as well as detached solar parks on land, see Figure 51. Different calculated interest rates are assumed for the different investments depending on whether they concern rooftop-mounted or detached installations. In this way we reflect the fact that private individuals (rooftops of houses) or smaller operators (apartment buildings and non-residential premises) probably have other preferences, in this case, lower calculated interest rates, than for example commercial operators in the energy industry (which are assumed to account for installations on land). On the other hand, it is assumed that the investment costs for more large-scale installations on land are lower in specific terms than for the rooftop applications.

[134] Profu (2018), Technical-economic cost assessment of solar cells in Sweden, study on behalf of the Swedish Energy Agency.



	SEK/MWh
	TWh

Figure 51 Production costs for solar electricity in Sweden on rooftops of houses (on the left; calculated interest rate 3% real), apartment buildings and non-residential premises (in the middle; calculated interest rate 4% real) and on land (on the right; calculated interest rate 6% real). A lifetime of 30 years is calculated for all investments.

In the modelling, we have omitted the combination of solar electricity and batteries. A battery solution would lead to a more even production (solar cells plus battery) over the day and thereby a higher proportion of self-consumption. However, in general, the modelling is slightly too blunt in terms of time (within a year) to fully include the different aspects of solar electricity production in combination with battery storage.

As mentioned in the previous chapter on aid and electricity certificates, it is assumed in the model calculations that a tax rebate of 60 öre/kWh electricity sold is received for rooftop applications. At the time of writing, nothing has been said about the continuation of this aid. However, this tax rebate is expected to remain until 2030. In the case of self-consumption, the electricity tax and variable electricity network charges are also avoided.

Carbon Capture and Storage (CCS)

Carbon capture and storage is included as an option to significantly decrease emissions from certain types of fossil power in all modelled countries. For practical and technical reasons, it is assumed that CCS is only available in new installations (the alternative may be a new conventional installation without CCS). Additionally investing in CCS in an existing installation is therefore not included. For CCS installations, a collection efficiency of 90% is assumed as well as a decrease in electrical efficiency of typically 10% compared with a conventional installation. The cost assumptions concerning CCS are largely based on IPCC (2005), IEA (2004) and the ENCAP project (2008) as well as separate assessments.[135] Typical CCS costs amount to around 40-60 EUR/tonne CO2 depending on technology and fuel (coal and natural gas). The modelling also includes the possibility of separating biogenic emissions (bio-CCS) from biofuel cogeneration in Sweden. The cost of this is assumed to be higher than for the large-scale fossil fuel-fired installations on the continent, more precisely around 60-80 EUR/t (including transport and storage; calculated interest rate of 7% real) but is partially offset by the revenue that we assume is received and which is equal to the price of CO2 in the EU ETS.[136]

The storage potential for separated CO2 (fossil and biogenic) is assumed to be almost endless for the modelled countries. However, it must be remembered that there are currently fairly large uncertainties regarding costs and potential for CCS in connection with power production. This is simply because it lacks commercial experience. Given this, a relatively conservative approach has been chosen in the assumptions.

District heating – Heat only boilers

District heating can be produced in cogeneration plants, heat only boilers (fuel or electricity) and heat pumps. Industrial waste heat and solar heat are also assumed (within certain limits) to be available for district heat supply. Previous sections have described some important assumptions for cogeneration. Table 19 presents key data for two typical heat only boilers, one solid fuel-fired and one gas-fired (fuel prices and instruments are fuel-specific and are added to the model but not shown in the table).

Table 19 Typical production costs for district heating in heating plants (heat only boilers).

	Investment (SEK/kW heat)	Fixed operations and maintenance (SEK/kW heat)	Variable operations and maintenance (SEK/MWh heat)	Efficiency level (%)	Lifetime (years)
Natural gas	4 000	25	15	90	30

[135] IPCC (2005), IPCC Special Report on Carbon Dioxide Capture and Storage, Cambridge University Press, ISBN-13 978-0-521-86643-9 and IEA (2004): Prospects for CO2 Capture and Storage, ISBN 92-64-10881-5. The ENCAP project

[136] The cost estimates for BECCS are partly taken from the climate policy choice investigation (Official State Report 2020:4, Road to a climate-positive future) which indicates a cost range of SEK 650-1 100 per tonne including transport and storage of separated CO2.

Biofuel, peat or hard coal	**8 000**	**100**	**20**	**90-95**	**30**

Industrial waste heat

In the model, the maximum potential for high-temperature waste heat from industry is assumed to follow what is shown in Table 20. For some of the model's sectors, a link between amount of waste heat and activity level within the sector has been made. However, availability in the model is mainly controlled by a separate supply, without a link to the model's industrial activity. The cost of using industrial waste heat is low in the model and is not intended to represent a market price, but rather the cost of exploiting the heat.

Table 20 Industrial waste heat potential in TIMES Nordic.

Model year	2020 [TWh]	2030 [TWh]	2040 [TWh]	2050 [TWh]
Industrial waste heat	**5**	**5.2**	**5.4**	**5.6**

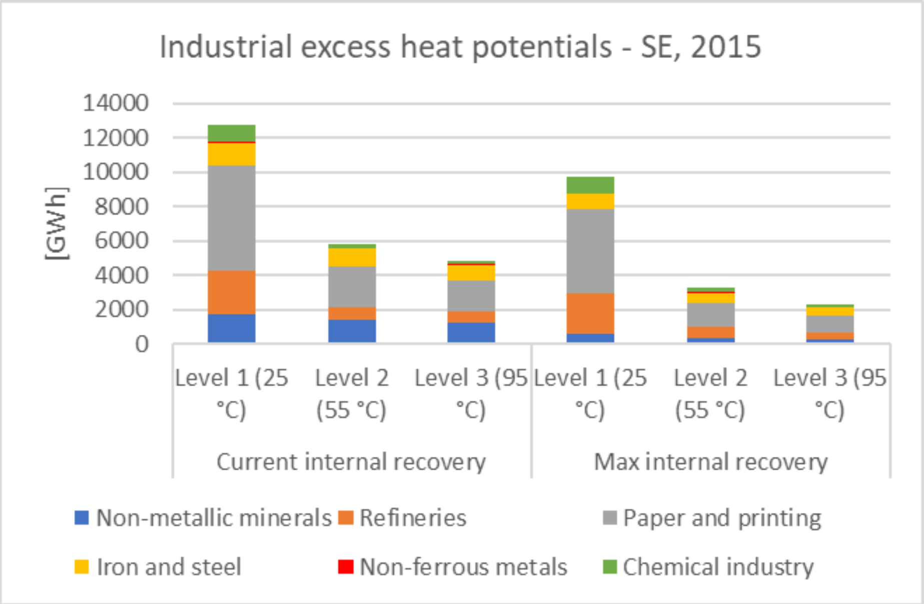
The potential in Table 20 is based on previous modelling work, inter alia linked to the work with long-term scenarios. Within the context of the Article 14 work, a new review has been made of the potential used, primarily based on the EU project Seenergies[137]. In this project, waste heat potential from industrial sites in the EU28 has been compiled (in total 1 842) based on the year 2015. 84 industrial sites are included for Sweden. Waste heat potentials are quantified for three levels of cooling temperature and for different degrees of internal heat recovery in industry – the current level of internal heat recovery and maximum degree of internal heat recovery.

