Rijksdienst voor Ondernemend Nederland

Heating and Cooling Potential Analysis

An assessment of the potential for an efficient heating and cooling supply in the Netherlands

>> Sustainable, agrarian, innovative and

An assessment of the potential for an efficient heating and cooling

Contents

1 Introduction

Background

Member States must produce a comprehensive assessment of the potential for energy-efficient heating and cooling in accordance with Article 14 of the 2018 European Energy Efficiency Directive (hereinafter the 'EED'). The first assessment was submitted in 2015[1]. A new assessment must be submitted by the end of 2020, in accordance with the amendments made to the assessment requirements in a delegated regulation in 2019[2]. These amended requirements bring the assessment in line with other European legislation for the Energy Union (such as the Governance Regulation and the Renewable Energy Directive Article 15(7). This Heating and Cooling Potential Analysis forms the Netherlands' assessment of the potential for efficient heating and cooling.

Objective

The potential analysis provides insight into the current and expected heating and cooling supply in the Netherlands, the economic potential for improving the sustainability of this supply and the country's policy in this area.

Method

The Heating and Cooling Potential Analysis is based on the following principles:

- the analysis is in line with the Netherlands' climate and energy policy, which is determined primarily by the National Climate Agreement[3] signed in 2019 and the implementation of this agreement; the analysis therefore provides insight into the Netherlands' implementation of the assessment in accordance with Article 14 of the EED;
- the analysis uses existing data corresponding to official statistics from Statistics Netherlands (CBS) and the analyses of the Netherlands Environmental Assessment Agency (PBL) wherever possible; unless otherwise stated, the definitions commonly used in the Netherlands apply here[4];

Reading guide

The structure of the potential analysis follows the format in Annex VIII to the EED, as stated in Annex I to the delegated regulation. Part I describes the current heating and cooling supply (Chapter 2) and the expectations for the period up to 2030 under current policy (Chapter 3). Part II describes the current objectives and contributions in relation to heating and cooling (Chapter 4) and which policy measures have been implemented and/or proposed (Chapter 5). Part III describes the potential for improving the sustainability of the heating and cooling supply (Chapter 6). Finally, Section IV describes possible new strategies and policy measures to realise this potential (Chapter 7).

1 https://ec.europa.eu/energy/topics/energy-efficiency/cogeneration-heat-and-power_en?redir=1#national-cogeneration-reports.

2 In accordance with delegated regulation C(2019)1616 of 4 March 2019.

3 https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord.

4 The figures for energy consumption from Statistics Netherlands (CBS) differ from the figures provided by Eurostat in relation to the treatment of unsold heat from CHP installations. Statistics Netherlands counts the useful heat consumption, including the unsold portion, as consumption. Eurostat does not count this as consumption, but counts part of the use of natural gas by CHP installations as unsold heat in the final energy consumption.

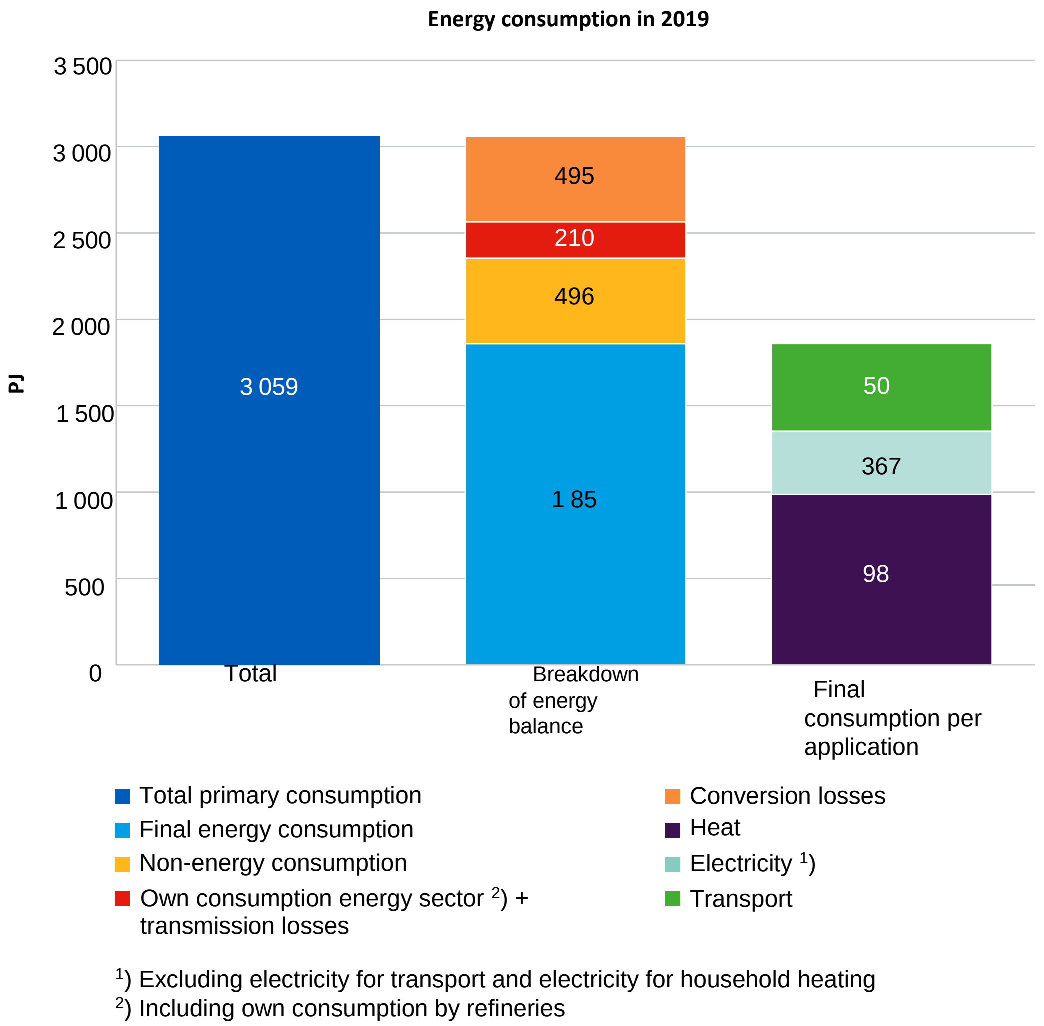
PART I

2 Current heating and cooling supply

2.1 Demand for heating and cooling

Heat accounts for more than half of final energy consumption
The total primary energy consumption in the Netherlands amounts to more than 3 000 petajoules (CBS and TNO, 2020)[5]. More than 1 856 petajoules of this are used by end users for energy purposes: industry, transport, households, services and agriculture. The rest consists of conversion losses, own use by the energy sector and non-energy consumption of primary energy sources. In 2019, more than half of the final energy consumption was used for heat, more than a quarter for transport and the rest, around 20%, for electrical applications (other than heat and transport) (see Figure 2.1). The total final energy consumption for heat is around 1 000 petajoules.

Figure 2.1 Breakdown of energy consumption in 2019.[6]



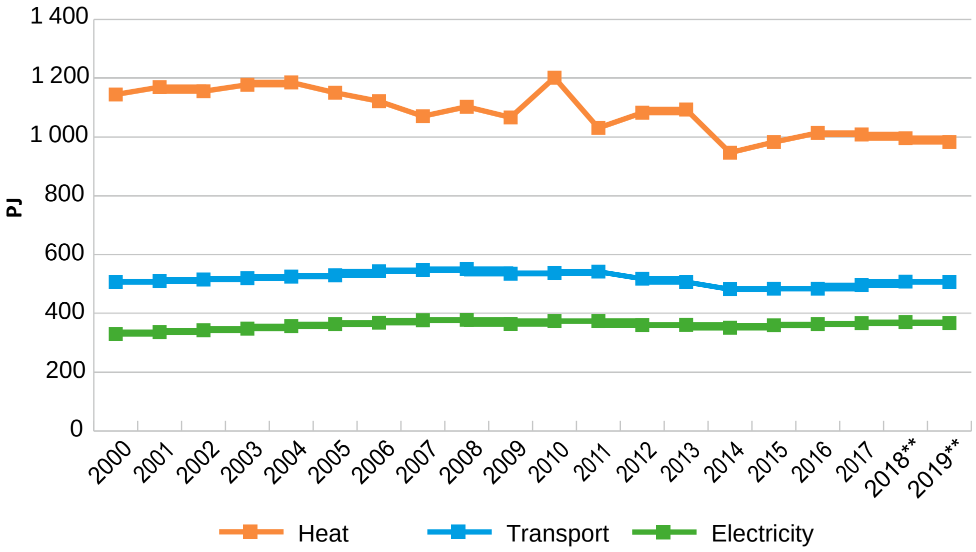
Source: CBS and TNO (2020)

5 The energy consumption for 2018 and 2019 given in this source is based on provisional statistics.

6 A number of choices were made in deriving this figure from the Energy Balance: The final energy consumption for transport includes the energy consumption for mobile machinery and the final energy consumption for electricity excludes consumption of electricity for transport and consumption of electricity for household heating.

The change in the contribution of heat to the final energy consumption over the course of a few years is due mainly to the impact of the weather (see Figure 2.2). In the cold year of 2010, 57% of the final energy consumption was used for heating. Over the past two decades, however, a trend towards relatively lower consumption of energy for heat and relatively higher consumption of energy for electrical applications can be identified.

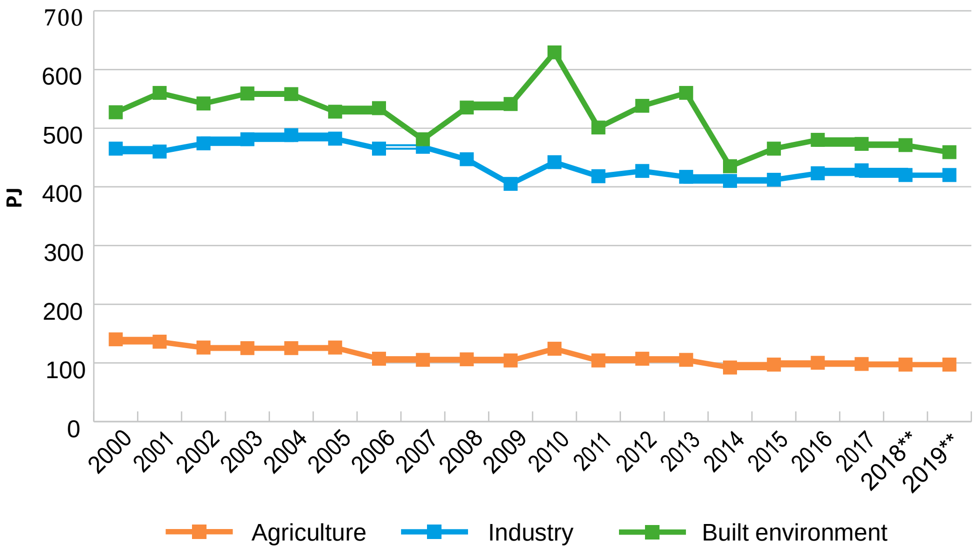
Figure 2.2 Final energy consumption by application.



Source: CBS and TNO (2020)

Around half of the final energy consumption for heat is energy consumption in the built environment (households and services), 40% is in the industrial sector and 10% is in agriculture (see Figure 2.3).

Figure 2.3 Final energy consumption for heat by sector.



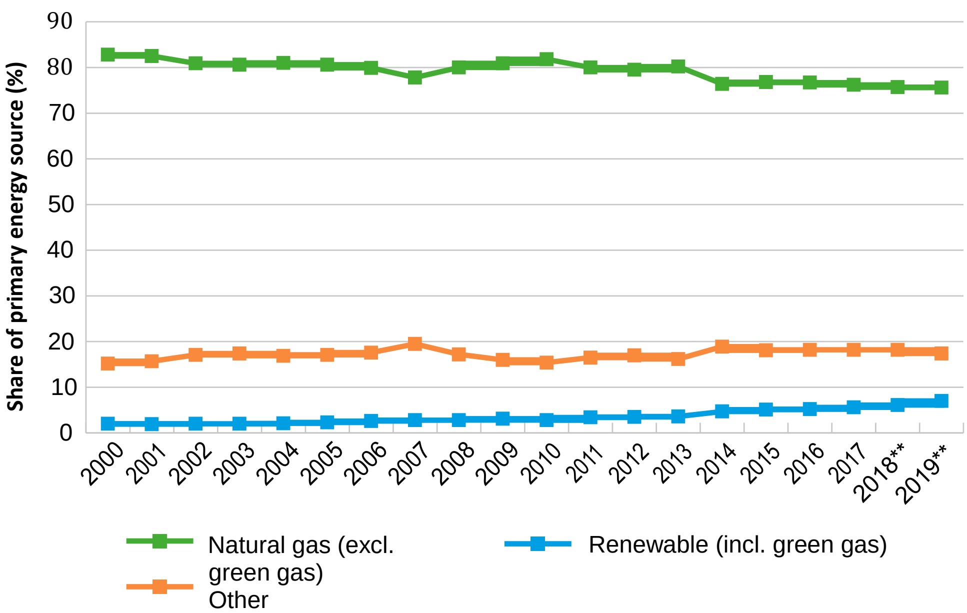
Source: CBS and TNO (2020)

Total energy consumption for cooling
The majority of the demand for cooling comes from chillers installed in locations where cooling is required, such as in buildings and in the food industry. This amounted to around 27 petajoules of electricity in 2015. This is relatively low in comparison with the total final energy consumption for heat, which is around 1 000 petajoules (see Figure 2.1).

2.2 Supply of heating and cooling

Heat comes primarily from the burning of natural gas
In 2019, 76% of the final energy consumption for heat came from the burning of natural gas (Figure 2.4). Much of this concerns burning of natural gas in boilers for own use, but it also comes from combined heat and power installations, owned either by consumers of heat or by third parties. In 2019, renewable energy accounted for 7% and other energy sources, such as waste gases from crude oil and coal, accounted for 17%.

Figure 2.4 Share of final energy consumption for heat by primary energy source.



Source CBS and TNO (2020)

The largest suppliers of heat in the Netherlands not only supply heat but are also developing cooling networks to deliver cooling, on a relatively limited scale. The supply of cooling via networks (which serve multiple buildings) accounted for 0.5 petajoules in 2015 and 2016, and 0.6 petajoules in 2018. The number of cooling networks identified was 20. Most cold comes from renewable sources (the soil or surface water) and a much smaller proportion comes from electric compression chillers. In large office buildings and hospitals in particular, cooling is also delivered through thermal energy storage (TES) systems. In recent years, the total cold extracted from the soil (which is equal to the heat discharged) via TES systems has amounted to around 2 petajoules (CBS, 2020a).

Built environment
Burning of natural gas in boilers and stoves accounts for a large proportion of the final energy consumption for heat in the built environment (see Table 2.1). Biomass accounts for around 5% and this relates to household consumption of wood. There is a margin of error of 30% (CBS, 2020b). The purchased heat and self-generated CHP heat primarily consist of heat from district heating, with short-term trends highly dependent on the weather during the heating season.

The electricity consumption for heat consists of electricity consumption for heat pumps, but also (and currently still) consumption of electricity by pumps for central-heating boilers and electric boilers.

Heat pumps extract heat from the environment (the soil, water or ambient air) in order to heat buildings. Heat extracted from the environment by heat pumps demonstrates a structural increase, which has been accelerating over recent years, particularly for homes (CBS, 2020c). More than 20% of natural-gas consumption by households is used for the preparation of tap water. Cooking consumes a relatively small amount of natural gas, around 2%.

Table 2.1 Final energy consumption for heat in the built environment IN 2019** in petajoules

	Households	Services	Total[1])
Crude oil	2	.	.
Natural gas[2])	274	115	389
Natural gas for space heating	209	.	.
Natural gas for hot tap water	60	.	.
Natural gas for cooking	6	.	.
Solar heating	1	0	1
Biomass	16	1	17
Purchased heat plus self-generated CHP heat	12	11	23
Purchased heat[3])	12	10	21
Self-generated CHP heat	0	1	1
Total electricity for heat	9	3	12
Electricity for heat pumps	2	3	5
Electricity for electric boilers	3	.	.
Electric radiators and electric underfloor heating	0	.	.
Electricity for pumps in central-heating boilers	4	0	4
Heat extracted from environment using heat pumps	5	6	11
Total[1])	319	140	459

Source: CBS and TNO (2020).

