Comprehensive assessment of the potential for efficient heating and cooling for Germany

[Comprehensive Assessment of Heating and Cooling for Germany]

In accordance with Article 14(1) and Annex VIII of Directive 2012/27/EU

Federal Ministry for Economic Affairs and Energy (BMWi)

Competent authorities:

- **Federal Office for Energy Efficiency (BfEE)**
- **Federal Environment Agency (UBA)**

Research institutes:

IREES - Institut für Ressourceneffizienz und Energiestrategien GmbH

ifeu - Institut für Energie- und Umweltforschung Heidelberg gGmbH

Fraunhofer Institute for Systems and Innovation Research (ISI)

Prognos AG

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Glossary of abbreviations

11th BImSchV	Eleventh Federal Immission Control Regulation
AGEB	Energy Balance Working Group
APEE	Energy Efficiency Incentive Programme
AS	Alternative scenarios
BAFA	Federal Office for Economic Affairs and Export Control
BBSR	Federal Office for Building and Regional Planning
BEW	Federal Programme for Efficient Heating Networks
BfEE	Federal Office for Energy Efficiency within the Federal Office for Economic Affairs and Export Control (BAFA)
GDP	Gross domestic product
BMWi	Federal Ministry for Economic Affairs and Energy
CB	Condensing boiler
RDF plant	Refuse-derived-fuel plant
RE	Renewable energies
EED	EU Energy Efficiency Directive
EEWärmeG	Renewable Energy Heating Act
SFH	Single-family house
EnEG	Energy Conservation Act
EnEV	Energy Conservation Regulation
E-PRTR	European Pollutant Release and Transfer Register
ECR	Energy-efficient construction and renovation
EU	European Union
EUA	European Union Allowances
STFH	Single and two-family house
GDEW	Energy Transition Digitisation Act
GEG	Building Energy Act
GEMOD	Building model developed by Ifeu
GIS	Geoinformation system
GWZ 2011	Building and housing census within the framework of the 2011 census of the Federal Government and *Länder* statistical offices
HZO	Support Programme for Heating Optimisation
ifeu	Institut für Energie- und Umweltforschung Heidelberg gGmbH
APC	Annual performance coefficient

KfW	Kreditanstalt für Wiederaufbau
KSG	Federal Climate Change Act
CHP	Combined heat and power
KWKG	Cogeneration Act
KWSB	Commission on Growth, Structural Change and Employment
LTRS	Long-term renovation strategy
MAP	Market Incentive Programme
AB	Apartment block
WIP	Waste incineration plants
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NAPEE	National Action Plan on Energy Efficiency
NECP	National Energy and Climate Plan
nETS	National Emissions Trading Scheme
NUTS	Nomenclature des unités territoriales statistiques (system for the clear identification and classification of geographical reference units in the EU)
RED II	EU Renewable Energy Directive
SoS Reg.	Regulation concerning measures to safeguard the security of gas supply
T_Rein	Geothermal reinjection temperature
T_Res	Geothermal reservoir temperature
GHG	Greenhouse gas
UBA	Federal Environment Agency
FLH	Full load hours
HP	Heat pump

A. Executive summary

In accordance with Article 14 of the European Energy Efficiency Directive 2012/27/EU (EED)[1], Member States have an obligation to notify to the European Commission an assessment of efficiency in heating and cooling every 5 years. The *Comprehensive assessment of the potential for efficient heating and cooling* for Germany is being submitted by means of this report. The aim of this report is to analyse the status quo in the area of heating and cooling in detail, determine the economic potential for switching over to efficient, renewable heating and cooling, and identify objectives, strategies and measures that will promote the realisation of these potentials. This assessment had to be drawn up for the first time by 31 December 2015 and must be updated by 31 December 2020.

Annex VIII of the Directive, published in Commission Delegated Regulation (EU) 2019/826 of 4 March 2019, defines the four parts that must be addressed in the comprehensive assessment (European Commission, 2019a):

- Part I – Overview of heating and cooling
- Part II – Objectives, strategies and policy measures
- Part III – Analysis of the economic potential for efficiency in heating and cooling
- Part IV – Potential new strategies and policy measures

The area of heating and cooling covers the final energy consumption for the thermal conditioning of buildings (space heating, hot water and air conditioning), as well as the final energy consumption for heating and cooling processes in industry and the trade, commerce and services sector. Within the framework of the *Comprehensive assessment of the potential for efficient heating and cooling* a distinction is made between ‘residential buildings’ (private households), ‘services’ (trade, commerce and services (TCS)) and ‘industry’ (industrial sector). In 2018 the final energy consumption in Germany in the area of heating and cooling came to around 1,321 TWh and therefore accounted for a 56% share in Germany’s total final energy demand or around an 80% share in the final energy demand of the private household, TCS and industrial sectors. The greatest share of final energy consumption for heating and cooling can be attributed to space heating. With regard to energy sources, 81% of the energy is supplied from fossil fuels and roughly 13% from renewables, with electricity accounting for the remainder. For district heating and cooling the share of renewable energies was 20% in 2018, with 72% of net heat generation attributable to CHP installations. The share of waste heat from industrial processes in the heat supplied to heating networks was 1.7% (Part I). In addition to the status quo, the forecast for heating and cooling up to 2050 from the National Energy and Climate Plan is also presented (Part II). Under the reference scenario, which covers the current policy measures, final energy consumption for heating and cooling is reduced by 17% from 2018 to 2030 and by 41% by 2050.

[1] DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, most recently amended by DIRECTIVE (EU) 2018/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

The analysis of the economic potential for efficiency in heating and cooling (Part III) develops alternative scenarios and compares them with a baseline scenario. To allow local differences in terms of heat sources and heat sinks to be examined, specifically during the analysis of efficient district heating, a small-scale approach is developed within which possible district heating potentials are first identified at municipality level on the basis of heating density. On the basis of the technical potentials identified for various renewable heat sources and waste heat, the optimal mix of energy sources is then determined for an efficient district heating supply. For the analyses under the alternative scenarios, as in the case of the baseline scenario, a 40% share is assumed for renewable energies and waste heat, as a national average, to allow the objectives laid down in Regulation (EU) 2018/1999 to be taken into account.

The results show that the alternative scenarios lead to lower greenhouse gas emissions and lower costs compared with the baseline scenario: the specific greenhouse gas emissions under the alternative scenarios amount to 138 g/kWh, compared with 153 g/kWh under the baseline scenario, resulting in savings of 2.35 million tonnes of CO_2-eq by 2030. The annual savings in the area of heat generation costs by 2030 come to €0.75 billion from a microeconomic perspective and €0.79 billion from a macroeconomic perspective. Furthermore, most locally available renewable heat sources (solar thermal, geothermal and waste heat) are used to a greater extent under the alternative scenarios compared with the baseline scenario, while biomass is conserved. If the potentials are fully exploited by 2030, a third of the municipalities considered will be able to achieve a target of a 40% to 100% share for renewable heat sources and waste heat. The cost-benefit analysis carried out also highlights the impacts on primary energy use, security of the energy supply and jobs.

Within the framework of the sensitivity analysis, changes in investment and operating costs and the discount rate, as well as variations in fuel and electricity prices and climate damage costs, are analysed. It becomes apparent that, even if there is variation in the parameters relating to operating and investment costs, heat generation costs are extremely resilient and the variation in the discount rate impacts on the baseline scenario and alternative scenarios to the same extent.

The savings can be attributed primarily to the optimised local use of renewable energies and waste heat in district heating, as the analyses at municipality level compare the technical potentials of various heat sources, determined on a small scale, with potential district heating areas in 2030.

The following potential new strategies and policy measures are derived from these insights (Part IV):

- Federal Programme for Efficient Heating Networks
- Waste Heat Utilisation Regulation or obligation to utilise the economic potential of industrial waste heat
- Municipal heat planning
- Extra-budgetary financing of support programmes, following the example of the Federal Programme for Efficient Heating Networks: modernisation levy

All the proposals and strategies presented in this report are subject to a more in-depth examination and an economic feasibility study that gives appropriate consideration to the economic costs of climate protection and the achievement of long-term targets, as well as the allocation of funds by the budgetary legislator, where applicable.

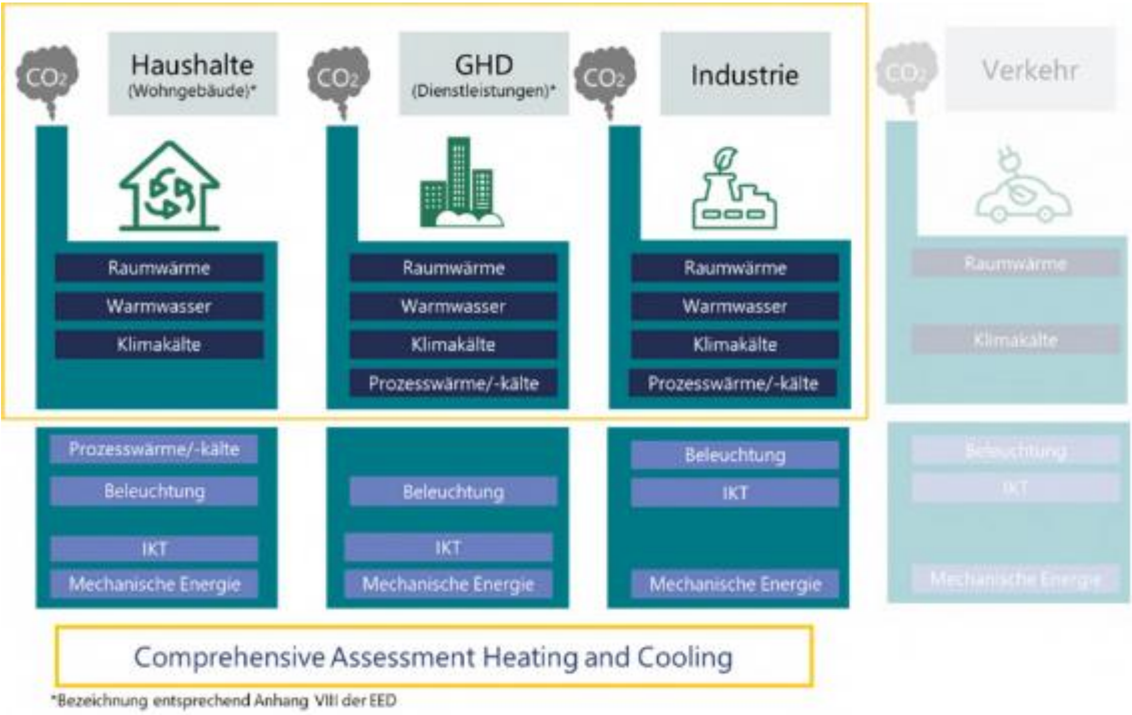
The *Comprehensive assessment of the potential for efficient heating and cooling* within the framework of the EED reveals that considerable potentials exist in the area of renewable heating and cooling – in particular with regard to grid-based heating – and identifies the measures that can be used to leverage these potentials.

B. Background and objectives

In accordance with Article 14 of the Energy Efficiency Directive 2012/27/EU (EED)[2], Member States have an obligation to notify to the European Commission an assessment of efficiency in heating and cooling every 5 years. The *Comprehensive assessment of the potential for efficient heating and cooling* for Germany is being submitted by means of this report. The aim of this report is to analyse the status quo in the area of heating and cooling in detail, determine the economic potential for switching over to efficient, renewable heating and cooling, and identify objectives, strategies and measures that will promote the realisation of these potentials.

A precise definition of heating and cooling is not provided in the EED. Figure 1 outlines the definition of heating and cooling used for this project, at the level of the energy use assessments forming part of the energy balance. The area of heating and cooling therefore comprises the applications of space heating, hot water and air conditioning in the demand sectors 'households', 'trade, commerce and services (TCS)' and 'industry'. Process heating and cooling in the TCS and industrial sectors are also taken into account. In the household sector only applications used for the thermal conditioning of buildings are therefore considered. This is because process heating and cooling in the household sector cover energy consumption for cooking and refrigeration. Such consumption can be allocated to the area of household appliances and is not addressed within the context of the technologies and measures examined here. In contrast to the definition of sectors within the framework of the Climate Action Plan 2050, all energy sources used to cover demand for heating and cooling are taken into account. Besides the examination at the level of demand sectors, district heating and cooling – as a transformation sector – have also been incorporated into the analysis in detail.

[2] DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, most recently amended by DIRECTIVE (EU) 2018/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 amending Directive 2012/27/EU on energy efficiency



Haushalte (Wohngebäude)*	Households (Residential)*
Raumwärme	Space heating
Warmwasser	Hot water
Klimakälte	Air conditioning
Prozesswärme/-kälte	Process heating / cooling
Beleuchtung	Lighting
IKT	ICT
Mechanische Energie	Mechanical energy
GHD (Dienstleistungen)	TCS (Services)
Industrie	Industry
Verkehr	Transport
*Bezeichnung entsprechend Anhang VIII der EED	*Description in accordance with Annex VIII of the EED

Source: Own figure of IREES

Figure 1: Definition of heating and cooling

The structure and content of the report[3] are based on the requirements set out in Article 14 of the EED and the associated Annex VIII (European Commission, 2019a). In

[3] On the comprehensive assessment of the national heating and cooling potential, in accordance with Article 14(1).

addition, the EU Commission's recommendations on the implementation of the EED have been taken into account in the preparation of this report (European Commission, 2019b; Jakubcionis et al., 2015). The numbering of the individual chapters follows the numbering of the points in Annex VIII of the EED. As far as possible, the content required by the Directive has been supplemented with other analyses that are relevant for the purpose of deriving technical solutions and policy measures. These include, for example, a more detailed presentation of the heating and cooling technologies used, a breakdown of process heating and cooling by temperature levels and an analysis of existing district heating and cooling network temperatures.

Part I of the report presents the status quo for heating and cooling, with demand broken down by relevant energy applications and demand sectors at final and useful energy level. The technologies used for heating and cooling are also described, as well as the potential for utilising waste heat and waste cold. In addition to the aggregated presentation at national level, a high spatial-resolution analysis of heating and cooling demand areas, existing and planned supply points and district heating transmission installations has been performed and is presented in maps. Besides this report, the results of the spatial analyses are also being made available on an interactive web platform to allow individual evaluations at municipality level. Alongside the analysis of the status quo, Part I also contains a forecast of the development of heating and cooling up to 2050, based on the assumption that the current policy framework will be maintained (reference scenario).

Part II of the report presents the relevant objectives, strategies and policy measures in the area of heating and cooling and assigns these to the five dimensions of the energy union – decarbonisation, energy efficiency, energy security, the internal energy market, and research, innovation and competitiveness.

Part III contains the analysis of the economic potential for efficiency in heating and cooling. This includes a spatially resolved analysis of efficient and renewable heating and cooling potentials depending on local heating and cooling demand, and alternative scenarios for heating and cooling are also developed. These are assessed, in terms of their cost-benefit impacts, against a baseline scenario from a microeconomic and macroeconomic perspective.

Part IV contains proposals for new strategies and policy measures, as well as an assessment of how these could contribute to the achievement of targets and/or the realisation of the potentials identified.

This report therefore addresses all relevant aspects of heating and cooling and thus represents an important basis for politicians, academics and economic actors who are planning concrete projects relating to the efficient, renewable supply of heating and cooling.

I. Overview of heating and cooling

Part I of the *Comprehensive Assessment of Heating and Cooling* presents the status quo in the area of heating and cooling in Germany. The aim here is to break down the relevant energy demand by sector and energy application, as well as the energy supply by technology. Such a detailed presentation allows the relevance of individual areas within heating and cooling to be assessed. Furthermore, the analysis serves as a basis for determining what the potential is for switching over to a renewable and efficient heating and cooling supply and where specific policy instruments should be focused.

The status quo is presented for 2018, the year for which the most recent energy statistics figures are available.

I.1. Assessment of annual heating and cooling demand

Current heating and cooling demand is quantified in terms of final energy and useful energy with the breakdown required in accordance with Annex VIII of the EED. Table 1 shows the sectoral breakdown as per the Directive and the assignment to final energy sectors in accordance with the energy balance in Germany.

Table 1: Sectoral breakdown of heating and cooling demand

	Annex VIII - Directive 2012/27/EU	**AGEB final energy sectors**
A	Residential	Households
B	Services	TCS
C	Industry	Industry
D	Any other sector that individually consumes more than 5% of total national useful heating and cooling demand	

The area of services comprises the trade, commerce and services (TCS) sector[4], which means that all heating and cooling demand areas are covered and the ‘other sectors’ item (D) is not relevant. The energy balance in Germany does not allow any further breakdown of the TCS sector by services and other sectors.

In addition to the sectoral breakdown, there is also a breakdown by different areas of application for heating and cooling demand (space heating and hot water, process heating and cooling, and air conditioning).

I.1.a. Final energy consumption for heating and cooling

The overview of final energy consumption for heating and cooling for the individual sectors is drawn up on the basis of the energy use assessments for Germany of the Ener-

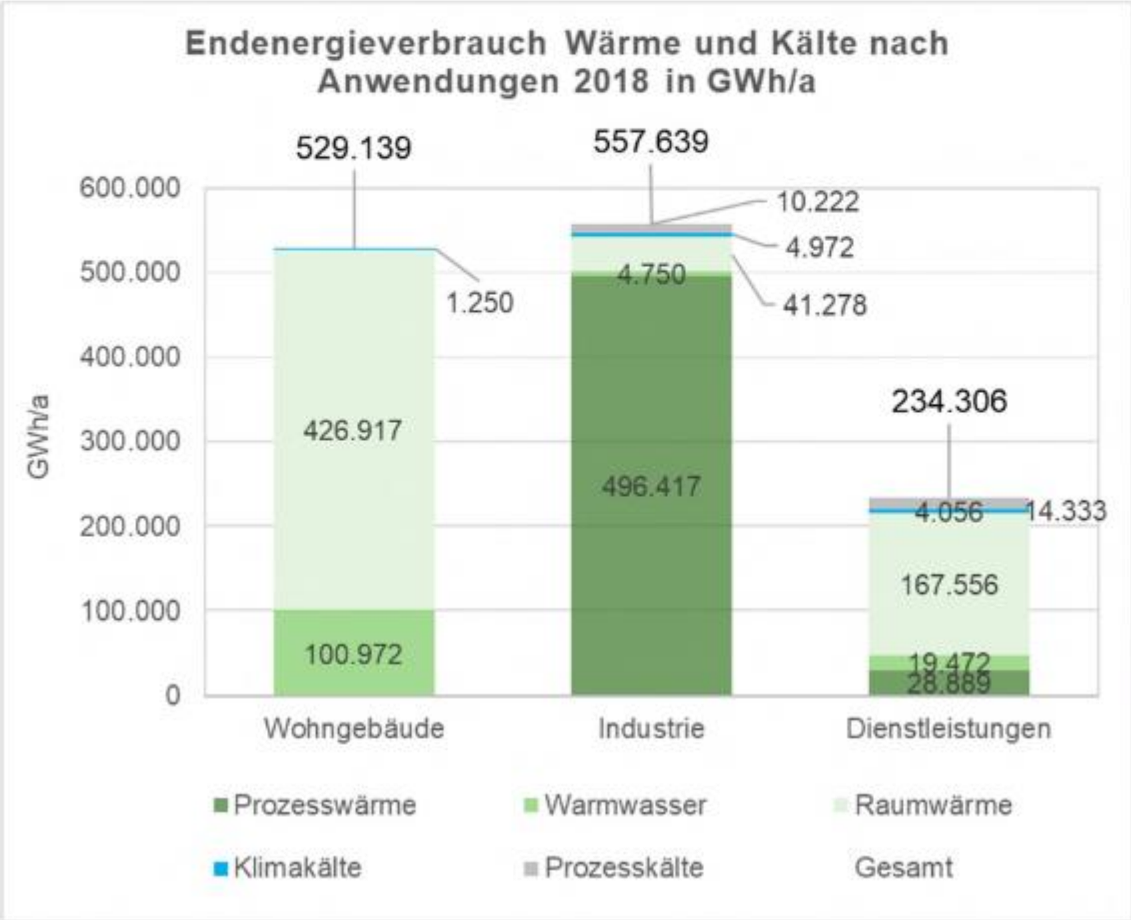
[4] In accordance with the AGEB’s definition, the TCS sector covers businesses in the processing and manufacturing industries with up to 19 employees, all businesses in the commerce and services sectors, agriculture and forestry, horticulture and military services, as well as the stationary energy consumption of Deutsche Bahn and airports (Schlomann et al., 2013).

gy Balance Working Group (AGEB). Figure 2 shows the final energy consumption of heating and cooling applications in Germany in the various sectors. This amounts to approx. 1,321 TWh/a in total. The final energy consumption for Germany as a whole in 2018 was approx. 2,499 TWh/a. This means that heating and cooling applications account for around 53% of national final energy consumption. It can be seen from Figure 2 that final energy consumption in the residential (529 TWh/a) and industrial (558 TWh/a) sectors is roughly double that of the services sector (234 TWh/a).

In the **residential** sector national final energy demand is roughly 636 TWh/a. The area of heating and cooling applications (including process heating and cooling applications, which are omitted from the other figures) therefore accounts for around 94% of residential final energy demand. In the residential sector the final energy consumption for space heating is particularly relevant at 427 TWh/a. A smaller share of final energy consumption (approx. 100 TWh/a) can be attributed to hot water preparation. Process heating and cooling applications are responsible for around 69 TWh/a in total. The remaining applications play only a minor role in the residential sector.

In the **industrial** sector national final energy demand is approx. 736 TWh/a. Heating and cooling applications therefore account for around 76% of final energy demand in industry. Demand for process heating is particularly relevant in the industrial sector. Within industry this amounts to approx. 496 TWh/a and therefore accounts for almost 90% of final energy demand for heating and cooling. Process heating is understood to refer to all applications that provide the temperatures needed for processes, such as steam generators or industrial furnaces. In the industrial sector a smaller share of final energy consumption (approx. 41 TWh/a) can be attributed to space heating. Cooling applications play a more minor role.

In the **services** sector national final energy demand is approx. 375 TWh/a. Heating and cooling applications therefore account for roughly 62% and thus around 234 TWh/a of the final energy demand in this sector. In the services sector, as in the residential sector, final energy consumption for space heating is particularly relevant, at roughly 168 TWh/a. There is also lower demand for hot water, process heating and cooling applications in the services sector.



Endenergieverbrauch Wärme und Kälte nach Anwendungen 2018 in GWh/a	Final energy consumption for heating and cooling by application in 2018 in GWh/a
Wohngebäude	Residential
Industrie	Industry
Dienstleistungen	Services
Prozesswärme	Process heating
Warmwasser	Hot water
Raumwärme	Space heating
Klimakälte	Air conditioning
Prozesskälte	Process cooling
Gesamt	Total

Source: Own figure based on AGEB (2020a)

Figure 2: Final energy consumption for heating and cooling applications in 2018 in GWh/a

I.1.b. Useful energy to satisfy demand for heating and cooling

No official statistics are available in Germany on useful energy demand. For this reason useful energy demand is determined on the basis of final energy consumption, the heating and cooling technologies used (cf. I.2) and the individual processes and generation technologies used. The results for Part I.1.b. therefore represent the aggregated results for Part I.2.a. A detailed presentation of the status quo in terms of the generation technologies used for heating and cooling in the individual applications and sectors can be found in Part I.2.a.

Determining useful energy in the area of industrial process heating and cooling using a uniform approach that incorporates generalised factors is difficult. For process heating and cooling the useful energy is therefore calculated on the basis of the FORECAST energy demand model[5] of Fraunhofer ISI, which uses different statistical surveys on technologies and processes as a basis. Using the energy demand data recorded in this model for individual processes and generation technologies, the useful energy demand is determined on the basis of the respective reference efficiencies. In the case of low-temperature heating and cooling processes for the thermal conditioning of buildings, average efficiencies at technology level are used. The results of the building modelling used in the scenarios set out in the National Energy and Climate Plan serve as a basis (Kemmler et al., 2020).

Table 2 shows the average reference efficiencies of the individual heating and cooling technologies that result from the structure of the processes and the installed technologies in the individual sectors for 2018 and are used to convert final to useful energy.

[5] https://www.forecast-model.eu/forecast-en/index.php

Table 2: Reference efficiencies for determining useful energy

Technology	Annual efficiency [%]		
	Space heating / cooling	**Hot water**	**Process heating / cooling**
Natural gas central heating	91	78	
Fuel oil central heating	85	69	
Coal central heating	74	55	
Natural gas stove heating / point-of-use WH	70	77	
Fuel oil stove heating / point-of-use WH	70	40	
Coal stove heating / point-of-use WH	65	40	
Electric central heating	98	92	
Electric stove heating / point-of-use WH	98	92	
Biomass central heating	83	62	
Biomass stove heating / point-of-use WH	65	40	
Solar thermal	100	100	
Cogeneration plant	91	78	
Heat pump	309	225	
District heating consumption	96	80	
Compression cooling systems	500		
Absorption cooling system	70		
Furnaces 500-1,000°C			62
Furnaces >1,000°C			60
Steam turbines			74
Gas turbines			61
Gas-fired boiler (process heating)			76
Oil-fired boiler (process heating)			73
Electric boiler (process heating)			78
Process cooling <-30°C			1
Process cooling -30°C - 0°C			168
Process cooling 0°C - 15°C			347

Point-of-use WH = point-of-use water heating

Source: Own calculation of Fraunhofer ISI, Kemmler et al. (2020)

The distinction between useful and final energy is therefore uniform for all applications and sectors[6]. The approach involving the use of reference efficiencies means that a statement on the efficiency of the system technology can be derived from the comparison of final and useful energy. However, it is not possible to derive the extent to which heating and cooling demand could be reduced by means of alternative processes or efficiency measures at building level.

Figure 3 presents the results for useful energy demand for heating. The results show that the efficiency of energy use is different in the various sectors. In the residential sector the useful energy demand is approx. 455 TWh/a and the efficiency of energy use around 86.3%. This is achieved primarily due to the high efficiency in the area of space heating. Natural gas central heating systems account for a particularly large share here and, with annual efficiency of 91%, exhibit a high degree of efficiency. The services sector has a useful energy demand for heating of 187 TWh/a with an efficiency of approx. 87.8% and is therefore also highly efficient. It is clear from the above that a high level of efficiency has already been achieved in the residential and services sectors. In these sectors reducing useful energy consumption (and therefore final energy consumption) and switching fuels are therefore particularly good options for decarbonising the heating supply. In industry the useful energy demand for heating is 350 TWh/a and the efficiency is around 64.6%. This is due in particular to the high demand for process heating. Especially relevant here are industrial furnaces, which have an average efficiency of 61%.

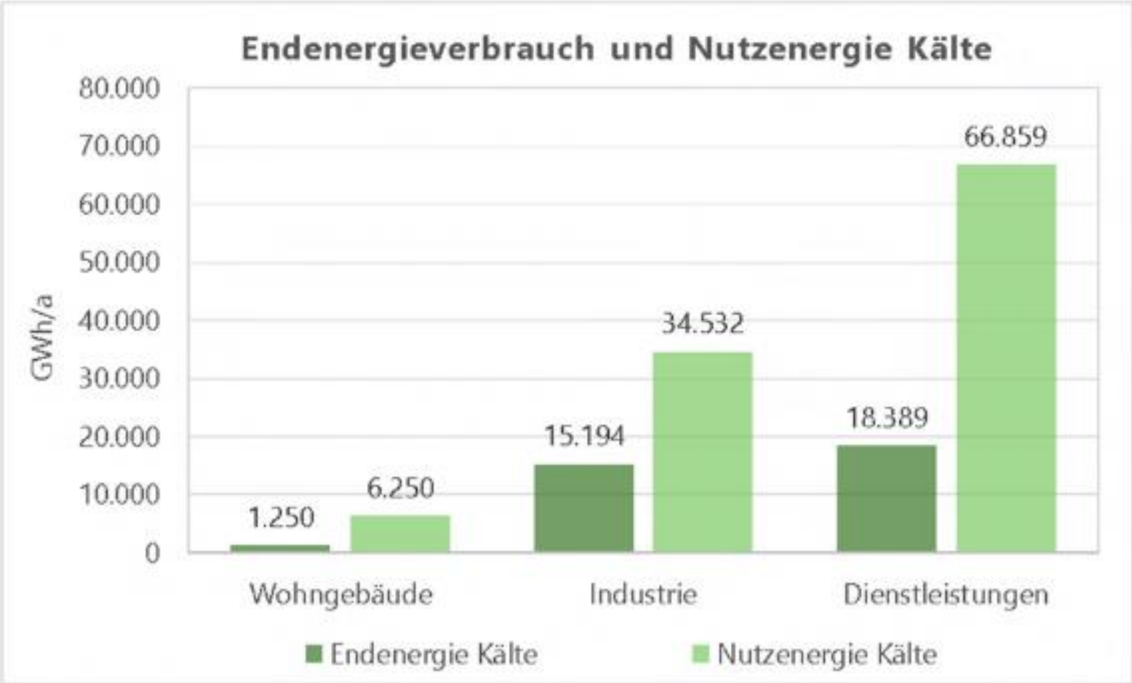
[6] In line with the energy balance at building level according to (DIN V 18599-2, 2011), the term 'useful energy' used here correctly represents the 'generator useful heat output to the heating system' or the 'generator useful cooling output to the cooling system'.

Endenergieverbrauch und Nutzenergie Wärme	Final energy consumption and useful energy for heating
Wohngebäude	Residential
Industrie	Industry
Dienstleistungen	Services
Endenergie Wärme	Final energy for heating
Nutzenergie Wärme	Useful energy for heating

Source: AGEB (2020); Federal Statistical Office 066, 064; AGEE-Stat (Working Group on Renewable Energy Statistics) (2020); Federal Statistical Office – microcensus supplementary survey; IWU (Institute for Housing and Environment) (2018); PROGNOS (2020); own calculation; Forecast Industry model

Figure 3: Final energy and useful energy consumption for heating in 2018

Figure 4 presents the results for useful energy in the area of cooling. For cooling applications particular use is made of compression cooling systems. With these systems (in a similar way to heat pumps) a large proportion of the energy needed is extracted from the environment. However, energy in the form of electricity is required to initiate the process. This electricity corresponds to the final energy demand. The useful energy consumption of the cooling application comprises the electricity used and the usable ambient energy. Consequently, for most applications the useful energy consumption is higher than the final energy consumption, as the ambient cold is not included in the final energy consumption. Cooling applications exhibit very high efficiency (500%) in the residential sector in particular. This is due to the fact that here energy is mainly used for space cooling and very low temperatures are not required. In the services sector the efficiency of cooling applications is somewhat lower (364%), as in this case some of the energy is also needed for process cooling applications, such as freezers, etc. A substantial portion of the energy is also used for process cooling in the industrial sector. In industry cooling applications have an average efficiency of around 227%.



Endenergieverbrauch und Nutzenergie Kälte	Final energy consumption and useful energy for cooling
Wohngebäude	Residential
Industrie	Industry
Dienstleistungen	Services
Endenergie Kälte	Final energy for cooling
Nutzenergie Kälte	Useful energy for cooling

Source: AGEB (2020); Federal Statistical Office 066, 064; AGEE-Stat (Working Group on Renewable Energy Statistics) (2020); Federal Statistical Office – microcensus supplementary survey; IWU (Institute for Housing and Environment) (2018); PROGNOS (2020); own calculation; Forecast model

Figure 4: Useful energy for cooling in 2018

I.2. Heating and cooling

I.2.a. Technologies for supplying heating and cooling

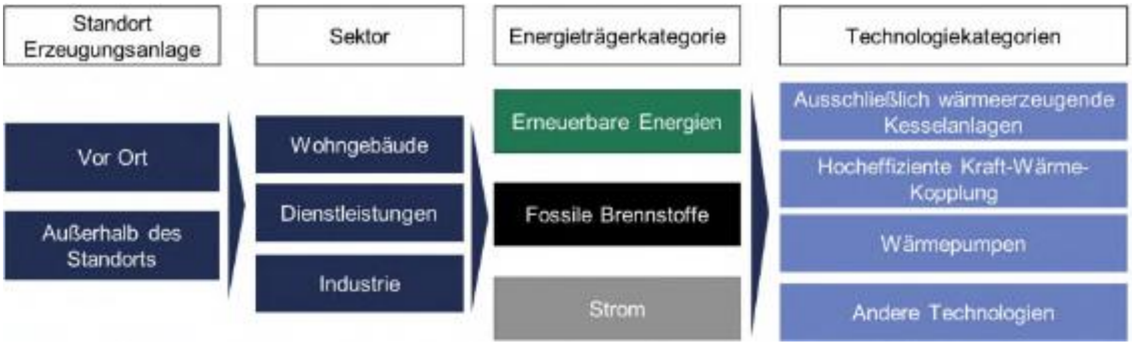
In accordance with the definition contained in the Directive, heating and cooling are broken down into the technology sectors shown below (Table 3). To aid understanding, the names of the technology categories used in Annex VIII of the EED have been translated into the customary breakdown on the basis of decentralised and centralised supply technologies.

Table 3: Breakdown of technologies for supplying heating and cooling

Annex VIII - Directive 2012/27/EU	**Allocation to technology**
Provided on-site in residential and service	Decentralised heating and cooling technologies in

sites	residential buildings and non-residential buildings (TCS)
Provided on-site in non-service and non-residential sites	Decentralised heating and cooling technologies in industry and other sectors
Provided off-site	Centralised heating and cooling technologies in heating networks

In addition to this breakdown, for all supplies a distinction is made based on whether they concern renewable energies, fossil fuels or electricity[7] and based on the technology categories used (Figure 5). As part of this analysis the generation technologies are also broken down further (cf. Table 2). A distinction is also made on the basis of temperature level for the process heating and process cooling applications. The breakdown by technology in Part I.2. provides the basis for the calculation of useful energy in the individual sectors.



Standort Erzeugungsanlage	Location of generation installation
Vor Ort	On site
Außerhalb des Standorts	Off site
Sektor	Sector
Wohngebäude	Residential
Dienstleistungen	Services
Industrie	Industry
Energieträgerkategorie	Energy source category
Erneuerbare Energien	Renewable energies
Fossile Brennstoffe	Fossil fuels
Strom	Electricity

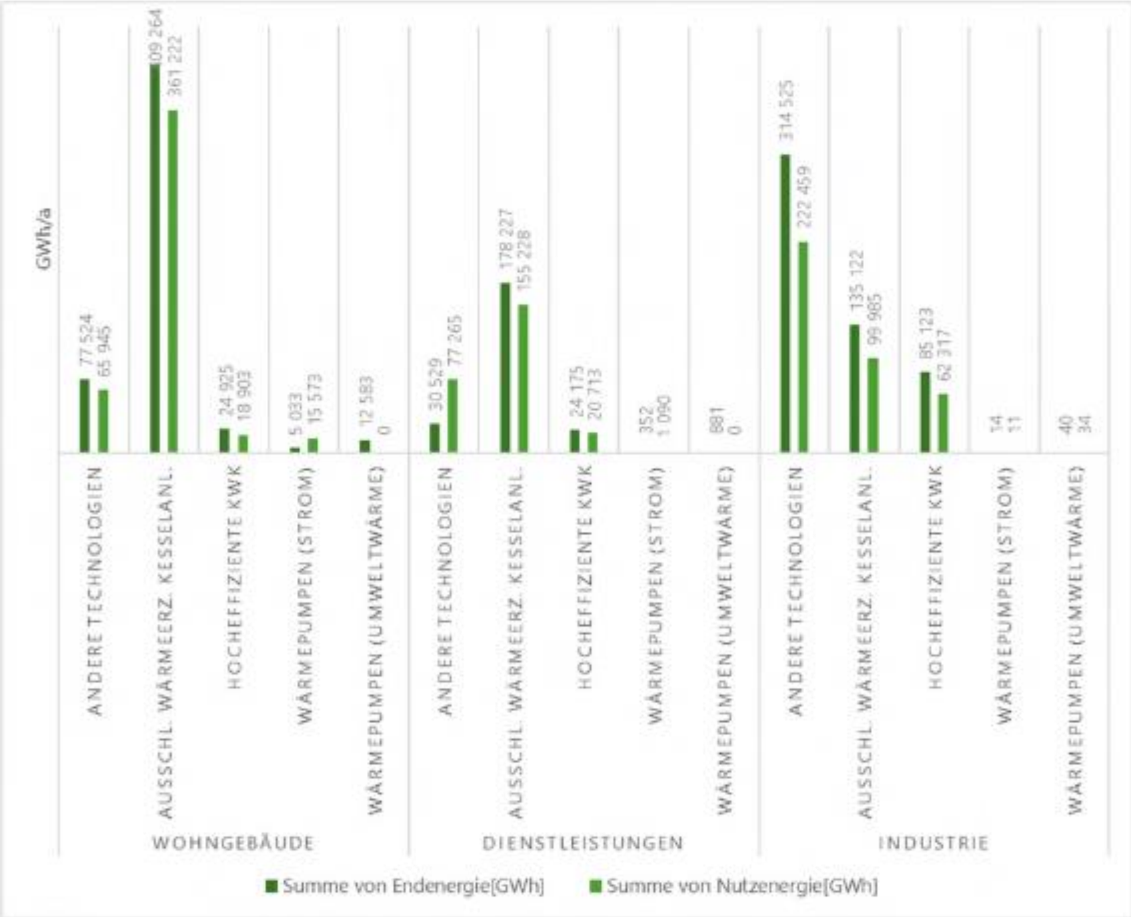
[7] Here the assessment is carried out at the level of final energy for the area of heating and cooling. Electricity is therefore presented as an energy source. The share of renewable energies in the area of electricity is not assessed here, as these are to be allocated to the electricity sector or transformation sector. The supply of heating and cooling via heat pumps is broken down on the basis of electricity and ambient heat.

Technologiekategorien	Technology categories
Ausschließlich wärmeerzeugende Kesselanla-gen	Heat-only boilers
Hocheffiziente Kraft-Wärme-Kopplung	High-efficiency heat and power cogeneration
Wärmepumpen	Heat pumps
Andere Technologien	Other technologies

Source: Own figure of IREES

Figure 5: Breakdown of heating and cooling in accordance with Annex VIII EED

Figure 6 presents the final and useful energy consumption of the individual sectors, broken down into the technology categories required by the Directive. It can be seen that, in the residential and services sectors, heat-only boilers in particular account for a large proportion of the energy demand. This is consistent with the energy demands of the individual sectors presented previously. In the residential and services sectors consumption for space heating and hot water is particularly relevant, and these are provided by heat-only boilers. In residential buildings approx. 409 TWh/a of final energy is used in heat-only boilers. Within the technology mix this corresponds to roughly 77% of final energy consumption. In the services sector approx. 178 TWh/a of final energy is used in heat-only boilers. Within the technology mix this corresponds to roughly 76% of final energy consumption. The ‘other technologies’ category is particularly relevant in industry. This mainly comprises technologies for supplying process heating, such as industrial furnaces or non-high-efficiency CHP installations. In the industrial sector approx. 315 TWh/a of final energy is used in the ‘other technologies’ category. Within the technology mix this corresponds to roughly 59% of final energy consumption. A detailed presentation of the results for the individual sectors can be found in the following chapters.



ANDERE TECHNOLOGIEN	OTHER TECHNOLOGIES
AUSSCHL. WÄRMEERZ. KESSELANL.	HEAT-ONLY BOILERS
HOCHEFFIZIENTE KWK	HIGH-EFFICIENCY CHP
WÄRMEPUMPEN (STROM)	HEAT PUMPS (ELECTRICITY)
WÄRMEPUMPEN (UMWELTWÄRME)	HEAT PUMPS (AMBIENT HEAT)
WOHNGEBÄUDE	RESIDENTIAL
DIENSTLEISTUNGEN	SERVICES
INDUSTRIE	INDUSTRY
Summe von Endenergie[GWh]	Sum of final energy[GWh]
Summe von Nutzenergie[GWh]	Sum of useful energy[GWh]

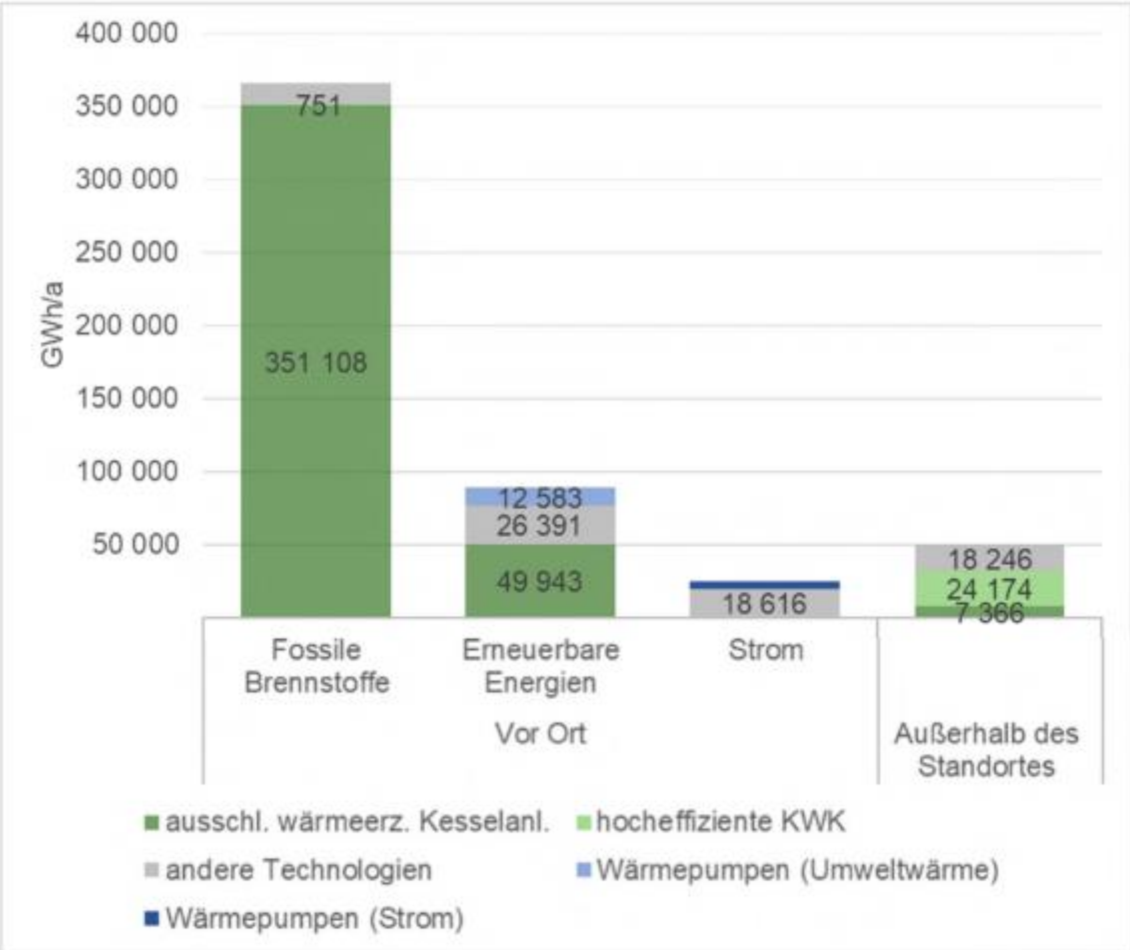
Source: Own calculation based on AGEB (2020a); AGEE-Stat (2020); Cischinsky & Diefenbach (2018); StaBuA (2020a, 2020b); Statische Ämter des Bundes und der Länder (2019); Wünsch et al. (2019); Forecast model

Figure 6: Final and useful energy consumption by technology categories

Heating and cooling in the residential sector

In addition to the energy use assessment of the Energy Balance Working Group (AGEB, 2020a), the basis for determining the heating and cooling supply in residential buildings is formed by the microcensus supplementary survey – Living in Germany (*Wohnen in Deutschland*), the housing stock data collection study 2016 (*Datenerhebung Wohngebäudebestand 2016*), new-build statistics and data from the current evaluation of the Cogeneration Act (KWKG).

Figure 7 shows the final energy consumption for heating and cooling for residential buildings at the level of technology categories, broken down as specified in Annex VIII of the EED. As already shown in the general overview of final energy consumption, cooling currently accounts for a very small share, with the result that the presentation at technology level is dominated by heating systems. Heat-only boilers have a dominant share under both fossil fuels and renewable energy sources. Decentralised high-efficiency CHP installations[8] account for a very small share of installed heat generators. In the residential sector the 'other technologies' category includes fossil-fuel single-room stoves and point-of-use water heating, as well as electric single-room heaters and solar thermal. 'Off site' shows the generation technologies used in the district heating mix, which are discussed in more detail at the end of this section for the entire district heating supply across all demand sectors.



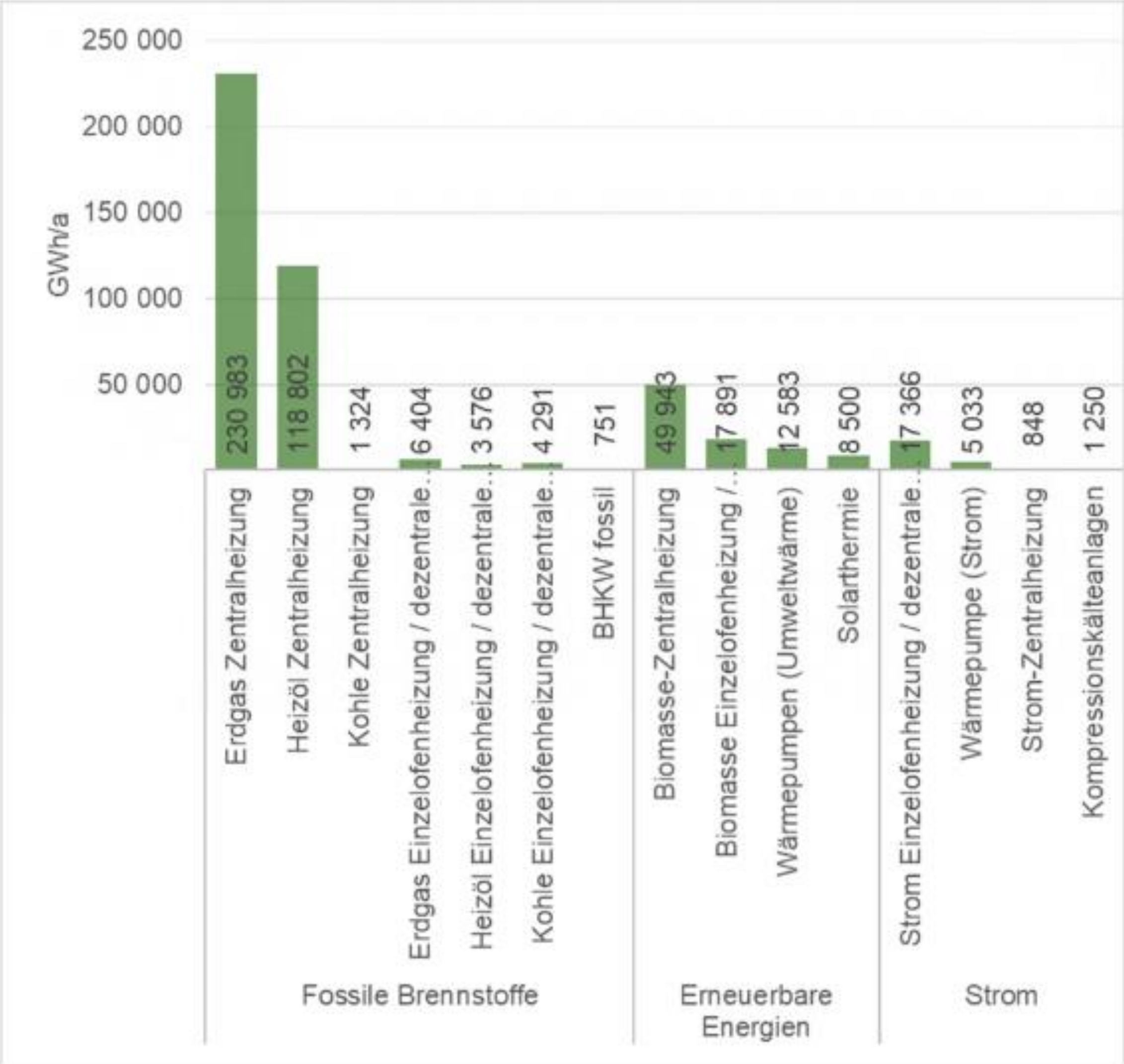
[8] The CHP installations installed in the residential sector should be placed in the capacity class up to 20 kWel (40–58 kWth). This segment is also referred to by manufacturers as mini-cogeneration plants or, in the capacity class up to 2.4 kWel, as nano-cogeneration plants.

Fossile Brennstoffe	Fossil fuels
Erneuerbare Energien	Renewable energies
Strom	Electricity
Vor Ort	On site
Außerhalb des Standortes	Off site
ausschl. wärmeerz. Kesselanl.	heat-only boilers
hocheffiziente KWK	high-efficiency CHP
andere Technologien	other technologies
Wärmepumpen (Umweltwärme)	heat pumps (ambient heat)
Wärmepumpen (Strom)	heat pumps (electricity)

Source: Own calculation based on AGEB (2020a); AGEE-Stat (2020); Cischinsky & Diefenbach (2018); StaBuA (2020a, 2020b); Statische Ämter des Bundes und der Länder (2019); Wünsch et al. (2019)

Figure 7: Heating and cooling in the residential sector in 2018

To obtain an overview of the installed decentralised supply technologies that are grouped together in the EED technology categories, Figure 8 shows an even more detailed breakdown of final energy consumption at technology level.



Erdgas Zentralheizung	Natural gas central heating
Heizöl Zentralheizung	Fuel oil central heating
Kohle Zentralheizung	Coal central heating
Erdgas Einzelofenheizung / dezentrale...	Natural gas stove heating / point-of-use...
Heizöl Einzelofenheizung / dezentrale...	Fuel oil stove heating / point-of-use...
Kohle Einzelofenheizung / dezentrale...	Coal stove heating / point-of-use...
BHKW fossil	Cogeneration plant – fossil
Fossile Brennstoffe	Fossil fuels
Biomasse-Zentralheizung	Biomass central heating
Biomasse Einzelofenheizung /...	Biomass stove heating / ...
Wärmepumpen (Umweltwärme)	Heat pumps (ambient heat)
Solarthermie	Solar thermal
Erneuerbare Energien	Renewable energies
Strom Einzelofenheizung / dezentrale...	Electric stove heating / point-of-use...

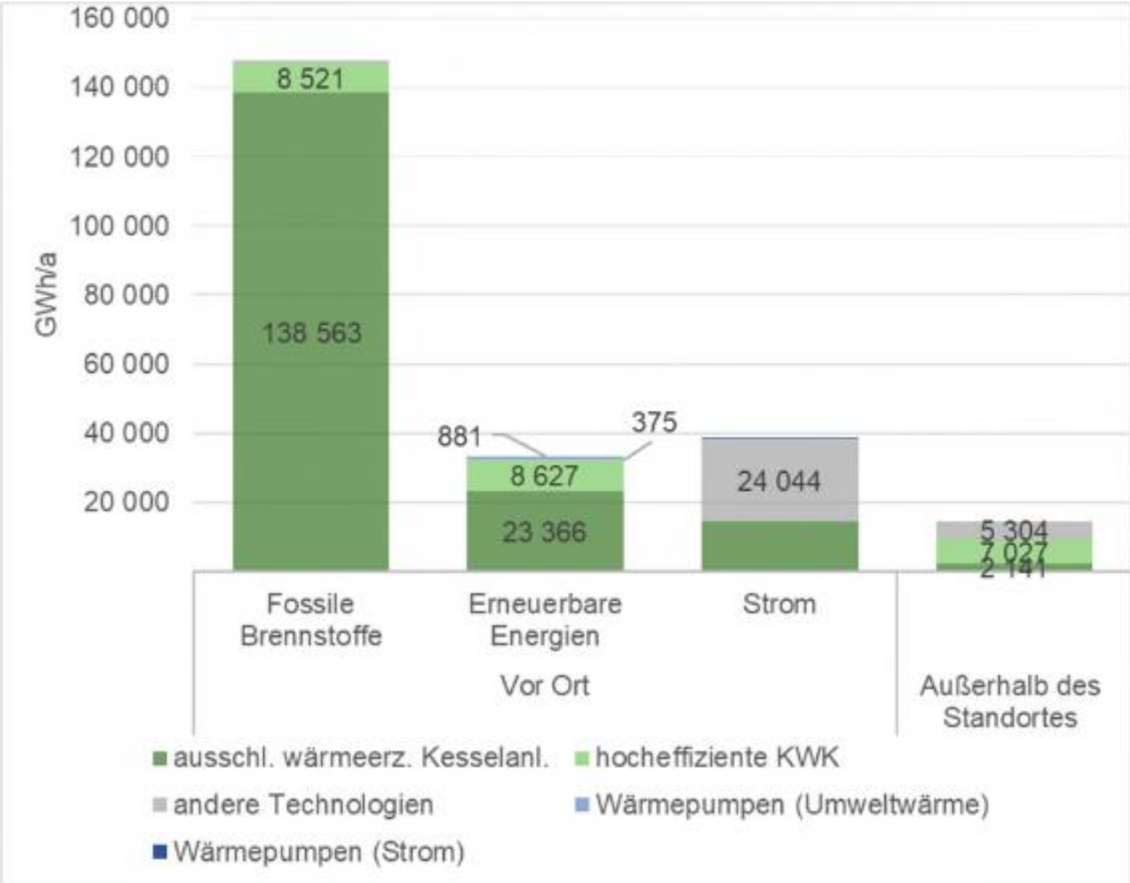
Wärmepumpe (Strom)	Heat pump (electricity)
Strom-Zentralheizung	Electric central heating
Kompressionskälteanlagen	Compression cooling systems
Strom	Electricity

Source: Own calculation based on AGEB (2020a); AGEE-Stat (2020); Cischinsky & Diefenbach (2018); StaBuA (2020a, 2020b); Statische Ämter des Bundes und der Länder (2019); Wünsch et al. (2019)

Figure 8: More detailed presentation of heating and cooling technologies in the residential sector in 2018

Heating and cooling in the services sector

Figure 9 shows the final energy consumption for heating and cooling at the level of energy source and technology categories for the services sector. In terms of the way the technologies split, the picture is similar to that in the residential sector. Differences can be seen in particular in the use of heat pumps and solar thermal, which to date account for only very limited shares in the non-residential building stock. Overall, the use of electricity is also higher than in the residential sector, which can be explained in particular by the higher share of air conditioning.



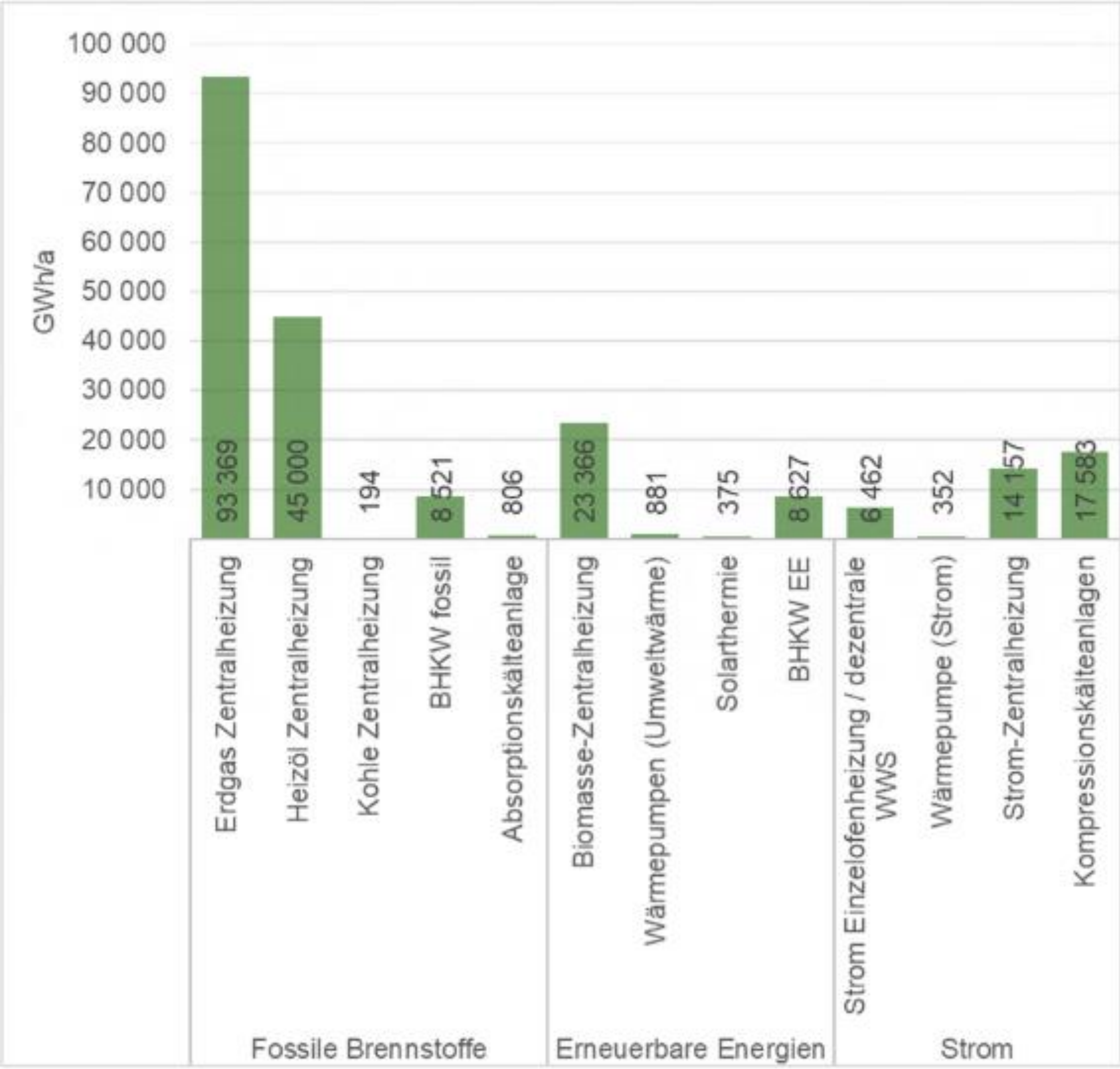
Fossile Brennstoffe	Fossil fuels
Erneuerbare Energien	Renewable energies

Strom	Electricity
Vor Ort	On site
Außerhalb des Standortes	Off site
ausschl. wärmeerz. Kesselanl.	heat-only boilers
hocheffiziente KWK	high-efficiency CHP
andere Technologien	other technologies
Wärmepumpen (Umweltwärme)	heat pumps (ambient heat)
Wärmepumpen (Strom)	heat pumps (electricity)

Source: Own calculation based on AGEB (2020a); AGEE-Stat (2020); Cischinsky & Diefenbach (2018); StaBuA (2020a, 2020b); Statische Ämter des Bundes und der Länder (2019); Wünsch et al. (2019)

Figure 9: Heating and cooling in the services sector in 2018

In line with the information presented for the residential sector, Figure 10 shows a more detailed breakdown of decentralised supply technologies that goes beyond the categorisation set out in the EED.



Erdgas Zentralheizung	Natural gas central heating
Heizöl Zentralheizung	Fuel oil central heating
Kohle Zentralheizung	Coal central heating
BHKW fossil	Cogeneration plant – fossil
Absorptionskälteanlage	Absorption cooling system
Fossile Brennstoffe	Fossil fuels
Biomasse-Zentralheizung	Biomass central heating
Wärmepumpen (Umweltwärme)	Heat pumps (ambient heat)
Solarthermie	Solar thermal
BHKW EE	Cogeneration plant – RE
Erneuerbare Energien	Renewable energies
Strom Einzelofenheizung / dezentrale WWS	Electric stove heating / point-of-use WH
Wärmepumpe (Strom)	Heat pump (electricity)
Strom-Zentralheizung	Electric central heating

Kompressionskälteanlagen	Compression cooling systems
Strom	Electricity

Source: Own calculation based on AGEB (2020); Federal Statistical Office 066, 064; AGEE-Stat (Working Group on Renewable Energy Statistics) (2020); Federal Statistical Office – microcensus supplementary survey; IWU (2018); PROGNOS (2020); own calculation; Forecast model

Figure 10: More detailed presentation of heating and cooling technologies in the services sector in 2018

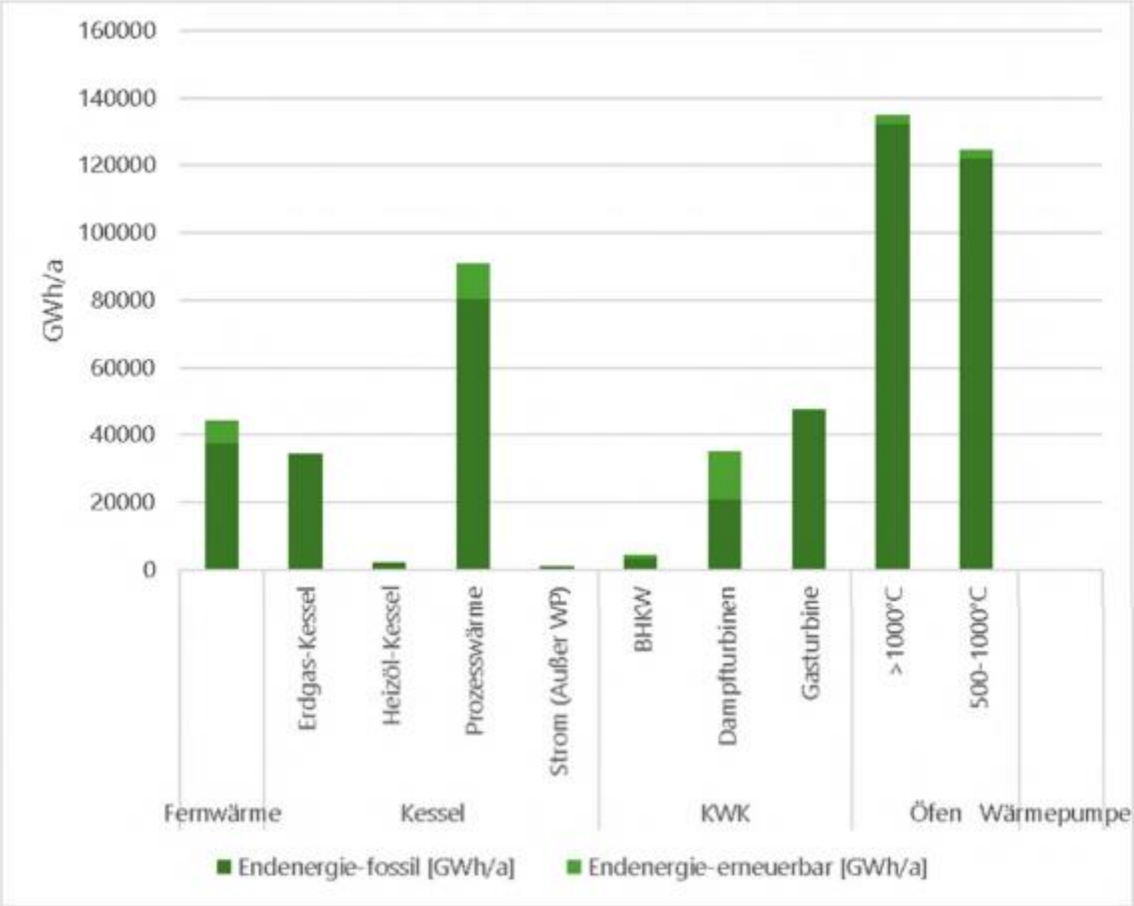
Heating and cooling in the industrial sector

For industry, as explained in Part I.1, the FORECAST energy demand model of Fraunhofer ISI is used, which employs a bottom-up approach to disaggregate the energy demand in industry at product level from different processes (e.g. blast furnace steel, flat glass, clinker), temperature levels and generation technologies. The production volume for the products is calculated from literature and sector-specific databases (World Steel Association, CEPI, Cembureau, Eurochlor, etc.), making it possible to determine the sector-specific process energy demand. To allow comparison of the data, various data sources are used, e.g. on company sizes or the Prodcom database[9] (Fraunhofer ISI, 2020). With regard to the space heating demand in industry, in line with the results of the AGEB, calculations are performed based on the specific energy demand per square metre and building areas. The results obtained in this way therefore provide an overview of the final energy used in industry, broken down by temperature level, technology area and technology. To ensure the consistency of the data, they are compared in aggregated form with the energy statistics (AGEB, 2020a) of the AGEB.

Figure 11 shows the final energy consumption for heating in industry in 2018. This amounts to a total of approx. 519 TWh[10]. The technologies presented here are broken down in greater detail than required by the Directive. For this reason the technologies have been aggregated into the prescribed categories. The CHP category shows all CHP installations (high-efficiency and non-high-efficiency). The final energy consumption due to high-efficiency CHP installations amounts to roughly 63,650 GWh in total. It can be seen that the lion's share of the final energy demand in industry in the area of heating can be attributed to the supply of process heating in furnaces. This alone accounts for around 254 TWh and therefore roughly 49% of the final energy required. A distinction is also made between final energy supplied from renewable and fossil sources. Energy from fossil fuels continues to dominate in industry. With the exception of district heating, the supply of heating in industry is allocated exclusively to the 'provided on-site in non-service and non-residential sites' category. District heating is allocated to the 'provided off-site' category.

[9] https://www.forecast-model.eu/forecast-en/content/methodology.php

[10] The minimal deviation of ~3% from the value given in Part I.1. for final energy demand is based on the disaggregation at individual technology level in AGEB's energy balance (2020). Fraunhofer ISI is also responsible for drawing up the industrial energy use assessments for the Energy Balance Working Group. An updated technology breakdown in the FORECAST energy demand model was used for the useful energy demand calculations presented here.

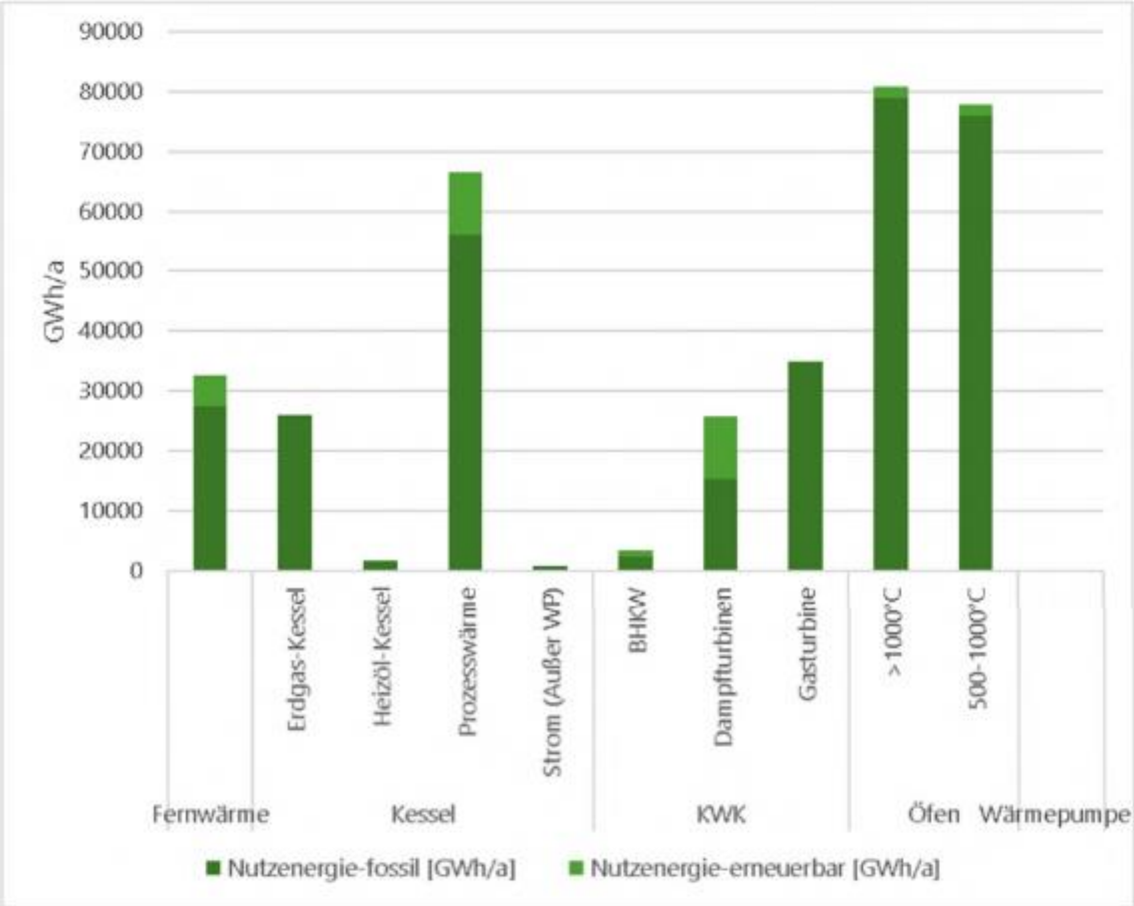


Erdgas-Kessel	Gas-fired boiler
Heizöl-Kessel	Oil-fired boiler
Prozesswärme	Process heating
Strom (Außer WP)	Electricity (excluding HP)
BHKW	Cogeneration plant
Dampfturbinen	Steam turbines
Gasturbine	Gas turbine
Fernwärme	District heating
Kessel	Boilers
KWK	CHP
Öfen	Furnaces
Wärmepumpe	Heat pump
Endenergie-fossil [GWh/a]	Final energy – fossil [GWh/a]
Endenergie-erneuerbar [GWh/a]	Final energy – renewable [GWh/a]

Source: Own calculation

Figure 11: Final energy consumption for heating in industry in 2018

Figure 12 shows the calculated useful energy for the supply of heating in industry. The technologies presented here are broken down in greater detail than required by the Directive. For this reason the technologies have been aggregated into the prescribed categories. The CHP category shows all CHP installations (high-efficiency and non-high-efficiency). The useful energy consumption due to high-efficiency CHP installations amounts to roughly 46,626 GWh in total. To calculate useful energy, as explained above, reference efficiencies for the individual technologies are recorded, from which the useful energy demand can be calculated. As in the case of the results for final energy consumption, here again the requirements of the Directive are exceeded and the technologies are assigned to the required categories.



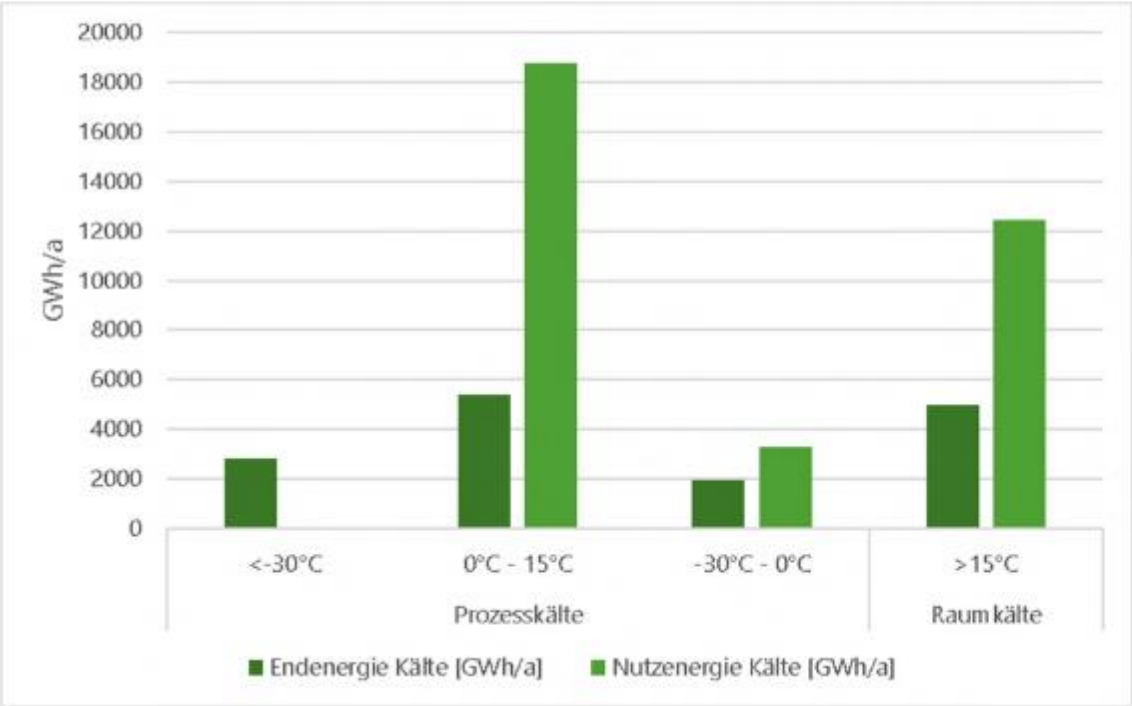
Erdgas-Kessel	Gas-fired boiler
Heizöl-Kessel	Oil-fired boiler
Prozesswärme	Process heating
Strom (Außer WP)	Electricity (excluding HP)
BHKW	Cogeneration plant
Dampfturbinen	Steam turbines
Gasturbine	Gas turbine
Fernwärme	District heating
Kessel	Boilers
KWK	CHP

Öfen	Furnaces
Wärmepumpe	Heat pump
Nutzenergie-fossil [GWh/a]	Useful energy – fossil [GWh/a]
Nutzenergie-erneuerbar [GWh/a]	Useful energy – renewable [GWh/a]

Source: Own calculation

Figure 12: Useful energy consumption for heating in industry in 2018

Figure 13 shows the final and useful energy consumption for cooling applications in industry for 2018. The technologies for supplying process cooling at temperatures below -30 °C exhibit very low efficiencies of only around 1% on average. The technologies for supplying process cooling above -30 °C have efficiencies of more than 100%. For this reason the useful energy exceeds the final energy for these technologies.



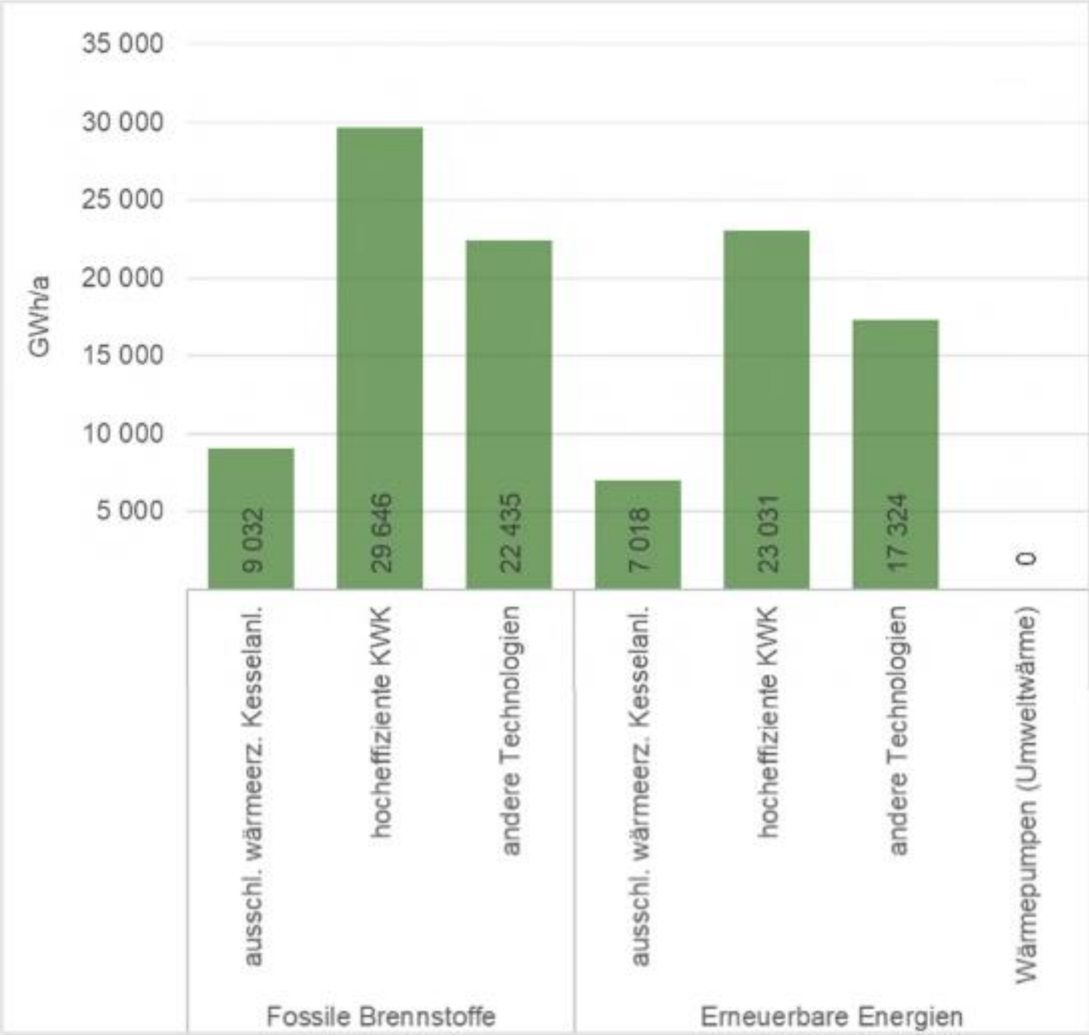
Prozesskälte	Process cooling
Raumkälte	Space cooling
Endenergie Kälte [GWh/a]	Final energy for cooling [GWh/a]
Nutzenergie Kälte [GWh/a]	Useful energy for cooling [GWh/a]

Source: Own calculation

Figure 13: Final and useful energy consumption for cooling in industry in 2018

Off-site heating and cooling supply (district heating)

The off-site heating and cooling supply comprises heating and cooling supplied via heating networks. Figure 14 shows the energy source and technology categories for this area. The extent to which the supply may differ between demand sectors has not been recorded in the statistics. The level of assessment shown in the following figure is the final energy, i.e. the quantity of transmitted heating and cooling that the demand sectors purchase from the heating network.[11]



ausschl. wärmeerz. Kesselanl.	heat-only boilers
hocheffiziente KWK	high-efficiency CHP
andere Technologien	other technologies
Fossile Brennstoffe	Fossil fuels
Wärmepumpen (Umweltwärme)	heat pumps (ambient heat)

[11] In Part I.2.c, on the other hand, net heat generation in the area of district heating is discussed at transformation sector level.