Figure 52 illustrates the waste heat potential that has been calculated for Sweden in the Seenergies project. The results show how decreasing temperatures in the district heating network mean increasing potentials for industrial waste heat. On the other hand, a higher degree of internal heat recovery in industries means a lower level of possible waste heat for the district heating system. Assuming a certain reduction in the general temperature in the district heating system, an increasing degree of internal heat recovery in industry, and increased industrial production over the modelled period, the potential level in TIMES Nordic (Table 20) was judged to be well balanced against the Seenergies project's data.

Figure 52 Industrial waste heat potential in Sweden for different temperature levels

[137] See https://www.seenergies.eu/ and https://tinyurl.com/sEEnergies-D5-1.

and degrees of internal heat recovery according to the Seenergies project (based on 2015).



Other countries

TIMES Nordic primarily includes the stationary energy systems (excluding transport) in four of the Nordic countries, namely Sweden, Norway, Finland and Denmark. In addition, the model covers electricity production and consumption and an aggregated modelling of district heating systems in Germany, Poland and the three Baltic States Estonia, Latvia and Lithuania. For resource reasons, the degree of detail in the modelling tool is lower for the other countries compared with the Swedish modelling. However, the database also includes a number of important energy and carbon dioxide taxes in the other countries, as well as some targeted aid for renewable electricity production. In Germany and Poland, we assume that the share of renewable electricity production is growing as a result of production targets and will constitute around 60-70% of the gross electricity consumption in Germany by 2050 (the share is currently around a third of that) and just under 30% in Poland by 2050. There is therefore no explicit representation of the aid system for these countries.

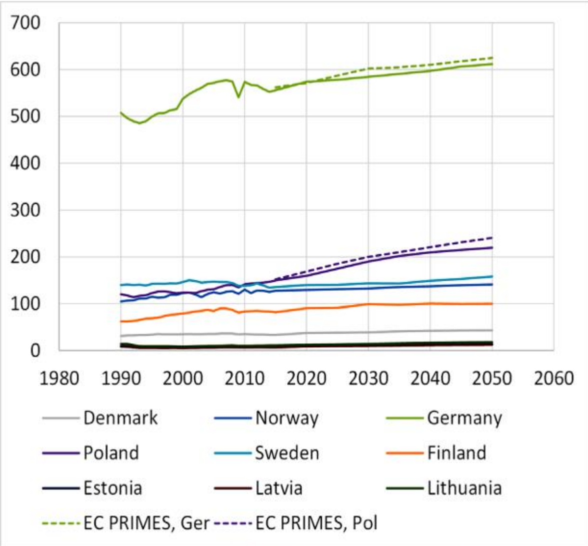
Figure 53 Countries in northern Europe that are included in TIMES Nordic (in dark blue).

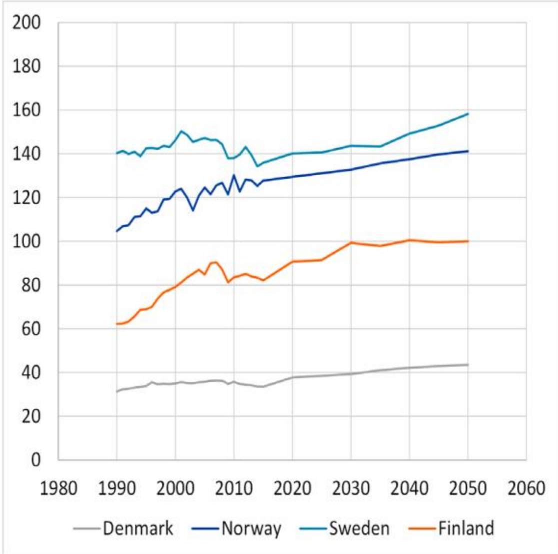
In the model, the included countries are not broken down further into subregions or price areas for electricity. Instead, each country constitutes a unique electricity price area. This also means that Sweden, for example, is treated as one electricity price area and not, as in reality, four different electricity price areas.

The assumed fuel prices (except some transmission and distribution surcharges and cost advantages depending on economies of scale) and some central technology data (costs and performance) are common to all countries represented in the model. However, wind accessibility and access to biomass are examples of parameters which are assumed to differ between the countries.

The conditions in the other countries in the modelling tool have a significant effect on the common electricity market and therefore on trends in Sweden. Renewable energy policies in neighbouring countries are one such factor that we have already mentioned and the trends in electricity demand are another. The assumed (gross) trend in electricity demand for all countries is presented in Figure 54 for the reference scenario. The data is based to a certain extent on the EU Commission's latest forecast (EC, 2016, 'EU Reference Scenario -2016 Energy, transport and GHG emissions Trends to 2050'), the Swedish Energy Agency's data in 'Long-term scenarios 2018' and on separate assumptions.

Figure 54 Gross electricity consumption in the included countries (all countries on the left, and the Nordic countries on the right). The electricity consumption is partly a model result for the Nordic countries (the example shows the reference case for this task) while the electricity consumption for other countries constitutes input data (Source 1990-2016: Eurostat)





Electricity trading with neighbouring countries

Electricity trading between the included countries is initially limited by existing transmission capacities. As of the model year 2025, it is assumed that the planned strengthened link between Germany and Sweden, the 700 MW Hansa PowerBridge will be in place. However, if it is profitable, there is an opportunity in the modelling tool to further strengthen transmission connections through new investments.[138] In the model, there is also an assumption of a reasonable upper pace of expansion for transmission capacity if it is profitable in the calculations. Electricity trading between the countries within the Nordic region and between the Nordic countries and Germany/Poland/Baltic States is in other words a model result.

The model also includes the possibility of imports from Russia to Finland. These imports are 5 TWh as of the model's starting year (2005) and are generally assumed to be cheap enough to be utilised (in recent years, however, these imports have fallen relatively sharply due to changes in the Russian electricity market).

The short-term balancing trade between the countries is not covered by the modelling as the time division within one calendar year is too blunt. The model uses 12 time increments or periods within one model year and it is therefore the electricity price differences between the different countries for these 12 periods which drive imports/exports and expansion of transmission capacity. In the modelling, we have therefore not used the entire existing transmission capacity but rather assumed that a smaller part (around 10%) is reserved for short-term

[138] For new transmission capacity between the countries in the model we assume an investment cost (translated into öre/kWh) of around 5-10 öre/kWh electricity transmitted, depending on which countries are linked. An assumption that the national backbone networks in each country must be strengthened slightly is also included in this cost estimate.

balancing trade, which in other words is not included in the model. Access to the remaining capacity is also assumed to be slightly limited due to any interruptions or weaknesses in each country's network etc. (a maximum utilisation factor of around 75% to and from the continent and around 85% between the Nordic countries is assumed).

Other

The lifetimes for different technologies vary. Typical technical lifetimes for electricity and district heat production are 30 years. For nuclear power and hydropower, longer lifetimes are assumed, typically 50 years. For small-scale technologies close to the user, shorter technical lifetimes are assumed, for example 20 years for geothermal heat pumps and pellet boilers. On the other hand, for infrastructure such as electricity networks and district heating networks, significantly longer lifetimes are assumed. The calculated interest rates also vary depending on which sector the investment is made in and provided that we assume an 'investors' perspective'. In this case, the calculated interest rate is between 3% and 10% (real) where investments in network infrastructure, for example, assume a rate in the lower part of the range, while investments in efficiency measures in the building stock, for example, assume a calculated interest rate in the upper part of the range. In the calculation cases where we apply a 'socioeconomic' perspective, an interest rate of 3.5% (real) is assumed throughout for all sectors and investments.