1 *Excluding consumption of electricity for heating in services*
2 *Including natural gas for block heating*
3 *Primarily heat from heat networks and a couple of tenths of a petajoule of heat from third-party CHP installations*

Industry
The final energy consumption for heat in the industrial sector changes from year to year, as a result of the economic situation and maintenance or outages at large installations. In the industrial sector too, burning of natural gas in boilers for own use is the main source of heat (see Table 2.2). Other sources do account for a larger share of the final energy consumption than in the case of households, however. The petrochemical industry burns a lot of waste gases from oil and the industrial sector uses a lot of steam generated in businesses' own CHP installations or purchased from energy companies (or joint ventures), other businesses or waste incinerators. Many joint ventures have been terminated over recent years, and the installations concerned have been taken over by the industrial sector, causing the final energy consumption for steam from businesses' own CHP installations to increase slightly again. Consumption of coal and coal products is stable and consists primarily of the burning of coal waste gases in the steel industry.

Table 2.2 Final energy consumption for heat in industry (excluding refineries) in petajoules

	2015	2016	2017	2018**	2019**
Coal and coal products	20	21	22	23	20
Crude oil and petroleum products[1])	106	119	117	119	107
Natural gas	180	181	187	181	188
Biomass	5	5	5	6	5
Purchased heat plus self-generated CHP heat	101	98	97	90	99
Purchased heat	94	86	81	75	.
Self-generated CHP heat	7	12	16	16	.
Electricity for heat	.	.	.	.	.
Non-biogenic waste and steam from chemical processes	0	0	1	1	1
Total	412	423	428	420	420

Source: CBS and TNO (2020)

1 *Mainly waste gases from oil. The decrease in 2019 is due to a large extent to maintenance*

Agriculture

The highest demand for heat in the agriculture sector comes from greenhouse horticulture. Burning of natural gas in boilers accounts for around half of the final energy consumption for heat in agriculture and heat from businesses' own gas-fired CHP installations makes up the other half (Table 2.3). The annual use of these installations depends on the market prices for electricity and natural gas. Over the past two years, the market situation for generation of electricity from natural gas has been favourable, which translates to a high use of gas-fired CHP installations in the agriculture sector.

The contribution of geothermal and biomass boilers to the supply of heat is increasing. In 2019, the share of these renewable sources increased to more than 10%. A limited number of horticulturists are connected to district heating, for example to the Rotterdam network (B3-hoek) and the Breda-Tilburg Heat Network.

The total demand for heat also varies according to the temperatures in the heating season, although demand is less dependent on temperatures than in the built environment. This table does not include the heat produced by greenhouse lighting. This is not counted as final energy consumption for heat, since lighting is the primary purpose. The lamps do emit a lot of heat, however.

Table 2.3 Final energy consumption for heat in agriculture in petajoules

	2015	2016	2017	2018**	2019**
Crude oil and petroleum products	1	1	1	1	1
Natural gas	44	50	44	39	34
Geothermal	2	3	3	4	6
Biomass	3	3	4	5	5
Purchased heat plus self-generated CHP heat	47	43	47	48	52
Purchased heat	4	4	4	4	4
Self-generated heat - CHP heat	43	39	43	44	48
Heat extracted from environment using heat pumps	0.3	0.3	0.3	0.3	0.3
Total electricity for heat	.	.	.	.	.
Electricity for heat - heat pumps	0.1	0.1	0.1	0.1	0.1
Electricity for heat - other	.	.	.	.	.
Total	97	100	98	97	97

Source: CBS and TNO (2020).

2.3 Installations that (have the potential to) supply (residual) heat or cooling

The previous section described the energy technologies used to supply heat. The purchase of (residual) heat was also discussed. This section provides an overview of different types of thermal installations that supply (residual) heat or cooling, or have the potential to be adapted to do so, as identified on the basis of data from the end of 2020 (mostly relating to the situation in 2017 or 2018).

Thermal power plants (more than 50 MW_{th})

According to the Heat Atlas, there are 269 combustion plants in the Netherlands with a thermal capacity of more than 50 MW, as
defined in European Directive 2001/80/EC (see Table 2.4). An overview of all individual large combustion plants can be found in the Heat Atlas (see Section 2.5). The data that the Heat Atlas uses here comes from the Pollutant Release and Transfer Register, which monitors emissions by these plants.

Table 2.4 Large combustion plants with a capacity of more than 50 MW_{th} (in 2017)

Sectors	Number	Cumulative capacity (MW_{th})
Electricity plants	69	40 833
Chemical and other industry	120	13 528
Steel industry	6	606
Heat plants	14	1 402
CHP installations (particularly for industry)	17	2 895
Refineries	43	4 251
Totals	269	63 515

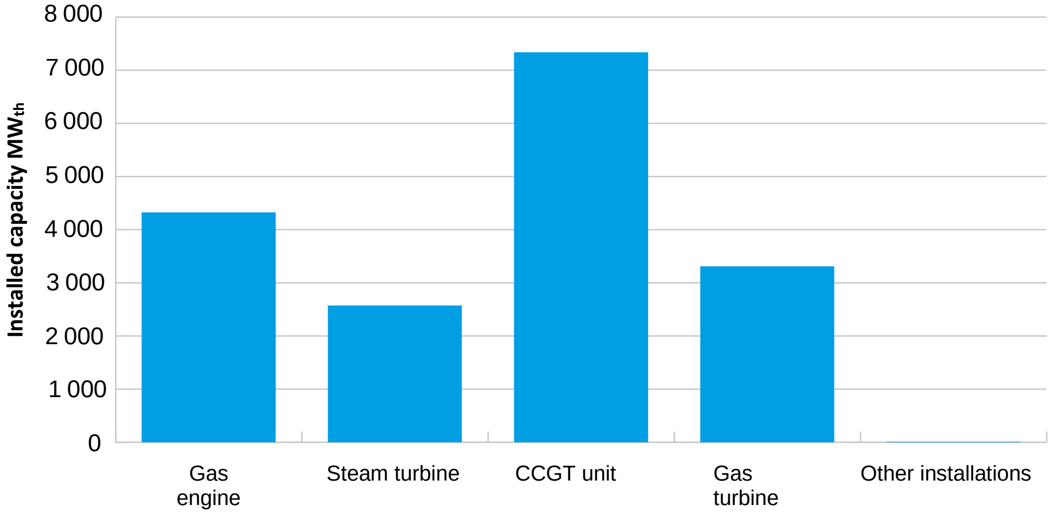
Source: Heat Atlas

Combined heat and power installations (more than 20 MW_{th})

In 2017, there were a total of 4 021 CHP installations, with a combined thermal capacity of 17 558 MW (see Figure 2.5). The largest number of CHP installations (around 2 500 gas engines) are in the greenhouse horticulture sector, with a combined thermal capacity of 3 611 MW. These CHPs are primarily used to heat greenhouses and for CO_2 fertilisation, but they also produce electricity, the majority of which is supplied back to the grid (9.9 GWh). The highest combined thermal capacity is in the industrial sector, where there is a capacity of 7 952 MW across 180 installations. Around half of these are gas engines. In the industrial sector, CHP installations are primarily used to produce steam. There are also many relatively small CHP installations in the services sector: more than 1 300, primarily gas engines, with a combined thermal capacity of 1 814 MW in 2017.

The CHP installations with the largest capacity are in the energy sector: 19 installations, mainly CCGT units, with a combined thermal capacity of 3 365 MW. These plants primarily supply electricity.

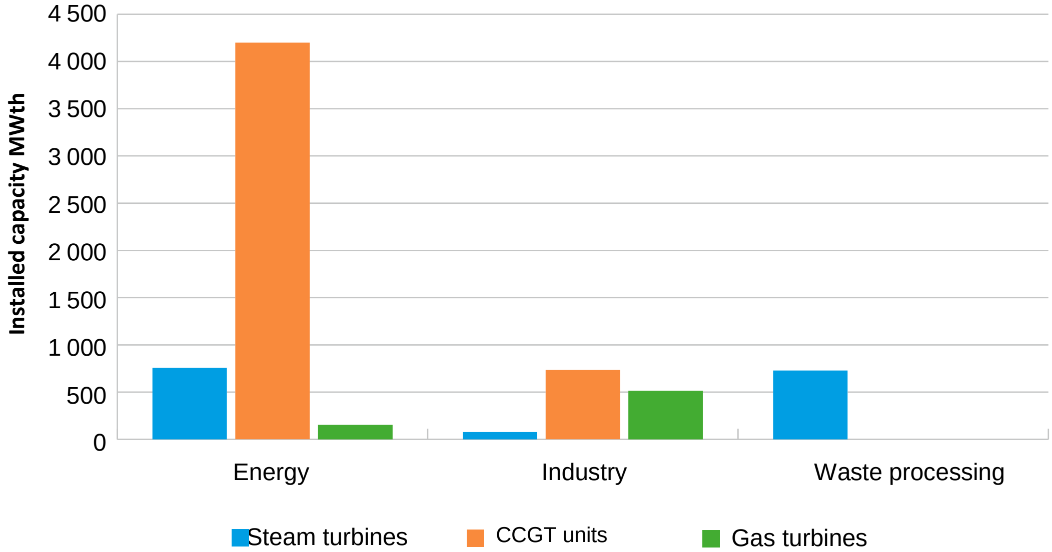
Figure 2.5 Combined heat and power (CHP) installations in 2017.



Source: CBS (2020d)

Based on provisional figures, in 2018 the installed capacity of large CHP installations, with an electrical capacity of more than 20 MW, was 7 163 MW_e (see Figure 2.6), across 71 installations. The majority of these, in terms of both numbers and capacity, are owned by energy companies.

Figure 2.6 Large combined heat and power (CHP) installations (>20 MW_e) in 2018.



Source: CBS (2020D), processed by CBS

Waste incinerators

There are 13 waste incinerators in the Netherlands (RWS, 2020). These generate energy in the form of electricity and/or heat through the processing of waste. The combined thermal capacity of the waste incinerators with CHP installations amounts to more than 2 500 MW. In 2018, the waste incinerators generated 4 204 GWh of electricity, measured directly from the turbines. Of the electricity generated, around 80% is supplied to the grid or to other off-site installations. The rest is used by the waste incinerators themselves, mainly for flue gas cleaning. Waste incinerators also supplied 14.9 petajoules of heat off-site in 2018. The temperature at which this heat is supplied varies depending on the installation. This is determined by the demand for heat in the area surrounding the installation.

The heat supplied is used for industrial processes, district heating or heating of greenhouses. Table 1.1 in Appendix I provides an overview of waste incinerators in the Netherlands.

Renewable energy installations (more than 20 MW_{th})

Thermal power plants for renewable energy also produce heat. In the Netherlands, large-scale renewable energy installations have been subsidised since 2008 through the Stimulation of Sustainable Energy Production+ scheme (SDE+). There are a total of 48 installations with a capacity of more than 20 MW_{th} (see Table 2.5) that either receive a subsidy or will receive one (once built)[7].

Table 2.5 Renewable energy installations subsidised through the SDE+ scheme (more than 20 MW_{th})

	Number of projects	Cumulative installed capacity (MW_{th})
Completed (in service)	**43**	**3 111**
Waste	11	797
Biomass	9	679
Biomass (co-firing)	4	891
Biomass heat	8	443
Geothermal heat	9	253
Green gas	2	48
Construction in preparation	**24**	**1 255**
Biomass	5	221
Biomass (co-firing)	2	386
Biomass heat	3	214
Geothermal heat	11	345
Green gas	3	89
Final total	67	4 366

Source: RVO (reference date 1 May 2020; only installations with a capacity of more than 20 MW_{th}).

Industrial installations (more than 20 MW_{th})

Industrial installations produce heat for production processes. According to the Heat Atlas, there are 27 industrial installations with a capacity of more than 20 MW_{th} in the Netherlands (see Figure 2.7 below and Table 1.2 in Appendix I).

Most of these installations supply steam for the business's production process. A limited number of installations supply heat in the form of steam to other industrial installations, via a steam network[8]. Steam networks can be found at large industrial clusters in the Netherlands, such as at Chemelot in Geleen or the industrial park at Delfzijl. There are also a couple of industrial clusters at the Port of Rotterdam where steam exchange takes place. There were 8 steam networks in 2018, with around 60 customers. The total supply of steam via steam networks was 37 petajoules (CBS and TNO 2020), which is more than the supply of hot water via heat networks. As in the case of heat for large heat networks, most steam comes from CHP installations fired with fossil fuels, often natural gas but sometimes also waste gases.

7 Excluding the categories solar, wind, waste and co-firing of biomass at electricity plants.

8 The supply of steam falls under the European Union definition of steam networks if this takes place via a network supplying two or more customers. This means that one-to-one relationships, such as a joint venture that only supplies one factory, do not count as district heating. According to the definition in this Directive, steam supply in the industrial sector therefore also falls under district heating.

2.4 District heating and cooling

Small and large district heating networks
In the monitoring of district heating and cooling, a distinction is made between large and small district heating networks (CBS and TNO, 2020). There is usually more data available for large district heating networks. Large district heating networks have buildings as their main customers and supply more than 150 TJ of heat a year to end users. The total supply of heat by the large networks is around 10 times higher than the supply of heat by the small networks. Small networks are understood to be all networks with the primary purpose of supplying heat to multiple buildings, which do not fall under the definition of large networks.

Table 2.6 shows the total number of connections (large and small consumers) and supply of heat by the large district heating networks. In 2018 there were 329 000 connections and 20.4 petajoules of heat was supplied. Table 2.7 shows the number of connections and the supply of heat by all small district heating networks combined (around 100). In addition to an increase in the number of connections, the number of small networks also increased. The increase does not necessarily mean that the networks themselves have begun to supply more.

Table 2.6 Overview of total number of connections and supply of heat by the large district heating networks

	Number of connections (x 1000)						Supply of heat in petajoules						
	2016	**2017**	**2018**	**2019****	**2020**	**2023**	**2016**	**2017**	**2018**	**2019****	**2020**	**2023**	**Heat supplier**
Utrecht	53.4	55.2	56.1	54.4	54.0	58.0	2.9	3.1	3.0	2.9	3.3	3.3	Eneco
Rotterdam	52.7	54.4	55.4	55.9	56.7	63.4	3.4	3.3	3.4	3.4	3.6	3.7	Eneco and Vattenfall
B3-Hoek	0.1	0.1	0.1	0.1	0.1	0.1	2.1	2.0	1.8	1.6	2.0	2.0	Eneco
The Hague	5.3	5.5	6.3	6.6	9.0	13.8	1.1	1.1	1.1	1.1	1.2	1.3	Eneco
Ypenburg	10.1	10.1	10.2	10.2	10.1	10.1	0.3	0.3	0.3	0.3	0.3	0.3	Eneco
Amsterdam South and East incl. Amstelveen	16.1	17.7	19.0	25.0	26.3	31.6	1.6	1.6	1.7	1.8	2.0	2.2	Vattenfall and Eneco
Amsterdam North and West	10.7	12.1	15.1	17.4	19.0	28.2	0.6	0.7	0.9	1.0	1.1	1.4	Westpoort Warmte
Almere	49.4	50.2	51.6	52.4	52.9	57.0	1.9	1.8	1.9	1.9	2.0	2.0	Vattenfall
Lelystad	4.8	4.8	4.8	4.8	4.8	4.8	0.2	0.2	0.2	0.2	0.2	0.2	Vattenfall
Leiden region	8.5	8.9	9.0	9.3	9.8	10.6	0.7	0.7	0.7	0.7	0.7	0.7	Vattenfall
Arnhem, Duiven and Westervoort	14.1	14.6	15.2	15.7	16.1	17.5	0.7	0.7	0.7	0.7	0.8	0.9	Vattenfall
Nijmegen	4.3	5.2	5.9	6.3	6.7	9.2	0.2	0.2	0.2	0.2	0.2	0.3	Vattenfall
Breda-Tilburg Heat Network	34.3	34.6	35.2	35.7	36.2	36.9	3.1	2.5	2.5	2.4	2.6	2.6	Ennatuurlijk
Enschede	4.4	4.4	4.7	5.0	7.0	7.6	0.5	0.5	0.5	0.5	0.5	0.6	Ennatuurlijk
Helmond	6.4	6.4	6.4	6.4	6.4	7.0	0.2	0.2	0.2	0.3	0.3	0.3	Ennatuurlijk
Eindhoven	1.8	2.3	2.4	2.6	3.6	6.6	0.2	0.2	0.2	0.2	0.2	0.3	Ennatuurlijk
Alkmaar	4.6	4.9	5.4	5.7	6.5	9.5	0.2	0.2	0.2	0.4	0.4	0.6	HVC
Purmerend	25.8	25.9	26.3	26.9	28.2	30.0	0.9	0.8	0.9	0.8	0.9	1.0	SVP
Dordrecht*	*	*	*	*	1.6	3.1	*	*	*	*	0.2	0.2	HVC
Total	**306.8**	**317.3**	**329.0**	**340.4**	**355.0**	**405.0**	**20.8**	**20.2**	**20.4**	**20.4**	**22.5**	**24.0**	

Source: CBS and TNO (2020).