Erneuerbare Energien	Renewable energies

Source: Own calculation based on AGEB (2020); Federal Statistical Office 066, 064; AGEE-Stat (Working Group on Renewable Energy Statistics) (2020)

Figure 14: Off-site heating and cooling supply (district heating)

I.2.b. Installations and potentials for waste heat and cold

The Directive provides for an overview of installations and potentials for the utilisation of waste heat and cold. This overview should identify installations that generate waste heat or cold and their potential heating or cooling supply, in GWh per year:

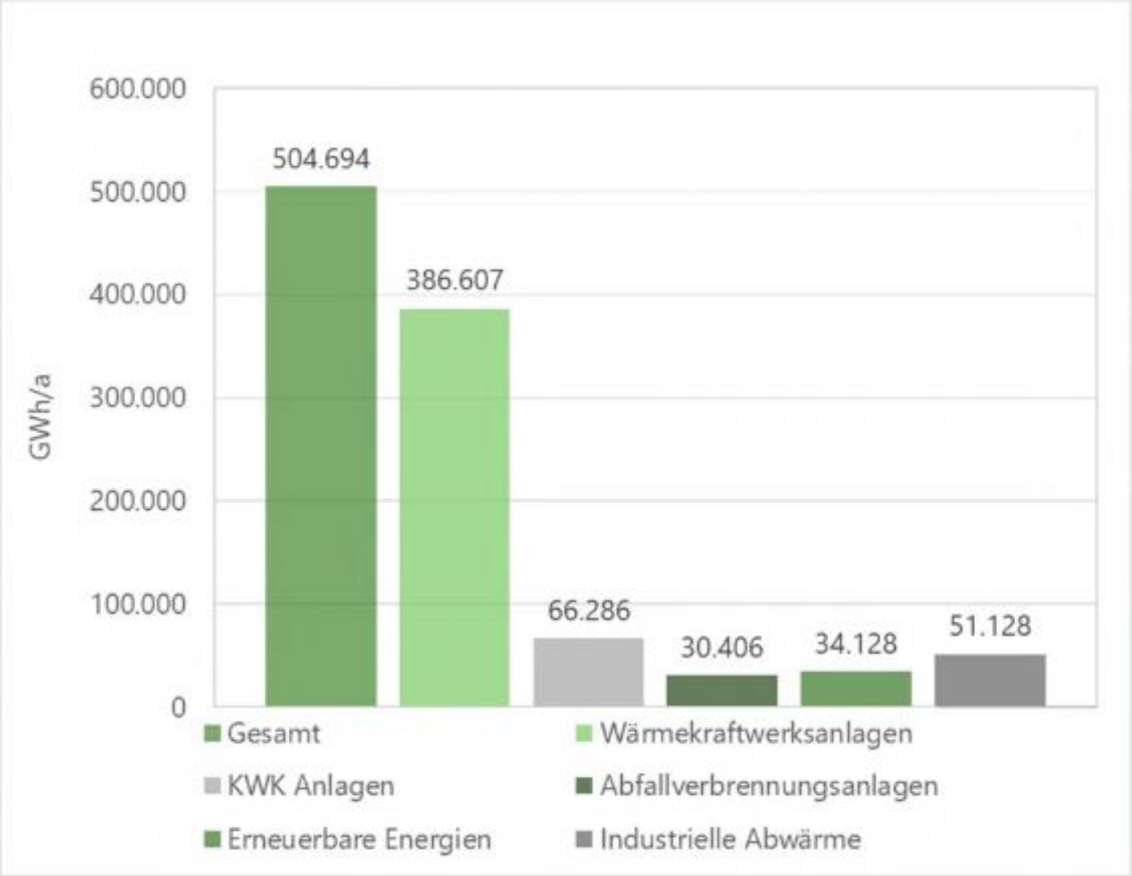
a) thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MW;
b) heat and power cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW;
c) waste incineration plants;
d) renewable energy installations with a total thermal input exceeding 20 MW other than the installations specified under point 2(b)(i) and (ii) generating heating or cooling using the energy from renewable sources;
e) industrial installations with a total thermal input exceeding 20 MW which can provide waste heat;

From a technical perspective, excess heat can be described as ‘unwanted’ heat generated by a process (Pehnt, 2010). From a social perspective it can be described as heat that is a by-product of processes and is not currently being used, but could be used in the future by society and industry (Viklund & Johansson, 2014). It is generated either as municipal waste heat in non-industrial processes (e.g. computer centres or sewage treatment plants) or in industrial processes that use process heating.

Whereas in Germany waste heat potentials are generally examined and discussed within the context of the possible use of waste heat from industrial processes, the definition in the Directive also covers the potentials arising from electricity generation installations within the public supply network (thermal power generation installations and CHP). The installations that generate waste heat and cold from renewable energies comprise thermal power generation installations, CHP installations and waste incineration plants that use renewable energy sources. In the case of thermal power generation installations, CHP installations and waste incineration plants the theoretical waste heat potential is shown. For waste heat from industrial processes the technical potential (supply potential) is indicated, together with the technical potential for use in heating networks (demand potential) as an additional element.

The types of installations are distinguished on the basis of EU Directive 2012/27/EU. Thermal power generation installations are therefore power plants without their own heat extraction. All power plants with heat extraction are taken into account as installations with cogeneration. Waste incineration plants (WIP) also cover refuse-derived-fuel (RDF) plants.

An overview of the waste heat potentials in Germany is presented in Figure 15. It can be very clearly seen that there is considerable potential in particular in the area of thermal power generation installations and CHP installations. It is worth reiterating here that the potentials for thermal power generation installations, CHP installations, waste incineration plants and renewable energies concern the purely theoretical potential.



Gesamt	Total
KWK Anlagen	CHP installations
Erneuerbare Energien	Renewable energies
Wärmekraftwerksanlagen	Thermal power generation installations
Abfallverbrennungsanlagen	Waste incineration plants
Industrielle Abwärme	Industrial waste heat

Source: Own calculation

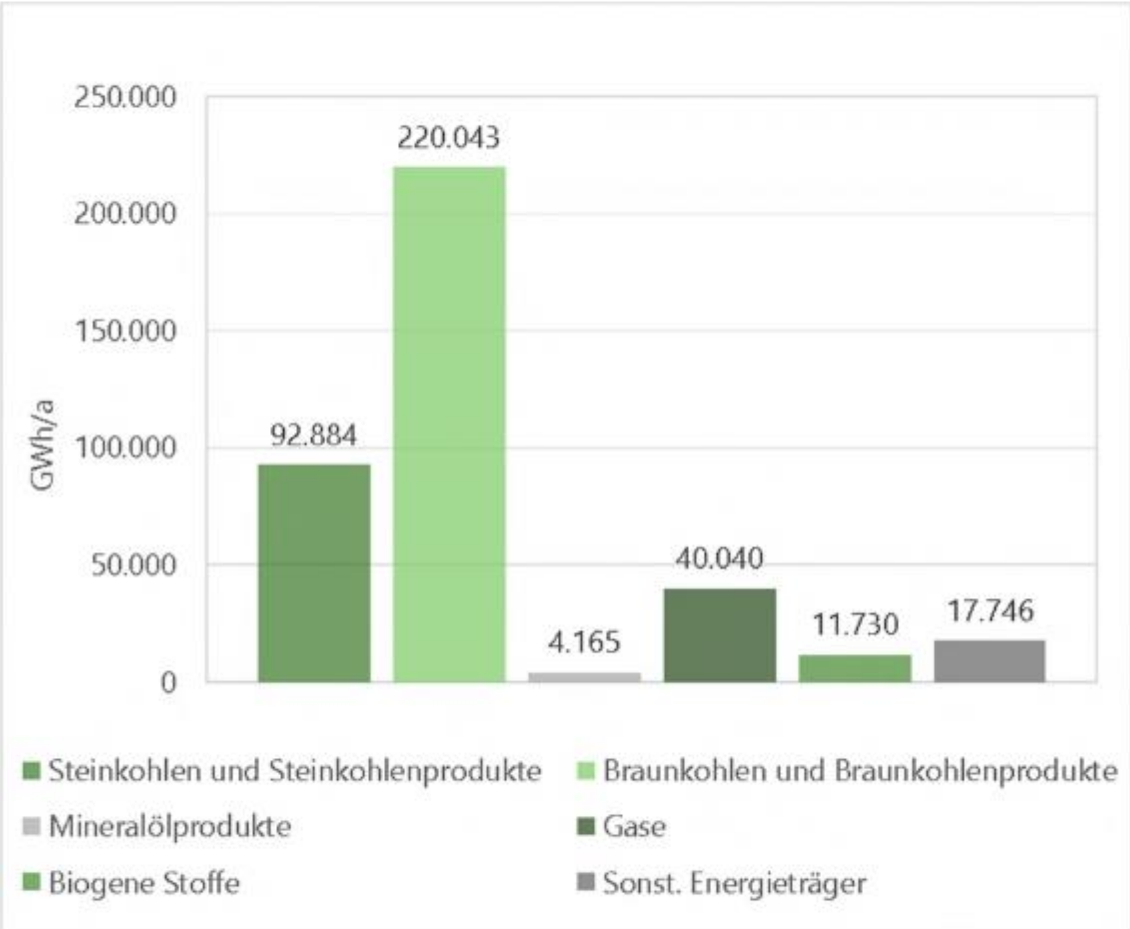
Figure 15: Potentials for waste heat utilisation in Germany

The Directive also requires waste cold to be considered in addition to waste heat. In Germany demand for cooling is very low overall by comparison with heating demand. In total, demand for cooling accounts for less than 5% of Germany's thermal energy demand. It generally takes the form of diffuse cold in cooling processes and is therefore difficult to recover. Waste heat is often found in flue gases, for example, and can thus be utilised more easily. For the reasons outlined above and due to the very minor role that cooling plays within the German energy system, waste cold is not examined in more detail within the context of this report.

Thermal power generation installations

To determine the potential quantity of waste heat from thermal power generation installations, use is made of data in accordance with Section 3 of the Energy Statistics Act (EnStatG). These data indicate the capacity, the energy generation and the energy source input, broken down by different energy sources. Installations for the generation of electricity and heat that have an electrical capacity greater than 1 MW are recorded here. All of these installations are used to assess the waste heat potential, which means that the requirements laid down are exceeded.

To determine the potential of the available waste heat, it is assumed that the energy generated in the form of electricity and the quantity of energy sources used does not change. This means that retrofitting to allow waste heat utilisation does not change the operation of the thermal power generation installations to date. For this reason the theoretical potential for waste heat generation is indicated here. Theoretically, the total amount of energy that is available in energy sources is released when these energy sources are burned. In thermal power generation installations some of this energy is converted into electricity and the remainder into heat / waste heat. Figure 16 shows the theoretical potential for the utilisation of waste heat from existing thermal power generation installations in Germany.



Steinkohlen und Steinkohlenprodukte	Hard coal and hard coal products
Mineralölprodukte	Mineral oil products
Biogene Stoffe	Biogenic substances
Braunkohlen und Braunkohlenprodukte	Brown coal and brown coal products
Gase	Gases

Sonst. Energieträger	Other energy sources

Source: Own calculation

Figure 16: Potential for utilisation of waste heat from thermal power generation installations

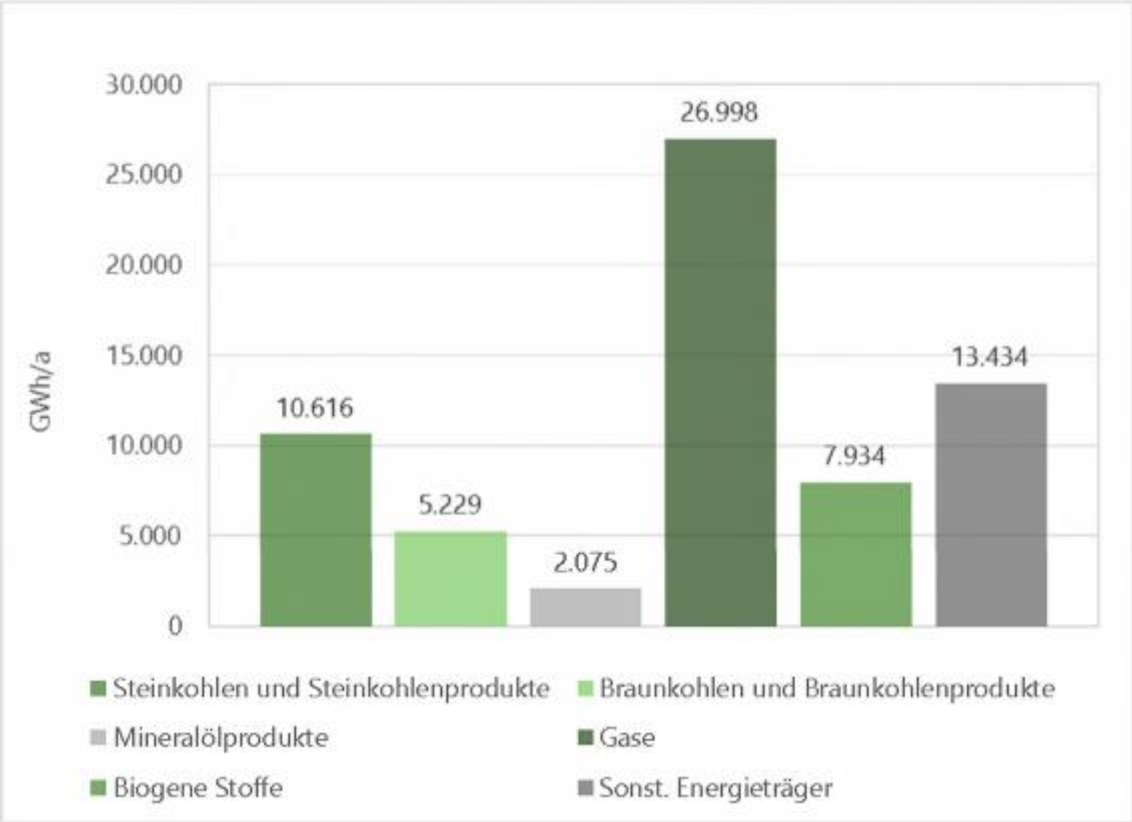
In the above figure natural gas, petroleum gas, mine gas, coke oven gas, blast furnace gas, converter gas, hydrogen and other manufactured gases are classified as gases. Solid biogenic substances, liquid biogenic substances, biogas, biomethane, sewage treatment plant gas, landfill gas and sewage sludge are classified as biogenic substances.

In total, this results in a potential of around 386 TWh for thermal power generation installations. In addition, there is also a theoretical potential for the utilisation of waste heat from nuclear power stations. This is not included in the figure, as the nuclear power plants that are still operating will be taken offline by the end of 2022 at the latest[12]. For the sake of completeness, however, it is pointed out that in 2018 the waste heat potential of nuclear power plants in Germany was approx. 154 TWh.

CHP installations

As in the case of thermal power generation installations, to determine the potentially usable waste heat from CHP installations, the theoretical potential is indicated. Here again data in accordance with Section 3 EnStatG are used. Figure 17 shows the potential for the utilisation of waste heat from existing CHP installations. Set against the potential from thermal power generation installations, it is clear that CHP installations primarily use natural gas as an energy source. Waste, which comes under the category of ‘other energy sources’, also accounts for a significant share of the energy sources used at CHP installations.

[12] Cf. Section 7 of the ‘Act on the peaceful use of nuclear energy and protection against its risks’ (‘*Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren*’)



Steinkohlen und Steinkohlenprodukte	Hard coal and hard coal products
Mineralölprodukte	Mineral oil products
Biogene Stoffe	Biogenic substances
Braunkohlen und Braunkohlenprodukte	Brown coal and brown coal products
Gase	Gases
Sonst. Energieträger	Other energy sources

Source: Own calculation

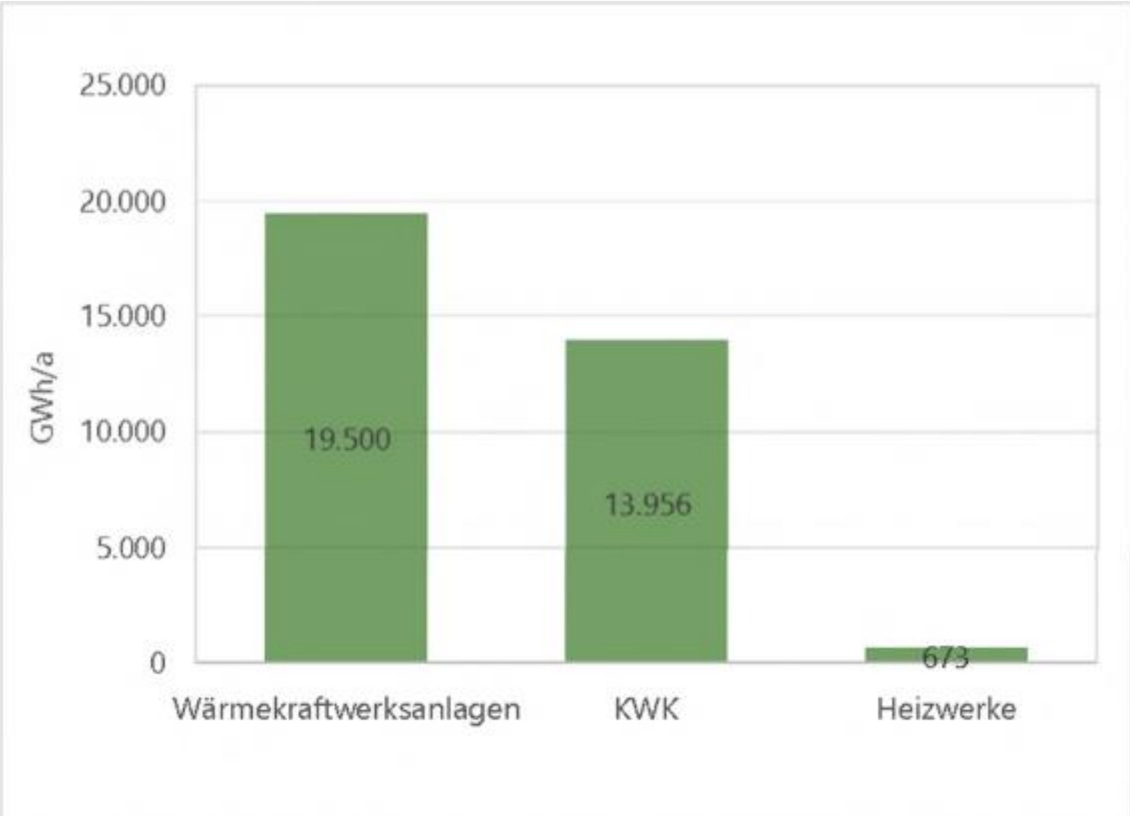
Figure 17: Potential for utilisation of waste heat from CHP installations

Waste incineration plants

To determine the waste heat potential of waste incineration plants, use is made of data in accordance with Section 3 and Section 5 EnStatG, in addition to the data collected in Part I.3.b. The data under Section 3 EnStatG include power plants for the general supply of energy, and those of industry, that run on waste. The data under Section 5 EnStatG include heating plants that run on waste. However, these account for only a very small portion of the heat generated from waste, as the bulk of the plants are used for combined heat and power generation. Methodologically speaking, to determine the potential of the quantity of waste heat, the theoretical potential is stated once again. The theoretical waste heat potential in this case is approx. **30 TWh**. Some of this potential is also covered in the sections on thermal power generation installations and CHP installations, as they also use waste as an energy source. More than 29 TWh of the waste heat potential stemming from waste is included in the sections on thermal power generation installations and CHP installations.

Renewable energy installations

In the text that follows thermal power generation installations, CHP installations and heating plants that use renewable energies as an energy source are referred to as renewable energy installations. Energy generation installations such as solar and wind farms, which are designated as renewable energies in the traditional sense, do not generate any usable waste heat. Figure 18 shows the waste heat potential of installations that use renewable energies as an energy source. Here again it is apparent that existing thermal power generation installations demonstrate greater potential for waste heat utilisation than CHP installations and heating plants. The potentials presented here are included in the general waste heat potentials of thermal power generation installations and CHP installations indicated above.



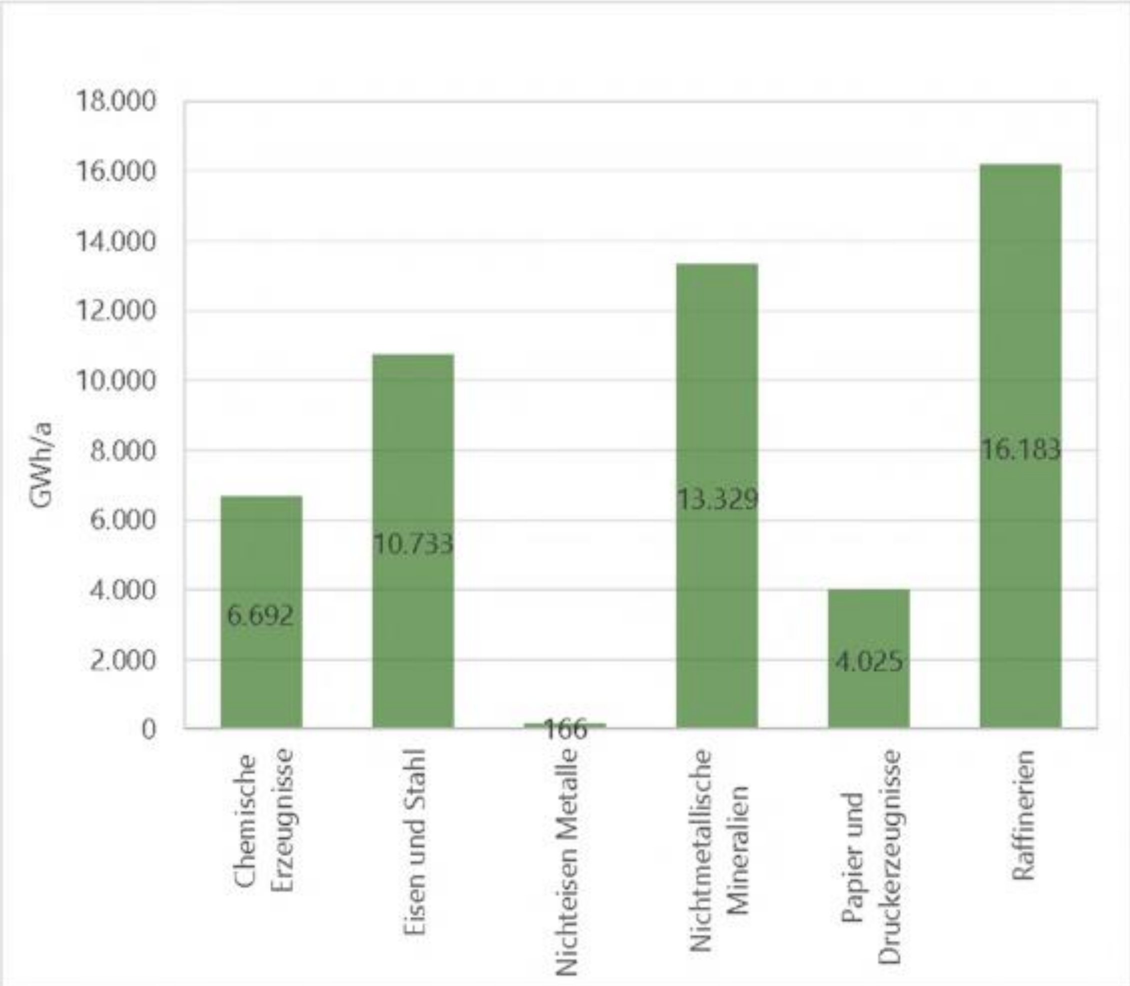
Wärmekraftwerksanlagen	Thermal power generation installations
KWK	CHP
Heizwerke	Heating plants

Source: Own calculation

Figure 18: Waste heat potential of installations that use renewable energies as an energy source

Industrial installations

Figure 19 shows the potential for industrial waste heat utilisation in Germany. This is based on the location database of Fraunhofer ISI, in which industrial locations are presented together with their production volumes and the technologies used. This database was expanded and added to within the framework of the EU-funded *sEEnergies* project[13]. The quantity of waste heat is calculated from this information, using the calculated energy source inputs and efficiencies as a basis. This results in a total quantity of industrial waste heat in Germany of approx. 51 TWh. A reference temperature of 25 °C is used here for calculation purposes. The waste heat from industrial installations that can be used in heating networks comes to around 8 TWh. This is determined by analysing the waste heat sources that are within a radius of no more than 10 km from an existing heating network[14]. Here the reference temperature is 95 °C, to allow the waste heat to be used directly in the heating network.



Chemische Erzeugnisse	Chemical products
Eisen und Stahl	Iron and steel
Nichteisen Metalle	Non-ferrous metals
Nichtmetallische Mineralien	Non-metallic minerals
Papier und Druckerzeugnisse	Paper and printed matter
Raffinerien	Refineries

[13] https://www.seenergies.eu/

[14] https://www.isi.fraunhofer.de/de/presse/2020/presseinfo-12-industrielle-abwaerme-fernwaerme.html

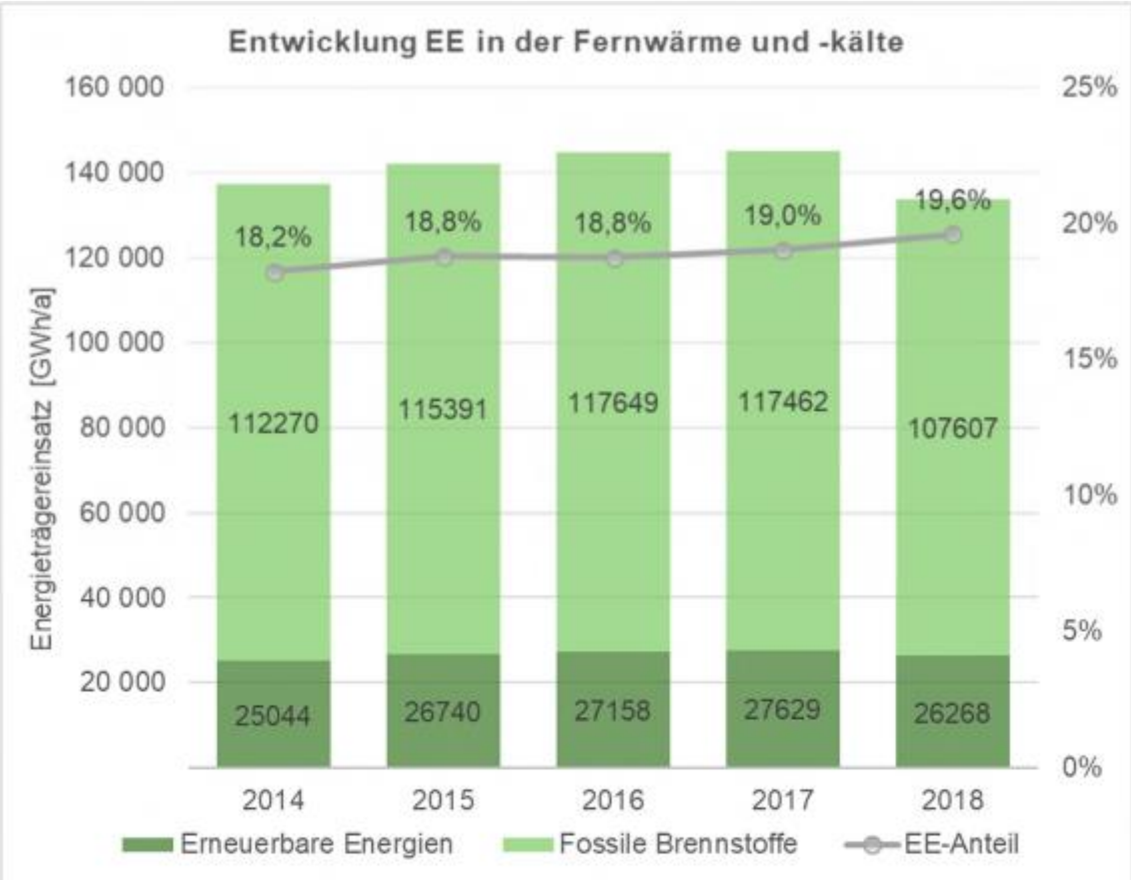
Source: Own calculation

Figure 19: Potential for industrial waste heat in Germany

I.2.c. Renewable energies and waste heat or cold in the district heating and district cooling sector

In addition to the presentation of waste heat and cold potentials, Annex VIII of the EED also requests the reported share of energy from renewable sources and from waste heat or cold in the final energy consumption of the district heating and cooling sector over the past 5 years.

Figure 20 shows the reported share of energy from renewable sources in the energy source input for district heating and cooling in accordance with the evaluation tables of the Energy Balance Working Group[15]. Over the period from 2014 to 2019 the share of renewable energies was relatively constant, rising from 18.2% to 19.6%.



Entwicklung EE in der Fernwärme und -kälte	Development of RE in district heating and cooling

[15] For 2018 there is a discrepancy between the data of the Energy Balance Working Group on renewable energies in district heating and the sum of renewable energies resulting from the surveys of the Federal Statistical Office ('annual survey on the generation and use of heat and on the operation of heating net-works' and 'monthly survey on electricity and heat generation for general supply'). The data of the Energy Balance Working Group are 4,399 GWh higher. This can be explained in part by the fact that own use of heat from sewage treatment plant gas and sewage sludge in sewage treatment plants, amounting to 2,158 GWh, is included in the district heating assessment of the Energy Balance Working Group.

Energieträgereinsatz [GWh/a]	Energy source input [GWh/a]
Erneuerbare Energien	Renewable energies
Fossile Brennstoffe	Fossil fuels
EE-Anteil	RE share

Source: AGEB (2020b). Includes own consumption of heat from sewage treatment plant gas and sewage sludge in sewage treatment plants without feed-in of waste heat from industrial processes

Figure 20: Energy source input for net heat generation in district heating and cooling and share of renewable energies

For the definition of relevant energy sources reference is made to the new version of the Renewable Energy Directive (Directive (EU) 2018/2001). As already stated under Section I.2.b, the term 'waste heat and cold' therefore covers not only waste heat from industrial processes, but also from electricity generation or CHP installations. Accordingly, Figure 21 shows the share of heat from CHP installations in district heating and cooling over the period from 2014 to 2018.

Entwicklung Abwärme/-kälte in der Fernwärme und -kälte	Development of waste heat / cold in district heating and cooling
Energieträgereinsatz [GWh/a]	Energy source input [GWh/a]
KWK-fossil	CHP – fossil
KWK-EE	CHP – RE
Ungekoppelte Erzeugung	Non-cogeneration
KWK-Anteil	CHP share

Source: AGEB, (2020b). Includes own consumption of heat from sewage treatment plant gas and sewage sludge in sewage treatment plants without feed-in of waste heat from industrial processes

Figure 21: Energy source input for net heat generation in district heating and cooling and share of waste heat / cold from CHP installations

To determine the industrial waste heat fed into district heating, the data collected on heat purchasing from the Federal Statistical Office's 'survey of heating network operators' (StaBuA, 2020a) is referred to. The survey was first performed in 2018 and therefore provides no information on preceding periods from 2014 onwards. For this reason the surveys of the AGFW (Energy Efficiency Association for Heating, Cooling and CHP), which are published in the annual main reports, are also used (AGFW, 2015, 2016, 2017, 2018, 2019). The Federal Statistical Office's survey reveals that 2,383 GWh of the heat fed into heating networks in Germany in 2018 was supplied by means of external purchasing from industry, which can be reported as utilisation of industrial waste heat in district heating. This value is also plausible when compared with the association data collected by the AGFW, if the waste heat utilisation indicated in the AGFW main reports is scaled by the coverage of the AGFW statistics[16]. As the Federal Statistical Office's survey on heating network purchasing is only available for 2018, for the preceding years from 2014 onwards the shares of industrial waste heat in district heating from the AGFW main reports are scaled by the coverage determined. Figure 22 shows the resulting supply of waste heat from industrial processes to heating networks over the period from 2014 to 2018 and the share in net heat generation for district heating / cooling (including waste heat).

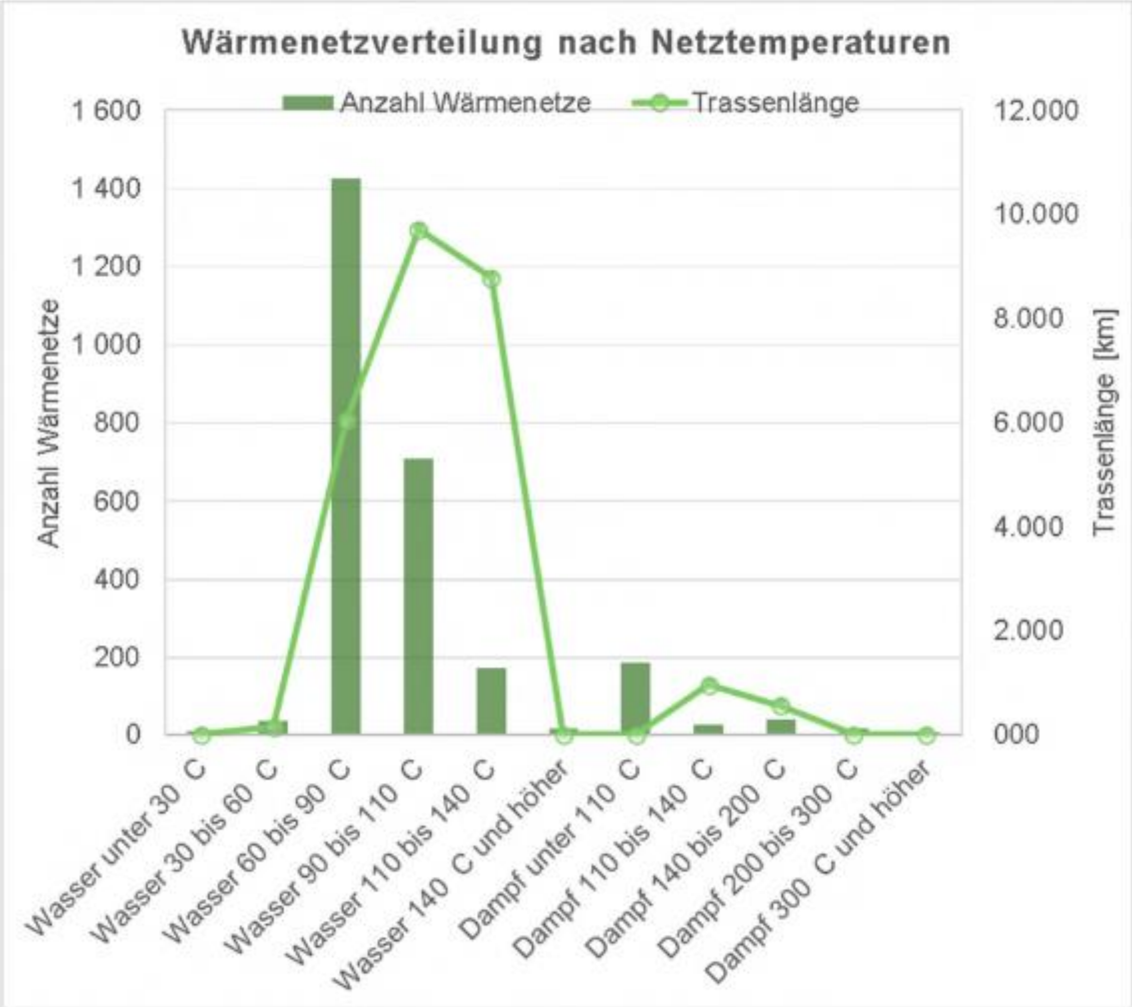
[16] The AGFW main reports publish the district heating purchasing and district heating generation of member companies that participate in the annual survey, including the supply of industrial waste heat, which is reported as 1,298 GWh for 2018. Comparing the recorded data on net heat generation for the supply of heating networks with the energy statistics allows coverage of 57% to be derived overall for the AGFW data. Assuming that the supply of waste heat to heating networks has the same coverage, the scaling of the waste heat from industrial processes indicated in the AGFW main reports also results in a value of around 2,300 GWh.

Entwicklung der Einspeisung industrielle Abwärme in der Fernwärme/-kälte	Development of supply of industrial waste heat in district heating / cooling
Wärmenetzeinspeisung [GWh/a]	Supply to heating network [GWh/a]
Industrielle Abwärme	Industrial waste heat
Anteile industrielle Abwärme	Shares of industrial waste heat

Source: Own calculation based on AGFW (2015, 2016, 2017, 2018, 2019); StaBuA (2020a)

Figure 22: Share of industrial waste heat in district heating and cooling

To increase the share of renewable energies in district heating / cooling in the future, there is also a need, in particular, for low supply and return temperatures in the heating networks. The term ‘third-generation heating networks’ is used to describe networks with supply temperatures below 100 °C. Fourth-generation networks are operated with supply temperatures below 70 °C (Lund et al., 2014). The current network temperatures in heating networks are therefore also a relevant factor for assessing the status quo. Figure 23 shows the distribution of network temperatures in German heating networks. With regard to network length, most networks have water as a heat-transfer medium and supply temperatures in a range between 90 °C and 140 °C. However, there are also already numerous heating networks with supply temperatures below 90 °C.



Wärmenetzverteilung nach Netztemperaturen	Breakdown of heating networks by network temperature
Anzahl Wärmenetze	Number of heating networks
Trassenlänge	Network length
Wasser unter 30 C	Water below 30 °C
Wasser 30 bis 60 C	Water 30 to 60 °C
Wasser 60 bis 90 C	Water 60 to 90 °C
Wasser 90 bis 110 C	Water 90 to 110 °C
Wasser 110 bis 140 C	Water 110 to 140 °C
Wasser 140 C und höher	Water 140 °C and above
Dampf unter 110 C	Steam below 110 °C
Dampf 110 bis 140 C	Steam 110 to 140 °C
Dampf 140 bis 200 C	Steam 140 to 200 °C
Dampf 200 bis 300 C	Steam 200 to 300 °C
Dampf 300 C und höher	Steam 300 °C and above

Source: StaBuA (2020a). Network length is not reported for all heating networks for confidentiality reasons

Figure 23: Network temperatures of heating networks in Germany in 2018

I.3. Heating and cooling maps for Germany

Part I(3) of Annex VIII requires the generation of maps of the entire national territory showing existing heating and cooling supply points identified under point 2(b) and district heating transmission installations.

The digital maps can be accessed via the following links:

- Presentation of heating and cooling demand areas at: https://ubagdi.maps.arcgis.com/apps/opsdashboard/index.html#/52d1b140fd38412ca3c854952f5ed8e5
- Presentation of existing and planned heating and cooling supply points and district heating transmission installations at: https://www.bfee-online.de/BfEE/DE/Monitoring/Potential_effiziente_Waerme-_Kaeltenutzung/potential_effiziente_waerme-_kaeltenutzung_node.htm

I.3.a. Heating and cooling demand areas

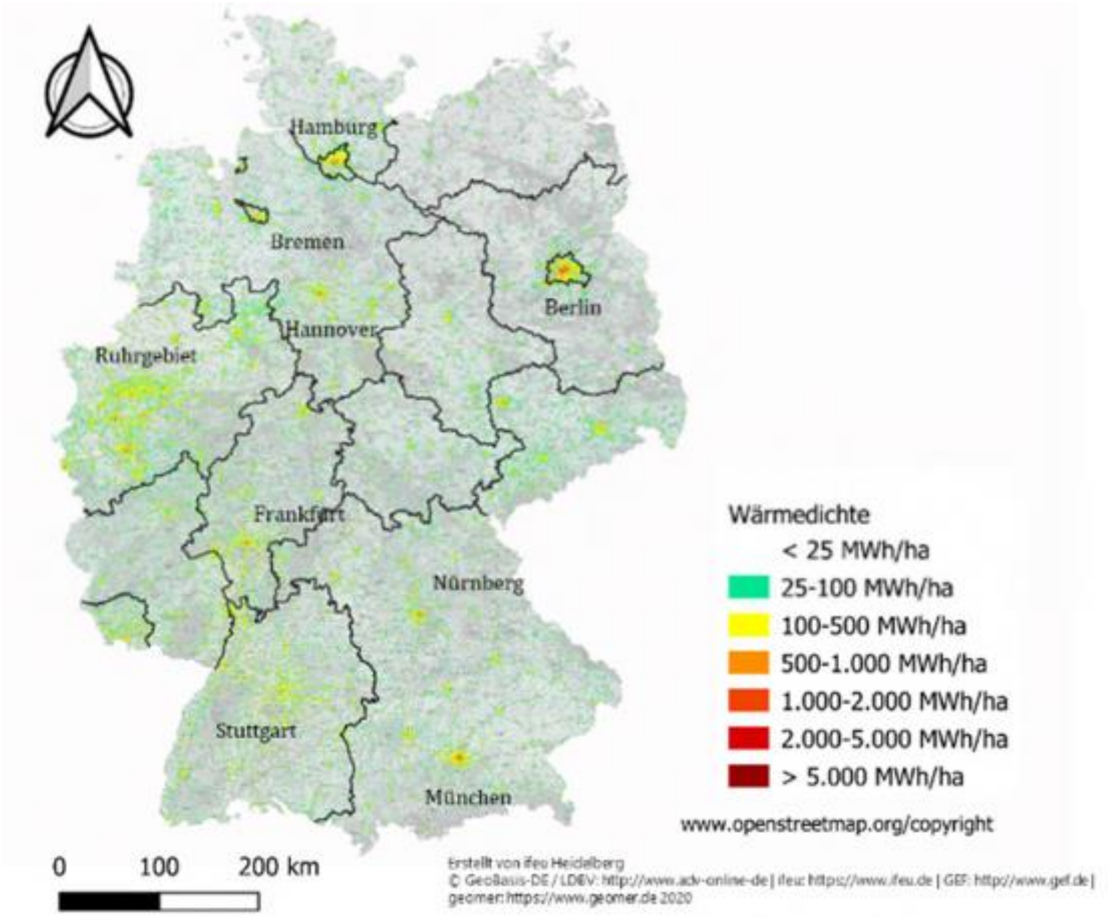
The maps of heating and cooling demand areas in Germany are presented on the basis of the spatially disaggregated data prepared as part of the analysis of economic potential. Please refer to Section III.1 for details of data generation. The data presented are broken down by useful and final energy demand and also shown for the residential, services and industrial sectors. They are also broken down on the basis of the applications space heating, hot water, process heating and cooling, and air conditioning.

In the following section one map is used to present the useful energy demand for space heating and hot water in the residential and services sectors, one map to present the final energy demand in the industrial sector and one map to present the useful energy demand for air conditioning in the residential and services sectors. Additional small-scale maps and an overview chart are included in the online presentation that has been developed. This can be accessed via the following link: https://ubagdi.maps.arcgis.com/apps/opsdashboard/index.html#/52d1b140fd38412ca3c854952f5ed8e5

In the figure showing energy demand in residential buildings and households the presentation is based on individual grid cells with a side length of 500 m x 500 m, using a heat atlas at individual building level[17] for the calculation. In the case of the figure for the industrial sector this small-scale presentation is not possible, as, in the interests of data protection and to safeguard economically sensitive information, it is necessary to check that there are at least three facilities within a spatial unit. This ensures that no conclusions can be drawn about individual industrial locations. The chosen presentation at district level (NUTS-3) allows more than 95% of the energy demand in industry to be mapped.

[17] See also https://www.ifeu.de/methoden/modelle/waermeatlas/

Figure 24 shows the useful energy demand for space heating and hot water in the residential and services sectors. Heating demand can be seen to be concentrated in the urban areas of Berlin, Hamburg, Bremen, Hannover, Frankfurt, Nuremberg, Stuttgart and Munich. High heating demand is also visible in the Ruhr area due to the high population density.

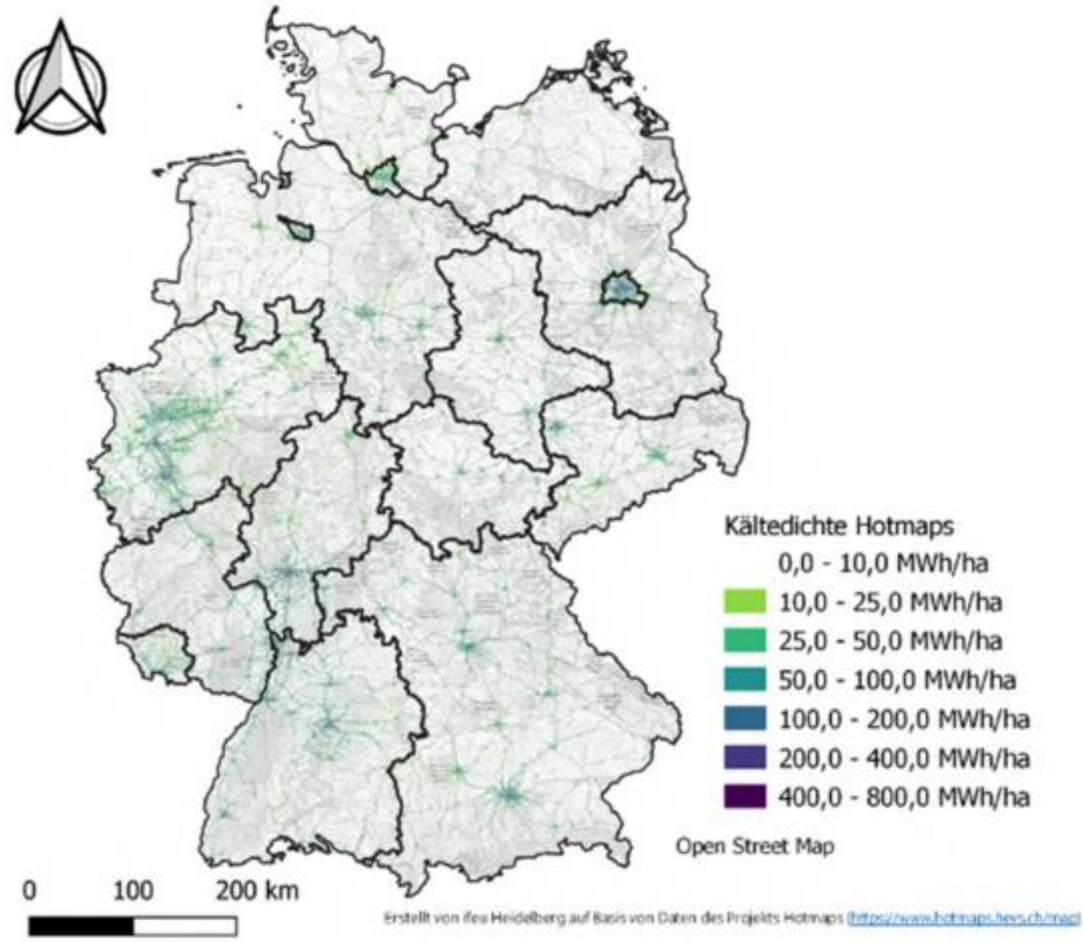


Ruhrgebiet	Ruhr area
Nürnberg	Nuremberg
München	Munich
Wärmedichte	Heating density
Erstellt von ifeu Heidelberg	Produced by ifeu Heidelberg

Source: Own figure (ifeu)

Figure 24: Presentation of useful energy demand for space heating and hot water in the residential and services sectors

Figure 25 shows the useful energy demand for cooling in the residential and services sectors on the basis of data of the open source project Hotmaps (HOTMAPS Project, 2020). Here again the concentration in the above-mentioned urban zones can be seen.

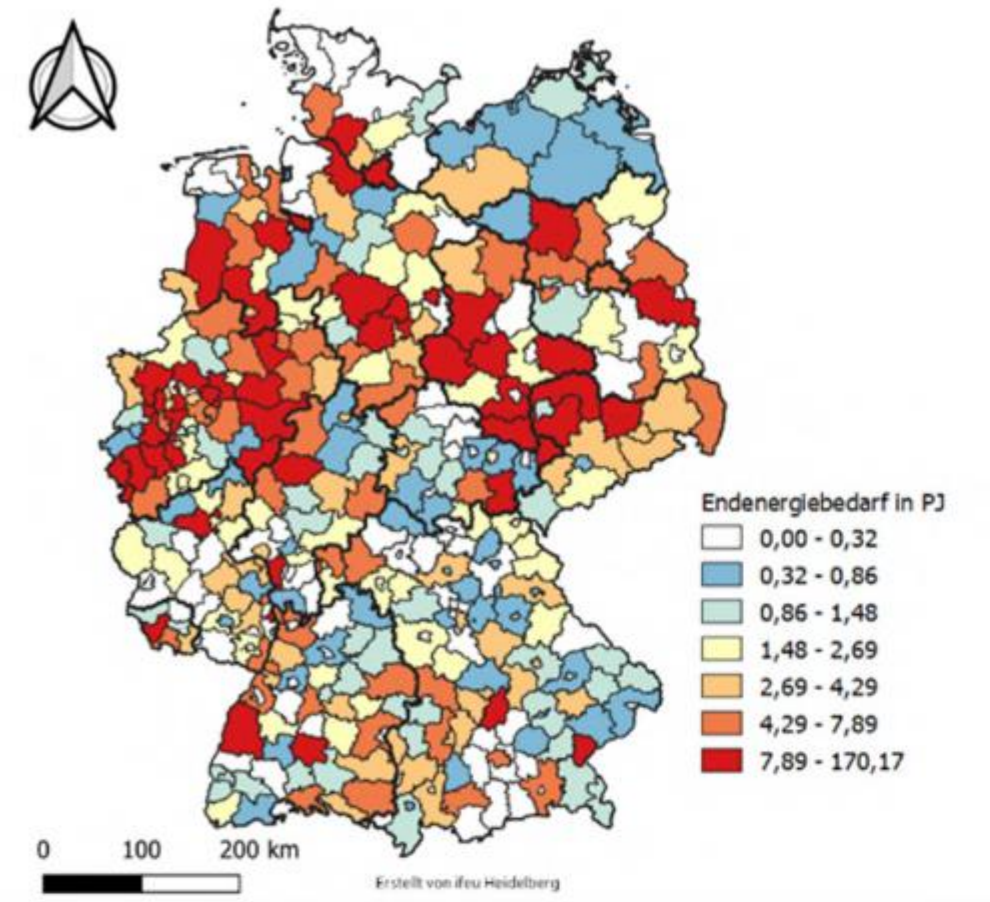


Kältedichte Hotmaps	Hotmaps cooling density
Erstellt von ifeu Heidelberg auf Basis von Daten des Projekts Hotmaps	Produced by ifeu Heidelberg based on data from the Hotmaps project

Source: Own figure (ifeu) based on Hotmaps (HOTMAPS Project, 2020)

Figure 25: Presentation of the useful energy demand for cooling in the residential and services sectors.

Figure 26 shows the final energy demand in industry for 2018 at district level. The energy-dense regions in Germany are situated in the Ruhr area in the west, in Saxony and Saxony-Anhalt in the east, as well as in Lower Saxony.



Endenergiebedarf in PJ	Final energy demand in PJ
Erstellt von ifeu Heidelberg	Produced by ifeu Heidelberg

Source: Own figure (ifeu) based on baseline scenario

Figure 26: Presentation of the final energy demand in industry for 2018 based on the baseline scenario for NUTS-3

The data at district level for useful and final energy on which the maps are based are presented in Annex I.1.

I.3.b. Existing heating and cooling supply points and district heating transmission installations

Annex VIII of the EED requires a map covering the entire national territory identifying existing heating and cooling supply points. This mapping includes the identification of installations that generate waste heat or cold and their potential heating or cooling supply, in GWh per year:

a) thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MW;
b) heat and power cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW;

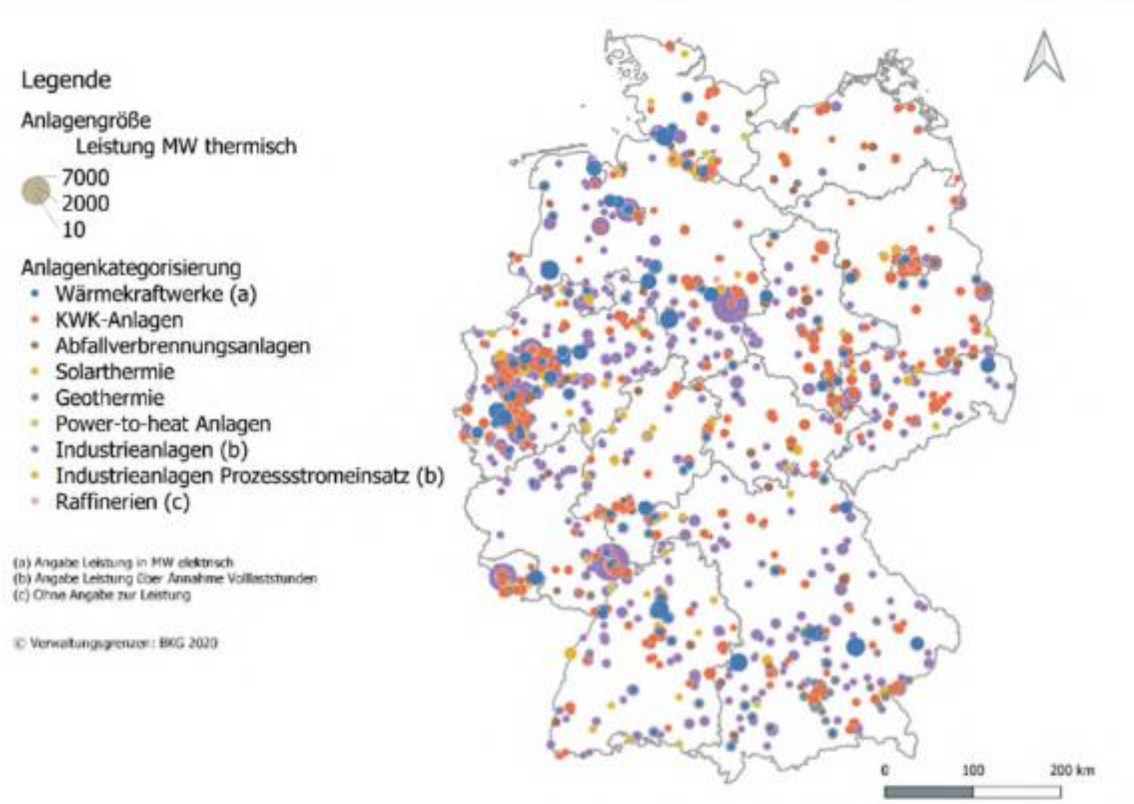
c) waste incineration plants;
d) renewable energy installations with a total thermal input exceeding 20 MW other than the installations specified under point 2(b)(i) and (ii) generating heating or cooling using the energy from renewable sources;
e) industrial installations with a total thermal input exceeding 20 MW which can provide waste heat;

The breakdown follows the same procedure used in Part I.2.b (cf. also I.2.b).

In the area of cooling supply points, cooling networks and cooling applications in industry are of particular relevance. Within industry cooling applications are mainly used in the food and tobacco industries, as well as in the basic chemicals industry. However, they are mostly used within the site, rather than to supply public infrastructures.

Mapping of installations

The result of the mapping of existing heating and cooling supply installations is shown in Figure 27.



Legende	Key
Anlagengröße	Installation size
Leistung MW thermisch	Capacity MW thermal
Anlagenkategorisierung	Installation categorisation
Wärmekraftwerke (a)	Thermal power plants (a)
KWK-Anlagen	CHP installations
Abfallverbrennungsanlagen	Waste incineration plants

Solarthermie	Solar thermal
Geothermie	Geothermal
Power-to-heat Anlagen	Power-to-heat plants
Industrieanlagen (b)	Industrial installations (b)
Industrieanlagen Prozessstromeinsatz (b)	Industrial installations process electricity input (b)
Raffinerien (c)	Refineries (c)
(a) Angabe Leistung in MW elektrisch	(a) Capacity indicated in MW electric
(b) Angabe Leistung über Annahme Volllast-stunden	(b) Capacity indicated based on assumption of full load hours
(c) Ohne Angabe zur Leistung	(c) No capacity indicated
Verwaltungsgrenzen: BKG 2020	Administrative boundaries: Federal Agency for Cartography and Geodesy (BKG) 2020

Source: Own figure based on UBA (2020); Bundesnetzagentur (2020a); Hermann & Bracker (2018); Flamme et al. (2018); LIAG - Leibnitz Institut für angewandte Geowissenschaften (2020); Bundesverband Geothermie (2019); Agentur Enerchange (2020) and Energy (2020); SDH - solar district heating (2017); Solites (2019); BSW-Solar (2019); AGFW (2020); Wünsch et al. (2019); Blömer et al. (2019); E-PRTR (2020); HOTMAPS Project (2020)

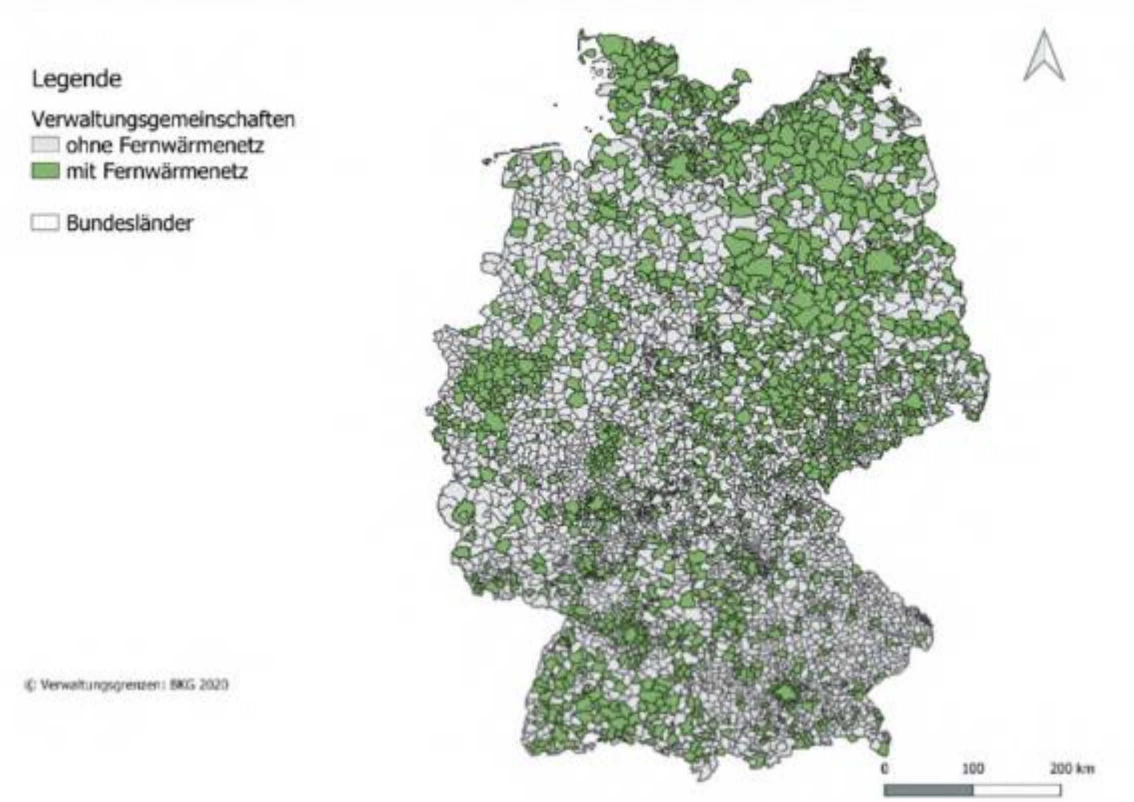
Figure 27: Cross-technology general overview of heating and cooling generation locations identified to date

The map makes clear that heating and cooling generation installations are not distributed uniformly across Germany, but are geographically concentrated. Densely populated areas, e.g. in North Rhine-Westphalia, and, in particular, the more industrialised Ruhr area, are areas of high concentration. In no small part for reasons linked to economic history, this is a focal point of industry and, due to the coal deposits present (as can also be seen in Lusatia), of energy generation. Isolated hotspots are also depicted in Germany's main population centres. A clear concentration of generation installations can be seen in the metropolitan areas around major cities. Examples of such areas include Berlin, Hamburg, Bremen, Munich and Mannheim.

The selection of locations for renewable energies is directly linked to the locally available potentials, as a result of which these follow their own spatial distribution. A clear difference is evident here between northern and southern Germany. In the more southern federal states there is greater potential due to the geographic location: on the one hand, higher radiation intensity for solar thermal and, on the other, higher geothermal potential due to hydrothermal deep waters in the southern-German Molasse basin.

For the presentation of district heating transmission installations, municipalities in Germany in which there is a district heating network for the centralised supply of space heating and domestic hot water in buildings are mapped. The results are shown in Figure 28. These are presented at the level of municipal associations. A higher-level breakdown at street level is not possible due to the limited data available in Germany. However, the figure does allow a comparison of available heat sources and energy-dense areas (see also Section I.3) with existing heating and cooling supply installations.

An overview graph of the existing and planned installations from I.3.c is available online via the following link: https://www.bfee-online.de/BfEE/DE/Monitoring/Potential_effiziente_Waerme-_Kaeltenutzung/potential_effiziente_waerme-_kaeltenutzung_node.htm. A comprehensive tabular presentation of the data on which the maps are based can be found in the annex under I.1 and I.2.



Legende	Key
Verwaltungsgemeinschaften	Administrative associations
ohne Fernwärmenetz	without district heating network
mit Fernwärmenetz	with district heating network
Bundesländer	Federal states
Verwaltungsgrenzen: BKG 2020	Administrative boundaries: Federal Agency for Cartography and Geodesy (BKG) 2020

Source: Own figure based on Statistische Ämter des Bundes und der Länder (2018).

Figure 28: Overview of municipalities with and without district heating

The map reveals that district heating networks in Germany are not uniformly distributed across the territory. In western Germany the available network structures are mostly centred around populous conurbations, e.g. in North Rhine-Westphalia, Baden-Württemberg and Schleswig-Holstein, as well as cities such as Munich and Hamburg.

For reasons linked to economic history, district heating networks are more widely distributed in eastern Germany. During the time of the German Democratic Republic (GDR) the centralised infrastructure for the supply of heating was expanded more intensively, due in particular to the lack of gas and oil.

I.3.c. Planned heating and cooling supply points and district heating transmission installations

The Directive requires a map covering the entire national territory identifying planned heating and cooling supply points (in accordance with Annex VIII of the EED). This mapping includes the identification of installations that generate waste heat or cold and their potential heating or cooling supply, in GWh per year:

a) thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MW;
b) heat and power cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW;
c) waste incineration plants;
d) renewable energy installations with a total thermal input exceeding 20 MW other than the installations specified under point 2(b)(i) and (ii) generating heating or cooling using the energy from renewable sources;
e) industrial installations with a total thermal input exceeding 20 MW which can provide waste heat;

For thermal power generation installations (a) and heat and power cogeneration installations (b) use is made of the published list of new plant capacity and plant closures of the Federal Network Agency (*Bundesnetzagentur*) (Bundesnetzagentur, 2020b). The data presented for waste incineration plants (WIP) (c), which within the framework of this project also cover refuse-derived-fuel (RDF) plants, are based on Flamme et al. (2018). The locations in this study are compared with the data requested under the 4th Federal Immission Control Regulation (BImSchV) and supplemented with an additional location (Jänschwalde).

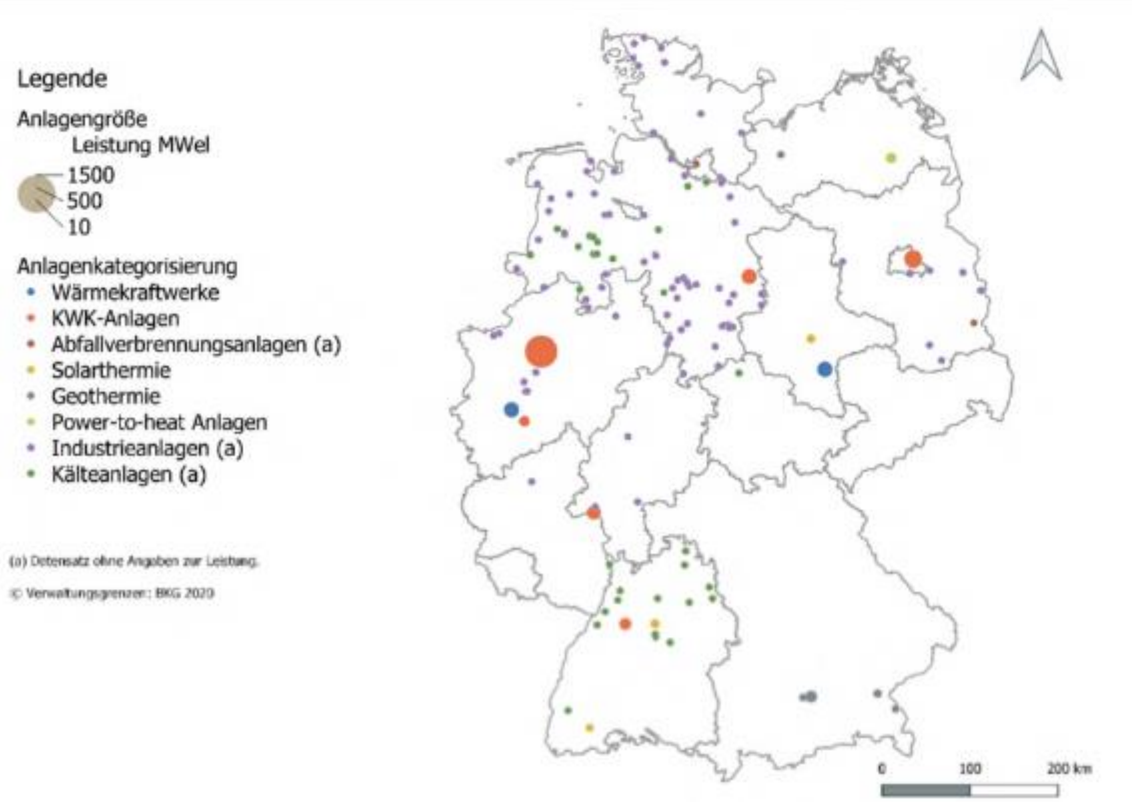
To fill the data gap in the area of industrial installations (e) and cooling installations, the data under the 4th BImSchV are identified as a potential data source. The 4th BImSchV requires a permit to be obtained for the construction and operation of defined installations from a certain capacity threshold or installation size. In addition to installations for heat generation, mining and energy, various industrial installations also fall under this requirement.

To obtain the relevant information, the corresponding data transmission offices of the federal states were contacted. Within the framework of bilateral discussions the data required were defined and made available to the research institutes. As a result of the federal structures, competences are organised differently from one federal state to another. In Bavaria, for example, responsibility for permits has been assigned to the district authorities, municipalities and mining authorities. Due to the resulting high number of authorities, with over 100 contact points, it was not possible to request the data from all these bodies. For all other federal states the data were transferred.

The data presented for renewable energies (d) are based on the same data sources already used for the presentation of existing installations under Part I.3.b. In addition to existing installations, the chosen databases also report installations that are being planned or are under construction.

Mapping of installations

The result of the mapping of planned heating and cooling installations is shown in Figure 29.



Legende	Key
Anlagengröße	Installation size
Leistung MWel	Capacity MWel
Anlagenkategorisierung	Installation categorisation
Wärmekraftwerke	Thermal power plants
KWK-Anlagen	CHP installations
Abfallverbrennungsanlagen (a)	Waste incineration plants (a)
Solarthermie	Solar thermal
Geothermie	Geothermal
Power-to-heat Anlagen	Power-to-heat plants
Industrieanlagen (a)	Industrial installations (a)
Kälteanlagen (a)	Cooling installations (a)
(a) Datensatz ohne Angaben zur Leistung	(a) Data set with no indications of capacity
Verwaltungsgrenzen: BKG 2020	Administrative boundaries: Federal Agency for Cartography and Geodesy (BKG) 2020

Source: Own figure based on Bundesnetzagentur (2020b); Flamme et al. (2018); LIAG - Leibnitz Institut für angewandte Geowissenschaften (2020); Bundesverband Geothermie (2019); Agentur Ener-change (2020) and Energy (2020); BSW-Solar (2019)

Figure 29: Cross-technology general overview of planned heating and cooling generation locations identified to date

Eight larger CHP installations are currently being planned, including in North Rhine-Westphalia, Berlin and Wolfsburg (site of an automotive manufacturer). Two thermal power generation installations are also being planned in Cologne and Halle/Saale.

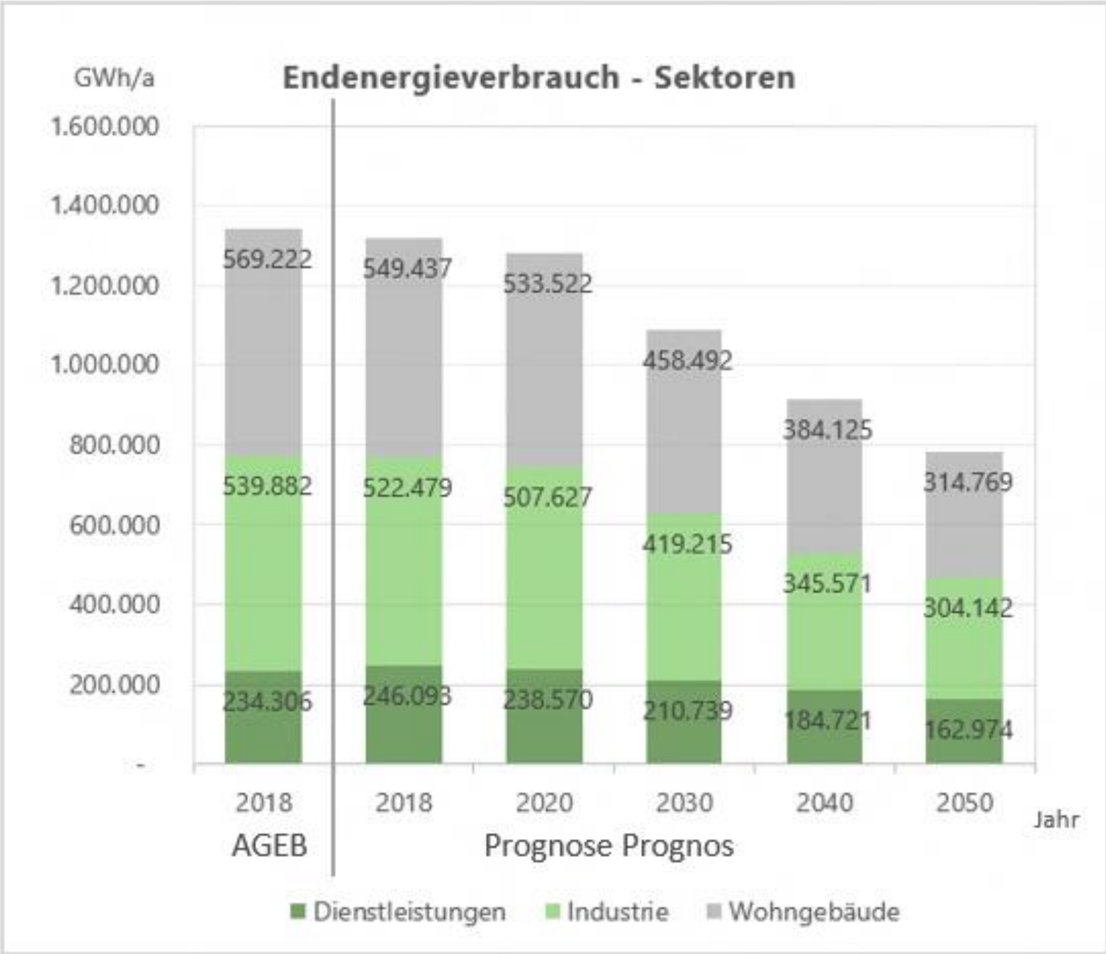
Planned geothermal and solar thermal installations are mainly found in the two southern federal states of Baden-Württemberg and Bavaria, which also have high geothermal potential. In the north there is a geothermal location in Schwerin and a solar thermal location in Bernburg (Saale).

Industrial installations for the generation of heating and cooling can be found in northwestern and southwestern Germany. However, it is worth reiterating the limited significance of the data here, as the differing levels of data quality at the respective federal state offices and the problem with the installation data under the 4th BImSchV, as outlined above, mean that data are not available for all federal states.

I.4. Forecast of heating and cooling demand trends

The forecast of heating and cooling demand trends for the next 30 years is presented below, giving particular consideration to the projections for the next 10 years. This is based on the scenario analysis drawn up as part of the preparation of the integrated National Energy and Climate Plan (NECP) (BMWi, 2020; Kemmler et al., 2020). It already takes into account the impact of existing policy instruments and of the decisions resulting from the Climate Action Programme 2030 (cf. I.4).

Figure 30 below shows the development of final energy consumption for heating and cooling under the Climate Action Programme 2030 reference scenario (CAP reference scenario). As this scenario involves modelled data based on the climate-adjusted values of the scenario starting year of 2016, there is divergence from the actual consumption data for 2018. These data are also presented in Figure 30 for information purposes.