The model's time horizon covers 2005 to 2050 in increments of five years. Until 2015, the existing system is therefore represented. This is based on normal years (as regards inflow into reservoirs and temperature) between 2005 and 2015 as well as until 2050. The calculation results for 2015, for example, may therefore differ from the actual outcome (there are naturally additional factors that the model is not able to represent and which consequently lead to differences between calculated values and reality). As we previously mentioned, a model year in turn is divided into 12 periods (four seasons and day/afternoon/night per season) as regards the demand and supply of electricity and district heating. For each period, the model consequently calculates a unique marginal cost. For other energy carriers such as fossil fuels and biofuels, no seasonal breakdown in pricing (or demand and supply) is assumed within one model year. However, prices, as shown earlier, generally change over the model years.

Annex B Modelling of the economic potential for heating and cooling

In the context of the assignment, TIMES Nordic has been developed further to represent cooling as well as an improved representation of the use of low-temperature waste heat for heat pumps in district heating production.

District cooling

Figure 55 shows a schematic image of included technologies and the energy flows in the model's representation of cooling. District cooling is the focus but individual cooling for non-residential premises is also represented. Four options for producing district cooling are included: free cooling (from lakes, etc.), compression cooling/cooling machines (without heat recovery), cooling from heat pumps (where the heat goes to the district heating system) and absorption cooling (which is powered by district heating). The model's 'cooling module' is an integrated part of the model and electricity and district heating used for district cooling production are therefore linked to the representation of the district heating and electricity system in the model. As with district heating, the model has an aggregated representation of district cooling at the Swedish level (i.e. not as a large number of different smaller systems as in reality). Table 21 states assumed costs and degrees of efficiency for compression and absorption cooling. In the model, the use of free cooling is associated with low costs but limited so that the proportion of production from this option is similar to the current situation for future years as well. A more comprehensive analysis of the future potential for free cooling in the district cooling system has not been possible in the context of this project. As regards the fourth option for district cooling, heat pumps in district heating production, the costs are attributed to heating but where additional benefit is obtained in the form of district cooling.

Figure 55. Schematic image of the model's representation of cooling

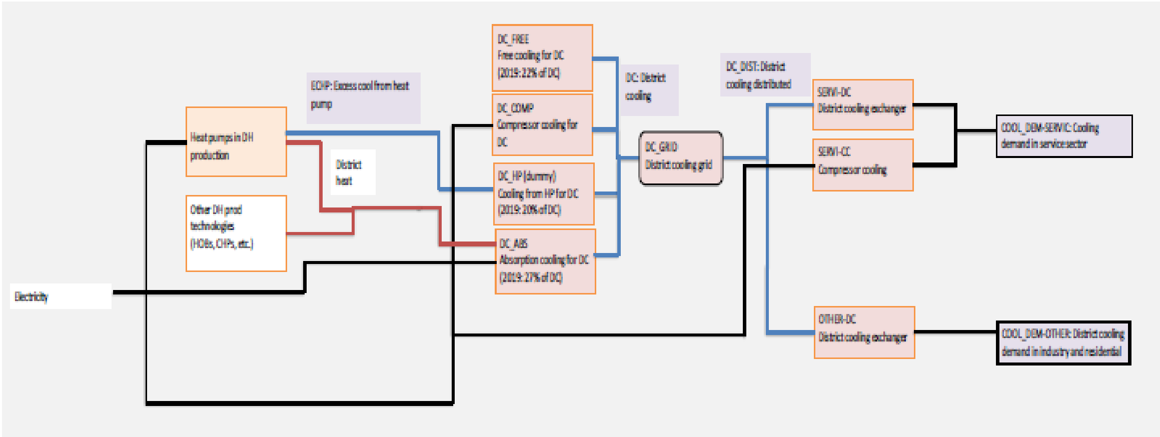


Table 21 Data for compression cooling and absorption cooling in the model (district cooling)

	Investment (SEK/kW cooling)	Fixed operations and maintenance (SEK/kW cooling)	Efficiency	Lifetime (years)
Compression cooling	4 000	160	5.1–5.5 (COP)	20
Absorption cooling	**4 500**	**180**	**0.8–0.85 (from district heating)**	**25**

In the model, demand for cooling largely consists of a demand for comfort cooling in non-residential premises, which can be accommodated either by district cooling or cooling machines (compression) in the building (individual cooling). In addition, there is a small residual item for other district cooling use, i.e. in industry and housing. Individual cooling solutions for industry and housing are not specifically represented in the modelling but electricity consumption linked to this is included in other types of electricity consumption for these sectors. Around 80% of district cooling consumption is currently assumed to take place in non-residential premises. Furthermore, 25% of comfort cooling in non-residential premises is assumed to currently be supplied by district cooling (based on information from the Heating Market in Sweden project).

Projections of the cooling demand for future years have been made for non-residential premises based on assumptions concerning three parameters: change in stock of non-residential premises (total area), change in the proportion of cooled areas in non-residential premises, and change in cooling demand per cooled area. The last parameter is assumed to depend on, inter alia, a warmer climate. Based on literature, previous scenario projects (including Heat Roadmap Europe and Nordic Energy Technology Perspectives 2016) and separate assessments, the following factors for changes in the cooling demand for non-residential premises from 2015 to 2050 have been assumed:

1.2 (increase in total area of non-residential premises) x 1.5 (increase in proportion of cooled area in non-residential premises) x 1.1 (increase specifically in cooling demand) = 2.0

The total demand for comfort cooling for non-residential premises is therefore expected to double from 2015 to 2050. Of the total cooling demand for non-residential premises assumed in the model, at least 20% and no more than 50% could be met by district cooling until 2050. Increasing market shares for district cooling in the model is linked to an increasing distribution cost, to simulate the fact that areas with lower cooling density (a less concentrated demand for cooling) then need to be developed. The literature base for this assessment has been limited and there are therefore uncertainties. An overview of assumed input data linked to district cooling distribution is given in Table 22. The district cooling demand for industry and housing is assumed to increase at the same rate as the estimated total cooling demand for non-residential premises.

Table 22 Data for district cooling distribution. The range for the variable cost shows the cost increase that is assumed for increasing market shares for district cooling.

	Investment (SEK/kW cooling)	Fixed operations and maintenance (SEK/kW heating)	Variable cost (SEK/MWh cooling)	Efficiency level (%)	Lifetime (years)
District cooling network	**8 000**	**300**	**0-75**	**0.92**	**50**

Waste heat for heat pumps in district heating production

The modelling linked to low-temperature waste heat sources and heat pumps in district heating systems has been focused on dividing up a previously aggregated heat pump technology in the model as well as updating the potential for related low-temperature waste heat sources, with a focus on heat from treatment plants and data centres.

The model representation of heat pumps for district heating production includes, after model development, production based on heat from: surrounding water (lakes etc.), industrial waste heat (low temperature), data centres, treatment plants and 'other'. The heat pump technologies differ in the model inter alia through different COP values (due to different temperatures of heat sources).

Updated potentials for low-temperature waste heat from water purification and data centres in the model are as follows:

- Water purification: 3.8 TWh (based on the Reuseheat project[139])
- Data centres: 1.3 TWh for reference case; 3.7 TWh for electrification case (based on Sweco, Reuseheat and separate assessments)

The above potentials concern available heat before upgrading in heat pumps (possible heat production from the heat pumps is thus slightly higher). Waste heat potential is stated on an annual basis and is assumed to be evenly 'distributed' throughout the year (it is therefore not possible to use the whole potential in the winter, for example).