** In 2019 AND PREVIOUS YEARS, Dordrecht was not yet a large network*

*** Provisional figures*

Table 2.7 Supply of heat by small district heating networks

	2015	2016	2017	2018
Connections x 1 000				
Natural-gas CHP	37.2	35.4	36.4	37.3
TES	12.9	13.4	14.1	14.3
Biomass	5.7	6.1	6.8	7.3
Other	2.6	2.9	4.8	5.0
Total	58.3	57.8	62.1	64.0
Heat in petajoules				
Natural-gas CHP	1.3	1.3	1.3	1.4
TES	0.5	0.6	0.6	0.6
Biomass	0.2	0.2	0.2	0.2
Other	0.1	0.1	0.1	0.1
Total	2.0	2.1	2.2	2.4

Source: CBS and TNO (2020).

Share of renewable energy in large district heating networks
The share of renewable energy for large district heating networks increased from 16% in 2016 to 30% in 2019 (CBS and TNO, 2020). CHP plants fired on fossil fuels dominate the supply of heat. The contribution made by these plants is slowly decreasing, however.

The supply of heat by existing installations for burning of waste wood increased significantly in 2018 and 2019. These installations were commissioned in 2008 and at that time they only generated electricity, since subsidies were only available for the generation of electricity. The SDE subsidy scheme has since been adjusted and subsidies are now also available for heat produced from biomass. As a result, these installations have been converted and now supply heat alongside a reduced amount of electricity. This heat supply from biomass is partly at the expense of the heat supply from waste incinerators at the same location.

Residual heat is included under fossil fuels. The information is not publicly available separately, due to the limited number of suppliers of residual heat and because Statistics Netherlands (CBS) does not yet have complete data, but certificates published by the district heating companies show that this amounted to around 1 petajoule in 2018.

Table 2.7 Heat supply to large district heating networks (in petajoules)

	2016	2017	2018	2019
Heat production				
Natural gas and coal	21.7	20.4	18.9	17.0
CHP (including auxiliary boilers at the site of natural-gas CHP installations)9	19.9	19.0	17.6	15.8
Natural-gas auxiliary boilers not at the site of natural-gas CHP installations	1.8	1.4	1.3	1.3
Household waste	5.4	5.8	4.7	5.0
Biogenic	2.9	3.1	2.5	2.6
Non-biogenic	2.5	2.7	2.3	2.4
Biomass	1.5	1.6	3.9	5.6
Total	28.6	27.7	27.6	27.6

[9] Including residual heat from fossil-fuel sources.

	2016	2017	2018	2019
Heat loss	7.8	7.5	7.1	7.2
Supply of heat	20.8	20.2	20.4	20.4
Share of renewable energy (% of heat production)	16	17	23	30

Source: CBS and TNO (2020).

For the small district heating networks, no information is available about the use of auxiliary boilers. It is therefore difficult to determine the share of renewable energy for the small networks.

2.5 Spatial distribution of heating and cooling

The Heat Atlas (www.warmteatlas.nl) produced by the Netherlands Heating Expertise Centre (ECW) is a digital, geographical map showing the (potential) supply and demand for heat in the Netherlands. The aim of this atlas is to provide market players and regions with insight into the possibilities for more sustainable heating of buildings and greenhouses in particular. The Heat Atlas is usually updated annually, as soon as new data becomes available. This takes place within the framework of the VIVET programme, which aims to improve the provision of information relating to the energy transition[10].

The demand for heat from buildings, greenhouses and the industrial sector is recorded in the Heat Atlas, and comes from a wide range of (mostly public) sources[11]:

- location data for buildings and houses comes from the Land Register's Addresses and Buildings Key Register (BAG)[12];
- the demand for heat from homes per district is determined on the basis of the use of natural gas according to Statistics Netherlands;
- the location of large buildings and greenhouses that are suitable for geothermal and thermal energy storage is based on topographic maps (TopNL and the Land Register[13]) and the Digital Elevation Model for the Netherlands (AHN)[14];
- the demand for heat from greenhouses is estimated on the basis of greenhouse area according to Statistics Netherlands (CBS) and the Netherlands Enterprise Agency (RVO);
- the location of industrial installations is based on the European Pollutant Release and Transfer Register (E-PRTR);
- the energy demand from the industrial sector is estimated on the basis of CO_2 emissions (according to the Environment Pollutant Release and Transfer Register produced by the National Institute for Public Health (RIVM)[15]) and the average energy mix in the sector (according to Statistics Netherlands).

The potential for thermal energy storage (with heat pumps) is based on soil data from the Netherlands Hydrological Instrumentarium (NHI)[16] and groundwater data from TNO (REGIS II)[17].

The potential for geothermal without a heat pump is based on data from the TNO geological department (ThermoGis)[18] and uses data collected by TNO on the basis of the Mining Act.

The potential for aquathermal for heat (with a heat pump) or cooling is based on data from the Association of Water Boards and Deltares.

10 https://www.cbs.nl/nl-nl/achtergrond/2019/14/vivet-betere-informatievoorziening-energietransitie.
11 For the sources used, see the Heat Atlas Catalogue: https://groepen.pleio.nl/file/download/61160011/Catalogus+WarmteAtlas.
12 https://www.kadaster.nl/zakelijk/registraties/basisregistraties/bag.
13 https://www.kadaster.nl/zakelijk/producten/geo-informatie/topnl.
14 https://www.ahn.nl/.
15 http://emissieregistratie.nl/erpubliek/bumper.nl.aspx.
16 http://www.nhi.nu/nl/index.php/data/.
17 https://www.dinoloket.nl/regis-ii-het-hydrogeologische-model.
18 https://www.thermogis.nl/.

The (potential for) residual heat in the Heat Atlas is based on:
- residual heat from large companies for direct use is based on data from municipalities and provinces, which they collect on the basis of the Environmental Management Act;
- residual heat from data centres with heat pumps is collected by a consultancy firm[19] and the Dutch Data Centre Association (DDA);
- the condensate heat potential from cooling installations with heat pumps is estimated for the food-processing industry, slaughterhouses, cold stores and supermarkets on the basis of the number of employees according to the Chamber of Commerce;
- residual heat from waste-water purification installations with a heat pump is determined by the Association of Water Boards (UvW).

Data on biogas (per municipality) is based on:
- biogas calculated on the basis of manure data (Statistics Netherlands on the basis of registration of manure by the Netherlands Enterprise Agency);
- biogas calculated on the basis of data on vegetables, fruit and garden waste (from Statistics Netherlands);
- Biogas calculated from the residual fraction of waste produced in arable farming of potatoes, sugar beet, grain and maize (Statistics Netherlands on the basis of the Netherlands Enterprise Agency's agricultural census);
- Biogas from grass (on the basis of the area of grasslands according to Statistics Netherlands on the basis of the Netherlands Enterprise Agency's agricultural census).

Data on infrastructure for the distribution of heat and natural gas is provided by network operators. Below are a number of examples of maps in the Heat Atlas:

Figure 2.6 Areas with homes and greenhouses

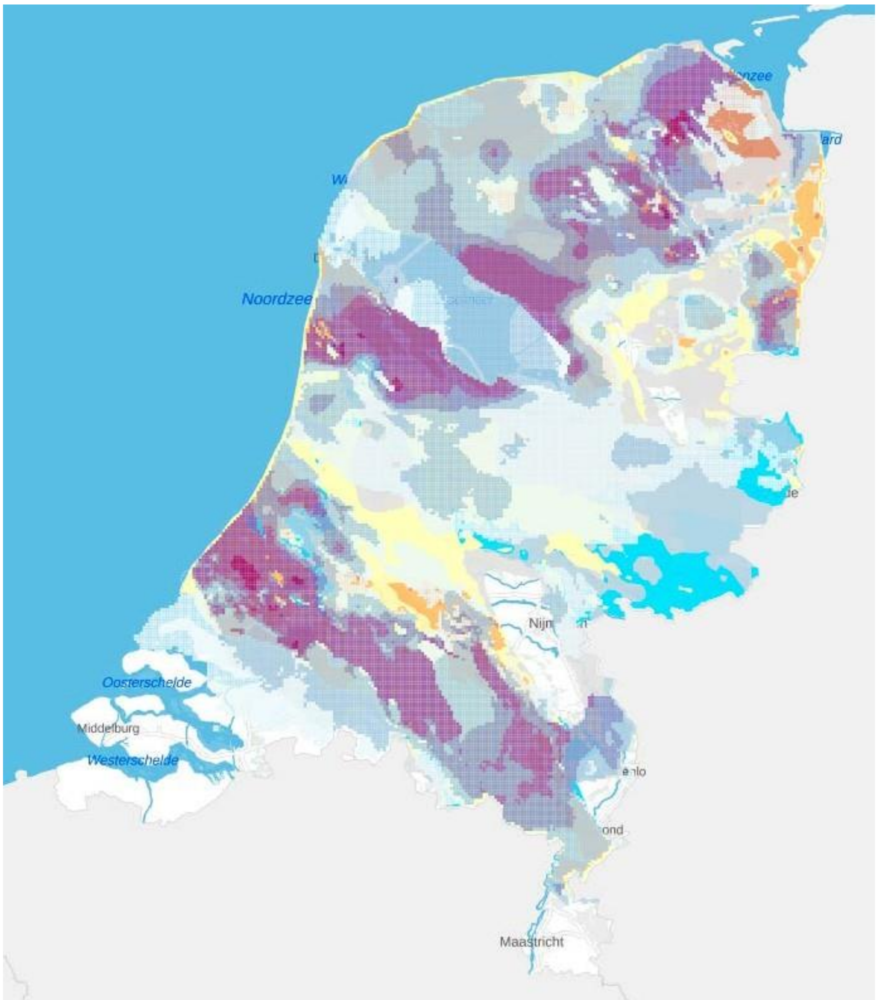
Source: Heat Atlas

19 https://www.rvo.nl/sites/default/files/2018/11/Warmte%20uit%20datacenters%20-%20november%202018.pdf.

Figure 2.7 Large combustion plants with a capacity of more than 50 MW_{th} (in 2017)

Source: Heat Atlas

Figure 2.8 Potential for geothermal; 'P50Capacity' indicates a 50% chance of the stated capacity



Geothermal P50 Capacity

- 0-1 MW_{th} per doublet (450 ha)
- 1.5 MW_{th} per doublet (450 ha)
- 5-10 MW_{th} per doublet (450 ha)
- 10-30 MW_{th} per doublet (450 ha)
- > 30 MW_{th} per doublet (450 ha)

Geothermal

- Potential: <30% chance of >= 5 MW_{th} capacity, Temp >45C
- Potential: 30-50% chance of >= 5 MW_{th} capacity, Temp >45C
- Potential: >50% chance of >= 5 MW_{th} capacity, Temp >45C
- Unfavourable: Individual aquifers > 10 m thick, Temp <45C
- Unfavourable: Individual aquifers > 10 m thick, Temp <45C
- Unfavourable: Individual aquifers > 10 m thick, Temp <45C

(source: Heat Atlas)

The location of (thermal) renewable energy installations that are receiving or have received a subsidy from the SDE(+)(+) scheme can also be found in the Heat Atlas.

3 Expected heating and cooling supply

3.1 Expected developments based on the Climate and Energy Outlook

The Netherlands Environmental Assessment Agency has estimated the expected demand for heat and the energy required for this in the Climate and Energy Outlook (KEV) 2020 (PBL, 2020a). The Climate and Energy Outlook covers both past developments (since 2000) and expected future developments (up to 2030). The Climate and Energy Outlook presents the most plausible developments in the field of energy and greenhouse gas emissions in the period up to 2030. The developments described involve inherent uncertainties, however, such as uncertainties surrounding developments within prices of energy sources and CO_2 emission allowances, the consequences of policy and interaction with international energy markets. Bandwidths have therefore been provided for the main parameters, reflecting these uncertainties. The Climate and Energy Outlook does not provide a projection beyond 2030, since the exogenous and policy-related uncertainty is so high that a scenario study is more appropriate here.

The estimated demand for heating and cooling and the estimated supply of heating and cooling are based on all relevant information available on 1 May 2020, such as expected economic and sectoral developments, technological developments, energy and CO_2 prices and adopted and proposed policy.

Some proposed policy had not yet been developed in sufficient detail at that time and was therefore not taken into account in the projections. This means that crucial policy measures have not yet been taken into account in the projected developments within the supply of heat. These include the package of measures for natural-gas-free districts and the CO_2 levy for the industrial sector. The projection for the demand and supply of heating and cooling described below is therefore not yet in line with expected improvement of sustainability as agreed in the National Climate Agreement (see Chapter 4).

3.2 Demand for heating and cooling

More than half of the final energy consumption is currently used for heating (see Section 2.1). Almost half of the final energy consumption for heating is used in the built environment, more than 40% is used in the industrial sector and 10% is used in agriculture. This breakdown within final energy consumption is not expected to change significantly in the period up to 2030. The share of the built environment will decrease slightly and the shares of industry and agriculture will increase slightly.

In 2019, the final energy consumption for heat was 969 petajoules and this falls in the projection with proposed policy to 885 petajoules by 2030, excluding consumption of electricity for heat. In the built environment, the consumption of electricity for heat was 12 petajoules in 2019, and this increases slightly in the projection to 22 petajoules in 2030. When heat from the soil and ambient air are included in this consumption of electricity, the final energy consumption for heat pumps increases to 44 petajoules by 2030; which is 11% of the total final energy consumption for heat in the built environment.

3.3 Supply of heating and cooling

Share of renewable heat doubles

In 2019, 76% of the final energy consumption for heat came from natural gas (CBS and TNO, 2020). In the projection with proposed policy, this share falls to around 68% in 2030. A large proportion of this comes from burning of natural gas in boilers for own use, but it also comes from combined heat and power installations, owned either by consumers of heat or by third parties. In 2019, renewable energy accounted for around 7% of the heat supply. In the projection with proposed policy, the share of renewable energy increases to 13% in 2030. Other energy sources, such as waste gases from crude oil and coal, accounted for around 17% of the final energy consumption for heat in 2019. This share will remain around the same up to 2030.

The share of renewable energy in heat networks is increasingly rapidly

The supply of heat from heat networks increases in the projection with proposed policy from around 25 petajoules in 2019 to 32 petajoules in 2030. This is only district heating and excludes supply of steam to the industrial sector. The projection for 2030 consists of 17 petajoules of heat supplied to households, 10 petajoules of heat supplied to services and 5 petajoules of heat supplied to agriculture.

The increase in the supply of heat to the built environment is the result of natural-gas-free new construction and the Starter Motor for Natural-gas-free Districts. In the Netherlands, this supply of heat is limited and contributes a few per cent to the total final energy consumption for heat.