Endenergieverbrauch – Sektoren	Final energy consumption – sectors
AGEB	AGEB
Prognose Prognos	Prognos forecast
Jahr	Year
Dienstleistungen	Services
Industrie	Industry
Wohngebäude	Residential

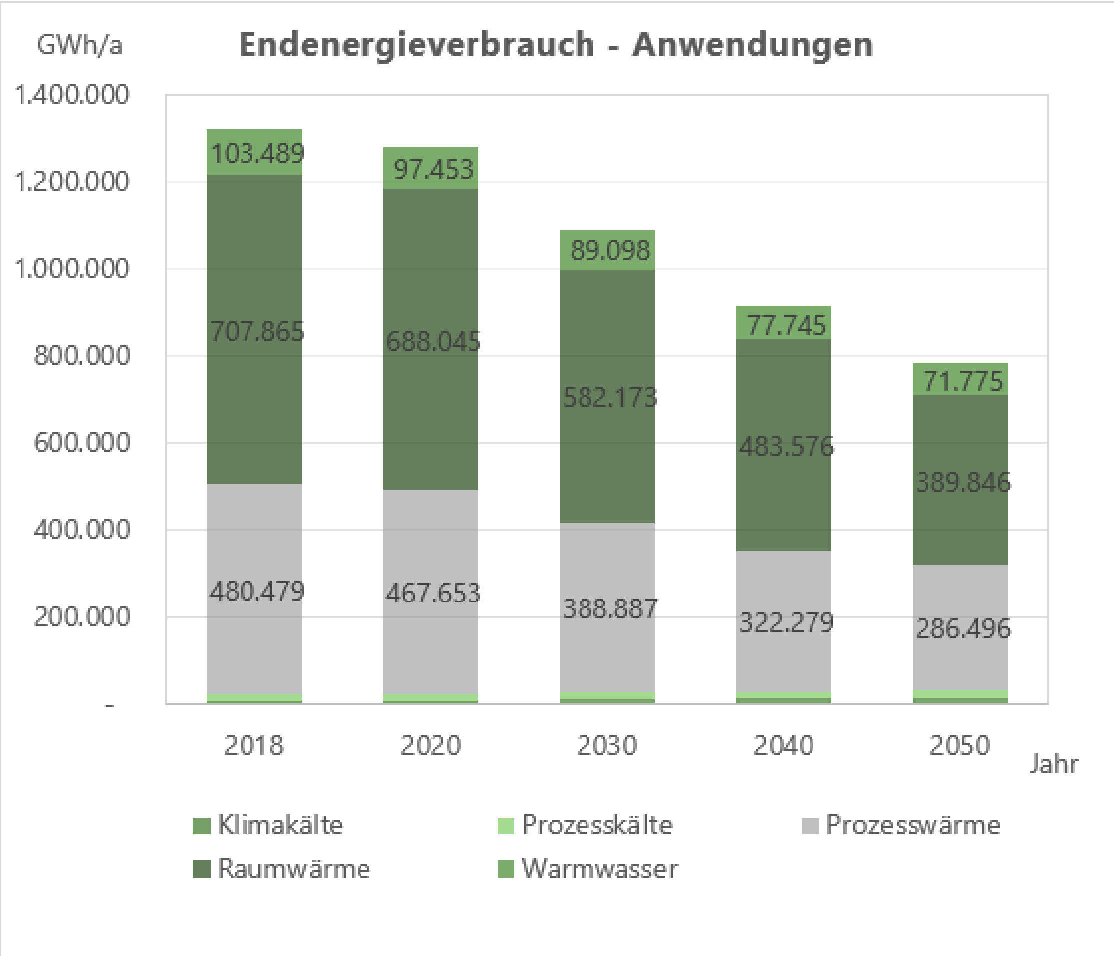
Source: AGEB (2020a); Kemmler et al. (2020)

Figure 30: Comparison of energy consumption forecast in the services, industry and residential sectors

Under the CAP reference scenario final energy consumption in the area of heating and cooling falls by 17% from 2018 to 2030 and by 41% by 2050 (Figure 30). In 2018 the shares of the individual sectors in energy demand for heating and cooling are 40% for industry, 42% for the residential sector and 19% for the services sector. As far as the individual sectors are concerned, the reductions in the residential and industrial sectors follow a similar path. The residential sector shows a decline of 17% by 2030 and 43% by 2050. In the industrial sector the reduction amounts to 20% by 2030 and 42% by

2050, while in the services sector final energy consumption for heating and cooling drops by 14% by 2030 and 34% by 2050.

Figure 31 compares the final energy consumption data in the area of heating and cooling, broken down by application. In 2018 the buildings sector accounts for around two fifths of final energy consumption. The buildings sector includes the applications space heating (54%), hot water (8%) and air conditioning (1%) (total for buildings sector of 62%). A little over a third of final energy consumption can be attributed to process heating (36%) and process cooling (1%) in the industrial and services sectors. The decline in the area of individual heating applications (space heating, hot water and process heating) amounts to an average of 17% (18% for space heating, 14% for hot water and 19% for process heating) by 2030 and 39% (45%, 31%, 40%) by 2050.



Endenergieverbrauch – Anwendungen	Final energy consumption – Applications
Jahr	Year
Klimakälte	Air conditioning
Prozesskälte	Process cooling
Prozesswärme	Process heating
Raumwärme	Space heating
Warmwasser	Hot water

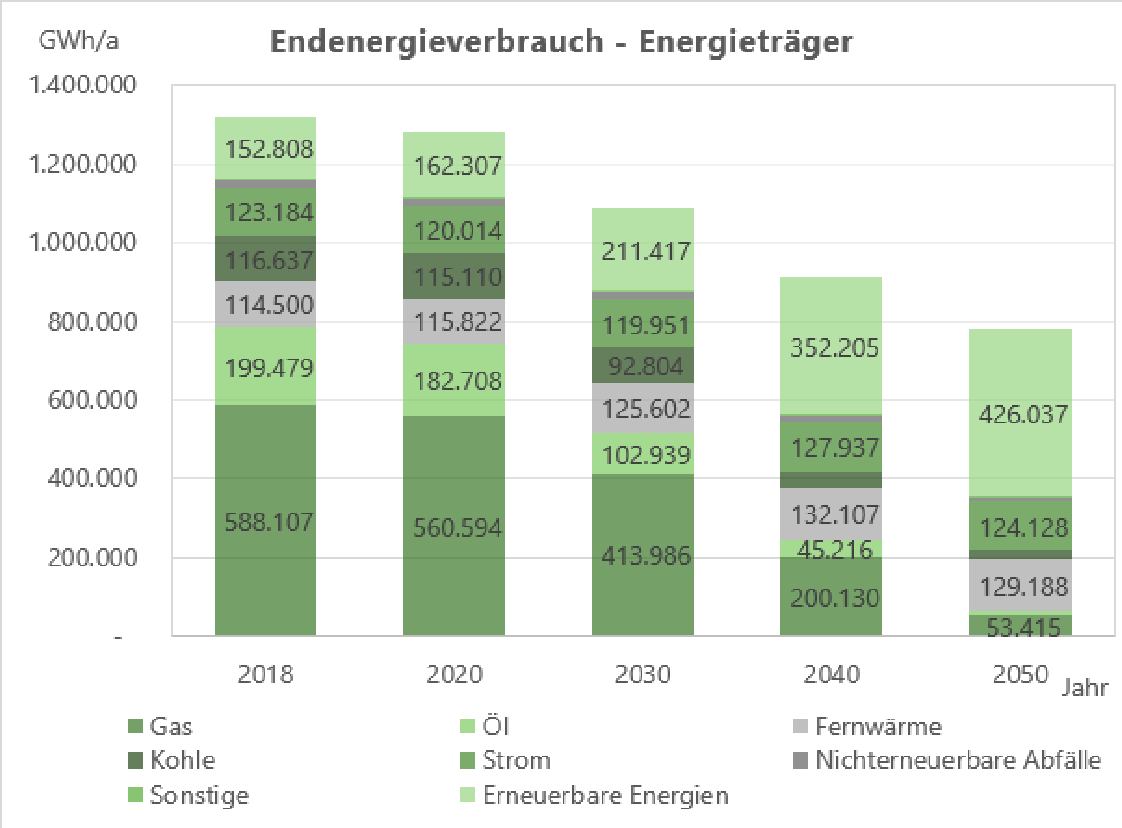
Source: Kemmler et al. (2020)

Figure 31: Final energy consumption forecast by application

In the area of cooling applications a varied picture emerges. Process cooling shows a smaller decline than process heating of 7% by 2030 and 13% by 2050, while energy consumption for air conditioning rises by 37% by 2030 and as much as 113% by 2050. Rising temperatures due to climate change have been taken into account in the scenario modelling. Nevertheless, the share of energy consumption for cooling is still just 4% of that for heating and cooling combined in 2050, meaning that, in spite of rising temperatures and an increasing need for air conditioning, in Germany the focus will continue to be placed on the area of heating over the next 30 years.

With regard to the contribution of heating and cooling to the achievement of the climate protection objectives, the development of the heating and cooling supply is a relevant factor, alongside the reduction in energy demand for the individual applications due to efficiency measures (see also Part II.5). The question here is, in particular, to what extent fossil fuels can be replaced by renewable energies both in the decentralised supply and in the centralised supply via heating networks.

Figure 32 shows the final energy consumption for heating and cooling, broken down by the various energy sources. In 2018, 45% of the final energy consumed for heating and cooling was generated from gas, 15% from fuel oil, 12% from decentralised renewable energies, 1% from non-renewable waste and 9% each from district heating, coal and electricity. The main energy source gas will decline by 30% by 2030 and by 91% by 2050. Energy generation from oil will be reduced by 48% by 2030 and by 94% by 2050. Coal use will decrease by 20% by 2030 and by 80% by 2050. Use of non-renewable waste will be reduced by 6% by 2030 and by 43% by 2050. Heat generation from electricity will initially fall by 3% by 2030, but then rise by 4% by 2050. Inefficient heat generation from electricity will decline, while the use of heat pumps will increase. Under this scenario the share of renewable energies rises by 38% by 2030 and by 179% by 2050, with the share of district heating climbing by 10% by 2030 and by 13% by 2050. In 2050 the resulting share of decentralised renewable energies in final energy consumption for heating and cooling stands at 54%.



Endenergieverbrauch – Energieträger	Final energy consumption – Energy sources
Jahr	Year
Gas	Gas
Kohle	Coal
Sonstige	Other
Öl	Oil
Strom	Electricity
Erneuerbare Energien	Renewable energies
Fernwärme	District heating
Nichterneuerbare Abfälle	Non-renewable waste

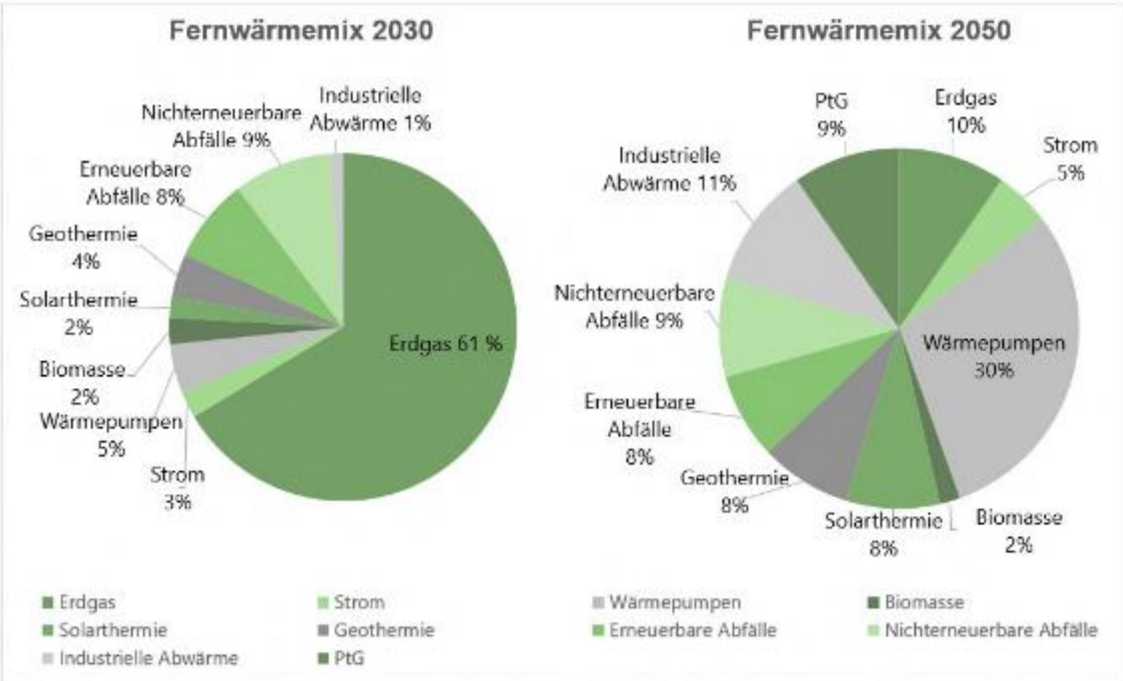
Source: Kemmler et al. (2020)

Figure 32: Final energy consumption forecast by energy source

To shed more light on the development of the energy source mix in district heating generation, the generation of district heating in 2030 and 2050 has been presented above, broken down by energy source (Figure 32). Under this scenario 21% of district heating will be generated from renewable energies in 2030. In addition, industrial waste heat accounts for a share of 1%. Generation of renewable district heating can be broken down as follows: 4% from heat pumps, 2% from biomass, 1% from biogas, 2% from solar thermal, 4% from geothermal and 7% from renewable waste. The remaining

78% of district heating will be supplied from fossil sources and electricity. Within this natural gas accounts for 61%, coal 6%, non-renewable waste 9% and electricity 2%.

Under this scenario a significant change in the energy sources used for district heating generation can be seen in 2050, by comparison with 2030. The share of renewable energies rises to 66%, with an additional 11% attributable to industrial waste heat. Use of fossil fuels and electricity falls accordingly to a share of 23%. The renewable energy mix mainly comprises heat pumps with a share of 30% (this includes not only the ambient heat, but also the share of electricity). The remaining proportion of renewable energies can be attributed to solar thermal, geothermal, renewable waste and synthetic gases (PtG), each with shares of 8% to 10%, as well as biomass with a 2% share. The remaining 23% of fossil-based district heating generation can be broken down into natural gas (10%), electricity (5%) and non-renewable waste (9%).

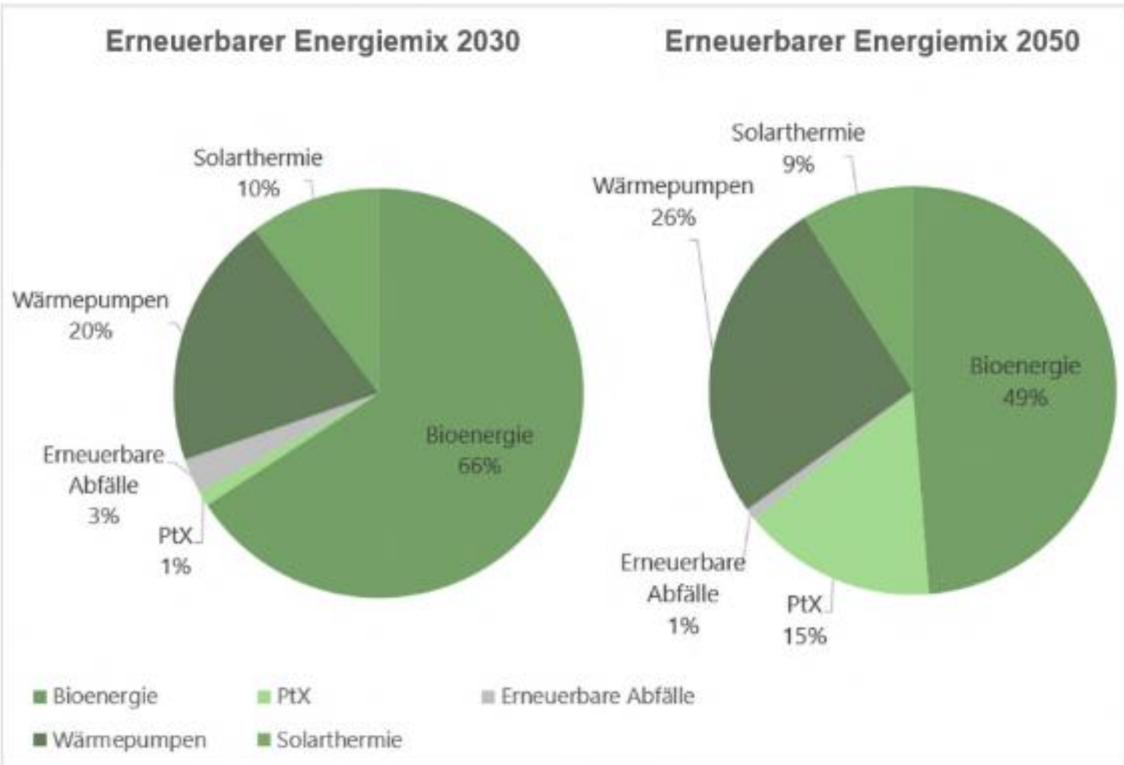


Fernwärmemix	District heating mix
Strom	Electricity
Wärmepumpen	Heat pumps
Biomasse	Biomass
Solarthermie	Solar thermal
Geothermie	Geothermal
Erneuerbare Abfälle	Renewable waste
Nichterneuerbare Abfälle	Non-renewable waste
Industrielle Abwärme	Industrial waste heat
Erdgas	Natural gas
PtG	PtG

Source: Kemmler et al. (2020)

Figure 33: District heating generation broken down by energy source in 2030 and 2050

In addition to the above comparison of the energy source mix in the area of district heating, a comparison of the shares of decentralised renewable energies in 2030 and 2050 is also shown below (Figure 34). In 2030 the share of renewable energies is 19% (excluding district heating) according to the CAP reference scenario. In 2050 the share of decentralised renewable energies in the final energy consumed to meet heating and cooling demand increases to 54% (district heating excluded). The shares of the various renewable energy sources in 2030 can be broken down as follows: at 66%, bioenergy generates the lion's share of renewable heat, followed by heat pumps at 20%, solar thermal at 10%, renewable waste at 3% and PtX at 1%. In 2050 the energy mix is expected to have changed as follows: bioenergy is still the main heat generator at 49%, followed by heat pumps at 26%, solar thermal at 9% and renewable waste at 1%. PtX is expected to make a substantial leap from 1% to 15% between 2030 and 2050.



Erneuerbarer Energiemix	Renewable energy mix
PtX	PtX
Erneuerbare Abfälle	Renewable waste
Wärmepumpen	Heat pumps
Solarthermie	Solar thermal
Bioenergie	Bioenergy

Source: Own figure based on Kemmler et al. (2020).

Figure 34: Share of renewable energies for decentralised heating and cooling in 2050

To ensure the energy supply is largely greenhouse gas neutral by 2050, further expansion of renewable energies is required. The indicative trajectory for the expansion of renewable energies is described in more detail in Part II.5. The individual policies and measures of the Climate Action Plan 2050 are explained in Part II.6.

II. Objectives, strategies and policy measures

Part II of the *Comprehensive assessment of the potential for efficient heating and cooling* presents the objectives, strategies and policy measures that are relevant to ensure an efficient heating and cooling supply. The presentation is divided into the planned contribution to the national objectives (Part II.5) and the overview of the existing policies and measures (Part II.6).

II.1. Planned contribution of the Member State to its national objectives, targets and contributions

By transforming the heating and cooling supply, it will be possible to make a relevant contribution to the achievement of national energy and climate protection objectives. The information presented below on the planned contribution of heating and cooling is based on the NECP. A detailed description of the individual policies and measures can be found in Part II.6. The planned contribution is structured on the basis of the five dimensions of the energy union:

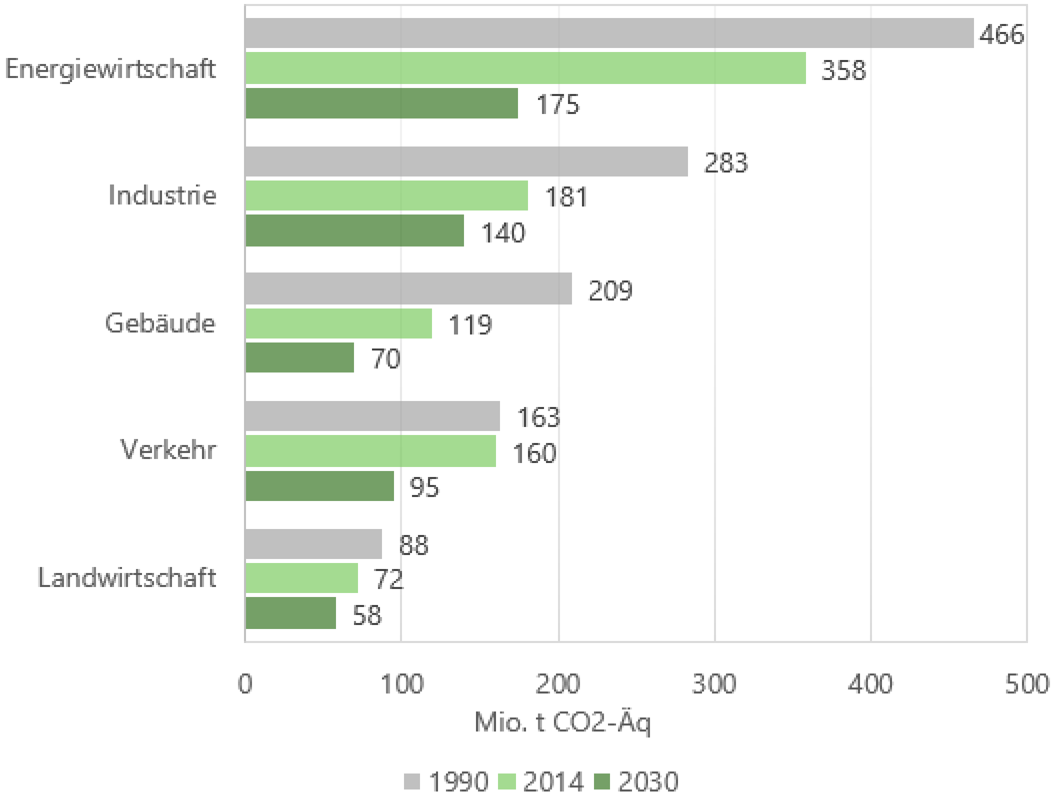
(1) Decarbonisation,
(2) Energy efficiency,
(3) Energy security,
(4) Internal energy market and
(5) Research, innovation and competitiveness.

The allocation of the planned contributions to the five dimensions of the energy union is a structural requirement that does not illustrate the relationships between the dimensions in detail. The dimensions are closely connected and complement each other. For reasons of clarity the planned contributions are assigned solely to the dimensions in question, following the example of the NECP.

Germany's NECP presented the overall impact of the measures for each sector. The energy-saving impacts of the measures under the energy efficiency dimension were reported in accordance with the requirements of the EU Regulation on the Governance of the Energy Union and Climate Action and in accordance with Article 7 of the EED (see the annex to the NECP). The contribution of these individual measures can be found in the annex to this report.

II.1.a. Decarbonisation dimension

The national objective under the decarbonisation dimension is a reduction in greenhouse gas emissions by at least 55% in 2030 relative to 1990. With the Climate Action Plan 2050, Climate Action Programme 2030 and Federal Climate Change Act (KSG) Germany has confirmed these objectives and underpinned them with sectoral targets (see also Part II.6). The sectoral targets resulting from the KSG are presented in Figure 35. The contribution of heating and cooling is split between the energy industry, industrial and buildings sectors in particular.

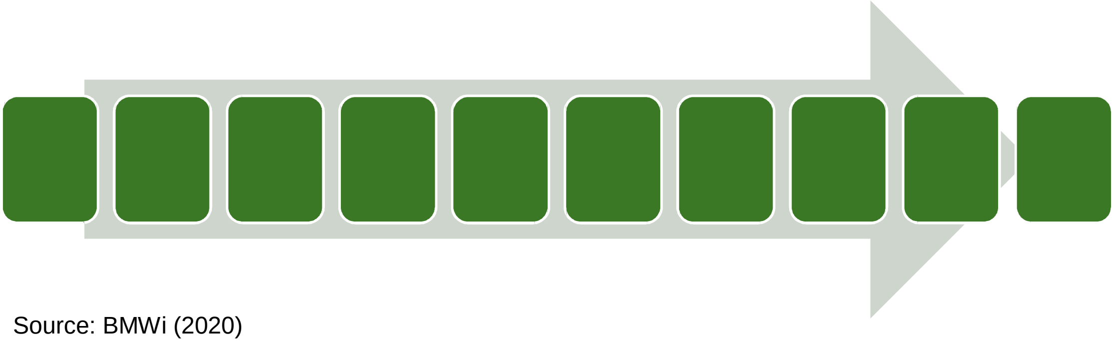


Energiewirtschaft	Energy industry
Industrie	Industry
Gebäude	Buildings
Verkehr	Transport
Landwirtschaft	Agriculture
Mio. t CO2-Äq	Millions of tonnes of CO_2-eq

Source: Bundesregierung (2019a)

Figure 35: Sectoral targets of the Federal Climate Change Act

In addition to the greenhouse gas reduction target, an indicative trajectory for the expansion of renewable energies is also presented in the NECP under the decarbonisation dimension. For the total share of renewable energies in gross final energy consumption an annual increase of 1.2 percentage points is indicated. This equates to an increase in the share from 18% in 2020 to 30% in 2030 (see Figure 36). The contribution of heating and cooling is taken into account in this indicative trajectory and is achieved by expanding renewable heating and cooling generation installations.



Source: BMWi (2020)

Figure 36: Linear indicative trajectory for the expansion of renewable energies, measured on the basis of gross final energy consumption (indicative trajectory based on energy concept)

The sectoral indicative trajectory for heating and cooling is subordinate to the higher-level indicative trajectory from Figure 36. For 2020 a target value of 14% has been defined for the share of renewable energies in final energy consumption for heating and cooling. Taking this target value as a basis, a share of 27% is being targeted for 2030, which results from an annual increase of 1.3 percentage points in accordance with RED II (see Figure 37).

Source: BMWi (2020)

Figure 37: Sectoral indicative trajectory for heating and cooling – share of renewable energies in final energy consumption for heating and cooling (indicative trajectory based on EU Renewable Energy Directive)

In addition to the increase in the share of renewable energies in final energy consumption, an indicative trajectory for renewable heat in heating networks has also been described in the NECP. Under RED II an annual increase in this share of 1% should be targeted from 2020 to 2030. For Germany this therefore results in a share of approx. 21% in 2021, 25% in 2025 and 30% in 2030 (see Figure 38). The expansion and conversion of heating networks is a key infrastructure element for the future heating supply. In spite of the fact that the heat demand of buildings will decline in the future, there is considerable potential for expanding heating networks.

Source: BMWi (2020)

Figure 38: Indicative trajectory for the share of renewable energies in heating networks (indicative trajectory based on EU Renewable Energy Directive)

In summary, the two indicative trajectories described in the buildings sector should lead to a share of renewable heat of 24% to 32% by 2030.

II.1.b. Energy efficiency dimension

In July 2018 the Member States of the EU, together with the European Parliament, set the target of reducing primary energy consumption by 32.5% by 2030, relative to the projected consumption value. To achieve this target, within the framework of its national Energy Efficiency Strategy 2050 (EffSTRA) Germany has set an efficiency target for 2030 of a 30% reduction in primary energy consumption (PEC), relative to 2008. This target corresponds to a PEC of approx. 240 Mtoe in 2030, including non-energy use, or a PEC of approx. 216 Mtoe excluding non-energy use. According to the Federal Government's models, the measures under the NECP will bring about a reduction in final energy consumption of 185 Mtoe by 2030.

From the Federal Government's perspective the national efficiency target is an appropriate contribution to the achievement of the EU's energy efficiency target for 2030. To achieve the EU efficiency target, current EU-wide primary energy consumption needs to be reduced by 18.5% relative to 2017. Compared to the average EU-wide saving, the German approach, involving a reduction in energy consumption (relative to 2017) of around 28%, stands up well.

The cumulative savings target under the EED for the 2021-2030 period is 1,110.14 TWh or 95.46 Mtoe of final energy. This target is notified on the basis of Annex III to Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action.

The buildings sector must also make an appropriate contribution to climate protection if the long-term target is to be achieved by 2050. For buildings the Federal Climate Change Act provides for a reduction path involving permitted annual emission levels by 2030; no more than 70 million tonnes of CO_2 equivalents (in accordance with the *Quellprinzip* ('source principle', allocation of emissions to sector of origin)) may be emitted by 2030.

Germany has defined overall efficiency as an initial indicator for the achievement of the climate protection targets (see Figure 39). A milestone, or an increase in efficiency in the area of heating and cooling, and consequently the contribution of heating and cooling to the efficiency target is currently determined on the basis of the Long-Term Renovation Strategy (LTRS) (see also Part II.6). As the contributions of certain individual sectors to the reduction in greenhouse gas emissions in Germany have not yet been determined, and in the light of the dynamics at European level, the indicative milestones after 2030 for buildings cannot be described in quantitative terms at present.

Gesamtenergieeffizienz nicht-erneuerbarer PEV [PJ]	2008 (Basisjahr)	2030
	4.400	2.000

Gesamtenergieeffizienz nicht-erneuerbarer PEV [PJ]	Overall energy efficiency of non-renewable PEC [PJ]
2008 (Basisjahr)	2008 (base year)

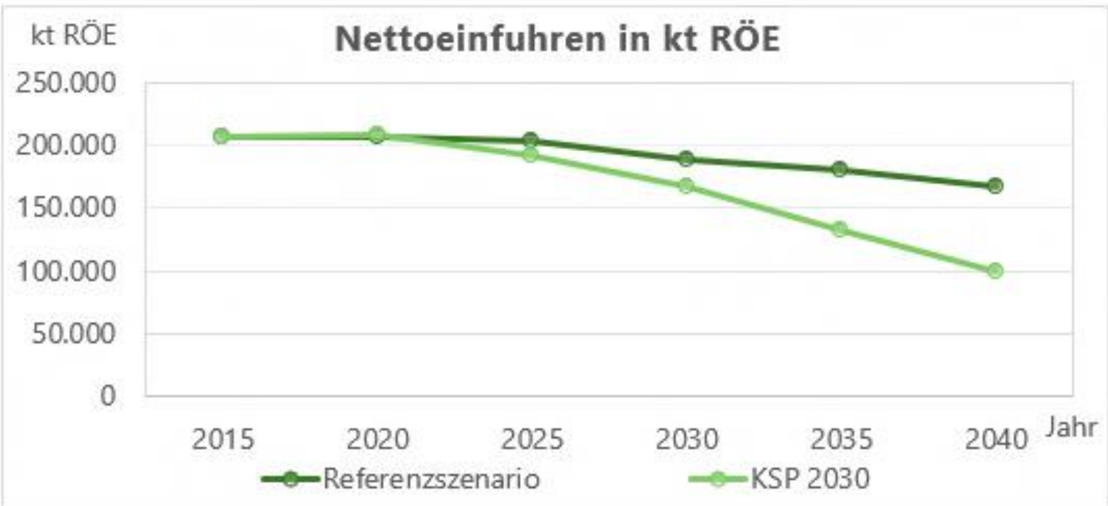
Source: BMWi (2020)

Figure 39: Indicative milestone in accordance with the Long-Term Renovation Strategy

II.1.c. Energy security dimension

Energy security is a qualitative target, which is why no quantitative targets have been laid down in the NECP. This target is centred around ensuring that energy demand in Germany is covered in all sectors and at all times. Within this context dependence on energy imports should also be reduced. In principle, the objectives and targets under the decarbonisation and energy efficiency dimensions have a stabilising effect on security of supply. National generation from renewable sources and improved energy efficiency can reduce the need for imports of limited fossil fuel resources.

To ensure this dimension also has an indicator and to gain a better overview by means of quantitative variables, net fuel imports can be used as a measure. In accordance with Eurostat's model calculation, presented in the annex to the NECP, net imports of solid fuels, crude oil, mineral oil products and gas will fall by 147,093 ktoe in total over the period from 2020 to 2040 (see Figure 40). As far as the assessment of energy security is concerned, however, imports of hydrogen and synthetic renewable fuels (PtX) will also need to be taken into account in the future. Under the NECP KSPr (comprehensive assessment of climate action programme) scenario, in 2050 the share of PtX in the supply of heating and cooling will be around 8% (34.5 TWh). To assess the energy security dimension, however, the future development of intra-European production and imports would also be needed. The share of imports of renewable fuels from outside Europe was not explicitly examined under the NECP scenario.



Nettoeinfuhren in kt RÖE	Net imports in ktoe
kt RÖE	ktoe
Referenzszenario	Reference scenario
Jahr	Year
KSP 2030	2030 CAP

Source: BMWi (2020)

Figure 40: Net imports of solid fuels, crude oil, mineral oil products and gas over the period from 2015 to 2040

II.1.d. Internal energy market dimension

Within the internal energy market dimension the NECP addresses the expansion of the energy transmission infrastructure for electricity and gas. Here the expansion of the gas networks can be placed within the context of the supply of heating. The 2020-2030 Gas Network Development Plan (NEP) focuses on green gases, their integration into the gas infrastructure and the planned merger of Germany's two gas market areas on 1 October 2021.

An additional aspect that is linked to the area of heating and cooling is sector coupling, which will allow renewable electricity to play an increasing role in the buildings, transport and industrial sectors and contribute to their decarbonisation. Sector coupling generates synergies when it comes to integrating high renewable energy shares and is therefore regarded as a key concept within the energy transition[18]. It also increases the resilience of the systems by ensuring greater redundancy and in this way strengthens security of supply. The framework conditions for sector coupling in Germany should thus be improved with a view to ensuring a level playing field for different sector coupling technologies (see also Part II.6).

As a final point within the internal energy market dimension the NECP deals with the question of energy poverty. Energy should remain affordable within the context of the energy transition. To ensure it remains affordable for all citizens, a series of strategies and measures has also been developed, which are discussed in Part II.6. The NECP does not describe quantitative targets and contributions for this dimension.

II.1.e. Research, innovation and competitiveness dimension

Within the research, innovation and competitiveness dimension national objectives and financing requirements for public and private research and innovation are addressed in connection with the energy union. Energy research is to be bolstered over the period up to 2030. To this end, around €1.3 billion a year in research support will be made available from 2020 to 2022. The central research-policy framework for energy research support in Germany is the Federal Government's 7th Energy Research Programme, which is multiannual and intended to guide the coordination of the support activities of the various ministries involved. The NECP does not describe quantitative targets and contributions for this dimension.

[18] In energy-efficient buildings modern heat pumps also operate with a high degree of efficiency at low temperatures. The increased flexibility achieved by integrating heat stores (in conjunction with heat pumps) and power stores (electric vehicles) creates opportunities to integrate high RE shares and in our view these outweigh the risks resulting from insufficient expansion of the distribution networks, for example.

II.2. Overview of existing policies and measures

A general overview is provided below of the policies and measures described in the NECP with a view to ensuring efficient heating and cooling.[19] In the NECP the policies and measures are described on the basis of the five dimensions of the energy union. The overview follows this structure and also presents the relevant policies and measures clearly in accordance with the five energy dimensions. Some of the policies and measures described contribute to the achievement of targets under several dimensions and can therefore be assigned to more than one dimension. To prevent duplication, they have been allocated to a dimension in accordance with the structure in the NECP.

To allow the policies and measures to be presented clearly, they have also been sorted into the following five types/categories of measures:

(1) Strategies and definitions of targets
(2) Economic instruments
(3) Regulatory measures
(4) Support
(5) Information and advice

Strategies and definitions of targets relate in particular to documents that describe and define climate and energy targets, as well as legislative texts that enshrine targets in law. Bodies that define and communicate targets are also assigned to this type of measure. Economic instruments are understood to refer to price-related instruments that control supply and demand through pricing. Within the context of this report these include, in particular, taxes, fees, tariffs, licences and certificates. Regulatory measures are regulatory or administrative instruments that create standards, requirements and prohibitions. Support covers binding regulations on the allocation of public funds. In contrast to economic instruments, support relates to the level of the payment flows, i.e. support generally reduces expenditure, as is the case within the framework of grants and/or subsidies. The last type of measure, information and advice, comprises measures used to provide and disseminate information.

It is not always possible to allocate the measures clearly to one of the five categories. Individual measures fulfil criteria of more than one category and could therefore be allocated to several categories. The classification should therefore be understood as a possible way of sorting the measures.

The policies and measures are presented with the section numbers from the NECP to allow them to be clearly allocated to the measures and their descriptions in the NECP. Furthermore, all the measures referred to below are listed with a brief description in the annex.

Due to the number of measures and policies, it is not possible to discuss all measures for each dimension. Key measures, i.e. newer measures and ones described in detail

[19] The policies and measures presented are those relating to efficient heating and cooling that were described in the most recent report in accordance with Articles 3, 20 and 21 and Article 27(a) of Regulation (EU) 2018/1999. The report in accordance with Articles 3, 20 and 21 and Article 27(a) of Regulation (EU) 2018/1999 is currently the NECP.

in the NECP, are presented and described below. Please refer to the NECP and/or annex for the description of the other measures.

II.2.a. Decarbonisation dimension

The relevant policies and measures for efficient heating and cooling under the decarbonisation dimension are presented clearly in Table 4. These measures contribute to the reduction of greenhouse gas emissions and to the expansion of renewable heat (see Part II.5).

Table 4: Overview of measures under the decarbonisation dimension

Strategies and definitions of targets	**Economic instruments**	**Regulatory measures**	**Support**	**Information and advice**
• Climate Action Plan 2050 • Climate Action Programme 2030 • Federal Climate Change Act (3.1.1.i.1.) • Development and implementation of a sustainable finance strategy (3.1.1.iii.2.) • National transposition of EU Directive 2003/87 by means of the Greenhouse Gas Emissions Trading Act (3.1.3.i.1.) • Sector coupling (3.1.3.ii.1.) • Further development of the KfW into a transformative investment bank (3.1.1.iii.3.) • Meseberg Climate Working Group (3.1.1.ii.3.)	• Carbon pricing in the heating and transport sectors (3.1.1.i.2. 3.2.iv.1.) • Minimum price in EU emissions trading (3.1.1.ii.1.) • Green Federal Government securities (3.1.1.iii.4.)	• Regulatory framework for the development of Renewable Energy Communities (3.1.2.v.6.) • Peer review process within the framework of the G20 (3.1.3.iv.1.)	• Support programme to expand landfill aeration and optimise gas capture (3.1.1.i.12.) • Further development and comprehensive modernisation of combined heat and power (3.1.2.i.8.) • European Climate Initiative (3.1.1.ii.2.) • National Climate Initiative (3.1.1.iii.1.) • Investments in storage technology (3.1.2.iii.2.) • KfW Renewable Energies Programme (3.1.2.iii.3.) • Heating Network Systems 4.0 (3.1.2.vi.1.) • Increasing conversion of heating networks to renewable energies and unavoidable waste heat (3.1.2.vi.2.) • Use of Biomass for Energy Production support programme (3.1.2.vii.1.) • Renewable Raw Materials support programme (3.1.2.vii.2.) • Phasing-out of grants for coal (3.1.3.iv.4.)	• 'Climate Action 2050' information campaign (3.1.1.i.13.) • Federal Government's subsidy report (3.1.3.iv.2.) • Comprehensive evaluation of tax advantages (3.1.3.iv.3.)

Source: BMWi (2020)

Key strategies and definitions of targets under the decarbonisation dimension are the **Climate Action Plan 2050**, the **Climate Action Programme 2030** and the **Federal Climate Change Act** (KSG) (BMWi, 2020, S. 73). The **Climate Action Plan 2050**, which was adopted in November 2016, describes a strategy for achieving the necessary transformation to a low-carbon economy in Germany (BMU, 2016). The **Climate Action Programme 2030** sets out the strategy of the Climate Action Plan 2050 in concrete terms and includes a detailed work plan for achieving the climate targets (Bundesregierung, 2019b). It was passed in October 2019. The climate targets have been enshrined in law in the **Federal Climate Change Act**, which entered into force on 18 December 2019. This provides for a gradual reduction in greenhouse gas emissions relative to 1990 levels, amounting to at least 55% by the target year of 2030 (Section 3 KSG) (see also Part II.5). Germany has also committed to pursuing net-zero greenhouse gas emissions by 2050 as a long-term target (Section 1 KSG) (see also Part II.5).

The measures under the Climate Action Programme 2030 are intended to support the achievement of targets and range from introducing new tax instruments to improving support programmes and making additional public investments. One key new economic instrument is national **carbon pricing for the heating and transport sectors** (BMWi, 2020, S. 73). From 2021 onwards companies that bring fuel oil, natural gas, petrol or diesel onto the market must pay a carbon price to do so. In the heating sector the new system therefore covers the emissions from heating generation of the buildings sector and of energy and industrial installations outside the European Emissions Trading Scheme.

Key support programmes for efficient heating and cooling under the decarbonisation dimension include, in particular, the **KfW Renewable Energies Programme** and the **Heating Network Systems 4.0** support programme (BMWi, 2020, S. 85 und 87). The purpose of the former, in the area of heating and cooling, is to provide low-interest finance for heat generation measures at combined heat and power installations, as well as for measures relating to the integration of renewable energies. Up to 100% of the eligible investment costs are financed, with a ceiling of €50 million per project. The Heating Network Systems 4.0 programme supports innovative heating network systems that predominantly make use of renewable energies and waste heat. Through this support programme, systemic support has been introduced for the first time in Germany in the area of heating infrastructure, supporting not only individual technologies and components, but also complete systems. The support programme was amended in December 2019.

The **further development of combined heat and power** (CHP) is also included as a measure in the NECP (BMWi, 2020, S. 83). This measure involves the future modernisation of CHP support and the extension of support until 2030. Support for CHP installations is enshrined in law in the Cogeneration Act (KWKG). Another new measure is the **increasing conversion of heating networks to renewable energies and unavoidable waste heat** (BMWi, 2020, S. 87). This measure has not yet been implemented, but has already been described in the NECP. During the 19th legislative period a support programme is to be developed that will supplement the Heating Network Systems 4.0 programme with a heating network transformation programme, which will contribute, in particular, to the decarbonisation of existing heating networks. The form that this measure will take is discussed more specifically in Part IV on potential new strategies and measures.

Lastly, the **phasing-out of grants for coal** should be highlighted as a crucial policy measure (BMWi, 2020, S. 97). Subsidies relating to the sale of domestic coal were paid for the last time in 2018 and coal mining then ended. Subsequent shutdown measures will continue to be subsidised until the end of 2022. Ending the generation of electricity and heat from coal will make a decisive contribution to the transformation of heating and cooling to an efficient, climate-neutral supply based on renewable energies.

II.2.b. Energy efficiency dimension

The relevant policies and measures under the energy efficiency dimension are listed in Table 5. The purpose of the strategies and measures shown is to increase energy efficiency in the area of heating and cooling (see Part II.5).

Table 5: Overview of measures under the energy efficiency dimension

Strategies and definitions of targets	**Economic instruments**	**Regulatory measures**	**Support**	**Information and advice**
• Energy Efficiency Strategy 2050 (3.2.i.1.) • National Action Plan on Energy Efficiency 2.0 (3.2.i.2.) • Efficiency First (3.2.i.3.) • Long-Term Renovation Strategy (3.2.ii.) • Energy Efficiency and Heat from Renewable Energy support strategy (3.2.viii.1.)	Asset Class Energy Efficiency (3.2.viii.4.)	• National efficiency label for old heating systems (3.2.ii.6.) • Building Energy Act (3.2.ii.7.) • Example-setting role of federal buildings (3.2.ii.19. and 3.2.iv.4.) • EU Ecodesign Directive – expansion of minimum standards (3.2.iv.2.) • Ambitious standards for energy label and ecodesign (3.2.iv.3.) • Energy-efficient procurement by public institutions (3.2.iv.5.) • Accelerated implementation of measures resulting from energy audit and energy management systems (3.2.iv.6.)	• Federal support for energy advice on residential buildings (3.2.ii.3. and 3.2.iv.10.) • Federal support for energy advice on non-residential buildings of municipalities / non-profit organisations (EBK) (3.2.ii.4. and 3.2.iv.11.) • Federal support for energy advice in small and medium-sized enterprises (3.2.ii.5. and 3.2.iv.12.) • CO_2 building renovation programme of the Federal Government (Energy-Efficient Construction and Renovation (EBS)) (3.2.ii.8.) • Market Incentive Programme (MAP) (3.2.ii.9.) • Energy Efficiency Incentive Programme (APEE) (3.2.ii.10.) • Support Programme for Heating Optimisation (HZO) (3.2.ii.11.) • Federal Support for Efficient Buildings (amalgamation of EBS, MAP, APEE, HZO) (3.2.ii.12.) • Tax support for energy-efficient renovation of buildings (3.2.ii.13.) • Support for serial	• PR campaign 'Germany Does It Efficiently' (3.2.ii.1.) • Independent advice from Verbraucherzentrale Bundesverband e. V. (Federation of German Consumer Organisations) (3.2.ii.2. and 3.2.iv.9.) • Federal Government / federal state dialogue on contracting (3.2.iii.2.) • Information on model contracts and guidelines (3.2.iii.4.) • Energy-efficiency and resource-efficiency networks of municipalities (3.2.iii.5.) • Supplier list of the Federal Office for Energy Efficiency (3.2.iv.8.)

Strategies and definitions of targets	Economic instruments	Regulatory measures	Support	Information and advice
			renovation (3.2.ii.14.) • Energy-efficient urban redevelopment (3.2.ii.15.) • Expansion of support programmes for heating networks, heat stores and cross-building investments (3.2.ii.16.) • Further development of the Future of Construction innovation programme (3.2.ii.17.) • Energy Transition Construction (3.2.ii.18.) • Further development of urban development support (3.2.ii.20.) • Support for advice on energy-saving contracting within the framework of the EBK (3.2.iii.1.) • Model projects for energy-saving contracting (3.2.iii.3.) • Support for energy management systems (3.2.iv.7.) • Support for resource efficiency (3.2.iv.20.) • Energy tax advantages (3.2.iv.22.) • Federal support for energy efficiency in the economy (3.2.viii.2.) • Support for mini-cogeneration plants (3.2.viii.3.) • Energy and Electricity Tax Act (peak-load balancing) (3.2.viii.5.)	• SME Initiative Energy Transition and Climate Protection (3.2.iv.13.) • Further development of efficiency networks (3.2.iv.17.) • Advice and information (3.2.iv.19.) • Further and vocational training (3.2.iv.21.) • Communication on energy efficiency (3.2.iv.23.) • Information and Competence Centre for Sustainable Construction (3.2.iv.24.) • Franco-German Energy Platform (3.2.vii.1.)

Source: BMWi (2020)

The energy efficiency dimension covers the majority of policies and measures in the area of efficient heating and cooling. A key strategy under this dimension is the cross-sector **energy efficiency strategy 2050** of December 2019, which includes major targets and instruments relating to the further development of energy efficiency policy (BMWi, 2020, S. 98). It defines an energy efficiency target for 2030 and a package of measures aimed at reducing primary energy consumption in Germany (see also Part II.5). The strategy also launches a broad-based dialogue process on the development of a long-term roadmap for halving primary energy consumption by 2050. To achieve the targets set out in the Energy Efficiency Strategy 2050, additional energy efficiency potentials need to be realised. Against this background, the further developed **National Action Plan on Energy Efficiency 2.0** (NAPEE 2.0) expands the existing energy efficiency policy and defines immediate measures and further work processes with a view to achieving the national efficiency and climate protection targets (BMWi, 2020, S. 98). NAPEE 2.0 and the Climate Action Programme 2030 are closely connected, as the majority of measures aimed at reducing energy consumption also lead to a cut in greenhouse gas emissions. Alongside these two strategies, the **Long-Term Renovation Strategy** (LTRS) should also be highlighted (BMWi, 2020, S. 99). Every Member State is required to submit such a strategy in accordance with the EU Directive on the energy performance of buildings with a view to drawing up a roadmap containing measures and nationally defined measurable progress indicators for the achievement of long-term climate targets and identifying pathways and incentives for the renovation of the national building stock. Germany published its LTRS in August 2020. The final key strategy described in the NECP is the **Energy Efficiency and Heat from Renewable Energy support strategy**, which includes a comprehensive concept for reforming the support of energy efficiency measures and heat from renewable energy (BMWi, 2020, S. 110). This strategy was presented in May 2017. Its recommendations will be implemented consistently up to 2021.

Alongside strategies and definitions of targets, the energy efficiency dimension also covers numerous regulatory instruments (see Table 5). A key regulatory measure that can be highlighted here is the **Building Energy Act** (GEG), which represents a new, uniform and coordinated set of rules on the energy requirements for new and existing buildings and on the use of renewable energies for the supply of heating and cooling to buildings (BMWi, 2020, S. 101). To create this Act, the Energy Conservation Regulation (EnEV), Energy Conservation Act (EnEG) and Renewable Energy Heating Act (EEWärmeG) were amalgamated and harmonised. The Act has been in force since 1 November 2020. European requirements relating to the energy performance of buildings are implemented in full through the GEG.

Key support programmes under the energy efficiency dimension include the **CO_2 building renovation programme of the Federal Government**, the **Market Incentive Programme** (MAP), the **Energy Efficiency Incentive Programme** (APEE), the **Support Programme for Heating Optimization** (HZO) and **Federal Support for Efficient Buildings**, which will bring together the programmes mentioned above (BMWi, 2020, S. 101 und 102). The **CO_2 building renovation programme of the Federal Government** has existed since 2006 and provides support, via the KfW programme Energy-Efficient Construction and Renovation (EBS), for energy-efficient renovations and the highly efficient new construction of residential and non-residential buildings, as well as individual renovation measures in the area of energy efficiency, with a view to implementing the long-term renovation strategy for buildings. The **MAP** supports renewable energy installations for heating and cooling, as well as certain heat stores and local heating networks. Two support components are available under the MAP. For smaller installations investment grants are awarded via the Federal Office for Economic Affairs and Export Control (BAFA). In the case of larger installations the Federal Government awards grants, within the framework of the KfW programme Renewable Energies – Premium, for the repayment of a portion of low-interest KfW loans. In January 2020 the MAP switched from the previous system of providing a fixed amount of support to proportionate financing and support rates were raised by ten percentage points. In order to increase the rate of replacement of oil heating systems, a ‘replacement premium’ with a funding percentage of up to 45% was integrated into the BAFA component of the MAP. The **APEE** bolsters the support available under the MAP with additional funds and supports the market introduction of stationary fuel cell heating systems. This support takes the form of a grant for stationary fuel cell heating systems with an electrical output of 0.25 to 5.0 kW via the KfW programme Energy-Efficient Construction and Renovation – Fuel Cell Grant. The **HZO** is intended to create incentives to replace inefficient heating and hot water circulation pumps with high-efficiency pumps and to optimise existing heating systems by means of hydraulic balancing. The support amounts to up to 30% of the net investment costs. Under the revamped **Federal Support for Efficient Buildings** these four existing investment support programmes in the area of buildings are being brought together under a single, comprehensive and modernised support offering and their content has been optimised (BMWi, 2020, S. 102). The new programme is due to be launched in 2021.

A support measure that has not yet been implemented, but is mentioned in the NECP is the **expansion of support programmes for heating networks, heat stores and cross-building investments** (BMWi, 2020, S. 102). The plan is to combine the support programmes for heating networks, heat stores and cross-building investments that supply buildings, installations or processes with renewable heating or cooling under a new support pillar (cf. also Part IV). Within this context the existing support programme Heating Network Systems 4.0 is also to be expanded (cf. decarbonisation dimension).

Alongside the support programmes already described, the various forms of **federal support for energy advice** are also included in the NECP (BMWi, 2020, S. 100). Energy advice helps to ensure that energy efficiency and renewable energies are incorporated into the planning and decision-making process and in this way that efficiency potentials are fully exploited. The federal support for energy advice is divided into federal support for energy advice on residential buildings, federal support for energy advice on non-residential buildings of municipalities / non-profit organisations and federal support for energy advice in small and medium-sized enterprises (see Table 4).

A key measure that can be highlighted within the category of information and advice is the information campaign '**Germany Does It Efficiently**', which comprises public relations work and specialist communication on concrete energy saving opportunities and possible forms of support (BMWi, 2020, S. 99).

II.2.c. Energy security dimension

The relevant policies and measures under the energy security dimension are listed in Table 6. These measures contribute to energy security and, within the context of efficient heating and cooling, to the security of the heating supply (see Part II.5).

Table 6: Overview of measures under the energy security dimension

Strategies and definitions of targets	Economic instruments	Regulatory measures	Support	Information and advice
• Future role of renewable gases and National Hydrogen Strategy (3.3.i.7.) • Solidarity between EU Member States within		• Security of supply for residential customers (3.3.i.1.) • Bi-directional capacity (3.3.i.3.) • (Natural gas) storage facilities (3.3.i.4.) • Energy Security Act –		• Provision of information (3.3.i.2.) • Gas prevention plan (3.3.i.5.) • 'Gas 2030' dialogue process (3.3.i.6.) • Gas emergency plan (3.3.i.12.)

Strategies and definitions of targets	Economic instruments	Regulatory measures	Support	Information and advice
the framework of the SoS Regulation (3.3.i.11 and 3.3.ii.1.)		Natural Gas (3.3.i.8.) • Regulation on the Security of the Gas Supply (GasSV) (3.3.i.9.) • Possible measures within the framework of orders pursuant to Section 1 of the GasSV (3.3.i.10.) • Energy Security Act – Petroleum (3.3.i.13.) • Petroleum Stockholding Act (3.3.i.14.) • Fuel Oil Supply Restrictions Regulation (3.3.i.18.) • Mineral Oil Equalisation Regulation (3.3.i.19.) • Mineral Oil Management Regulation (3.3.i.20.)		• Mineral Oil Data Act (3.3.i.15.) • National Emergency Strategy Organisation (3.3.i.21.) • Gas Coordination Group (3.3.ii.2.) • Prevention and emergency plan consultations (3.3.ii.3.) • Risk groups (3.3.ii.4.) • Pentalateral Gas Forum (3.3.ii.5.) • Cooperation in regional groups within the framework of the trans-European energy networks – gas (3.3.ii.6.) • Cooperation in regional groups within the framework of the trans-European energy networks – oil (3.3.ii.7.) • Annual Coordinating Meeting of Entity Stockholders (3.3.ii.8.)

Source: BMWi (2020)

A key strategy in the NECP under the energy security dimension is the **national hydrogen strategy**, which deals with the future role of renewable gases (BMWi, 2020, S. 113). The strategy document was published in June 2020 (BMWi and Bundesregierung, 2020). Hydrogen technologies and alternative energy sources based on them are an integral component of the energy transition and contribute to its success. Germany has therefore adopted a national hydrogen strategy, which incorporates an action plan for boosting the market uptake of hydrogen technologies.

In addition to strategies, regulatory measures play a particularly crucial role under this dimension. They regulate the security of the energy supply and therefore also the security of efficient heating and cooling. A key regulatory instrument within this context is the **security of supply for residential customers** (BMWi, 2020, S. 112). Under the Energy Industry Act network operators are required to take the security of supply for residential customers into account at all times. If there is a risk of congestion in the gas supply, the network must be operated and capacities, including transit capacities, allocated and planned in such a way that the security of supply for residential customers is maintained for as long as possible. **Storage facilities** are key to securing the supply of natural gas (BMWi, 2020, S. 112). In accordance with their obligations to ensure security of supply, gas traders are responsible for the use of commercial storage facilities in Germany.

Security of the heating supply is also underpinned by the **Energy Security Act** (BMWi, 2020, S. 113 und 115). The instruments available under the Energy Security Act, in combination with the **Regulation on the Security of the Gas Supply**, are only used in an emergency to ensure that the essential need for natural gas is met in the event of an immediate risk or disruption to the supply of natural gas, where this risk or disruption cannot be eliminated, or cannot be eliminated promptly or only through disproportionate means, using market-based measures. The scope of the Energy Security Act also covers petroleum and petroleum products.

With the European Regulation concerning measures to safeguard the security of gas supply[20] (SoS Regulation) a mechanism has also been introduced to promote **solidarity amongst EU Member States** with the aim of significantly increasing the resilience of the European gas system (BMWi, 2020, S. 114). Germany is working intensively on the structure of a possible process for supplying gas on the basis of solidarity and the associated compensation scheme. The development of the solidarity mechanism is characterised by a substantial exchange of information between Member States, in particular in the **Gas Coordination Group** (BMWi, 2020, S. 119).

II.2.d. Internal energy market dimension

The policies and measures for efficient heating and cooling under the internal energy market dimension are listed in Table 7. The measures listed contribute to an increase in interconnectivity. Within the context of efficient heating and cooling the measures focus primarily on expanding gas networks and increasing flexibility (see Part II.5). Some of the measures under this dimension also address the theme of energy poverty.

Table 7: Overview of measures under the internal energy market dimension

Strategies and definitions of targets	Economic instruments	Regulatory measures	Support	Information and advice
• Gradual reduction and phase-out of coal-fired electricity generation based on the recommendations of the Commission on Growth, Structural Change and Employment (3.4.3.i.1.) • Sector coupling (3.4.3.i.2.) • Flexible CHP installations as a transitional technology (3.4.3.ii.8.)	Fee-based incentives and incentive regulation (3.4.2.i.6.)	• Utilisation Before Limitation measure (3.4.3.ii.7.) • Protection of energy consumers (3.4.3.iv.1.) • Basic and auxiliary supply concept (3.4.3.iv.2.) • Smart Meters Operation Act (3.4.3.v.4.)	• Changes to housing allowance, tenancy law and energy law (3.4.3.iv.5.) • Transfer payments (3.4.3.iv.6.) • Accompanying structural policy measures in connection with the gradual reduction and phase-out of coal-fired electricity generation (3.4.3.iv.7.) • Smart Border Initiative (3.4.3.vi.4.)	• Network Development Plan – Gas (3.4.2.i.7.) • Monitoring of gas network expansion projects (3.4.2.i.8.) • Market master data registers (3.4.3.v.3.)

Source: BMWi (2020)

A key measure under the internal energy market dimension is the **gradual reduction and phase-out of coal-fired electricity generation based on the recommendations of the Commission on Growth, Structural Change and Employment** (KWSB) (BMWi, 2020, S. 125). At the beginning of 2019 the KWSB presented extensive recommendations relating to how the gradual phase-out of coal-fired electricity generation could be implemented and financed in a socially acceptable way in accordance with the climate targets. The KWSB's key energy policy recommendations were implemented by means of the **Coal Phase-Out Act**, which entered into force on 14 August 2020. Although, in the first instance, the Act mainly relates to the generation of electricity from coal, it also affects the heating supply, as many coal-fired power plants are also heat generators.

Another key objective/strategy included in the NECP is **sector coupling** (BMWi, 2020, S. 126). The use of renewable electricity in the areas of heating, industry and transport

[20] Regulation (EU) 2017/1938 of 25 October 2017 concerning measures to safeguard the security of gas supply and repealing Regulation (EU) No 994/2010

should be driven forward to replace fossil fuels. To this end, steps should be taken to examine how barriers to sector coupling could be removed. Programmes and demonstration projects should be implemented to support sector coupling. The use of **flexible CHP installations as a transitional technology** also falls within this context (BMWi, 2020, S. 129). New and modernised CHP installations can make an important contribution to reducing greenhouse gas emissions by 2030 and also play a role after that. Pilot projects for flexible, innovative CHP installations are to be set up and calls for funding will thus be published under the KWKG (cf. decarbonisation dimension).

A key support instrument referred to in the NECP under the internal energy market dimension are the **changes to housing allowance, tenancy law and energy law** (BMWi, 2020, S. 132). To avoid social hardship resulting from rising heating costs, in particular due to the introduction of carbon pricing for the heating sector, housing allowance recipients will be supported by a 10% increase in the housing allowance budget. Changes to tenancy law and energy law will also be examined that provide for the limited passing on of carbon pricing. This should lead to a double incentive effect: it should encourage tenants to act in an energy-efficient way and landlords to invest in climate-friendly heating systems and/or energy-efficient renovations.

II.2.e. Research, innovation and competitiveness dimension

The policies and measures for efficient heating and cooling under the research, innovation and competitiveness dimension are listed in Table 8. The measures contribute to funding and support for research in the area of heating and cooling.

Table 8: Overview of measures under the research, innovation and competitiveness dimension

Strategies and definitions of targets	Economic instruments	Regulatory measures	Support	Information and advice
Strategic Energy Technology Plan (3.5.ii.1.)		Energy Transition Digitisation Act (3.5.i.14.)	• 7th Energy Research Programme of the Federal Government (3.5.i.1. and 3.5.iii.1.) • Finance and climate protection (3.5.i.3.) • Future of Construction initiative's model project for experimental construction (3.5.i.6.) • 'Solar Construction / Energy-Efficient City' support initiative (3.5.i.7.) • EU ETS Innovation Fund: further development of the NER300 programme (3.5.i.11.) • Smart Energy Showcases – Digital Agenda for the Energy Transition (3.5.i.13.) • Greater involvement of start-ups in energy research (3.5.i.16.) • Digital Innovation Hub for Climate (3.5.i.19.) • European Research Area Cofund (3.5.ii.2.) • Greco-German Research Cooperation and Funding of Upcoming Researchers (3.5.ii.5.) • Franco-German Fellowship Programme (3.5.ii.6.) • Franco-German Research Funding for a Sustainable European Energy Supply (3.5.ii.7.)	

			• EU Framework Programme for Research and Innovation – Horizon 2020 (3.5.iii.2.) • 'SME-innovative' research funding initiative (3.5.iii.5.)	

Source: BMWi (2020)

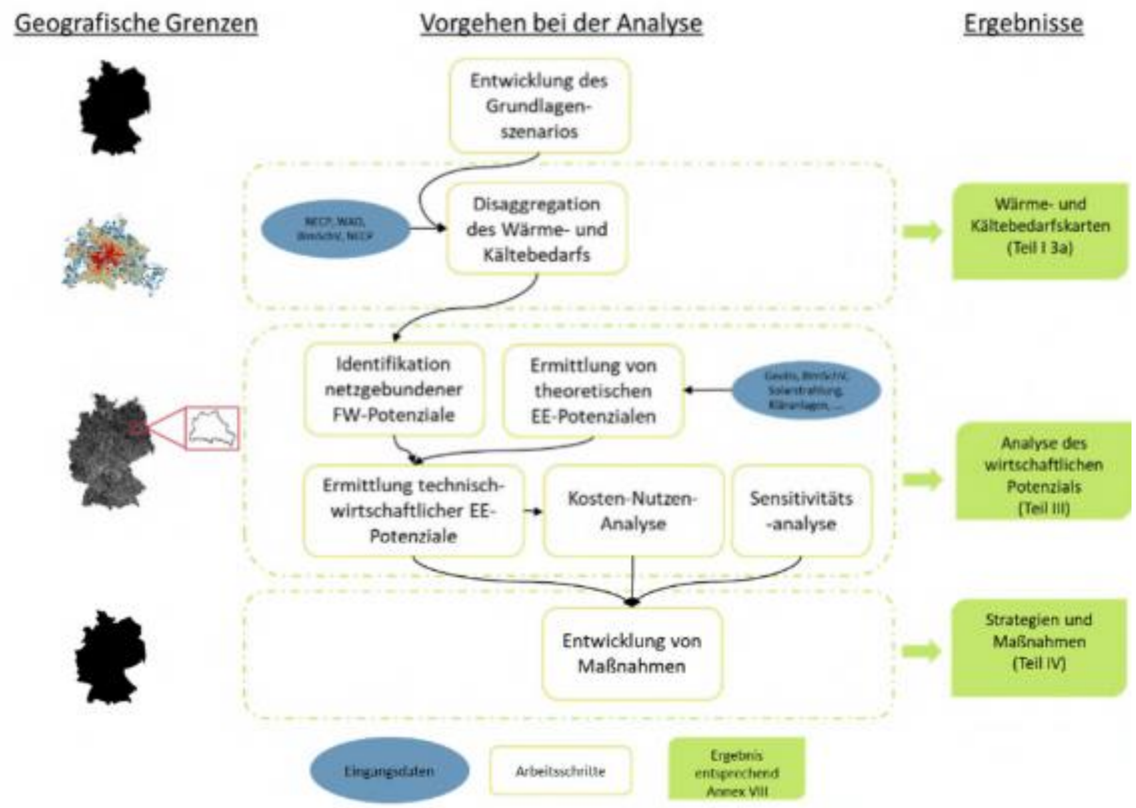
A relevant regulatory instrument under the research, innovation and competitiveness dimension is the **Energy Transition Digitisation Act** (GDEW), which forms the basis for cross-sector digitisation (BMWi, 2020, S. 139). To implement the Act, necessary additional measures are being taken that significantly influence the further development of technical standards and the regulatory framework, e.g. to ensure better integration of renewable energies and flexible loads into the grid.

This dimension also covers numerous programmes designed to support energy research. The largest support programme is probably the **7th Energy Research Programme** of the Federal Government (BMWi, 2020, S. 136). This was adopted by the Federal Cabinet in September 2018. Improving and accelerating the technology and innovation transfer is a particular focus of this programme. With this in mind, energy transition living labs are being set up and financially supported as a new pillar of research funding. Four of the five topics in total are relevant to efficient heating and cooling. The first of these focuses on the energy transition in consumption sectors. In accordance with the 'efficiency first' principle, the project support focuses on efficient energy use and reducing consumption. The second topic is centred around energy generation and therefore, in the area of heating, around renewable and low-emission heat generation technologies (in particular bioenergy, geothermal energy and thermal power plants). The third topic deals with system integration. Here the focus is placed on grids, storage facilities and sector coupling as new research areas. The efficient and economical storage of renewable energies is a key research objective. The final relevant topic relates to cross-system research themes. These include energy systems analysis, energy-relevant aspects of digitisation, resource efficiency, CO_2 technologies and materials research, as well as social aspects.

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

III.1. Overview of procedure

The analysis of the economic potential for efficiency in heating and cooling is based on a newly developed quantitative approach. An overview of the procedure is provided in Figure 41.



Geografische Grenzen	Geographical boundaries
Vorgehen bei der Analyse	Analysis procedure
Ergebnisse	Results
Entwicklung des Grundlagenszenarios	Development of baseline scenario
NECP, WAD, BImSchV, NECP	NECP, German Heat Atlas, BImSchV, NECP
Disaggregation des Wärme- und Kältebedarfs	Disaggregation of heating and cooling demand
Wärme- und Kältebedarfskarten (Teil I 3a)	Heating and cooling demand maps (Part I 3a)
Identifikation netzgebundener FW-Potenziale	Identification of net-bound district heating potentials
Ermittlung von theoretischen EE-Potenzialen	Determination of theoretical RE potentials
Geotis, BImSchV, Solarstrahlung, Kläranla-gen,...	Geotis, BImSchV, solar radiation, sewage treatment plants,...
Ermittlung technisch-wirtschaftlicher EE-Potenziale	Determination of techno-economic RE poten-tials

Kosten-Nutzen-Analyse	Cost-benefit analysis
Sensitivitätsanalyse	Sensitivity analysis
Analyse des wirtschaftlichen Potenzials (Teil III)	Analysis of economic potential (Part III)
Entwicklung von Maßnahmen	Development of measures
Strategien und Maßnahmen (Teil IV)	Strategies and measures (Part IV)
Eingangsdaten	Input data
Arbeitsschritte	Work steps
Ergebnis entsprechend Annex VIII	Result in accordance with Annex VIII

Source: Own figure (ifeu)

Figure 41: Overview of data sources, work steps, results in accordance with Annex VIII and the spatial resolution of the data

The first step involves selecting and developing the baseline scenario, taking the requirement set out in Article 14(3) of the EED into account. Based on the available models and data sources, the system boundaries are also identified and adequate geographical boundaries required for the analysis of economic potentials are defined. The methodology for assessing the alternative scenarios is then developed. This involves determining which technical solutions seem to be appropriate and could theoretically be used on the basis of the local conditions (determination of technical demand potentials), how future district heating potentials could be identified and how the various alternative scenarios could be assessed (determination of economic potentials of various technologies for efficient heating and cooling). Building on this, a comprehensive cost-benefit analysis and sensitivity analysis are performed.

III.2. Geographical boundaries and system boundaries

Part III(8)(c) of Annex VIII of Delegated Regulation (EU) 2019/826 stipulates that 'the geographical boundary shall cover a suitable well-defined geographical area' and 'the cost-benefit analyses shall take into account all relevant centralised or decentralised supply resources available within the system and geographical boundary' and heating and cooling demand trends and characteristics (European Commission, 2019a). Commission Recommendation (EU) 2019/1659 also states that large Member States are recommended 'to divide their territory further into regions (e.g. NUTS-1[21]), in order to make energy mapping and planning exercise more manageable, and allowing to take account of different climatic zones'. The aim is to 'identify opportunities for synergies between heating and cooling demand and sources of waste and renewable heat and cold within the geographical boundary' (European Commission, 2019b).

The European Commission's recommendation also specifies that geographical factors should be taken into account when selecting the system boundaries: for example, heating and cooling consumers should be considered at the same time as the supply of

[21] This corresponds to the federal states in Germany.

heating and cooling to identify potential for the exchange of energy (European Commission, 2019b).

Whereas an analysis at national level cannot take into account important criteria for the use of various heating and cooling supply technologies, such as the geographical proximity between a heat source and heat sink, the isolated examination of individual heating and cooling consumers ignores the possibilities of a cost-efficient centralised supply. Selecting appropriate indicators and an appropriate spatial resolution for the analysis is therefore essential.

The following decision-making factors are relevant for the analysis of the economic potential for efficiency in heating and cooling:

- assumptions relating to the development of heating and cooling consumption in Germany, broken down by sectors (residential, services and industry) and applications (space heating and hot water, process heating and cooling, and air conditioning);
- the spatial distribution and concentration of heating and cooling consumption;
- local possibilities for integrating renewable energies and high-efficiency CHP;
- the availability of heating network infrastructure.

From an economic perspective, various renewable energy sources (e.g. deep geothermal energy) and waste heat can usually only be exploited by integrating them into heating networks. As the economic assessment of heating networks has to take into account not only the costs of generation, but also the costs of constructing the heating network, centralised solutions become particularly attractive from an economic perspective when there is a sufficiently high number of, ideally large, heating consumers who are geographically concentrated. To allow such areas to be identified within Germany, heating density is used in these analyses: this is a measure that describes the annual heating sales per defined area of land.

Depending on the size of the area of land to which the heating densities relate, this is associated with various challenges. If the underlying areas of land that are selected are too large, important aspects for analysing the use of grid-based infrastructure cannot be taken into account. For example, interesting heating consumers cannot be identified if they are aggregated with less energy-intensive zones within the area of land (e.g. parks or transport infrastructure). In addition, if smaller units of area are considered, this increases the (calculation) effort involved in the assessment and the uncertainties due to limited data availability. While information regarding building geometry and use is available within the research project at individual building level (for details see III.3.c), information relating to the age classes of residential buildings in Germany is only available on the basis of 100 m x 100 m grid cells.

Various publicly accessible web platforms and tools use heating densities based on 100 m x 100 m grid cells for heating and cooling plans (e.g. Hotmaps[22], Thermal Atlas in Heat Roadmap Europe[23]). This spatial unit is also used for the analysis of the eco-

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[22] https://www.hotmaps.eu/, accessed on 30.7.2020

[23] https://heatroadmap.eu/peta4/, accessed on 30.7.2020

nomic potential for efficiency in heating and cooling in this research project, as there are sufficient empirical data available from the Heat Atlas 2.0 of the ifeu[24].

By defining limit values for heating densities, it is then possible to identify areas that prequalify for a grid-based energy supply. For the analyses within this project a limit value of 15 GWh/km^2 is used for space heating and hot water in residential and non-residential buildings. This value is based on the energy use plan guidelines drawn up by the Technical University of Munich on behalf of the Free State of Bavaria (Hausladen & Hamacher, 2011) and on the guidelines for the climate-friendly transformation of the heating supply (Hertle et. al, 2015).

However, as a centralised supply to individual areas of land – and thus to small groupings of heating consumers – often cannot be achieved in a viable way due to economic and technical barriers (e.g. customary capacity classes for technologies or technological systems), a minimum capacity is also defined for the corresponding technologies, in addition to the heating density.

Against this background, heating densities are allocated to individual heating density classes (corresponding to the system boundaries in the analyses) and the absolute heating sales within these classes are shown. To allow the local conditions and regional structures to be taken into account, this takes place within administrative boundaries (geographical boundary). To this end, the heating sales per heating density class are analysed for each of the 4,674 municipal associations in Germany and used for the subsequent analyses. The corresponding approaches used to identify the necessary installed capacity for the individual technologies, based on the heating demand, are set out in Section III.6.a.i.

In accordance with the procedure used for known European projects (e.g. Heat Roadmap Europe 4, Hotmaps), the heating density is determined for space heating and hot water demand in the residential, services and industrial sectors. The demand for process heating is also shown for each municipal association and taken into account in the analysis of the various alternative scenarios.

III.3. Baseline scenario

The information on heating and cooling demand in terms of assessed useful energy and quantified final energy consumption is required for the following analyses of the economic potentials of various heating and cooling supply options and the development of alternative scenarios, as well as for the generation of the maps (see I.3) used to visualise the heating and cooling demand areas. As set out in Commission Recommendation 2019/1659, the results of the integrated energy and climate plan for Germany (NECP, Bundesministerium für Wirtschaft und Energie, (2020)) serve as a baseline scenario. The developed target scenario II is used, which reflects the measures and strategies adopted in Germany and also meets the targets under Regulation (EU) 2018/1999 in the areas of energy efficiency and renewable energies (Kemmler et al., 2020).

[24] See also https://www.ifeu.de/methoden/modelle/waermeatlas/

III.3.a. Useful and final energy demand by sector

In addition to a sectoral breakdown (residential, services and industry), the data are also broken down for the various applications (space heating, hot water, process heating and cooling, and air conditioning). The data available for the baseline scenario in 2018 are presented in Table 9.

Table 9: Overview of underlying assumptions for the baseline scenario in 2018[25]

Sector	Application	Useful energy [TWh]	Final energy [TWh]
Industry	Space heating and hot water		59
	Process heating		455
	Process cooling		4.5
	Air conditioning		4.2
Services	Space heating and hot water		203
	Process heating		26
	Process cooling		13
	Air conditioning		4.3
Residential	Space heating and hot water	456	505
	Cooling		0.5

With regard to the requirements that must be met to fulfil the reporting obligation, gaps in the data can be seen in relation to the useful energy demand in the industrial and services sectors and the useful energy consumption for cooling in the residential sector. To fill these data gaps, use is made of the results from Section I.1.b, data from the Hotmaps open source mapping and planning tool for heating and cooling, and our own calculation, which are detailed below:

- Useful energy demand in industry on the basis of final energy consumption: for the overall *Comprehensive assessment of the potential for efficient heating and cooling* in accordance with Annex VIII of Delegated Regulation (EU) 2019/826 it is necessary, in Part I, to identify the heating and cooling demand in terms of assessed useful energy and quantified final energy consumption in GWh per year for the residential, services and industrial sectors. With this in mind, the corresponding efficiencies for process heating are recorded for the economic sectors in the Forecast industry model. Generally, an efficiency of 2.5 is recorded for space cooling and of 3.48 for process cooling (in the case of applications

[25] The useful energy consumption shown excludes the use of firewood and small, mobile electric heaters. The consumption is just under 42 TWh and low efficiencies are assumed.

from 0 °C to 15 °C, with a figure of 1.68 for applications from -30 °C to 0 °C). For details see Section I.1.b.