As indicated above, different potentials for data centres are assumed depending on the scenario. The electrification case assumes a more significant expansion of the data centre industry than the reference case. The electrification case also includes a higher electricity demand from data centres than the reference case. In total, the electricity consumption from data centres is assumed to reach 7 TWh towards the end of the analysis period, while electricity consumption in data centres for the reference case is assumed to be 2 TWh. The assessment of the waste heat potential primarily includes assumptions concerning location parameters (proximity to district heating systems with possible outlets) and technical aspects (proportion of energy consumption that can be recovered).

The model's maximum potential for waste heat to heat pumps from data centres has been calculated in three main steps:

1. 75% is assumed to be able to be recovered technically based on data from the EU project *Reuseheat*.
2. Furthermore, 15% of the data centres are assumed to be far away from district heating networks (based on *Reuseheat*).
3. The potential for data centres has then been divided up within the country (electricity areas) and compared with district heating production in each electricity area in order to make an assessment for a reasonable maximum number of heat pumps in relation to other production. This resulted in our

[139] Persson, U. (2018). Accessible urban waste heat, Reuseheat, Deliverable 1.4. Available at https://www.reuseheat.eu/wp-content/uploads/2019/02/D1.4-Accessible-urban-waste-heat.pdf.

further adjusting the potential down slightly for electricity areas 1 and 2 (which are assumed to have a relatively large share of the data centres) but not for electricity areas 3 and 4.

The above assumptions give the maximum potential for heat pumps through data centres in the model, but this is not achieved in most cases.

For district heating production based on heat from surrounding water, industrial waste heat and other, capacity limits are set based on the current situation.

Annex C Scenario assumptions table

Table 23 gives an overview of all baseline scenarios, sensitivity scenarios and technology scenarios and their assumptions.

Table 23 Overview of baseline scenarios, sensitivity scenarios and technology scenarios.

	Scenario	Term	CALCULATED INTEREST RATE	CO2 PRICE	ELECTRICITY DEMAND	COGENERATION EXPANSION	EFFICIENCY IMPROVEMENTS	HEAT PUMP EXPANSION	NUCLEAR POWER, NEW PERMITTED?	NUCLEAR POWER, EXISTING INSTALLATIONS LIFETIME	BIOFUEL, ACCESS TO STAT. SECTOR	ACCESS TO WASTE
Baseline	Ref-Inv (RI)	S1A_RI	+	-	0	0	0	0	0 (Yes)	0	0	0
	Klimat-Inv	S2A_KI	+	+	0	0	0	0	0 (Yes)	0	0	0
	KlimatEl-Inv (KIE)	S3A_KIE	+	+	+	0	0	0	0 (Yes)	0	0	0
	Ref-Sam	S1B_RS	-	-	0	0	0	0	0 (Yes)	0	0	0
	Klimat-Sam	S2B_KS	-	+	0	0	0	0	0 (Yes)	0	0	0
	KlimatEl-Sam	S3B_KSE	-	+	+	0	0	0	0 (Yes)	0	0	0
Technology	RI KVV plus	T1A_RIKP	+	-	0	+	0	0	0 (Yes)	0	0	0
	RI KVV minus	T2A_RIKM	+	-	0	-	0	0	0 (Yes)	0	0	0
	RI VP plus	T3A_RIHP	+	-	0	0	0	+	0 (Yes)	0	0	0
	RI Eff plus	T4A_RIEM	+	-	0	0	+	0	0 (Yes)	0	0	0
	RI Eff minus	T0A_RIEN	+	-	0	0	-	0	0 (Yes)	0	0	0
	KIE KVV plus	T5A_KIKP	+	+	+	+	0	0	0 (Yes)	0	0	0
	KIE KVV minus	T6A_KIKM	+	+	+	-	0	0	0 (Yes)	0	0	0
	KIE VP plus	T7A_KIHP	+	+	+	0	0	+	0 (Yes)	0	0	0
	KIE Eff plus	T8A_KIEM	+	+	+	0	+	0	0 (Yes)	0	0	0
	KIE Eff minus	T9A_KIEN	+	+	+	0	-	0	0 (Yes)	0	0	0
Sensitivity	RI Avfall mindre	K1A_RIA	+	-	0	0	0	0	0 (Yes)	0	0	-
	RI Biokonkurrens	K3A_RIB	+	-	0	0	0	0	0 (Yes)	0	-	0
	RI Kärnkraft mer	K5A_RINP	+	-	0	0	0	0	No	+	0	0
	KIE Avfall mindre	K2A_KIEA	+	+	+	0	0	0	0 (Yes)	0	0	-
	KIE Biokonkurrens	K4A_KIEB	+	+	+	0	0	0	0 (Yes)	0	-	0
	KIE Kärnkraft mindre	K6A_KIEN	+	+	+	0	0	0	No	0	0	0

0	Conditions according to basic assumptions
+	Higher
-	Lower

Annex D Bio-CCS in the electricity and heating sector in Sweden[140]

In Sweden's cogeneration and heat plants, electricity and heat are largely produced by incinerating biofuels. The incineration generates emissions of biogenic carbon dioxide and these installations can therefore contribute to negative emissions through CCS technology. The opportunities to apply CCS in cogeneration and heat plants are relatively good, due to factors such as high carbon dioxide concentration in the flue gases and the fact that excess steam can be used which reduces the need for extra energy input. Emissions of biogenic carbon dioxide in the electricity and heating sector amounted to a total of nearly 16 million tonnes of carbon dioxide in 2018.

Emissions from cogeneration and heat production in Sweden are largely biogenic, which represents a potential for negative emissions. Furthermore, the possibility of applying CCS in cogeneration and heat plants is relatively good. Some advantages are:

- Often constitute relatively large point source emissions, i.e. large annual carbon dioxide flows.
- The carbon dioxide concentration in the flue gases is relatively high (10-20%).
- Power plants often have few emission sources (compared with refineries, for example).
- Excess steam can be recovered as district heating, which reduces the need for extra energy input.

Despite the fact that the excess heat can be used in a district heating network, separation of carbon dioxide still requires a certain amount of energy in the form of electricity or heating. This lowers the efficiency of the installation and results in a larger amount of fuel being needed to produce the same amount of electricity and heating in an installation with CCS, compared with an equivalent installation without CCS. A consequence may also be that the same amount of fuel is used but that the electricity production from the installation is lower. A modelling of bio-CCS applied to Stockholm

Exergi's biofuel-fired boiler showed that electricity production would reduce by 0.25

[140] The Swedish Energy Agency (2020), Process-related and negative emissions – current situation and conditions for conversion. A current analysis in The Industrial Leap, ER 2020:28.

MWh per tonne of separated carbon dioxide.[141]

Other general complications associated with CCS also apply to cogeneration and heat plants, such as the challenge of profitability, the fact that CCS technology may need to be adapted specifically to the installation depending on the composition of the flue gases (which is linked to the fuel that is fired) or the fact that the installation's location (for example whether it is coastal or not) affects the cost of transport for disposal.

The Industrial Leap and negative emissions

Within the context of The Industrial Leap, several research projects are ongoing focusing on carbon capture technologies within CCS. An example of one such project aims to increase the understanding of which chemical technical challenges and opportunities need to be taken into account before the conversion to oxyfuel incineration of black liquor in recovery boilers in the Swedish pulp and paper industry.[142]

Some of the projects completed so far in The Industrial Leap are described in more detail below, specifically two feasibility studies and a pilot project.