Fossil-fuel-fired CHP plants dominate the supply of heat. The contribution made by these plants is decreasing, however. In 2019, around 28% of the supply of heat came from renewable sources, this increases in the projection to almost 50% by 2030. The production of heat by waste incinerators remains more or less constant at 5 petajoules, with around half of this counting as renewable energy. The production of heat from biomass increases in the projection with proposed policy from 6 petajoules in 2019 to around 15 petajoules in 2030. The production of heat from geothermal for the built environment also increases to around 2 petajoules in 2030. This results in a combined total of 20 petajoules of renewable heat production. After subtraction of heat losses in the network, around 15 petajoules of heat supply remain. The 0.6 petajoules of heat supply from thermal energy storage are also taken into account. This results in a combined total of 20 petajoules of renewable heat production. After subtraction of heat losses in the network, around 15 petajoules of heat supply remain.

Use of biomass for heat is uncertain
In this Climate and Energy Outlook projection, the sustainability of district heating networks is improved primarily through heat from biomass.
The projection was produced before the Social and Economic Council of the Netherlands (SER) published the advisory report ‘Biomass in Balance’ in July 2020. The SER recommends reducing the use of bio-based raw materials for low-value applications such as heating of buildings over the course of the coming years (SER, 2020). The projection for improvement of the sustainability of district heating networks in this Climate and Energy Outlook is therefore uncertain. Instead of making heat production using biomass more sustainable, the focus will be on developing geothermal and aquathermal projects. These technologies are more expensive, more innovative and smaller scale than biomass, which means that improving sustainability may be more expensive or take more time than indicated in this projection.

Supply of steam to industry
Not only hot water for the built environment but also steam for the industrial sector can be transported from the producer to one or more consumers through pipes. Steam is much more difficult to transport over long distances than hot water, and steam pipes are generally no more than a couple of kilometres long. Steam networks can be found at large industrial clusters in the Netherlands, such as Chemelot in Geleen or the industrial park at Delfzijl. There are also a couple of industrial clusters at the Port of Rotterdam where steam exchange takes place.

The total supply of heat to the industrial sector in 2018 was 75 petajoules, including 37 petajoules of steam supplied via steam networks (CBS and TNO, 2020). As in the case of heat for the large heat networks, most steam comes from CHP installations fired with fossil fuels, often natural gas but sometimes also waste gases. In 2019, waste incinerators supplied around 8 petajoules to the industrial sector, half of which can be counted as renewable. The supply of steam from biomass was around 3 petajoules in that year. The supply of steam to the industrial sector amounted to around 70 petajoules in 2019 and about 10% of this was from renewable sources. There is no data on the projected supply of steam to the industrial sector.

PART II

4 Objectives in relation to heating and cooling

4.1 National climate goals and contribution to European climate and energy goals

The Dutch Climate Act establishes goals in relation to reducing emissions of greenhouse gases. By 2030, the Netherlands' emissions of greenhouse gases must be 49% lower than in 1990. By 2050, emissions must 95% lower, and generation of electricity should be carbon neutral[20]. Since heating and cooling make a significant contribution to national CO_2 emissions[21], major improvements will need to be made to the sustainability of the heating and cooling supply in the Netherlands, in order to achieve these goals.

In accordance with European agreements, the Netherlands is also contributing to the European climate and energy targets for 2030.
These goals have not been translated to (energy for) heating and cooling, but they do require significant improvement to the sustainability of (energy for) the consumption of heating and cooling in the Netherlands. The Integrated National Energy and Climate Plan (NECP) that the Netherlands submitted to the European Commission at the end of 2020 states the following[22]:

1) the Netherlands aims to achieve a primary energy consumption of 1 950 petajoules by 2030 (excluding consumption for
non-energy purposes), within the framework of Article 3 of European Directive 2012/27; in terms of final energy consumption, this contribution translates to an expected final energy consumption of 1 837 petajoules by 2030;
2) the energy-saving obligation for the period 2021 to 2030, in accordance with Article 7 of European Directive 2012/27, amounts to a cumulative figure of 924 petajoules for the Netherlands[23]. This saving should be achieved through national policy;
3) the Netherlands has chosen to focus on achieving a share of 27% for renewable energy, with an indicative trajectory of a minimum of 16.3% in 2022, 19.6% in 2025 and 22.5% in 2027, in accordance with Article 4 of European Regulation 2018/1999;
4) increasing the share of renewable energy in the heating and cooling sector by an average of 1.3% per year (consumption of residual heat is included here) in accordance with Article 23 of European Regulation 2018/2001; the use of renewable energy and residual heat in the supply of heat through district heating should increase by an average of at least 1% per year (Article 24);
5) Indicative milestones for improvement of the sustainability of the built environment in accordance with Article 4(b)(3) of European Regulation 2018/1999. The Netherlands expresses this in indicative maximum emissions of greenhouse gases: 15.3 in 2030, 8.4 in 2040 and 1.5 in 2050 (in Mt of CO_2 equivalents).

4.2 Sector targets and milestones

The Climate Agreement includes sectoral targets aimed at achieving a 49% reduction in greenhouse gas emissions by 2030 (see Table 4.1). Although these do not apply specifically to heating and cooling, significant improvement of the sustainability of heating and cooling will be required in order to achieve these targets. The Climate Agreement does establish a number of specific milestones in relation to heating and cooling, however (see Table 4.1).

20 https://wetten.overheid.nl/BWBR0042394/2020-01-01.
21 In 2019, more than half of the national final energy consumption was used for heat. Most heat is generated through burning of fossil fuels (see Section 2.1).
22 https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en.
23 The Integrated National Energy and Climate Plan (NECP) gives an expected energy-saving obligation of 925 petajoules (page 38). On the basis of new (now finalised) statistics for 2016, 2017 and 2018, the energy-saving obligation amounts to 924 petajoules.

Table 4.1 Remaining sector emissions of greenhouse gases and specific milestones in relation to heating and cooling in accordance with the Climate Plan

Sector[24]	Emissions in 2019 (Mt CO_2 equivalents)[25]	Remaining emissions in 2030 (Mt CO_2 equivalents, including bandwidth)[26]	Specific milestones in relation to heating and cooling
Built environment	23.3	15.2 - 17.7	• By 2030, 1.5 million existing homes and buildings must have been made natural-gas-free. • By 2030, the CO_2 intensity of the heat supplied to homes must have been reduced by 70% in comparison with current central-heating boilers. By 2050, the heat supplied must be fully sustainable.
Industry	56.7	39.9	• Innovations in relation to electrification and CO_2-free heating systems • Development of necessary infrastructure
Agriculture (including greenhouse horticulture[27])	26.4	20.2-22.8	• An external heat supply for the greenhouse horticulture sector of a total of 10 petajoules per year. • Completion of 35 extra geothermal projects in the period up to 2030

Sources: emissions in 2019 (RIVM, 2020); remaining emissions and specific milestones (EKZ, 2020a).

24 The reductions and milestones for the electricity, mobility and land-use sectors have not been included, since consumption of energy for heating and cooling in these sectors is limited.

25 Based on provisional statistics.

26 Remaining emissions are the projected emissions in 2030 according to the baseline trajectory in the Climate and Energy Outlook produced by the Netherlands Environmental Assessment Agency (PBL).

27 The contribution of greenhouse horticulture to the total reduction in emissions by the agriculture sector envisaged in the National Climate Agreement amounts to 1.8-2.9 Mt CO_2 reduction.

5 Policy measures in relation to heating and cooling

5.1 National climate and energy policy

The current Dutch climate and energy policy is described in the Climate Plan, which is updated every five years and was published for the first time in 2020, covering the period 2021 to 2030[28]. The policy set out here is based broadly on the National Climate Agreement of June 2019, in which public authorities, businesses and other organisations made agreements on measures to be taken to achieve the reduction target of 49%[29]. The most important agreements are described in the Integrated National Energy and Climate Plan (NECP), which the Netherlands submitted to the European Commission at the end of 2020. In line with broader energy and climate policy in the Netherlands, policy measures mainly relate to reduction of emissions of greenhouse gases. These policy measures aim both to reduce energy consumption and increase the share of renewable energy. As in the case of the objectives and target values described in Chapter 4, some of the policy measures will also make a (significant) contribution to improving the sustainability of consumption of heating and cooling in the Netherlands.

The following paragraphs provide an overview of the main (general) policy measures for the built environment, industry and greenhouse horticulture that will contribute to improving the sustainability of consumption of heating and cooling in the Netherlands. Appendix II contains an overview of all (general) policy measures relevant to improving the sustainability of heating and cooling in the Netherlands.

5.2 General policy measures

The Netherlands has implemented a range of policy measures that are not limited to any one sector. Target groups from a variety of sectors can often make use of these general policy measures. The measures relate to energy taxes, environmental legislation and various subsidies and/or fiscal advantages for implementation of energy-saving measures and investment in renewable energy and/or technologies that reduce emissions of CO_2. There are also policy measures that stimulate innovation in energy technologies.

5.3 Policy for the built environment

The biggest challenge in the built environment is insulating existing buildings and making these natural-gas-free, with more than 1.5 million natural-gas-free homes and other buildings by 2030. These include owner-occupied homes, rental homes and non-residential construction. By 2050, all more than 7 million homes and 1 million other buildings must have been made sustainable. The national policy includes a wide range of measures, with a combination of thematic and target-group specific instruments. There are both measures that promote short-term, cost-effective energy-saving interventions in buildings and measures that facilitate extensive renovation of buildings. There are two elements in the approach to improving the sustainability of the built environment: supporting and assisting individual homeowners and a district-oriented approach.

In order to assist individual homeowners and help them to make their homes more sustainable, insight into the (technical) possibilities and financial support are important. An insulation standard per home type will provide owners with clear information about how they can improve the insulation of their home. This standard will be translated into targets for each insulation measure. Other measures, such as a digital platform that provides homeowners with information about sustainability measures and the corresponding indicative energy savings will also make a contribution here. Homeowners can make use of schemes such as the Investment Grant for Sustainable Energy (ISDE) and Subsidy for Energy Savings at Home (SEEH)[30].

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28 https://www.rijksoverheid.nl/documenten/beleidsnotas/2020/04/24/klimaatplan-2021-2030.

29 https://www.klimaatakkoord.nl/klimaatakkoord.

30 The Subsidy for Energy Savings at Home (SEEH) will form part of the Investment Grant for Sustainable Energy (ISDE) from January 2021.

The district-oriented approach aims to improve the sustainability of the built environment district by district. In this way, residents and building owners (such as bakers, schools, etc.) can be involved in improving the sustainability of the district. The district is also the easiest scale at which to implement alternatives to natural gas step-by-step at natural junctures, and limit the costs. Municipalities manage the district-oriented approach. In order to learn how the district-oriented approach can best be implemented, test beds for natural-gas-free districts were started in 2018. Within the rental sector, the housing associations play a central role in making a start on improving the sustainability of their housing stock. Other large landlords will also be making agreements about interim targets. Housing associations often own a large number of similar homes. This makes them very suitable to act as a starter motor and make a start on improving the sustainability of the built environment. The starter motor is the first step in scaling up improvement of the sustainability of housing stock. By connecting 100,000 homes to heat (district heating or heat pumps) in the short term, we can begin to reduce the costs of renovation and reduce CO_2 emissions. Housing associations are eligible for financial resources to support them in their efforts to make their housing stock more sustainable. Financial support is available through the Renovation Accelerator and a discount on the Landlord Levy for housing associations who wish to improve sustainability.

In non-residential construction, the focus is on improving the sustainability of existing commercial and social buildings, such as offices, schools and care institutions. A coherent package of standardisation and support instruments will be implemented here, in cooperation with umbrella organisations. The most significant measure is the introduction of a legal energy-performance standard for buildings from 2021. This includes a target for 2030. There is a legal final standard for 2050. All non-residential construction must have been converted to be low-carbon by this time.

The Netherlands' approach to improving the sustainability of the built environment is described in more detail in the Long-term Renovation Strategy that the Netherlands submitted to the European Commission in March 2020[31].

5.4 Policy for industry

By 2050, the Netherlands aims to have a thriving, circular and globally leading industrial sector, in which emissions are close to zero. The challenge faced by the industrial sector requires a future-focused public-private approach, in which the business world invests in a sustainable future, the government supports and facilitates this through targeted measures and the focus is on creating (new) value.

The industrial sector can shape the transition through measures such as process efficiency, energy saving, CCS, electrification, use of blue and green hydrogen and acceleration of circularity (such as recycling of plastics, bio-based raw materials or steel2chemicals). Blue hydrogen (a combination of electricity generated from fossil fuels and CCS), green hydrogen (based on energy generated from renewable sources) and the circular economy are ideal areas in which the Netherlands can distinguish itself internationally.

The industrial sector can and must take action itself: it is expected that the industrial sector will need to invest between 10 and 15 billion euro in order to meet the climate targets for 2030 alone32. Various policy measures are being implemented to encourage the industrial sector to reduce its emissions of greenhouse gases. The industrial sector mainly falls under the EU emissions trading scheme (ETS). National policy measures are also being implemented, for example:

- The Environmental Management Act: The Environmental Management Act now requires companies to take energy-saving measures with a payback period of five years or less. When updating the Environmental Management Act, the government aims to ensure an integrated climate approach, taking both energy-saving measures and sustainable generation of energy into account.
- National CO_2 levy: a national CO_2 levy will be introduced from 2021, ensuring a reduction of 14.3 Mt of emissions in comparison with the baseline projection is achieved by 2030. This concerns an objective CO_2 levy set by the government, based on verifiable benchmarks, equal to the European ETS benchmarks as a maximum;

31 https://www.rijksoverheid.nl/documenten/rapporten/2020/03/06/lange-termijn-renovatiestrategie-op-weg-naar-een-co2-arme-gebouwde-omgeving.

32 https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken-en-klimaat/documenten/kamerstukken/2020/05/15/kamerbrief-met-visie-kabinet-op-verduurzaming-basisindustrie-2050.

- Subsidies for measures to reduce CO_2 emissions: The roll-out of measures to reduce CO_2 is supported by the SDE++ grant scheme. In order to ensure that the implementation of CCS does not have a negative impact on technologies required to achieve the long-term transition, subsidies through the SDE++ grant scheme for CCS are limited to technologies, processes and sectors for which there is no cost-effective alternative, and there is a ceiling for subsidisation of industrial CCS of 7.2 Mt.
- Cluster approach: a large proportion of industrial emissions come from regional clusters. With support from the government, a multi-year industrial frontrunners programme will be developed for each of the five industrial regions, in which efficiency improvements go hand in hand with improving the sustainability of raw materials and CO_2 reduction.

In order to resolve coordination problems (e.g. in the construction of infrastructure and in knowledge development), reduce technical upscaling and oversupply risks and ensure long-term investment security, a public service obligation has been imposed through legislation and regulations. The government aims to meet this obligation in four ways: stimulating innovation, supporting upscaling of demonstrated innovations, facilitating development of the necessary infrastructure and legislation. The government is working on a National Energy Network Programme (PEH), focused on providing sufficient space for the national energy network in good time[33].

5.5 Policy for greenhouse horticulture

The Climate Agreement sets the ambition for the greenhouse horticulture sector to be fully climate-neutral by 2040. The transition in greenhouse horticulture depends partly on external parties who will need to facilitate the supply of captured CO_2 and residual heat to the sector.

A CO_2 ceiling was agreed with the greenhouse horticulture sector in the 2013 Energy Agreement. This system will remain in place until 2030. Work is under way to determine whether individualisation of CO_2 emission allocations is possible. The transition will be actively supported by the ‘Greenhouse as an Energy Source’ programme, which forms part of the multi-year agreement on the energy transition in greenhouse horticulture. This programme is a public-private cooperation between the sector and the Ministry of Agriculture, Nature and Food Quality (LNV), in which a wide range of instruments will be implemented: from knowledge and innovation development and transfer of knowledge to provision of subsidies through the Investments in Energy Efficient Greenhouse Horticulture (EG) and Greenhouse Horticulture Market Introduction for Energy Innovations (MEI) subsidy schemes.

Appendix II provides an overview of the individual policy measures that are relevant for consumption of heating and cooling in the built environment, industry and greenhouse horticulture.