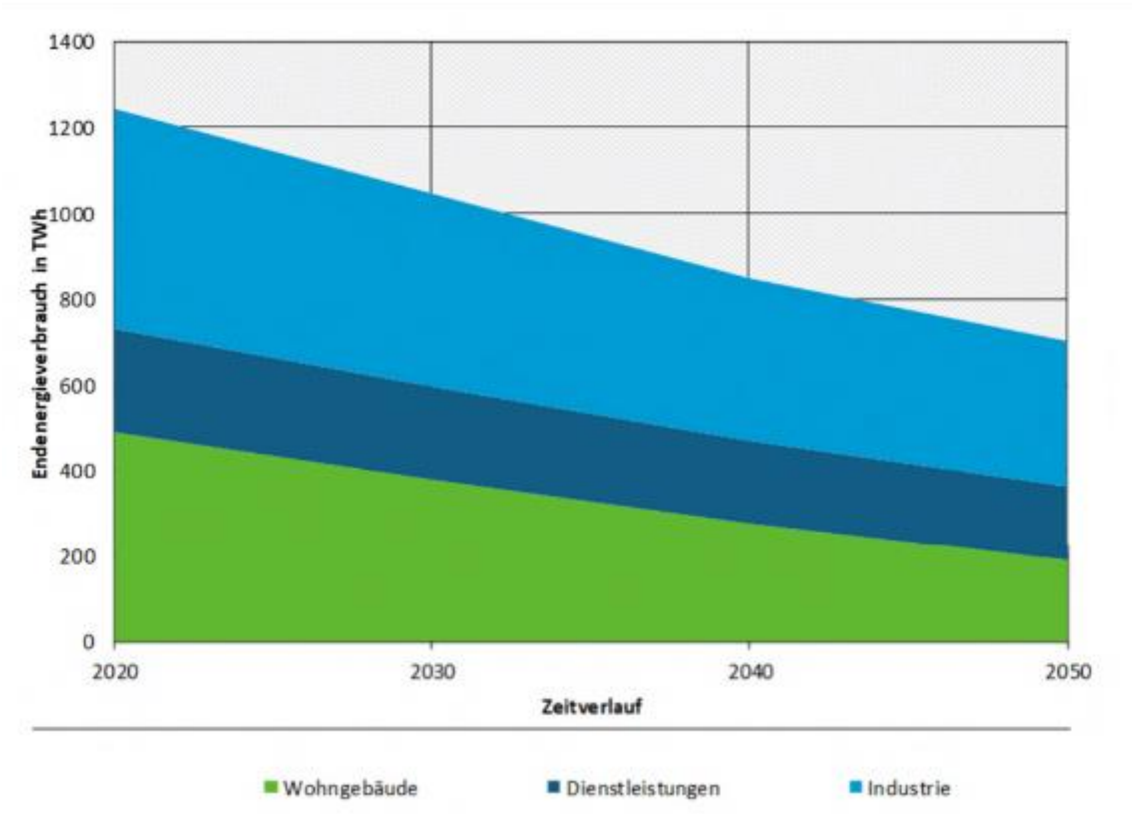
- Useful energy demand in the services sector: to determine the useful energy demand in the services sector for space heating and hot water, the average efficiencies for residential buildings, which are available broken down by individual technology, are applied to the energy source mix in the services sector. The useful energy demand is derived in this way. For process cooling the same procedure is followed as in the case of industry. The average efficiency across all branches of industry is taken as the efficiency for process heating.
- To calculate the realised useful energy demand, use is made of the results from Section I.1.b. The mapping in Section I.3.a is based on the data from Hotmaps (Pezzutto et al., 2019), as possible additional potentials are also of interest here. A detailed description can be found in Section III.3.c.

The complete presentation of useful energy demand and final energy consumption for 2018 in accordance with the baseline scenario and additional assumptions is shown in Table 10.

Table 10: Overview of available information from Prognos and additional information based on the parallel project and Hotmaps for the baseline scenario in 2018. Additions based on our own calculations are indicated in green

Sector	**Application**	**Useful energy [TWh]**	**Final energy [TWh]**
Industry	Space heating and hot water	46	59
	Process heating	308	455
	Process cooling	11.9	4.5
	Air conditioning	10.4	4.2
Services	Space heating and hot water	173	203
	Process heating	22.6	26
	Process cooling	33.59	13
	Air conditioning	15.6	4.3
Residential	Space heating and hot water	456	472
	Cooling	2.5	0.5

The development of final energy demand over time for the various sectors under the baseline scenario is presented in Figure 42.



Endenergieverbrauch in TWh	Final energy consumption in TWh
Zeitverlauf	Time
Wohngebäude	Residential
Dienstleistungen	Services
Industrie	Industry

Source: Own figure (ifeu) based on own calculations and Kemmler et al. (2020)

Figure 42: Development of final energy consumption for space heating, hot water, process heating and cooling, and air conditioning under the baseline scenario

III.3.b. Current and future mix of heating and cooling supply and associated rate of replacement

All framework parameters for the generation of the baseline scenario are based on target scenario II and the following statements from the ‘energy projections and impact assessments for 2030/2050’ in Kemmler et al. (2020).

Assumptions on the renovation rate and heating system replacement rate

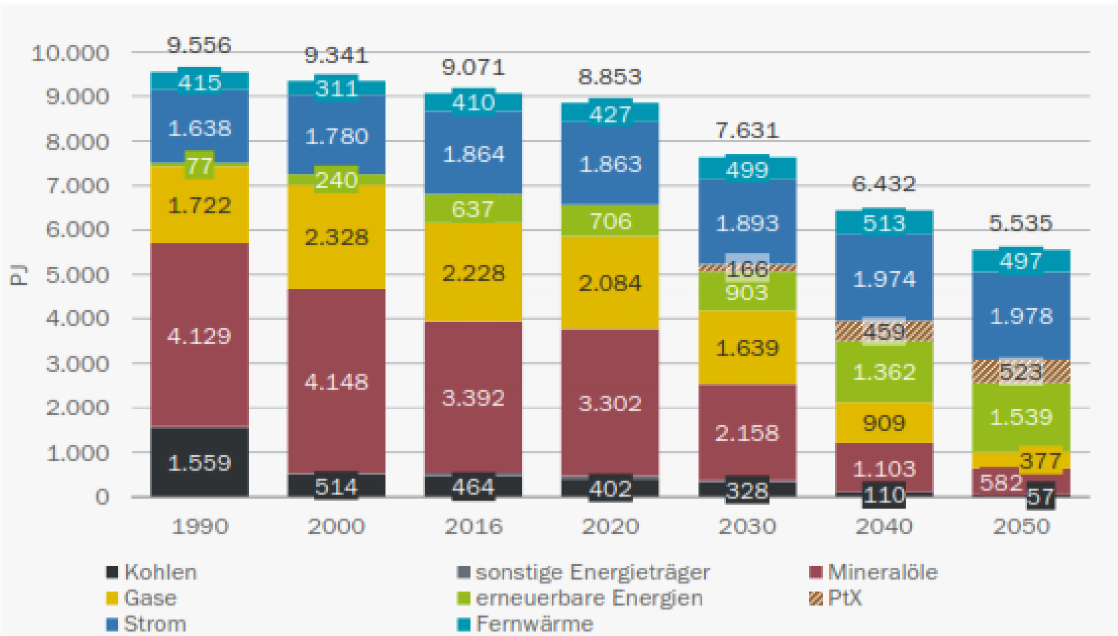
Under the baseline scenario the average specific consumption following complete renovations is reduced by 2030 to 70 kWh/m^2 of living space in the case of single- and two-family houses (STFH), and to 55 kWh/m^2 of living space for apartment blocks (AB). The strategic premises for the 2030 to 2050 period under the baseline scenario anticipate that the average specific consumption in the event of complete renovations will fall to around 40 kWh/m^2 of living space by 2050. These values take into account the saving resulting from ventilation systems with heat recovery.

The considerable importance accorded to the energy performance of buildings is also reflected in the renovation rate. From 2020 onwards there is a significant increase in the renovation rate as a result of the measures. By 2030 this increases to 1.6% for STFH and 1.8% for AB on account of the measures introduced. Over the long term the renovation rate for both STFH and AB rises to around 2% (in relation to the total building stock, with partial renovations aggregated to complete renovations).

Under the baseline scenario the structure of the heating supply up to 2030 is influenced to a great extent by the carbon price under the national Emissions Trading Scheme for heat, the support programmes, including support for heating networks, and the statutory 'fleet requirements' for heat generators. Sales of fossil-based gas- and oil-fired heating systems decline significantly by 2030. The share of gas-fired heating systems drops to below 20% by 2030 and that of oil-fired heating systems to 1%. This decline continues after 2030. By contrast, the share of electric heat pumps rises; in 2050 their share in the systems sold annually reaches just under 80% (2030: 65%). The remaining sales can be attributed to biomass heating systems, heating networks and solar thermal installations (for auxiliary heating). A heating system is replaced roughly every 25 years.

Energy source mix by sector and district heating generation

The development of final energy consumption across all sectors is shown in Figure 43 below. Under the baseline scenario final energy consumption is reduced by 13% to 2,120 TWh by 2030, relative to 2016.



Kohlen	Coals
Gase	Gases
Strom	Electricity
sonstige Energieträger	Other energy sources

erneuerbare Energien	Renewable energies
Fernwärme	District heating
Mineralöle	Mineral oils
PtX	PtX

Source: Kemmler et al. (2020)

PtX comprises PtL and PtG

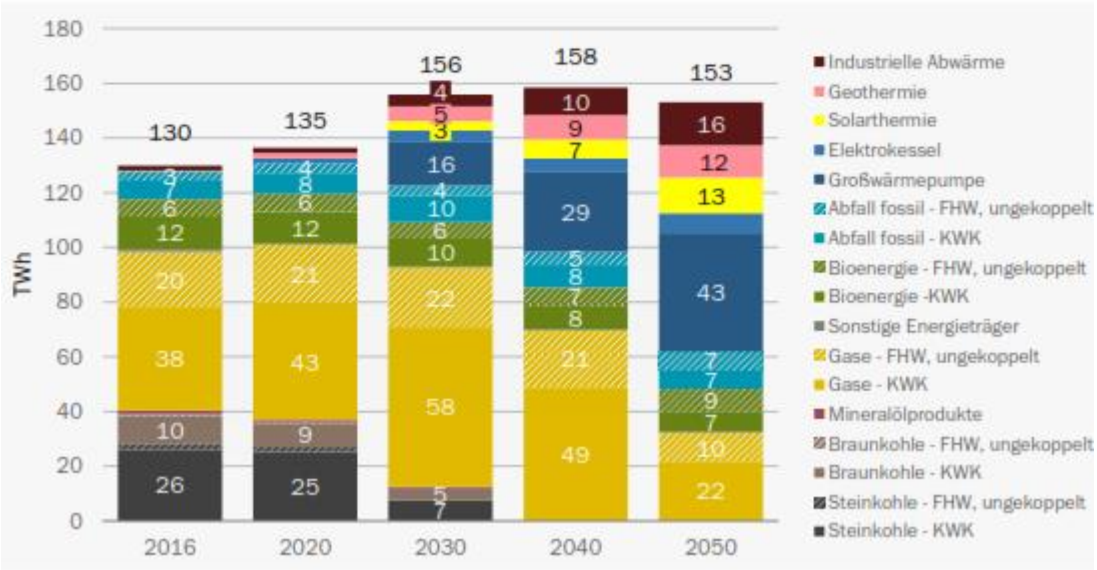
Figure 43: Final energy consumption by energy source across all sectors

Under the baseline scenario the final energy consumption of private households falls to 542 TWh by 2030. The fossil fuels fuel oil, natural gas and coal account for a declining share in the final energy consumption of households. This falls from 59% in 2016 to 41% in 2030. In 2050 the share of fossil fuels in consumption still stands at 13% under the baseline scenario. Consumption of renewable energies increases markedly over time, reaching 127 TWh by 2030 and 164 TWh by 2050. Relative to 2016, this corresponds to an increase of 86% by 2050. This rise is closely connected with the increased use of heat pumps and the ambient heat used in this case. On the other hand, consumption of biomass in private households falls sharply by more than 40% by 2050, relative to 2016. The consumption of district heating increases from around 51 TWh in 2016 to 64 TWh in 2030. After 2030 it no longer shows a significant upward trend; the further rise in home connections is offset by efficiency gains in the area of the building envelope.

Final energy consumption in the TCS and agriculture sectors falls from 388 TWh in 2016 to 354 TWh (-8.7%) in 2030. The consumption of fossil fuels decreases to 485 PJ by 2030, whereas electricity consumption rises to 151 TWh. District heating consumption in the TCS sector increases steadily from 13 TWh in 2016 to 29 TWh in 2030 and 34 TWh in 2050.

Under the baseline scenario final energy consumption in industry decreases by 18% to 597 TWh between 2016 and 2030 and by a further 20% to 446 TWh by 2050. Increasing use is made of electricity and biomass in industry. District heating consumption drops slightly from 48 TWh in 2020 to 43 TWh in 2030.

Due to the expansion of district heating networks, the generation of district heating follows a continuous upward trend up to 2040 (cf. Figure 44). After 2040 district heating generation falls slightly, as the efficiency gains in buildings can no longer be entirely offset by new connections. The structure of district heating generation changes significantly over the period up to 2050. As a result of the phase-out of coal-fired electricity generation, the lion’s share of district heating generated by coal-fired CHP installations will disappear by 2030. Renewable energy and waste heat will consistently increase their shares in generation, which will also lead to a decline in the significance of natural gas after 2040. By 2030 renewable energies and waste heat will account for a share of around 40% in district heating.



Industrielle Abwärme	Industrial waste heat
Geothermie	Geothermal
Solarthermie	Solar thermal
Elektrokessel	Electric boiler
Großwärmepumpe	Large-scale heat pump
Abfall fossil – FHW, ungekoppelt	Fossil waste – district heating plant, non-cogeneration
Abfall fossil – KWK	Fossil waste – CHP
Bioenergie – FHW, ungekoppelt	Bioenergy – district heating plant, non-cogeneration
Bioenergie – KWK	Bioenergy – CHP
Sonstige Energieträger	Other energy sources
Gase – FHW, ungekoppelt	Gases – district heating plant, non-cogeneration
Gase – KWK	Gases – CHP
Mineralölprodukte	Mineral oil products
Braunkohle – FHW, ungekoppelt	Brown coal – district heating plant, non-cogeneration
Braunkohle – KWK	Brown coal – CHP
Steinkohle – FHW, ungekoppelt	Hard coal – district heating plant, non-cogeneration
Steinkohle – KWK	Hard coal – CHP

Source: Kemmler et al. (2020)

Figure 44: District heating generation by energy source

Additional comments on the baseline scenario can be found in Section III.7.

III.3.c. Spatial disaggregation of heating and cooling demand

To perform the spatial analysis of the economic potential for efficiency in heating and cooling at the level of individual municipal associations in Germany, it is necessary to spatially disaggregate the baseline scenario, which was developed for the whole country. As a result of the various data sources used, the presentation of the data on heating demands in residential buildings and in the services sector, as well as on heating and cooling demands in industry, needs to be broken down (see Sections III.3.c.i and III.3.c.ii). Furthermore, due to gaps in the data, a separate approach is needed for the classification of air conditioning in residential buildings and the services sector (III.3.c.iii).

The underlying data sources and corresponding small-scale results are described and presented in the following sections. The maps included as part of the spatial disaggregation also fulfil the requirements of Part 1(3)(a) of Annex VIII on the mapping of heating and cooling demand areas in terms of assessed useful energy and quantified final energy consumption (see also Section I.3).

III.3.c.i. Residential buildings and services sector

For the spatial breakdown of heating demand in residential buildings and in the services sector it is possible to make use of the heat atlas developed at the ifeu in collaboration with Geomer GmbH and GEF Ingenieur AG (Ifeu et al., o. J.). This model is based on around 50 million 3D building geometries with Level of Detail 1 (LoD1) of the Working Committee of the Surveying Authorities (AdV), which are used for the spatial representation of energy-efficient renovation scenarios in a GIS environment. To make this possible, the data were prepared and enriched with spatial data on age classes from the 2011 building and housing census and secondary data sets on building use. The spatial heating demand modelling is based on a classification of individual building geometries into four energy-related residential building types (19.4 million buildings) and a further ten energy-related non-residential building types (3.2 million buildings). In addition, data on the treated floor area, the area of individual building units, age and the geographic location in climatic zones are also recorded for each building in accordance with DIN 18599.[26]

To allow the spatial disaggregation of the baseline scenario, the nationally available results of the baseline scenario for the base year of 2018, broken down by residential buildings and service sector buildings, are disaggregated according to the shares of individual buildings in the total residential building or service building stock. Developments up to 2050 with regard to building demolition and energy-efficient modernisation of existing buildings are included in the baseline scenario and are therefore added to the individual buildings for the reference years 2030 and 2050. The different climatic zones in Germany can be taken into account by means of the locations of the buildings.

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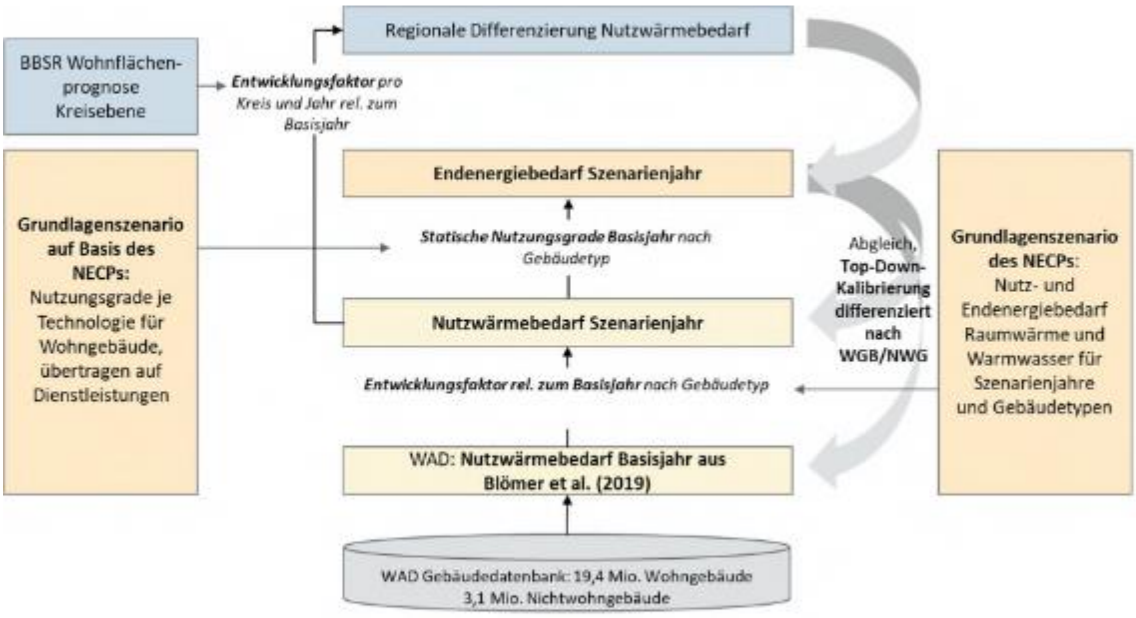
[26] A detailed description of the model can be accessed via the following link: https://www.ifeu.de/wp-content/uploads/Modellbeschreibung_Waermeatlas_2.0.pdf (last accessed: 23.7.2020)

Due to the lack of information on where new buildings will be erected in the future, no assumptions can be made on the spatial expansion of the built-up area. The corresponding additional heating and cooling demands are allocated to already built-up areas in accordance with the energy-related building types.

Taking the small-scale population forecast of the Federal Office for Building and Regional Planning (BBSR) into account allows regional differences in the development of living space within Germany to be factored in (BBSR, 2015). This forecast includes the development of living space for all districts up to 2030, broken down by single- and two-family houses and apartment blocks. These data thus make it possible to take demographic trends in individual regions explicitly into account. As part of the unpublished second interim report within the project 'AiRE – *Szenarienbasierte Analyse der Anforderungen an die Infrastrukturen im Rahmen der Energiewende und Auswirkungen auf deren Planung und Finanzierung*' ('Scenario-based analysis of infrastructure requirements within the context of the energy transition and impacts on their planning and financing') the ifeu has performed an extrapolation to 2050 and this has been used for the present projection (Pfluger et al., ongoing). The disaggregated heating demands for 2030 and 2050 are scaled in accordance with the demographic trend and then recalibrated to the specified demand for the reference year. A schematic representation of the regional disaggregation of the baseline scenario based on the calibrated heat atlas is shown in Figure 45.



BBSR Wohnflächenprognose Kreisebene	BBSR living space forecast at district level
Entwicklungsfaktor pro Kreis und Jahr rel. zum Basisjahr	Development factor per district and year relative to base year
Regionale Differenzierung Nutzwärmebedarf	Regional breakdown of useful heat demand
Grundlagenszenario auf Basis des NECPs: Nutzungsgrade je Technologie für Wohngebäude, übertragen auf Dienstleistungen	Baseline scenario on basis of NECP: efficiencies for each technology for residential, transferred to services
Endenergiebedarf Szenarienjahr	Final energy demand for scenario year
Statische Nutzungsgrade Basisjahr nach	Static efficiencies in base year by building type

Gebäudetyp	
Nutzwärmebedarf Szenarienjahr	Useful heat demand in scenario year
Entwicklungsfaktor rel. zum Basisjahr nach Gebäudetyp	Development factor relative to base year by building type
WAD: Nutzwärmebedarf Basisjahr aus Blömer et al. (2019)	German Heat Atlas: useful heat demand in base year from Blömer et al. (2019)
WAD Gebäudedatenbank: 19,4 Mio. Wohngebäude 3,1 Mio. Nichtwohngebäude	German Heat Atlas buildings database: 19.4 million residential buildings 3.1 million non-residential buildings
Abgleich, Top-Down-Kalibrierung differenziert nach WGB/NWG	Comparison, top-down calibration broken down by residential/non-residential
Grundlagenszenario des NECPs: Nutz- und Endenergiebedarf Raumwärme und Warmwasser für Szenarienjahre und Gebäudetypen	Baseline scenario of NECP: useful and final energy demand for space heating and hot water for scenario years and building types

Source: Interim report within the project 'AiRE – Scenario-based analysis of infrastructure requirements within the context of the energy transition and impacts on their planning and financing' (Benjamin Pfluger et al., ongoing)

Figure 45: Schematic representation of the linking of the model to the regionalisation of data under the baseline scenario in the buildings sector on the basis of the heat atlas

As no additional information is available on the spatial disaggregation of process heating demand in the services sector, the national values are allocated to the individual buildings in this sector in accordance with the procedure used for space heating and hot water.

For the analysis of the economic potential for efficiency in heating and cooling, and to identify suitable areas for a grid-based heating supply, heating density is used as a parameter for the selection (details can be found in Section III.1).

To allow heating densities to be derived on the basis of information at individual building level, a grid with a side length of 100 m x 100 m is created for Germany and the information at individual building level is added together within the individual grid cells. The results are then aggregated at municipality level. The following information can therefore be presented within the defined administrative boundaries of the municipal associations:

- Name of municipality;
- Area;
- Heating sales (useful and final energy) in the municipality for residential buildings and buildings in the services sector, and also broken down by sector, for 2018, 2020, 2030 and 2050;
- Share of heating sales per density class (<5 GWh/km^2, 5-15 GWh/km^2, 15-30 GWh/km^2 and >30 GWh/km^2);
- Relative development of living space by 2030 in relation to 2018;
- Average heating density in GWh/km^2.

This information at individual municipality level is supplemented by other indicators in the area of industry and relating to cooling demand.

A summary of the data processing is shown in Figure 46.

NECP Daten für gesamtes Bundesgebiet, differenziert nach Sektoren und Anwendungen	NECP data for whole of Germany, broken down by sector and application
Gebäudescharfer Atlas um detaillierte Rauminformationen zu berücksichtigen	Atlas at individual building level to take detailed spatial information into account
Wärmedichte als Indikator für Analyse und für Kartierung	Heating density as indicator for analysis and mapping
Gemeindegrenze als administrative Einheit für Bewertung von Versorgungsoptionen	Municipality boundary as administrative unit for assessing supply options

Source: Own figure (ifeu)

Figure 46: Presentation of data processing and the various administrative and geographical boundaries

III.3.c.ii. Industrial sector

To allow the small-scale presentation of demand for process heating and cooling and the subsequent analysis of the heating and cooling supply, it is also necessary to link data from industrial locations to the national results for process heating and cooling, space heating and hot water under the baseline scenario. This can be achieved by building on the methodological approach developed as part of the NENIA project (Blömer et al., 2019). To work out, within this project, the waste heat potential that is theoretically available in the manufacturing industry for net-bound use, available data on location-specific fuel use and thermal process power applications were first prepared and combined. To this end, use was made of the emissions declaration of installations that are subject to authorisation in accordance with the 11th Federal Immission Control Regulation (11th BImSchV), the emissions data from the European Pollutant Release and Transfer Register (E-PRTR) and locations with relevant thermal process power use. Please refer to Blömer et al., (2019, p. 41 et seq.) for a detailed description of the approach. The explanation below focuses on the adaptation within the framework of the present report.

Operators of incineration plants that are subject to authorisation are required, from a rated thermal input of 1 MW, to submit an emissions declaration to the competent federal state authorities for immission control. These data are collected every 4 years at the end of the year and were published in 2012 and 2016. As the analyses within the framework of Blömer et al. (2019) were still using the data from the 2012 reporting year, the updated information from the 16 federal state offices on the 2016 emissions declarations was collected and prepared accordingly for the analyses.

The emissions data from the European Pollutant Release and Transfer Register (E-PRTR) also include annual records of location-related emissions from industrial undertakings. Here the thresholds for the emissions recorded relate to the annual emissions – generally >100,000 t CO_2/year – and a large proportion of businesses in the manufacturing industry and energy sector are therefore covered. The Federal Environment Agency makes the collected data publicly available in geo-referenced form. To guarantee data consistency, an update to 2016 is also performed. So that fuel use can be derived, in accordance with Blömer et al. (2019) emission factors based on fuel use and CO_2 emissions are calculated from public statistics and applied to the location-specific information relating to CO_2 emissions.

As the process heating and cooling demand of electricity-based processes is not recorded within the framework of the 11th BImSchV or the E-PRTR, in Blömer et al. (2019) a comprehensive literature search was performed to determine thermal electricity inputs, from which corresponding locations with a thermal electricity input were derived. These data are also taken over for the analyses below.

The following steps are undertaken as part of the present research project:

- Preparation of data for location database for 2016 on the basis of data under the 11th BImSchV and the E-PRTR, in line with Blömer et al. (2019);
- Disaggregation of the national information under the baseline scenario;
- Preparation of location-specific data for analysis and mapping.

Preparation of data for location database (1): The data on fuel inputs from the emissions declarations of all 16 federal states under the 11th BImSchV are combined and any incorrect and implausible data removed. The fuel input Q_{in} [kj] at the individual locations can be calculated from the product of the annual input quantity m_i [kg] and the calorific value Calorific value$_i$ [kj/kg]. Locations without an input quantity or figure for fuel used are therefore irrelevant for the rest of the analysis and can be filtered out. In addition, the scope of the assessment covers those economic activities whose primary purpose is the production of economic goods within the manufacturing industry. For this reason the economic activities are limited to C10-C33, excluding C19. Within a site several locations may be recorded separately in the database under the 11th BImSchV. These are aggregated using the location information and economic activity, as in Blömer et al. (2019) an automated comparison with manually researched reference data was developed based on this information. Implausible entries with regard to calorific value data and fuel quantities are adjusted by means of a spatial comparison with the prepared 2012 data from Blömer et al. (2019).

As in the case of Blömer et al. (2019), additional locations are identified on the basis of a spatial comparison of the data under the 11th BImSchV and the E-PRTR. For all locations under the 11th BImSchV, any locations in the E-PRTR database that are within a radius of 500 m are also taken into account. A comparison of the four-digit

economic activity codes therefore allows additional entries in the E-PRTR database to be identified.
As Blömer et al. (2019) made reference to data gaps, particularly in the area of large chemical parks, within the framework of this report additions are made to the procedure for mapping process heating and cooling demand in the chemicals sector. This involves eliminating the information on chemicals (economic activity C20) from the data under the 11th BImSchV, and from the E-PRTR data, and generating a new georeferenced location list on the basis of the E-PRTR and manual searches relating to chemical sites.
Table 11 shows the number of locations and the calculated fuel input, broken down by data source.
In comparison with the data under the baseline scenario for 2018, 110 of the 38 TWh of thermal electricity input in the area of process heating can be depicted. Overall, 379 TWh of the total process heating demand of 454 TWh can be identified on a location-specific basis.

Table 11: Overview of fuel inputs in the location database developed

Data source	**Number of locations**	**Fuel input [TWh]**
11th BImSchV excluding C20	4,771	208
Additional E-PRTR locations excluding C20	29	44
Thermal electricity inputs	116	31
Chemical sites	40	97
Total	4,956	379

<u>Disaggregation of the national results under the baseline scenario (2):</u> The location database developed can be used to disaggregate the national results under the baseline scenario. Within this context, in addition to process heating and cooling demand, the demand for space heating, hot water and air conditioning is also broken down.

The economic activities serve as a reference for the spatial disaggregation. Demand for process heating and cooling under the baseline scenario is available broken down by economic activity. All of the location database’s primary data sources also contain information on economic activities. Due to classification differences, the economic activities are allocated in the following way, as presented in Table 12.

For each economic activity in accordance with the baseline scenario, all appropriate locations are identified in the location database and their location-specific fuel input is determined relative to the total fuel input of the economic activity. The national heating and cooling demands for the economic activity in question are then allocated in accordance with these shares.

Table 12: Allocation of economic activities under the baseline scenario to economic activities in accordance with the NACE classification in the location database

Classification of economic activities under the	**Allocation to NACE classi-**

baseline scenario	fication
Processing of iron and steel, tubes	24
Electrical equipment	26,27
Electrical appliances	13,14,15,16,18,21,30,31,32,33
Food and tobacco	10,11,12
Quarrying and mining	8
Glass and ceramics	23
Basic chemicals	20
Rubber and plastic products	22
Motor vehicles, trailers and semi-trailers	29
Manufacture of machinery and equipment	28
Metal products	25
Non-ferrous metals and casting	24
Paper	17
Basic iron and steel and ferro-alloys	24
Other chemical industry	20
Other economic activities	13,14,15,16,18,21,30,31,32,33
Manufacture of other transport equipment	30
Cement, tiles, concrete, stone and minerals	23

Source: Own figure based on Kemmler et al. (2020)

Preparation of location-specific data for analysis and mapping (3): As in the case of the data for residential buildings and buildings in the services sector, the location-specific data on heating and cooling demand in industry is presented in aggregated form for municipal associations and taken into account in the analyses of the economic potential for efficiency in heating and cooling.

III.3.c.iii. Cooling demand

Article 14(3) of the EED requires an analysis of the potential for efficient cooling, in addition to that for heating. Whereas cooling plays a significant role in some European countries, accounting for a share in final energy demand of up to 38% and in useful energy demand of up to 72% in Malta, in Germany, with a share of 3% of final energy demand and 10% of useful energy demand, it is below the EU averages (EU 28 + 3) of 4% and 14% respectively (Fleiter et al., 2016). The lesser significance of cooling in Germany's final energy consumption is also shown in Figure 43.

Mapping air conditioning in residential buildings and in the services sector presents particular challenges: whereas virtually all buildings in Germany are heated[27], only a fraction of them are cooled. No detailed record of the share of cooled buildings and their locations is available for Germany.

[27] According to Statistische Ämter des Bundes und der Länder (2020), the energy source used for heating was not specified for just 0.12% of homes.

In Schlomann et al. (2015) a large-scale survey on energy consumption in the TCS sector was performed in 2014. This revealed that 20% of business premises use air-conditioning systems or devices (of which 11.3% are centralised air-conditioning systems, 3.3% decentralised split systems and 3% mobile systems, with multiple technologies used at 2% of business premises). As no further information is available on the locations of these business premises, knowledge of the distribution across sectors (e.g. up to 75% of hospitals are air-conditioned) also does not allow allocation on a location-specific basis.

In the residential sector the authors do not have access to any information on the number of cooled buildings. However, according to the baseline scenario, at 0.5 TWh cooling accounts for less than 1% of the total final energy consumption in residential buildings.

For this reason, as was the case for the generation of the maps, use is made of data from Hotmaps (HOTMAPS Project, 2020), according to which the theoretical useful energy demand in Germany stands at 85.4 TWh (compared with a heating demand of 730 TWh).

III.4. Determination of appropriate technical solutions

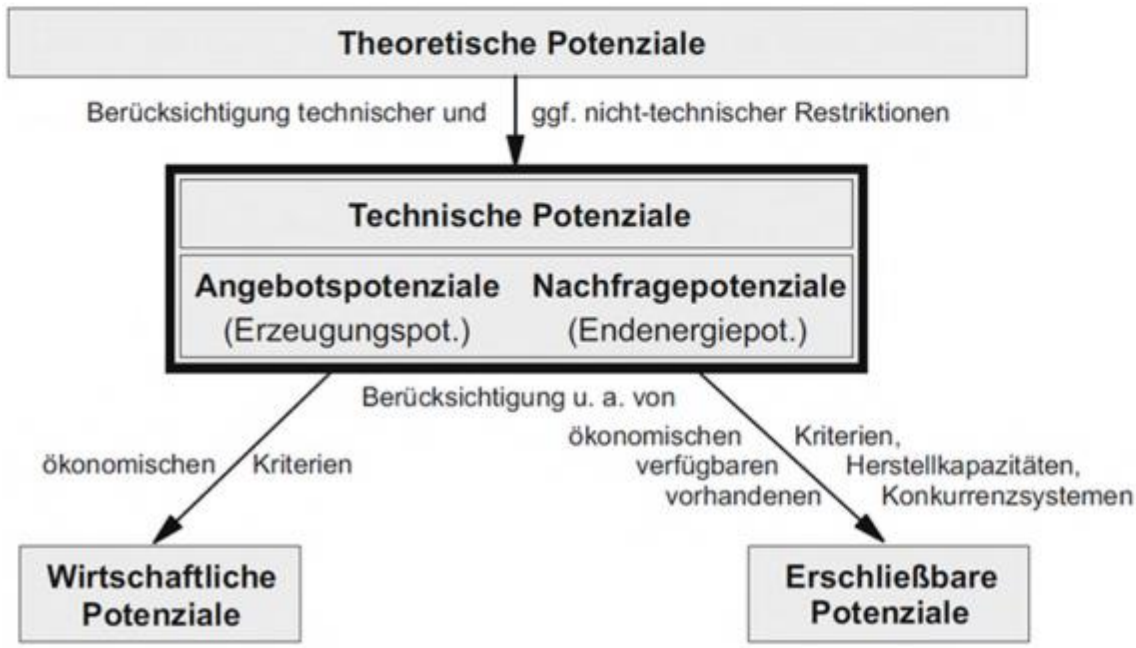
The analysis of the economic potential for efficiency in heating and cooling in accordance with Article 14(3) of the EED should include an assessment of the following technologies:

- Industrial waste heat and cold;
- Waste incineration;
- High-efficiency cogeneration;
- Renewable energy sources other than those used for high-efficiency cogeneration;
- Heat pumps;
- Reducing heat and cold losses from existing district networks.

The technical and economic parameters used for the analysis are appended in the form of technology profiles (see Annex V).

<u>Determination of renewable energy and waste heat potentials:</u> To be able to assess the use of renewable energies and waste heat for heating and cooling, it is relevant to consider spatial restrictions affecting the quantity of renewable energies and waste heat that can be used for the supply of heating and cooling.

This research project identifies, on the basis of available spatial information, whether relevant renewable energy or waste heat potentials can be realised within the geographical boundaries defined for the analysis. To allow the corresponding methodological approach to be categorised, the concept of potential is defined in more detail below. Figure 47 shows a definition of the concept of potential in accordance with Kaltschmitt et al. (2013) and this is explained accordingly below.



Theoretische Potenziale	Theoretical potentials
Berücksichtigung technischer und ggf. nicht-technischer Restriktionen	Consideration of technical and, where applicable, non-technical restrictions
Technische Potenziale	Technical potentials
Angebotspotenziale (Erzeugungspot.)	Supply potentials (generation pot.)
Nachfragepotenziale (Endenergiepot.)	Demand potentials (final energy pot.)
Berücksichtigung u.a. von	Consideration of inter alia
ökonomischen Kriterien	economic criteria
verfügbaren Herstellkapazitäten	available production capacities
vorhandenen Konkurrenzsystemen	existing rival systems
Wirtschaftliche Potenziale	Economic potentials
Erschließbare Potenziale	Realisable potentials

Source: Kaltschmitt et al. (2013)

Figure 47: Classification of the concept of renewable energy potential in accordance with Kaltschmitt et al. (2013)

The aim of the analysis of the potential for efficiency in heating and cooling in accordance with Article 14(3) of the EED is to identify the economic potential for Germany and perform a small-scale assessment of the use of various technological supply options. To make this possible, first of all the theoretical potential has to be determined, which corresponds to the physically usable energy supply over a defined period of time within a defined geographic area. As this potential does not yet incorporate a spatial comparison with possible heat sinks, for the purposes of the following analyses it is relevant to determine the technical potentials of the various renewable energy sources for the supply of heating and cooling. The technical potentials describe the portion of the theoretical potentials that can be realised by means of technologies that are already known (supply potentials) and can also be integrated into possible heat sinks (demand potentials).

The following approach has been chosen to identify technical potentials:

1. For all geographic areas (=municipal associations) the portion of the theoretical potential that can be realised using known technologies is assessed (supply potentials).
2. There is also an initial comparison of the distance from the heat source to possible heat sinks. The restrictive limit values chosen relating to distance and heating density or sales are small enough so as not to pre-empt a detailed technical and economic assessment, while nevertheless revealing only relevant potentials.
3. Assumptions relating to sink temperatures that are relevant for determining potentials are varied as far as possible to take the future conversion of heating networks to low-temperature networks into account. This applies in particular to the use of deep geothermal energy and industrial waste heat.

Details on the approach and the results at municipal association level, as well as the definition of limit values for the individual technologies, can be found in Section III.6.a. Restriction to the actual economic potential is carried out in the subsequent assessment of alternative scenarios (see Section III.6). Within this context possible full load hours and combinations of different technologies or technological systems at regional level (municipal associations) are also explicitly considered and analysed.

III.4.a. Technologies and framework data considered for the assessment of economic potential

The following technologies are included in the assessment of alternative scenarios:

- Industrial waste heat and cold
- Waste incineration
- Fossil-based CHP (high-efficiency)
- Deep geothermal
- Solar thermal (free-field)
- Solar thermal in combination with seasonal storage
- Biomass heating plant
- Large-scale heat pumps
- Electric boilers

Fossil-fuel heating plants are also taken into account and the question of reducing network losses is addressed (see also III.6.b).

In line with the baseline scenario, all renewable energy sources, including biomass, and waste heat and cold are taken into consideration as renewable energies.

The following section presents the technical and economic technology-related assumptions that form the basis for assessing the alternative scenarios.
The technical and economic parameters of the technologies in question are based on the technology profiles and are presented in Table 13 using the example of 10 MW installations. The costs of solar thermal represent an average between the costs of flat-

plate and evacuated-tube collectors and include the costs of a heat store. In principle, tank thermal energy storage with a capacity of 300 m^3 per 1 MW_{th} is envisaged for daily storage. This means that the ratio of storage volume to collector area lies within the optimum range (Sørensen et al., 2012). In addition, pit thermal energy storage is envisaged to allow seasonal storage for municipalities with considerable solar thermal potential (see also Section III.6.a.i). The store has a capacity of 3,000 m^3 per MW_{th}, which is in keeping with realised major projects, in particular in Denmark (e.g. in Dronninglund).

High-efficiency CHP represents a special case. The heat generation costs are determined by dividing the total generation costs of the installations between electricity and heat generation. The heat generation price that can be achieved in typical district heating networks is also taken into account here. A mixed price resulting from primary heat from gas-fired boilers and the marginal costs of heat extraction (electricity revenues x power loss factor) from existing CHP installations has been used to approximate this.

For the costs of waste heat utilisation from thermal waste treatment plants it is assumed that, as the primary purpose of the plants is waste disposal, there will be no investment costs for heat generation and the price of the heat will be in line with that for fossil-based generation[28]. The price of heat is determined by means of indexation against the gas price.

[28] The maximum amounts of heat possible in 2030 are specified exogenously on the basis of a comprehensive study of the waste industry (Flamme et al., 2018, see also Section III.5.b). Projections of the volume of waste and possible heat extraction have already been taken into account explicitly in the study. The construction of new thermal waste treatment plants is not considered in the present analysis.

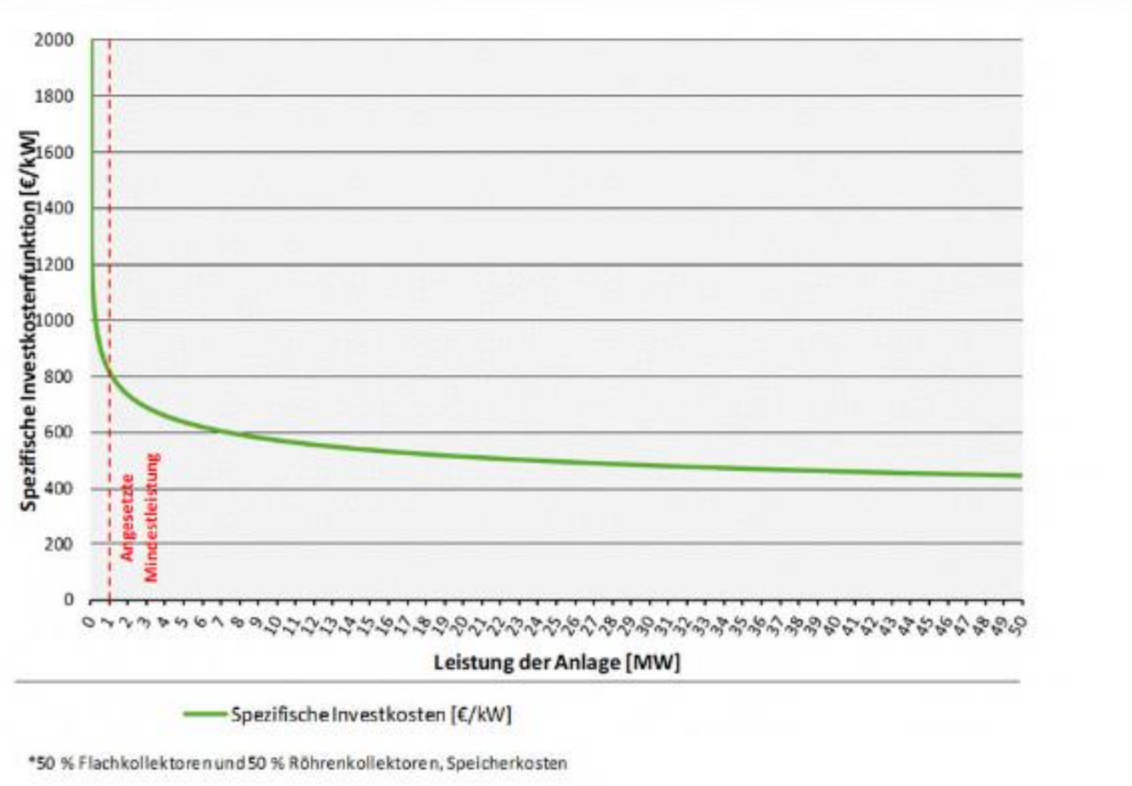
Table 13: Overview of parameters and technologies considered, using the example of 10 MW installations

Technology	Investment costs [€/kW$_{th}$]	Fixed operating costs [€/kW$_{th}$]	Variable operating costs [€/MWh]	Efficiency	Minimum capacity [MW$_{th}$]	Technology profile
Industrial waste heat	409	8.2	-	APC: 9	0.2	V.13
Natural gas CHP[1]	126	9	7	50%	0.01	V.11
Geothermal[2]	2,885	27	-	APC: 9.5	5	V.4
Solar thermal with daily storage	659	-	1.5	100%	1	V.15
Solar thermal with seasonal storage	762	-	1.5	87%	2.5	V.15
Biomass-fired boiler	505	4	0.2	84%	0.01	V.2
Waste heat heat pump	631	2	2.4	APC: 3	0.4	V.8
Air source heat pump	799	2	2.4	APC: 2.7	0.4	V.6
Electric boiler	111	1	0.2	98%	0.01	V.3
Gas-fired boiler	120	3-4	0.5	90%	0.01	V.1 V.2

[1]Costs relate exclusively to use allocated to district heating
[2]ORC installations not taken into account

For each technology the cost functions of the technology profiles include capacity-dependent economies of scale, which apply to a defined thermal capacity range. If the indicated range is exceeded, the required capacity is divided between several installations.

In addition, minimum capacities are introduced to avoid small, expensive installations for which connection to district heating would not make sense. The minimum capacities assumed can also be taken from Table 13. To clarify the approach, the cost function for solar thermal is plotted as an example in Figure 48. In the low part of the capacity range the specific investment costs rise sharply. For this reason a minimum capacity of 1 MW_{th} is assumed in the case of solar thermal. Consequently, solar thermal will only be used in municipalities where the realisable potential is greater than the assumed minimum capacity.



Spezifische Investkostenfunktion [€/kW]	Specific investment cost function [€/kW]
Angesetzte Mindestleistung	Assumed minimum capacity
Leistung der Anlage [MW]	Capacity of installation [MW]
Spezifische Investkosten [€/kW]	Specific investment costs [€/kW]
50 % Flachkollektoren und 50 % Röhren-kollektoren, Speicherkosten	50% flat-plate collectors and 50% tube collec-tors, storage costs

Source: Own figure (Prognos) based on technology profiles

Figure 48: Specific investment cost function for solar thermal without storage costs

Connection pipelines to the heating network are required to allow locally confined renewable heat sources to be exploited. This applies in particular to the use of solar thermal, waste heat and geothermal, as these are linked to specific locations (free-field sites, industrial sites, rivers, geothermal storage facilities, etc.). As, within the framework of the analysis of potentials, all potentials within a radius of up to one kilometre are taken into account, an average length of 750 m is taken as a basis for the connection pipeline for each technology (cf. Table 14). For technologies that are not dependent on local potentials (biomass heating plants, CHP installations, fossil-fuel boilers, etc.), no connection pipelines have been considered.

Table 14: Length of connection pipeline by technology

Technology	Length of connection pipeline [m]
Solar thermal	750
Industrial waste heat	750
Geothermal	750
Waste heat HP	750

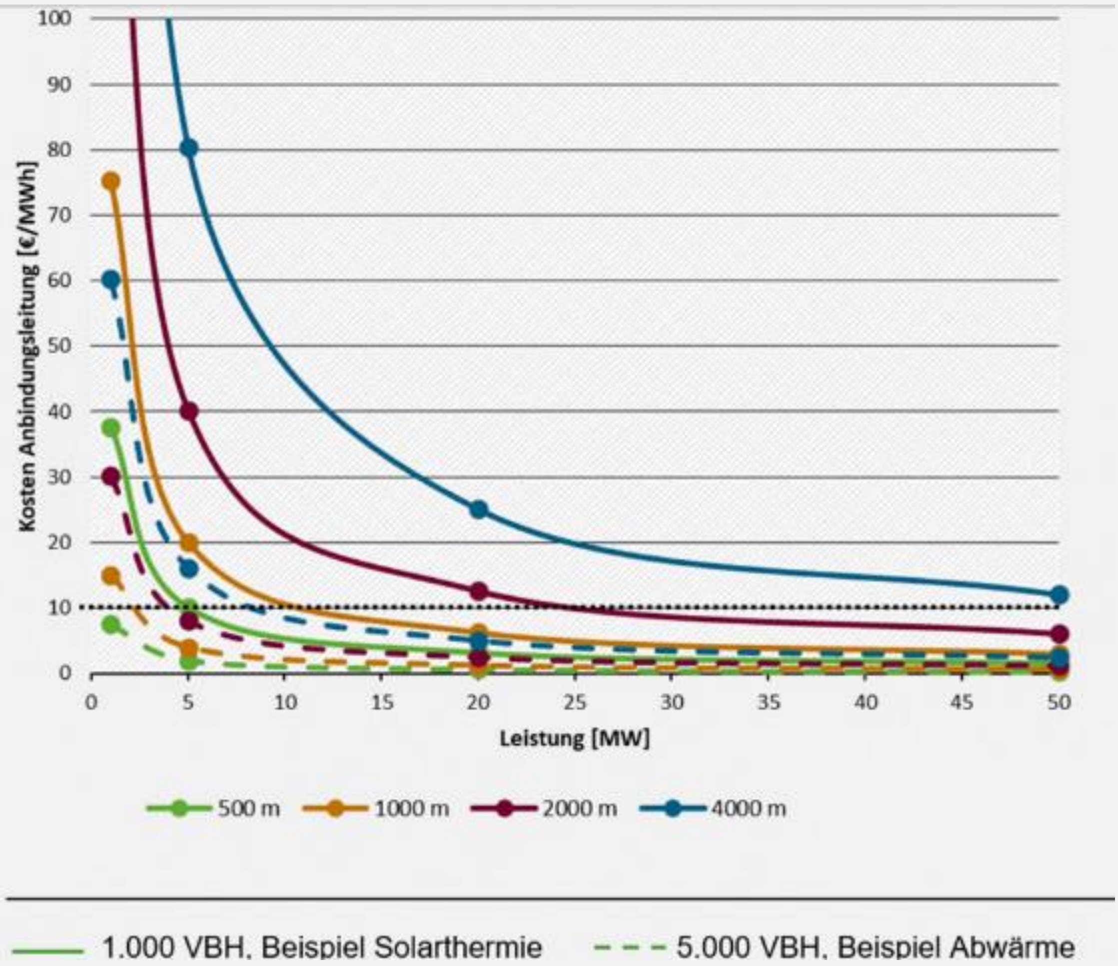
The costs of the connection pipeline depend on the nominal diameter and therefore on the connected thermal capacity. The estimated costs in Table 15 are based on current costs of realised projects and represent the average between the costs in inner-city and new-build areas.

Table 15: Costs of the connection pipeline

Capacity [MW]	Costs [€/m]
0-5	900
5-20	1,200
20-50	1,500
> 50	1,800

Digression: possible length of district heating connection pipeline

When specific projects are carried out, from an economic perspective it may also be possible to span larger distances between the heat source and sink, depending on the local conditions. The costs of the connection pipeline depend on the capacity of and, in particular, also on the quantity of heat supplied by the technology (and therefore on its full load hours). To illustrate the influence that connection costs have on heat generation costs, Figure 49 below shows the connection costs for the examples of solar thermal (1,000 FLH assumed by way of example, continuous lines) and industrial waste heat (5,000 FLH assumed by way of example, dotted lines), depending on capacity and pipeline length. A sum of €10/MWh can be assumed as a realistic mark-up due to the connection pipeline. In the case of solar thermal it becomes clear that the mark-up resulting from the connection pipeline can account for a significant proportion of the heat generation costs. A mark-up of less than €10/MWh is only achieved from a capacity of 5 MW and a pipeline length of 500 m in the case of solar thermal. It is apparent that in individual cases – in particular if there are large quantities of heat and a high number of full load hours – longer connection pipelines may also make sense. Taking the example of waste heat, connection pipelines with lengths of more than 2 km pay off from 5 MW.



Kosten Anbindungsleitung [€/MWh]	Costs of connection pipeline [€/MWh]
Leistung [MW]	Capacity [MW]
1.000 VBH, Beispiel Solarthermie	1,000 FLH, example of solar thermal
5.000 VBH, Beispiel Abwärme	5,000 FLH, example of waste heat

Source: Own figure (Prognos)

Figure 49: Connection costs depending on capacity and pipeline length

The GHG and primary energy factors underlying the analysis are listed in Table 16 (factors for electricity are based on internal calculations and those for the other energy sources on Pehnt et al. (2018)). Methodologically speaking, these conform to the final-energy-consumption-based accounting approach (*Verursacherbilanz*) and the Energy Conservation Regulation (EnEV). The factors for electricity for 2030 are based on internal calculations in accordance with the National Energy and Climate Plan (NECP, Bundesministerium für Wirtschaft und Energie, (2020)). In contrast to the Building Energy Act (GEG), a primary energy factor of 0.1 is used for waste to take any energy consumption during transport, thermal treatment and disposal of waste into account

(Pehnt et al. (2018)).[29] As in the case of the NECP's baseline scenario, the Finnish method is used as an allocation method for the assessment of CHP.

Table 16: GHG and primary energy factors

Energy source	**GHG factor [gCO_2-eq/kWh]**	**Primary energy factor**
Electricity[1]	258	1
Natural gas	240	1.1
Solid biomass	40	0.2
Waste	25	0.1

[1]related to 2030, own calculation based on baseline scenario

III.5. Determination of technical potentials

The following sections explain the restrictions that have to be observed with regard to technical potentials during the subsequent assessment of the various technologies in relation to the administrative boundaries of the municipal associations. Both the methodological approaches and the results are documented.

III.5.a. Industrial waste heat

The methodology developed as part of the project '*EnEff: Wärme – netzgebundene Nutzung industrieller Abwärme* (NENIA)' ('EnEff: heat – net-bound utilisation of industrial waste heat) (Blömer et al., 2019) is taken as a basis for identifying the theoretical potentials of industrial waste heat. In addition to the fuel data used to map process heating and cooling demand (see also III.3.c), installation operators are also obliged to report emissions data under the 11th BImSchV. These data contain information on the annual operating hours t_i [h/a] of the installation i, the average volumetric flow rate of flue gas V_i [m^3/h] for the installation and the temperature of the flue gas flows T_i [°C]. In line with the approach in Blömer et al. (2019), the quantities of sensible heat Q_{ab} can be determined as follows (assumptions have to be made regarding a reference temperature $T_{ref,i}$ (heat sink temperature)):

$$Q_{ab} = \sum_{i \in i} t_i * \dot{V}_i * \rho_i * c_{p,i} * (T_i - T_{ref,i})$$

For density ρ_i and specific heat capacity $c_{p,i}$ it is possible to use properties for nitrogen[30], as its content by volume in combustion processes with ambient air in the flue gas flows represents a dominant share (78–85%) (Blömer et al., 2019). A temperature of 30 °C has been defined as the reference temperature $T_{ref,i}$ for determining the theoretical potential, as this temperature is the minimum needed to make waste heat usable via heat pumps.

[29] The GEG did not enter into force until after this analysis was drawn up. For that reason the updating of the factors has been disregarded for the purposes of this study.

[30] $\rho_i = \frac{1.293kg}{m3}; c_{p,i} = 1.007\frac{KJ}{kg*K}$

The following approach has been chosen to determine the technical potential for individual municipal associations:

1. Preparation of emissions data under the 11th BImSchV in line with Blömer et al. (2019) and determination of theoretical potential of individual locations;
2. Determination of technical potential by means of a heat-source and heat-sink comparison for the locations and possible heating demand areas on the basis of the baseline scenario and aggregation of potentials at municipal association level.

Determination of theoretical potential: The emissions data under the 11th BImSchV are prepared in accordance with Blömer et al., (2019, page 53 et seq.). Following the georeferencing of the data, emission processes at the same location that have identical waste gas parameters and operating hours and an identical volumetric flow rate and temperature are filtered out. If there is a lack of data relating to waste gas parameters or zero values, the data are supplemented with sector-specific parameters to allow the quantities of sensible heat to be derived. The theoretical potentials on the basis of the data from 2016 amount to 135 PJ, based on a reference temperature of 35 °C. To allow the influence of the sink temperature on the corresponding potentials to be taken into account in the assessment of the alternative scenarios for heating and cooling, the reference temperature is adjusted:

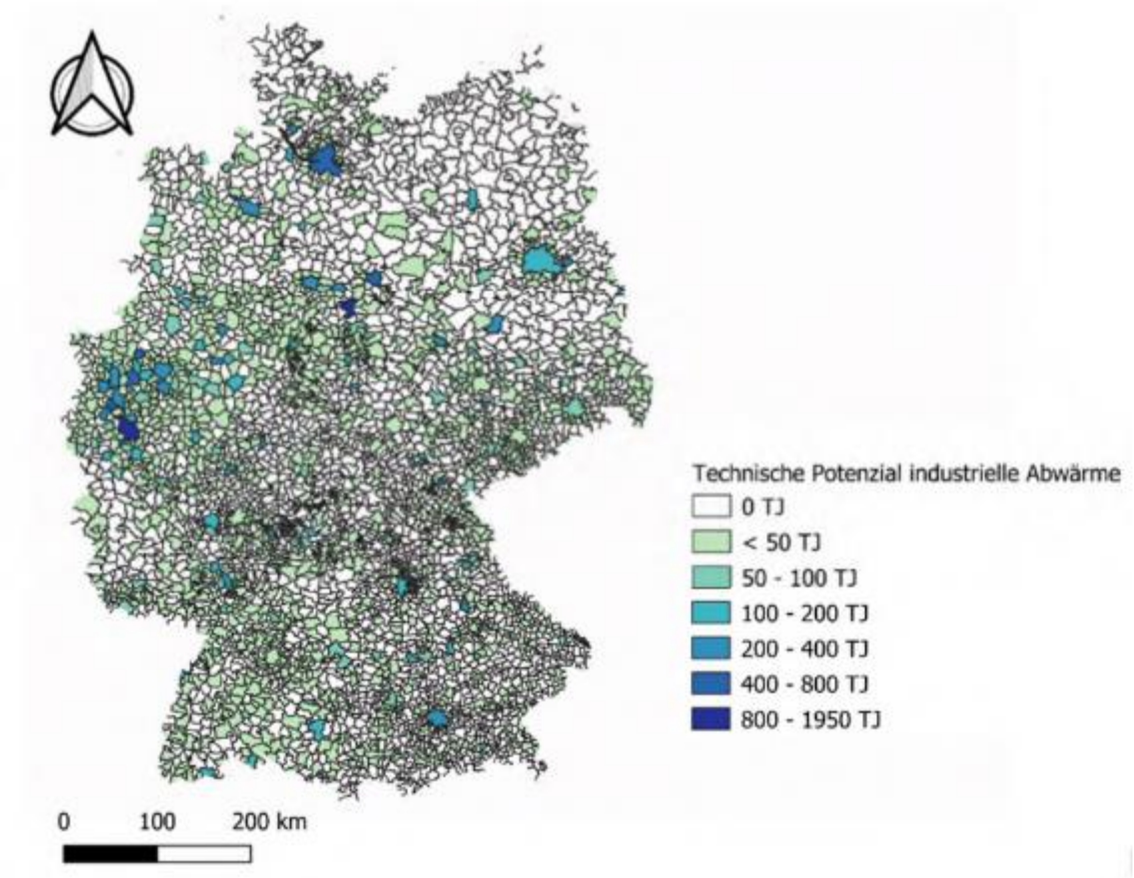
- The theoretical waste heat potential that can be utilised in existing heating networks without additional upgrading via heat pumps (Tref >= 125 °C) amounts to 26 TWh.
- The theoretical waste heat potential that can be utilised in local heating networks or low-temperature networks without additional upgrading via heat pumps (75 °C <= Tref < 125 °C) amounts to 7.5 TWh.
- The theoretical waste heat potential that can be utilised in heating networks via heat pumps (30 °C <= Tref < 75 °C) amounts to 3.9 TWh.

Determination of technical potential: Taking the location-specific results for theoretical potentials as a basis, the technical potentials are determined based on a spatial approach. For the locations identified in the previous step an analysis is performed to determine whether possible heat sinks are present in the immediate vicinity. In keeping with the approach used to determine the potentials for sewage treatment plants or energy from waste water (see Section III.5.g) and the potentials for centralised solar thermal systems (see Section III.5.e), the disaggregated baseline scenario is taken as a basis for identifying heating demand areas with a heating density >15 GWh/km^2, heating sales of at least 1 GWh and a permissible distance of no more than 1 km to the heat sources. Overall, the technical demand potential determined in this way comes to 32.1 TWh, which can be broken down as follows on the basis of heat sink temperature:

- The technical waste heat potential that can be utilised in existing heating networks without additional upgrading via heat pumps (Tref >= 125 °C) amounts to 22.3 TWh.
- The technical waste heat potential that can be utilised in local heating networks or low-temperature networks without additional upgrading via heat pumps (75 °C <= Tref < 125 °C) amounts to 6.2 TWh.

- The technical waste heat potential that can be utilised in heating networks via heat pumps (30 °C <= Tref < 75 °C) amounts to 3.6 TWh.

An overview of the spatial distribution of the technical waste heat potentials for the individual municipal associations is provided in Figure 50.

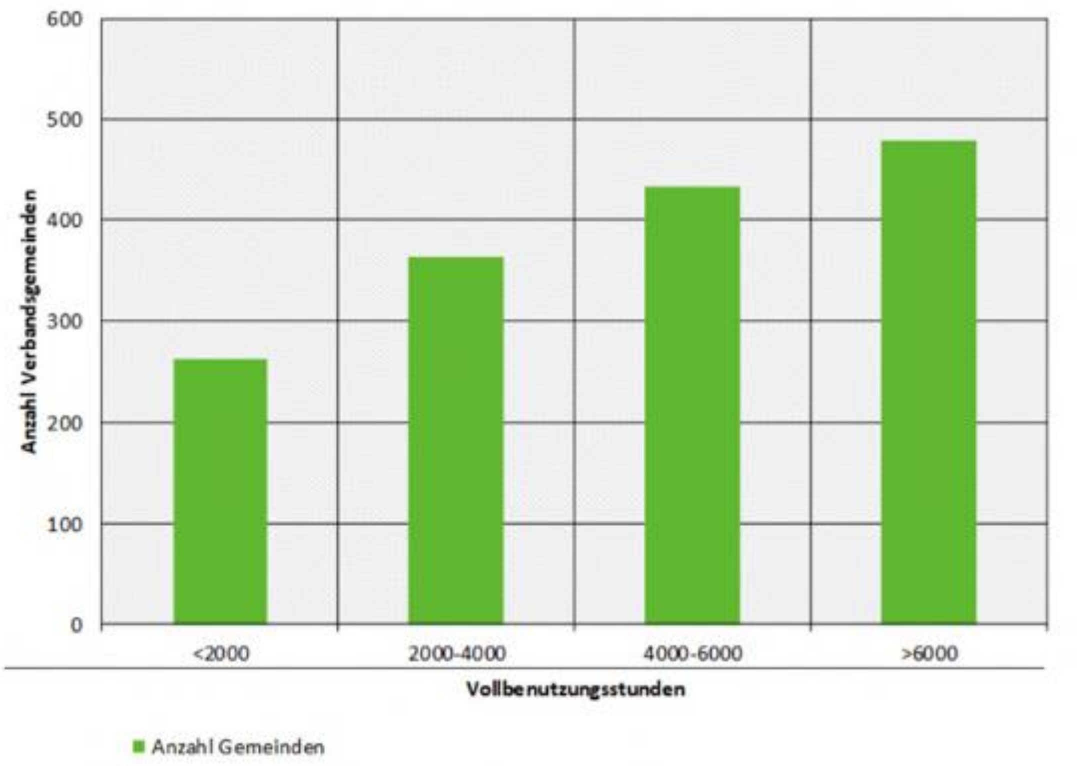


Technische Potenzial industrielle Abwärme	Technical potential of industrial waste heat

Source: Own figure (ifeu)

Figure 50: Presentation of the technical potentials determined for industrial waste heat

Based on the information available in the data under the 11th BImSchV, the potentials of industrial waste heat for the centralised supply of space heating and hot water are determined on the basis of average operating hours. For each municipal association these can therefore be averaged across the potential locations present within a municipality. An overview of the full load hours of municipalities with technical waste heat potential is provided in Figure 51. The weighted average across all municipalities with possible waste heat potential is approx. 4,700 full load hours. The municipality-specific information on full load hours is incorporated into the analysis of the alternative scenarios.



Anzahl Verbandsgemeinden	Number of municipal associations
Vollbenutzungsstunden	Full load hours
Anzahl Gemeinden	Number of municipalities

Source: Own figure (ifeu) based on data under the 11th BImSchV

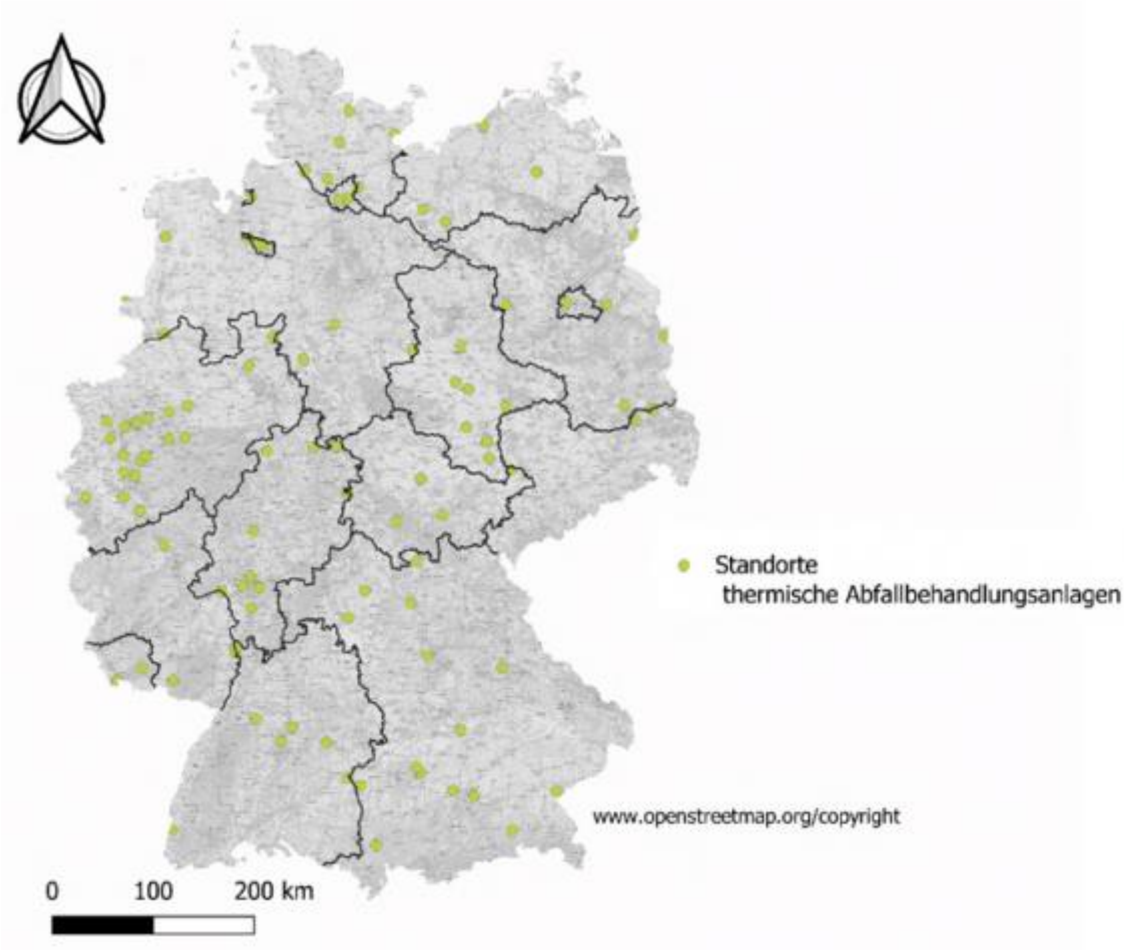
Figure 51: Municipal associations for which a technical waste heat potential could be determined, broken down by full load hours

III.5.b. Thermal waste treatment plants

For thermal waste treatment plants it is assumed that the plants currently in operation will still be operating in 2030[31]. The plants mapped in Section I.3.b from Flamme et al. (2018) are therefore selected. They are linked to the corresponding quantities of heat for 2018 provided by the Federal Statistical Office. In the case of energy from industrial and other waste, this results in a net heat generation potential of around 25 TWh. In Flamme et al. (2018) it is assumed that the heat output of waste incineration plants and RDF plants will decline by 9% by 2030. The potential in 2030 will therefore stand at approx. 24 TWh.

The net heat generation is disaggregated in accordance with the individual plant capacities presented in Flamme et al. (2018). The locations are shown in Figure 52.

[31] In Fritz & Pehnt (2018b) it was pointed out that the potential of thermal waste treatment plants that are not yet connected to the network has been virtually exhausted. Only two plants do not yet have a heat extraction system.



Standorte thermische Abfallbehandlungsanla-gen	Locations of thermal waste treatment plants

Source: Own figure (ifeu) based on Flamme et al. (2018)

Figure 52: Presentation of WIP and RDF plant locations

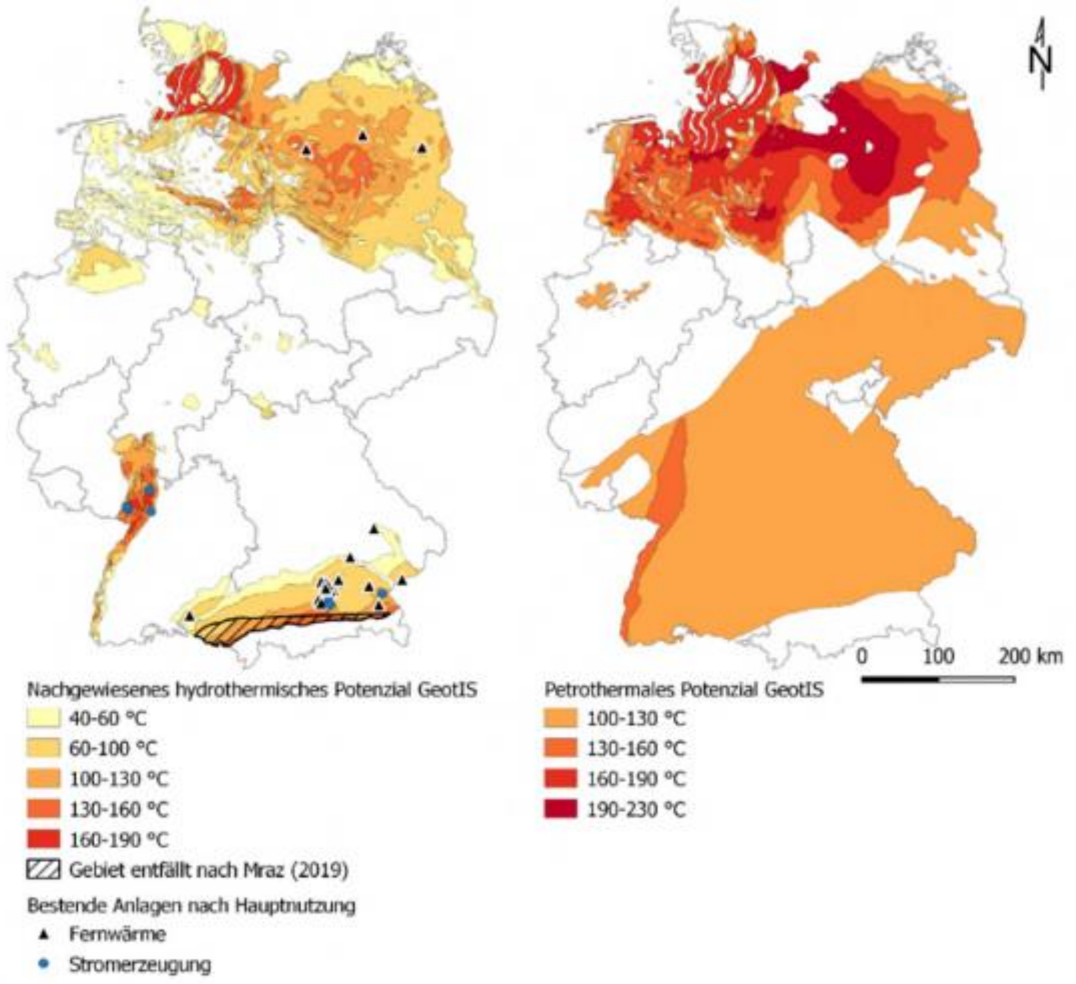
III.5.c. High-efficiency CHP

In the case of combined heat and power no local potentials are taken as a basis, as, in principle, this technology can be utilised anywhere. All known climate action scenarios assume an increasing share of renewable energies and fossil-fuel-free technologies in the electricity mix, which means that the share of CHP in electricity generation is limited over the long term.

A slight expansion of CHP is still expected by 2030: the current evaluation of the Co-generation Act assumes that 110 TWh of electricity will be generated from CHP in 2020 and 120 TWh in 2025, compared with 117 TWh in 2017 (Wünsch et al., 2019). A slight expansion of CHP is still expected by 2030: the current evaluation of the Cogeneration Act assumes that 110 TWh of electricity will be generated from CHP installations in 2020 and 120 TWh in 2025 (Fraunhofer IFAM et al., 2019). The Federal Environment Agency’s RESCUE study also shows an increase in CHP installations by 2030, followed by a significant reduction in the capacities and full load hours of gas-fired CHP over the period up to 2050. According to this study, grid-based heat generation from CHP installations of around 35 TWh is assumed for 2030 (Purr et al., 2019).

III.5.d. Deep geothermal

To allow the technical supply potential of geothermal to be spatially allocated, use is made of the information from the geothermal information system GeotIS[32], in which proven hydrothermal[33] and petrothermal[34] reservoirs are presented on a small scale by temperature level (Agemar et al., 2014; LIAG - Leibnitz Institut für angewandte Geowissenschaften, 2020). In addition to measured data, the database is based on derived underground models for the spatial interpolation of geological parameters and is updated on an ongoing basis. In 2019 the hydrothermal potential zone in the southern-German Molasse basin was reduced on the basis of geological findings according to Mraz (2019) and this is taken into account in the assessment of existing studies of potential. The areas are presented in Figure 53.



Nachgewiesenes hydrothermisches Potenzial	Proven hydrothermal potential GeotIS

[32] https://www.geotis.de/

[33] Hot water present

[34] No hot water present, but injection of water as a heat-transfer medium is theoretically possible.

GeotIS	
Gebiet entfällt nach Mraz (2019)	Area no longer applicable according to Mraz (2019)
Bestende Anlagen nach Hauptnutzung	Existing installations by principal use
Fernwärme	District heating
Stromerzeugung	Electricity generation
Petrothermales Potenzial GeotIS	Petrothermal potential GeotIS

Source: Own figure (ifeu) based on Agemar et al., 2014; LIAG - Leibnitz Institut für angewandte Geowissenschaften (2020)

Figure 53: Location of proven hydrothermal reservoirs (left) and petrothermal reservoirs (right) by temperature level in the GeotIS geothermal information system.

As the methods involved in utilising petrothermal reservoirs are still relatively untested and considerably more costly to realise (Plenefisch et al., 2015), within the framework of this research project only hydrothermal potentials are taken into account in the analysis of alternative scenarios (proven hydrothermal resources).

Potentials in water protection areas[35], nature conservation areas and national parks are left out of consideration in the location-specific calculation.

With regard to the geothermal extraction potential of all areas with a hot water temperature T_{res} > 65 °C, it is possible to establish the following correlation from the mass flow of the reservoir $\dot{m}$ [kg/s], the specific heat capacity of water c_p [kJ/kg*K][36] and the temperature spread of the production water T_{Res} and the reinjection temperature T_{Rein}.

$$\dot{Q}_{geo} = \dot{m} * c_p * (T_{Res} - T_{Rein})$$

This theoretical potential is reduced by a discount factor for unsuccessful drillings (25% according to Sandrock et al. (2020)).

Furthermore, a minimum distance of 2 km at the earth's surface between the production and reinjection well is taken as a basis and other assumptions are made that, overall, lead to a conservative estimate.

All in all, this results in a technical supply potential of around 47 GW in Germany for a reinjection temperature of 65 °C. In the event of the active utilisation of geothermal energy using heat pumps to raise the temperature, taking a reinjection temperature of 35 °C into account, the technical supply potential increases to 98 GW.

---

[35] All water protection areas are excluded here. This is because the database does not contain a classification of protection levels I, II and III. Source: (BfG - Bundesanstalt für Gewässerkunde, 2009)

[36] The mass flow is differentiated on a regional basis at the level of the three higher-level zones (North German Basin, Upper Rhine Rift and southern-German Molasse Basin) using the average for existing installations according to GeotIS. (North German Basin: 35 kg/s, Upper Rhine Rift: 90 kg/s, southern-German Molasse Basin: 125 kg/s.) The specific heat capacity of the thermal water extracted is set at 4.0 kJ/kg*K, based on the assumption of low salinity.

III.5.e. Large-scale solar thermal installations

The potential of solar thermal collectors in terms of supply to the district heating network is calculated using a GIS-based Python model of IREES. Potential free-field sites and suitable heat sink areas are combined.