Test of Bio-CCS in the Värtan cogeneration plant in Stockholm.

With support from The Industrial Leap, Stockholm Exergi has carried out a project where a test facility is built in which long-term tests of the separation method Hot Potassium Carbonate (HPC) have been carried out. This has been done on part of the flue gas flow from the wood chip-fuelled cogeneration plant KVV8 at the Värtan plant. Despite the fact that there are several thousand studies on CCS in condensing power plants, CCS in cogeneration processes is a relatively unexplored area. The main difference between the applications is that the possibility of recovering low-value heat as district heating paves the way for the use of completely different technologies, compared to condensing installations where only electricity is produced. The general goal of the project was to solve unresolved issues, such as unexpected problems in the event of unforeseen side reactions, before building a large-scale HPC installation at a cogeneration plant. The results from the study show, inter alia, that general degradation did not occur but that the degree of capture stayed the same during the whole test period, and that the degree of capture was at the expected level of around 10%. By putting this test installation into operation, Stockholm Exergi has gained valuable knowledge which provides a good basis for being able to develop the test installation further. However,

[141] Official State Report 2020:4, Road to a climate positive future, climate political choice investigation.

[142] The Swedish Energy Agency's project database P50859-1, registration number 2020-008018.

Stockholm Exergi states that the individual cost of fully implementing the technology in an installation is too great at this stage without some form of economic instrument and updated regulatory framework.[143]

Uppsala Municipality could become climate neutral through bio-CCS

Through a feasibility study, Vattenfall AB and Stuns Stiftelse Uppsala Science Park in Uppsala have examined the possibility of reducing carbon dioxide emissions through bio-CCS and how this could be included in Uppsala Municipality's long-term planning together with the business world. The focus of the study has been heat and electricity production-related biogenic carbon dioxide. The goal of the study has been, inter alia, to quantify system costs for separation. The results of the study show that a climate-positive Uppsala is possible if investments are made in both waste-based and bio-based CCS. In Uppsala, the lowest costs can be achieved when the separation installation is linked to the waste blocks, which have significantly more operating hours than the pure biofuel blocks. The results of the project also show that it is practically possible to build a CCS installation for around 200 000 tonnes carbon dioxide per year in Vattenfall's installation in Uppsala. Together with low emissions from traffic operations in Uppsala, this should result in the municipality achieving negative emissions as regards local climate impact. The system cost is estimated to be SEK 850–1 250/year/resident, where capture accounts for the largest cost, followed by shipping and final storage.[144]

Feasibility study for bio-CCS in Stora Enso

A feasibility study for bio-CCS has been carried out to help determine whether it is possible (technically, operationally, economically and market-wise) to install a full-scale bio-CCS installation in the Swedish part of Stora Enso's sulphate use. The aim was also to investigate safe places for storage and transport there. The project considers it technically and operationally possible to introduce a system for the capture, transport and storage of biogenic emissions in Swedish use in Stora Enso. However, there are currently weak market forces and no profitability in such a project, but this assumes that there are other financing/grant systems. The project has the potential to contribute in the long term to negative emissions from Stora Enso's emission sources of biogenic carbon dioxide.[145]

143 The Swedish Energy Agency's project database P49101-1, registration number 2019-013114.

144 The Swedish Energy Agency's project database P49869-1, registration number 2019-022504.

145 The Swedish Energy Agency's project database P49897-1, registration number 2019-022605.

Annex E Annex VIII to Article 14 of the Energy Efficiency Directive

Annex VIII

Potential for efficiency in heating and cooling

The comprehensive assessment of national heating and cooling potentials referred to in Article 14(1) shall include and be based on the following:

Part I

OVERVIEW OF HEATING AND COOLING

1. Heating and cooling demand in terms of assessed useful energy[146] and quantified final energy consumption in GWh per year[147] by sectors:

   a) residential;

   b) services;

   c) industry;

   d) any other sector that individually consumes more than 5% of total national useful heating and cooling demand;

2. identification, or in the case of point 2(a)(i), identification or estimation, of current heating and cooling supply:
   a) by technology, in GWh per year[148], within sectors mentioned under point 1 where possible, distinguishing between energy derived from fossil and renewable sources:

   i) provided on-site in residential and service sites by:

   — heat only boilers;

   — high-efficiency heat and power cogeneration;

   — heat pumps;

   — other on-site technologies and sources;

[146] The amount of thermal energy needed to satisfy the heating and cooling demand of end-users.

[147] The most recent data available should be used.

[148] The most recent data available should be used.

ii) provided on-site in non-service and non-residential sites by:

— heat only boilers;

— high-efficiency heat and power cogeneration;

— heat pumps;

— other on-site technologies and sources;

iii) provided off-site by:

— high-efficiency heat and power cogeneration;

— waste heat;

— other off-site technologies and sources;

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

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

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

iii) waste incineration plants;

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

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

c) reported share of energy from renewable sources and from waste heat or cold in the final energy consumption of the district heating and cooling[149] sector over the past 5 years, in line with Directive (EU) 2018/2001;

[149] The identification of 'renewable cooling' shall, after the methodology for calculating the quantity of renewable energy used for cooling and district cooling is established in accordance with Article 35 of Directive (EU) 2018/2001, be carried out in accordance with that Directive. Until then it shall be carried out according to an appropriate national methodology.

3. a map covering the entire national territory identifying (while preserving commercially sensitive information):
   a) heating and cooling demand areas following from the analysis of point 1, while using consistent criteria for focusing on energy dense areas in municipalities and conurbations;

   b) existing heating and cooling supply points identified under point 2(b) and district heating transmission installations;

   c) planned heating and cooling supply points of the type described under point 2(b) and district heating transmission installations;

4. a forecast of trends in the demand for heating and cooling to maintain a perspective of the next 30 years in GWh and taking into account in particular projections for the next 10 years, the change in demand in buildings and different sectors of the industry, and the impact of policies and strategies related to the demand management, such as long-term building renovation strategies under Directive (EU) 2018/844;

Part II

OBJECTIVES, STRATEGIES AND POLICY MEASURES

5. planned contribution of the Member State to its national objectives, targets and contributions for the five dimensions of the energy union, as laid out in Article 3(2)(b) of Regulation (EU) 2018/1999, delivered through efficiency in heating and cooling, in particular related to points 1 to 4 of Article 4(b) and to paragraph (4)(b) of Article 15, identifying which of these elements is additional compared to integrated national energy and climate plans;
6. general overview of the existing policies and measures as described in the most recent report submitted in accordance with Articles 3, 20, 21 and 27(a) of Regulation (EU) 2018/1999.

Part III

ANALYSIS OF THE ECONOMIC POTENTIAL FOR EFFICIENCY IN HEATING AND COOLING

7. an analysis of the economic potential[150] of different technologies for heating and cooling shall be carried out for the entire national territory by using the cost-benefit analysis referred to in Article 14(3) and shall identify alternative scenarios for more efficient and renewable

[150] The analysis of the economic potential should present the volume of energy (in GWh) that can be generated per year by each technology analysed. The limitations and interrelations within the energy system should also be taken into account. The analysis may make use of models based on assumptions representing the operation of common types of technologies or systems.

heating and cooling technologies, distinguishing between energy derived from fossil and renewable sources where applicable.