33 https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken-en-klimaat/documenten/rapporten/2020/05/20/startnotitie-programma-energiehoofdstructuur.

PART III

6 Analysis of potential for efficient heating and cooling

This chapter provides an analysis of the economic potential for a more efficient and sustainable supply of heat to the built environment, industry and greenhouse horticulture. The analyses are based on studies in line with current, national policy (as described in Chapters 4 and 5). This concerns both sector-specific studies and the results of a national study carried out by the Netherlands Environmental Assessment Agency (PBL) in 2018 into the potential and costs[34] of measures to reduce national greenhouse gas emissions by 49% by 2030, in comparison with 1990 (PBL, 2018). The measures investigated in that study therefore relate not only to improvement of the sustainability of the heating and cooling supply, but also to the supply of electricity, for example.

The potential analysis does not include cooling, since the demand for cooling - and therefore also the potential for more efficient and more sustainable cooling - is limited in the Netherlands (see Section 2.1). There is also relatively little data available on the potential for more efficient and more sustainable cooling technologies. Fact sheets have been produced about the cooling of buildings, however, covering various cooling technologies and taking into account their sustainability, implementation and use, the current status of the technology and the role played by users. The fact sheets can be found on the Topsector Energy website[35]. Demand for cooling is expected to increase significantly. In Europe as a whole, an increase of more than 50% is expected by 2030. Since the demand for cooling remains very limited in the Netherlands, the increase may be even greater.

6.1 Potential in the built environment

The built environment consists of homes and buildings in the commercial, services and government sectors. The demand for energy consists primarily of the demand for heat for space heating, hot water and cooking and the demand for electricity for appliances and lighting. There are a wide range of different measures for reduction of emissions and the costs vary significantly, depending on the specific measure, the specific circumstances in which it is implemented and the stage at which it is implemented (new construction, existing construction with or without a natural replacement opportunity, whether or not during large-scale renovations). Green gas and heat networks are measures that are applicable to multiple sectors, in addition to the built environment.

Table 6.1 provides an overview of the technical potentials in 2030 for the built environment. The potentials are not cumulative, since they may (partially) overlap or may be a combination of separate measures. Zero-on-the-meter (NOM) renovation, for example, is a combination of extensive insulation, solar PV, heat recovery etc.

34 The costs stated in (PBL, 2018) are the national costs in accordance with the environmental cost methodology (VROM, 1998). They therefore provide an idea of the costs for Dutch society as a whole, regardless of who bears these costs. These are net additional costs in comparison with the reference scenario (the National Energy Outlook produced by the ECN and PBL in 2017, based on adopted and proposed policy, but with no rounds of the SDE+ grant scheme after 2019). The costs are not constant over time but depend on the future costs of technologies and future fuel prices, which generally depend in turn on international developments. The costs for the government and the costs for end users, such as households or businesses, vary from the national costs, due to levies, subsidies and differences in interest rates and depreciation periods used by end users, for example.

35 https://www.topsectorenergie.nl/tki-urban-energy/kennisbank/factsheets-koudetechnieken.

Table 6.1 Potential and national costs of measures to reduce CO_2 emissions in the built environment by 2030

Option	Technical potential [Mt]	of which direct	of which indirect	Costs [€m]	Cost-effectiveness [€/tonne]
Homes					
A+++ appliances	0.5	0.1	0.4	-10	-30 (-70 to 240)
Solar PV	4.9	0	4.9	540	110
Heat supply new construction	0.2	0.6	-0.4	50	230
Insulation	3.3	3.3	0	970	300 (-100 to 750)
Zero-on-the-meter renovation	12	11	1	4 800	400
All-electric new construction	0.03	0.6	-0.6	15	460
Heat pump/solar boiler	5.5	9	-3.5	2650	490 (190 to 880)
Heat recovery	1.8	2.4	-0.6	1400	810 (570 to 1 100)
Control and feedback/optimisation	1.7	1.4	0.3	5200	3080 (-180 to 5 050)
Commercial, services and government					
LED lighting	0.9	0	0.9	0	0
Heat recovery	0.7	0.6	0.1	0	0
Solar PV	3.4	0	3.4	40	10
Energy consumption optimisation	2.7	0.7	2	220	80 (-170 to 490)
Solar boiler/heat pump	0.8	2	-1.2	60	80 (80 to 290)
All-electric new construction	0.1	0.6	-0.5	10	150
Heat supply new construction	0.2	0.6	-0.4	40	230
Thermal energy storage	1.7	2.3	-0.6	470	280 (280 to 290)
Insulation	1.7	1.6	0.1	3 200	1870 (70 to 6640)

Source: PBL 2018

The Netherlands has chosen to make municipalities responsible for improving the sustainability of the built environment. All municipalities must draw up a plan (at district level) by the end of 2021 on how they plan to make the built environment more sustainable. They must indicate which districts they plan to tackle before 2030 and the envisaged final picture in 2050. The aim is that 1.5 million homes will have been made natural-gas-free by 2030, as agreed in the Climate Agreement. A template[36] is available as a guide for drawing up this document, in which the national costs of removing the supply of natural gas are listed per district of the municipality (there are 13 808 districts in the Netherlands). Five strategies have been modelled (per district and municipality):

1. Individual electrical heat pump
2. A district heating network with a medium-temperature or high-temperature source
3. A district heating network with a low-temperature source
4. Green gas
5. Hydrogen

The models (per district and municipality) can be found in the start analysis viewer: https://expertisecentrumwarmte.nl/leidraad/startanalyse/default.aspx. This viewer shows the costs of the various strategies per district. The municipalities can use this as a basis for their heat transition vision, in addition to a local analysis, input from the relevant stakeholders and specific information about the strategies.
A Heating Expertise Centre (ECW) has been set up to support municipalities with drawing up this vision*37*.
The model has been produced by the Netherlands Environmental Assessment Agency (PBL).

36 https://www.expertisecentrumwarmte.nl/leidraad/default.aspx.
37 See www.expertisecentrumwarmte.nl.

All input has been validated at a number of stakeholder meetings and the entire model is open source[38]. The input for the model includes a database of all the buildings in the Netherlands, the demand for heat from the buildings calculated on the basis of age and energy label, an overview of the heat sources (see the Heat Atlas) and key figures on the costs of technologies.

In addition to this model, a study on the costs for end users is expected at the end of 2020. The aim is to provide municipalities with insight into the costs for end users when drawing up the heat transition vision. This study will provide a complete picture of the most common home types and provide insight into where sustainability improvements are already bearing fruit and which strategies result in which costs for end users (BZK, 2020a).

For municipalities considering using heat sources outside their own municipality, each Regional Energy Strategy (RES) region will provide a Regional Structure for Heat (RSW), as part of the RES. This Regional Structure for Heat provides an insight into the (potential) source locations, their size and an estimate of when the source will be available[39].

To start gaining experience, a natural-gas-free districts programme has been set up, in which a grant is provided to municipalities in order to gain experience of creating a gas-free district in a test bed[40]. There are currently 27 test beds (see Figure 6.1). For the second round of natural-gas-free district test beds, 71 municipalities submitted an application and 19 have been accepted (BZK 2020b). The selected municipalities will receive a financial contribution from the government in order to make homes and other buildings natural-gas-free or natural-gas-free-ready through a district-oriented approach.

38 See www.pbl.nl/vesta.
39 https://www.regionale-energiestrategie.nl/ondersteuning/handreiking/opgave+res/34+opgave+gebouwde+omgeving/default.aspx
40 https://www.aardgasvrijewijken.nl.

Figure 6.1 Natural-gas-free District Test Beds (first round) (source: Natural-gas-free Districts Programme)

Grey dots: second round of natural-gas-free district test beds (October 2020)
Yellow dots: first round of natural-gas-free-district test beds (October 2018)

6.2 Potential in industry

The Netherlands is aiming for a thriving, circular and globally leading industrial sector in which emissions of greenhouse gases are close to zero by 2050. It has been agreed in the Climate Agreement that emissions of greenhouse gases will be limited to 39.9 Mt of CO_2 equivalents by 2030. In the (energy-intensive) industrial sector, energy use for a very wide range of processes is dominant (high-temperature and low-temperature heat, electricity). Energy-saving measures are often process-specific. The measures investigated by the Netherlands Environmental Assessment Agency (PBL) in 2018 can be divided into very broad categories (see Table 6.2). In comparison with other sectors, there is less data available for the industrial sector and the data is less up-to-date. Potentials and costs for the industrial sector are therefore indicative.

Table 6.2 Potential and national costs of measures to reduce emissions of CO_2 in the industrial sector by 2030

Option	Technical potential [Mt]	of which direct	of which indirect	Costs [€m]	Cost-effectiveness [€/tonne]
Electrification of industry	-2.4	5.4	-7.8	570	n/a
Recycling	2.2	1.9	0.3	-310	-140 (-160 to -120)
Process efficiency low-cost	3.3	3.1	0.2	-410	-120 (-190 to -50)
Process efficiency medium-cost	1	0.7	0.3	-30	-30 (-50 to 0)
Process efficiency high-cost	3.2	2.3	0.9	100	30 (10 to 50)
CCS Industrial process emissions low (NH3 production, H2 production)	1.5	1.5	0	55	50
CCS Industrial emissions steel industry	5.5	5.5	0	290	40 - 60
CCS Refineries (excl. hydrogen)	6	6	0	520	60 - 100
CCS Industrial emissions general	10.5	10.5	0	1085	70 - 120
CCS waste incinerators	3	3	0	335	85 - 135
CCS coal-fired plants	13	13	0	455	35
CCS gas-fired plants	4.1	4.1	0	255	62
Biomass boilers industry	7.9	7.9	0	760	95 (70-150)

Source: PBL 2018

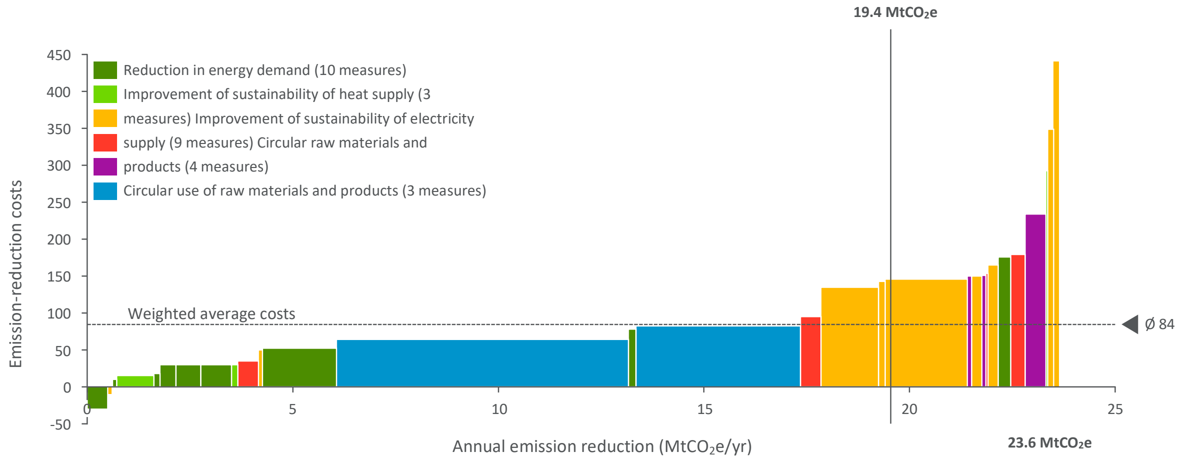
In order to support negotiations on agreements for the industrial sector in the 2019 Climate Agreement, Navigant (2018) carried out a study into the costs[41] of reducing emissions of greenhouse gases[42]. In comparison with the 2018 study by the Netherlands Environmental Assessment Agency (PBL), this study is more specific with respect to the industrial sector. This study not only includes measures to improve sustainability of the demand for heating and cooling, such as reducing the demand for energy and improving the sustainability of the supply of heat, but also other measures to reduce CO_2 emissions, such as improving the sustainability of the generation of electricity and carbon capture and storage. The costs given by Navigant therefore do not focus specifically on measures for heating and cooling. The use of residual heat by buildings and greenhouses has also been included as a measure, although this will in fact result in a reduction of emissions outside the industrial sector.

Navigant estimates the annual reduction potential in the period up to 2030 at 23.6 Mt of CO_2 equivalents (see Figure 6.2). The average cost per reduced tonne of CO_2 is EUR 89. All measures to reduce emissions by the Dutch industrial sector have been taken into account here. Reductions in emissions outside the industrial sector have not been taken into account. Supply of residual heat to heat networks is not included, for example. Investments in electrical infrastructure have also not been taken into account.

41 Including OPEX and discounted CAPEX, assuming a discount rate of 10% and a depreciation period of 15 years.

42 In order to meet the agreements, the study assumed that emissions in 2030 would have been reduced by 19.4 Mt of CO_2 equivalents, in comparison with the situation in 2018.

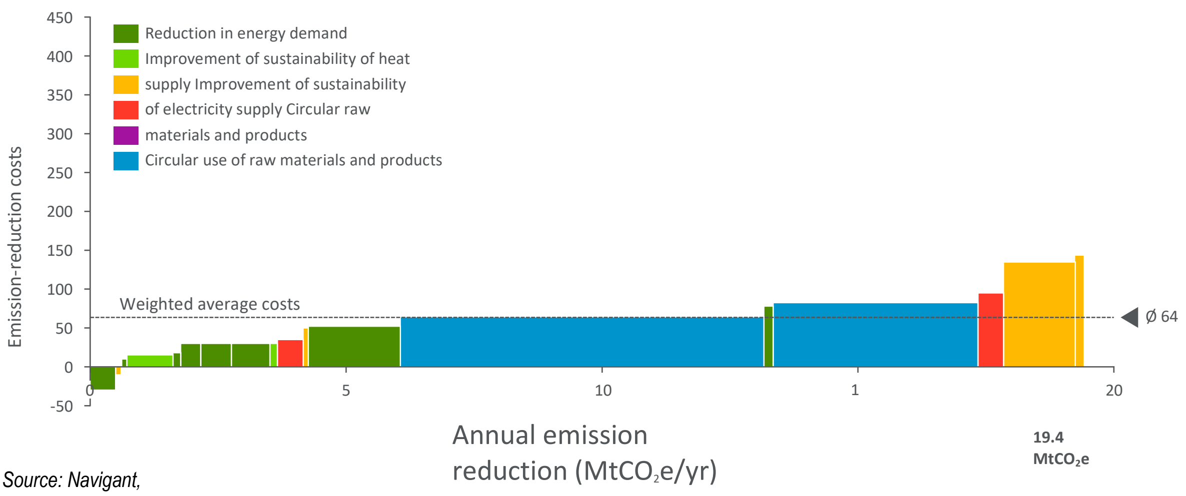
Figure 6.2 Cost curve for potential measures to reduce greenhouse gas emissions in the industrial sector



Source: Navigant, 2018

If the most affordable measures to reduce emissions by 19.4 Mt of CO_2 equivalents per year are taken, the average weighted emission-reduction costs fall to EUR 64 per tonne of CO_2 (with a margin of error of ± EUR 19 per tonne) (see Figure 6.3). The total reduction through CCS (incl. blue hydrogen) amounts to 11.1 Mt. If the use of CCS is limited to a reduction of 7 Mt of CO_2 per year, more expensive measures will need to be taken in order to achieve the climate goal. The average costs will then increase to EUR 83 per tonne of CO_2 reduction.