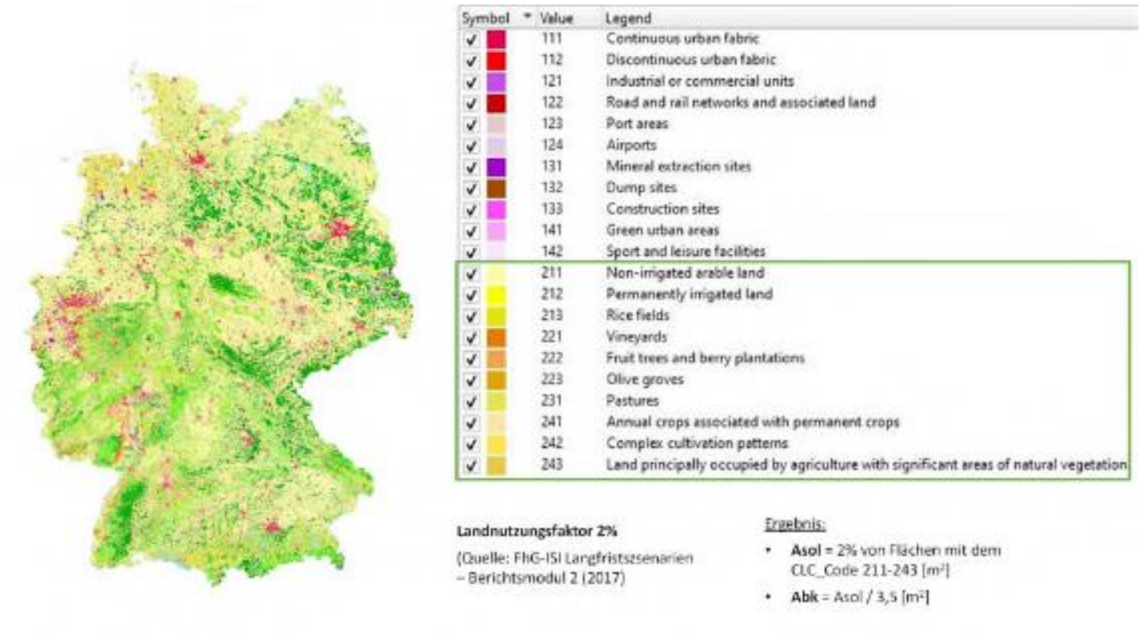
As the geographical proximity of the heat source and sink is a crucial factor when it comes to using centralised solar thermal energy in district heating regions, the aim of the GIS model is to identify suitable areas for large free-field solar thermal installations in immediate proximity to suitable heat sinks. Heating demand regions that are suitable to be supplied via heating networks are determined using a minimum heating density of 15 GWh/km² (see also Section III.2). In the GIS model 1,000 m is assumed to be the maximum distance between free-field collector sites and the heating network supply point to reduce heat losses between the solar system and heat source[37]. The solar thermal GIS model is developed in four steps:

1. In the first step possible free-field sites are identified on which solar thermal collectors could be installed. This is based on the data from CORINE Land Cover dating from 2018 (Copernicus, 2018).
2. In the second step the potential monthly solar collector yield is determined on the basis of spatially resolved weather data on solar irradiation and surface temperature taken from the data of the German Meteorological Service (Deutsche Wetterdienst - Außentemperatur, n.d.; Deutsche Wetterdienst - Solarstrahlung, 2020; Deutsche Wetterdienst - Sonnenscheindauer, 2018) at the level of a 1 km^2 grid for Germany.
3. In the third step heating demand regions are identified that are suitable to be supplied via heating networks. This is based on the Hotmaps heating density map (HOTMAPS Project, 2020), scaled by the useful energy demand for 2018 under the baseline scenario at municipality level (see also Section III.3.c).
4. In the final step the suitable locations for free-field sites and suitable heating demand regions are combined. This involves performing a radius search at grid cell level in the Python model using the defined maximum distance between suitable heating demand regions and potential areas for solar thermal free-field collector installations. For the calculation of potential only areas that are close to a corresponding heating demand region are taken into account.

<u>1 Determination of suitable free-field sites:</u> **First of all** the CORINE Land Cover data are analysed. The CLC 2018 data set classifies land use into 44 different land use categories with a minimum mapping unit of 25 hectares. This data set is developed by the European Environment Agency (EEA) on the basis of the photo-interpretation of satellite images. Ten categories representing different types of agricultural areas are taken into account as possible areas for solar thermal collectors. In accordance with the study by (Pfluger et al., 2017) on the determination of photovoltaic free-field site potentials, a land use factor of 2% is assumed. This indicates how much of the agricultural area could theoretically be used as areas with solar potential (Asol). To prevent shad-

[37] For larger collector areas of more than 20,000 m² a distance of up to 2 km can also be applied (Vergleiche dazu (*Solar district heating guidelines*, 2012)), although this has been disregarded in this national analysis of potential.

owing effects, the gross collector area is calculated by dividing the identified solar areas (Asol) by a factor of 3.5 *(*Solar district heating guideline, 2012). The CORINE Land Cover data are presented in Figure 54.



Landnutzungsfaktor 2%	Land use factor 2%
(Quelle: FhG-ISI Langfristszenarien – Berichtsmodul 2 (2017)	(Source: FhG-ISI long-term scenarios – reporting module 2 (2017))
Ergebnis:	Result:
Asol = 2% von Flächen mit dem CLC_Code 211-243 [m^2]	Asol = 2% of areas with the CLC_Code 211-243 [m^2]
Abk = Asol / 3,5 [m^2]	Agc = Asol / 3.5 [m^2]

Source: CORINE Land Cover

Figure 54: CORINE Land Cover data for Germany

2 Calculation of the potential solar yield: **In the second step** the data sets of the German Meteorological Service (DWD) are analysed and prepared to calculate the solar collector yield. The data sets of the DWD Climate Data Centre describe an average of the incident short-wave horizontal solar radiation (global radiation) for Germany at grid level. These data are generated from quality-controlled ground measurements at the DWD stations and radiation values derived from satellites. To calculate the potential collector yield at 1 km^2 grid level, the average monthly outdoor temperatures and the average monthly sunshine are also used. Figure 55 shows the calculated collector yield in 2018 based on the data sets used and collector-specific technical data.

Collector yield per month:

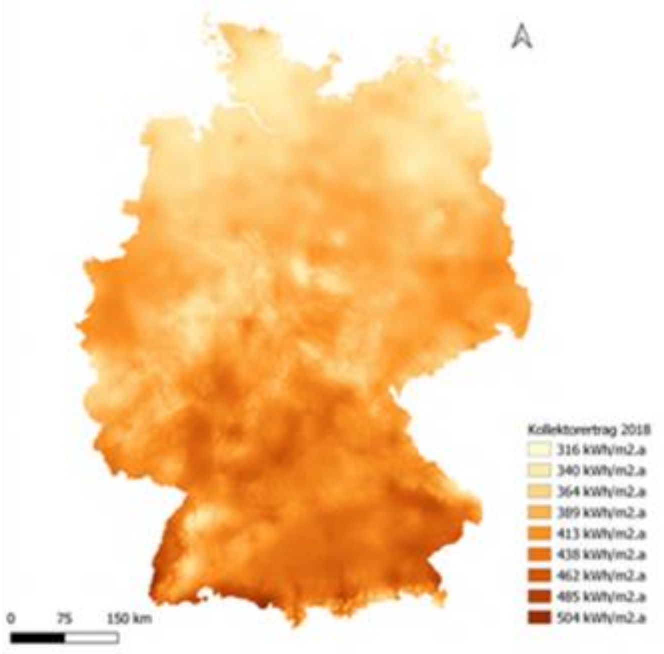
$$q_{sys,m} = g_{s,m} * \left| \eta - A_1 \frac{T_K - t_{u,m}}{\frac{g_{s,m}}{h_{s,m}}} - A_2 \frac{(T_K - t_{u,m})^2}{\frac{g_{s,m}}{h_{s,m}}} \right|^2$$

Location-specific parameters from DWD GIS data

- $g_{s,m}$: Monthly global radiation [kWh/m^2]
- $t_{u,m}$: Average monthly temperature [C°]
- $h_{s,m}$: Monthly sunshine [h]

Solar collector technical data:

- Optical efficiency (η) = 0.8
- Loss factor (A_1) = 3.8
- Loss factor (A_2) = 0.009
- Collector temperature (T_k) = 75 °C



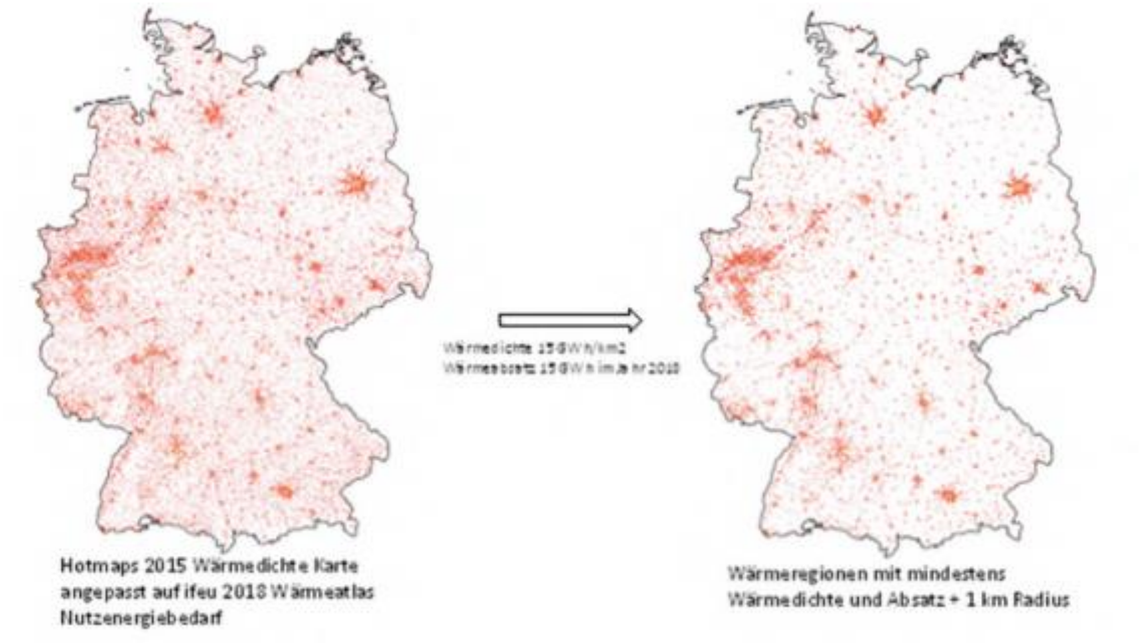
Kollektorertrag 2018	Collector yield 2018

Source: Own figure (IREES)

Figure 55: Calculated collector yield at 1 km² grid level in 2018

<u>3 Determination of suitable heating demand regions:</u> **In the third step** the suitable heating demand regions are determined. In this project regions with a minimum heating density of 15 GWh/km² and an annual heating demand of more than 15 GWh are defined as suitable regions for large-scale solar thermal installations.

For this analysis use is made of the heating density map of the Hotmaps project, which relates to 2015 and has been scaled on the basis of the baseline scenario for useful energy demand in 2018 at municipal association level. The adapted heating density map and the identified heating regions are shown in Figure 56.

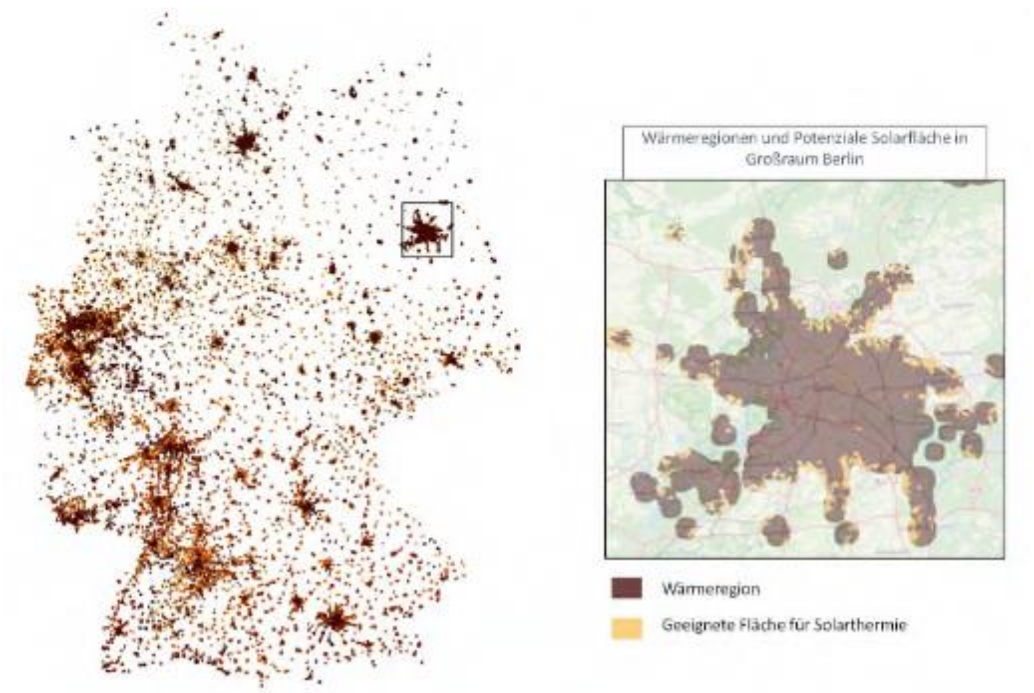


Hotmaps 2015 Wärmedichte Karte angepasst auf ifeu 2018 Wärmeatlas Nutzenergiebedarf	Hotmaps 2015 heating density map adapted to useful energy demand in ifeu 2018 Heat Atlas
Wärmedichte 15 GWh/km2	Heating density 15 GWh/km^2
Wärmeabsatz 15 GWh im Jahr 2018	Heating sales 15 GWh in 2018
Wärmeregionen mit mindestens Wärmedichte und Absatz + 1 km Radius	Heating regions with at least the above heat-ing density and sales + 1 km radius

Source: Own figure (IREES) based on Hotmaps

Figure 56: Adapted Hotmaps heating density map (left) and identified heating regions (right)

<u>4 Determination of potential for solar supply to heating networks:</u> **In the final step** the potential free-field sites that could be used for the solar supply to heating networks are determined on the basis of the heating regions identified. The developed Python model determines regions that are up to 1 km away from the heating region. If the regions identified are agricultural areas on the basis of the CLC code, the corresponding regions are interpreted as suitable solar areas. Figure 57 shows the identified areas with technical potential for Germany (left) and the greater Berlin region (right).

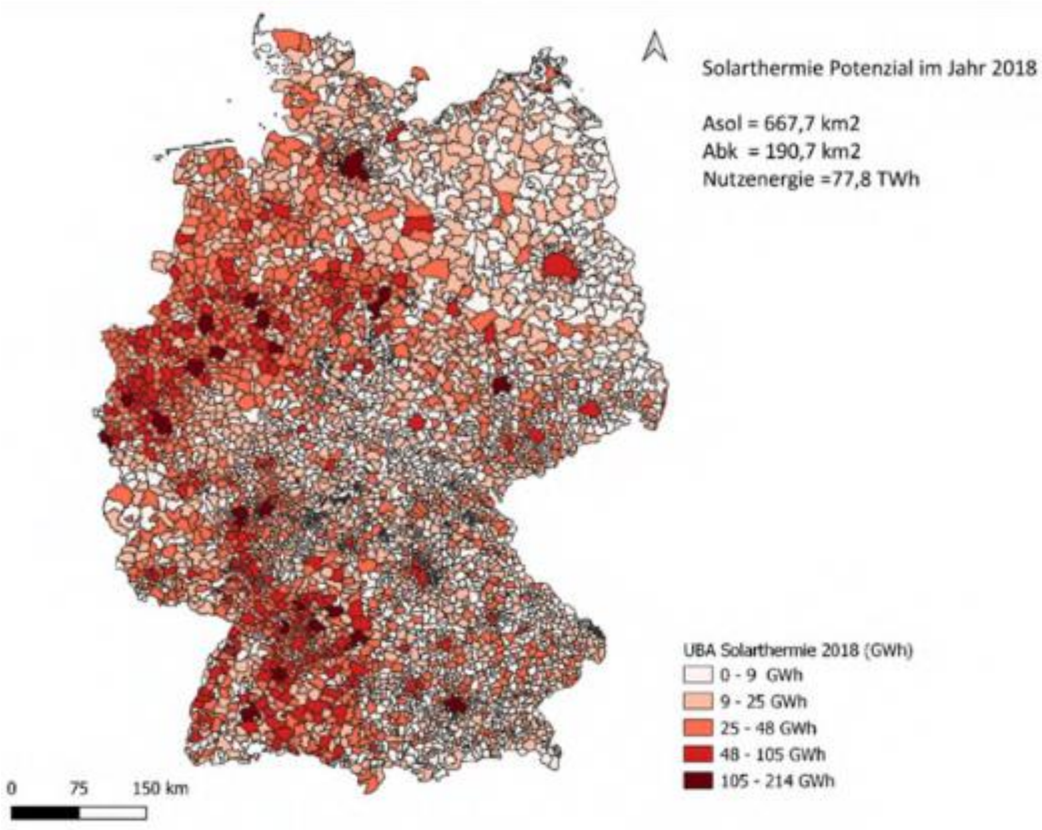


Wärmeregionen und Potenziale Solarfläche in Großraum Berlin	Heating regions and solar potentials in greater Berlin region
Wärmeregion	Heating region
Geeignete Fläche für Solarthermie	Suitable area for solar thermal power

Source: Own figure (IREES)

Figure 57: Identified areas with technical potential for Germany (left) and the greater Berlin region (right)

Figure 58 shows the resulting technical potentials for Germany at municipal association level for 2018. The total solar thermal gross collector area that has been identified with potential for use in suitable heating demand areas is around 190 km². This corresponds to roughly 0.05% of Germany’s total surface area. The technical potential of the solar heat generated by it is approx. 80 TWh.



Solarthermie Potenzial im Jahr 2018	Solar thermal potential in 2018
Asol = 667,7 km2	Asol = 667.7 km^2
Abk = 190,7 km2	Agc = 190.7 km^2
Nutzenergie = 77,8 TWh	Useful energy = 77.8 TWh
UBA Solarthermie 2018 (GWh)	UBA solar thermal 2018 (GWh)

Source: Own figure (IREES)

Figure 58: Solar thermal potentials (free-field installations) at municipal association level for Germany in 2018

Due to the assumptions made, however, there are considerable uncertainties associated with the results of the analysis of potential. Firstly, the land use factor of 2% is assumed and applied universally. Actual land use can be higher or lower, however, depending on the local conditions. Furthermore, with regard to the calculation of the potential solar yield, uniform technical data are assumed for the collector. In practice, large collector arrays will consist of two types of collector to allow, on the one hand, the optimum design point to be achieved for the use of solar radiation for lower supply and return temperatures and, on the other, to allow the water temperature to be raised to the temperature level required for district heating. Furthermore, due to the data available, land prices cannot be taken into account directly as a significant restriction of potential.

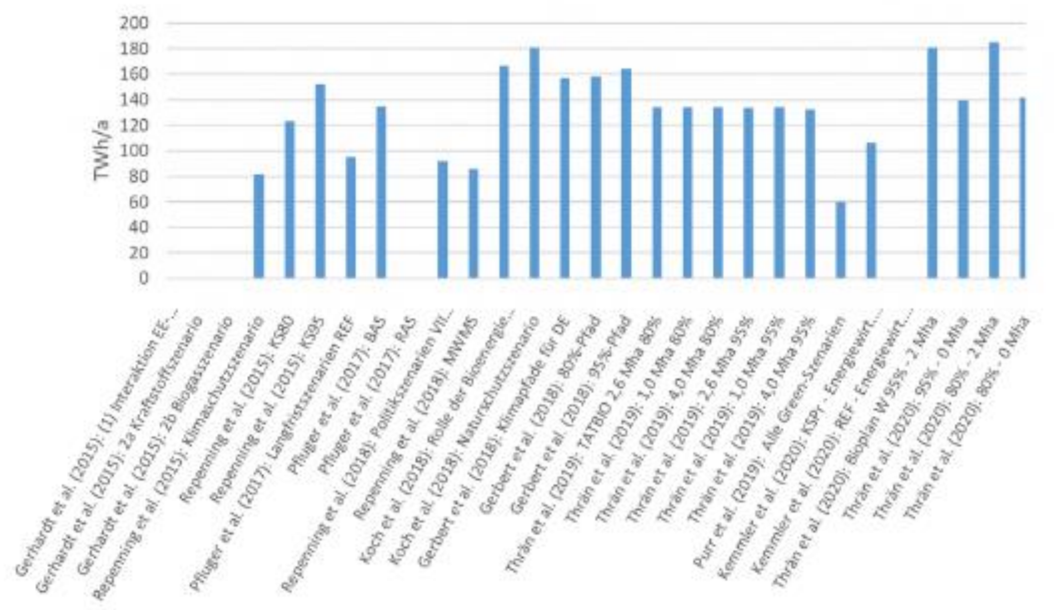
III.5.f. Biomass

Biomass currently plays a dominant role in renewable heating and cooling: in 2019 around 152 TWh of heat was supplied from biomass in Germany, representing 86% of renewable heating and cooling (AGEE-Stat, 2020). When it comes to the energy-related use of biomass, in particular cultivated biomass, in the future it will be necessary to give greater consideration to limits to the potential of sustainably produced and available biomass, competition for use and land, the optimum sectoral distribution of biomass from a climate protection perspective and air pollution control.

As biomass is transportable, rather than locally resolved biomass potentials at municipality level, a potential for the whole of Germany has been taken as a basis for the underlying analysis of the economic potential for efficiency in heating and cooling. In the heating market biomass should be used in particular where, after efficiency potentials have been exploited, it offers energy-related added value and few other decarbonisation options are available.

Research on the economic potentials resulting from biomass for 2030 that have been allocated in energy system models was carried out as part of the reporting obligation in accordance with Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. The results of this analysis are presented in Figure 59 and, for 2030, show a range in most studies of between 80 and 160 TWh per year for the use of biomass in overall heating and cooling generation (centralised and decentralised in all sectors). In the light of current use, an increase in future potential should not therefore be assumed. Current studies reveal the expected maximum value for biomass use on the overall heating and cooling market for 2030 to be around 185 TWh.

In the NECP roughly 25 TWh of biomass was used in district heating, depending on the scenario.



Gerhardt et al. (2015): (1) Interaktion EE-…	Gerhardt et al. (2015): (1) Interaction of RE…
Gerhardt et al. (2015): 2a Kraftstoffszenario	Gerhardt et al. (2015): 2a Fuel scenario

Gerhardt et al. (2015): 2b Biogasszenario	Gerhardt et al. (2015): 2b Biogas scenario
Repenning et al. (2015): Klimaschutzszenario	Repenning et al. (2015): Climate protection scenario
Repenning et al. (2015): KS80	Repenning et al. (2015): Climate protection scenario 80
Repenning et al. (2015): KS95	Repenning et al. (2015): Climate protection scenario 95
Pfluger et al. (2017): Langfristszenarien REF	Pfluger et al. (2017): Long-term scenarios – reference
Pfluger et al. (2017): BAS	Pfluger et al. (2017): Baseline scenario
Pfluger et al. (2017): RAS	Pfluger et al. (2017): Low-restriction scenario
Repenning et al. (2018): Politikszenarien VII…	Repenning et al. (2018): Policy scenarios VII…
Repenning et al. (2018): MWMS	Repenning et al. (2018): 'With-additional-measures' scenario
Koch et al. (2018): Rolle der Bioenergie…	Koch et al. (2018): Role of bioenergy…
Koch et al. (2018): Naturschutzszenario	Koch et al. (2018): Nature conservation scenario
Gerbert et al. (2018): Klimapfade für DE	Gerbert et al. (2018): Climate pathways for Germany
Gerbert et al. (2018): 80%-Pfad	Gerbert et al. (2018): 80% pathway
Gerbert et al. (2018): 95%-Pfad	Gerbert et al. (2018): 95% pathway
Thrän et al. (2019): TATBIO 2,6 Mha 80%	Thrän et al. (2019): TATBIO (techno-economic analysis and transformation pathways of energetic biomass potential) 2.6 Mha 80%
Thrän et al. (2019): 1,0 Mha 80%	Thrän et al. (2019): 1.0 Mha 80%
Thrän et al. (2019): 4,0 Mha 80%	Thrän et al. (2019): 4.0 Mha 80%
Thrän et al. (2019): 2,6 Mha 95%	Thrän et al. (2019): 2.6 Mha 95%
Thrän et al. (2019): 1,0 Mha 95%	Thrän et al. (2019): 1.0 Mha 95%
Thrän et al. (2019): 4,0 Mha 95%	Thrän et al. (2019): 4.0 Mha 95%
Purr et al. (2019): Alle Green-Szenarien	Purr et al. (2019): All green scenarios
Kemmler et al. (2020): KSPr - Energiewirt…	Kemmler et al. (2020): KSPr (comprehensive assessment of climate action programme) – energy ind…
Kemmler et al. (2020): REF - Energiewirt…	Kemmler et al. (2020): Reference – energy ind…
Thrän et al. (2020): Bioplan W 95% - 2 Mha	Thrän et al. (2020): Bioplan W (system solutions for bioenergy in the heating sector) 95% - 2 Mha
Thrän et al. (2020): 95% - 0 Mha	Thrän et al. (2020): 95% - 0 Mha
Thrän et al. (2020): 80% - 2 Mha	Thrän et al. (2020): 80% - 2 Mha
Thrän et al. (2020): 80% - 0 Mha	Thrän et al. (2020): 80% - 0 Mha

Source: Ortner et al. (ongoing)

Figure 59: Economic potentials for heat from biomass for 2030 under various energy scenarios

III.5.g. Energy from waste water, sewage treatment plants

The GIS waste water model focuses on determining the technical potential of waste water from sewage treatment plants as a heat source for large-scale heat pumps. Although sewage treatment plants are generally built a certain distance away from settlement areas, there are many heating consumers (residential buildings and services sector) with a heating density of at least 15 GWh/km² in the immediate vicinity (less than 1 km). The aim of the model is to identify the technical potential. All the data sets used are presented in Table 17. The waste water GIS model is developed in three steps:

1. Definition of locations and technical parameters of sewage treatment plants.
2. Identification of technical potentials for waste water.
    a) Use of Hotmaps 2015 heating density map scaled by the values of the ifeu heat atlas for municipalities for 2018
    b) Max. distance of 1 km between sewage treatment plants and possible heat sinks
3. Definition of properties of heat pumps.
    a) Assumptions from ifeu short study '*Kommunale Abwässer als Potenzial für die Wärmewende*' ('Potential of urban waste water for the heating transition') commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (Fritz & Pehnt, 2018) (temporal availability factor, rainwater factor)
    b) Technical data of heat pumps (APC, supply and return temperature, HP efficiency, capacity factor)

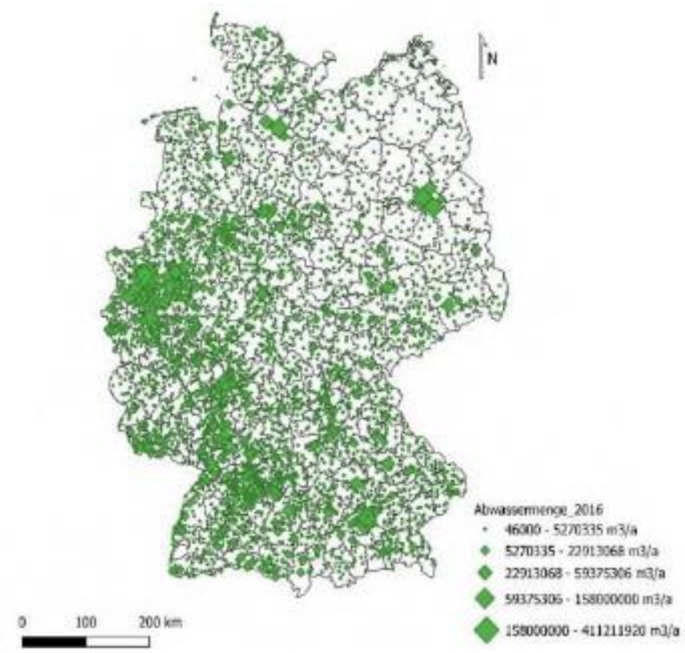
Table 17: Data sets and data formats used in the GIS waste water model

Data set	Data format	Source
EU Urban Waste Water Treatment Directive	Vector	EU-Kommunalwasserrichtlinie Karte,Umwelt Bundesamt (2016)
Hotmaps 2015 heating density map	100 m grid	Hotmaps Project, (2020a)
Useful energy demand in 2018 heat atlas	csv	Baseline scenario, disaggregated on the basis of the ifeu heat atlas

To identify the locations and technical parameters of sewage treatment plants, first of all a data set originating from the European Urban Waste Water Treatment Directive is used (Umwelt Bundesamt, 2016). Member States are obliged to give the EU Commission regular status reports on the implementation of the requirements under the Directive. The data set contains the information for all urban sewage treatment plants that are subject to the reporting requirement and on which Germany reports to the EU Commission.

This reporting comprises information on settlement areas (agglomerations) with more than 2,000 inhabitants, as well as on the sewage treatment plants that treat the waste water from these settlement areas and their discharge points (disposal of treated waste water to surface waters, for example). Due to difficulties in defining the boundaries of settlement areas, Germany reports settlement areas as sewage treatment plants (1:1). This means that a settlement area corresponds to the catchment area of a sewage treatment plant.

For settlement areas it is necessary to report, in accordance with the requirements of the Directive, the extent to which the accumulated waste water is collected in collecting systems and fed into a treatment process. The urban sewage treatment plants treat the waste water produced by households, industrial and commercial waste water that is discharged into public collecting systems or the sewage treatment plant, as well as rainwater and extraneous water that also ends up in the collection systems. The sewage treatment plants considered are shown in the following figure.

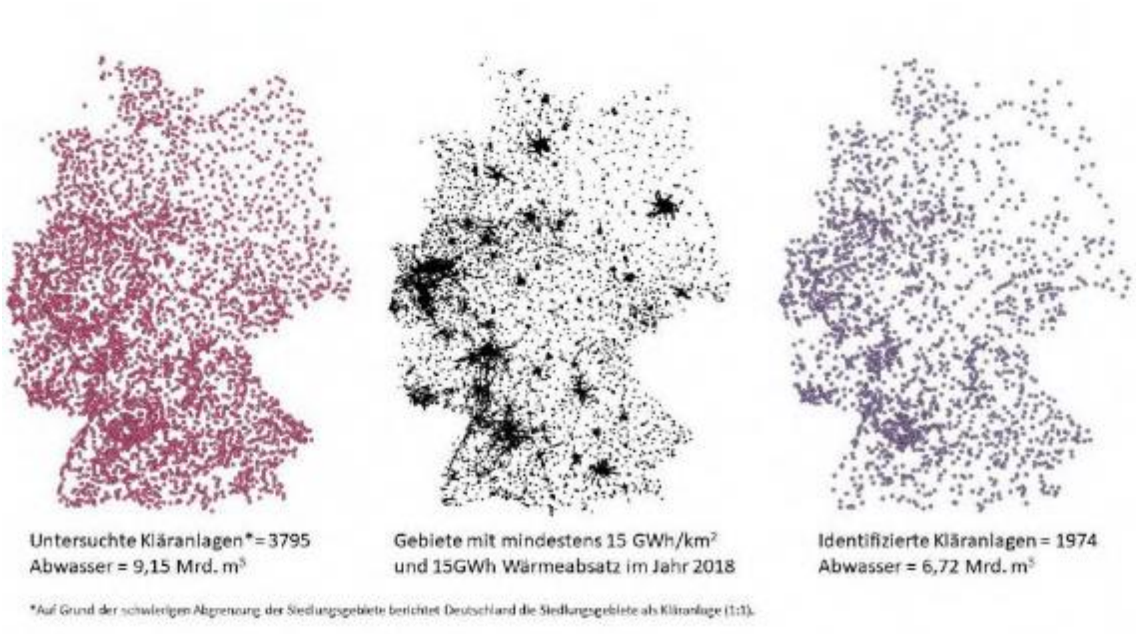


Abwassermenge_2016	Waste water volume 2016

Source: Own figure (IREES) based on (Umwelt Bundesamt, 2016)

Figure 60 Sewage treatment plants and waste water volume in 2016

In the second step plants are identified that lie within a radius of 1 km of heat sinks with a heating density of at least 15 GWh/km^2. Of the 3,795 existing sewage treatment plants, 1,974 are within 1 km of heating areas. Figure 61 shows the locations of the existing 3,795 sewage treatment plants (left), the areas with a heating density of at least 15 GWh/km^2 (centre) and the identified plants (right).



Untersuchte Kläranlagen* = 3795	Sewage treatment plants analysed* = 3,795
Abwasser = 9,15 Mrd m^3	Waste water = 9.15 billion m^3
Gebiete mit mindestens 15 GWh/km^2 und 15GWh Wärmeabsatz im Jahr 2018	Areas with a heating density of at least 15 GWh/km^2 and 15 GWh in heating sales in 2018
Identifizierte Kläranlagen = 1974	Sewage treatment plants identified = 1,974
Abwasser = 6,72 Mrd. m^3	Waste water = 6.72 billion m^3
*Auf Grund der schwierigen Abgrenzung der Siedlungsgebiete berichtet Deutschland die Siedlungsgebiete als Kläranlage (1:1).	*Due to difficulties in defining the boundaries of settlement areas, Germany reports settlement areas as sewage treatment plants (1:1).

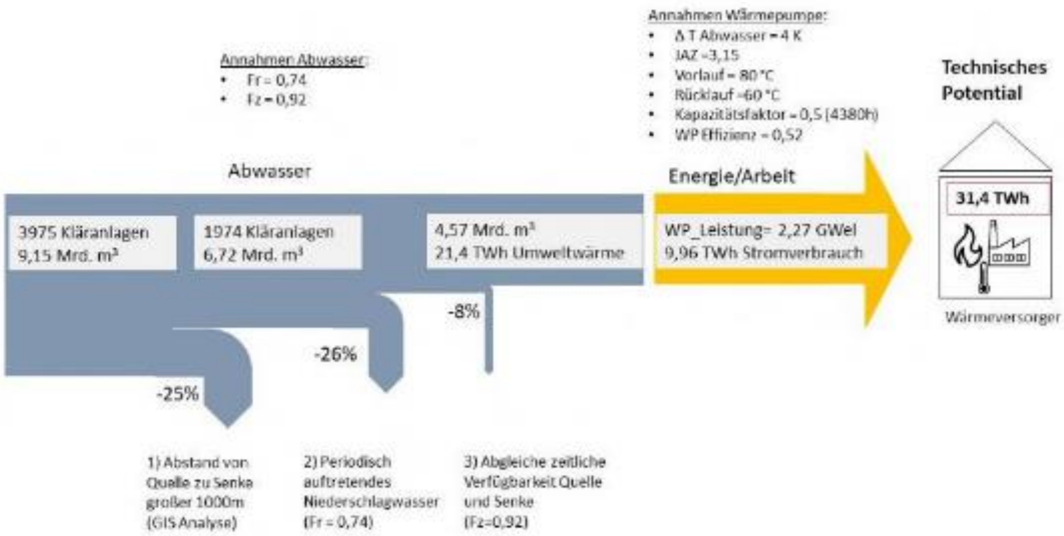
Source: Own figure (IREES) based on (HOTMAPS Project, 2020; Umwelt Bundesamt, 2016)

Figure 61 Identification of sewage treatment plants that lie within 1 km of heating regions

In the third step assumptions taken from the ifeu report by Fritz & Pehnt (2018) are used so that only non-fluctuating waste water is taken into account[38]. Two factors influence the recorded total waste water volume treated by the sewage treatment plants. The first of these is the rainwater factor (Fr), which reduces the total volume of water by 26%, while the second is the temporal availability factor (Fz) between the volume of treated waste water and the available heating demand and reduces the total waste water volume by a further 8%.

Besides quantifying the share of useful heat demand that can be met by extracting waste water heat from the sewer before the sewage treatment plant, the assumptions also provide valuable insights into the waste water reported and its temporal availability.

[38] The waste water volume is reduced by rainwater and by residual water, which fluctuates over time.



Annahmen Abwasser: Fr = 0,74 Fz = 0,92	Assumptions for waste water: Fr = 0.74 Fz = 0.92
Annahmen Wärmepumpe: Δ T Abwasser = 4K JAZ = 3,15 Vorlauf = 80°C Rücklauf =60°C Kapazitätsfaktor = 0,5 (4380h) WP Effizienz = 0,52	Assumptions for heat pump: Δ T waste water = 4K APC = 3.15 Supply = 80 °C Return = 60 °C Capacity factor = 0.5 (4,380h) HP efficiency = 0.52
Technisches Potenzial 31,4 TWh Wärmeversorger	Technical potential 31.4 TWh Heat supplier
Abwasser	Waste water
3975 Kläranlagen 9,15 Mrd. m^3	3,975 sewage treatment plants 9.15 billion m^3
1974 Kläranlagen 6,72 Mrd. m^3	1,974 sewage treatment plants 6.72 billion m^3
4,57 Mrd. m^3 21,4 TWh Umweltwärme	4.57 billion m^3 21.4 TWh ambient heat
Energie/Arbeit WP_Leistung = 2,27 Gwel 9,96 TWh Stromverbrauch	Energy/work HP_capacity = 2.27 GWel 9.96 TWh electricity consumption
1) Abstand von Quelle zu Senke großer 1000m	1) Distance from source to sink greater than

(GIS Analyse)	1,000 m (GIS analysis)
2) Periodisch auftretendes Niederschlagwasser (Fr = 0,74)	2) Periodic accumulation of rainwater (Fr=0.74)
3) Abgleiche zeitliche Verfügbarkeit Quelle und Senke (Fz = 0,92)	3) Comparisons of temporal availability of source and sink (Fz=0.92)

Source: Own figure based on Fritz & Pehnt (2018)

Figure 62: Losses of waste water energy potential based on annual waste water volume

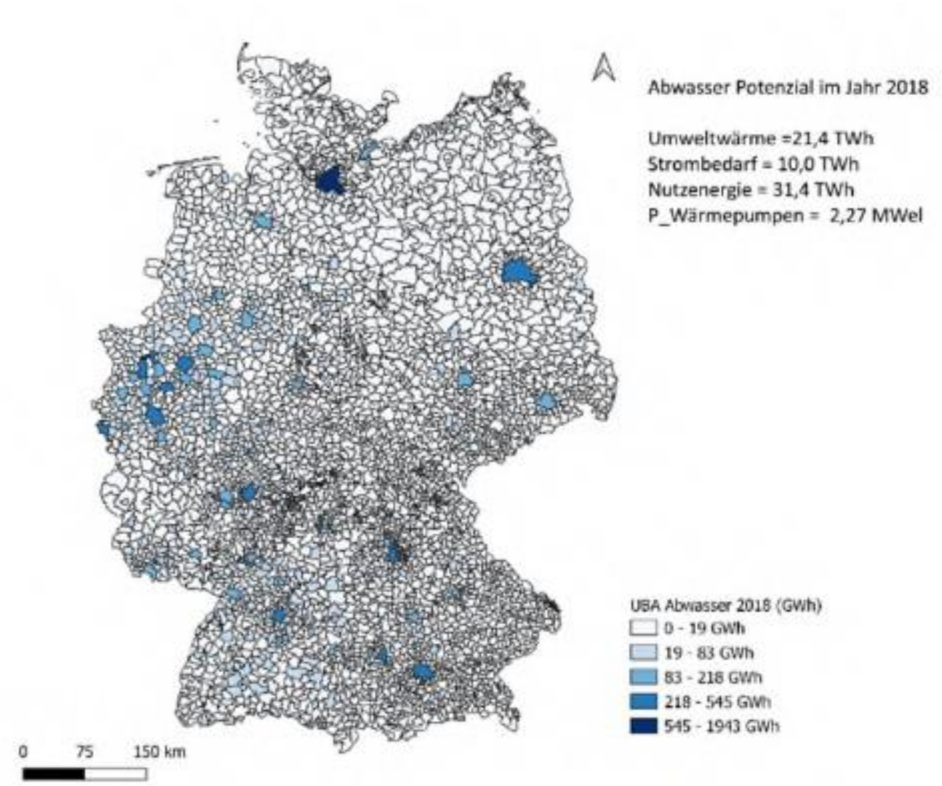
The formulas presented in Table 18 are used to calculate the technical potentials and installed capacities of the heat pumps required. It can be seen from the results in Figure 62 that the useful heat from waste water potentials in 2018 is around 31 TWh. With a capacity factor of 0.5 (based on 4,380 full load hours), the installed heat pump capacity required to exploit this is around 2.27 GW. The annual performance coefficient of the heat pump is calculated for supply and return temperatures of 80 °C/60 °C and waste water temperatures of 15 °C/11 °C. The Lorentz efficiency of the heat pump is set at 52% and is based on information on existing large-scale heat pumps in Helsinki, Finland (Foster et al., 2016).

Table 18: Basis for calculating technical potential

Symbol	**Description**	**Unit**	**Value/formulas**
$Q_{abwasser}$	Quantity of heat from waste water	GWh	$Q_{abwasser} = \dot{m} * Fr * Fz * c_p * \Delta T * 8760$
m	Quantity of waste water	[kg]	
Fr	Rainwater factor		0.74
Fz	Temporal availability factor		0.92
Cp	Specific heat capacity of water	[Wh/kg*K]	-
ΔT	Used waste water temperature difference	[K]	-
Q_{strom}	Quantity of heat from heat pump compressor	GWh	$Q_{strom} = Q_{abwasser}/(JAZ - 1)$
APC	Heat pump annual performance coefficient for: Supply/return temperatures of 80/60 °C Heat source (waste water) temperatures of 15/11 °C Heat pump Lorentz efficiency = 52%	-	3.15
Q_{nutz}	Useful heat	GWh	$Q_{nutz} = Q_{abwasser} + Q_{strom}$
$P_{verdichter}$	Installed electrical capacity of heat pump	GWel	$P_{verdichter} = Q_{verdichter}/t_{VBH}$

Symbol	Description	Unit	Value/formulas
t_{VBH}	Full load hours	[h/a]	4,380

The limitation of the model is that the assumptions on temporal availability and the rainwater factor from the ifeu report are applied on a constant basis. However, temporal availability and the rainwater factor can vary from one location to another and can therefore directly influence the potential useful energy that can be covered by energy from waste water. An additional limitation of the model is the assumption that all sewage treatment plants within a radius of 1 km of a region with a heating density of at least 15 GWh/km² can be connected to existing or new district heating networks.



Abwasser Potenzial im Jahr 2018	Waste water potential in 2018
Umweltwärme = 21,4 TWh	Ambient heat = 21.4 TWh
Strombedarf = 10,0 TWh	Electricity demand = 10.0 TWh
Nutzenergie = 31,4 TWh	Useful energy = 31.4 TWh
P_Wärmepumpen = 2,27 Mwel	P_heat pumps = 2.27 MWel
UBA Abwasser 2018 (GWh)	UBA waste water 2018 (GWh)

Source: Own figure (IREES)

Figure 63: Waste water potentials at municipality level for Germany in 2018 based on the volume of waste water at sewage treatment plants in 2018

III.5.h. Large-scale heat pumps

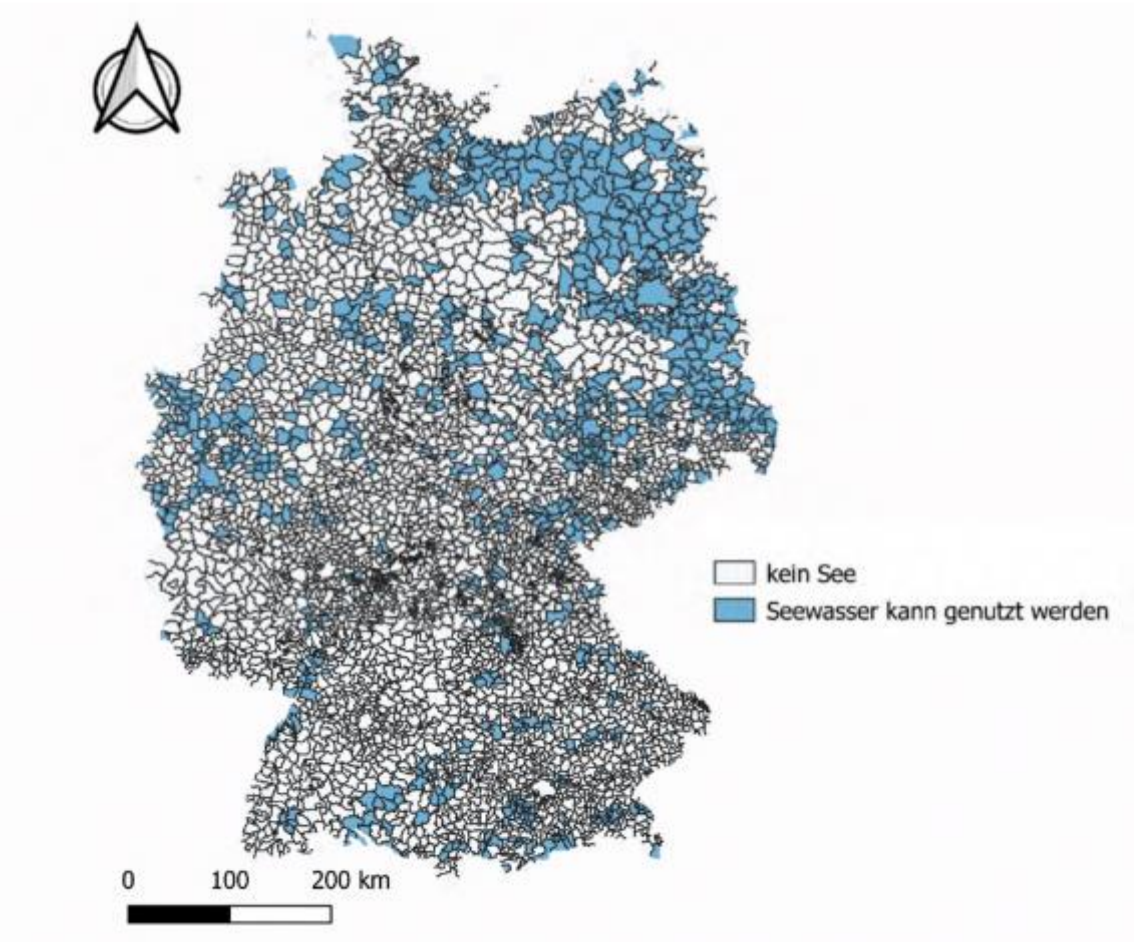
For the use of centralised large-scale heat pumps (river source heat pumps, lake source heat pumps, air/water heat pumps and brine/water heat pumps) local theoretical and technical potentials can only be presented to a limited extent, as there is still a lack of nationwide studies in this area.

In Gerhardt et al. (2019) the potential of river source heat pumps up to 2030 was analysed for Germany's four biggest rivers (Rhine, Weser, Elbe and Danube) and their tributaries. The theoretical potential and possible heat sinks at a distance of 1, 2 and 3 km from the rivers and tributaries were determined on the basis of long-term averages for drainage volumes and temperatures. For 2030 a potential of 50 TWh was reported with a COP of 2.2.

The aforementioned source also determined the potential for heat pumps in lakes in a similar way to that used to identify the potentials of river source heat pumps. The heating demand of residents within a distance of 1 km was determined for all German lakes larger than 50 ha and supply and demand were compared. In this way it was possible to identify a potential of 28.5 TWh for 2030, taking electricity into account, with a COP of 2.65. To assess the use of river source heat pumps for the administrative districts of the municipal associations, municipalities were identified whose heating demand areas are within a 1 km radius of lakes with an area of 50 ha and above. This concerns 752 of the 4,764 municipal associations. The corresponding spatial distribution is shown in Figure 64.

To calculate the alternative scenarios, the total potential of 28.5 TWh is distributed evenly across all municipalities. This results in a potential of 13 MW per municipality.

The potential of centralised air source heat pumps and brine/water heat pumps that use near-surface geothermal energy is limited primarily by their integration into heating networks, as the technical supply potential is not actually subject to any restrictions. Space restrictions or local requirements relating to noise emissions and other aspects are left out of consideration here, as there is no robust source available relating to nationwide potentials.



kein See	no lake
Seewasser kann genutzt werden	lake water can be used

Source: Own figure (ifeu) based on Gerhardt et al. (2019)

Figure 64: Presentation of municipal associations according to whether there is usable lake water within 1 km of the heating demand areas

III.5.i. Determination of district heating potentials

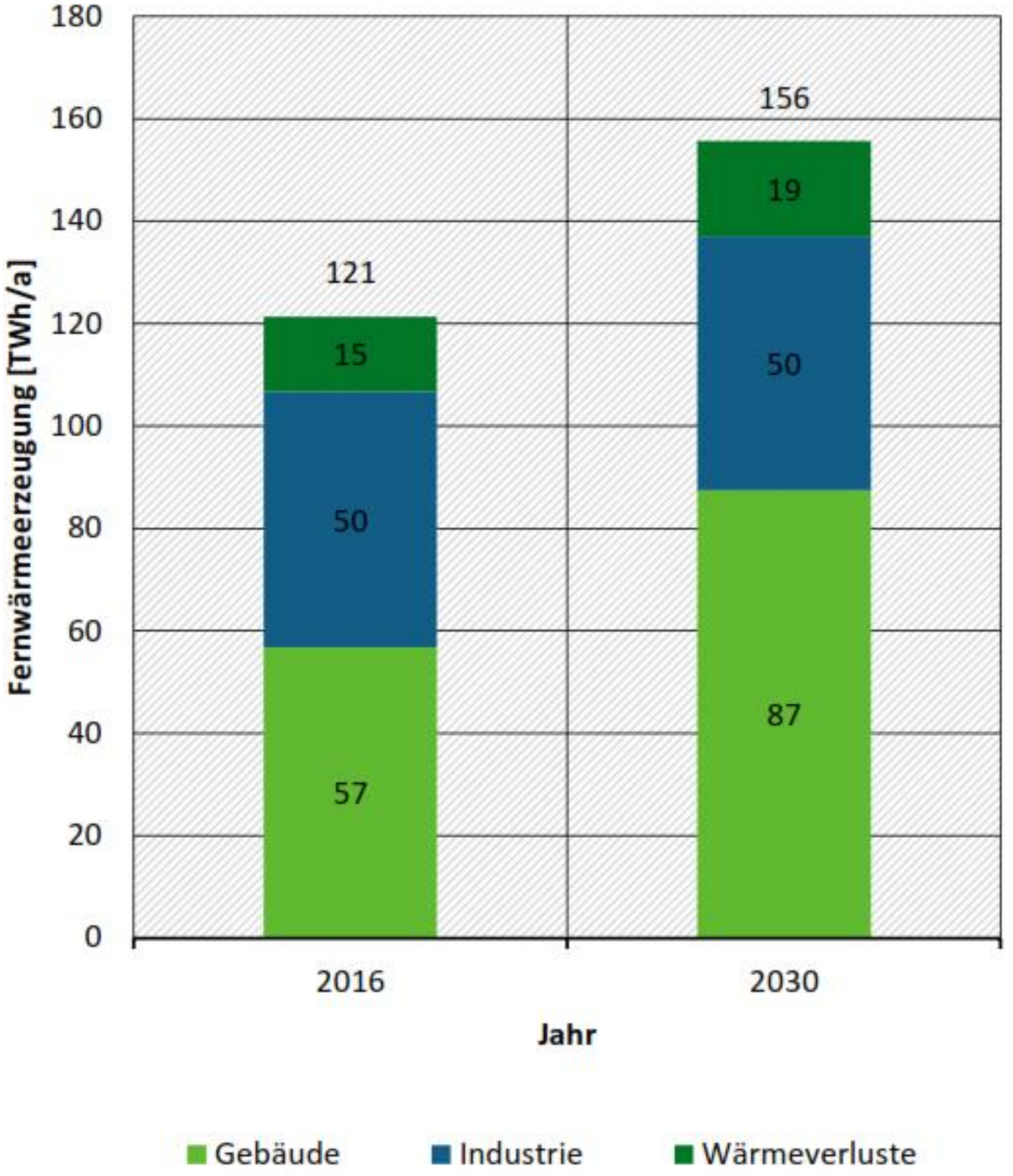
District heating potentials are determined on the basis of the heating density of the individual municipalities (see also III.3.c). The share of each municipality with a heating density of at least 15 GWh/km^2 is categorised as potentially suitable for supply via district heating and the heating demand in the corresponding heating density classes is added together. Assuming a connection rate of 100% in suitable areas, this results, on the basis of the spatially disaggregated baseline scenario, in a theoretical district heating potential of 466 TWh/a in 2030 for buildings, which comprises the space heating and hot water demand in both residential and non-residential buildings (TCS including industrial buildings). On top of this there is district heating consumption in industry for process heating, which stood at around 50 TWh/a in 2016 and is assumed to be constant. In total, the theoretical district heating potential is therefore roughly 516 TWh/a. The share of heating demand that is theoretically suitable to be met via the district heating supply, based on the heating density, thus corresponds to around 47% of the total heating consumption in 2030.

To derive a realistic demand potential in 2030, the following assumptions are made regarding the district heating connection rate, in addition to the heating density:

- Buildings: expansion and new construction of district heating in areas with a heating density of at least 15 GWh/km^2;
- In municipalities with existing district heating: 50% increase in connection rate (max. 100% per municipality);
- Municipalities without district heating: new connection of approx. 100 municipalities that account for the lion's share of heating demand and have a heating density of at least 15 GWh/km^2, connection with a 15% district heating share in 2030;
- Industry and TCS: coverage of 12% of the total process heating demand via district heating (constant up to 2030) (Kemmler et al., 2020);
- 12% heat losses (AGFW, 2019).

A specific district heating demand and a heat load are therefore calculated for each municipality for 2030. These underlie the assessment of the alternative scenarios. In addition to heating density, when it comes to determining suitability for district heating minimum absolute heating sales per municipality of 1 GWh and minimum capacities per technology are also taken into account.

For 2030 this results in a demand potential of 137 TWh/a for district heating. The potential for district heating generation plus heat losses is therefore 156 TWh/a. Overall, on the basis of the assumptions made, it is assumed that in 2030 around 1,640 municipalities will be connected to a district or local heating network and these are incorporated into the analysis of the central scenarios.



Fernwärmeerzeugung [TWh/a]	District heating generation [TWh/a]
Jahr	Year
Gebäude	Buildings
Industrie	Industry
Wärmeverluste	Heat losses

Source: Own figure (Prognos)

Figure 65: Development of district heating generation by 2030

III.5.j. Determination of district heating distribution costs

The costs of the district heating distribution network are determined based on the approaches of Persson & Werner (2011) and Persson et al. (2019). In Persson & Werner (2011) the distribution costs C_d [€/GJ] are identified as a significant cost component of the overall costs of district heating and indicated as a function of the plot ratio e. The plot ratio expresses the ratio of the building floor area to the land area. The costs can be placed within the following relationship, where α corresponds to the annuity factor, C_1 and C_2 are two cost components in €/m or €/m^2, the diameter needed for distribution d_a has a logarithmic relationship to building density, q is the specific heating demand [GJ/m^{2}a] and *w* is a function of building density [m]:

$$C_d = \frac{\alpha * (C_1 + C_2 * d_a)}{e * q * w}$$

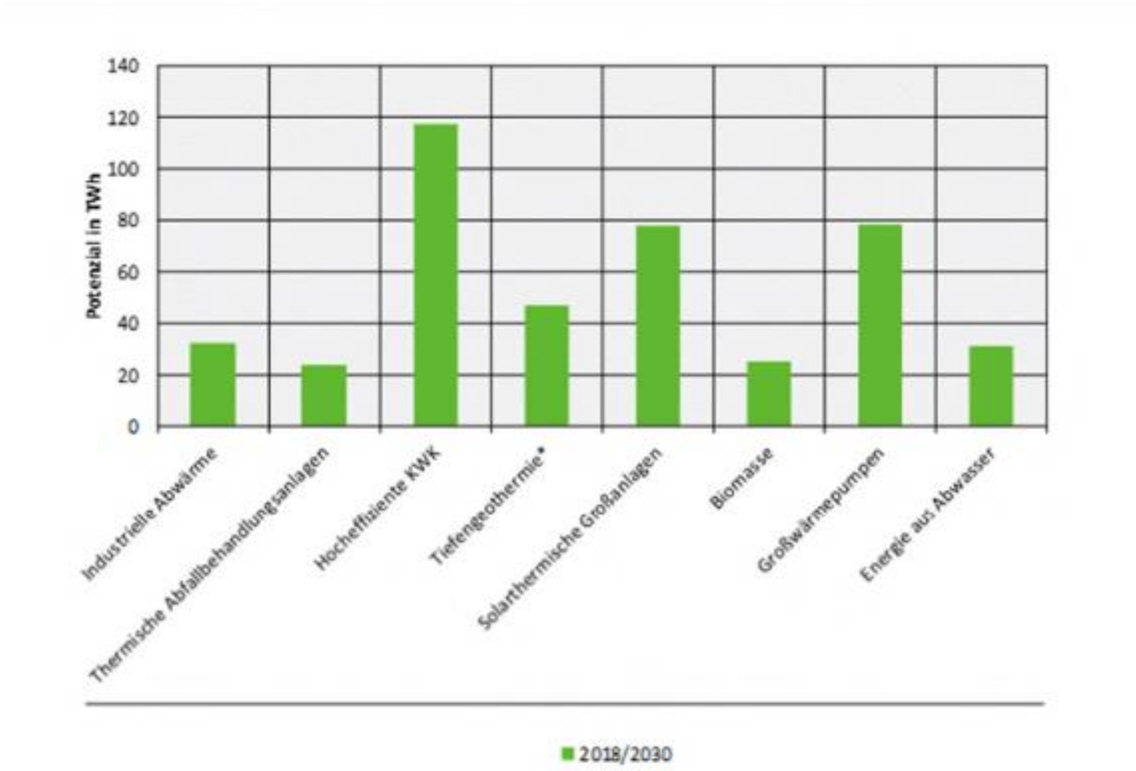
In accordance with the analyses in Persson et al. (2019), costs of €212/m are assumed for C_1 and costs of €4,464/m^2 for C_2.

In keeping with the framework parameters for the economic analysis, an interest rate of 5.5% is assumed and the costs are calculated for an underlying depreciation period of 20 years. Taking the heat atlas at individual building level into account, the building density for all 100 m x 100 m grid cells and the specific heating demand per hectare for 2018 and 2030 can be calculated and presented as an average for each municipality. The distribution costs determined vary depending on building density between €9.7/MWh and €40.3/MWh in 2018 and between €11.1/MWh and €40.7/MWh in 2030. These results are incorporated into the assessment of supply options on a municipality-specific basis.

III.5.k. Summary of technical potentials determined

The technical potentials on which the economic analysis of efficiency in heating and cooling is based are shown in Figure 66 for 2030. The technical potentials of the individual energy sources/technologies range from 25 TWh for biomass to 117 TWh for high-efficiency CHP. In the case of deep geothermal energy the technical potentials relate to the capacity and are not based on any full load hours.

In total, the technical potentials amount to roughly 385 TWh. It is important to bear in mind that there may be some geographical overlap between the individual potentials. Within the framework of the analysis of the economic potential for efficiency in heating and cooling, the extent to which this restricts the economic potentials is analysed in Section III.6 on the basis of the alternative scenarios, specifying a required share of renewable energies.



*… Potential in GW

Potenzial in TWh	Potential in TWh
Industrielle Abwärme	Industrial waste heat
Thermische Abfallbehandlungsanlagen	Thermal waste treatment plants
Hocheffiziente KWK	High-efficiency CHP
Tiefengeothermie*	Deep geothermal*
Solarthermische Großanlagen	Large-scale solar thermal installations
Biomasse	Biomass
Großwärmepumpen	Large-scale heat pumps
Energie aus Abwasser	Energy from waste water

Source: Own figure (ifeu) based on previous analyses

Figure 66: Summary of technical potentials determined

III.6. Development of alternative scenarios

III.6.a. Approach

The Directive and Part III(8)(iii) of Annex VIII require the development of alternative scenarios to the baseline that take into account energy efficiency and renewable energy objectives of Regulation (EU) 2018/1999. The alternative scenarios for analysing the grid-based heating supply consist of various technological systems (combinations of technologies) within system boundaries (heating density of more than 15 GWh/km^2) in the local geographical units considered (municipal associations). Each of these combinations (alternative scenarios) is assessed from an economic and ecological perspective and subsequently compared with the baseline scenario. An example of the approach is presented in Table 19.

First of all, the share of the heating demand of each municipal association that is suitable to be met via the grid-based heating supply is determined, based on the analysis of heating density. Taking the local potentials for renewable energies and waste heat and their required share in the centralised heating supply in 2030 into account, the economic potentials of the grid-based heating supply are determined. To this end, various technological systems are analysed for each municipal association (alternative scenarios) and the optimum alternative scenario with regard to heat generation costs is selected (see Sections III.6.b.i, III.6.b.ii).

In the analysis of decentralised supply options the costs of different applications (primarily different uses and efficiency levels) are compared. A geographical examination is not performed in this case, as the specific location has less of an influence on the use of the different technological options (see Sections III.6.b.iv to III.6.b.vi). The centralised supply of cooling is examined in a separate section (see Section III.6.b.v).

The various alternative scenarios are assessed in relation to costs and greenhouse gas emissions and/or primary energy savings. The optimum composition of the alternative scenarios for the grid-based heating supply is incorporated into the subsequent cost-benefit and sensitivity analyses.

Table 19: Approach for development of alternative scenarios

	Technological system according to ranking 1	**Technological system according to ranking 2**	**Technological system according to ranking 3**	
Municipality 1	Alternative scenario 1	Alternative scenario 2	Alternative scenario 3	
Municipality 2	Alternative scenario 4	Alternative scenario 5	Alternative scenario 6	
…				

III.6.a.i.Approach for determination of alternative scenarios in 2030

The assessment of the alternative scenarios is based on the district heating demand and renewable heat potentials for 2030, which are available at individual municipality level (see also Sections III.3.c and III.5).

To analyse the possible heating supply of the municipalities, a method based on the monthly heating energy balance method (*Monatsbilanzverfahren*) in accordance with DIN V 4108-6 is used. This method is able to illustrate seasonal fluctuations in heating demand and in the supply of renewable heat sources and waste heat and requires only moderate computing capacities. A finer temporal resolution (weeks, days, hours) with a higher degree of precision would make sense if more detailed input data were available for each municipality (e.g. actual heat load profile, structure of heating demand, highly precise data on potentials collected using an entirely bottom-up approach). The following steps are carried out for each municipality to assess the supply options:

1. Determination of district heating potential;
2. Determination of geographically confined renewable heat and waste heat potentials;
3. Specification of the share of renewable energies and waste heat in district heating generation;
4. Definition of monthly district heating demand;
5. Determination of maximum monthly heat generation of the technologies;
6. Definition of sequences for determining the technological systems (six variants);
7. Determination of heat generation and capacity for each technology;
8. Economic and ecological assessment of alternative scenarios and selection of preferred supply option for each municipality

The calculations are performed for different technological systems for each municipality (based on different targets regarding the share of renewable energies and waste heat). In the final step an optimum technological system (combination of technologies) can be selected for each municipality.

Determination of district heating potential

The district heating potential for 2030 is determined for each municipality as described in Section III.5.i.

Determination of geographically confined renewable heat potentials

Information on technical supply potentials is available for each municipality. These are explained in Section III.5.

It should also be noted that the following assumptions are made with regard to the usable share of the potentials in district heating:

- Industrial waste heat: use of potential from 75 °C, taking the specific full load hours for each municipality into account;
- Deep geothermal: use of potential from a reinjection temperature of 65 °C, meaning that it can be used directly in 90 °C networks;
- In the area of electric boilers there is potential in the northern federal states with a surplus of renewable electricity (Schleswig-Holstein, Mecklenburg-Western

Pomerania, Lower Saxony and Brandenburg), representing 10% of the required heat load of the municipalities;

- Assumed minimum capacity for renewable heat generators and waste heat for integration into heating networks, see Table 13.
- Heat pumps: locally confined heat sources that can be exploited for district heating via a heat pump are designated as ‘waste heat HP’. Waste heat from sewage treatment plants, surface waters and industrial waste heat between 35 °C and 75 °C is taken into account.
- ‘Air source HP’ is used to designate heat pumps whose use is not significantly restricted by local conditions and that can be used flexibly (primarily air source heat pumps, but also heat pumps for the utilisation of near-surface geothermal and low-temperature deep geothermal energy).

Specification of the share of renewable energies and waste heat in district heating generation

Before heat generation in the municipalities is analysed, a share of renewable energies and waste heat in district heating is specified. This value is based on the baseline scenario; a target of a 40% share of renewable energies and waste heat in district heating is derived for district heating generation in 2030. The alternative scenarios therefore take into account the national and European energy efficiency and renewable energy objectives (Regulation (EU) 2018/1999). Within the framework of the assessments, use of waste heat and cold is presented below as renewable energy, in line with the baseline scenario. Following the approach used for the NECP, the use of waste heat from waste incineration plants is therefore also allocated entirely to the renewable share.

The following approaches could be envisaged to achieve a 40% share of renewable energies in district heating:

a) Fixed allocation: specification of a 40% share of renewable energies and waste heat for all municipalities.
b) Dynamic allocation: specification of a variable share depending on locally available potentials, with the aim of achieving a 40% share in total for Germany as a whole. The share of renewable energies may therefore be significantly higher than 40% in some municipalities and significantly lower in others (cf. Table 20). A sensible criterion for deriving the RE share is the capacity of the non-fluctuating, locally available potentials compared with the required heat output. Waste incineration plants, geothermal energy and waste heat from industry, sewage treatment plants and surface waters are categorised as non-fluctuating, locally confined technologies. The potentials for biomass and heat pumps that can be used independently of location (air source heat pumps and heat pumps for the utilisation of near-surface geothermal energy) are not locally confined and are therefore not included in the specified figure. Potentials for solar thermal energy and electric boilers, as fluctuating technologies, have also not been included.

The results of the model runs during a preliminary analysis showed that heat generation costs under the dynamic variant are only marginally higher than under the variant with a fixed target for renewable energies and waste heat. The differences in terms of

GHG emissions and PE factors are negligible. Nevertheless, the following significant aspects can be highlighted under the dynamic variant:

- The locally available potentials are exploited more efficiently at municipality level, squeezing the share of biomass. Compared with the fixed variant, savings of approx. 10 TWh are achieved in the supply of heating from biomass.
- Just under a third of all municipalities are able to supply more than 40% renewable heat, and in some cases substantially more (see Table 20). In 316 municipalities the potentials significantly exceed demand – these municipalities can cover 100% of their district heating demand from locally available, non-fluctuating renewable energy. In these cases neither biomass, nor location-independent heat pumps or fossil fuels are required. Making sure these potentials are optimally exploited in 2030 is therefore particularly advantageous with a view to avoiding lock-in effects by 2050.
- From the results of the dynamic variant it is possible to obtain more meaningful insights, which are examined in detail during the cost-benefit analysis.

In view of the aspects listed above, only the dynamic variant is dealt with below. This variant is optimised and analysed in detail.

Table 20: Specification of the share of renewable energies in district heating generation under the dynamic variant and number of municipalities out of a total of 1,640

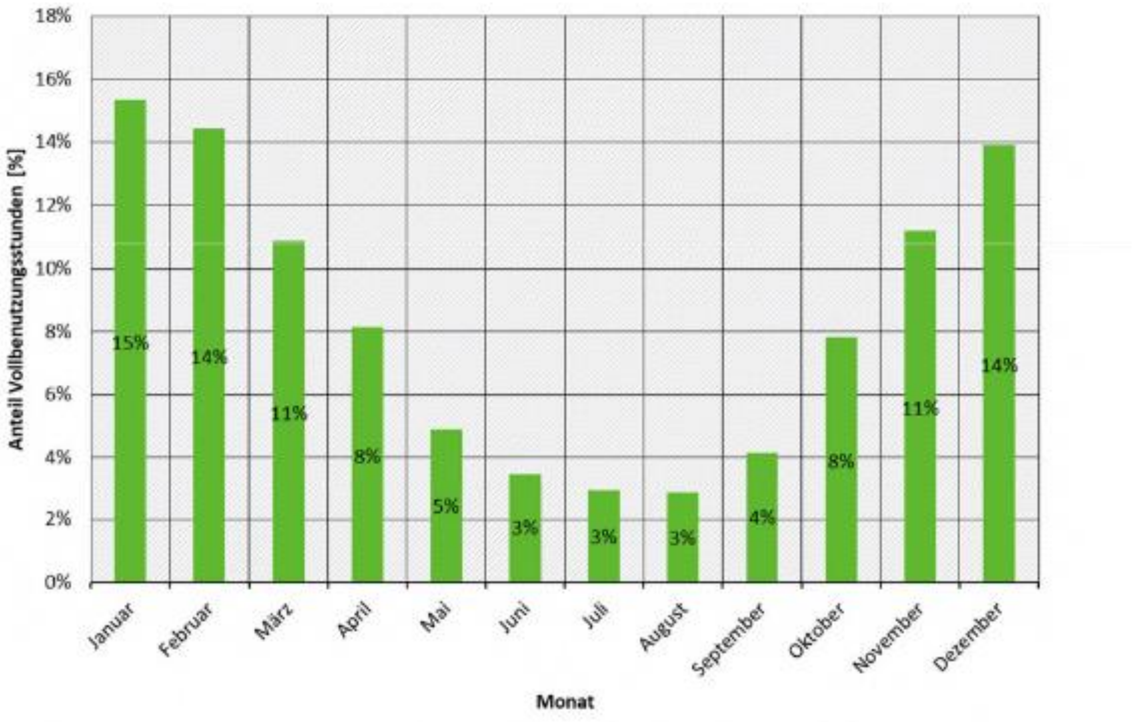
Quotient of the capacity of the non-fluctuating, locally available potentials and the heat load	**Specification of the share of renewable energies**	**Frequency**
> 0.00	20%	833
> 0.10	25%	97
> 0.20	30%	147
> 0.40	40%	107
> 0.60	60%	78
> 0.80	80%	62
> 1.00	100%	316

The remaining 60% share in district heating is covered by fossil-based heat generation technologies. Both CHP installations and boilers can be used for this. The thermal capacity of the CHP installations is set at 30% of the maximum demand of the network in question. A boiler is also used to cover peaks in demand.

For the period up to 2050 a model run with a specified renewable heat share of 100% is also calculated for all networks, in addition to the two 40% variants.

Definition of monthly district heating demand

For the purposes of the monthly heating energy balance method, the heating demand of a municipality, which is available as an annual value, is divided up into monthly values. The heating demand in buildings (residential buildings and non-residential buildings (TCS)) and the process heating demand (TCS and industry) are taken into account and the load profile of a large district heating network is taken as a basis (cf. Figure 67). Compared with the load profile of a residential building, and with around 2,900 full load hours and a summer load, this also incorporates the heating demand from process heating.



Anteil Vollbenutzungsstunden [%]	Share of full load hours [%]
Monat	Month
Januar	January
Februar	February
März	March
April	April
Mai	May
Juni	June
Juli	July
August	August
September	September
Oktober	October
November	November
Dezember	December

Source: Own figure (Prognos)

Figure 67: Load profile of district heating

Determination of maximum monthly heat generation of the technologies

In the next step the coverage of monthly heating demand by the available renewable heat and waste heat potentials is examined. The thermal capacity of the respective heating technologies and the maximum achievable number of operating hours in the month in question are used as input data. For most technologies continuous availability, less maintenance and repair times, is assumed, resulting in an availability of 85% (corresponding to 625 hours per month or 7,500 hours per year). In the case of solar thermal a maximum of 1,100 full load hours a year is assumed, which predominantly fall in the summer months (Table 21, based on the survey of potential in III.5.e). If seasonal storage is used, some of the availability is shifted into autumn. The charging and discharging of the store are taken into account on the basis of finely resolved weather data, allowing the annual distribution of heat generation to be determined. For the electric boiler the annual full load hours are set at a maximum of 500 hours without seasonal fluctuations.

The product of the available thermal capacity of the respective heating technologies and the maximum achievable number of operating hours in the month in question results in the maximum possible heat generation of the technology concerned in each month.

Table 21: Maximum available monthly full load hours by technology

	Solar thermal	**Solar thermal with seasonal storage**	**Electric boiler**	**All others**
January	20	21	42	625
February	45	46	42	625
March	93	95	42	625
April	111	109	42	625
May	160	138	42	625
June	143	105	42	625
July	143	93	42	625
August	145	86	42	625
September	118	139	42	625
October	69	214	42	625
November	35	36	42	625
December	17	17	42	625
Total	**1,100**	**1,100**	**500**	**7,500**

Source: Own figure (Prognos)

In addition, the share of solar thermal is capped at a maximum of 15% of the municipality's annual heating demand, as it is assumed that daily storage is sufficient up to this share. Solar thermal with seasonal storage is used if the solar thermal potential of the municipality in question is particularly high and exceeds 60% of the maximum demand. In this case the combination with solar storage can cover up to 30% of the annual heating demand. The electric boiler is capped at 5% of the annual quantity of heat.

Definition of sequence of technologies for determining technological systems (six variants)

Which of the available potentials are used to what extent in a municipality depends on the sequence in which or priority with which the individual technologies are employed. The technology placed in first position is exploited as a priority. If additional quantities of RE or waste heat are needed to meet the target, the technologies ranked next in the list are used until the heating demand for a month is covered in full. As technologies that are higher up the list are prioritised, a different technological system results for each sequence. This effect is explained in the following section using a sample municipality (Figure 68 and Figure 69).

Overall, six rankings are examined, which are presented in Table 22. Common to all rankings is the fact that the locally confined potentials (waste incineration plants, solar thermal, geothermal, industrial waste heat and waste heat HP[39]) are used first. Heat pumps that use ambient air or near-surface geothermal energy as a heat source and biomass are not locally confined and are therefore used with lower priority, if the other renewable heat and waste heat potentials are insufficient to achieve the desired targets.

In principle, waste incineration plants are assumed to have a relatively high position, as the heat from these plants is available in any case at a high temperature level and would otherwise have to be emitted unused into the environment. Solar thermal is also prioritised in most rankings, as it could otherwise be squeezed out by other technologies, in particular over the summer months, when solar irradiation is highest and district heating demand is lowest. Heat sources that have to be utilised via a heat pump tend to be ranked lower than those that can be used directly.

Table 22: Ranking of technologies in variants 1 to 6

Ranking 1	Ranking 2	Ranking 3	Ranking 4	Ranking 5	Ranking 6
WIP	WIP	Solar thermal	WIP	WIP	Geothermal
Solar thermal	Industrial waste heat	Solar thermal with seasonal storage	Geothermal	Industrial waste heat	Solar thermal

[39] Locally confined heat sources that can be exploited for district heating via a heat pump are designated as 'waste heat HP'. Waste heat from sewage treatment plants, surface waters and industrial waste heat between 35 °C and 75 °C is taken into account. 'Air source HP' is used to designate heat pumps whose use is not significantly restricted by local conditions and that can be used more flexibly (air source heat pumps and heat pumps for the utilisation of near-surface geothermal and low-temperature deep geothermal energy).

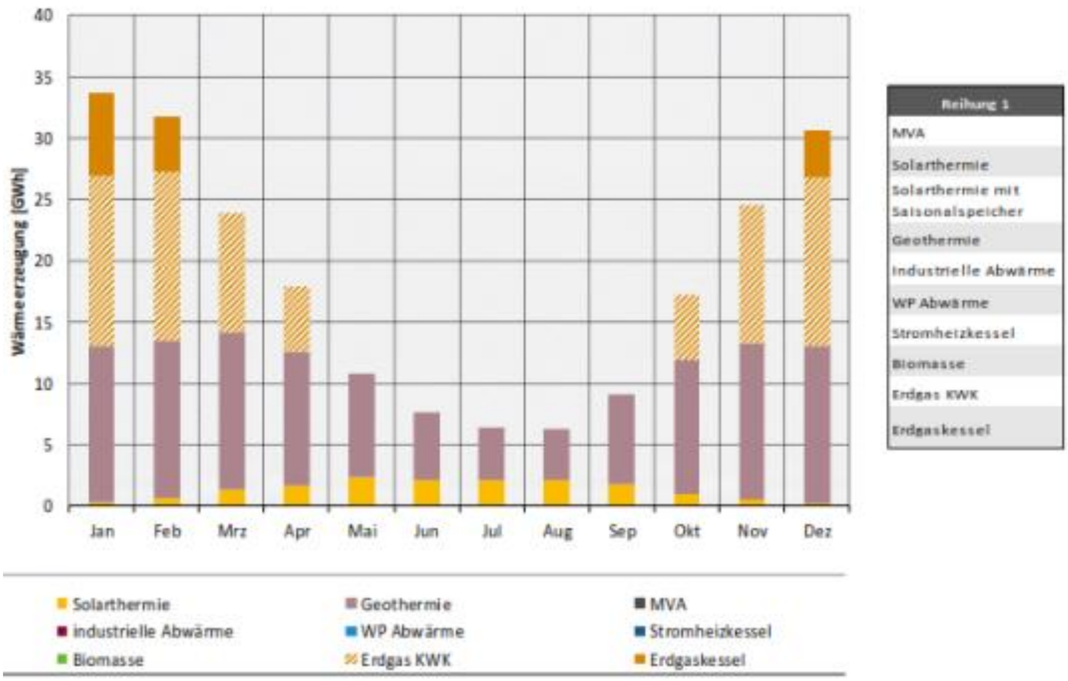
Ranking 1	Ranking 2	Ranking 3	Ranking 4	Ranking 5	Ranking 6
Solar thermal with seasonal storage	Waste heat HP	WIP	Solar thermal	Waste heat HP	Solar thermal with seasonal storage
Geothermal	Solar thermal	Geothermal	Solar thermal with seasonal storage	Geothermal	WIP
Industrial waste heat	Solar thermal with seasonal storage	Industrial waste heat	Industrial waste heat	Solar thermal	Industrial waste heat
Waste heat HP	Geothermal	Waste heat HP	Waste heat HP	Solar thermal with seasonal storage	Waste heat HP
Electric boiler	Electric boiler	Electric boiler	Electric boiler	Electric boiler	Electric boiler
Biomass and HP	Biomass and HP	Biomass and HP	Biomass and HP	Biomass and HP	Biomass and HP
Natural gas CHP	Natural gas CHP	Natural gas CHP	Natural gas CHP	Natural gas CHP	Natural gas CHP
Gas-fired boiler	Gas-fired boiler	Gas-fired boiler	Gas-fired boiler	Gas-fired boiler	Gas-fired boiler

Source: Own figure (Prognos)

Determination of heat generation and capacity for each technology

As described above, the coverage of monthly heating demand is determined on the basis of the sequence of the technologies and the specified RE and waste heat share.