The following technologies should be considered:

a) industrial waste heat and cold;

b) waste incineration;

c) high efficiency cogeneration

d) renewable energy sources (such as geothermal, solar thermal and biomass) other than those used for high efficiency cogeneration;

e) heat pumps;

f) reducing heat and cold losses from existing district networks.

8. this analysis of economic potential shall include the following steps and considerations:

a) Considerations:

i) the cost-benefit analysis for the purposes of Article 14(3) shall include an economic analysis that takes into consideration socioeconomic and environmental factors[151] and a financial analysis performed to assess projects from the investors' point of view. Both economic and financial analyses shall use the net present value as criterion for the assessment;

ii) the baseline scenario should serve as a reference point and take into account existing policies at the time of compiling this comprehensive assessment[152] and be linked to data collected under Part I and point 6 of Part II of this Annex;

iii) alternative scenarios to the baseline shall take into account energy efficiency and renewable energy objectives of Regulation (EU) 2018/1999. Each scenario shall present the following elements compared to the baseline scenario:

— economic potential of technologies examined using the net present value as criterion;

— greenhouse gas emission reductions;

[151] Including the assessment referred to in Article 15, paragraph 7 of Directive (EU) 2018/2001.

[152] The cut-off date for taking into account policies for the baseline scenario is the end of the year preceding to the year by the end of which the comprehensive assessment is due. That is to say, policies enacted within a year prior to the deadline for submission of the comprehensive assessment do not need to be taken into account.

— primary energy savings in GWh per year;

— impact on the share of renewables in the national energy mix.

Scenarios that are not feasible due to technical reasons, financial reasons or national regulation may be excluded at an early stage of the cost-benefit analysis, if justified based on careful, explicit and well-documented considerations.

The assessment and decision-making should take into account costs and energy savings from the increased flexibility in energy supply and from a more optimal operation of the electricity networks, including avoided costs and savings from reduced infrastructure investment, in the analysed scenarios.

b) Costs and benefits

The costs and benefits referred to under point 8(a) shall include at least the following benefits and costs:

i) Benefits:

— value of output to the consumer (heating, cooling and electricity);

— external benefits such as environmental, greenhouse gas emissions and health and safety benefits, to the extent possible;

— labour market effects, energy security and competitiveness, to the extent possible.

ii) Costs:

— capital costs of plants and equipment;

— capital costs of the associated energy networks;

— variable and fixed operating costs;

— energy costs;

— environmental, health and safety costs, to the extent possible;

— labour market costs, energy security and competitiveness, to the extent possible.

c) Relevant scenarios to the baseline:

All relevant scenarios to the baseline shall be considered, including the role of efficient individual heating and cooling.

i) the cost-benefit analysis may either cover a project assessment or a group of projects for a broader local, regional or national assessment in order to establish the most cost-efficient and beneficial heating or cooling solution against a baseline for a given geographical area for the purpose of planning;

ii) Member States shall designate the competent authorities responsible for carrying out the cost-benefit analyses pursuant to Article 14. They shall provide the detailed methodologies and assumptions in accordance with this Annex and establish and make public the procedures for the economic analysis.

d) Boundaries and integrated approach:

i) the geographical boundary shall cover a suitable well-defined geographical area;

ii) the cost-benefit analyses shall take into account all relevant centralised or decentralised supply resources available within the system and geographical boundary, including technologies considered under point 7 of Part III of this Annex, and heating and cooling demand trends and characteristics.

e) Assumptions:

i) Member States shall provide assumptions, for the purpose of the cost-benefit analyses, on the prices of major input and output factors and the discount rate;

ii) the discount rate used in the economic analysis to calculate net present value shall be chosen according to European or national guidelines;

iii) Member States shall use national, European or international energy price development forecasts if appropriate in their national and/or regional/local context;

iv) the prices used in the economic analysis shall reflect socio economic costs and benefits. External costs, such as environmental and health effects, should be included to the extent possible, i.e. when a market price exists or when it is already included in European or national regulation.

f) Sensitivity analysis:

(i) a sensitivity analysis shall be included to assess the costs and benefits of a project or group of projects and be based on variable factors having a significant impact on the outcome of the calculations, such as different energy prices, levels of demand, discount rates and other.

Part IV

POTENTIAL NEW STRATEGIES AND POLICY MEASURES

9. Overview of new legislative and non-legislative policy measures[153] to realise the economic potential identified in accordance with points 7 and 8, along with their foreseen:

a) greenhouse gas emission reductions;

b) primary energy savings in GWh per year;

c) impact on the share of high-efficiency cogeneration;

d) impact on the share of renewables in the national energy mix and in the heating and cooling sector;

e) links to national financial programming and cost savings for the public budget and market participants;

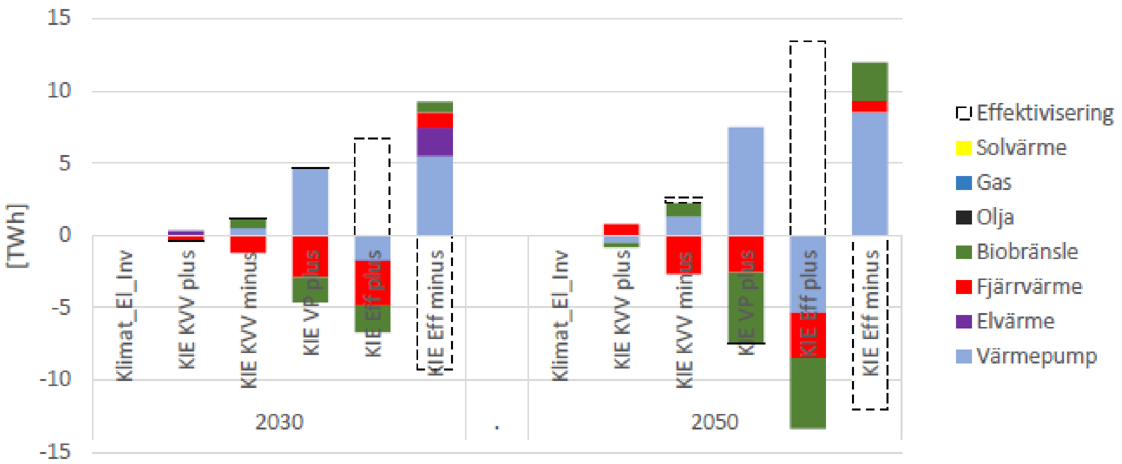
f) estimated public support measures, if any, with their annual budget and identification of the potential aid element.

[153] This overview shall include financing measures and programmes that may be adopted over the period of the comprehensive assessment, not prejudging a separate notification of the public support schemes for a State aid assessment

Annex F More technology scenarios

Figure 56 shows the effect of the alternative assumptions in the technology scenarios, here with the KlimatEl_Inv scenario as a base and benchmark case. More and less cogeneration (in KIE-KVV plus and KIE-KVV minus) in the 2050 perspective has relatively little effect on district heating use, but as can be expected, a certain increase can be seen with additional KVV capacity and a certain decrease is seen with reduced KVV capacity. Increased opportunities for heat pump use (as in KIE-VP plus) primarily result in a reduction in pellet use, but also a reduction in district heating use. The alternative energy efficiency cases, where use of efficiency measures can be said to be maximised (in the scenario KIE-Eff plus) and minimised (in the scenario KIE Eff minus) have consequences for heat pumps, pellets and district heating.