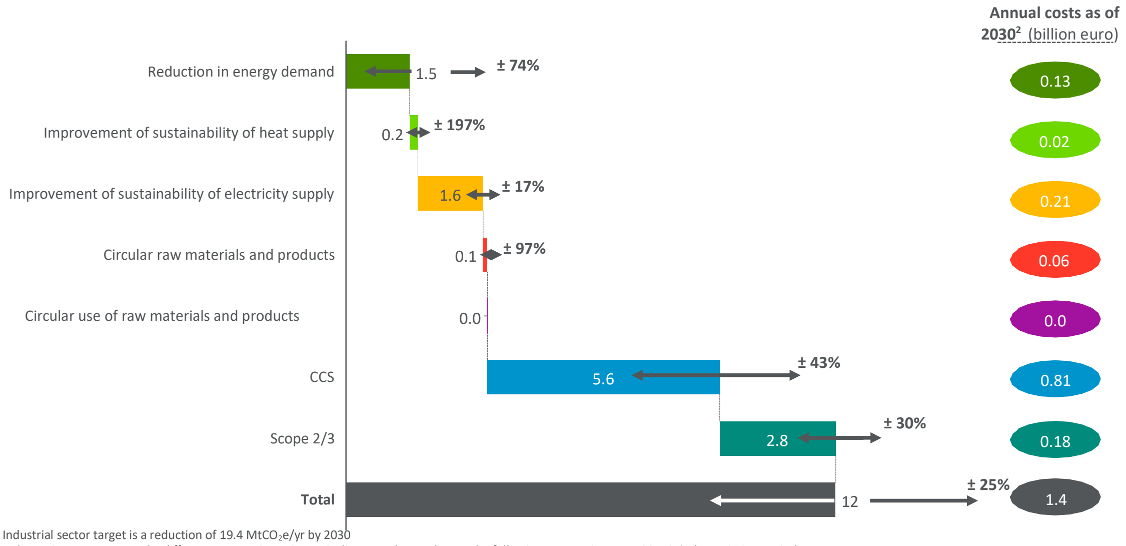
Figure 6.3 Cost curve for potential measures to reduce greenhouse gas emissions in the industrial sector



Source: Navigant, 2018

The cumulative costs up to 2030 amount to an estimate of between 9 and 15 billion euro (Navigant, 2018), including measures that will reduce emissions outside the industrial sector. In this case, the annual costs as of 2030 will be EUR 1.4 billion, around EUR 0.2 billion of which will be for measures that reduce emissions outside the industrial sector.

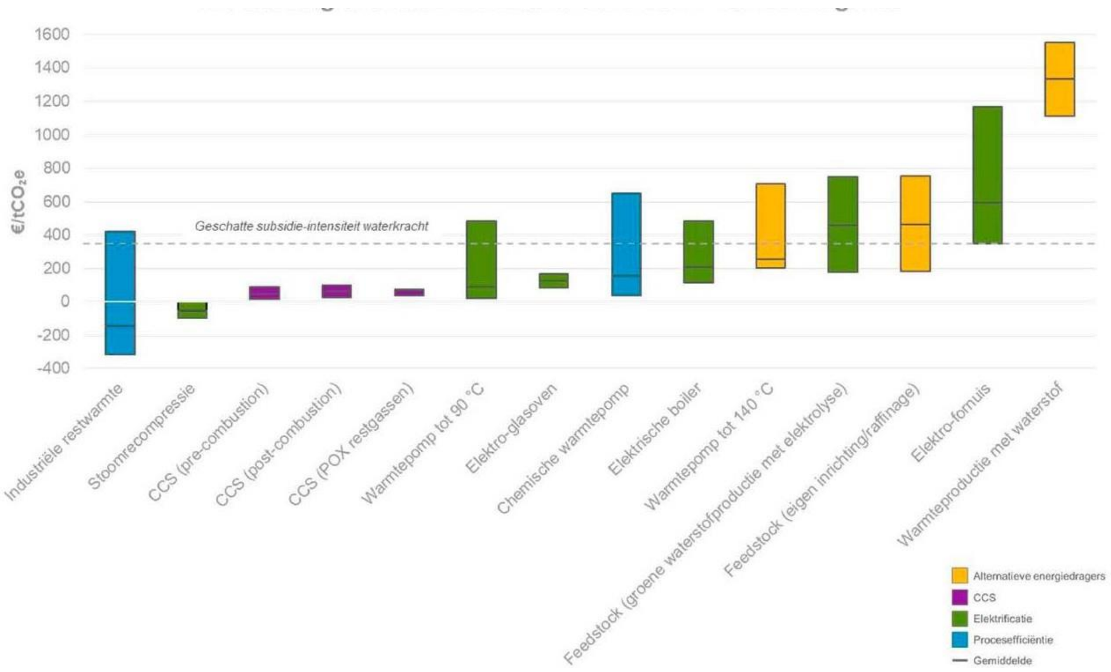
Figure 6.4 Annual costs as of 2030 for the reduction target in the industrial sector (in billion euro)



[1] Industrial sector target is a reduction of 19.4 $MtCO_2e$/yr by 2030
[2] Unless primary sources make different assumptions, CAPEX is discounted according to the following assumptions: WACC: 10%; depreciation period 15 years.

Source: Navigant, 2018

Figure 6.5 Estimated subsidy intensity for SDE++ technologies



Source: Navigant, 2019

Figure 6.5 key

Dutch	**English**
€/tCO_2e	€/tCO_2e
Geschatte subsidie-intensiteit waterkracht	Estimated subsidy intensity hydropower
Industriële restwarmte	Industrial residual heat
Stoomrecompressie	Mechanical vapour recompression
CCS (pre-combustion)	CCS (pre-combustion)
CCS (post-combustion)	CCS (post-combustion)
CCS (POX restgassen)	CCS (POX waste gases)
Warmtepomp tot 90 °C	Heat pump up to 90 °C
Elektro-glasoven	Electric glass furnace
Chemische warmtepomp	Chemical heat pump
Elektrische boiler	Electric boiler
Warmtepomp tot 140 °C	Heat pump up to 140 °C
Feedstock (groene waterstofproductie met eletroylyse)	Feedstock (green hydrogen production with electrolysis)
Feedstock (eigen inrichting/raffinage)	Feedstock (own facility/refinement)
Elektro-fornuis	Electric furnace
Warmteproductie met waterstof	Heat production with hydrogen
Alternative energiedragers	Alternative energy sources
CCS	CCS
Elektrificatie	Electrification
Procesefficiëntie	Process efficiency
Gemiddelde	Average

As a follow-up to the study carried out in 2018, in 2019 Navigant investigated the extent to which 20 industrial technologies might be suitable for the (at that time) proposed expansion of the SDE+ subsidy scheme, to SDE++. This expansion means that not only renewable energy technologies but also other technologies that reduce emissions of CO_2 are eligible for a subsidy. Many of the technologies investigated have an impact on the supply of heat in the industrial sector (such as electric boilers, kilns and furnaces and high-temperature heat pumps). Cost data was collected for the technologies, a market consultation was carried out and estimates of the basic costs, market value and necessary subsidies (the subsidy intensity in euro per reduced tonne of CO_2 equivalent) were produced.

Figure 6.5 shows the average and total range of the subsidy intensity for each technology. The subsidy intensity gives an indication of technologies' additional costs in comparison with current technologies. The technologies are ranked by average subsidy intensity. The dotted line shows the maximum subsidy intensity of the current SDE+ technologies (EUR 366 per tonne of CO_2 emission reduction). The available data was limited, so the subsidy intensity should be viewed as an initial estimate. The result is also not always representative and does not reflect the full range across the various sectors.

The subsidy intensity per technology shows a wide range, due to the case-specific factors, such as implementation costs, full-load hours and/or sector-related requirements. Some technologies have a negative subsidy intensity. This indicates that the technology can already be implemented profitably in specific cases, even without an SDE++ subsidy. It should be noted here that the scope of the market consultation was limited, which means that the response for some technologies was low and not always representative.

6.3 Potential in greenhouse horticulture

The share of greenhouse horticulture in the final energy consumption for heat amounts to 10% of the national total (see Section 2.1). This heat is primarily produced by businesses themselves through burning of natural gas in boilers or CHP installations (see Section 2.2). The use of renewable energy sources (such as biogas and geothermal) is increasing. Consumption of heat in greenhouses has also fallen. For crops that used 35 to 40 $m^3/(m^2$ year) ten years ago, for pioneering horticulturists this has fallen to 25 to 30 $m^3/(m^2$ year), primarily thanks to the use of screens and precise dehumidification (De Zwart et al, 2019). This trend is expected to continue,
but the use of natural gas (for heating and CO_2 fertilisation) will remain dominant in the period up to 2030 under current policy (see Section 3.2). In principle, this results in high potential for further sustainability and efficiency improvements in particular.

Options for improvement of sustainability

The Climate Agreement includes an ambition for the greenhouse horticulture sector to be fully climate-neutral by 2050. There are a range of available technologies that should be able to facilitate this (PBL, 2018 and De Zwart et al., 2019). The demand for energy can also be reduced by improving insulation of greenhouses (with screens), heat recovery and use of LED lamps. The remaining demand for energy can be met sustainably through connection to an infrastructure with high-value (residual) heat from renewable sources, implementation of geothermal and use of low-value (residual) heat in combination with heat pumps.

The feasibility of the various options for the different crops depends on the technical possibilities, pre-conditions and economic parameters, such as the costs and benefits of adaptation of the greenhouse and the 'boiler house'. The costs and benefits are determined to a large extent by the costs of the energy sources and the energy infrastructure. These parameters are determined partly by market developments and partly by policy measures such as subsidies, energy taxes and the sustainable energy surcharge (ODE).

An important consideration to take into account for improvement of the sustainability of greenhouse horticulture is the use of CO2 from the flue gases produced by boilers and CHP installations for CO2 fertilisation. In the case of a supply of heat based entirely on renewable sources, either the production of greenhouses will reduce due to the lower CO2 concentration or an alternative supply of CO2 will need to be found (such as an external supply). In both cases, this results in additional costs that need to be taken into account for improvement of the sustainability of the heating and cooling supply in greenhouse horticulture.

Costs of improving the sustainability of the supply of heat

In Table 6.3, geothermal and LED lighting are presented separately as larger options, while other measures are grouped together under Greenhouse as an Energy Source (other). For some of the greenhouse horticulture acreage, biomass boilers or biomass CHP installations could be implemented. The table only shows the additional potential in comparison with the reference scenario, which does not assume an accelerated replacement of existing greenhouses. In the case of a complete switch to renewable heat in greenhouse horticulture (excluding biomass), there will no longer be a source of CO_2 for assimilation. This could lead to a loss of productivity, unless other sources of CO_2 with which to fertilise crops are found. The possible additional costs of this have not been taken into account here.

Table 6.3 Potential and national costs of measures to reduce emissions of CO_2 in greenhouse horticulture by 2030

Option	Technical potential [Mt]	of which direct	of which indirect	Costs [€m]	Cost-effectiveness [€/tonne]
Geothermal greenhouses	1.1	1.2	-0.1	-20	-20
LED lighting greenhouses	0.3	-0.1	0.4	-60	-200
Greenhouse as an Energy Source	1.9	1.9	0	130	70
Biomass boilers greenhouse horticulture	2	2	0	250	125 (90-170)

Source: PBL 2018

The total energy costs from an investor's perspective for various options for improving the sustainability of the supply of heat to greenhouses have been studied by De Zwart et al (2019). The costs for heat, electricity and CO_2 have all been taken into account here, as well as the costs for maintenance and depreciation of the installations. This has been studied for six different crop types, which each have a specific consumption profile in relation to heat, lighting and CO_2[43]. Due to the significant impact of market prices for energy sources and policy measures (subsidies, taxes, levies etc.), three different scenarios were studied, with different assumptions about these parameters (see Table 6.4).

Table 6.4 Price scenarios in the 'Horticulture without Fossil Energy' study

Scenario	Key factors
Reference	Current situation continues.
Transition	Policy stimulates renewable energy, but does not preclude use of energy from fossil fuels; moderate CO_2 prices and energy tax on natural gas
Sustainable	Policy is focused on a fossil-fuel-free supply of energy; high CO_2 prices and energy tax on natural gas

De Zwart et al, 2019

In all of the heat-supply systems studied, the use of alternative heat sources has been optimised.
The aim is not to achieve 100% coverage, but to achieve an economically responsible level of coverage, which means that a small amount of energy from solid, liquid or gaseous fuels will usually still be required. These are used in a boiler, which also functions as a back-up supply. Use of CHP installations is also not totally excluded. For CO_2 fertilisation it is assumed that CO_2 will be supplied externally with a variable price (fixed for each scenario).[44]

The variable cost of the different systems for the production of heat has been calculated on the basis of cost data for various technologies and the assumptions made in the price scenarios. For some technologies, the variable cost is truly variable (costs per unit of heat do not depend on use) but, due to the investment costs, there is also a dependence on the number of equivalent full-load hours of utilisation for most technologies.

In the reference scenario, a CHP installation with a high feed-in to the grid is a very cheap option for heat (see Table 6.5). High-value heat from geothermal can also supply relatively cheap heat, provided high equivalent full-load hours are realised.

43 Tomato cultivation without lights, tomato cultivation with lights, chrysanthemum cultivation with lights, alstroemeria cultivation with lights, warm potted plant cultivation and radish cultivation.

44 Supply of CO_2 by lorry at EUR 6 per tonne (reference), EUR 10 per tonne (transition scenario) or EUR 15 per tonne (sustainable scenario). The requirement for CO_2 has been studied in more detail by Van der Velden and Smit (2019).

Table 6.5 Variable cost of heat in the reference scenario (euro per kWh)

Hours	1 000	2 000	3 000	4 000	5 000	6 000	7 000
Boiler	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Boiler with CO_2	0.13	0.13	0.13	0.13			
CHP	0.24	0.18	0.16	0.16	0.17	0.18	0.19
CHP with CO_2	0.10	0.01	-0.02	-0.03			
CHP with ES	0.04	-0.03	-0.04	-0.05	-0.04		
Geo	1.06	0.53	0.35	0.26	0.21	0.18	0.15
HP (after Geo) (COP=5)	0.22	0.17	0.16	0.15	0.15	0.15	0.15
HT	0.29	0.22	0.20	0.19	0.18	0.17	0.17
LT+HP	0.35	0.27	0.24	0.23	0.22	0.22	0.22
Surf.+TES+HP (COP=4.5)	0.32	0.23	0.20	0.19	0.18		
Greenhouse heat+HP (COP=4)	0.33	0.27	0.25	0.24	0.24	0.24	
Greenhouse heat+TES+HP (COP=4)	0.41	0.31	0.28	0.26	0.25		

Source: De Zwart et al (2019)

In the transition scenario, there are high costs associated with the use of fossil energy, which means that this is priced out of the market (see Table 6.6). Geothermal becomes attractive in terms of variable costs, particularly combined with installation of a heat pump. In the sustainable scenario, this trend becomes more pronounced (see Table 6.7)

Table 6.6 Variable cost of heat in the transition scenario (euro per kWh)

Hours	1 000	2 000	3 000	4 000	5 000	6 000	7 000
Boiler	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Boiler with CO_2	0.35	0.35	0.35	0.35			
CHP	0.71	0.64	0.63	0.63	0.64	0.65	0.66
CHP with CO_2	0.43	0.33	0.31	0.30			
CHP with ES	0.31	0.25	0.24	0.24	0.25		
Geo	1.58	0.79	0.53	0.40	0.32	0.26	0.23
HP (after Geo) (COP=5)	0.27	0.23	0.21	0.21	0.20	0.20	0.20
HT	0.44	0.33	0.30	0.28	0.27	0.26	0.25
LT+HP	0.47	0.37	0.34	0.32	0.31	0.31	0.31
Surf.+TES+HP (COP=4.5)	0.39	0.30	0.27	0.25	0.24		
Greenhouse heat+HP (COP=4)	0.39	0.34	0.32	0.31	0.31		
Greenhouse heat+TES+HP (COP=4)	0.47	0.38	0.35	0.33	0.32		

Source: De Zwart et al (2019).