This results in a month-by-month heat generator balance for each municipality. Figure 68 shows this for a sample municipality with a specified RE and waste heat share of 60% for ranking 1. This municipality has no potentials resulting from waste incineration plants, which is why solar thermal potentials (yellow) are prioritised in accordance with ranking 1. These are followed by geothermal energy (violet). Its potentials exceed those needed to cover 60% of the required quantity of heat, which is why during transitional seasons and in summer this technology is only used to a limited extent. Fossil-based CHP is allocated 30% of the heat load and covers a further significant share of heating demand during transitional seasons and in winter in particular. Over the winter months the boiler is needed to ensure heating demand is covered in full.



Wärmeerzeugung [GWh]	Heat generation [GWh]
Mrz	Mar
Mai	May
Okt	Oct
Dez	Dec
Reihung 1	Ranking 1
MVA	WIP
Solarthermie	Solar thermal
Solarthermie mit Saisonalspeicher	Solar thermal with seasonal storage
Geothermie	Geothermal
Industrielle Abwärme	Industrial waste heat
WP Abwärme	Waste heat HP
Stromheizkessel	Electric boiler
Biomasse	Biomass
Erdgas KWK	Natural gas CHP
Erdgaskessel	Gas-fired boiler

Source: Own figure (Prognos)

Figure 68: Monthly heat generation structure of a sample municipality with an RE and waste heat share of 60%, ranking 1, and the resulting technological system

The potentials and resulting exploitation by technology for the same sample municipality (renewable heat and waste heat share of 60%, ranking 1) are shown in Table 23.

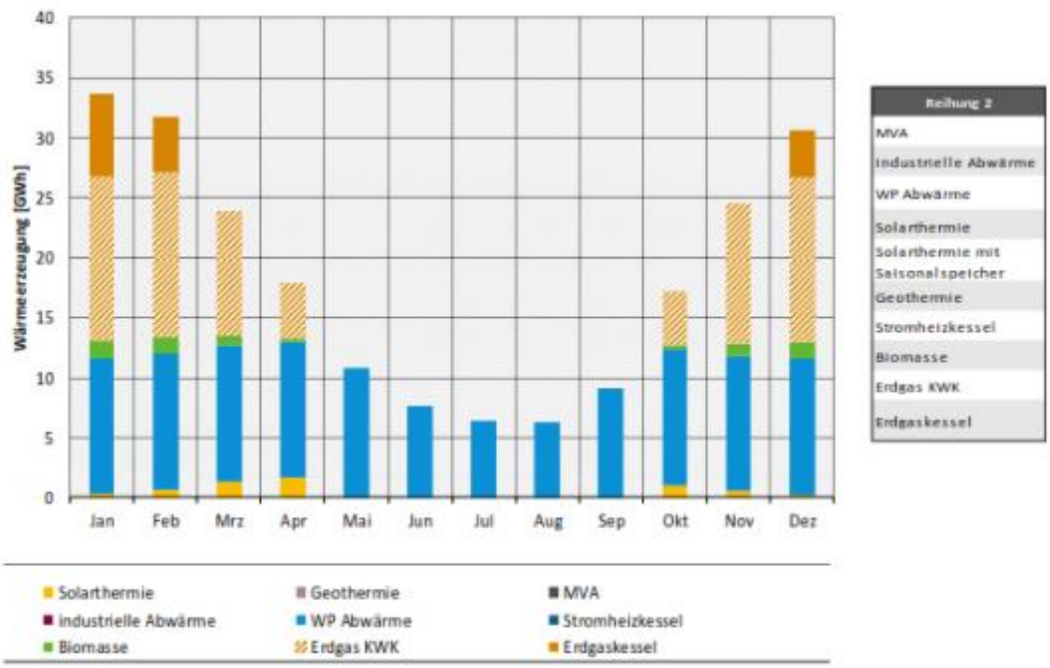
The sample municipality has the following potentials: 15 MW for solar thermal, 30 MW for geothermal and 18 MW each for waste heat HP and electric boilers. In total, the available potential exceeds the heat load of 67 MW to be covered via district heating. The total capacity of non-fluctuating potentials (geothermal and waste heat HP) is 48 MW (quotient of capacity and heat load: 72%) and the municipality is therefore allocated an RE target of 60%. In this municipality significantly more than 40% of the heating demand can thus be met using renewable energies.

The maximum capacity per technology represents the thermal capacity to be installed for each technology. The quotient of the annual quantity of heat and the thermal capacity results in the annual full load hours of the installations in each municipality. The coverage rate results from the quotient of heat generation per technology and the total district heating demand. These values are used to determine the heat generation costs, for the cost-benefit analysis in Section III.7 below and to assess the exploitation of locally confined renewable heat potentials.

Table 23: Annual heat potential values and the actual heat generation structure for a sample municipality with an RE and waste heat share limited to 60%, ranking 1

Variant 1	**Potential**		**Utilisation**			**Coverage rate**
	MW	**FLH**	**MW**	**FLH**	**GWh**	
WIP						0%
Solar thermal	15	1,100	15	16	1,100	7%
Geothermal	30	7,500	20	116	5,649	53%
Industrial waste heat						0%
Waste heat heat pump	18	7,500				0%
Air source heat pump						0%
Electric boiler	18	500				0%
Biomass-fired boiler						0%
CHP		7,500	22	73	3,305	33%
Boiler		7,500	11	15	1,381	7%
Total	**81**	**24,100**	**68**	**220**	**11,434**	**100%**

Depending on the sequence of the technologies, a different technological system applies for the municipality. Figure 69 below shows the monthly heat generation values in the case of an RE and waste heat share of 60% for the same sample municipality in accordance with ranking 2. Due to the change in the sequence of the technologies, the waste heat heat pump is now prioritised. In this ranking solar thermal is lower down and in summer is therefore squeezed out by the waste water heat pump. The shortage in the heat needed to achieve the target for renewable energies and waste heat is covered by biomass. As geothermal is only employed from a minimum capacity of 10 MW, it is no longer used in this ranking.



Wärmeerzeugung [GWh]	Heat generation [GWh]
Mrz	Mar
Mai	May
Okt	Oct
Dez	Dec
Reihung 2	Ranking 2
MVA	WIP
Industrielle Abwärme	Industrial waste heat
WP Abwärme	Waste heat HP
Solarthermie	Solar thermal
Solarthermie mit Saisonalspeicher	Solar thermal with seasonal storage
Geothermie	Geothermal
Stromheizkessel	Electric boiler
Biomasse	Biomass
Erdgas KWK	Natural gas CHP
Erdgaskessel	Gas-fired boiler

Source: Own figure (Prognos)

Figure 69: Monthly heat generation structure of a sample municipality with an RE and waste heat share of 60%, ranking 2, and the resulting technological system

The figures make clear that a different technological system results for each municipality depending on the ranking. Consequently, for the municipality in question either technological system 1, combining the solar thermal, geothermal and fossil technologies, or technological system 2, comprising solar thermal, waste heat HP, biomass and fossil technologies, can be used.

A total of 1,640 municipalities are examined with the grid-based heating supply in mind and, overall, six variants are calculated in each case for the different rankings. This results in a total of 9,840 alternative scenarios that are calculated and subsequently compared as part of this analysis.

Economic and ecological assessment of the alternative scenarios

For the economic assessment of the alternative scenarios the heat generation costs are determined at individual municipality level. The following results from the technical assessment for each municipality and technology are taken as a basis here: the quantity of heat to be generated, the thermal capacity to be installed and the resulting full load hours. Building on this, the heat generation costs can be calculated on the basis of the following cost components:

- Investment costs for the installations
- Costs of the connection pipeline
- Fixed and variable operating costs
- Fuel costs
- District heating distribution costs

The investment and operating costs and the efficiencies are based on the framework data presented in Section III.4.a and on the technology profiles (cf. Annex V). The energy prices and interest rates underlying the analysis are also shown in the annex in Section IV.

Existing support mechanisms, such as the KWKG, are taken into account indirectly, in line with the procedure in the NECP.

In the case of investment costs for installations and connection pipelines the net present value is calculated in relation to 2030 and an interest rate of 5.5%. A depreciation period of 20 years is assumed. No reinvestments or residual values of installations are taken into account.

In addition to the economic assessment, the GHG emissions resulting from heat generation and the associated primary energy demand are calculated for each municipality on the basis of the emission factors presented in Section III.4.a. The results are used as input data for the cost-benefit analysis. The preferred technological systems for each municipality are selected on the basis of the heat generation costs and this is described more precisely under Section III.6.b.i.

III.6.a.ii. Procedure for determining decentralised options

The baseline scenario was drawn up on the basis of sectoral energy models. These are bottom-up models that can provide a detailed illustration of the technologies and their use in the sectors. The four demand sectors of industry, trade, commerce and services (TCS), transport and private households were illustrated using simulation models and a pan-European electricity market model was also used[40].

In the area of heating and cooling the models are also used to determine, for the period up to 2050, which shares of heating and cooling demand are suitable to be met by the centralised supply and for which share decentralised technologies need to be used. Corresponding influencing factors (e.g. times when thermal renovations are carried out within the building stock or the possible boiler replacement rate depending on the policy framework) are taken explicitly into account.

As the corresponding expected price developments are also considered in the scenarios, the derived decentralised mix in the sectors can be used as the most economic variant under the applicable framework conditions.

In addition to the energy source mix under the baseline scenario, within the framework of the report various options for the efficient supply of heating for different supply cases (reference buildings) are examined and compared on the basis of the resulting heat generation costs. The following decentralised technologies are included, depending on their relevance for the supply case in question:

- Brine/water heat pump
- Air/water heat pump
- Wood pellet boiler
- Hybrid system with gas-fired condensing boiler and solar thermal flat-plate collector
- Natural gas cogeneration plant and peak-load boiler

The gas-fired condensing boiler (gas-fired CB) is used as a standard fossil-based technology for the ranking of cost-efficiency.

The calculation is performed for various supply cases. In the area of residential buildings these are a single-family house and an apartment block, in renovated and non-renovated condition in each case. The geometry and component U-values of the reference residential buildings are based on the building typology of the Institute for Housing and Environment (*Institut für Wohnen und Umwelt* (IWU)) (Loga et al., 2015). Here buildings in age class E (1958–1968) are used, which make up the largest proportion of the building stock (Statistisches Bundesamt, 2019).

For the services sector an office and a retail building are analysed, in renovated and non-renovated condition in each case. Their design is based on the non-residential model buildings for energy-related analyses, developed by the Fraunhofer Information Centre for Planning and Building (*Fraunhofer IRB)* and the Centre for Environmentally Conscious Building (*Zentrum für Umweltbewusstes Bauen*) (Klauß, 2010). The U-values are based on the study '*Typologie und Bestand beheizter Nichtwohngebäude in*

[40] Details can be found in Kemmler et al. (2020)

Deutschland' ('Typology and stock of heated non-residential buildings in Germany') (Dirich et al., 2011)[41]. An overview of the reference supply cases is shown in Table 24.

Table 24: Overview of reference supply cases

Reference buildings	**Useful/net floor area in accordance with GEG* [m²]**	**Building heat load[42] [kW]**	**Generator useful energy output for space heating and hot water[43] [KWh/a]**
SFH non-renovated	161	19	44,014
SFH renovated	161	8	23,045
AB non-renovated	3,327	224	567,207
AB renovated	3,327	104	262,833
Office building non-renovated	1,676	186	441,011
Office building renovated	1,676	137	228,359
Retail building non-renovated	2,243	182	546,015
Retail building renovated	2,243	152	425,126

*GEG: Building Energy Act; Source: Own figure

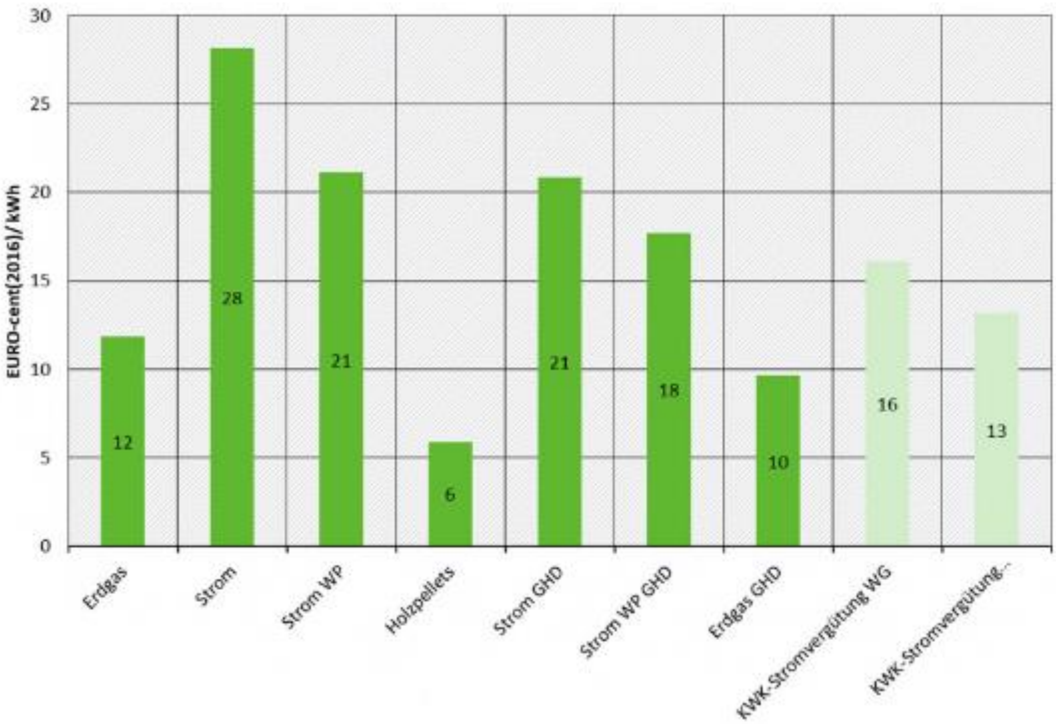
For the presentation of the techno-economic parameters of the decentralised supply options examined, please refer to the technology profiles in Annex V. As in the case of the alternative scenarios for the centralised supply of heating, to assess the decentralised technologies the energy prices from the baseline scenario are taken as a basis and the 2030 energy price is used for the cost calculation (cf. Section IV.1)[44]. Figure 70 makes clear that, under the assumptions made regarding the development of the carbon price within the national Emissions Trading Scheme and a proportionate feed-in of renewable gas (PtG), there is a significant increase in the price of natural gas, which has a major impact on the cost-efficiency of decentralised RE supply options. In addition to energy prices, the payment for generated CHP electricity that is assumed in the cost-efficiency calculation is also indicated. This is made up proportionately of electricity purchases avoided and the feed-in tariff.

[41] The useful and final energy demand for the reference buildings are calculated using the building simulation program ZUB-HELENA.

[42] Calculated in accordance with DIN EN 12831

[43] In accordance with DIN 18599 the generator useful energy output (Q out generator) is the useful energy including losses resulting from storage, distribution and transmission.

[44] In the cost-benefit analysis in Section III.7 the energy costs are discounted over the period from 2030 to 2050.



EURO-cent(2016)/kWh	euro cent (2016)/kWh
Erdgas	Natural gas
Strom	Electricity
Strom WP	Electricity HP
Holzpellets	Wood pellets
Strom GHD	Electricity TCS
Strom WP GHD	Electricity HP TCS
Erdgas GHD	Natural gas TCS
KWK-Stromvergütung WG	CHP electricity payment (residential)
KWK-Stromvergütung...	CHP electricity payment...

*Electricity and natural gas price development based on assumptions under the baseline scenario.

Own assumptions: heat pump tariff 25% discount on regular electricity price; development of wood pellet price in accordance with price projections from *Politikszenarien IX* (Policy scenarios IX) (Harthan et al., 2020); CHP electricity payment refers to the imputed specific income from decentralised CHP electricity generated, based on the assumption that between 56% and 58% is fed in and the remainder is factored into the relevant electricity purchasing costs as electricity purchases avoided. The CHP bonus (installations up to 50 kWel) for electricity for own consumption or electricity fed in of 4 cents/kWh and 8 cents/kWh respectively under the KWKG is taken into account.

Source: Own figure (IREES), price projection based on Kemmler et al. (2020)

Figure 70: Energy prices for residential buildings and the services sector (TCS) in 2030

Heating supply costs are calculated with and without support under the Market Incentive Programme[45]. However, as the figures are from a 2030 perspective, the bonus for the replacement of oil-fired boilers is not taken into account in the support.

Table 25: Current investment support under the Market Incentive Programme (MAP) for decentralised heating supply technologies

Reference technology	MAP support as a percentage of investment costs*
Reference system: gas-fired CB	-
Brine/water heat pump	35%
Air/water heat pump	35%
Wood pellet boiler	35%
Hybrid system with gas-fired CB and solar thermal flat-plate collector for hot water (small solar thermal)	
Hybrid system with gas-fired CB and solar thermal flat-plate collector to cover 25% of heat load (large solar thermal)	30%
Natural gas cogeneration plant	-
*** excluding bonus for replacement of oil-fired boilers CB = condensing boiler MAP = market incentive programme**	

Source: Own figure in accordance with BAnz AT 31.12.2019 B3 MAP support guidelines

III.6.b. Results

III.6.b.i. Centralised supply in 2030

Comparison of alternative scenarios for achievement of renewable energy and waste heat targets

For each of the 1,640 municipalities that qualify for the grid-based heating supply on the basis of heating density and heating sales, six different technological systems (combinations of technologies) are determined, resulting in a total of 9,840 alternative scenarios (cf. Section III.6.a.i). Table 26 shows the results of the alternative scenarios for the various technological systems in aggregated form across all the municipalities. An economic and ecological assessment is performed for the various alternative scenarios. The most cost-efficient technological system is selected for each municipality on the basis of the heat generation costs (cf. ‘AS optimised’ column). In the optimised variant, overall, the resulting average heat generation costs come to €62.8/MWh[46]. It is

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[45] In accordance with the guidelines on support for renewable energy measures in the heating market of 30.12.2019 (Federal Gazette (BAnz), official section (AT), 31.12.2019 B3)

[46] Energy-weighted and including distribution costs

noticeable that the aggregated alternative scenarios in accordance with ranking 1 are frequently the most cost-efficient. In 1,421 municipalities the heat generation costs are lowest here, compared with the other rankings. This is due to the fact that heat generation costs comprise both investments and operating, fuel, connection and distribution costs. The alternative scenarios in accordance with ranking 1 are most often the most cost-efficient variant in terms of the sum of operating and fuel costs for each municipality. This trend can be explained by the lower operating and fuel costs of thermal waste treatment plants, solar thermal and, to a lesser extent, geothermal systems (all three technologies are prioritised in ranking 1), compared with the waste heat HP (prioritised in ranking 2). Nevertheless, this finding does not apply to every municipality. In more than 200 municipalities the alternative scenarios in accordance with other rankings are used.

From an ecological perspective, there is only a very minimal difference between the average GHG factors and PE factors, which is to be expected given that the same 40% target for renewable energies and waste heat applies. The most favourable technological system is selected for each municipality, with the result that the optimum situation comprises a mix of technological systems.

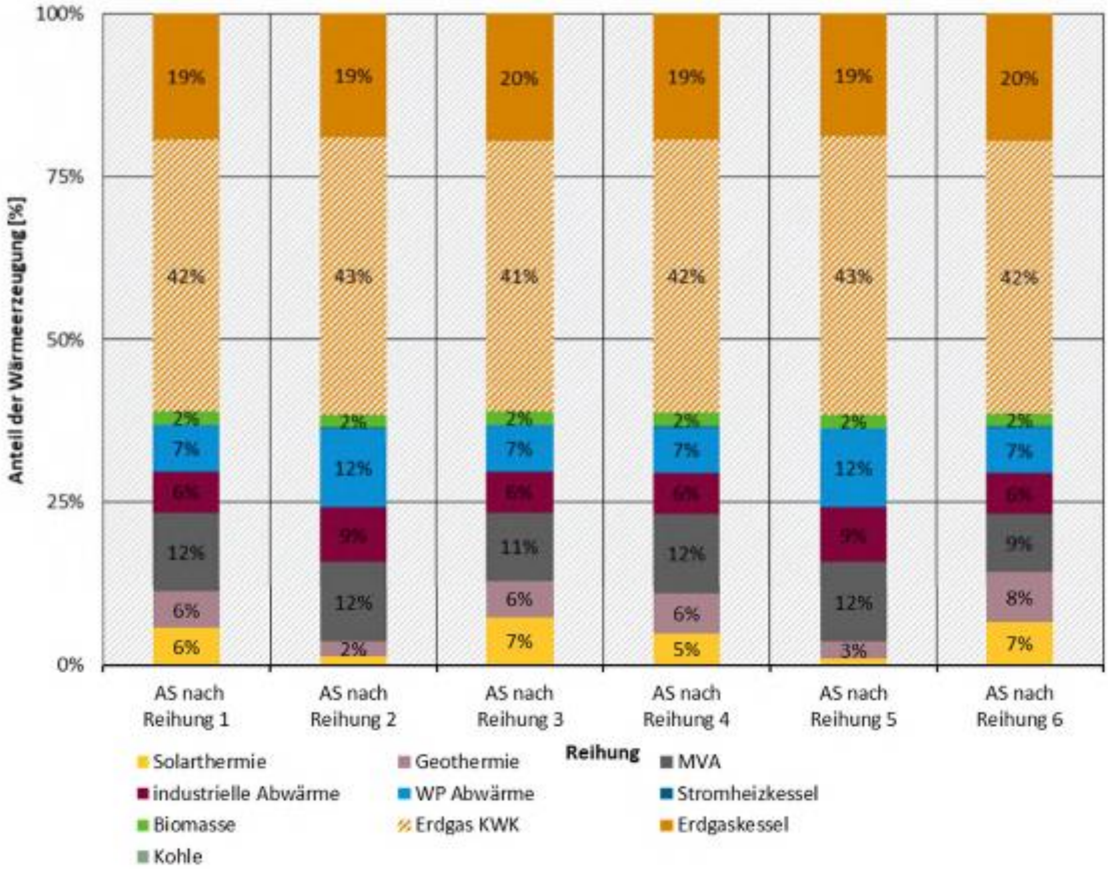
Table 26: Economic and ecological assessment of aggregated alternative scenarios (AS) in accordance with the various rankings (Rx)

Variable		AS optimised	AS in acc. with R1	AS in acc. with R2	AS in acc. with R3	AS in acc. with R4	AS in acc. with R5	AS in acc. with R6
Investment in installations	million euro	**12,021**	13,518	9,909	14,447	13,080	9,583	14,629
Heat generation costs / Most cost-efficient variant	Number of municipalities	**1,640**	1,421	159	31	15	6	8
Operation-related costs* / Most cost-efficient variant	Number of municipalities	**1,640**	1,577	1	48	1	1	12
GHG emissions	g/kWh	**138**	136	141	136	137	141	137
PE factor		**0.62**	0.62	0.63	0.61	0.62	0.63	0.62

*Operating costs and fuel costs

The technical results of the individual rankings are discussed in more detail below.

Figure 71 shows the composition of district heating generation in the six model runs performed. It is noticeable that the locally confined potentials of industrial waste heat, geothermal and solar thermal have different contributions in all model variants depending on the ranking, in particular in variants 2 and 5 relative to the other rankings. It is therefore apparent that the merit order of the individual technologies significantly influences the composition of the overall system. In addition, it is clear to see that the dynamic specification of the RE and waste heat share in the overall system also leads to an RE and waste heat share of around 40% and the fossil-fuel-fired base is virtually identical in all six cases.



Anteil der Wärmeerzeugung [%]	Share of heat generation [%]
AS nach Reihung...	AS in accordance with ranking...
Reihung	Ranking
Solarthermie	Solar thermal
industrielle Abwärme	Industrial waste heat
Biomasse	Biomass
Kohle	Coal
Geothermie	Geothermal
WP Abwärme	Waste heat HP
Erdgas KWK	Natural gas CHP
MVA	WIP
Stromheizkessel	Electric boiler

Erdgaskessel	Gas-fired boiler

Source: Own figure (Prognos)

Figure 71: Shares of individual generation technologies in the district heating supply in accordance with the various rankings for 2030

For the rest of the examination and the cost-benefit analysis the optimum technological system, in terms of the lowest heat generation costs, is selected for each municipality.

Evaluation of optimum alternative scenarios

To allow the results for the individual municipalities to be presented clearly, the municipalities are divided into clusters based on the following criteria:

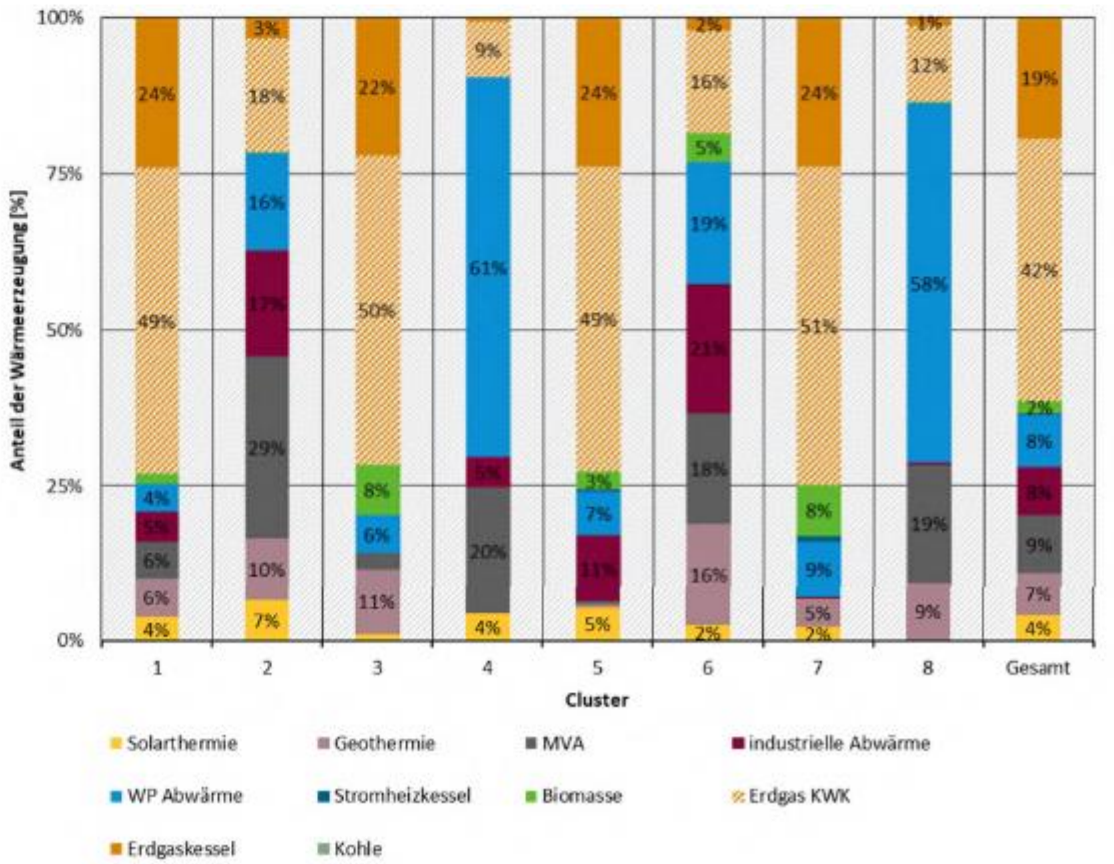
- Type of municipality (urban/rural)
- Usage structure (consumption solely by residential buildings and the TCS/services sector or also consumers from the industrial sector)
- Share of renewable energies

This results in the eight clusters shown in Table 27.

Table 27: Distribution of municipalities by cluster

Cluster	Description	Number of municipalities
1	urban, with industry, RE and waste heat target up to 40%	234
2	urban, with industry, RE and waste heat target over 40%	174
3	urban, without industry, RE and waste heat target up to 40%	272
4	urban, without industry, RE and waste heat target over 40%	66
5	rural, with industry, RE and waste heat target up to 40%	236
6	rural, with industry, RE and waste heat target over 40%	144
7	rural, without industry, RE and waste heat target up to 40%	442
8	rural, without industry, RE and waste heat target over 40%	72
Total	**all clusters**	**1,640**

With regard to the exploitation of potentials, there are clear differences between the clusters (Figure 72). Clusters with industry and a high RE and waste heat share (clusters 2 and 6) have shares of industrial waste heat and waste heat from waste incineration plants that are considerably higher than average. In clusters with a high target for renewable energies and waste heat that do not have any industry (clusters 4 and 8) high shares of the heating demand are covered by the waste heat heat pump, which also includes the use of sewage treatment plants and surface waters. In municipalities with a low RE and waste heat share more biomass is used.



Anteil der Wärmeerzeugung [%]	Share of heat generation [%]
Cluster	Cluster
Gesamt	Total
Solarthermie	Solar thermal
WP Abwärme	Waste heat HP
Erdgaskessel	Gas-fired boiler
Geothermie	Geothermal
Stromheizkessel	Electric boiler
Kohle	Coal
MVA	WIP
Biomasse	Biomass
industrielle Abwärme	Industrial waste heat
Erdgas KWK	Natural gas CHP

Source: Own figure (Prognos)

Figure 72: Shares of individual generation technologies in the district heating supply in the clusters in 2030, dynamic

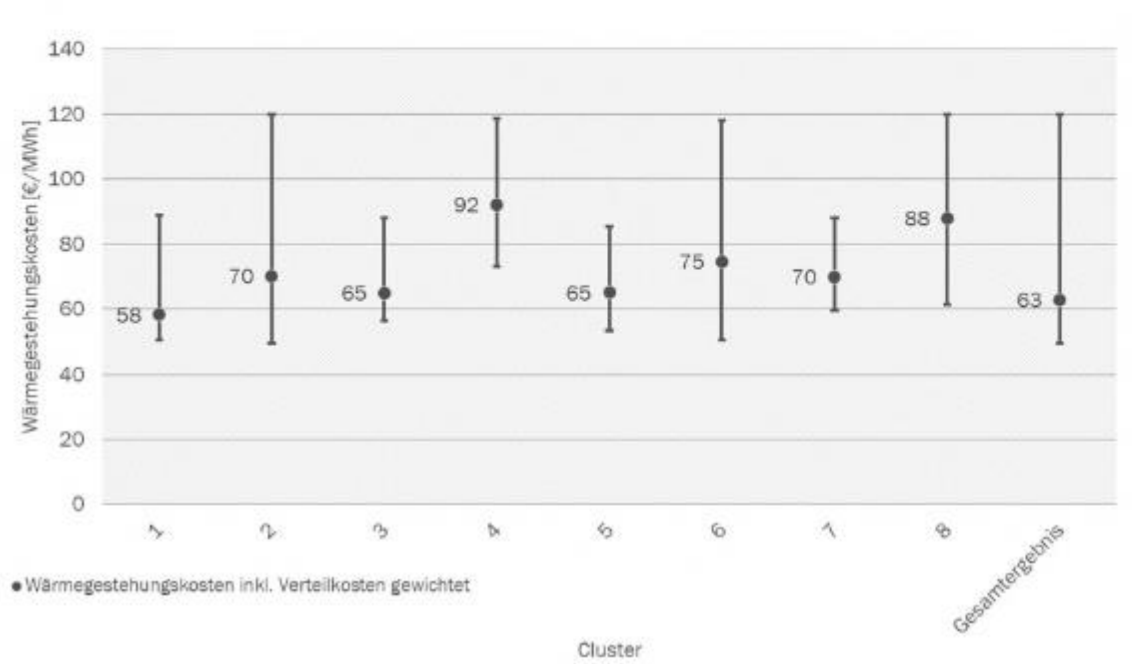
The comparison with the baseline scenario in Table 28 clearly shows that most locally available renewable energies (solar thermal, geothermal and waste heat) are used to a greater extent under the alternative scenarios than under the baseline scenario. Consequently, slightly less biomass is needed to achieve the target of a 40% share for renewable energies and waste heat in district heating generation by 2030. Waste heat from waste incineration plants and electric boilers are also used less than under the baseline scenario. The overall potential of a maximum of 25 TWh from biomass in the area of district heating is not fully exploited. Consequently, other heat sources that are not confined to the local area, such as air source heat pumps or near-surface geothermal energy, which can also be used to realise the target, are not essential to achieve the targeted 40% share for renewable energies and waste heat by 2030.

Table 28: Heat generation of the individual generation technologies in district heating in 2030 compared with the baseline scenario

Quantity of heat [TWh]	**All clusters**	**Baseline scenario**
Solar thermal	6.3	3.5
Geothermal	10.8	5.3
WIP	14.4	13.5
Industrial waste heat	11.9	4.34
Waste heat HP	13.2	15.8
Electric boiler	0.2	4.2
Biomass	3.2	16.1
Natural gas CHP	65.5	59.2
Gas-fired boiler	30.0	21.9
Coal	-	12.0
Total	**155.5**	**155.8**

The average weighted heat generation costs[47] that result from the specific technology mix for each municipality in the individual clusters are shown in Figure 73. As an average for all municipalities, the resulting heat generation costs are €63/MWh. In clusters with a high RE and waste heat share (clusters 2, 4, 6 and 8) the heat generation costs are slightly higher on average than in clusters with a low RE and waste heat share, where higher shares are supplied by more cost-efficient fossil fuels.

[47] These take into account the costs of the connection pipeline, the costs of district heating distribution and generation. Costs of building transfer stations are not considered.



Wärmegestehungskosten [€/MWh]	Heat generation costs [€/MWh]
Wärmegestehungskosten inkl. Verteilkosten gewichtet	Heat generation costs incl. distribution costs, weighted
Gesamtergebnis	Overall result
Cluster	Cluster

Source: Own figure (Prognos)

Figure 73: Heat generation costs of district heating by cluster including distribution costs in 2030

The average weighted heat generation costs of the respective RE and waste heat technologies can be found in Table 29. In the individual municipalities, however, the heat generation costs deviate from the average presented, as, due to the small-scale approach employed and the fact that local conditions are explicitly taken into account (in particular the availability of the heat source and the load profile of district heating), different sizes of installation are used. The associated variable specific investment costs, as already examined in the methodological approach presented under Section III.6.a, vary accordingly. As large installations supply significantly more heat, the respective energy-weighted average for heat generation costs lies within the lower part of the technology-specific ranges.

Table 29: Heat generation costs of district heating by RE and waste heat technology, excluding distribution costs, in 2030

Technology	Average heat generation costs, energy-weighted [€/MWh]
Solar thermal	43
Solar thermal with seasonal storage	59
Geothermal	40

WIP	56
Industrial waste heat	32
Waste heat HP	74
Biomass	44
Electric boiler	195

Source: Own figure (Prognos)

Reducing network losses

Over the last 20 years the network losses from district heating networks have remained relatively constant, fluctuating in a range between 11% and 14% (AGFW, 2019). A reduction has not been observed over this period, which is why a value of 12% has also been assumed for 2030 for the assessment of the alternative scenarios.

Assuming that 20% of networks are modernised by 2030 and these networks reduce their network losses to 8%, average network losses would fall to 11.2%, resulting in a drop in district heating consumption by 0.1%. This could contribute to a further reduction in energy costs and improve the cost-efficiency of the alternative scenarios, although it is not taken into account explicitly in the development of the alternative scenarios.

Interactions with electricity system

As the shares of renewable electricity generation increase in Germany, so too do the demand for and the benefits of more flexible electricity consumption. Alongside the transport sector, individual industrial applications and decentralised heat pumps, the area of district heating generation will also have an important role to play here. Intelligent use of large-scale heat pumps, electric boilers and CHP installations (with heat storage) will help at the following levels in particular:

- Integration of renewable electricity generation by maximising electricity consumption at times of high RE electricity generation
- Reduction in the load at times when there is a high residual load (reduces expensive power generation at these times and reduces the need for capacity to be made available)
- Reduction in network congestion and the need for network expansion
- Supply of balancing energy

During the assessment and decision-making process, costs and energy savings that result, under the analysed scenarios, from increased flexibility in the energy supply and from optimised operation of the electricity networks should be taken into account, including avoided costs and savings from reduced infrastructure investments. These aspects are not examined in depth within the context of this reporting obligation.

III.6.b.ii. Centralised supply in 2050

To provide an outlook for 2050, the share of renewable energies and waste heat in heat generation is set at 100% in all municipalities. The results are presented in the following section.

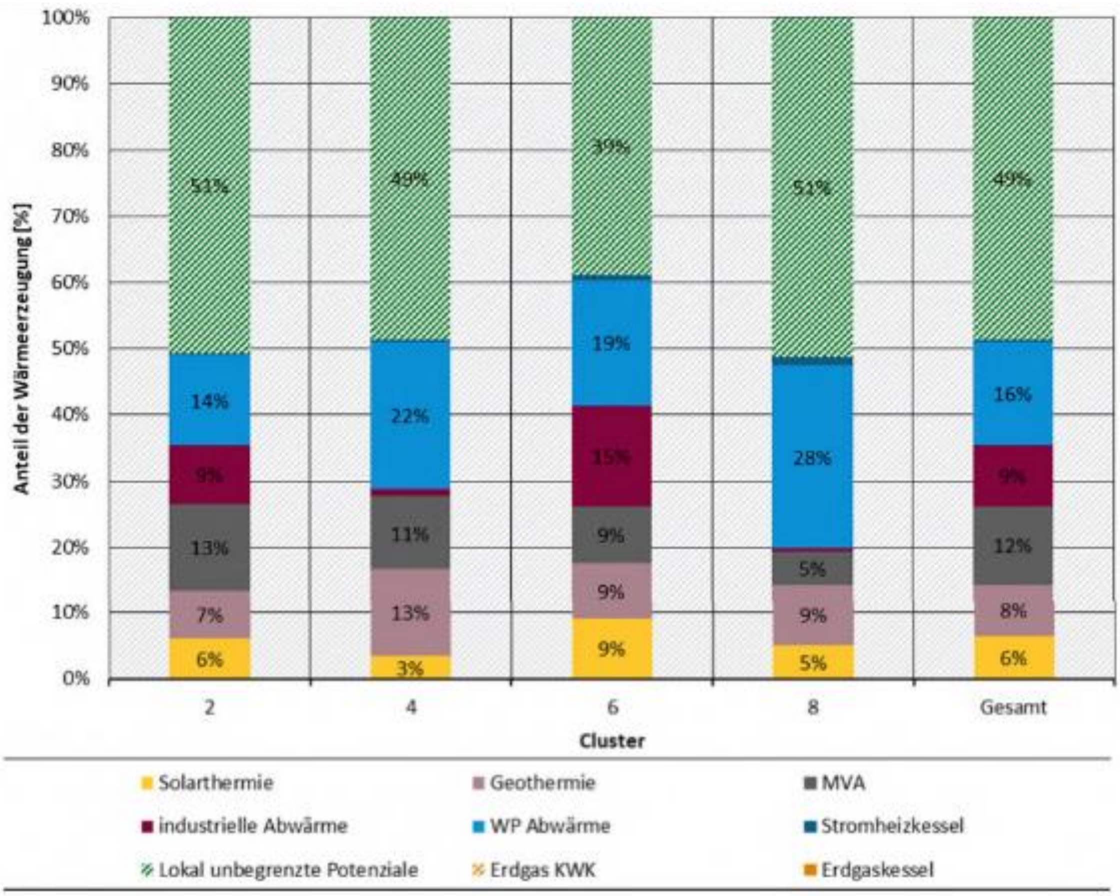
District heating demand in 2030 is taken as a basis for the analysis, although the decline in final energy demand by 2050 is virtually cancelled out by the increasing expansion of district heating. Under the baseline scenario district heating demand in 2050 is 153 TWh and is therefore only slightly lower than the district heating demand of 156 TWh in 2030.

Only the four clusters with a high RE and waste heat target are included in this analysis.

Table 30: Distribution of municipalities by cluster in the 100% RE variant in 2050

Cluster	**Description**	**Number of municipalities**
2	urban, with industry, RE and waste heat target over 40%	408
4	urban, without industry, RE and waste heat target over 40%	338
6	rural, with industry, RE and waste heat target over 40%	380
8	rural, without industry, RE and waste heat target over 40%	514
Total		**1,640**

In the event that heat generation is covered entirely by renewable energies and waste heat, an average of 51% of heating demand can be met by means of locally confined heat sources (Figure 74). The other 49% can be met using technologies that are not confined to the local area, such as air source heat pumps and near-surface geothermal energy, biomass, or synthetic gases and/or hydrogen.



Anteil der Wärmeerzeugung [%]	Share of heat generation [%]
Cluster	Cluster
Gesamt	Total
Solarthermie	Solar thermal
industrielle Abwärme	Industrial waste heat
Lokal unbegrenzte Potenziale	Potentials not confined to local area
Geothermie	Geothermal
WP Abwärme	Waste heat HP
Erdgas KWK	Natural gas CHP
MVA	WIP
Stromheizkessel	Electric boiler
Erdgaskessel	Gas-fired boiler

Source: Own figure (Prognos)

Figure 74: Shares of individual generation technologies in the district heating supply in the clusters in 2050

The heat generation of the individual technologies is shown in Table 31. Around 76 TWh are covered by potentials not confined to the local area. Biomass, air source heat pumps and near-surface geothermal, which are not dependent on regional potentials, can be considered in particular, as well as low-temperature deep geothermal. In addition, synthetic gases can also be used. In the case of biomass a maximum potential of 25 TWh is assumed in the area of district heating. Existing studies of potential as part of the reporting obligation under the RED II reveal an economic potential, as regards use in district heating, of around 44–73 TWh in 2030 for the use of centralised air source heat pumps and of 29–113 TWh/a in 2030 for the use of centralised heat pumps with near-surface geothermal energy as a heat source (Ortner et al., 2020). Low-temperature deep geothermal, which can be utilised via heat pumps, has a potential of 51 GW (see also Section III.5.d).

In total, there are therefore sufficient technologies and heat sources available to achieve a district heating supply consisting entirely of renewable heat, including to cover the share of potentials that are not confined to the local area.

Table 31: Heat generation of the individual generation technologies in district heating in 2050

Quantity of heat [TWh]	**All clusters, RE and waste heat target of 100%**
Solar thermal	10.0
Geothermal	12.4
WIP	18.5
Industrial waste heat	14.3
Waste heat HP	24.2
Electric boiler	0.6
Potentials not confined to local area	75.7
Natural gas CHP	-
Gas-fired boiler	-
Total	**155.6**

The economic and ecological assessment of generation using 100% renewable heat is shown in Table 32. For this purpose the quantity of heat supplied by potentials that are not confined to the local area is allocated to biomass and air source heat pumps at a level of 25% and 75% respectively. The assessment has been performed using the energy prices for 2030 and cannot therefore be directly applied to the assessment for 2050. The investment and the heat generation costs are higher than in the case of the 40% RE and waste heat variants, but the ecological impact is expected to be lower.

Table 32: Economic and ecological assessment of district heating generation with a 100% RE share in 2050

Variable	**Unit**	**RE3, opt.**
Investment in installations	million euro	30,213

Heat generation costs – weighted and including heat generation costs	€/MWh	83.5
Renewable heat share	%	100%
GHG emissions	g/kWh	60
PE factor		0.24

III.6.b.iii. Centralised supply of cooling

When it comes to the centralised supply of cooling, it is possible to use heating networks in combination with absorption cooling systems or to construct a separate district cooling network.

The benefit of using the heating network is that it is possible to take advantage of existing infrastructures. However, absorption cooling systems are in direct competition with air-conditioning systems, which usually represent the more cost-efficient alternative. In Schöpfer (2015) it was shown that absorption cooling systems are economical if the price of heat is between €2 and €20/MWh, which is well below the average price of heat in Germany.

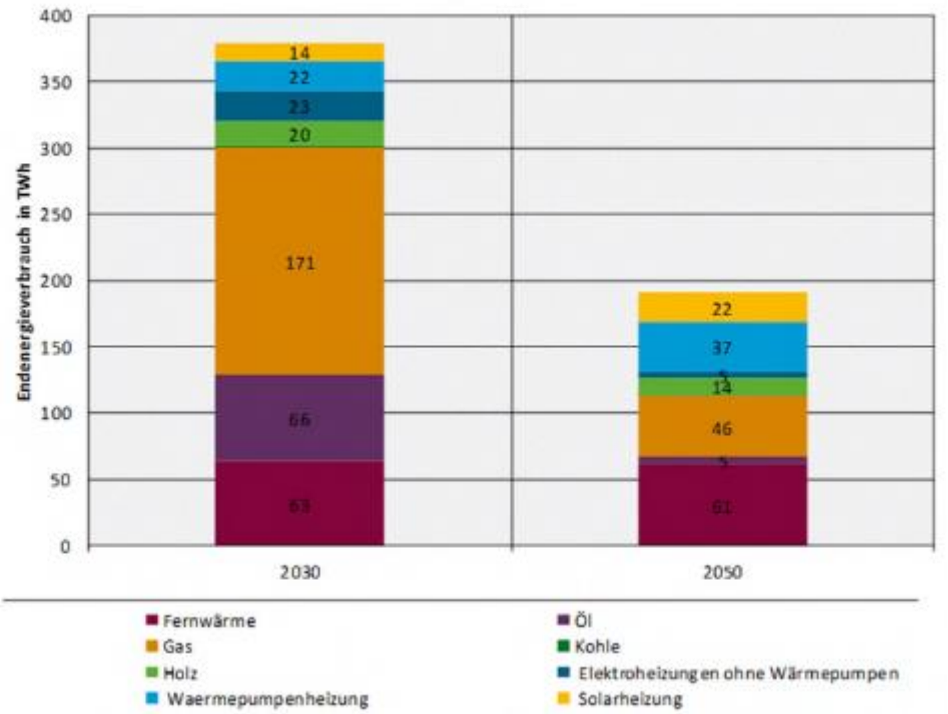
On the other hand, there are savings in the area of energy and operating costs, as absorption cooling systems have a much lower electricity demand than decentralised air-conditioning systems. Due to Germany's geographical location, however, the full load hours for air conditioning are so low that they usually do not compensate for the higher investment costs. Typical full load hours in Germany are roughly 500 h for office buildings and around 350 h for educational buildings (Heinrich et al., 2014).

One major advantage of using heating networks for the supply of cooling would be that it allows better exploitation of renewable energies or waste heat that cannot otherwise be fully integrated into networks on account of the low load in summer (in particular solar thermal, waste heat from waste incineration plants or industrial waste heat). As the networks are primarily used for the supply of heating, the peak load in Germany would not be increased, but the full load hours could be expanded.

Separate district cooling networks have also been constructed in Germany in isolated cases, e.g. in Chemnitz and Munich. These are generally used to cool large non-residential buildings, such as universities, office buildings or shopping centres. A concept setting out how district cooling potentials could be determined on the basis of cooling density maps has also been presented as part of the Horizon 2020 project Hotmaps (Odgaard, 2020). However, this also makes reference to local characteristics, which can significantly influence cost-efficient use (e.g. presence of a number of non-residential buildings).

III.6.b.iv. Decentralised heating supply options – residential buildings and services sector

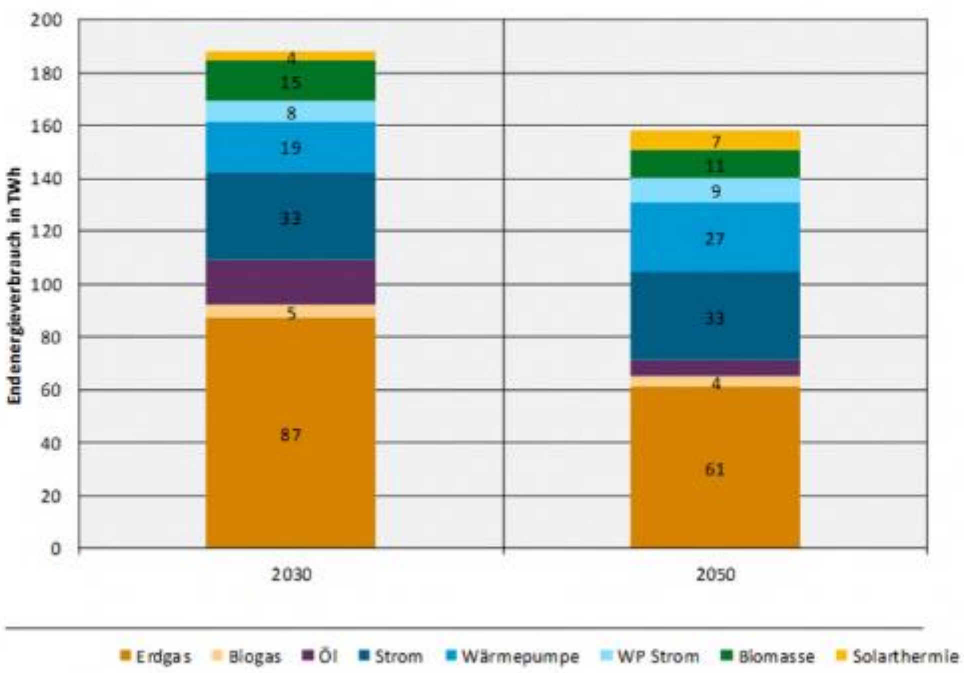
Figure 75 and Figure 76 show the use of energy sources in the decentralised supply under the baseline scenario in 2030 and 2050 for residential buildings and the services sector. The final energy consumption presented corresponds to the economic potentials of the decentralised heating supply in these sectors. As the baseline scenario makes assumptions relating not only to the potentials of the energy sources for decentralised use, but also to developments in efficiency within the building stock, taking life cycles into account, a variation in the energy source mix is not expedient (see also Section III.6.a.ii).



Endenergieverbrauch in TWh	Final energy consumption in TWh
Fernwärme	District heating
Gas	Gas
Holz	Wood
Waermepumpenheizung	Heat pump heating system
Öl	Oil
Kohle	Coal
Elektroheizungen ohne Wärmepumpen	Electric heating systems without heat pumps
Solarheizung	Solar heating

Source: Own figure (Prognos)

Figure 75: Decentralised supply options in 2030 and 2050 for the residential sector



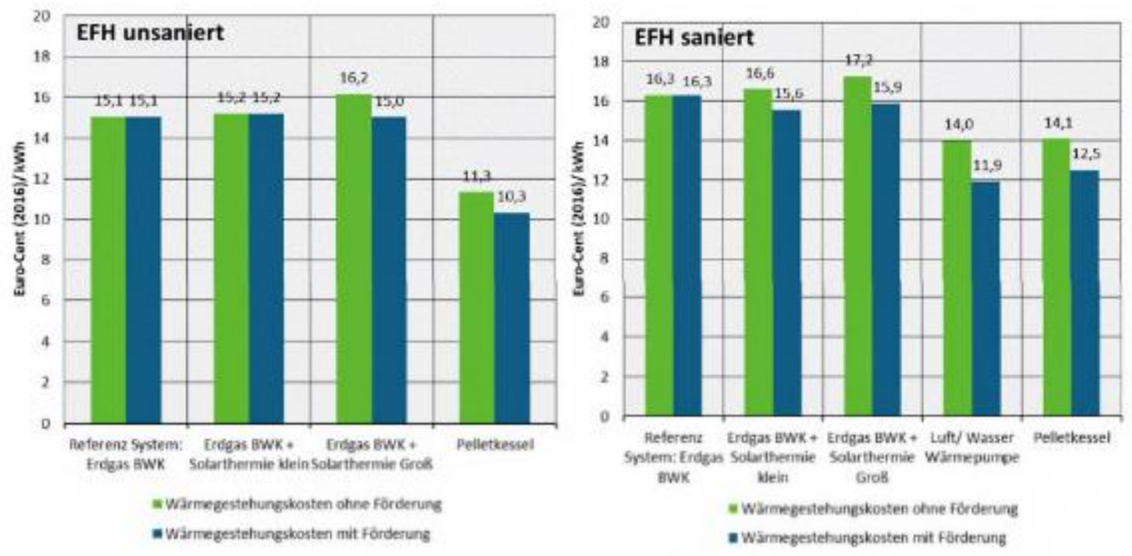
Endenergieverbrauch in TWh	Final energy consumption in TWh
Erdgas	Natural gas
Biogas	Biogas
Öl	Oil
Strom	Electricity
Wärmepumpe	Heat pump
WP Strom	Electric HP
Biomasse	Biomass
Solarthermie	Solar thermal

Source: Own figure (Prognos)

Figure 76: Decentralised supply options in 2030 and 2050 for the services sector

The following figures show the results of the decentralised supply options examined for the individual reference building types in renovated and non-renovated condition. In all cases it is the specific heating supply costs that are shown. These are generally lower if the buildings in question are in non-renovated condition, as the annual heating demand is higher in that case. However, the absolute annual heating supply costs of the same supply systems are higher for non-renovated buildings than renovated buildings, as not only are the energy costs higher, but the heat generators also have to be larger in size due to the higher heat load.

For a non-renovated single-family house the specific heating supply costs in 2030 (without subsidy) are between 11.3 cents/kWh and 16.2 cents/kWh (Figure 77). Compared with the gas-fired condensing boiler as a fossil-based reference system, the hybrid system with small solar thermal installation and the pellet boiler are economical. Monovalent heat pump systems are unsuitable for this building type, due to the high supply temperatures, and are therefore only taken into consideration for renovated buildings. In this case the heat generation costs without subsidies are between 14 cents/kWh and 17.2 cents/kWh. The most cost-efficient option is the air/water heat pump. For the reference supply cases involving buildings in renovated condition, heating circuit supply temperatures of 55 °C and return temperatures of 45 °C are taken into account, which means that heat pumps can also be used.



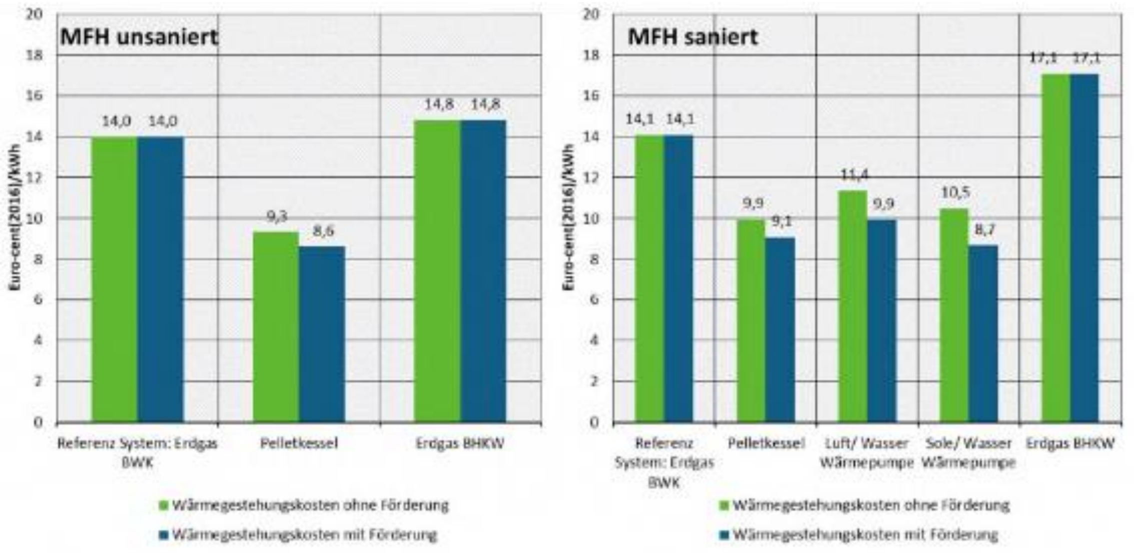
SFH ... Single-family house

EFH unsaniert	SFH non-renovated
Euro-Cent(2016)/kWh	euro cent(2016)/kWh
Referenz System: Erdgas BWK	Reference system: gas-fired CB
Erdgas BWK + Solarthermie klein	Gas-fired CB + small solar thermal
Erdgas BWK + Solarthermie groß	Gas-fired CB + large solar thermal
Pelletkessel	Pellet boiler
Wärmegestehungskosten ohne Förderung	Heat generation costs without subsidy
Wärmegestehungskosten mit Förderung	Heat generation costs with subsidy
EFH saniert	SFH renovated
Luft/Wasser Wärmepumpe	Air/water heat pump

Source: Own figure (IREES)

Figure 77: Heating supply costs of decentralised technologies for the reference case of single-family houses in 2030

The results for the apartment blocks examined are shown in Figure 78. For non-renovated buildings, a decentralised natural gas cogeneration plant is also included in the comparative studies, in addition to the pellet boiler. The heating supply costs are between 9.3 and 14.8 cents/kWh (without subsidies). Here again, based on the assumed development in the energy price by 2030, the pellet boiler is more cost-efficient than the fossil-based reference system. The cogeneration plant, on the other hand, results in slightly higher costs. For buildings in renovated condition both heat pump systems also have significantly lower specific heating supply costs than the fossil-based reference system. On the other hand, the cogeneration plant is the option with the highest costs. Compared with an economic assessment from today's perspective, the framework conditions for the decentralised cogeneration plant change significantly, based on the assumptions for 2030, as the spread between the gas and electricity price narrows. Fuel purchasing costs rise sharply, while the value of the electricity generated falls due to a decline in the electricity purchase price.



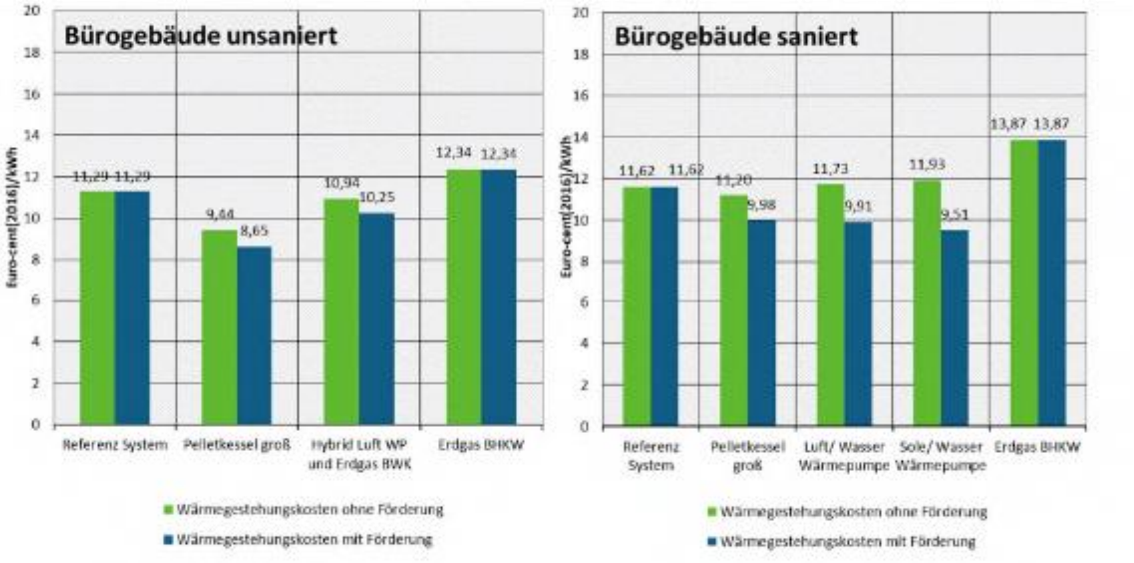
AB …. Apartment block

MFH unsaniert	AB non-renovated
Euro-cent(2016)/kWh	euro cent(2016)/kWh
Referenz System: Erdgas BWK	Reference system: gas-fired CB
Pelletkessel	Pellet boiler
Erdgas BHKW	Natural gas cogeneration plant
Wärmegestehungskosten ohne Förderung	Heat generation costs without subsidy
Wärmegestehungskosten mit Förderung	Heat generation costs with subsidy
MFH saniert	AB renovated
Luft/Wasser Wärmepumpe	Air/water heat pump
Sole/Wasser Wärmepumpe	Brine/water heat pump

Source: Own figure (IREES)

Figure 78: Heating supply costs of decentralised technologies for the reference case of apartment blocks in 2030

Figure 79 shows the results for office buildings as a reference study for the services sector. For buildings in non-renovated condition the heating supply costs are between 9.4 cents/KWh and 12.3 cents/kWh in 2030. In addition to the pellet boiler, for non-renovated buildings a bivalent hybrid system consisting of a heat pump and gas-fired boiler is shown, which is also suitable for higher heating circuit temperatures and is cost-efficient in the examination from a 2030 perspective. In the case of renovated buildings the heating supply costs without subsidies are very close together for all supply options, ranging between 11.2 cents/kWh and 13.9 cents/kWh. All the renewable heating supply systems examined are cost-efficient compared with the gas-fired condensing boiler.

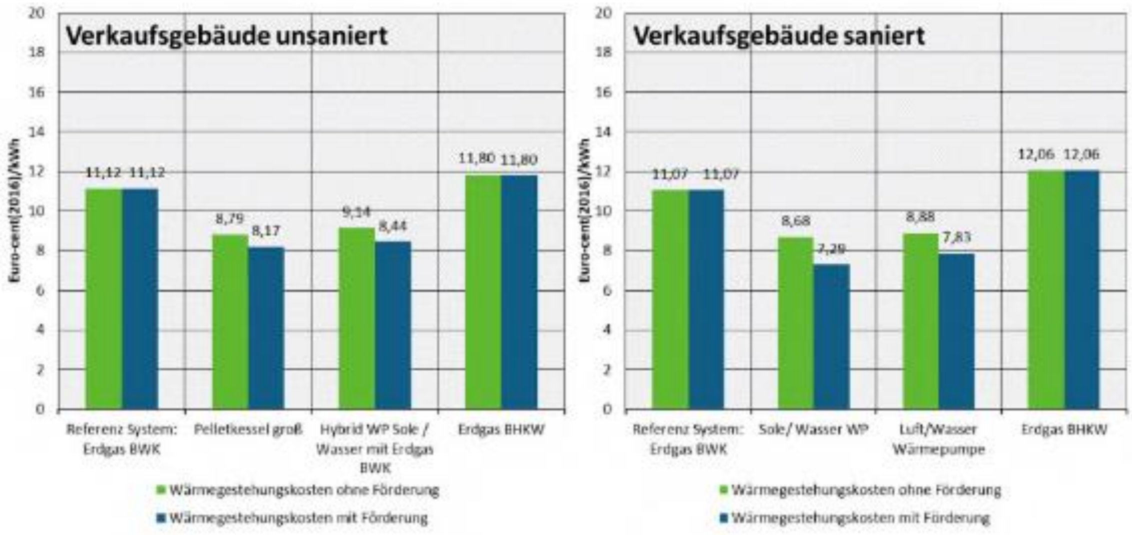


Bürogebäude unsaniert	Office building non-renovated
Euro-cent(2016)/kWh	euro cent (2016)/kWh
Referenz System	Reference system
Pelletkessel groß	Large pellet boiler
Hybrid Luft WP und Erdgas BWK	Hybrid air source HP and gas-fired CB
Erdgas BHKW	Natural gas cogeneration plant
Wärmegestehungskosten ohne Förderung	Heat generation costs without subsidy
Wärmegestehungskosten mit Förderung	Heat generation costs with subsidy
Bürogebäude saniert	Office building renovated
Luft/Wasser Wärmepumpe	Air/water heat pump
Sole/Wasser Wärmepumpe	Brine/water heat pump

Source: Own figure (IREES)

Figure 79: Heating supply costs of decentralised technologies for the reference case of office buildings in 2030

Figure 80 shows the heating supply costs for the retail buildings examined as a second reference case for the services sector. The results in terms of the cost-efficiency of individual systems are in line with those for the office buildings reference case. The specific heating supply costs are between 8.8 and 11.8 cents/kWh for non-renovated retail buildings and between 8.7 and 12.1 cents/kWh for renovated buildings.



Verkaufsgebäude unsaniert	Retail building non-renovated
Euro-cent(2016)/kWh	euro cent(2016)/kWh
Referenz System: Erdgas BWK	Reference system: gas-fired CB
Pelletkessel groß	Large pellet boiler
Hybrid WP Sole / Wasser mit Erdgas BWK	Hybrid brine/water HP with gas-fired CB
Erdgas BHKW	Natural gas cogeneration plant
Wärmegestehungskosten ohne Förderung	Heat generation costs without subsidy
Wärmegestehungskosten mit Förderung	Heat generation costs with subsidy
Verkaufsgebäude saniert	Retail building renovated
Sole/Wasser WP	Brine/water HP
Luft/Wasser Wärmepumpe	Air/water heat pump

Source: Own figure (IREES)

Figure 80: Heating supply costs of decentralised technologies for the reference case of retail buildings in 2030

The examination of decentralised heating supply options for different supply reference cases reveals the range of resulting heating supply costs for the various efficient, renewable systems. On the one hand, it can be seen that, based on the assumptions made here relating to energy price and carbon price development by 2030, the renewable heating technologies are cost-efficient, compared with the decentralised fossil-based reference. On the other, it also emerges that the heating supply costs are significantly higher than the heat generation costs of a centralised supply in the suitable heating network regions (cf. Section III.6.b), underlining the relevance of a centralised renewable heating supply for the municipalities identified (see Section III.5.i and Section III.6.b.i).

III.6.b.v. Decentralised supply of cooling in buildings

With regard to the supply of cooling, a detailed comparison of different generation technologies is not performed. In spite of high growth rates under all scenarios, air conditioning continues to play a minor role in terms of energy demand in 2050. Nevertheless, an increasing number of air-conditioning systems are being installed as a result of rising summer temperatures and changing user demands in the area of comfort, although the number of hours for which they are used is well below the figure for heating. In many cases efficiency measures and passive cooling could replace active air conditioning or greatly reduce demand and the area to be cooled. Consequently, to reduce GHG emissions in the area of cooling, the individual building and renovation concepts are more relevant than a comparison of different generation technologies. These include efficiency measures relating to the building envelope, measures to ensure summer thermal insulation, passive cooling and efficient cooling distribution systems.

III.6.b.vi. Decentralised heating and cooling in industry: industrial CHP installations

This section deals with the potential of industrial CHP installations that are not connected to heating networks. The estimate relates to projections under the baseline scenario (Kemmler et al., 2020), from which the industrial heating demand has been derived by temperature level. For the determination of potential, the applications hot water, air conditioning, space heating, and process heating and cooling are taken into account, with generation on the basis of fossil or biogenic fuels. District heating is not considered to form part of the CHP potential, as the focus is explicitly on the decentralised potential. The actual technical potential for supplying industrial process heat from CHP waste heat is determined by the simultaneous demand for electricity and heat at a suitable temperature level on the same site. The temperature level of the heat that can be usefully supplied from waste heat resulting from the CHP process is highly process dependent, which means that the general estimate here should be regarded as an upper limit. In principle, the electrical power efficiency of the CHP installation falls as the temperature of the extracted heat rises. In this estimate it is assumed that process heat up to a temperature level of 200 °C can be extracted from the CHP process. The assumption is made that process heat can only be supplied at a higher temperature of up to 500 °C through heat extraction from the waste gas of gas turbine processes, which further limits the realisation of this potential. Increasing the flexibility of the load regulation of industrial CHP installations, in particular in view of an increasing share of fluctuating energy sources, represents an additional challenge and is left out of consideration here.

The results of the estimate can be found in Table 33. A decline of 143 PJ is seen up to 2030, which can be attributed to the predicted expansion of renewable heat. The estimated CHP potential for 2018 and 2030 corresponds to 36% and 35% respectively of the total industrial heating demand. As heating demand decreases overall, the percentage difference is minimal. A more marked decline is expected by 2050.

Table 33: Decentralised CHP heating potential in industry on the basis of the baseline scenario

CHP potential by applica-	**2018**	**2030**	**2050**

tion [TWh]			
Space heating, hot water and air conditioning	56	43	28
Process heating (<200 °C) and process cooling	140	114	66
Total	**196**	**156**	**94**
Process heating (200–500 °C)[48]	29	24	16
Total, including partially usable potential	**225**	**180**	**110**

[48] Partially usable potential

III.7. Cost-benefit analysis in accordance with Annex VIII

In this section the cost-benefit analysis is performed for the alternative scenarios developed (cf. III.6). As explained in Section III.6, the alternative scenarios represent a combination of location-specific, centralised heating supply systems in individual German municipalities, taking location-specific conditions, such as RE and waste heat potentials and heating demand densities, into account. It is assumed that the investments will be made in 2030 and will have a lifespan of 20 years. The cost-benefit analysis therefore shows annual results. To allow the location-specific results for the centralised heating supply from Section III.6 to be ranked, the specific heat generation costs under the alternative scenarios are also compared with location-independent, decentralised supply technologies. This makes it possible to show in which municipalities a centralised or decentralised option is more advantageous.

The cost-benefit analysis assesses the alternative scenarios against the baseline scenario. Under all alternative scenarios the consumption sectors are therefore assumed to have the same efficiency level. The difference lies in the heating and cooling technologies used. As already explained, the alternative scenarios were developed primarily as alternative centralised supply options for the municipalities identified as suitable regions for a heating network[49]. For the cost-benefit analysis this means that the difference between the baseline scenario and alternative scenario lies in the assessment of the centralised, heating-network-based supply. Please refer to Section III.6.b.iv for an assessment of decentralised supply options for different supply cases. The results of the cost-benefit analysis are used to assess the modified generation structure in terms of the differential costs and differential benefits relative to the baseline scenario. Microeconomic cost and benefit effects are also quantified, in addition to the macroeconomic costs and avoided external costs. To conclude, an indicative assessment is performed of the impact on jobs and of energy security, as well as a qualitative assessment of the increase in competition.

The cost-benefit analysis comprises the assessment of the alternative scenarios from a macroeconomic and microeconomic perspective. The macroeconomic analysis is referred to in Annex VIII of the EED as the economic analysis and the microeconomic analysis as the financial analysis.[50]

The macroeconomic (economic) cost-benefit analysis considers socioeconomic factors and environmental factors to assess the well-being of society as a whole and is therefore used for policymaking. The microeconomic (financial) cost-benefit analysis takes the viewpoint of a private investor.

The cost-benefit analysis is based on the discounted cash flow method, examining annual heat generation costs. To comply with the Directives, the costs and benefits resulting from baseline and alternative scenarios are quantified, assessed and compared in the analysis (Figure 81). On the cost side, capital-related costs of generation installations and the distribution infrastructure, demand-related costs (energy costs) and oper-

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[49] All influencing factors relevant for the analysis have already been taken into account in the analysis of the baseline scenario in relation to centralised supply options. Varying the parameters is therefore not expedient.

[50] The terms ‘macroeconomic’ and ‘microeconomic’ are used below.

ating costs are taken into account in both analyses. The difference between the macroeconomic and microeconomic perspective results from the different interest rates and the price components to be considered.

Gesamtwirtschaftliche Perspektive	Macroeconomic perspective
Wirtschaftliche Kosten-Nutzen-Analyse	Economic cost-benefit analysis
Einzelwirtschaftliche Perspektive	Microeconomic perspective
Finanzielle Kosten-Nutzen-Analyse	Financial cost-benefit analysis
Kapitalgebundene Kosten der Erzeugungsanlagen	Capital-related costs of generation installations
Kapitalgebundene Kosten der Verteilung	Capital-related costs of distribution
Energiekosten	Energy costs
Betriebskosten	Operating costs
Fiskalkorrekturen für Transferzahlungen zwischen Akteuren innerhalb der Wirtschaft	Fiscal corrections for transfers between agents within the economy
Keine Mehrwertsteuer	No value-added tax
Keine Energiesteuer	No energy tax
Keine Zuschüsse	No subsidies
Vermögenstransfer von Steuerzahlern auf Unternehmen sind zu berücksichtigen	Transfers of wealth from taxpayers to companies to be taken into account
Tatsächliche Zahlungsströme aus Sicht der Investoren	Actual payment flows from investors' perspective
Mehrwertsteuer auf Kosten und Einkünfte (außer Projektträger kann diese zurückfordern)	Value-added tax on costs and income (unless developer can claim this back)
Zuschüsse	Subsidies
Externe Kosten durch die Verbrennung fossiler Brennstoffe auf Umwelt und Gesundheit	External costs for environment and health due to burning of fossil fuels
CO_2-Kosten aus EU-ETS und nEHS	CO_2 costs from EU ETS and nETS
Weitere makro-ökonomische Effekte, falls	Other macroeconomic impacts, if possible

möglich (Arbeitsplatzeffekte, Energiesicherheit,	(impact on jobs, energy security
Soziale Diskontierungsrate	Social discount rate
Finanzielle Diskontierungsrate	Financial discount rate

Source: Own figure (IREES)

Figure 81: Definition of macroeconomic and microeconomic cost-benefit analysis

By comparison with the microeconomic perspective, the macroeconomic perspective involves making fiscal corrections for transfers between agents within the economy that do not have any economic impact. The macroeconomic perspective does not take any taxes or subsidies into account, for example. On the other hand, externalities such as the impact of burning fossil fuels on the environment and health are taken into account on the basis of their monetised value. Other macroeconomic impacts of investments in the energy system should also be quantified, if possible. When taking future payment flows and price changes into account, a social discount rate is used that reflects society's view as to how future benefits and/or costs should be valued. In the case of the microeconomic perspective, on the other hand, the assessment of the project from the investor's perspective is incorporated into the discount rate, which takes the risk and return expectations for the investment into account.

The cost and benefit effects under the alternative scenarios are determined in the form of a comparison against the baseline scenario, with a specified energy source mix for the latter. The alternative scenarios examined in this study represent a regionally optimised supply mix, taking the locally available potentials for different centralised heating network supply options into account. In this way the cost-benefit analysis examines the effects of the modified energy source mix that results under the alternative scenarios for the grid-based heating supply, compared with the supply of district heating under the baseline scenario.

III.7.a. Key framework data for the cost-benefit analysis

The detailed description of the framework data used can be found in Annex IV. Of particular relevance for the cost-benefit analysis are the imputed interest rates and the cost rates for assessing climate damage, which are estimated in accordance with the methodological convention of the Federal Environment Agency (see Table 34). In addition, for the assessment of energy costs from the macroeconomic perspective the price components relating to energy and electricity taxes and levies such as the EU ETS need to be separated out as pure transfers (see Table 35).

Table 34: Overview of framework data for calculation of the cost-benefit analysis and sensitivity calculation

	Microeconomic perspective	**Macroeconomic perspective**
Interest rate	5.5%	2%
Depreciation period	20 years	20 years
Assessment of climate-related damage [€/tCO_2-eq]		222.50

Source: Own figure (IREES) in accordance with methodological convention 2.0 (UBA, 2012) and methodological convention 3.0 (Matthey & Bünger, 2019)

Table 35: Input data on taxes and levies for the cost-benefit analysis and sensitivity calculation

Taxes			**Emission factors**		
Energy tax – natural gas	0.55	ct/kWh	**Emission factor – natural gas**	0.24	t/MWh
Energy tax – coal	0.12	ct/kWh	**Emission factor – coal**	0.34	t/MWh
Electricity tax	2.05	ct/kWh			

Sources: BMJV (2006); Bundesamt für Wirtschaft und Ausfuhrkontrolle (2019)

III.7.b. Approach for determining the cost effect

In the cost-benefit analysis the alternative scenarios are compared with the baseline scenario. A detailed explanation of the composition of the baseline scenario can be found in Section III.3.