Figure 56 Difference in useful energy for heating with alternative assumptions in the technology scenarios and KlimatEl-Inv



	[TWh]
	Klimat_El_Inv
	KIE KVV plus
	KIE KVV minus
	KIE VP plus
	KIE Eff plus
	KIE Eff minus
	Efficiency improvements
	Solar heat
	Gas
	Oil
	Biofuel
	District heating
	Electric heating
	Heat pumps

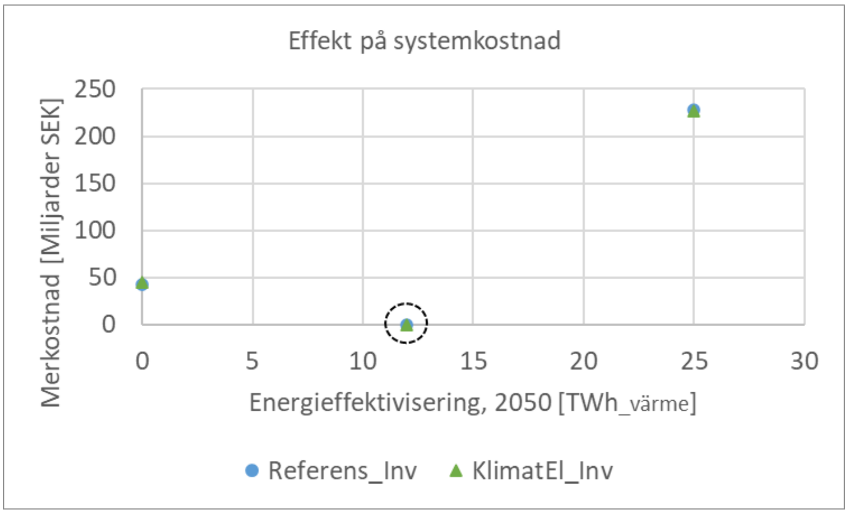
The energy efficiency measures referred to in the above report are improvements in efficiency that reduce the net heat demand (not conversion measures). In addition to the technology scenarios Eff plus and Eff minus these measures are mainly handled endogenously in the model, i.e. rate and degree of efficiency is a model result. Costs and potentials may differ considerably, both between different measures and even partially between measures of the same type, but in different sectors. Looking at our calculations, the calculated differences in efficiency are relatively small. This is because there are a number of measures that are profitable and robust in all cases. The additional measures are too expensive to be used in any of the scenarios. The explanation for this is that the energy prices differ too little between the scenarios for this to affect the degree of efficiency. This is because a price difference at the producer level is mitigated when it is passed down to the end-user level, where additional surcharges are added, such as taxes and electricity network costs. The market price for the energy product, for example, electricity, is only one element among many in the consumer price. However, there is a clear difference in the outcome for efficiency improvements between the calculations that assume an investors' perspective and those which are instead based on a socioeconomic perspective. In the latter case, the calculated interest rate for efficiency measures is significantly lower (same calculated interest rate as for all investments) which thereby increases the profitability. This is even more significant for measures which only have a cost of capital.

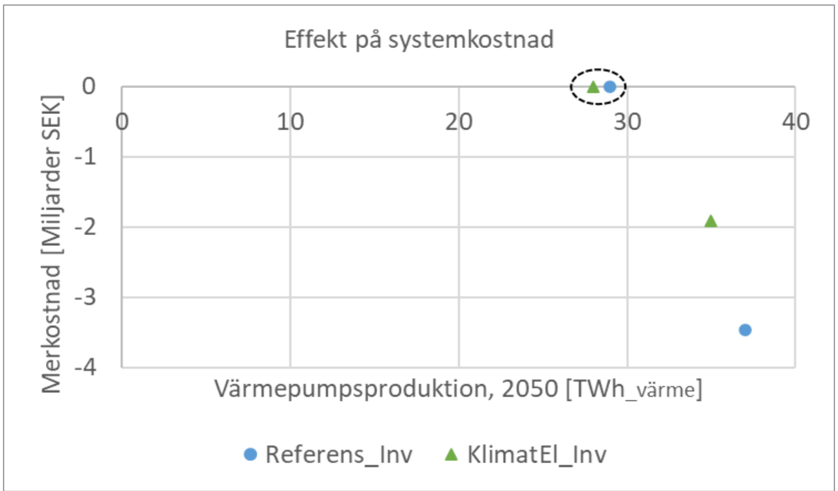
Effect on system costs – energy efficiency improvements and heat pumps

As supplementary information to the results related to the energy mix, Figure 57 shows the effect on the model's system cost of the technology scenarios in which alternative conditions in the buildings' energy consumption are tested: lower and higher degree of energy efficiency (Eff minus and Eff plus) and a higher proportion of heat pumps in individual heating (VP plus). The illustrated difference in system costs concerns the entire modelled period (2005 to 2050) and is expressed as a net present value to the model's base year 2005 (a discount rate of 3.5% is used in the analysis). The system costs are affected by the trend over the entire period. The figure shows the degree of efficiency and heat pump production for each case, but only for one of the model years (2050) for graphics reasons.

The system cost includes all costs (such as investment costs, operating and maintenance costs, fuel costs and tax costs) that arise in all parts of the system (such as at the supply, distribution and user levels). It is a complex parameter but can still give an indication of the size of the cost for different types of measures/system changes. However, energy efficiency measures should not be compared against heat pumps on the basis of these cost results – starting levels in the baseline scenarios, the size of the change in the technology scenarios and the way the scenarios are defined affect the impact on the system cost and make such comparisons difficult.

Figure 57. Effect on system costs of different degrees of energy efficiency improvements (top) and different levels of heat pump production as a result of changed market conditions (bottom), expressed as additional costs for technology scenarios compared with baseline scenarios (circled). Top image based on Ref, KlimatEl, Eff minus and Eff plus, all with investors' perspective. Bottom image based on Ref, KlimatEl, and VP plus, all with investors' perspective.





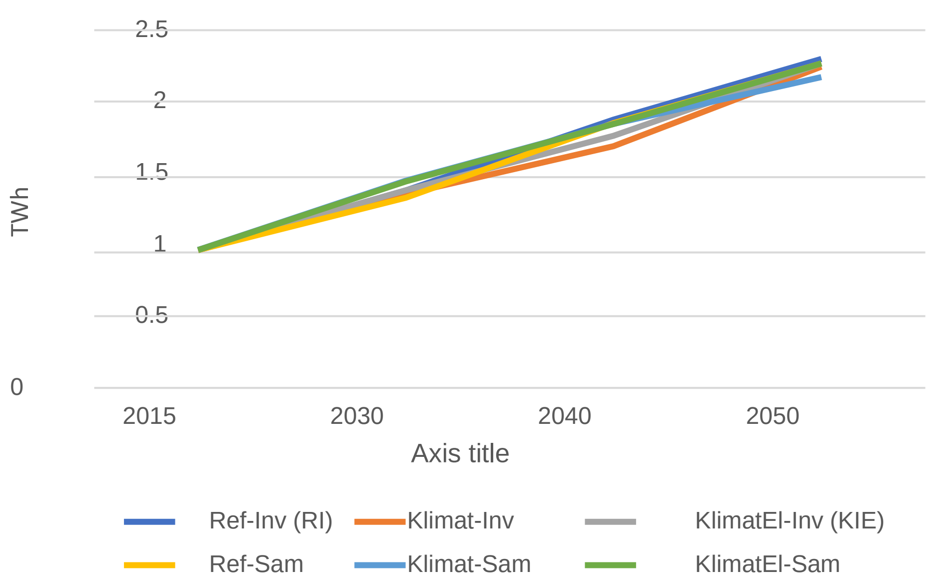
	Effect on system costs
	Additional costs [billion SEK]
	Referens_Inv
	KlimatEl_Inv
	Energy efficiency improvements, 2050 [TWh_heat]
	Heat pump production, 2050 [TWh_heat]

It is clear from Figure 57 (top image) that foregoing energy efficiency measures completely gives increased system costs of approximately SEK 50 billion in relation to the degree of efficiency in the baseline scenarios. Having a degree of efficiency that is approximately twice as high as in the baseline scenarios increases the system costs even more (over SEK 200 billion). It should be noted that the high additional costs for increased energy efficiency improvements are linked here to a very high level of energy efficiency improvements, where comparatively expensive measures are also used. A lower level of increased efficiency improvements in relation to the baseline scenarios could have given a smaller cost increase in relation to degree of efficiency.