Table 6.7 Variable cost of heat in the sustainable scenario (euro per kWh)

Hours	1 000	2 000	3 000	4 000	5 000	6 000	7 000
Boiler	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Boiler with CO_2	0.38	0.38	0.38	0.38			
	1.38	1.25	1.18	1.14	1.11	1.08	1.06
CHP	1.04	0.99	0.98	0.98	0.99	1.00	1.01
	1.14	1.11	1.08	1.06			
CHP with CO_2	0.60	0.50	0.48	0.47			
CHP with ES	0.90	0.84	0.84	0.83	0.85		
Geo	3.08	1.54	1.03	0.77	0.62	0.51	0.44
HP (after Geo) (COP=5)	0.22	0.18	0.16	0.15	0.15	0.15	0.15
HT	1.41	0.75	0.53	0.42	0.36	0.31	0.28
LT+HP	0.92	0.54	0.42	0.36	0.32	0.30	0.28
Surf.+TES+HP (COP=4.5)	0.33	0.24	0.21	0.19	0.18		
Greenhouse heat+HP (COP=4)	0.33	0.27	0.26	0.25	0.24		
Greenhouse heat+TES+HP (COP=4)	0.41	0.31	0.28	0.27	0.26		
Geo (50%)	1.54	0.77	0.51	0.38	0.31	0.26	0.22

Source: De Zwart et al (2019)

Use of heating systems for six crops
The energy costs for heat described above were then used to estimate the use of the various heating systems for the six different crops (whether or not in combination with an energy-efficient greenhouse). This was carried out using an optimisation model[45]. The model minimises the costs for heat flow and CO_2 with the given capacities of the installation. So an optimised CHP operation pattern, use of geothermal or residual heat and use of a heat pump and boiler are determined for each month.

It is assumed that a boiler will also be present in the boiler house in all cases. The boiler is used as a back-up supply, but can also be deployed at peak times. Of course use of the boiler will increase as the output of the CHP and/or alternative heat sources decreases. CHP is also included as a possibility in all cases, in the first instance because there appears to still be a place for CHP in the transition scenario, but also because many horticulturists have a CHP, the lifespan of which could be significantly extended with a thorough overhaul.

In the reference scenario, the use of sustainable heat sources usually results in an increase in energy costs. It is only in tomato cultivation without lights and potted plant cultivation that a significant reduction in costs can be achieved. This is primarily due to the low energy costs and advantageous feed-in conditions for supply of electricity back to the grid.

In the transition scenario and sustainable price scenario, energy-efficient greenhouses generally do deliver a cost advantage. It is only in the cultivation of radish that the absolute energy consumption is too low to justify investing in an energy-efficient greenhouse. A heat pump reduces energy costs in almost all situations. Heat pumps can use heat from surface water, residual heat from businesses and/or geothermal.
Heat pumps therefore appear to be a future-proof option, which could replace the central role played by CHP installations in the future. The CHP capacity used falls significantly in the transition scenario in comparison with the current situation and, in the sustainable scenario, CHP is no longer cost-effective for any crop. For greenhouses that are not located close to heat infrastructures, recovery of the greenhouse heat generally results in a reduction in energy costs.

The energy costs for heat can vary significantly by crop, depending on the option chosen for improvement of sustainability. For warm potted plant growers without lighting and for tomato growers in particular, the range of costs for various options is relatively wide, both in the sustainable scenario and – to a slightly lesser degree – in the transition scenario. For radish cultivation and floriculture meanwhile, the range is very narrow.

45 The AAB boiler-house simulation programme.

Finally, one important conclusion from the scenario studies is that options that minimise energy costs in the transition scenario also appear to remain cost-effective in the sustainable scenario. Investments made for the medium term therefore also retain their value in the long term.

The results and findings per crop are explained in more detail in Appendix III.

6.4 Coherence between sectors

In order to make use of the potential for improvement of sustainability in the built environment, industrial sector and greenhouse horticulture, the coherence between the sectors also needs to be taken into account (EZK, 2020b). Electrification of the industrial sector requires major investments in the electricity sector. The replacement, transportation, use and storage of CO_2 necessitates an infrastructure, which will require investment. The new hydrogen infrastructure that is expected to be developed in the industrial sector will also be important for sustainable mobility, flexibility in the energy system and parts of the built environment, for example. To facilitate the supply of residual heat to buildings and greenhouses, investments need to be made in heat networks. Various examples and studies have shown, for example, that the financing and profitable operation of a heat network, while maintaining security of supply and affordability for the user, is not self-evident (EZK, 2020c).

Improving the sustainability of the supply of heat is therefore closely linked to developments within Dutch energy supply and energy infrastructure. This means that the way in which the separate sectors can achieve improved sustainability is uncertain. Berenschot outlines four climate-neutral scenarios for the supply of energy in the Netherlands, in which the role played by (de)centralised renewable energy generation, the use of biomass and the use of green hydrogen vary significantly (Berenschot, 2020). Different regions will also need to coordinate, for example in relation to infrastructure and the use of heat sources. The first evaluation of the Regional Energy Strategies by the Netherlands Environmental Assessment Agency reveals that the network operators foresee obstacles (PBL, 2020b). The overall progress made on improving the sustainability of energy supply at both a national and sector level will be monitored and evaluated annually. Policy will be adjusted where necessary (see Section 7.1).

PART IV

In the Climate Plan, the government aims to reduce emissions of greenhouses gases by 49% by 2030, in comparison with 1990 (see Chapters 4 and 5). The Climate Act requires the government to periodically evaluate progress towards achieving the climate goals and account for this, adjusting policy where necessary.

The Climate and Energy Outlook is published by the Netherlands Environmental Assessment Agency every year. The Climate and Energy Outlook provides an overview of the emission levels achieved and a projection of the emissions of greenhouse gases in the Netherlands, broken down by sector and by type of final consumption (e.g. heat). The Climate and Energy Outlook also provides an insight into the developments and measures affecting emissions of greenhouse gases. The Climate and Energy Outlook is submitted to both houses of the States General by 1 November every year.

A Climate Policy Monitor is published annually to closely monitor progress on policy. The first Climate Policy Monitor was published in October 2020, as an appendix to the 2020 Climate Memorandum (EZK, 2020d). This monitor looks at progress on policy at four levels:

1. Progress in the implementation programme;
2. Changes to preconditions for the transition;
3. Changes among target groups;
4. Policy results.

The separate levels in the monitor mean that any obstacles in the chain from agreement to eventual policy result can be identified in good time. The Climate Policy Monitor uses existing data and existing monitoring instruments within the various sectors wherever possible, and will be published annually starting in 2020.

Insights from the Climate Policy Monitor and insights from the Climate and Energy Outlook will be used to make interim adjustments to policy. The monitoring data can also be used to evaluate the measures and the policy that contributes to achieving the climate goals.

The Council of State will publish an opinion on the Climate Memorandum every year. In this opinion, the Council of State will primarily look at administrative aspects of policy, such as the relationship between the State and other public authorities, the feasibility and enforceability of measures and the resulting financial consequences.

In October 2020, the government submitted the first Climate Memorandum to parliament, on the basis of the Climate Act (EZK, 2020d). This Climate Memorandum includes the government's opinion of the progress on climate policy and states the priorities for 2021. The government's opinion is based on the Netherlands Environmental Assessment Agency's 2020 Climate and Energy Outlook and the 2020 Climate Policy Monitor. The Council of State also published a review of the Climate Memorandum.

The key priorities in the Climate Memorandum that are relevant for heating and cooling are:
- through the Regional Energy Strategies and the Heat Transition Vision, significant steps will be taken towards achieving the transition at a local level over the course of 2021. The State will make instruments available for the implementation;
- with the online consultation for the proposed 'Collective Heat Supply Act', the first steps have been taken towards a new legislative framework. The framework should ensure (i) the development of collective heat systems through new rules of play, (ii) increased transparency within setting of tariffs, (iii) more detailed definition of the requirements for security of supply and (iv) clarification of the requirements for improvement of sustainability;

- with the establishment of the National Heat Fund, attractive financing conditions have been created for owner-occupiers;
- work will be carried out with parties to intensify the Greenhouse as an Energy Source programme, a significant step in the climate transition for the greenhouse horticulture sector;
- The main measures for the industrial sector discussed in the Climate Agreement will be implemented in 2021. The most important measures for the industrial sector transition are the innovation programmes, the Energy and Climate Innovation Demonstration Scheme (DEI+), expansion of the SDE+ scheme to SDE++ and the introduction of the CO_2 levy. Work is also under way on the expansion of the energy-saving obligation.

7.3 Impact of COVID-19 pandemic and recovery

The consequences of the COVID-19 pandemic will have an impact in all areas of society, including climate policy. The reduction in CO_2 emissions expected for 2020 will be unprecedented: greater than during the financial crisis of 2008. At the same time, without structural changes, these emissions will soon begin to increase again: to previous levels or higher. The government therefore believes it is necessary to continue working towards a more sustainable economy and society after the crisis. The Climate Agreement in the Netherlands and the Green Deal in Europe focus on longer-term objectives, but also form the basis for a green recovery from the economic crisis in the short term.

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2) Emissions Register (www.emissieregistratie.nl); accessed on 16-11-2020.

Appendices

Appendix I Additional figures

Table 1.1 Waste incinerators (in 2018)

Location name	Installed thermal capacity MW_{th}	Installed electrical capacity (MW_e)	Gross electricity generated (GWh)	Heat supplied (TJ)	Use of generated heat
EEW Energy From Waste Delfzijl B.V.	180	36	185	1257	Industry
REC Harlingen	106	17	141	1 705	Salt production
Attero Noord B.V. GAVI Wijster	180	54	390	327	Processing industry
Twence Afval en energie	220	56	343	1 519	Industry and district heating
ARN B.V.			169	813	STP
AVR Afvalverwerking B.V.	120	31.4	144	698	District heating
HVCafvalcentrale, Alkmaar	243	71.2	450	293	District heating
AEB Amsterdam	495	154	936	1 112	Water network + district heating
AVR Afvalverwerking Rijnmond	394	140	416	4 489	Processing industry + district heating
HVCafvalcentrale, Dordrecht	112	32.5	135	971	Processing industry + STP
ZAVIN C.V.	4.1	-	-	-	-
AEC Moerdijk	339	16.2	617	1 618	CHP
SUEZ ReEnergy	124	39	279	101	Greenhouse horticulture + district heating
Total	2 517	647	4 205	14 903	

*Source: RWS (2020)**

Table 1.2 Industrial installations with a potential capacity for residual heat of more than 20 MW_{th}

Company name	Capacity for residual heat (MW_{th})
Dow Benelux BV Hoek	462.5
Chemelot Site Permit BV	200
YARA Sluiskil BV	181
Air Liquide Nederland BV	132.73
Delesto BV	117
Trinseo Netherlands	100
Eastman Chemical Middelburg BV	100
Cargill Benelux BV	100
Century Aluminum Vlissingen B V	100
Akzo Nobel Chemicals BV Hengelo	86.5
Air Products Nederland BV Pernis	78.91
ExxonMobil Chemical Holland BV RAP	61.7
Air Liquide Pergen VOF	57.36
DS Smith Paper De Hoop Mill	48.75
Air Products Nederland BV Botlek	45.11
Suiker Unie Dinteloord	40
Shell Nederland Chemie BV Moerdijk	35
Abengoa Bioenergy	34.41
Cabot BV	32.26
IHC Krimpen Shipyard BV	26.83
Chemours Netherlands BV	24.5
Eurogen CV	23.12
Indorama Holdings Rotterdam BV	22.65
Aluminium en Chemie Rotterdam BV	22.01
Suiker Unie Vierverlaten	22
Akzo Nobel Chemicals BV Botlek	21.23
Phoenix 3D	21

Source: Heat Atlas (data on: MT heat sources, start analysis by Netherlands Heating Expertise Centre, filtered by 'industry' and by a capacity of more than 20 MW). The capacity stated is an estimate by the Netherlands Environmental Assessment Agency (PBL) of the available supply of residual heat (PBL, 2020c).

Appendix II Policy measures

Target sector	Policy measure	Status	Instrument type
General	Aquathermal (Green Deal 229)	Ongoing	Agreement
General	Climate and Energy Innovation Demonstration Scheme (DEI+)	Ongoing	Economic (subsidy)
General	Energy Tax & Surcharge for Sustainable Energy (EB & ODE)	Ongoing	Economic (fiscal)
General	Energy Investment Deduction Scheme (EIA)	Ongoing	Economic (fiscal)
General	Gas Act (incl. amendment concerning natural-gas-free new construction)	Ongoing	Regulation (Dutch legislation)
General	Green Deals (GD)	Ongoing	Agreement
General	Green investment: green projects scheme	Ongoing	Economic (fiscal)
General	Integrated Knowledge and Innovation Agenda and Multi-annual Mission-oriented Innovation Programmes (MMIPs)	Ongoing	Agenda/outline plan
General	Investment Subsidy for Sustainable Energy for Small Systems (ISDE-KA)	Ongoing	Economic (subsidy)
General	Climate Agreement	Ongoing	Agreement
General	Climate Act 2019	Ongoing	Regulation (Dutch legislation)
General	National Programme for Regional Energy Strategies	Ongoing	Agenda/outline plan
General	Environment Act and National Environment Vision (NOVI)	Proposed/pro posal	Regulation (Dutch legislation)
General	Participation of the Community in Sustainable Energy Projects (Green Deal 221)	Ongoing	Agreement
General	Environmental Investment Rebate (MIA) and Arbitrary Depreciation of Environmental Investments (VAMIL)	Ongoing	Economic (fiscal)
General	Sustainable Energy Transition Subsidy Scheme (SDE++):	Proposed/pro posal	Economic (subsidy)
General	Renewable Energy Scheme (HER)	Ongoing	Economic (subsidy)
General	Topsector Energy (TSE)	Ongoing	Economic (subsidy)
General	Hydrogen programme	Proposed/pro posal	Agreement
General	Environmental Management Act (Wm): Framework and energy-saving obligation	Ongoing	Regulation (Dutch legislation)
General	Environmental Management Act - Information obligation	Ongoing	Regulation (Dutch legislation)
Built environment	Value Added Tax (VAT): reduced rate for insulation	Ongoing	Economic (fiscal)
Built environment	Building Decree: Energy label C obligation for office buildings	Ongoing	Regulation (Dutch legislation)
Built environment	'Iedereen Doet Wat' ('Everybody Does Something) Campaign	Ongoing	Information/awareness
Built environment	Digital platform	Proposed/pro posal	Information/awareness
Built environment	Netherlands Heating Expertise Centre (ECW)	Ongoing	Information/awareness
Built environment	National Energy Saving Fund (NEF)	Ongoing	Economic (loan/credit)
Built environment	Utility Construction Standards and Route Maps	Proposed/pro posal	Regulation (standards)
Built environment	Natural-gas-free Districts (NAW), Large-Scale Test Beds Programme, Transition Visions for Heat	Ongoing	Economic (subsidy)

Target sector	Policy measures	Status	Instrument type
Built environment	Reduction of Energy Consumption Scheme (RRE)	Complete	Economic (subsidy)
Built environment	Landlord Levy Sustainability Reduction Scheme (RVV Verduurzaming)	Ongoing	Economic (fiscal)
Built environment	Renovation Accelerator Subsidy Scheme (part of Starter Motor)	Ongoing	Economic (subsidy)
Built environment	Home Standards and Targets	Proposed/proposal	Regulation (standards)
Built environment	Promoting the Construction and Maintenance of Sports Accommodations (amended from 2019 with energy measures) (BOSA)	Ongoing	Economic (subsidy)
Built environment	Subsidy for Energy Savings at Home (SEEH)	Ongoing	Economic (subsidy)
Built environment	Flexible Mortgage for Energy Saving Measures (WEW)	Ongoing	Regulation (other)
Built environment	Heat Fund and building-related financing	Proposed/proposal	Economic (loan/credit)
Built environment	District-oriented approach	Ongoing	Other n/a
Built environment	Housing Valuation System & EPV Energy Performance Allowance (WWS)	Ongoing	Regulation (other)
Greenhouse horticulture	CO_2 sector system for greenhouse horticulture	Ongoing	Economic (market price)
Greenhouse horticulture	Greenhouse as an Energy Source Programme	Ongoing	Agreement
Greenhouse horticulture	Market introduction for energy innovations (MEI)	Ongoing	Economic (subsidy)
Greenhouse horticulture	Investments in Energy Efficient Greenhouse Horticulture Scheme (EG) and Precursors to Energy Efficient and Renewable Energy Greenhouse Horticulture Subsidy (EHG), Investments in Environmentally Friendly Measures (MMI) & Investments in Energy Savings (IRE)	Ongoing	Economic (subsidy)
Industry	Industrial cluster/frontrunner programmes	Proposed/proposal	Other/not applicable
Industry	National CO_2 levy for industry	Proposed/proposal	Economic (market price)

A more detailed description of these policy measures can be found in Appendix 4 of the final Integrated National Energy and Climate Plan, which the Netherlands sent to the European Commission at the end of 2019[46]. This overview only includes cross-sectoral policy measures and policy measures that apply specifically to the built environment, industrial sector and greenhouse horticulture. Only policy measures that have a direct impact on heating and cooling have been included in this overview. Policy measures focused on electricity, mobility and that are not focused on energy (e.g. land use) have not been taken into account. The Netherlands Heating Expertise Centre (ECW) has been added to this overview as a policy measure.