The Directive specifies that the scenarios should be assessed using a dynamic investment calculation based on the net present value method or the equivalent annual cost method. The heat generation costs consist of the capital, operating and energy costs of the heat and cold generation installations. In addition, the distribution costs for district heating are taken into account for each municipality, depending on heating density. For the alternative scenarios the heat generation costs are calculated for each municipality and technology. As there is no cost assessment for the baseline scenario in the NECP report, this scenario is also assessed. Compared with the alternative scenarios, the baseline scenario does not represent a regionally optimised supply mix at municipality level, but specifies the generation mix in aggregated form for Germany as a whole. The cost assessment is performed on the basis of the specific heat generation costs of the relevant generation technologies that make up the energy source mix under the alternative scenarios.

Energy costs

To calculate energy costs, it is assumed that the investments are made in 2030, which means that the development of energy prices from 2030 to 2050, in accordance with the assumed price path, is relevant for the energy cost calculation. Energy prices are discounted over a period of 20 years.

To discount the future cash flows to 2030, the year under consideration, it is necessary to calculate the annuity factor ($ANF_{n,i}$) with the duration (n) and discount rate (i) in accordance with Formula 1.

Formula 1: Calculation of the annuity factor

$$ANF_{n,i} = \frac{(1+i)^n * i}{(1+i)^n - 1}$$

To take future energy price changes into account in accordance with the assumed energy price path, price-dynamic annuity factors (AF) are calculated from the equivalent annual cost of the relevant energy price changes from 2030 to 2050 (M) (Formula 2).

Formula 2: Calculation of the discount factor

$$AF_j = \frac{1 - \left(\frac{1 + M_j}{i}\right)^n}{i - M} * ANF$$

für jeden Energieträger j

für jeden Energieträger j	for each energy source j

Source: VDI 2067-1 (2012)

The energy price to be assumed is finally calculated by multiplying the discount factor by the energy price in the year of investment.

As no taxes or levies are taken into account from a macroeconomic perspective, as a result of fiscal corrections, separate energy prices have to be calculated in both variants.

Operating costs (repair and maintenance)

The annual operating costs are assumed to be constant over the period under consideration.

Capital costs

The capital costs result from the equivalent annual cost (a) of the capital-related payment (C_0) in the year of investment, by means of which this payment is divided into constant cash flows over the depreciation period of the installations (Formula 3).

Formula 3: Calculation of the equivalent annual cost

$$a = C_0 * ANF_{n,i}$$

Source: VDI 2067-1 (2012)

The microeconomic and macroeconomic perspectives are examined separately for the alternative scenarios. In both cases capital, operating and energy costs are calculated for each municipality and technology. The differential costs result from the comparison of the total costs of the heating supply under the alternative scenarios with the baseline scenario. To determine the benefit effects, the primary energy use, GHG emissions and resulting external costs of the alternative scenarios and baseline scenario are compared.

III.7.c. Calculation of generation costs under the baseline scenario

To allow a comparison with the alternative scenarios, heat generation costs also need to be calculated for the baseline scenario. For the energy source mix under the baseline scenario, reference technologies are assumed for the investments, from which resulting capital costs and energy and operating costs are calculated. Table 36 shows the composition of the energy sources in the district heating supply under the baseline scenario, with an indication of the final energy supplied in TWh in 2020 and 2030, as well as the assumed reference technologies as a basis for determining the associated investments.

Table 36: Energy source mix and reference technologies used in the district heating supply under the baseline scenario

Reference – centralised (TWh)	2020	2030	Reference technologies for calculation of investments
Natural gas	63.8	80.2	75% CHP, 25% heating plant
Coal	36.1	12.0	75% CHP, 25% heating plant
Electricity	1.7	4.2	100% heating plant
Heat pumps*	-	15.8	100% water source heat pump
Bioenergy	18.2	16.1	75% CHP, 25% heating plant
Solar thermal	-	3.5	90% flat-plate collector, 10% evacuated tube
Geothermal	2.0	5.3	100% geothermal – direct
Non-renewable waste	11.2	13.5	75% CHP, 25% heating plant
Industrial waste heat	0.5	4.4	90% direct (heat exchanger), 10% waste-heat heat pump
Other	1.4	0.9	Divided between other energy sources
Total	**134.9**	**155.8**	

*For the assessment of heat pumps both the ambient energy and electricity used are indicated.

Source: Own assumptions based on Kemmler et al. (2020)

To calculate the heat generation costs of the technology mix under the baseline scenario, use is made of the energy-weighted generation costs for each technology used for the grid-based heating supply under the alternative scenarios. As coal as an energy source still accounts for a relevant share in 2030 under the baseline scenario compared with the alternative scenarios, it is also assessed using a reference technology and the associated costs. To calculate the investments and/or the resulting capital costs, the investments for a CHP steam turbine from the technology profiles are used (see Annex V.9). As in the case of the alternative scenarios, an investment in 2030 is taken as a basis. An operating period of 4,000 full load hours is assumed for each of the installations. For coal CHP an efficiency of 38% is assumed, as well as allocation factors for thermal capacity of 35% for primary energy and GHG emissions and 20% for heating costs (see also natural gas CHP in Table 13). As in the case of the other CHP technologies, the allocation is based on the Finnish method. An efficiency of 70% is assumed for the coal-fired heating plant. Besides capital and energy costs, fixed operating costs of €40,000/MW and variable operating costs of €1/MWh are taken into account (see technology profile CHP steam turbine in Section V.9).

Table 37 shows the results of the heat generation costs calculation for the assessment of the energy source coal under the baseline scenario from a microeconomic perspective. For the coal CHP reference technology the resulting specific heat generation costs are €36/MWh and for the coal-fired heating plant are €37/MWh.

Table 37: Calculation of heat generation costs for the energy source coal from a microeconomic perspective

	Coal CHP	Coal-fired heating plant
Cost function for coal [€ millions/MW]	1.00	1.12
2020 investment costs [€ millions]	2,263	842
Spec. investment costs [€ millions/MW]	1	1.1
Spec. capital costs [€/MWh]	7	8
2030 operating costs [€ millions]	99	33
Spec. operating costs [€/MW]	44,000	44,000
Spec. operating costs [€/MWh]	11	11
Energy costs [€/MWh]	18	18
Spec. heat generation costs [€/MWh]	36	36.8

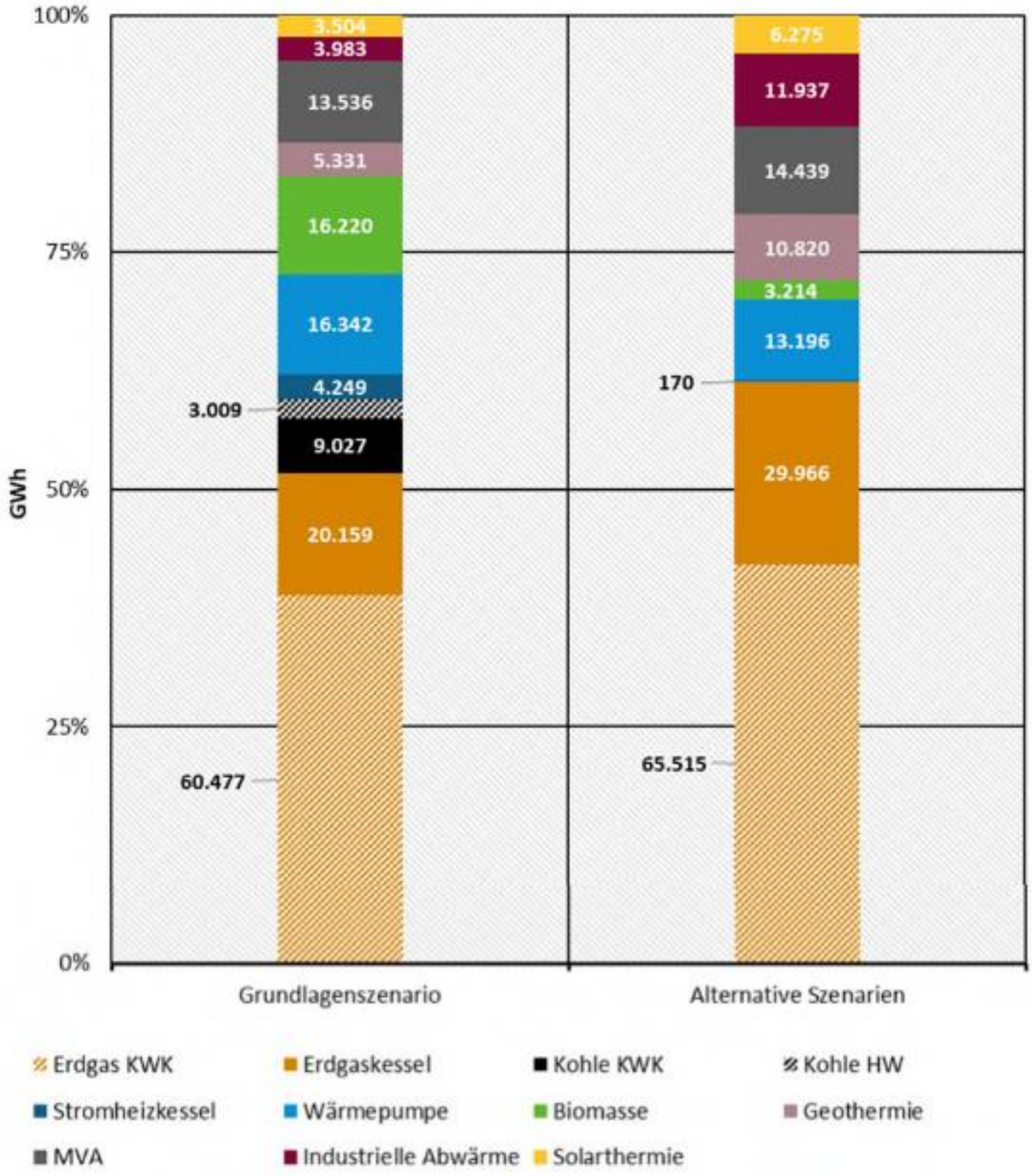
Source: Own figure (IREES) with data from Kemmler et al. (2020)

The calculation from a macroeconomic perspective is performed in the same way as the microeconomic calculation, with energy prices corrected accordingly for taxes and carbon levies and a social discount rate of 2% taken into account.

III.7.d. Results

III.7.d.i. Final energy supply via district heating

Figure 82 compares the final energy supplied via district heating under the alternative scenarios and the baseline scenario, broken down by generation technology. The removal of coal as an energy source under the alternative scenarios is compensated for by means of larger volumes of natural gas. Other differences can be seen in the use of electric boilers, which account for significantly higher shares in the district heating generation mix under the baseline scenario. The alternative scenarios are based on a detailed, regional high-resolution analysis of the potential for using renewable energies in the centralised supply, which means that it was possible to optimise their use relative to the baseline scenario. Consequently, direct and indirect waste heat, geothermal and solar thermal are used to a greater extent under the alternative scenarios, while biomass use is lower.



Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios
Erdgas KWK	Natural gas CHP
Stromheizkessel	Electric boiler
MVA	WIP
Erdgaskessel	Gas-fired boiler
Wärmepumpe	Heat pump
Industrielle Abwärme	Industrial waste heat
Kohle KWK	Coal CHP
Biomasse	Biomass
Solarthermie	Solar thermal

Kohle HW	Coal-fired heating plant
Geothermie	Geothermal

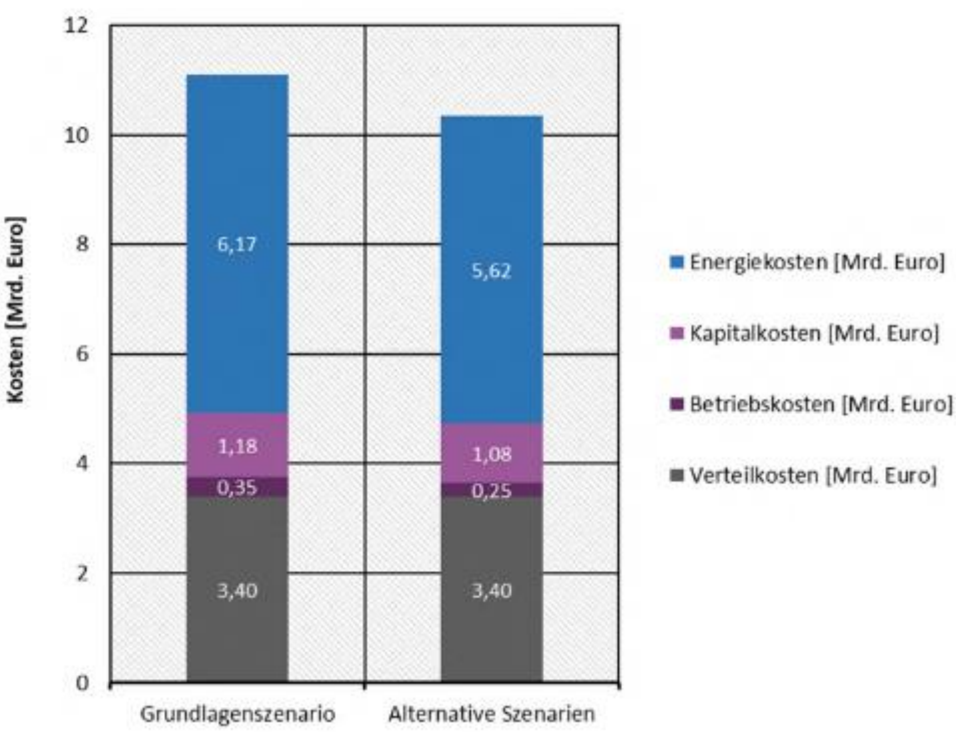
Source: Own figure (IREES)

Figure 82: Annual final energy supplied via district heating under the baseline scenario and alternative scenarios in GWh

III.7.d.ii. Economic potential from a microeconomic perspective

For the alternative scenarios the resulting average, energy-weighted heat generation costs are €67/MWh[51] and the average GHG emissions 138 g/kWh. In the case of the baseline scenario the average, energy-weighted heat generation costs resulting from the analysis are €71/MWh and the GHG emissions 153 g/kWh. The differential costs between the baseline scenario and alternative scenarios result from the difference between the total annual costs (absolute heat generation costs) under both scenarios (Figure 83). From a microeconomic perspective there are annual negative differential costs of €0.75 billion. Based on the assumptions made, the alternative scenarios are therefore more cost-efficient than the baseline scenario and lead to an annual cost saving of €0.75 billion. Differences can be seen in particular in the area of energy costs. There are lower energy costs under the alternative scenarios due to the use of natural gas instead of coal, lower use of biomass and electric boilers, and greater use of solar thermal energy. As both cases are ambitious scenarios, the total costs are close together. However, it is apparent that optimising and using locally available RE and waste heat potentials allows a more cost-efficient supply mix to be achieved at individual municipality level.

[51] The average heat generation costs under the alternative scenarios that result from the cost-benefit analysis are higher than those presented in Section III.6, as here the energy price development over the period from 2030 to 2050 is taken into account, rather than the energy prices for 2030.



Kosten [Mrd. Euro]	Costs [billion euro]
Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios
Energiekosten [Mrd. Euro]	Energy costs [billion euro]
Kapitalkosten [Mrd. Euro]	Capital costs [billion euro]
Betriebskosten [Mrd. Euro]	Operating costs [billion euro]
Verteilkosten [Mrd. Euro]	Distribution costs [billion euro]

Source: Own figure (IREES)

Figure 83: Microeconomic perspective: total annual costs of the district heating supply for the baseline scenario and alternative scenarios

Comparison of specific heat generation costs and GHG emissions of the technologies used under the alternative scenarios

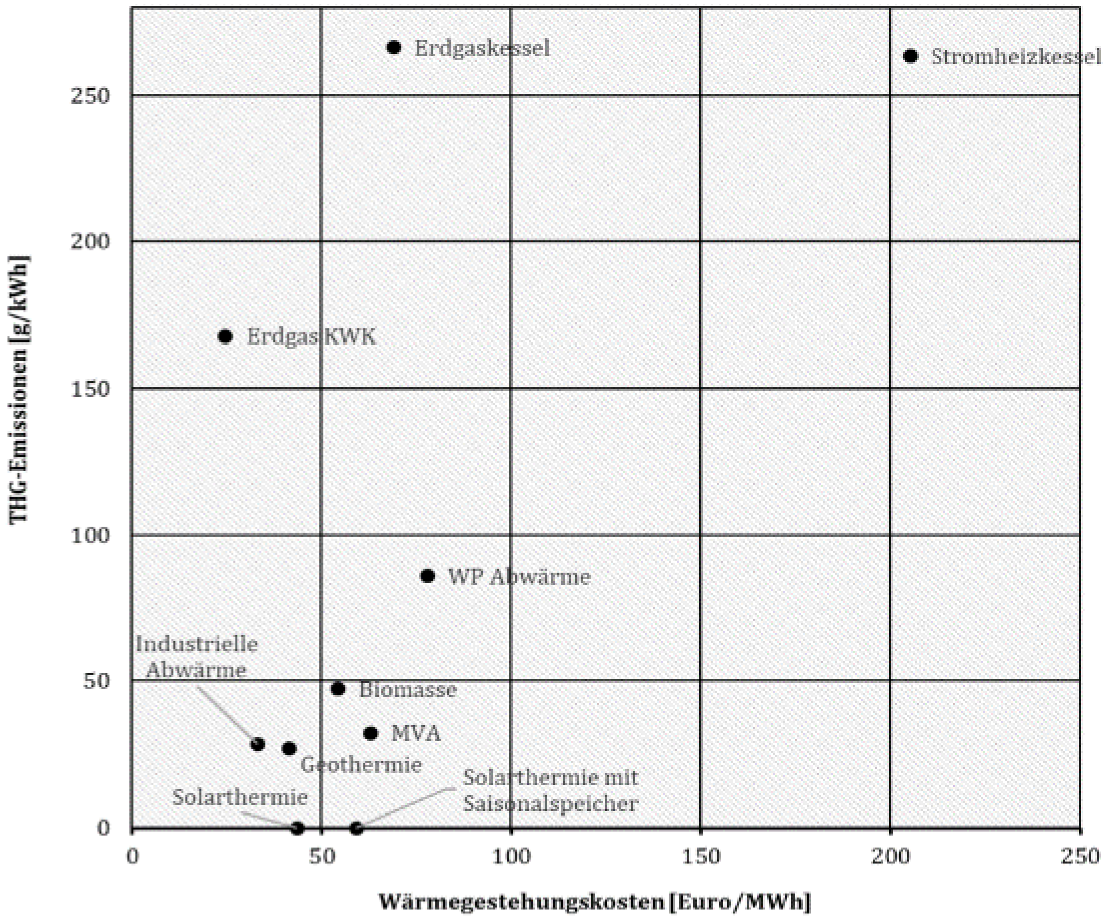
Figure 84 shows costs and benefits at technology level by relating specific heat generation costs from a microeconomic perspective to specific GHG emissions[52]. It should be noted that in the figure the costs are calculated as an average across all municipalities, which means that different installation dimensions and full load hours are incorporated into it. A direct comparison of costs at installation level is therefore impossible. In the comparison of technologies under the alternative scenarios, for example, the electric boiler has the highest heat generation costs, as it has high energy costs and only very low operating hours[53]. For the assessment of specific GHG emissions the average emission factor for electricity in 2030 is assumed[54]. Possible cost and benefit aspects

[52] In this figure without distribution costs

[53] Electric boilers are used as a lower-ranked RE option to achieve the prescribed RE and waste heat shares in the municipality. See Table 22 and the following sections.

[54] The combination with storage tanks and the monetary advantages due to sector coupling are not taken into account explicitly in the analysis and could reduce the costs.

that result from sector coupling incentives and electricity-market-driven operation at times with very low or negative electricity prices and a high level of renewable electricity feed-in, and thereby also low GHG emissions, are not taken into account here. Under real conditions an electricity-based heating supply in the area of district heating may therefore also be placed in the bottom left-hand corner of Figure 84 – low heat generation costs and low GHG emissions. As the analysis takes into account the expansion of renewables and waste heat in 2030 under the assumed scenario, the specific GHG emissions of the gas-fired boiler and electric boiler are of the same order of magnitude, assuming that the average emission factor for electricity in 2030 applies. Compared with the gas-fired boiler, and assessing electricity and heat in accordance with the Finnish model, efficient natural gas CHP performs better on both the costs and benefits side. In the bottom left-hand part of the graph renewable technologies can be found, as well as waste heat utilisation and waste incineration plants. Of the renewable technologies, the heat pump has the highest heat generation costs. As with the analysis of the electric boiler, here again benefits resulting from electricity-market-driven operation have not been quantified. For waste incineration plants no capital costs for the plant and connection have been taken into account, as only existing plants that are already integrated into heating networks have been taken as a basis. Furthermore, operating costs (personnel, repair and maintenance) have not been allocated to heat generation, as these are covered by the payments received for accepting the waste. Only auxiliary energy costs therefore apply.



THG-Emissionen [g/kWh]	GHG emissions [g/kWh]
Wärmegestehungskosten [Euro/MWh]	Heat generation costs [€/MWh]

Erdgaskessel	Gas-fired boiler
Stromheizkessel	Electric boiler
Erdgas KWK	Natural gas CHP
WP Abwärme	Waste heat HP
Industrielle Abwärme	Industrial waste heat
Biomasse	Biomass
MVA	WIP
Geothermie	Geothermal
Solarthermie	Solar thermal
Solarthermie mit Saisonalspeicher	Solar thermal with seasonal storage

Source: Own figure (IREES)

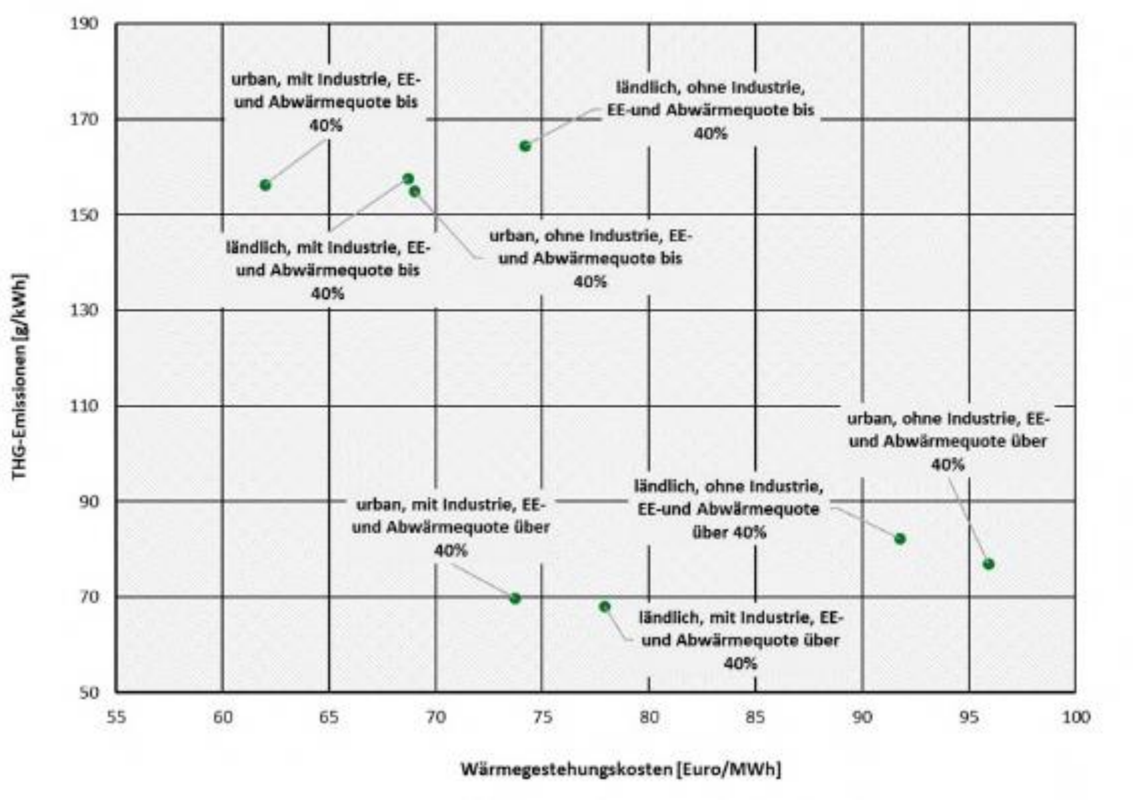
Figure 84: Comparison of specific heat generation costs and GHG emissions of technologies in the district heating supply under the alternative scenarios in 2030[55]

Comparison of specific heat generation costs and GHG emissions under the alternative scenarios by supply area cluster

Figure 85 shows the specific heat generation costs and GHG emissions of the clusters derived in Section III.6.b.i, which group together municipalities with similar structures in terms of the share of renewables and waste heat, as well as building density. It can be seen that, in most cases, due to the higher heating density and high level of heating sales, the costs in urban areas are lower than those in rural areas. The rural cluster with industry and a high RE and waste heat share, where inexpensive industrial waste heat can be integrated to a greater extent, is an exception. On the other hand, the urban cluster without industry and an RE and waste heat share above 40% is more expensive to supply than rural areas.

The cheapest specific heat generation costs can be found in the cluster ‘urban, with industry, RE and waste heat share up to 40%’. This is due primarily to the use of inexpensive industrial waste heat and the use of natural gas CHP and a gas-fired boiler. However, the GHG emissions in this cluster are comparatively high on account of the greater use of fossil fuels. The lowest specific GHG emissions can be found in the cluster ‘rural, with industry, RE and waste heat share over 40%’. Within this cluster the use of technologies is extremely diverse. In addition to the use of natural gas CHP, waste incineration plants and geothermal energy, the presence of industry makes it possible to use industrial waste heat directly, as well as indirectly via heat pumps.

[55] The cost differences compared with the figure in the previous analyses in Section III.6 are due to the fact that discounted interest rates are taken into account



THG-Emissionen [g/kWh]	GHG emissions [g/kWh]
urban, mit Industrie, EE- und Abwärmequote bis 40%	urban, with industry, RE and waste heat share up to 40%
ländlich, ohne Industrie, EE- und Abwärmequote bis 40%	rural, without industry, RE and waste heat share up to 40%
ländlich, mit Industrie, EE- und Abwärmequote bis 40%	rural, with industry, RE and waste heat share up to 40%
urban, ohne Industrie, EE- und Abwärmequote bis 40%	urban, without industry, RE and waste heat share up to 40%
urban, ohne Industrie, EE- und Abwärmequote über 40%	urban, without industry, RE and waste heat share over 40%
urban, mit Industrie, EE- und Abwärmequote über 40%	urban, with industry, RE and waste heat share over 40%
ländlich, ohne Industrie, EE- und Abwärmequote über 40%	rural, without industry, RE and waste heat share over 40%
ländlich, mit Industrie, EE- und Abwärmequote über 40%	rural, with industry, RE and waste heat share over 40%
Wärmegesteheungskosten [Euro/MWh]	Heat generation costs [€/MWh]

Source: Own figure (IREES)

Figure 85: Comparison of specific GHG emissions and heat generation costs of the district heating supply under the alternative scenarios by supply area cluster in 2030

Comparison of specific heat generation costs and GHG emissions at municipality level, taking the decentralised supply options into account

The following figures present the technological systems under the alternative scenarios in the 1,640 municipalities that are suitable for supply via a heating network (cf. III.6). The figures help to rank the results of the cost-benefit analysis and also provide important insights for planning decarbonisation strategies at town/city and municipality level.

In Figure 86 each of the municipalities represents a point, with the resulting specific heat generation costs[56] of the relevant technological system under the alternative scenarios on the x axis and the resulting specific GHG emissions on the y axis. The energy-weighted values for the individual municipalities can be used to calculate the result for Germany as a whole under the alternative scenarios (red point). To allow the results of the alternative scenarios at municipality level and overall to be ranked, the figure also contains the specific heat generation costs and GHG emissions under the baseline scenario (black point). In addition to the comparison of the centralised supply options, the average heat generation costs of the decentralised RE technologies (green) and of the decentralised natural gas supply with condensing boiler (grey) are also shown for 2030 in the form of lines (cf. III.6.b.iv).

It becomes clear that all municipalities that are suitable for a centralised supply via a heating network have significantly cheaper heat generation costs with the optimised technological systems compared with the gas-fired condensing boiler as a decentralised fossil-based reference technology in 2030. Compared with the decentralised RE heating technologies, the centralised technological systems also represent the cheaper option in almost all municipalities identified as having heating network potential. The comparison highlights the relevance of the centralised supply via heating networks in ensuring an efficient and climate-friendly supply of heating. However, the analysis also illustrates the substantial differences between municipalities resulting from the regional conditions in terms of heating demand and the regional RE and waste heat potentials. Some 1,197 municipalities are above the average value for the baseline scenario, for example.

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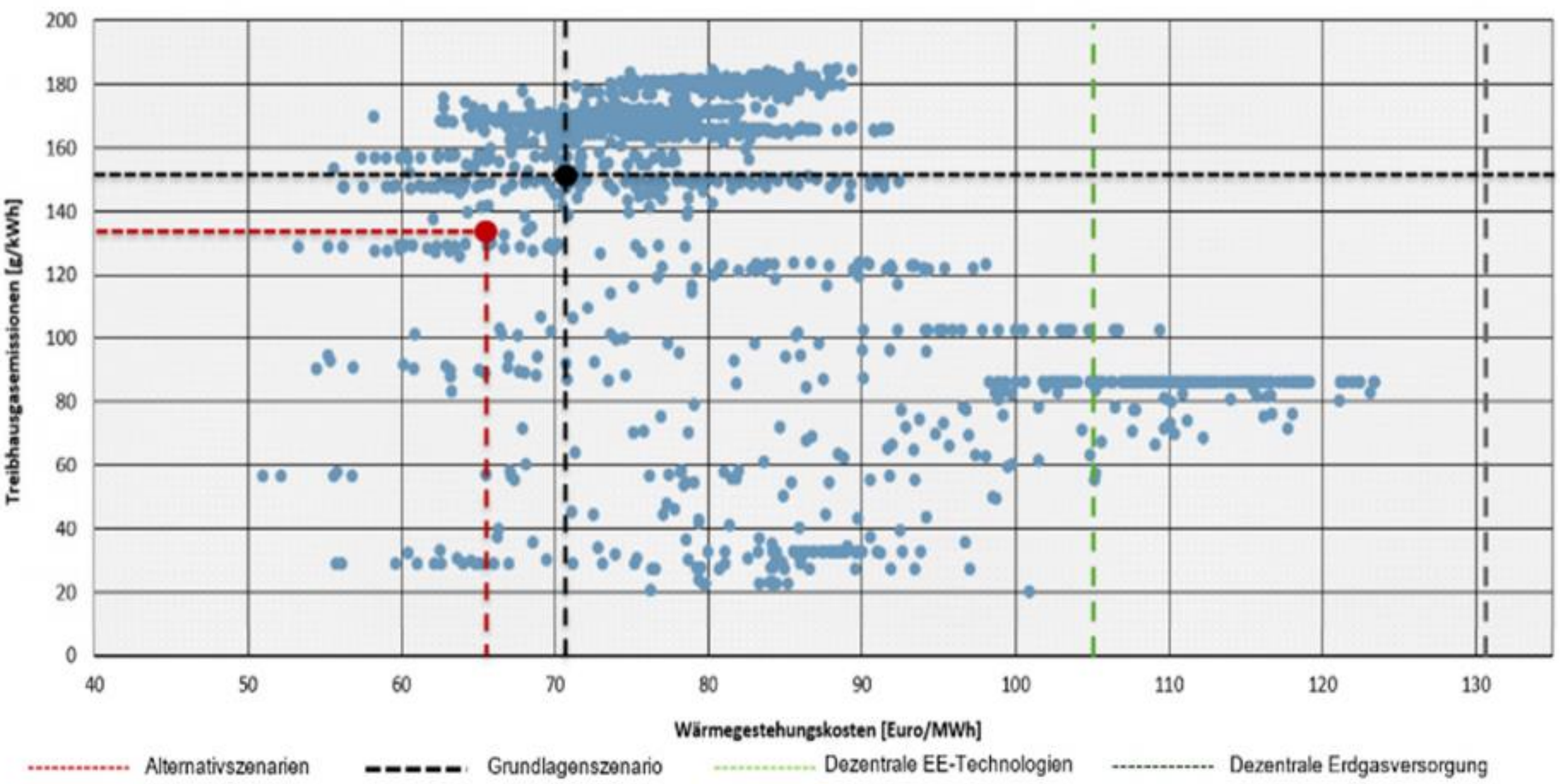
[56] The distribution costs for the grid-based heating supply are also taken into account.



Treibhausgasemissionen [g/kWh]	Greenhouse gas emissions [g/kWh]
Wärmegestehungskosten [Euro/MWh]	Heat generation costs [€/MWh]
Alternativszenarien	Alternative scenarios

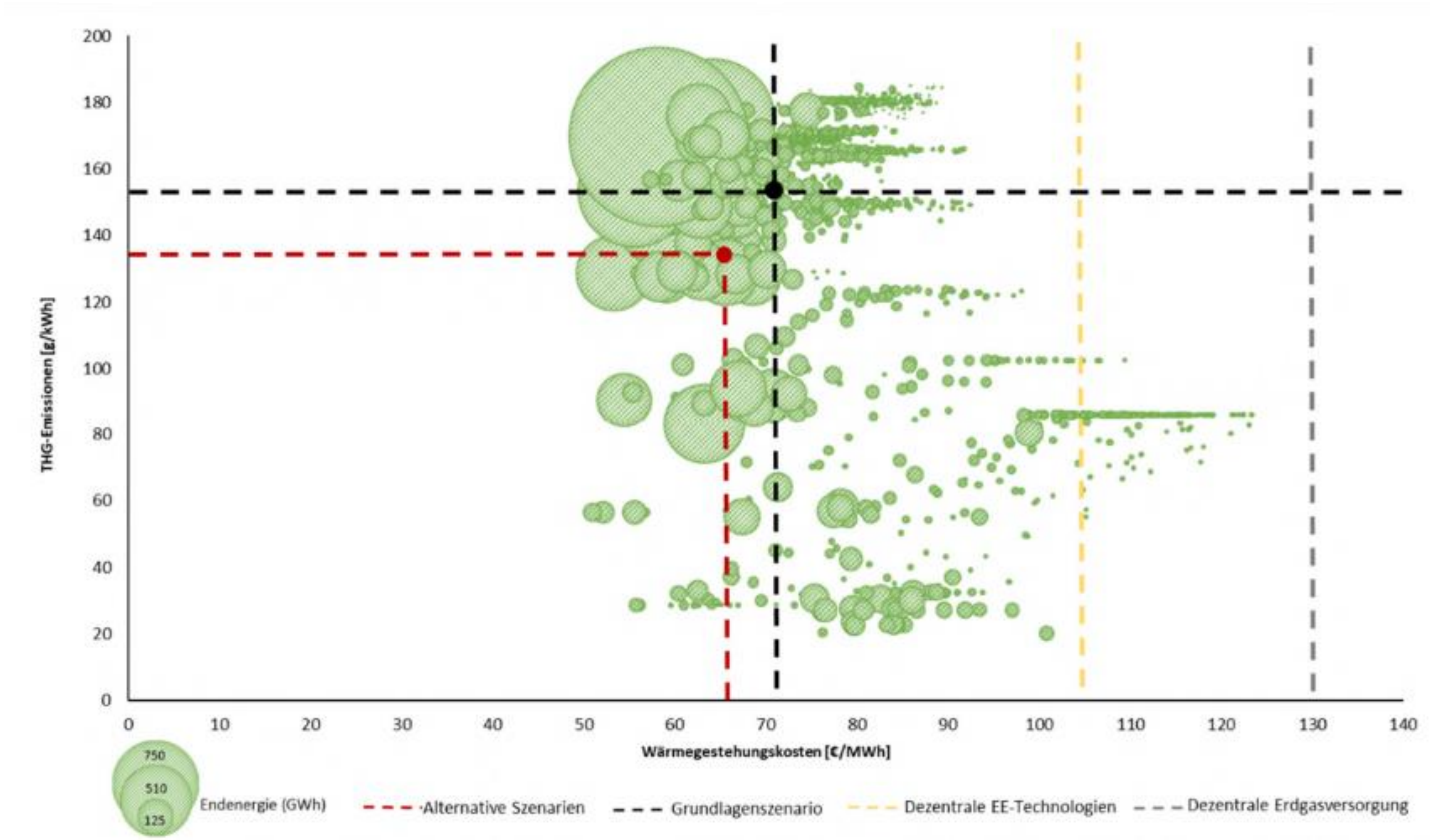
Grundlagenszenario	Baseline scenario
Dezentrale EE-Technologien	Decentralised RE technologies
Dezentrale Erdgasversorgung	Decentralised natural gas supply

Source: Own figure (IREES)

Figure 86: Specific GHG emissions and heat generation costs of the district heating supply for the municipalities examined under the alternative scenarios compared with the average values for the baseline scenario, as well as costs of decentralised supply options, in 2030

To allow the relevance of these municipalities to the overall results to be assessed, Figure 87 adds the dimension of annual district heating supply in GWh (shown in green) to the analysis.

It is apparent that higher specific costs and GHG emissions for the centralised heating supply systems are associated with a lower district heating supply. This is due, on the one hand, to the fact that the average heating distribution costs in areas with a high heating density (urban areas) are lower than in areas where the overall heating density is lower (rural areas). However, there are also municipalities where the supply of district heating is low in absolute terms and the heat generation costs and GHG emissions are also low, which means that other factors relating to heat generation are relevant. For the most part, municipalities that have higher specific GHG emissions and higher heat generation costs than the average values under the baseline scenario and alternative scenarios have only a low district heating supply. Nevertheless, the diagram shows that the level of the specific emissions does not correlate with the size of the supply via heating networks. The exploitation of local renewable energy and waste heat potentials is the crucial factor. In municipalities with very high final energy demand these potentials may be limited by the availability of land, for example. It should be noted that a complete comparison between the baseline scenario and alternative scenarios is not possible, as no spatial analysis is available for the baseline scenario and consequently there are no values at municipality level.



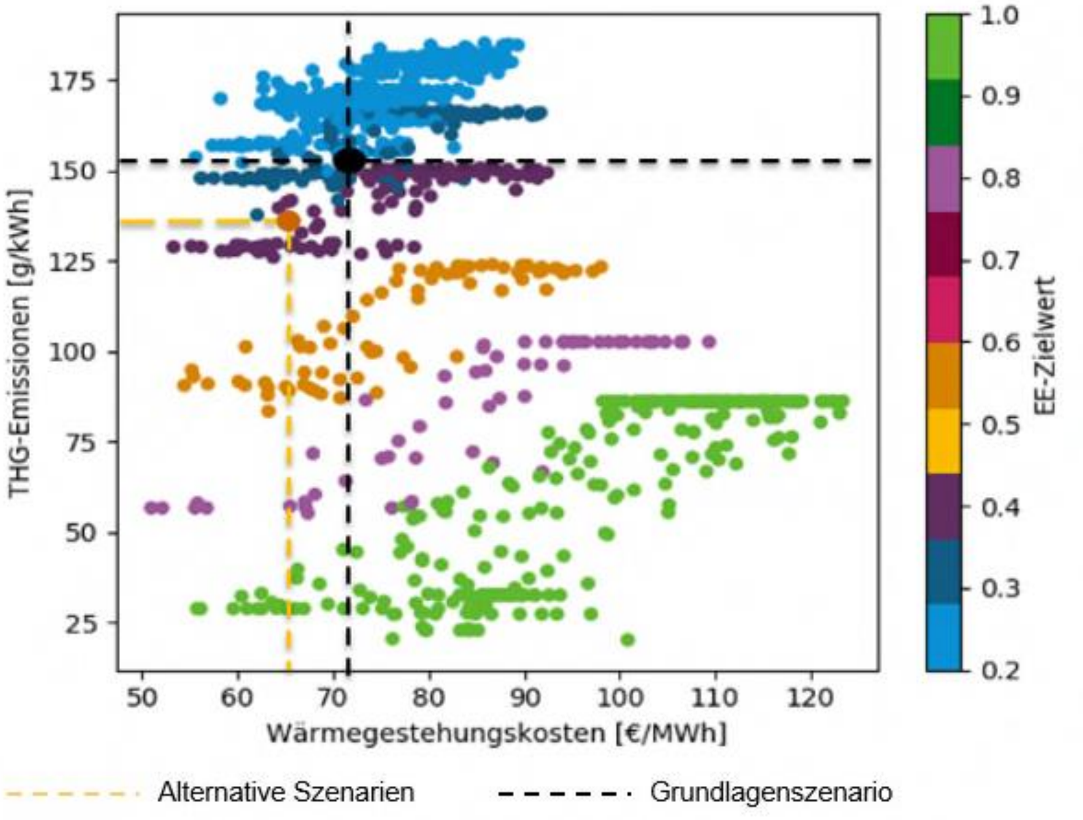
THG-Emissionen [g/kWh]	GHG emissions [g/kWh]
Wärmegestehungskosten [€/MWh]	Heat generation costs [€/MWh]

Endenergie (GWh)	Final energy (GWh)
Alternative Szenarien	Alternative scenarios
Grundlagenszenario	Baseline scenario
Dezentrale EE-Technologien	Decentralised RE technologies
Dezentrale Erdgasversorgung	Decentralised natural gas supply

Source: Own figure (IREES)

Figure 87: Specific GHG emissions and heat generation costs of the municipalities examined under the alternative scenarios compared with the baseline scenario and the alternative scenarios, with an indication of the final energy supplied via district heating, in 2030

To illustrate the influence of exploiting local RE potentials, Figure 88 adds the target value, resulting from the analyses, for renewable energies and waste heat in the relevant district heating mix to the two preceding figures (cf. Section III.6.a.i). It is apparent that municipalities with specific GHG emissions from the centralised supply of heating that are above the level of the baseline scenario have a share of RE and waste heat of 20% to 30% and thus have access to only limited local potentials for the centralised heating supply. A particularly great effort will therefore be needed in these municipalities to make the transformation to a renewable heating supply.



THG-Emissionen [g/kWh]	GHG emissions [g/kWh]
Wärmegestehungskosten [€/MWh]	Heat generation costs [€/MWh]
EE-Zielwert	RE target value
Alternative Szenarien	Alternative scenarios
Grundlagenszenario	Baseline scenario

Source: Own figure (IREES)

Figure 88: Specific GHG emissions and heat generation costs of the municipalities compared with the baseline scenario and alternative scenarios in 2030, with the share of renewable energies and waste heat in heating network final energy consumption indicated in accordance with Table 20

On the other hand, municipalities with a target value for renewable energies and waste heat of at least 80% have significantly higher specific heat generation costs than the baseline scenario. As highlighted above, in these municipalities there is substantial local renewable energy potential and technologies such as geothermal energy, industrial waste heat and waste incineration plants are used. Figure 88 makes clear that there is a causal connection between specific GHG emissions / heat generation costs and the target value for renewable energies and waste heat. Figure 87 shows, furthermore, that final energy demand is also a decisive factor with regard to the level of specific heat generation costs.

With the 2050 target in mind, strategies therefore need to be developed for both the decentralised and centralised supply of heating that allow full decarbonisation. As shown in Section III.6.b.ii, in addition to the consistent exploitation of local RE potentials, such as geothermal and solar thermal energy and waste water / waste heat, there is also a need, in particular, for large-scale heat pumps, PtH, and biogenic and synthetic fuels for the centralised supply. Whereas, to date, the advantages of a supply via heating networks have been assessed in particular on the basis of heating densities, and thus distribution costs, the analysis reveals that the cost-efficient exploitation and supply of climate-neutral heat should in fact be regarded as the decisive criterion. Bearing in mind that local potentials vary, there is a need to develop and implement integrated concepts at local level. Depending on the conditions, these should examine not only the balance between the decentralised and centralised heating supply, but also highlight the necessary level of ambition required in the area of energy efficiency measures. In certain municipalities that have insufficient local renewable heat or waste heat potentials, despite having relevant heating densities, it may therefore make more sense, with the achievement of targets in mind, to focus more on energy efficiency and decentralised technologies.

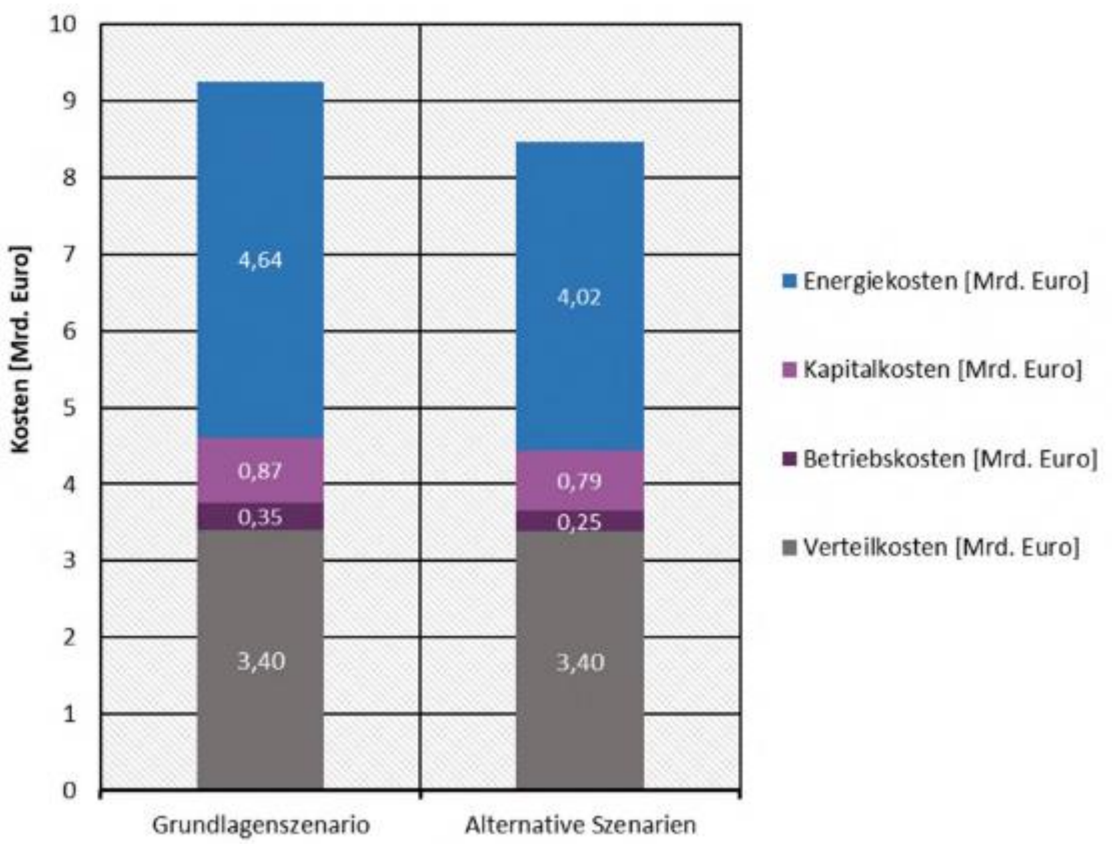
III.7.d.iii. Economic potential from a macroeconomic perspective

Table 38 shows the heat generation costs under the baseline scenario and alternative scenarios from a macroeconomic perspective. Due to fiscal corrections, there are lower absolute costs from a macroeconomic perspective, as these corrections mainly relate to taxes and levies in the area of energy costs. The capital costs are also lower under both scenarios on account of the applied discount rate of 2%. Under the cost-efficient alternative scenarios the absolute costs are around €0.79 billion per year lower compared with the baseline scenario. This roughly corresponds to the differential costs in the microeconomic analysis (cf. Figure 83). Around €0.09 billion of the savings can be allocated to operating costs, around €0.07 billion to capital costs and around €0.62 billion to energy costs.

Table 38: Macroeconomic perspective: annual differential costs for the centralised district heating supply

Costs [billion euro]	**Baseline scenario**	**Alternative scenarios**	**Differential costs [billion euro]**
Distribution costs	3.40	3.40	
Operating costs	0.35	0.25	-0.09
Capital costs	0.87	0.79	-0.07
Energy costs	4.64	4.02	-0.62
Heat generation costs	**9.26**	**8.47**	**-0.79**

Source: Own figure (IREES)



Kosten [Mrd. Euro]	Costs [billion euro]
Grundlagenszenario	Baseline scenario
Alternatieve Szenarien	Alternative scenarios
Energiekosten [Mrd. Euro]	Energy costs [billion euro]
Kapitalkosten [Mrd. Euro]	Capital costs [billion euro]
Betriebskosten [Mrd. Euro]	Operating costs [billion euro]
Verteilkosten [Mrd. Euro]	Distribution costs [billion euro]

Figure 89: Macroeconomic perspective: total annual costs of the district heating supply for the baseline scenario and alternative scenarios

Source: Own figure (IREES)

III.7.d.iv. GHG emissions and primary energy savings

Table 39 shows the avoided GHG emissions and the resulting external cost saving on account of avoided climate damage under the alternative scenarios compared with the baseline scenario. Overall, the specific GHG emissions under the alternative scenarios are 15 g/kWh lower than under the baseline scenario. In absolute terms emissions of

2.35 million tonnes of CO_2-eq are avoided per year. Given the estimated climate cost rate of €222.5 per tonne of CO_2-eq (cf. III.8.a), the avoided annual climate costs amount to roughly €522 million.

Table 39: Annual GHG emissions and climate damage associated with the district heating supply under the baseline scenario and alternative scenarios

	Baseline scenario	**Alternative scenarios**	**Avoided emissions [millions of tonnes of CO_2-eq]**	**Avoided costs of climate-related damage [million euro]**
Specific GHG emissions [g/kWh]	153	138		
GHG emissions [millions of tonnes of CO_2-eq]	23.8	21.4	2.4	
Climate damage [million euro]	5,292	4,769		522

Source: Own figure (IREES)

Table 40 shows the annual primary energy use and the primary energy factors determined for the technologies used under the baseline scenario and alternative scenarios. Overall, the primary energy use required for the latter is 4,742 GWh (4.7%) lower per year.

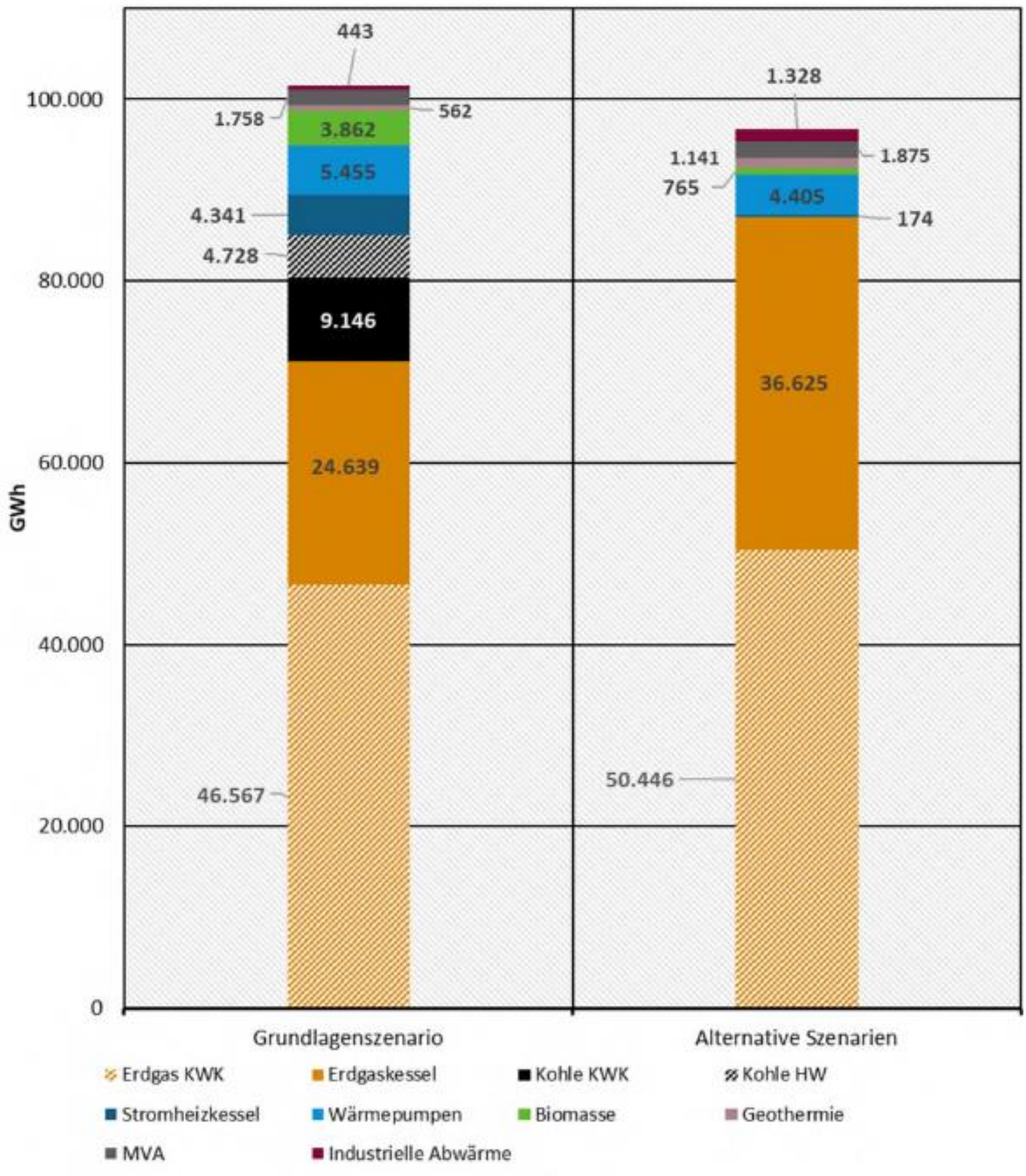
Table 40: Annual primary energy use and PE factors of the technologies used in the district heating supply under the baseline scenario and alternative scenarios

	Primary energy use		**PE factor**	
Technologies	**Baseline scenario**	**Alternative scenarios**	**Baseline scenario**	**Alternative scenarios**
Natural gas CHP	46,567	50,446	0.77	0.770
Gas-fired heating plant	24,639	36,625	1.22	1.222
Coal CHP	9,146		1.01	
Coal-fired heating plant	4,728		1.57	
Electrically-powered heating plant	4,341	174	1.02	1.022
Heat pump (electricity and ambient heat / waste heat)	5,455	4,405	0.33	0.334
Bioenergy CHP / heating plant	3,862	765	0.234	0.238
Geothermal	562	1,141	0.10	0.105
Waste CHP / heating plant	1,758	1,875	0.13	0.130
Waste heat – direct	443	1,328	0.11	0.111

Totals	**101,501**	**96,759**		

Source: Own figure (IREES)

Figure 90 provides a clear illustration of annual primary energy use, broken down by technology and energy source. It is apparent that under the alternative scenarios the energy source natural gas accounts for a dominant share of primary energy use. The next largest share of primary energy use can be attributed to heat pumps. Under the baseline scenario, in addition to the use of natural gas, coal also accounts for a significant proportion of primary energy consumption. Electricity in electrically-powered heating plants, heat pumps and biomass also have substantial shares.



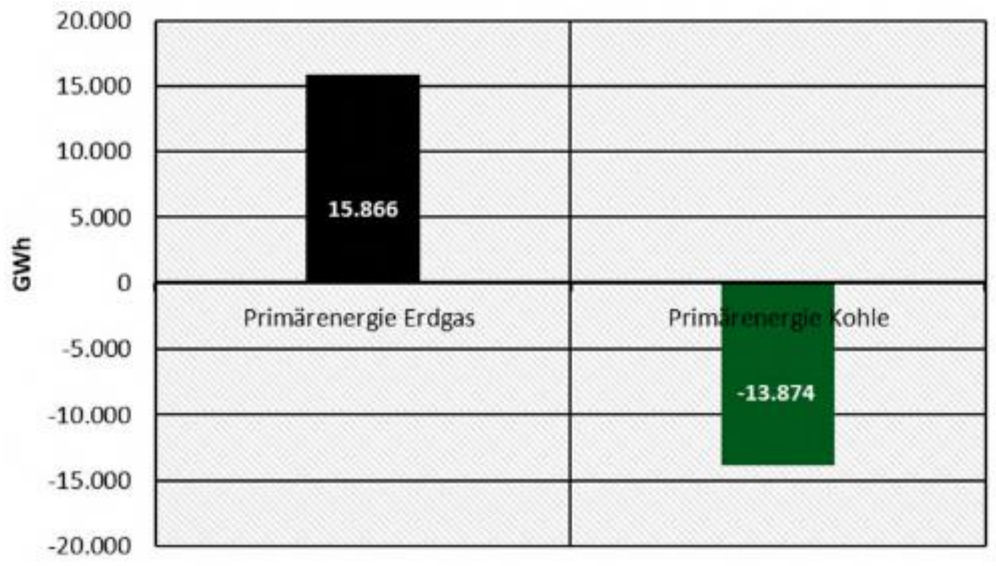
Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios
Erdgas KWK	Natural gas CHP
Stromheizkessel	Electric boiler
MVA	WIP
Erdgaskessel	Gas-fired boiler
Wärmepumpen	Heat pumps
Industrielle Abwärme	Industrial waste heat
Kohle KWK	Coal CHP
Biomasse	Biomass
Kohle HW	Coal-fired heating plant
Geothermie	Geothermal

Source: Own figure (IREES)

Figure 90: Annual primary energy use of the district heating supply, broken down by technology, for the baseline scenario and alternative scenarios

III.7.d.v. Energy security

The impacts of the alternative scenarios on energy security are based on a qualitative approach. For energy security the indicator is the reduction in energy source imports from outside Europe. The main energy sources for which imports are relevant under the alternative and baseline scenarios are natural gas and coal, as renewable energies and waste heat are available locally. Figure 91 shows the difference in the primary energy use of these energy sources between the alternative scenarios and baseline scenario.



Primärenergie Erdgas	Primary energy natural gas
Primärenergie Kohle	Primary energy coal

Source: Own figure (IREES)

Figure 91: Annual difference in the primary energy use of the energy sources natural gas and coal in the district heating supply under the baseline scenario and alternative scenarios

Under the alternative scenarios coal use is 13,874 GWh lower in total, which corresponds to a reduction in hard coal imports of 7,631 GWh. This value results from an examination of primary energy consumption from coal in 2030. According to the baseline scenario, 345 TWh of hard coal and 282 TWh of brown coal will be needed in 2030, which corresponds to a ratio of 55% hard coal to 45% brown coal. Since 2019 Germany has been entirely dependent on imports for hard coal (Bundesministerium für Wirtschaft und Energie, 2020).

The lower imports of 7,631 GWh result from applying the 55% share for hard coal under the baseline scenario to the overall lower use of 13,874 GWh under the alternative scenarios, based on the assumption that the remaining primary energy demand is covered by brown coal, which is mined entirely in Germany. Furthermore, 15,866 GWh more natural gas is used under the alternative scenarios than under the baseline scenario. With 97% dependence on imports of natural gas in 2030, this corresponds to natural gas imports that are 15,390 GWh higher compared with the baseline scenario.

In purely arithmetical terms, the share of imported energy sources under the alternative scenarios is slightly higher in total than under the baseline scenario. However, as the differences, measured in terms of the total primary energy use for heating and cooling, are marginal and are also below 2% in relation to the district heating supply, no relevant influence on changes in energy security can be derived from the indicator.

III.7.d.vi. Impact on jobs

The assessment of possible impacts on jobs can only be discussed in qualitative terms. According to Fleiter et al. (2017), possible macroeconomic effects resulting from changes to the energy supply can be attributed to additional investments in heating and cooling technology and the corresponding economic stimuli in certain sectors that account for a high proportion of value added in relation to these technologies. An additional potential stimulus results from a reduction in energy costs, which, although leading to lower demand in the energy sector, could induce higher demand in other sectors due to the capital freed up, which in turn results in a structural change in consumer spending. The change in energy imports can be cited as a third effect. This leads to a change in the balance of trade and consequently to higher aggregate demand. According to Fleiter et al. (2016), a rise in total investments and a reduction in total energy costs and total energy imports due to efficiency measures and the increase in the supply of renewable heating and cooling have a positive impact on gross domestic product (GDP) and jobs.

However, the cost-benefit analysis compares two scenarios that are very close together in terms of these indicators, meaning that no statement can be made regarding any difference between the baseline scenario and alternative scenarios as regards a positive macroeconomic effect.

III.8. Sensitivity analysis

The aim of the sensitivity analysis is to analyse the uncertainties and the ranges of outcomes. To this end, the key techno-economic assumptions are varied and their impacts on the cost-benefit analysis are examined from a microeconomic and macroeconomic perspective. In total, ten sensitivity calculations are performed (cf. Table 41). Besides the impacts on the net present value, changes in climate costs are also taken into account. The sensitivity analysis thus determines the robustness of the alternative scenarios in relation to changes in certain parameters. On the one hand, the results make it possible to assess the absolute changes that result from varying parameters within the relevant scenarios. On the other, it is also possible to assess to what extent the relative benefit possibly changes between alternative scenarios and therefore how robust a scenario is in relation to the uncertain framework conditions.

Figure 92 summarises the uncertainties resulting from the key assumptions for the cost-benefit analysis and shows how these can be parameterised in the sensitivity analysis. For the performance of the sensitivity analysis in the *Comprehensive assessment of the potential for efficient heating and cooling* the EU Commission's Joint Research Centre (JRC) also recommends varying the investment and operating costs, a high- and a low-price variant for electricity and fuels and a high and a low value for the assessment of damage due to climate change (Jakubcionis et al., 2015).

Unsicherheit	Parameter in der Sensitivitätsanalyse
Technologieentwicklung/technologisches Lernen	▪ Spezifische Investitionen in Wärme und Kälteversorgungstechnologien ▪ Spezifische Betriebskosten
Regulatorischer Rahmen	▪ Strom- und Brennstoffpreise aufgrund veränderter Umlagen, Steuern, CO_2-Preise, etc.
Weltmarktpreise fossiler Brennstoffe	▪ Strom- und Brennstoffpreise
Risikobewertung und Marktzinsveränderung	▪ Diskontierungsrate
Bewertung der Klimafolgeschäden	▪ Spezifische Klimakosten

Unsicherheit	Uncertainty
Parameter in der Sensitivitätsanalyse	Parameters in the sensitivity analysis

Technologieentwicklung/technologisches Lernen	Technology development / technological learning
Spezifische Investitionen in Wärme und Kältever-sorgungstechnologien	Specific investments in heating and cooling supply technologies
Spezifische Betriebskosten	Specific operating costs
Regulatorischer Rahmen	Regulatory framework
Strom- und Brennstoffpreise aufgrund veränderter Umlagen, Steuern, CO_2-Preise, etc.	Electricity and fuel prices due to adjusted levies, taxes, carbon prices, etc.
Weltmarktpreise fossiler Brennstoffe	Global market prices for fossil fuels
Strom- und Brennstoffpreise	Electricity and fuel prices
Risikobewertung und Marktzinsveränderung	Risk assessment and change in market inter-est rates
Diskontierungsrate	Discount rate
Bewertung der Klimafolgeschäden	Assessment of damage due to climate change
Spezifische Klimakosten	Specific climate costs

Source: Own figure (IREES)

Figure 92: Uncertainties in the assumptions and parameters in the sensitivity analysis

III.8.a. Framework data

The proposed range for the parameters is presented in Table 41. The JRC's recommendations are followed for the variation of investment and operating costs (Jakubcionis et al., 2015). With regard to the variation of fossil fuel prices, the assumption relating to the development of carbon pricing in the NECP provides an indicator for the possible ranges. The maximum price of €65/tonne of CO_2-eq targeted in 2026 results in an increase in fuel prices of 12% for natural gas and 13% for fuel oil in 2026, compared with the assumed price path development without carbon pricing. For the lower fuel price variant in the sensitivity calculation it is assumed that the carbon price within the national Emissions Trading Scheme (nETS) will remain constant at €65/tonne of CO_2-eq[57]. In the case of the EU ETS the 2020 price of €15.5/tonne of CO_2-eq is assumed to be constant as a lower variant. The carbon pricing under the nETS that is assumed to apply in the NECP, with an increase to €285/tonne in 2035, is already considered to be very high. To analyse the impacts of a further increase in the price of fossil fuels on the cost-efficiency of innovative heating systems, a rise in fossil fuel prices is assumed in the sensitivity calculation. As the differences between the baseline and alternative scenarios lie only in the area of the district heating supply, only the assumptions relating to the EU ETS price are relevant for the sensitivity calculation. Here an additional increase in the carbon price is assumed that will see this rise to €56/GJ in 2035.

[57] For ease of presentation the nominal prices are stated here, as these have been communicated in relation to the national Emissions Trading Scheme. In the analysis these are converted to real prices based on 2016 prices.

For the assessment of damage due to climate change the cost rates for a time preference rate of 0% are assumed as an upper variant, in accordance with the recommendations of the UBA (Matthey & Bünger, 2019). As explained in Annex 0, here again an average is taken from the rates indicated for 2030 and 2050. This results in a cost rate for the upper variant of €700/tonne of CO_2-eq. For the lower variant in the sensitivity analysis an average of the cost rates between 2020 and 2030 is assumed[58].

For established technologies, such as natural gas CHP, no technological developments, and consequently no economies of scale, are assumed. In the sensitivity analysis lower specific investment and operating costs are therefore calculated only for RE technologies and the technology industrial waste heat.

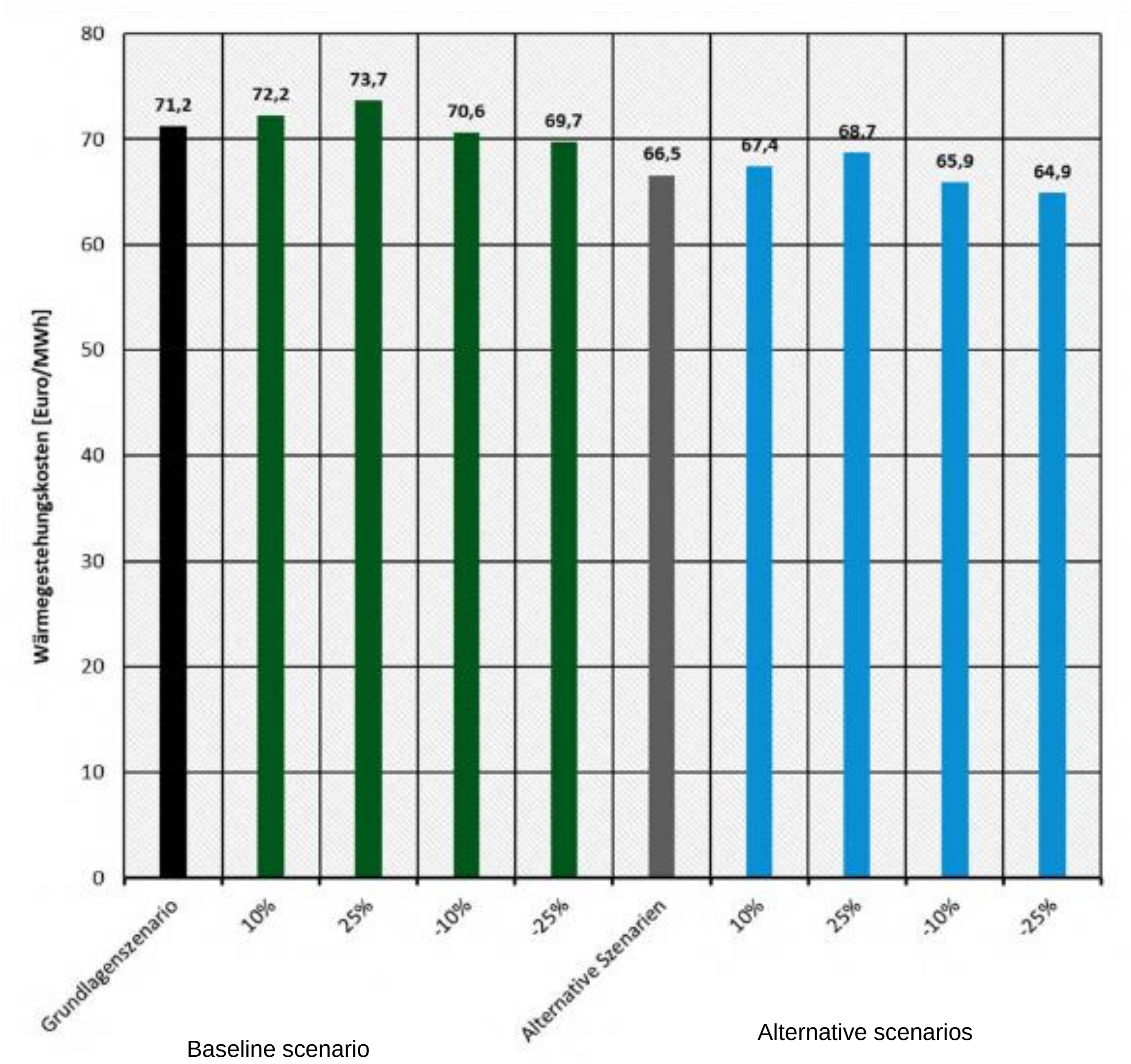
Table 41: Parameterisation of sensitivity analysis

Parameter	Upper variant	Lower variant
Specific investment and operating costs	+25%, +10%	-25%, -10%
Fossil fuel prices	EU ETS: 2025: €31/EUA 2030: €45/EUA 2035: €56/EUA	EU ETS: 2025: €16/EUA 2030: €16/EUA 2035: €16/EUA
Discount rate	10%	1%
Damage due to climate change	€700/tCO_2-eq	€196/tCO_2-eq

III.8.b. Results

Figure 93 shows the specific heat generation costs under the alternative scenarios and the baseline scenario with varying specific operating and investment costs, from a microeconomic perspective. As explained in Annex IV, a 10% or 25% reduction in these costs is calculated only for RE technologies and industrial waste heat, as additional learning effects and economies of scale can be assumed for these technologies. On the other hand, a 10% or 25% increase is applied for all technologies. Due to these assumptions, the change in the specific heat generation costs is also not linear. It can be seen that the increase or reduction in investment costs only has a minor impact on heat generation costs (increased or reduced by a maximum of €2.5/MWh).

[58] In (Matthey & Bünger, 2019) cost rates are indicated for 2016, 2030 and 2050. Use of interpolation is envisaged for the years in between, resulting in a cost rate of €187/tonne of CO_2-eq for 2020. This results in an average of €196/tonne of CO_2-eq between 2020 and 2030.



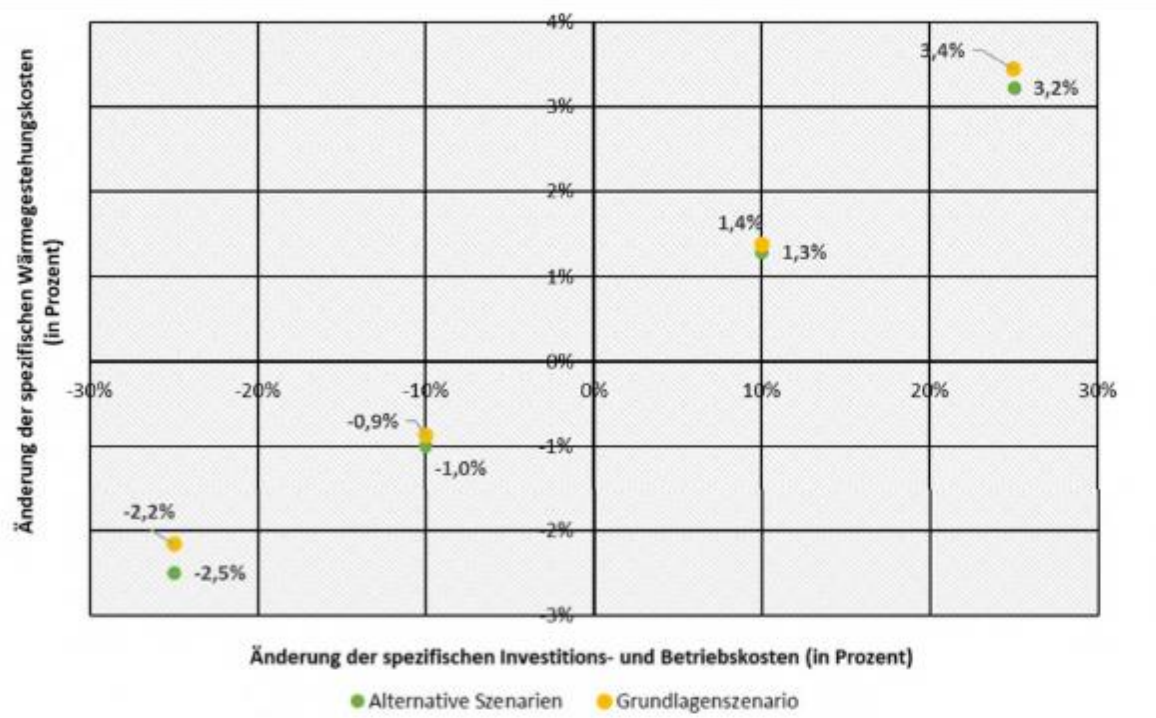
Wärmegestehungskosten [Euro/MWh]	Heat generation costs [€/MWh]
Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios

Source: Own figure (IREES)

Figure 93: Specific heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with varying specific investment and operating costs in 2030

In Figure 94 it is apparent that if operating and investment costs increase by 10%, the specific heat generation costs under the alternative scenarios rise by 1.3%. They rise by around 3.2% in the event of a 25% increase in these costs. If the operating and investment costs decrease by 10%, the specific heat generation costs fall by 1%, and by 2.5% in the event of a 25% cost reduction. Under the baseline scenario the specific heat generation costs rise by 1.4% in the event of a 10% increase in operating and investment costs and by 3.4% if there is a 25% increase. If the operating and investment costs decrease by 10%, the specific heat generation costs fall by 0.9%, and by 2.2% in the event of a 25%

cost reduction. Overall, it can be stated that the heat generation costs under all scenarios are very robust to operating and investment costs.