Figure 57 (bottom image) shows that an increased potential for heat pumps decreases the system costs. This is because certain types of heat pumps, primarily geothermal heat and air-to-air heat pumps, are cost-efficient technologies in the baseline scenarios and further increasing their potential lowers the system costs. Assumed limits for market shares for these heat pumps are, in other words, limited in the baseline scenarios. However, for practical reasons, such assumptions are necessary (see also Appendix A).

While for the energy efficiency cases the outcome will be the same for the additional cost for Referens_Inv and KlimatEl_Inv conditions, for the alternative heat pump case (VP-Plus), a lower cost saving can be seen with KlimatEl_Inv conditions than with Referens_Inv conditions.

Figure 58. District cooling supplies for all baseline scenarios.



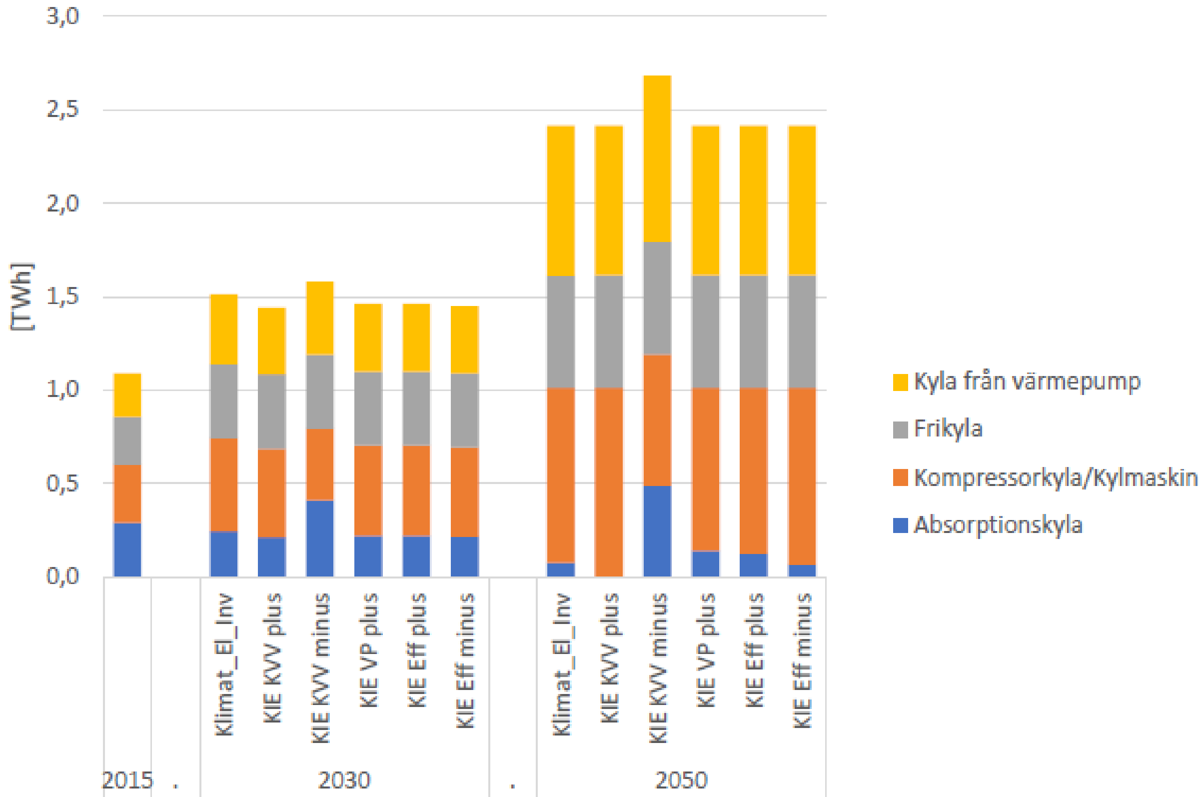
Using free cooling from lakes or other bodies of water is a favourable way of producing district cooling and in the model results, this option is expanded to the extent permitted in the modelling. Using cooling from heat-producing heat pumps in the district heating network is also largely a cost-efficient option but is linked to and limited by the potential for sufficient heat pump capacity. Absorption coolers[154] and compression coolers are options that have few technical limits on potential. For the vast majority of the modelled technology scenarios, based on the baseline scenario KlimatEl_Inv, compression coolers are chosen to a higher extent than absorption coolers (Figure 59).

The cost of district heating is therefore in most cases not sufficiently low in relation to the electricity price to justify investment in absorption cooling before compression cooling.

It should be noted that, as for district heating, the model shows an aggregated representation of district cooling at the Swedish level. Special conditions which may benefit one solution or another at the local level are therefore not recorded.

[154] Absorption coolers use district heating to operate the cooling process. Access to cheap district heating therefore makes absorption coolers more profitable.

Figure 59. District cooling production in the baseline scenario KlimatEl_Inv including other technology scenarios.



	TWh
	Cooling from heat pumps
	Free cooling
	Compression cooling/Cooling machine
	Absorption cooling
	Klimat_El_Inv
	KIE KVV plus
	KIE KVV minus
	KIE VP plus
	KIE Eff plus
	KIE Eff minus
	Klimat_El_Inv
	KIE KVV plus
	KIE KVV minus
	KIE VP plus
	KIE Eff plus
	KIE Eff minus

Although most of the modelled scenarios display the trends shown above, there are examples in the results where absorption cooling is given more consideration. Common to these cases is that during summer, when the demand for cooling is at its greatest, a relatively large supply of cheap heat has arisen in relation to heat demand. Among the modelled scenarios, this takes place, for example, in the scenario KIE_KVV_minus, i.e. in the case where it is assumed that no new investments are made in cogeneration. As a result of a lack of investment in cogeneration, higher district heating prices can be seen during the winter, but these are lower in the summer. With a good availability of capacity in cheap heat production, such as waste-fired heat only boilers in the summer, absorption coolers are in a better position than in the vast majority of the other modelled scenarios.

Similar effects can also be seen in the sensitivity analysis case with reduced access to biofuel for electricity and heat production (Bio minus). The increased biofuel competition in this case leads to a slightly reduced district heating demand and instead sees a conversion to primarily individual heat pumps. However, as biofuel use in the district heating sector is particularly large in the winter, the potential for cheap summer production (such as waste heat and waste incineration) is not affected to any great extent. The generally reduced district heating demand therefore benefits absorption cooling, with a focus on production during the summer.