46 https://www.rijksoverheid.nl/documenten/rapporten/2019/11/25/bijlage-bij-kamerbrief-over-de-langere-termijn-strategie-klimaat.

Appendix III Use of heating systems in greenhouse horticulture

Results of the model calculations for six different crops, taken from De Zwart et al (2019). See Section 6.3 for an explanation.

Tomato cultivation without lights

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	8.33	400	0	21.27	0	0	25.36	0	0			
Geothermal and CHP	7.87	300	100	15.08	0	400	22.66	0	300	16.37	0	500
Geothermal + HP and CHP	8.20	200	200	14.68	0	250	20.40	0	250	16.03	0	250
HT heat and CHP	8.12	300	400	15.00	0	500	18.37	0	500			
LT heat + HP and CHP	N/a	400	0	17.96	100	400	21.74	0	300			
Surface Wat. + HP/TES and CHP	N/a	400	0	15.56	100	500	15.43	0	500			
Greenhouse heat + HP and CHP	N/a	400	0	20.75	200	200	22.95	0	300			
Greenhouse heat + HP/TES and CHP	N/a	400	0	18.04	200	500	17.97	0	500			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (Geo 50%)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	7.20	300	0	15.92	100	0	19.05	0	0			
Geothermal and CHP	N/a	300	0	13.64	0	300	18.47	0	100	15.17	0	300
Geothermal + HP and CHP	N/a	300	0	12.74	0	250	17.57	0	150	14.00	0	250
HT heat and CHP	N/a	300	0	12.36	0	500	16.12	0	300			
LT heat + HP and CHP	N/a	300	0	14.53	100	300	18.12	0	200			
Surface Wat. + HP/TES and CHP	N/a	300	0	13.02	100	400	13.65	0	400			
Greenhouse heat + HP and CHP	N/a	300	0	N/a	100	0	N/a	0	0			
Greenhouse heat + HP/TES and CHP	N/a	300	0	15.16	100	400	15.52	0	400			

In the transition scenario, geothermal still offers the lowest total energy costs for the standard greenhouse, but a heat pump does need to be installed, and CHP is no longer used. For energy-efficient greenhouses too, the use of geothermal with extra cooling down using a heat pump offers low energy costs, but the use of high-temperature waste heat from the industrial sector results in even lower energy costs and CHP is no longer used here either.

In the sustainable price scenario, the use of heat from surface water offers the lowest energy costs for both greenhouse types (standard and energy-efficient). These are of course higher than in the transition scenario, and twice the energy costs under current market conditions. A good second option in the sustainable price scenario is the use of greenhouse heat in combination with thermal energy storage. This is logical given that the technology used here is similar in many ways to the use of heat from surface water. The difference is that the regeneration of the aquifer in the summer with recovered greenhouse heat is more expensive than regeneration of the aquifer with heat from surface water. If the cost of geothermal was halved, however, as is expected on the basis of current trends, this would become the most suitable heat source for both greenhouse types.

Tomato cultivation without lights

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	30.67	500	0	51.77	0	0	54.64	0	0			
Geothermal and CHP	30.57	400	100	46.53	200	300	52.64	0	200	48.43	0	300
Geothermal + HP and CHP	N/a	500	0	45.98	100	250	51.49	0	200	47.53	0	250
HT heat and CHP	N/a	500	0	47.24	100	400	50.10	0	300			
LT heat + HP and CHP	N/a	500	0	47.94	100	400	52.71	100	200			
Surface Wat. + HP/TES and CHP	N/a	500	0	45.63	100	400	48.17	0	400			
Greenhouse heat + HP and CHP	N/a	500	0	48.14	100	300	50.85	100	300			
Greenhouse heat + HP/TES and CHP	N/a	500	0	48.57	100	300	51.26	100	300			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	32.46	400	0	45.93	300	0	46.12	0	0			
Geothermal and CHP	N/a	400	0	45.34	200	200	N/a	0	0	44.32	0	200
Geothermal + HP and CHP	N/a	400	0	44.95	200	150	45.67	0	50	43.79	0	200
HT heat and CHP	N/a	400	0	44.61	100	300	45.00	0	200			
LT heat + HP and CHP	N/a	400	0	45.21	100	300	N/a	0	0			
Surface Wat. + HP/TES and CHP	N/a	400	0	44.09	100	300	43.46	0	400			
Greenhouse heat + HP and CHP	N/a	400	0	N/a	300	0	N/a	0	0			
Greenhouse heat + HP/TES and CHP	N/a	400	0	N/a	300	0	N/a	0	0			

In the transition scenario price regime, the various alternative heat sources do result in cost reductions in comparison with typical current technology. In this price scenario, use of an energy-efficient greenhouse is also cost-effective. The lowest energy costs are achieved with use of surface water in combination with seasonal storage and a heat pump. The model calculates that a small CHP installation does still need to be connected to the energy-supply system. If surface water cannot be used, alternative heat sources connected to some kind of heat infrastructure become an attractive option. Only if connection to a heat infrastructure is not possible is the use of greenhouse heat an option for the standard greenhouse. For an energy-efficient greenhouse, the use of greenhouse heat is not attractive.

In the sustainable price scenario, the ranking of alternative heat-supply systems remains essentially unchanged, but CHP disappears in almost all cases. A (small) CHP installation remains an attractive option only for the standard greenhouse, where there is a high requirement for electricity, which increases even further with use of a heat pump. In energy-efficient greenhouses, CHP is no longer cost-effective under the sustainable price scenario.

Chrysanthemum cultivation with lights

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	16.27	400	0	30.51	300	0	32.44	0	0			
Geothermal and CHP	N/a	400	0	28.20	200	200	30.77	0	100	26.94	0	300
Geothermal + HP and CHP	N/a	400	0	28.13	0	200	29.27	0	150	26.16	0	200
HT heat and CHP	N/a	400	0	28.66	200	300	28.23	0	300			
LT heat + HP and CHP	N/a	400	0	29.33	100	300	30.08	0	200			
Surface Wat. + HP/TES and CHP	N/a	400	0	27.72	100	300	26.50	0	300			
Greenhouse heat + HP and CHP	N/a	400	0	N/a	300	0	29.57	0	300			
Greenhouse heat + HP/TES and CHP	N/a	400	0	30.26	100	300	29.26	0	300			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	19.27	300	0	28.01	300	0	29.79	0	0			
Geothermal and CHP	N/a	300	0	27.20	300	100	29.28	0	100	26.79	0	200
Geothermal + HP and CHP	N/a	300	0	27.47	100	150	28.44	0	100	26.19	0	150
HT heat and CHP	N/a	300	0	27.24	200	200	27.54	0	200			
LT heat + HP and CHP	N/a	300	0	28.01	200	200	28.69	0	100			
Surface Wat. + HP/TES and CHP	N/a	300	0	27.35	200	200	26.05	0	300			
Greenhouse heat + HP and CHP	N/a	300	0	N/a	300	0	N/a	0	0			
Greenhouse heat + HP/TES and CHP	N/a	300	0	N/a	300	0	28.46	0	300			

Under the prices in the transition scenario, an energy-efficient greenhouse does result in lower energy costs, and the use of alternative heat sources results in most cases in lower total energy costs. For a standard greenhouse, the use of surface water is the best option, but for an energy-efficient greenhouse it is geothermal, closely followed by high-temperature residual heat. Interestingly, for chrysanthemum cultivation in an energy-efficient greenhouse, addition cooling down using a heat pump is not cost-effective. This may be because of the reasonably broad output levels used in the optimisation, however, since it is also clear that the differences in the calculated total costs for chrysanthemum cultivation are all very small. Small differences in the assumptions made therefore result in a different ranking, but the effect on the total cost for energy remains limited.

This also applies in the sustainable price scenario, in which a geothermal source that can be installed for half of the current expected cost results in the lowest total cost of all options. If geothermal is not available at low cost, the use of surface water once again results in the lowest total energy costs.

Alstroemeria cultivation with lights

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	15.99	200	0	26.73	200	0	25.96	0	0			
Geothermal and CHP	N/a	200	0	25.39	100	100	25.50	100	100	23.75	100	100
Geothermal + HP and CHP	N/a	200	0	25.32	0	100	25.10	0	100	23.35	0	100
HT heat and CHP	N/a	200	0	26.09	0	200	24.47	0	100			
LT heat + HP and CHP	N/a	200	0	26.72	100	100	N/a	0	0			
Surface Wat. + HP/TES and CHP	N/a	200	0	25.93	0	200	24.22	0	200			
Greenhouse heat + HP and CHP	N/a	200	0	N/a	200	0	25.77	0	200			
Greenhouse heat + HP/TES and CHP	N/a	200	0	26.71	0	200	25.18	0	200			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	30.52	100	0	38.12	100	0	36.23	0	0			
Geothermal and CHP	N/a	100	0	N/a	100	0	N/a	0	0	35.86	0	100
Geothermal + HP and CHP	N/a	100	0	37.86	0	50	N/a	0	50	35.37	0	50
HT heat and CHP	N/a	100	0	38.06	0	100	36.14	0	100			
LT heat + HP and CHP	N/a	100	0	N/a	100	0	N/a	0	0			
Surface Wat. + HP/TES and CHP	N/a	100	0	38.11	0	100	35.73	0	100			
Greenhouse heat + HP and CHP	N/a	100	0	N/a	100	0	36.18	0	100			
Greenhouse heat + HP/TES and CHP	N/a	100	0	37.73	0	100	35.40	0	100			

In the transition scenario, geothermal offers the lowest total energy costs, but it is immediately noticeable that the difference in cost between use of the various alternative heat sources is very small. For alstroemeria cultivation, the same applies as for chrysanthemum cultivation, i.e. it makes little difference which system is used for the supply of energy. For alstroemeria cultivation, even the system most common at present, with a boiler and CHP installation, is not much more expensive than the cheapest alternative system in the transition scenario. For a standard greenhouse this is a geothermal source with a capacity of 100 kW/ha and for an energy-efficient greenhouse it is use of heat released by ground cooling in the summer (after storage in a seasonal buffer). CHP offers few advantages here so, where the model does include a CHP installation in the boiler-house options, outputs will be small (100 to 200 kWe/ha).

In the sustainable price scenario, the differences between the various options are even smaller. If geothermal can be implemented for less than the current expected costs in the future, this will result in the lowest costs, and otherwise the use of surface water results in the lowest costs for a standard greenhouse. For an energy-efficient greenhouse, the use of summer heat surpluses from ground cooling, after storage in a seasonal buffer, and use of a heat pump once again offer good possibilities here for a cost-effective supply of sustainable energy for heating.

Heated potted plant cultivation

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	7.15	500	0	18.49	0	0	22.11	0	0			
Geothermal and CHP	6.49	300	200	11.49	0	400	17.86	0	300	11.98	0	400
Geothermal + HP and CHP	6.35	100	200	10.44	0	250	15.12	0	250	10.75	0	250
HT heat and CHP	6.83	100	400	11.25	0	500	13.76	0	400			
LT heat + HP and CHP	N/a	500	0	13.53	100	400	16.07	0	300			
Surface Wat. + HP/TES and CHP	6.80	100	300	11.18	0	400	10.21	0	400			
Greenhouse heat + HP and CHP	N/a	500	0	17.81	100	300	18.40	0	300			
Greenhouse heat + HP/TES and CHP	N/a	500	0	15.21	100	400	13.77	0	400			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	6.77	300	0	14.84	100	0	17.35	0	0			
Geothermal and CHP	6.75	300	100	11.19	0	300	15.78	0	200	11.67	0	300
Geothermal + HP and CHP	6.72	100	150	9.99	0	250	13.93	0	150	10.33	0	250
HT heat and CHP	6.58	100	300	10.23	0	400	12.71	0	300			
LT heat + HP and CHP	N/a	300	0	12.06	100	300	14.49	0	200			
Surface Wat. + HP/TES and CHP	6.69	100	200	10.49	0	400	10.09	0	400			
Greenhouse heat + HP and CHP	N/a	300	0	14.82	0	200	15.66	0	200			
Greenhouse heat + HP/TES and CHP	N/a	300	0	13.08	100	300	12.40	0	400			

In the transition scenario, geothermal is the most appropriate system for warm potted plant cultivation. Since the efficiency of geothermal increases significantly with the addition of a heat pump, this is recommended here too. The use of surface water in combination with a seasonal storage system and a heat pump is a good second option. Only if there was no possibility of connecting the business to an energy infrastructure (with high-value or low-value energy) would the use of greenhouse heat in combination with TES and a heat pump be a possible option. Since the heat pump runs on electricity, the addition of a small CHP installation is also attractive here.

In the sustainable price scenario, the use of surface water still results in the lowest total energy costs, followed by use of greenhouse heat with TES and a heat pump. Geothermal comes in third place if using the current expected costs but, if geothermal could be implemented for half of this cost, the total energy costs for use of geothermal would make it the cheapest option for warm potted plant cultivation. As with all other crops, CHP is not a cost-effective option in the sustainable price scenario.

Radish cultivation

Reference greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	2.76	200	0	5.75	0	0	6.59	0	0			
Geothermal and CHP	N/a	200	0	5.29	0	100	N/a	0	0	5.56	0	100
Geothermal + HP and CHP	N/a	200	0	5.05	0	100	6.55	0	50	5.15	0	150
HT heat and CHP	2.73	100	200	4.11	0	300	5.76	0	100			
LT heat + HP and CHP	N/a	200	0	5.10	0	200	6.57	0	100			
Surface Wat. + HP/TES and CHP	N/a	200	0	4.48	0	200	4.33	0	200			
Greenhouse heat + HP and CHP	N/a	200	0	N/a	0	0	N/a	0	0			
Greenhouse heat + HP/TES and CHP	N/a	200	0	5.48	0	200	5.14	0	200			

E-efficient greenhouse	Reference			Transition			Sustainable			Sustainable (50% Geo)		
	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.	E. costs	CHP	Alt. H.
Options	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth	€/m²	kWe	kWth
CHP and boiler	3.19	100	0	5.04	0	0	5.31	0	0			
Geothermal and CHP	N/a	100	0	5.04	0	100	N/a	0	0	5.12	0	100
Geothermal + HP and CHP	N/a	100	0	4.73	0	50	N/a	0	0	4.71	0	50
HT heat and CHP	N/a	100	0	4.23	0	100	5.19	0	100			
LT heat + HP and CHP	N/a	100	0	4.67	0	100	N/a	0	0			
Surface Wat. + HP/TES and CHP	N/a	100	0	4.42	0	100	4.39	0	100			
Greenhouse heat + HP and CHP	N/a	100	0	N/a	0	0	N/a	0	0			
Greenhouse heat + HP/TES and CHP	N/a	100	0	4.48	0	100	4.45	0	100			

In the transition scenario, connection to a high-temperature energy infrastructure appears to offer the lowest total costs, followed by use of surface water in combination with a seasonal storage system and a heat pump. Geothermal comes in third place, but a heat pump must be installed to provide extra cooling down in order to increase capacity if necessary. Use of CHP is not a consideration in the transition price scenario.

In the sustainable price scenario, the use of surface water offers the lowest total energy costs, followed by use of greenhouse heat with TES. In the sustainable price scenario, geothermal is only relevant if it can be implemented for half the current expected costs, but even then geothermal comes in third place.

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