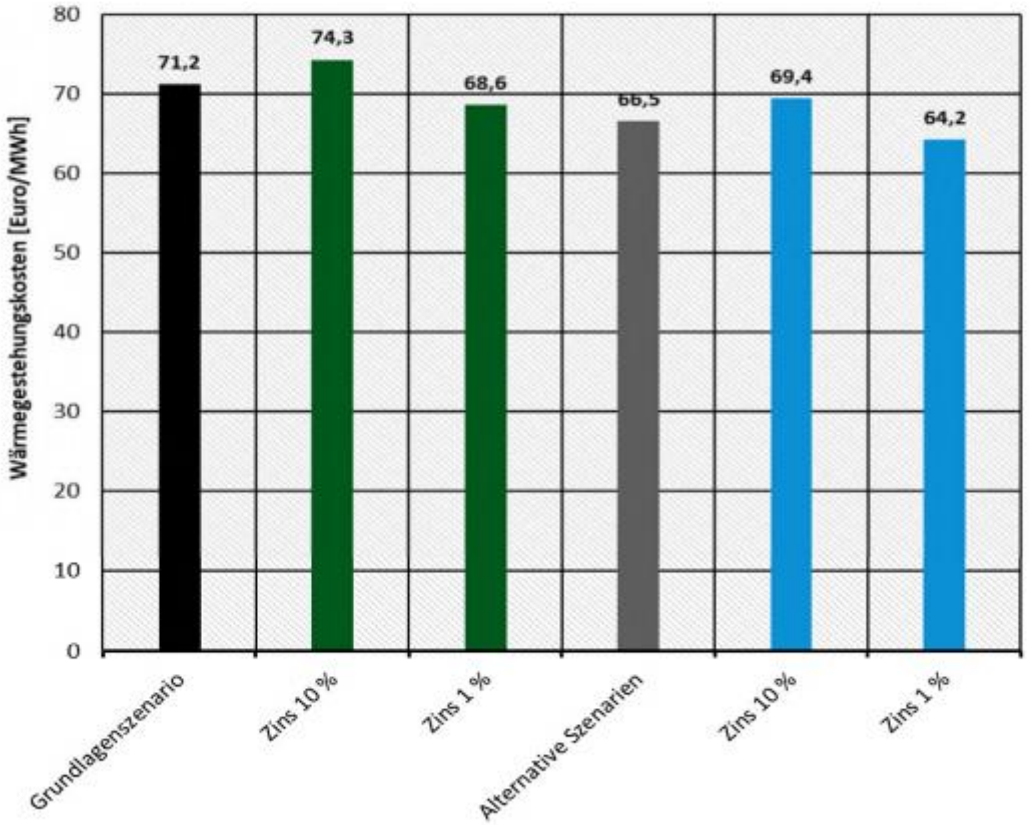


Änderung der spezifischen Wärmegestehungskosten (in Prozent)	Change in specific heat generation costs (in per cent)
Änderung der spezifischen Investitions- und Betriebskosten (in Prozent)	Change in specific investment and operating costs (in per cent)
Alternative Szenarien	Alternative scenarios
Grundlagenszenario	Baseline scenario

Source: Own figure (IREES)

Figure 94: Change in specific heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with varying specific investment and operating costs in 2030

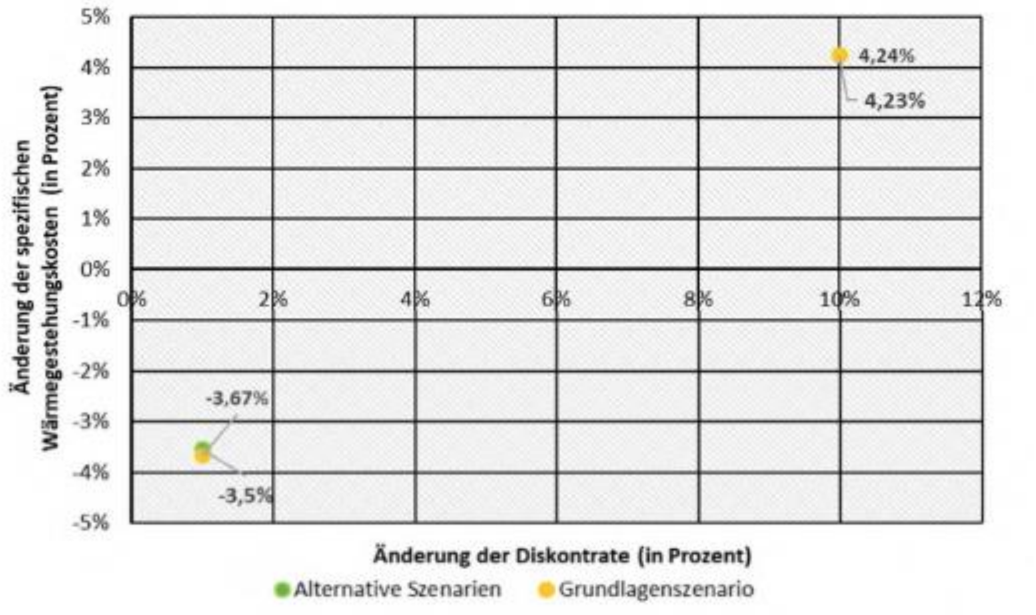
Figure 95 shows the level of specific heat generation costs under the baseline scenario and alternative scenarios with a varying discount rate, from a microeconomic perspective. Figure 96 shows the percentage change in specific heat generation costs in the event of a change in the discount rate. If the discount rate changes by 10%, this results in an increase in heat generation costs of around 4.2% to €69/MWh under the alternative scenarios. In the event of a discount rate of 1%, on the other hand, heat generation costs fall by 3.5% to €64/MWh. If the discount rate increases, the specific heat generation costs change by almost the same amount under the baseline scenario as under the alternative scenarios. On the other hand, if the discount rate is low, the specific heat generation costs fall by around 3.7%.



Wärmegestehungskosten [Euro/MWh]	Heat generation costs [€/MWh]
Grundlagenszenario	Baseline scenario
Zins	Interest
Alternative Szenarien	Alternative scenarios

Source: Own figure (IREES)

Figure 95: Specific heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with a varying discount rate in 2030

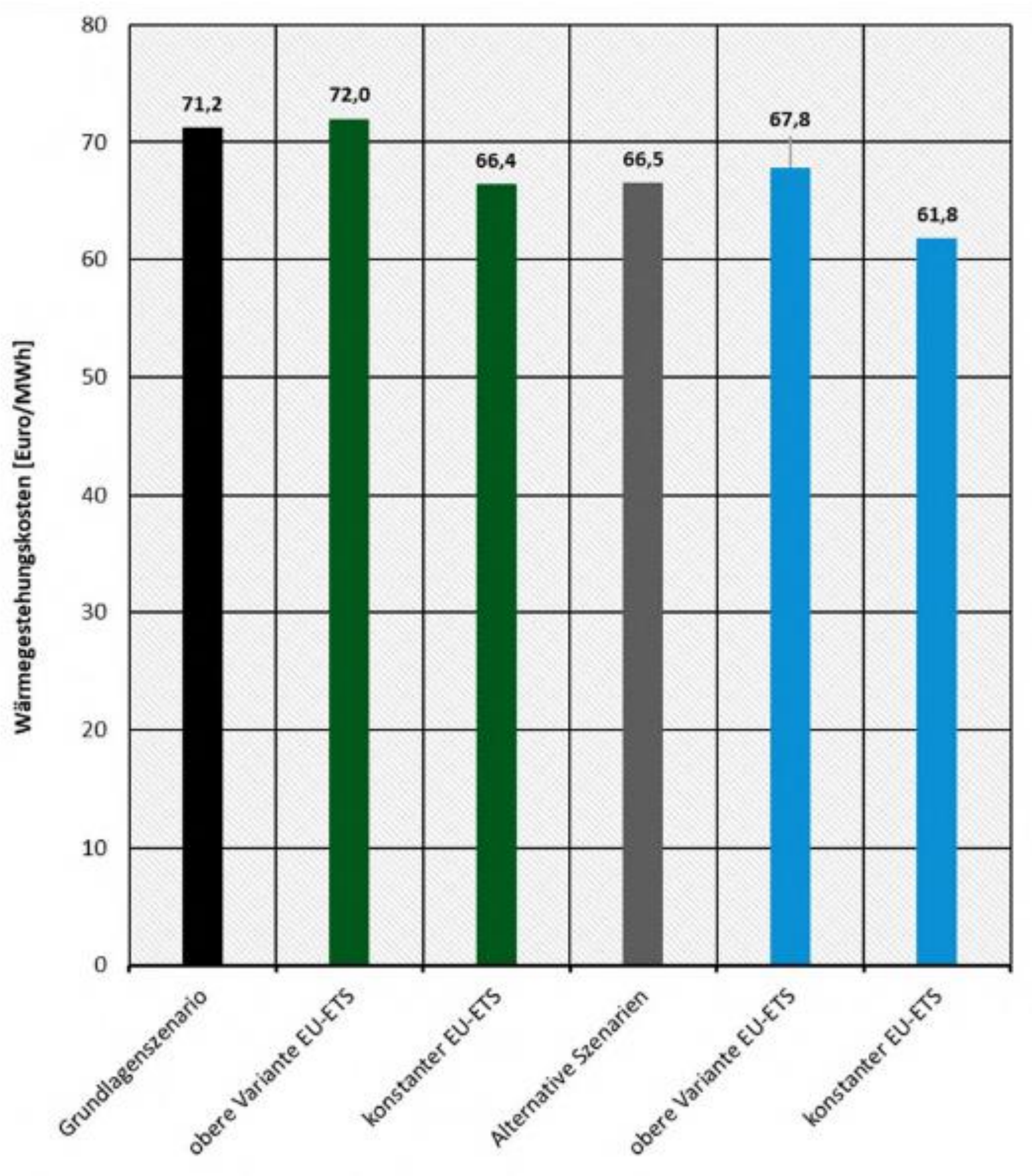


Änderung der spezifischen Wärmegestehungskosten (in Prozent)	Change in specific heat generation costs (in per cent)
Änderung der Diskontrate (in Prozent)	Change in discount rate (in per cent)
Alternative Szenarien	Alternative scenarios
Grundlagenszenario	Baseline scenario

Source: Own figure (IREES)

Figure 96: Change in specific heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with a varying discount rate in 2030

Figure 97 shows the level of specific heat generation costs under the baseline scenario and alternative scenarios with a varying EU ETS. The lower variant corresponds to a constant price of €15.65/tonne of CO_2-eq. The higher variant corresponds to an increase in the price from €16/tonne of CO_2-eq in 2020 to €45/tonne of CO_2-eq in 2030 and to €56/tonne in 2035. From 2035 onwards it is assumed that the higher variant of the EU ETS will be consistently €12.5 above the price projection of the actual EU ETS on which the preceding analyses are based.

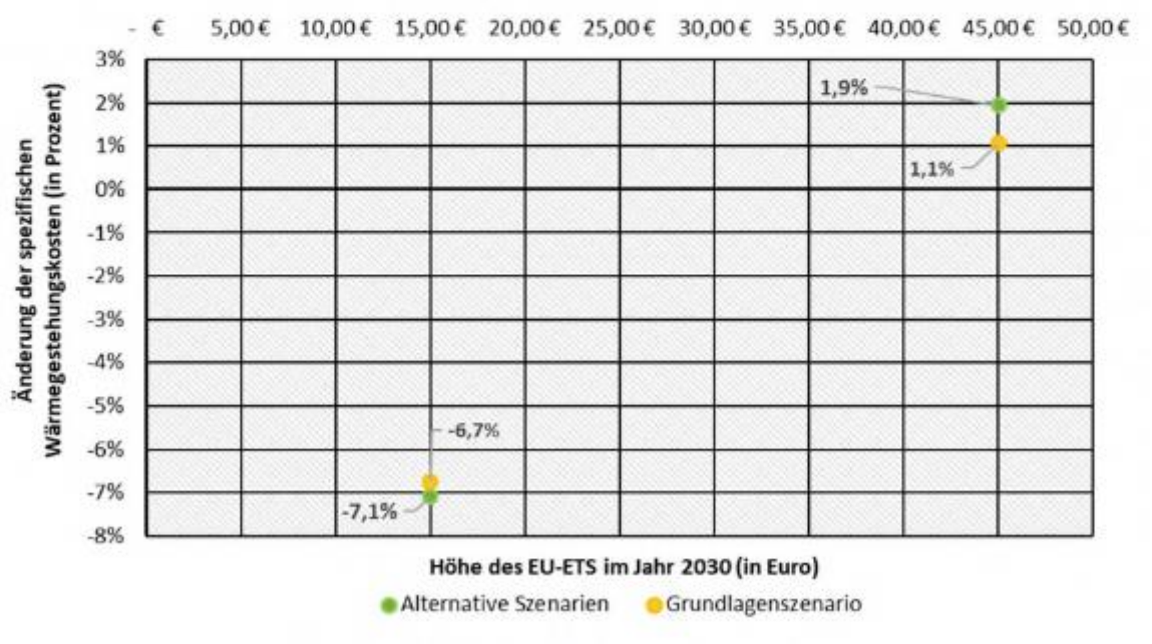


Wärmegestehungskosten [Euro/MWh]	Heat generation costs [€/MWh]
Grundlagenszenario	Baseline scenario
obere Variante EU-ETS	Upper variant EU ETS
konstanter EU-ETS	Constant EU ETS
Alternative Szenarien	Alternative scenarios

Source: Own figure (IREES)

Figure 97: Specific heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with a high and constant EU ETS in 2030

In the case of the higher variant of the EU ETS the specific heat generation costs under the alternative scenarios rise by around 2%, as can be seen in Figure 98. With a constant EU ETS of €15.5/tonne the specific heat generation costs under the alternative scenarios fall by around 7%. Under the baseline scenario the specific heat generation costs rise by around 1% in the case of a higher EU ETS, but fall by 6.7% if the EU ETS is constant.



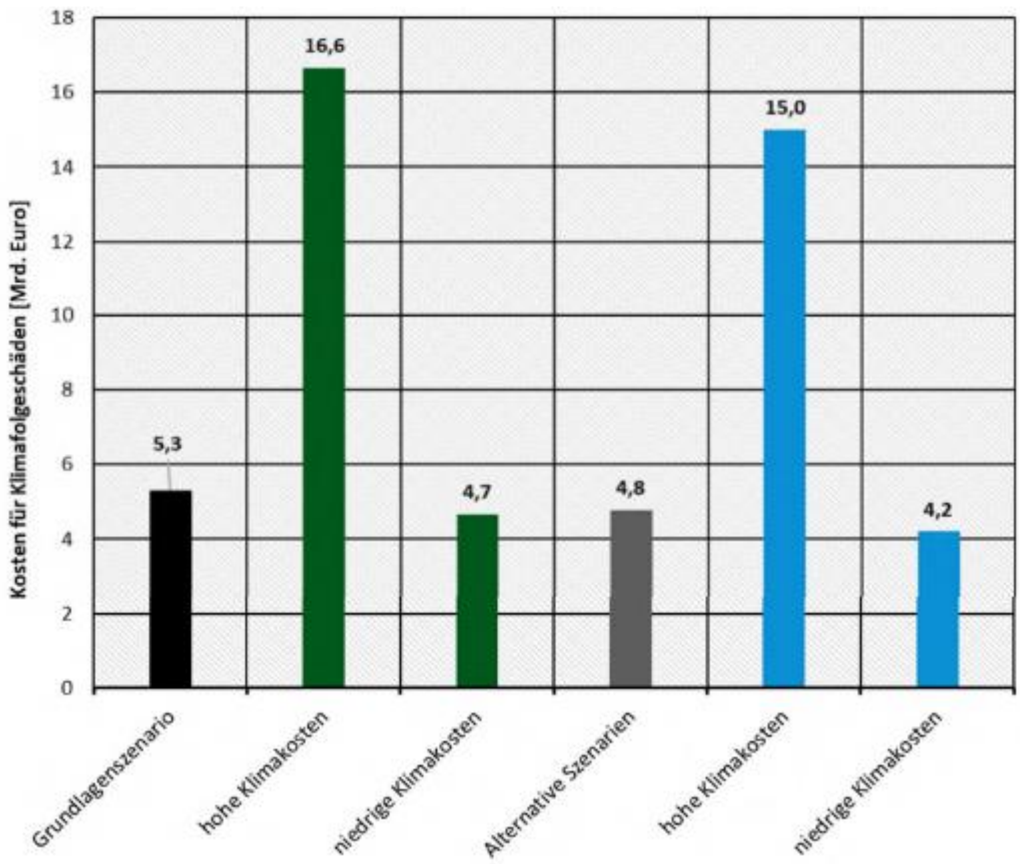
Source: Own figure (IREES)

Änderung der spezifischen Wärmegestehung-skosten (in Prozent)	Change in specific heat generation costs (in per cent)
Höhe des EU-ETS im Jahr 2030 (in Euro)	Level of EU ETS in 2030 (in euro)
Alternative Szenarien	Alternative scenarios
Grundlagenszenario	Baseline scenario

Source: Own figure (IREES)

Figure 98: Change in specific annual heat generation costs of the district heating supply under the baseline scenario and alternative scenarios with a high and constant EU ETS in 2030

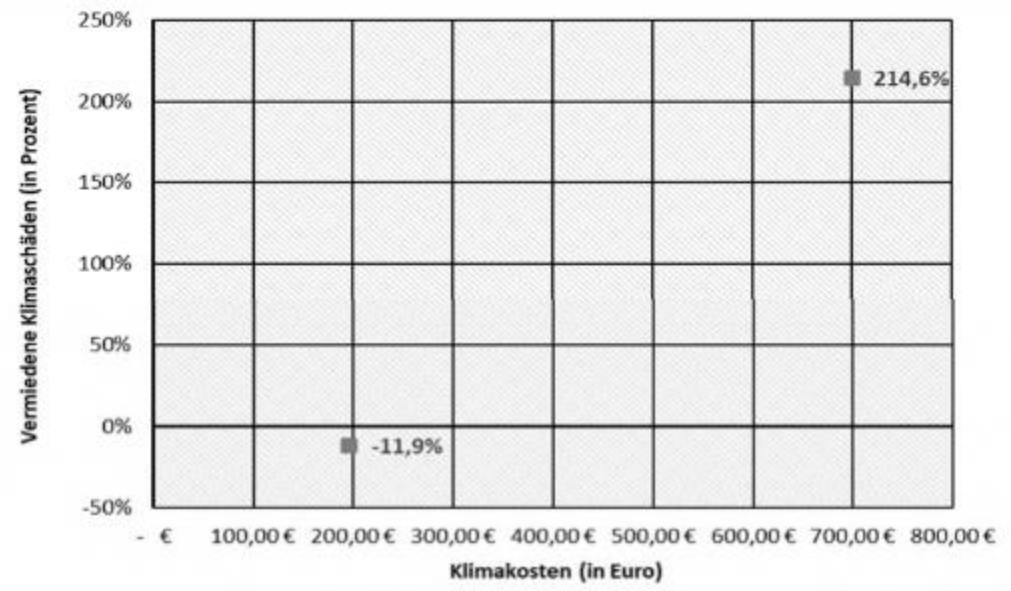
The costs of damage due to climate change are calculated at macroeconomic level. Climate costs of €222.5/tonne of CO_2-eq are used in the cost-benefit analysis. Figure 99 shows the absolute costs of damage due to climate change under the baseline scenario and alternative scenarios for varying cost levels of €700/tonne and €196/tonne. In the event of an increase to €700/tonne the costs under the baseline scenario and alternative scenarios rise equally by around 215% to €16.6 billion and €15 billion per year respectively. In the event of a reduction to €196/tonne the costs under the baseline scenario and alternative scenarios fall by around 12% to €4.7 billion and €4.2 billion respectively (see Figure 100).



Kosten für Klimafolgeschäden [Mrd. Euro]	Costs of damage due to climate change [billion euro]
Grundlagenszenario	Baseline scenario
hohe Klimakosten	High climate costs
niedrige Klimakosten	Low climate costs
Alternative Szenarien	Alternative scenarios

Source: Own figure (IREES)

Figure 99: Annual costs of damage due to climate change from the district heating supply under the baseline scenario and alternative scenarios with varying climate costs



Vermiedene Klimaschäden (in Prozent)	Climate damage avoided (in per cent)
Klimakosten (in Euro)	Climate costs (in euro)

Source: Own figure (IREES)

Figure 100: Change in annual costs of damage due to climate change from the district heating supply under the baseline scenario and alternative scenarios with varying climate costs

III.9. Findings of the cost-benefit analysis and sensitivity analysis

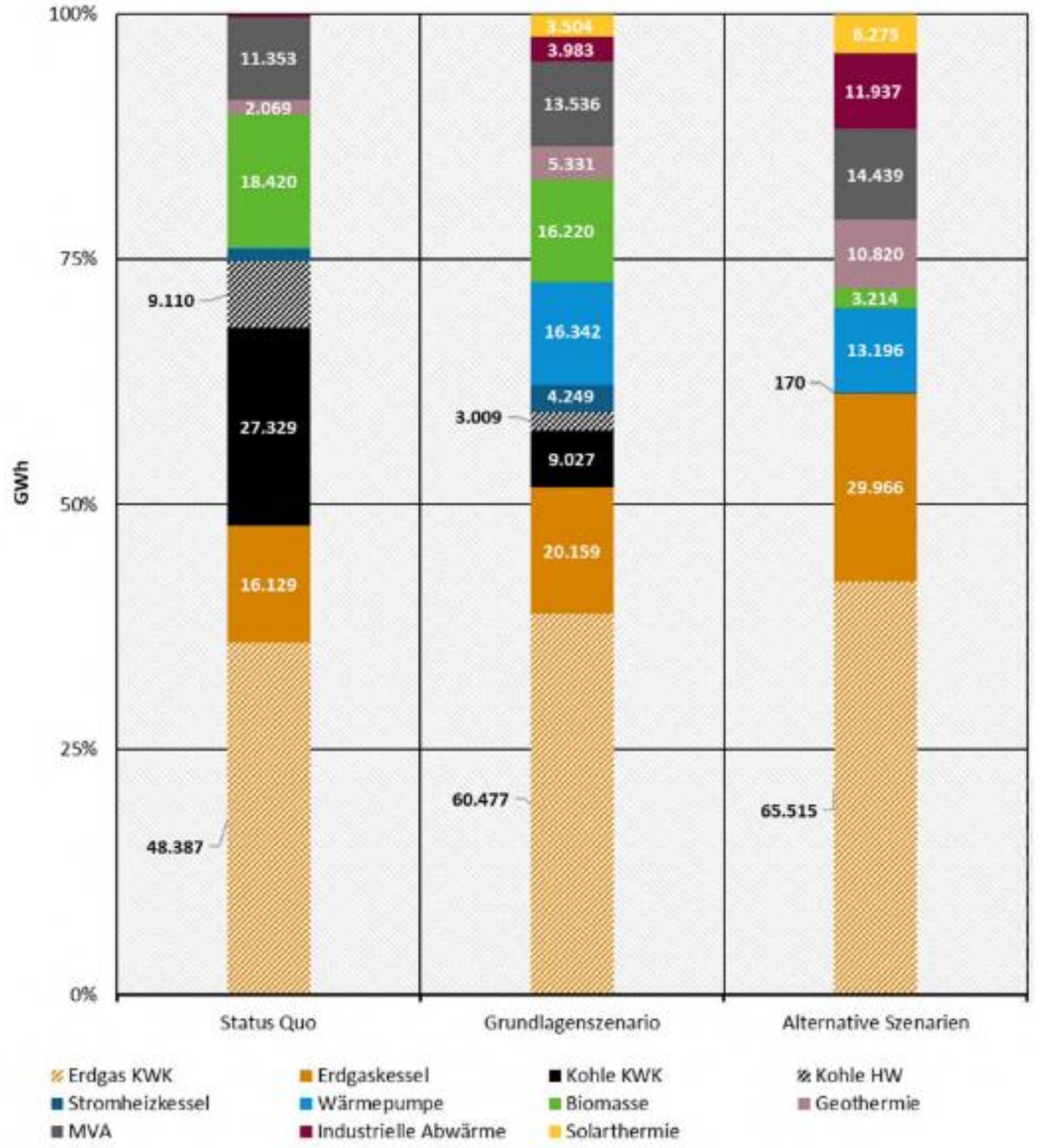
The alternative scenarios in 2030 are characterised primarily by the fact that, compared with the baseline scenario, locally available RE potentials and/or waste heat are utilised more effectively, less biomass is used and coal is replaced by natural gas.

Overall, based on the assumptions made for the calculation, the alternative scenarios have lower costs. In addition, the results of the highly regionally resolved examination carried out as part of this report reveal a more robust picture compared with the baseline scenario with regard to the transformation of heating and cooling at municipality level. The comparison of cost-benefit effects in the form of specific heat generation costs and GHG emissions at municipality level illustrates the differences and thereby underlines the relevance of the analysis performed and of using the insights gained to develop climate-neutral heating strategies at local level. With the achievement of the 2030 and 2050 climate protection objectives in mind, it is clear that the previous practice of assessing centralised heating supply options on the basis of local heating demand and heating densities is insufficient and that, in particular, local decarbonisation potentials via RE and waste heat also need to be taken into account for the assessment of costs and benefits. While it is apparent that high heat generation costs can result for the centralised supply of heating in municipalities with lower heating densities, in such cases, if the heating density is sufficiently high, these costs are below the costs of a decentralised fossil-based supply in 2030. If inexpensive local RE and waste heat potentials are available, the resulting heat generation costs are lower than the average under the baseline scenario even for smaller municipalities with a low district heating supply.

In addition, the alternative scenarios have far lower annual GHG emissions, even if, on a geographical level, the emissions of some municipalities under the alternative scenarios exceed the average for the baseline scenario. It should be stressed, however, that in those municipalities the locally available RE and waste heat potentials are low and more RE would have to be exploited to achieve low specific GHG emissions. Over the medium term this could be realised by increasing the use of biogenic and/or synthetic renewable fuels or location-independent heat pumps.

Overall, it must be underlined that the cost-benefit analysis performed here represents a comparison between two ambitious climate policy scenarios. If, however, the comparison is made against the status quo or a heating and cooling reference development that is less ambitious from a climate policy perspective, the positive benefit effect of the efficient, renewable supply emerges more clearly. The changes under the alternative scenarios are therefore also analysed below against the heating and cooling supply under the baseline scenario for 2020 (see also Table 36).

Figure 101 compares the energy source mix under the alternative scenarios with the heating and cooling supply under the baseline scenario in 2020 as a ‘status quo reference development’. The baseline scenario in 2030 is also indicated for comparison. In addition, Figure 102 shows the GHG emissions (in millions of tonnes) under these scenarios. Compared with the ‘status quo reference development’, with specific GHG emissions of 201 g/kWh, around 6 million tonnes of CO_2-eq are saved annually under the alternative scenarios. The saving under the alternative scenarios compared with the baseline scenario in 2030 is 2.4 million tonnes of CO_2-eq. The high GHG emissions of the status quo result from the fact that use is made primarily of fossil fuels. In the case of the status quo the energy sources natural gas and coal account for a share of roughly 75%, with renewable energies (excluding electric boilers) and waste heat utilisation amounting to 24%. Both the baseline scenario in 2030 and the alternative scenarios have a substantially higher share of renewable energies in the energy source mix. Under the baseline scenario the share of renewable energies (excluding electric boilers) and waste heat is just under 38%. In the case of the alternative scenarios renewable energies (excluding electric boilers) and waste heat account for a share of a little under 40%.

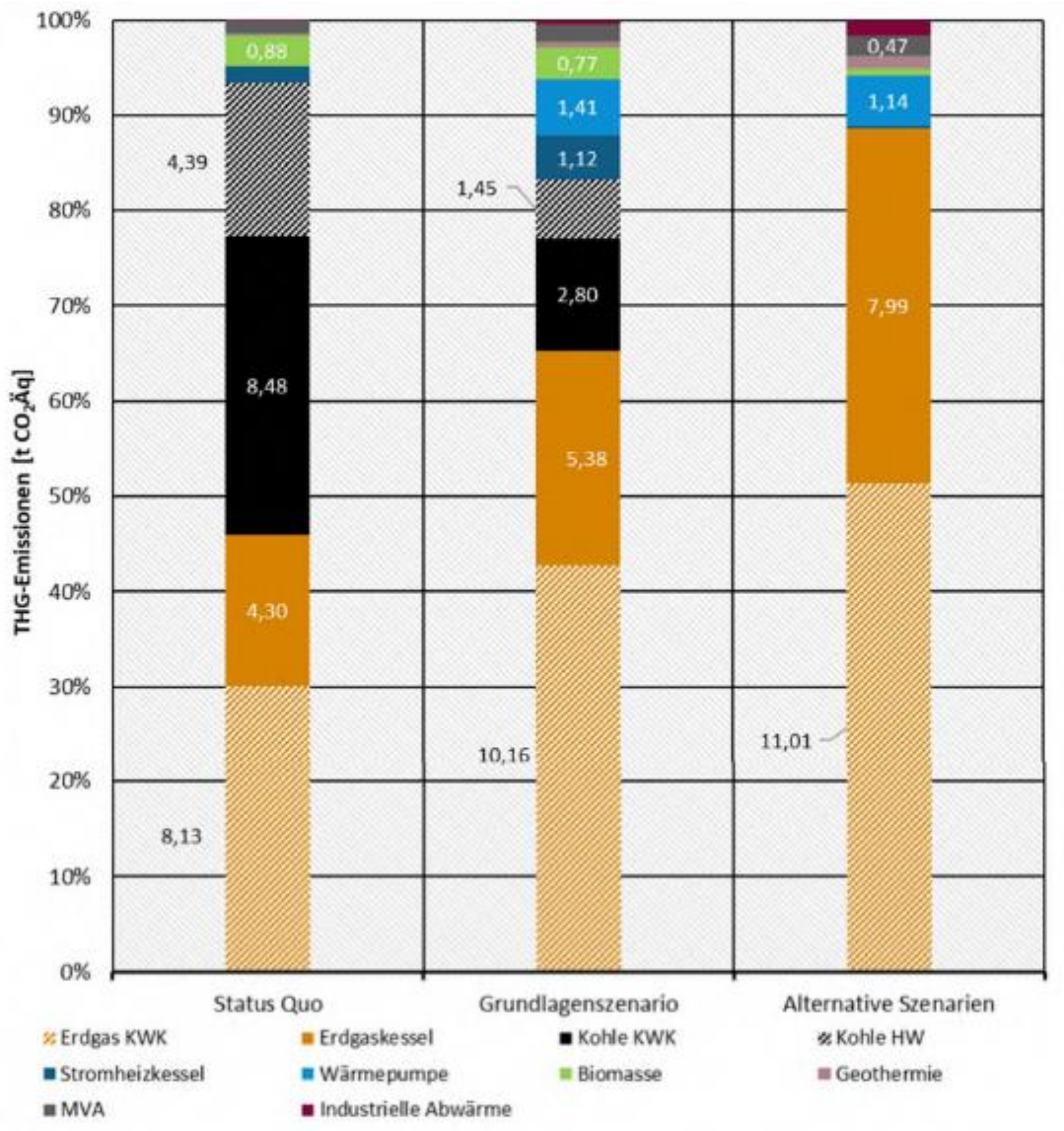


Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios
Erdgas KWK	Natural gas CHP
Stromheizkessel	Electric boiler
MVA	WIP
Erdgaskessel	Gas-fired boiler
Wärmepumpe	Heat pump
Industrielle Abwärme	Industrial waste heat
Kohle KWK	Coal CHP
Biomasse	Biomass
Solarthermie	Solar thermal
Kohle HW	Coal-fired heating plant

Geothermie	Geothermal

Source: Own figure (IREES)

Figure 101: Energy source mix of district heating under the baseline scenario in 2020 (status quo), the baseline scenario in 2030 and the alternative scenarios in 2030



THG-Emissionen [t CO_2Äq]	GHG emissions [t CO_2-eq]
Grundlagenszenario	Baseline scenario
Alternative Szenarien	Alternative scenarios
Erdgas KWK	Natural gas CHP
Stromheizkessel	Electric boiler
MVA	WIP
Erdgaskessel	Gas-fired boiler
Wärmepumpe	Heat pump
Industrielle Abwärme	Industrial waste heat
Kohle KWK	Coal CHP
Biomasse	Biomass
Kohle HW	Coal-fired heating plant
Geothermie	Geothermal

Source: Own figure (IREES)

Figure 102: GHG emissions (in millions of tonnes) of the district heating supply under the baseline scenario in 2020 (status quo), the baseline scenario in 2030 and the alternative scenarios in 2030

IV. Potential new strategies and policy measures

Part IV(9) of Annex VIII requires an overview of new legislative and non-legislative policy measures to realise the economic potential identified in Sections III.6 and III.7 (European Commission, 2019a). These measures are to be assessed together with foreseen developments in respect of the following indicators:

- greenhouse gas emission reductions
- primary energy savings in GWh per year
- impact on the share of high-efficiency cogeneration
- impact on the share of renewables in the national energy mix and in the heating and cooling sector
- links to national financial programming and cost savings for the public budget and market participants
- estimated public support measures, if any, with their annual budget and identification of the potential aid element

With the Climate Action Programme 2030 the Federal Government adopted a comprehensive package of measures in 2019 that is now being put into law and is therefore already included in the reference calculations for the NECP and the baseline scenario and consequently in the analyses of the economic potential for efficiency in heating and cooling. Details of the adopted measures can also be found in Section II.

Within the framework of this report measures are identified that could complement and add to these already very extensive measures. The main criteria for identifying measures were:

- Potential relevance
- Compatibility with long-term targets
- Innovativeness
- Scope
- Cost-efficiency

Table 42 summarises the measures developed together with the corresponding savings effects in accordance with the template in Commission Recommendation 2019/1659. The measures are described in greater detail below.

These measures are proposals that have been developed as part of the process of drawing up this report. They are subject to a more in-depth examination and an economic feasibility study that gives appropriate consideration to the economic costs of climate protection and the achievement of long-term targets, as well as the allocation of funds by the budgetary legislator, where applicable. The Federal Government has not adopted them at this stage.

Table 42: Overview of measures and corresponding savings effects

Brief description of the possible new strategy or policy measure	Main objective of the new strategy or policy measure	Expected GHG emission reductions (2030)	Primary energy savings [GWh/a] (2030)	Impact on the share of high-efficiency co-generation	Impact on the share of renewables in the national energy mix and in the heating and cooling sector	Links to national financial programming and cost savings for the public budget and market participants	Estimated public support measures, if any, with their annual budget and identification of the potential aid element
Federal Programme for Efficient Heating Networks	Step up the expansion of heating networks and their conversion to defossilised heating networks	4.1 million tonnes of CO_2-eq if the overall framework conditions are positive	28 TWh if the overall framework conditions are positive	Squeezes out fossil-based CHP; positive impact on CHP and combined heat and power generation using geothermal energy and biomass	Increases the share significantly by up to 23 TWh in 2030	No cost savings for the public budget	Funding requirement of around €10.5 billion from 2020 to 2030 At present €1.15 billion is available between 2020 and 2024 State aid assessment performed, approval based on guidelines on State aid for environmental protection and energy
Implementation of economic measures to promote use of industrial waste heat by	Leverage a relevant portion of the economic waste heat utilisation potentials	Approx. 7.7 million tonnes of CO_2-eq in total in 2030, of which	Total of 30.6 TWh, of which 19.8 TWh through use by individual busi-	Cannot be determined at present	Cannot be determined at present	Reduces use of available support programmes for economic measures, funds are freed up to	Not a support measure

Brief description of the possible new strategy or policy measure	**Main objective of the new strategy or policy measure**	**Expected GHG emission reductions (2030)**	**Primary energy savings [GWh/a] (2030)**	**Impact on the share of high-efficiency co-generation**	**Impact on the share of renewables in the national energy mix and in the heating and cooling sector**	**Links to national financial programming and cost savings for the public budget and market participants**	**Estimated public support measures, if any, with their annual budget and identification of the potential aid element**
means of a Waste Heat Utilisation Regulation in accordance with the Federal Immission Control Act (BImSchG)	in industry, including through the supply to heating networks	4.8 million tonnes of CO_2-eq through use by individual businesses and 2.9 million tonnes of CO_2-eq through net-bound use	nesses and 10.8 TWh through net-bound use			make other measures cost-effective	
Municipal heat plans for the long-term structuring of the heating supply	Implement the heating transition, achieve climate protection objectives in the area of buildings	Accompanying measure, so no direct contribution to reducing GHG emissions	Accompanying measure, so no direct contribution to primary energy savings	Use of CHP through sector coupling, CHP possibly squeezed out by RE and waste heat in the medium term	Significant impacts, as increasing the share of renewable energies in the heating supply is a primary objective	Significant potential for increased take-up of funding	Principle of concomitant financing
Pricing of fossil fuels for heat generation that is not already taxed	Switch some of the funding under the Federal Programme for Effi-	1.9 million tonnes of CO_2-eq	1,625 GWh	No effects beyond Federal Programme for Efficient Heating	No effects beyond Federal Programme for Efficient Heating Net-	Medium-term reduction in the burden on the federal budget, as planned funding	None

Brief description of the possible new strategy or policy measure	Main objective of the new strategy or policy measure	Expected GHG emission reductions (2030)	Primary energy savings [GWh/a] (2030)	Impact on the share of high-efficiency co-generation	Impact on the share of renewables in the national energy mix and in the heating and cooling sector	Links to national financial programming and cost savings for the public budget and market participants	Estimated public support measures, if any, with their annual budget and identification of the potential aid element
through the ETS	cient Heating Networks to extra-budgetary funds			Networks (BEW) and Fuel Emissions Trading Act (BEHG)	works (BEW) and Fuel Emissions Trading Act (BEHG)	would no longer be needed	

IV.1. Federal Programme for Efficient Heating Networks (BEW)

Description of measure

Heating networks constitute an important structural element in many energy scenarios. They contribute to the exploitation of renewable energies and waste heat potentials at optimised macroeconomic and microeconomic costs, as well as to a sustainable supply of heat to densely populated areas or heat sinks in the vicinity of large, climate-friendly heat sources.

At present, however, heating networks in Germany are still predominantly fossil-based: the temperature level, hydraulic concepts and network concepts are often geared towards the centralised supply of heat from large power plants. Significant conversion measures are therefore needed to ensure the efficient use of renewable energies. Around three quarters of district heating generation can be attributed to the direct use of fossil fuels, in particular in coal- and gas-fired cogeneration plants. To allow conversion to efficient networks with high shares of renewable energies and unavoidable waste heat, however, a variety of measures are required:

1. To efficiently integrate renewable energies and unavoidable waste heat, low temperatures are usually required in heating networks and are therefore a prerequisite at the customers with a need for heat. There are insufficient fuel-free sources of thermal energy available to ensure an energy- and cost-efficient comprehensive heating supply (covering space heating, hot water and process heating in commercial and industrial areas) at the current temperature level of district heating networks and heating circuits in buildings. A process of transformation to low temperatures therefore needs to be initiated by means of investments in networks and heat sinks (primarily the building envelope and heat distribution). Such a process is also required for reasons of efficient energy use.
2. Fossil-based heat generation capacities must be replaced to a large extent by renewable energies or unavoidable waste heat. At present, however, these often have significantly higher heat generation costs than comparable fossil-based technologies, in spite of the carbon pricing via the BEHG or emissions trading, or are subject to other barriers.
3. Although the current support landscape offers support for heat generators based on renewable energies, it does so in a patchy and insufficient way. The support ceilings for large-scale heat pumps, for example, are much too low; due to the high taxes and levies on electricity, support for investments in large-scale heat pumps is also insufficient. In the case of geothermal energy, on the other hand, the overall support can be regarded as too low (restriction to doublet system, low support for drilling costs) and in the merit order on the market it competes with fossil-based CHP installations, which receive higher support. Other system transformation measures, such as the digitisation of building transfer stations, are not supported at all at present.
4. At the same time, this transformation process is protracted and takes place, often in stages, over a number of years or decades, for reasons including the historical development of networks and a diverse generation structure (ifeu et al., 2020).

The Federal Programme for Efficient Heating Networks (BEW) addresses these weaknesses.

Specification of the proposal

The barriers referred to above are eliminated or ameliorated by means of a multi-level support concept. The basic approach of the support programme involves, on the one hand, according more favourable treatment to new networks with high shares of climate-friendly energy sources and, on the other, creating long-term prospects for operators of existing networks. At the same time, consideration is given to the fact that, within the framework of the Federal Programme for Efficient Buildings, support is given to so-called building networks, i.e. heating pipes linking buildings, albeit only under restrictive conditions (according to the draft version of 10.10.2020: only if the land belongs to the same owner). This proposal is distinguished from other support instruments, in particular relating to CHP, in detail in ifeu et al. (2020).

The concept is centred around ‘heating network transformation plans’, by means of which network operators develop a concrete strategy setting out the transformation steps that are needed to achieve defossilisation.

In accordance with the basic concept developed by ifeu et al. (2020), the support programme focuses on the following support pillars[59]:

- **Support for the preparatory conceptual design** of heating networks, either in the form of feasibility studies for new networks or transformation plans for existing networks. ‘The heating network transformation plan identifies a development path for existing heating networks with specific implementation measures for the next 30 years to achieve a target state of a decarbonised heating network. With this in mind, the transformation plan analyses how and by means of which specific measures accelerated decarbonisation and, if appropriate, the expansion or conversion of the district heating network could be achieved and how the network could be integrated optimally into the overall energy system. (…) The transformation plans must outline the path to achieving a target state by 2050 in which a specific heating network is supplied entirely with heat from climate-friendly energy sources. The decarbonisation path should rely as much as possible on locally available, climate-friendly energy sources, primarily renewable energies, waste heat and energy efficiency. New gas-fired CHP is not excluded in principle, although a realistic path for the phasing-out of fossil-based CHP that does not consist solely of switching to synthetic fuels must be outlined in advance’ (ifeu et al., 2020).
  The interdependencies with municipal heat planning are explained in detail in ifeu et al. (2020). In the best-case scenario the transformation plan is able to entirely incorporate the overall strategic planning, the analysis of the potential for renewables and waste heat and other elements, and focus on specifying the packages of measures for the heating network.
- **Support for individual measures** relating to solar thermal installations, large-scale heat pumps, biomass boilers (prerequisites: emission limits, proof of use of sustainable fuels, large boilers exceeding 10 MW or networks exceeding 50 km in length in accordance with planning concept: operating hours limited to

[59] The following description is based on ifeu et al. (2020)

use in situations in which energy efficiency is optimised), heating networks and heat stores, at a level of 40% of the eligible total investment costs under certain conditions. The support rate is calculated on the basis of a cost-efficiency calculation compared with a fossil-based reference and also compared with the support rates of other support programmes. This support for individual measures has been devised for smaller networks or situations in which straightforward, quick access to support is crucial, for example.

- **Systemic support**: on the basis of the above-mentioned transformation plan, which combines measures in existing heating networks into sensible packages of measures, support is given to measures that are necessary to defossilise networks. This relates, for example, to investments in heat generators, expansion, new construction, optimisation and redensification of heating networks, efficiency and digitisation measures, heat stores, measures at end customers, etc. These packages of measures also receive support at a level of 40% of the eligible investment costs. The systemic measures supported follow the logic of packages of measures presented in the transformation plan. These may also be individual measures that are not listed under support for individual measures, if they contribute to the decarbonisation of the network.
- To reduce the profitability gap that remains after deduction of the investment support and/or to provide a performance-related incentive to achieve the highest possible feed-in of renewable heat, a feed-in tariff or operating subsidy is paid for solar thermal energy, large-scale heat pumps and, where applicable, geothermal energy.

Konzept des Förderprogramms	Support programme concept
1 Vorbereitung: Förderung von Machbarkeitsstudien und Wärmenetz-Transformationsplänen Förderquote: 60 %	1 Preparation: support for feasibility studies and heating network transformation plans Support rate: 60%
Investive Grundförderung für EE-	Basic investment support for RE heat gener-

Wärmeerzeuger, Netzinfrastruktur und Transformationsmaßnahmen Förderquote: 40 % *	ators, network infrastructure and transformation measures Support rate: 40% *
2 Einzelmaßnahmenförderung („Easy Access“)	2 Support for individual measures (‘easy access’)
Kein Trafoplan erforderlich Förderfähig: Solarthermie Großwärmepumpe Biomasse mit Nebenanforderungen Wärmespeicher (bei >50 % EE) Wärmenetze (bei >50 % EE) ****	No transformation plan required Eligible for support: Solar thermal Large-scale heat pump Biomass with additional requirements Heat stores (>50% RE) Heating networks (>50% RE) ****
3 Systemische Förderung für Maßnahmenpakete	3 Systemic support for packages of measures
Neue Netze Bedingung: Machbarkeitsstudie, Anforderungen Wärmenetze 4.0, in Neubaugebieten Tvl<75 °C Förderfähig: EE-Erzeuger, Abwärmeeinkopplung, Wärmenetzte, Wärmespeicher, Maßnahmen beim Endkunden, Planung	New networks Condition: feasibility study, Heating Networks 4.0 requirements, in new-build areas supply temp.<75 °C Eligible for support: RE generators, waste-heat feed-in, heating networks, heat stores, measures at end customer, planning
Bestandsnetze Bedingung: Transformationsplan*** Förderfähig: Darin empfohlene Maßnahmen/Maßnahmenpakete, wenn sie einen Beitrag zur Dekarbonisierung leisten, z.B. EE-Erzeuger, Abwärmeeinkopplung, Wärmenetzte, Wärmespeicher, Netzverdichtung, Netzoptimierung, Temp.absenkung, Maßnahmen beim Endkunden, Planung	Existing networks Condition: transformation plan*** Eligible for support: Measures/packages of measures recommended therein, if they contribute to decarbonisation, e.g. RE generators, waste-heat feed-in, heating networks, heat stores, network densification, network optimisation, temp. reduction, measures at end customer, planning
4 Zusätzliche erfolgsabhängige Betriebsprämie für EE-Erzeuger, Förderung über 10 Jahre: Solarthermie X Ct/kWh_{th} Tiefe Geothermie je nach Projekt Großwärmepumpe abh. von JAZ bis max. X Ct/kWh_{th}	4 Additional performance-related operating subsidy for RE generators, support over 10 years: Solar thermal X Ct/kWh_{th} Deep geothermal dependent on project Large-scale heat pump dependent on APC up to max. X Ct/kWh_{th}
Weitere flankierende Förderelemente	Other accompanying support elements
* Ausnahme: Bohrkosten Geothermie 25%	* Exception: geothermal drilling costs 25%
** Ausnahme: Klimaschonende Wärmequelle mit Quellentemp. > 95 °C	** Exception: climate-friendly heat source with source temp. >95 °C
*** Vereinfachung für kleine Netze	*** Simplification for small networks
**** In Neubaugebieten TVL<75 °C	**** In new-build areas supply temp. <75 °C

Source: ifeu et al. (2020)

Figure 103: Basic concept of Federal Programme for Efficient Heating Networks

Details of the structure are currently being worked out in a report (ifeu et al., 2020).

Assessment of measure

Qualitative assessment: Thanks to the combination of investment and operating aid, the BEW is able to mitigate three barriers: the lack of profitability from an overall costs perspective, the investment hurdle and the competition – in terms of merit order – with (mostly fossil-based) heat from CHP, which is supported under the KWKG.

An alternative to this support programme – in particular to the support for heat generators – would be the systematic optimisation of the regulatory framework, e.g. with regard to the government-induced electricity price components applicable to electricity from heat pumps and geothermal pumps, but also carbon pricing that is geared more towards the costs of damage (and is therefore significantly higher). It is essential that these last two approaches are followed up in the future. However, as, from a political perspective, it is doubtful that they could be implemented in the short or medium term, the support presented is necessary to allow the rapid expansion of climate-friendly district heating.

In addition, with the operating aid a performance-related support element is introduced for the first time in the area of heating that provides compensation for the kWh of heat fed in and thereby rewards efficient and yield-oriented operation.

Whether it is possible to 'surpass' fossil-based CHP with this instrument, however, also depends on the framework conditions for support under the KWKG, which should be relaxed significantly in the future to avoid internal competition in the area of support.

Assessment of GHG and primary energy savings, impact on the share of high-efficiency cogeneration and renewable energies: For the quantitative assessment of this instrument an estimate of a possible indicative trajectory that was calculated in ifeu et al. (2020) is used. Overall, this estimate is based on optimistic developments, e.g. simplified framework conditions as a result of, in particular, municipal heat planning (see also measure 4). Under this estimate, largely triggered by the BEW and based on an analysis of the current market and of expansion potentials and market capacities, around 1,300 MW of solar thermal capacity, 2,100 MW of geothermal capacity, 1,975 MW of large-scale heat pumps, 1,050 MW of biomass boilers and 766 MW of waste heat installations will be installed by 2030. On top of this are heating networks and storage facilities, as well as other optimisation measures, all of which are on an upward trajectory. Overall, approx. €12 billion is invested by 2030.[60]

In this way it is possible, via the BEW, to expand renewable district heating generation to a supply of around 23 TWh by 2030. This is more than the required increase of one percentage point in the share of renewable heat in district heating, as required by Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II).

[60] Setting a time limit for biomass support could be considered.

The generation of renewable heat referred to above is associated with greenhouse gas savings of around 4.15 million tonnes and approx. 28 TWh of primary energy savings in 2030. High-efficiency fossil-based cogeneration is not supported by this instrument.

If such a programme were to continue after 2030, the additional RE feed-in of 23 TWh in 2030 could also be increased further. The aim is to have completely defossilised heating networks by 2050.

Table 43: Estimate of the increase in renewable heat fed into heating networks as a result of the BEW

Renewable heat or waste heat		**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Total	**TWh**	**0.1**	**0.7**	**1.7**	**2.9**	**4.4**	**7.1**	**10.8**	**14.9**	**19.1**	**23.1**
Solar	GWh	10	35	110	210	360	510	710	910	1,110	1,310
Deep geothermal	GWh	0	0	0	0	0	800	2,400	4,400	6,400	8,400
Heat pump	GWh	100	300	700	1,300	2,100	3,100	4,300	5,500	6,700	7,900
Biomass boiler	GWh	0	150	450	750	1,050	1,500	1,950	2,400	2,850	3,150
Waste heat	GWh	0	210	429	657	897	1,152	1,419	1,698	1,992	2,298

Source: ifeu et al. 2020

Table 44: Use of support (allocated to year of installation)

Support required over the support period		**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
for eligible installations											
Total support	**million euro**	**76**	**307**	**498**	**659**	**845**	**1,251**	**1,662**	**1,785**	**1,790**	**1,779**
Solar	million euro	5	12	37	49	73	73	98	98	98	98
Deep geothermal	million euro	0	0	0	0	0	240	480	600	600	600
Heat pump	million euro	71	142	284	426	568	710	852	852	852	852
Biomass boiler	million euro	0	16	32	32	32	48	48	48	48	32
Waste heat	million euro	0	14	15	15	16	17	18	19	20	20
Heating networks	million euro	0	64	64	64	80	80	80	80	80	80
Heat stores	million euro	0	54	57	59	62	64	68	72	76	80
Other optimisation measures	million euro	0	4	8	12	12	16	16	16	16	16
Feasibility studies and transformation plans	million euro	0	1	2	2	2	2	2	1	1	1

Source: ifeu et al. 2020

Links to national financial programming and support measures: It is fundamentally important that there can be no double funding from other federal programmes. The EEG and KWKG support RE installations that supply heat from combined heat and power. These installations are not supported under the BEW. A similar delimitation applies in relation to the Energy Efficiency in the Economy programme (waste heat) and the new Federal Support for Efficient Buildings programme (BEG) (building transfer stations, household networks).

IV.2. Waste Heat Utilisation Regulation or obligation to utilise the economic potential of industrial waste heat

Description of measure

Nationally, there is considerable unexploited waste heat potential in the manufacturing industry. Papapetrou et al. (2018), for example, refer to a total technically usable waste heat potential for German industry of 76 TWh. This project has determined a technical demand potential of 115.6 PJ (32.1 TWh) for the net-bound use of industrial waste heat.

Various barriers have to be overcome to allow industrial waste heat to be used. Often little attention is paid to this topic, as it is not a core element of a company's activities. A Waste Heat Utilisation Regulation could significantly increase the quantities of waste heat used. It could tie in with the fundamental duty of operators of plants that are subject to authorisation to use energy sparingly and efficiently ('energy efficiency requirement'), as defined in Section 5(1)(4) of the BImSchG. In terms of enforcement practice, an insufficient definition for the enforcement authorities often presents an obstacle to the concrete implementation of the energy efficiency requirement. A Waste Heat Utilisation Regulation could remedy this. The external utilisation of industrial waste heat in heating networks is referred to explicitly in the Climate Action Programme 2030: '*Waste heat from industrial undertakings should make a significant contribution in particular to the climate-friendly supply via municipal district heating networks'.*

Against this background, another proposal would be to oblige companies that have access to waste heat in excess of defined thresholds (GWh, full load hours and temperature) to draw up a waste heat utilisation concept and implement measures. The waste heat utilisation concept could build on existing energy management systems and audit results and could be taken into account in energy management control and improvement processes. It should contain a list of all technically feasible measures for internal and external use, taking geospatial conditions into consideration (available internal and external waste heat sinks within an acceptable geographical proximity, and other limiting and facilitating factors). The possible measures identified, along with their energy saving potentials and cost-efficiency, must be demonstrated within the framework of the recertification of energy management.

As the Waste Heat Utilisation Regulation would have to be enacted as a regulation in accordance with Section 7(1)(2(a)) of the BImSchG, which makes reference not only to the construction, but also to the operation of installations, it must be assumed that existing plants that have already received authorisation under immission control legislation could be covered by a Waste Heat Utilisation Regulation.

For existing installations the regulation should include the obligation to take all efficiency improvement measures, within an appropriate period, that have a positive net present value based on a maximum of 80% of the typical service life of the relevant type of installation. This measure of profitability takes the necessary proportionality considerations into account and thus creates legal certainty for installation operators and enforcement authorities. To determine the net present value, a suitable imputed interest rate should be chosen from a microeconomic perspective. In the current period of low interest rates, 8% would seem appropriate.

In the case of new installations or replacement investments it must be demonstrated that all economic options for the avoidance of waste heat have been exploited and any remaining unavoidable quantities of waste heat are used, as in the case of existing installations, provided that the measures satisfy the profitability criterion. The Waste Heat Utilisation Regulation will be binding on all installation operators, subject to an appropriate introduction phase. The regulation will require evidence of compliance with the obligation to ensure cost-efficient utilisation of industrial waste heat potentials to be provided every 5 years.

However, it should be borne in mind that, when it comes to implementing a Waste Heat Utilisation Regulation based on Section 5(1)(4) of the BImSchG for installations participating in the ETS, additional compulsory measures to increase energy efficiency are excluded (so-called exclusion clause, Section 5(2), sentence 2, of the BImSchG). An amendment to the BImSchG that removes this exclusion clause would therefore be required. [61]

Assessment of measure

Assessment of GHG and primary energy savings: The above-mentioned figure of 76 TWh from (Papapetrou et al., 2018) is assumed to be the addressable technical potential. In addition, based on the regional heating demand figures determined and taking a minimum threshold into account, a technical demand potential for the net-bound use of industrial waste heat of 32 TWh is identified in this project.

As this concerns technical and not economic potentials, and it can also be assumed that the economic potential is not addressed by one measure alone, an assumption has to be made regarding the total potential that can be leveraged via this measure. Until further estimates of economic potential are available, it is assumed that, in total, 25% of the potentials referred to, i.e. 19 TWh, could be leveraged via the measure 'Waste Heat Utilisation Regulation/obligation to utilise waste heat'. There are barriers in the area of net-bound use in particular, as an obligation for the supplying company to supply heat can only be successfully applied if the potential consumers actually purchase the heat. As it is a question of regulatory law, the estimated impact of the measure, representing 25% of the total potential, has therefore been set at a conservative level.

In the case of the net-bound supply, this results in a potential of 8 TWh to be leveraged via this measure. There is a remaining potential of 11 TWh for waste heat utilisation by individual businesses.

In principle, before waste heat is utilised, checks should first be performed at existing installations, if technically possible, with a view to preventing waste heat and corresponding measures should be taken, where economical. There is a wide range of technical options available for the use of waste heat by individual businesses (exam-

[61] As an alternative to the introduction of a Waste Heat Utilisation Regulation, based on the BImSchG as enabling legislation, as outlined here, in principle there is also the option of introducing waste heat utilisation obligations for beneficiaries of exemptions from charges, levies and taxes, as effective compensatory measures in the area of energy and climate policy.

ples: heat recovery, e.g. for the preheating of products; internal use, e.g. as heat for processes on site; power generation, etc.). However, the GHG and primary energy savings to be determined are linked to these, as the substituted energy supply, and consequently its primary energy and emission factors, depend on the technical options used. Simplifying assumptions therefore also have to be made here. In principle, the thermal utilisation of industrial waste heat should be given preference over power generation, due to the higher efficiency with which the heat is used. Frequently, power generation options are also not economical. It is therefore assumed that 80% of the potential has a thermal application and the remaining 20% is used for power generation. To determine the substitution effect, the final energy structure (excluding electricity) of the 2017 energy balance (as cited in *Energieeffizienz in Zahlen* (Energy Efficiency in Figures), BMWi 2019) is referred to in respect of the portion utilised for thermal applications. For reasons of simplicity, it is assumed that the quantities of waste heat put to thermal use replace the energy sources proportionately in accordance with this structure. Only the two most relevant fossil fuels, hard coal and gases (assumption: natural gas), with shares of 13.8% and 34.9% in final energy use respectively, are taken into account. This is then scaled accordingly, which means the assumption is made that 28.35% of the addressed waste heat potential replaces hard coal and 71.65% replaces natural gas as an energy source. With regard to the share used for power generation, it is assumed that electricity purchased from third parties with the primary energy and emission factor of the German electricity mix in 2030 is substituted, applying the emission factor from the BMWi's long-term scenarios.

In the case of the energy source structure that is substituted with net-bound potentials, use is made of the AGFW main report for 2018 (AGFW, 2019). Once again it is assumed that only fossil fuels are substituted. Natural gas (45%), hard coal (27%) and brown coal (10%) account for dominant shares here. These values are again scaled to 100%.

The waste heat used for thermal applications substitutes useful energy. The conversion, initially to final energy saved, involves the use of useful energy factors. Here a distinction is made on the basis of process heating and district heating generation in cogeneration plants, but not on the basis of energy sources. For the substitution of third-party electricity with power generated from waste heat an efficiency of 20% is assumed. Lastly, the substituted quantities of final energy are converted to saved quantities of primary energy using primary energy factors and converted to GHG savings using emission factors for the respective energy sources. Reference is made here to the UBA publication *CO_2-Emissionen für fossile Brennstoffe* (CO_2 Emissions for Fossil Fuels) (Juhrich, 2016), a current UBA estimate of the 2019 emission factor for the German electricity mix (UBA 2020), and the AGFW main report for 2018 (AGFW, 2019), as well as our own estimates.

The evaluation approach described results in a primary energy saving of 31 TWh in 2030, of which around 20 TWh is achieved from the utilisation of waste heat by individual companies and around 11 TWh from the net-bound utilisation of waste heat. In total, as a result of the associated substitution and avoidance effects, GHG savings of 7.7 million tonnes of CO_2 can be expected, of which 4.8 million tonnes of CO_2 can be attributed to utilisation by individual companies and 2.9 million tonnes of CO_2 to net-bound utilisation.
The results are summarised in Table 45.

Table 45: Estimated primary energy and GHG savings in 2030 as a result of the Waste Heat Utilisation Regulation measure

	Waste heat potential-addressed [TWh]	Primary energy saved [TWh]	Avoided CO_2 emissions in 2030 [millions of tonnes of CO_2-eq]
Utilisation by individual companies	11	19.8	4.8
Net-bound utilisation	8	10.8	2.9
Totals	19	30.6	7.7

Impact on the share of high-efficiency cogeneration and renewable energies: A Waste Heat Utilisation Regulation is not expected to have any direct impacts on the share of high-efficiency cogeneration or renewable energy. As far as the possible substitution of the feed-in via CHP is concerned, the substitution potential is too low, which means that, due to the high shares of fossil-based CHP, it can be assumed that only these will be replaced, and only then if the cost-efficiency of supplying industrial waste heat is greater than that of fossil-based CHP. It can thus be assumed that only less efficient fossil-based CHP will be replaced.

Links to national financial programming, cost savings and support measures: Due to the regulatory nature of this measure, there are no direct links to national support programmes, although there are indirect ones. If there is an obligation to take individual measures to utilise waste heat, these cannot be supported through investment support programmes. However, as only cost-efficient measures have to be implemented, this can be regarded positively, as it could tend to free up funds to support the market entry of technologies that, although highly efficient, have not been economical to date, for example.

IV.3. Municipal heat planning

Description of measure

At present the energy transition is mainly being realised in the electricity sector. However, considerable efforts are still required to achieve a climate-neutral energy supply within the building stock by 2050. To identify potentials and strategies in the area of heating and cooling, municipal heat planning represents an accompanying strategic instrument alongside existing economic incentives.

It allows an integrated approach to be taken to the heating transition on the ground, one that is tailored to the local conditions. The aim is to identify long-term, sustainable, cost-efficient heating solutions for the municipality in question. Compared with existing specific support programmes, heat planning is an instrument that makes it possible to get involved in structuring the heating supply. As a planning instrument, municipal heat planning allows indicative trajectories, strategies and investments to be developed at an early stage on the basis of the plan drawn up (Maaß, 2020). In this connection it should be noted that heat plans can include various strategies. Where the focus is placed in the area of decarbonising the heating supply will depend on the local conditions and there may be differences in terms of intensity and level of ambition. Municipal heat planning should therefore take into account the possibility of reducing heating demand through efficiency measures, as well as grid-based heating infrastructures and the centralised and decentralised potentials for utilising renewable energies and unavoidable waste heat. In addition to the technical prerequisites – an available gas and heating network infrastructure – it is also necessary to take the building stock and local generation potentials, as well as local actors and/or citizens' interests, into account. Due to the long reinvestment cycles within the building stock and heating network infrastructure and the land requirements for generation installations, appropriate strategies and specific implementation steps should be defined in good time. Furthermore, municipal heat planning allows profitable long-term investments to be made in cost-intensive infrastructures, such as heating networks. The strategic structuring of the heating supply means that generation technologies can be chosen cost-efficiently and used over the long term. If municipalities' are given extended scope to act, the heat plan can serve as an instrument for controlling the long-term heating supply (Steinbach, Popovski & Fleiter, 2017).

Municipal heat planning comprises the following elements:

1. An **analysis of the status quo** involving a systematic and qualified survey of current heating demand or consumption, the existing heat generation and distribution infrastructure and information on existing building types and age classes.
2. An **analysis of potential** to determine available potentials with a view to achieving a climate-neutral heating supply from the use of renewable energies, waste heat, CHP and possible heating network areas in the municipality.
3. **Development of a climate-neutral scenario** for 2050, with interim targets for 2030, relating to the future development of heating demand and the supply structure.
4. **Development of a concept** with possible actions for achieving an efficient and decarbonised heating supply (Staatsministerium Baden-Württemberg, 2020).

To implement compulsory heat planning in Germany, the necessary legal conditions must be created. When it comes to the structuring of the measures, it is crucial to consider which elements should be incorporated into municipal heat planning to achieve a corresponding impact and how these could be enshrined in law.

Status quo in the area of heat planning in Germany

In Germany heat plans are currently drawn up as an informal planning instrument of the municipalities with a view to structuring the supply of heating over the long term, in particular through support under the Local Authorities Guideline as part of the National Climate Initiative (NCI).

Up to the end of 2018, 13,941 measures had been financed under the Local Authorities Guideline, with Baden-Württemberg accounting for the largest share (2,739) (A. Nagel, 2018). Within the Local Authorities Guideline heat plans fall under the category of climate protection concepts. Since 2011 the share of climate protection concepts in the total number of approved applications has been in decline, however (Nationale Klimaschutzinitiative, 2020). Up to the end of 2017 support was mainly given to investment measures. In Baden-Württemberg a total of 95 climate protection sub-concepts were approved up to the end of 2017, of which 10 projects were in the area of integrated heat utilisation (Klimaschutz- und Energieagentur Baden-Württemberg, 2018). With the amendment of the Baden-Württemberg Climate Change Acts introduced this year, the federal state government of Baden-Württemberg has adopted compulsory heat planning for municipalities. The legal text of 14 October 2020 reads as follows:

‘Paragraph 7 c: Municipal heat planning

Municipal heat planning is an important process to help municipalities to achieve their climate protection objectives in the area of heating. Through municipal heat planning the municipalities develop a strategy to realise a climate-neutral heating supply and thereby contribute to the achievement of a climate-neutral building stock by 2050. (Landtag von Baden-Württemberg, 2020)

Under the Baden-Württemberg Climate Change Act urban districts and major district towns are obliged to undertake heat planning. This corresponds to 10% of the municipalities and 50% of the population of the federal state. Urban districts and major district towns are obliged to draw up their plans by the end of 2023 and publish them in federal state databases and online. In return they receive a flat-rate payment and a grant depending on their population. The municipal heat plans must be updated at least every 7 years, although there is no obligation to implement them (Energiezukunft, 2020; Landtag von Baden-Württemberg, 2020).

Recording data on the infrastructure, consumption and generation structure, and potentials is essential for comprehensive heat planning. By means of an enabling rule, in Baden-Württemberg energy suppliers, chimney sweeps and companies have therefore been obliged to collect data on heating consumption and on potentials for the utilisation of waste heat, and to make these data available (Staatsministerium Baden-Württemberg, 2020).

When drawing up the heat plans the municipalities receive support, in the form of advice and guidance, from a newly established Competence Centre of the federal state’s Climate Protection and Energy Agency (KEA) (Zeitung für Kommunalwirtschaft, 2020).

Status quo in the area of municipal heat planning abroad

Denmark is the global leader in the area of municipal heat planning and the grid-based supply of heating. There heat planning is carried out at both national and municipal level. At national level the Danish Ministry of Climate, Energy and Building, which supervises the national energy agency (DEA), is largely responsible in this area. As the regulatory authority and central organisation for energy policy in Denmark, within the area of municipal heat planning the DEA defines the framework conditions that apply to heat planning in the municipalities, such as data collection and the division of the area into supply zones. In addition, it draws up compulsory guidelines for the municipalities and a technology catalogue of possible generation technologies, as well as specifying information for the cost-benefit analysis.

The municipalities are responsible for implementing heat planning. Data collection to optimise the heating supply and the construction of installations are local responsibilities. Municipalities can approve or reject the construction of installations and even have the authority to expropriate land from owners. In addition, the municipalities divide up their area into so-called heating supply zones and it is decided which infrastructure will be used in which areas on the basis of the settlement structure.

The original approach to heat planning in Denmark was as follows:

1. Determination of local heating demand and technologies used, and identification of alternative, cost-efficient possibilities that are available locally, with aggregation at regional level
2. Drafting of future scenarios relating to local heating consumption and aggregation at regional level
3. Identification of locations for technologies, installations and pipelines in regional plans
4. Local drafting of heat plans on the basis of regional plans, incorporating specific projects
5. Approval by the Danish Energy Agency (Chittum & Alberg Ostergaard, 2014).

In Austria municipal heat planning or spatial energy planning is currently being trialled, together with numerous project partners, as a pilot project in the three regions of Styria, Vienna and Salzburg. The aim of the project is to accelerate the heating transition by developing the bases for introducing spatial energy planning within the administrative processes of the pilot regions. These bases include data at individual building level, a heat atlas for identifying renewable potentials and the WÄRMEApp (HEATApp), as the core element of the project. This presents the urban contexts, such as the potentials of renewable energy sources and the need for infrastructure and energy, and in this way allows long-term energy and infrastructure planning by the municipalities (Green Energy Lab, o. J.).

As part of the project, in Vienna power to issue statutory regulations has been granted in relation to energy spatial plans, similar to the heating supply zones in Denmark (see above). The energy spatial plans define areas in which a connection to district heating is compulsory or only the use of highly efficient solutions is permitted. If a construction project lies within an energy spatial plan zone, the use of fossil fuels is excluded. An initial analytical study of energy zones for Vienna was conducted in Fritz (2016).

Reasons for introducing compulsory municipal heat planning

Heating and cooling based on renewable energies cannot be achieved across the entire country using a single universal solution. On the other hand, the use of local, individual, centralised and decentralised technologies requires comprehensive underlying data and activities at local level. With the help of heat plans, individual, cost-efficient concepts can be developed at municipality level, on the basis of local conditions, potentials, infrastructure requirements and citizens' needs. The introduction of compulsory municipal heat planning in the Baden-Württemberg Climate Change Act is based on the reasoning that an efficient and methodical approach is only possible on the basis of a comprehensive strategy (Energiezukunft, 2020; F. Nagel, 2019a).

Although minimum requirements relating to content have applied to the concepts drawn up to date within the framework of the Local Authorities Guideline, these can differ greatly in terms of detail, as there are no standards for individual parts of the report (BMU, 2020, S. 31ff). For this reason, the varying levels of ambition and objectives mean that heat plans can only be compared to a limited extent. An obligation to draw up plans in the area of heating and cooling makes it possible to introduce a coordinated, shared and standardised planning instrument. Furthermore, national climate protection objectives can be transferred to the federal states and municipalities and the individual heat plans can ultimately be combined to form a substantial overall system.

A standardised approach is also beneficial when it comes to recording the data needed for the analysis of potential. To obtain this information, municipalities need to have a right to information vis-à-vis municipal utilities, energy suppliers, public bodies and chimney sweeps (Jugel et al., 2019a). Standardisation supports the harmonisation of requirements in the area of data and data protection, creating a level playing field for the analysis of potentials and simplifying data collection (cf. Maaß, 2020b). Compulsory heat planning should not be regarded as a regulatory support instrument that obliges private actors to take more specific measures, but is actually a planning and information tool at municipal level. However, this measure does transfer additional tasks to local government level, which, against the background of local self-government, could be considered legally controversial, in particular when it comes to the specific implementation of a mandatory self-government task. As a result of the fight against climate change and its consequences, municipalities are being assigned a range of new duties(UBA, 2015); within this context, by law their right to manage their own affairs has to be protected to a certain extent (Deutscher Bundestag, 2011). In this connection representatives of the German Association of Towns and Cities are criticising the persistent undermining of local self-government. They argue that, although the municipal level is closest to citizens, due to an increase in expenditure and mandatory duties, those tasks that shape local life are only being carried out insufficiently (Landsberg et al., 2010). In principle, however, these are not arguments against the introduction of compulsory municipal heat planning, as such a task is also in the interests of citizens and allows for active participation. The planning of the heating supply is best organised locally, involving the relevant actors and taking citizens' interests and data availability into account. If this were to take place at federal state level, local citizens could not be involved, or could only be involved to a limited extent. Furthermore, as a result of the tasks involved, municipal heat planning is already closely connected with existing local government tasks, such as urban development planning. As a holistic task, it coordinates and links existing activities and adds missing elements to them (Jugel et al., 2019).

In Baden-Württemberg municipal heat planning was therefore also introduced on a compulsory basis, as this means that the principle of concomitant financing applies, which obliges the federal state to assume the costs. In spite of existing support programmes offered by the NCI and the federal state, the heating transition is making only sluggish progress in the municipalities. The principle of concomitant financing goes beyond the possibilities of the support offered by the NCI and supports the municipalities with all tasks involved in municipal heat planning. If provision has been made for the assumption of costs, this takes precedence over support (Energiezukunft, 2020; F. Nagel, 2019b).

Legal basis for heat planning

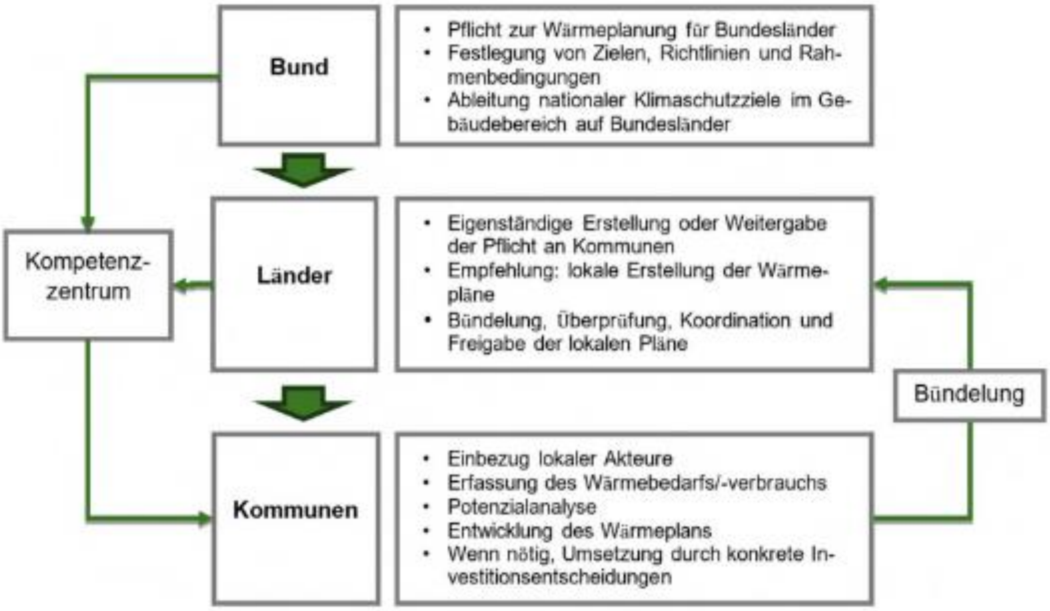
On the basis of the prohibition of intervention (Art. 84(1), sentence 7, of the Basic Law (GG)), the Federal Government is not permitted to transfer tasks directly to municipalities. Nevertheless, in exceptional cases it is possible to enshrine compulsory tasks for municipalities in law. However, as imposing a compulsory task restricts the right of municipalities to manage their own affairs, the compulsory task must be based on reasons associated with the public interest and be sufficiently important to justify restricting the municipalities' right to manage their own affairs. These conditions are not met in the case of municipal heat planning. In addition, the state can transfer delegated matters to the municipalities. These include administrative tasks, with the municipality acting as the lowest level. Delegated matters are intended as a way of transferring tasks from the state to municipalities, allowing local knowledge to be used and measures to be embedded locally within municipalities. As municipal heat planning is not an administrative task, this possibility does not apply. The Federal Government can also assign compulsory tasks subject to a right of instruction. These are used if uniform performance of a task is desirable, as in this case stipulations are made regarding whether and how to carry out the task (Bundestag, 2011).

It is therefore proposed that heat planning be established at national level as a compulsory task for the jurisdiction of the federal states. Consequently, the federal states would have to draw up heat plans in accordance with the stipulations of federal law for the area under their jurisdiction. The federal states could comply with this obligation by drawing up their own plans or could transfer the obligation to the municipalities or regional planning associations by means of their own federal state law. In that case, however, due to the principle of concomitant financing enshrined in the federal state constitutions, they would have to make corresponding funds available to the municipalities (Bundestag, 2011).

Proposal for the implementation concept

For reasons of local embedding and geographical proximity, and the resulting improved availability of demand and consumption data, heat planning should be carried out at municipal level. On the basis of these data, individual solutions could be developed that are cost-efficient for the municipalities and take local conditions and structures into account. As a result of land use and urban development planning, the municipalities already have experience in the area of the heating supply to buildings and their competences are also enhanced through their role as responsible planning authorities. Insufficient competences to draw up heat plans at municipal level could be compensated for by means of a competence centre at national level or several centres in the federal states.

In the event of heat plans being drawn up at municipal level, however, it is possible that, from the perspective of the federal state as a whole, individual heat planning is not optimal. It is therefore recommended that, following the Danish example, the plans be drawn up locally and bundled at regional level. The plans are then checked, coordinated and approved at a higher level. In this way it is also possible to coordinate neighbouring areas where it makes sense for heat plans to be drawn up jointly and overarching infrastructures to be installed.



Kompetenzzentrum	Competence centre
Bund	Federal Government
Pflicht zur Wärmeplanung für Bundesländer	Heat planning obligation for federal states
Festlegung von Zielen , Richtlinien und Rahmenbedingungen	Determination of targets, guidelines and framework conditions
Ableitung nationaler Klimaschutzziele im Gebäudebereich auf Bundesländer	Transfer of national climate protection targets in the area of buildings to federal states
Länder	Federal states
Eigenständige Erstellung oder Weitergabe der Pflicht an Kommunen	Independent drafting or obligation passed on to municipalities
Empfehlung: lokale Erstellung der Wärmepläne	Recommendation: local drafting of heat plans
Bündelung, Überprüfung, Koordination und Freigabe der lokalen Pläne	Bundling, verification, coordination and approval of local plans
Bündelung	Bundling
Kommunen	Municipalities
Einbezug lokaler Akteure	Involvement of local actors
Erfassung des Wärmebedarfs/-verbrauchs	Recording of heat demand / consumption
Potenzialanalyse	Analysis of potentials
Entwicklung des Wärmeplans	Development of heat plan
Wenn nötig, Umsetzung durch konkrete Investitionsentscheidungen	If necessary, implementation by means of concrete investment decisions

Source: Own figure (IREES)

Figure 104: Possible implementation concept for compulsory municipal heat planning in Germany

The obligation to carry out municipal heat planning should result in a formal planning instrument and a coordinated approach between national and municipal level. Heat plans should be drawn up in an application-oriented manner. Implementation should involve making concrete decisions, and not only investment decisions, on the basis of the heat plan.

To ensure uniform heat planning, there is a need for central guidelines, framework conditions and objectives to be handed down from national level. The climate protection objectives defined at federal level concern the heating supply for 2030 and 2050 and should be transferred to the federal states and municipalities. Specific, long-term (interim) targets serve as a basis for heat planning. Furthermore, a standardised approach to drawing up heat plans should be developed. Quality requirements for the individual steps, including data collection, recording of heating demand and consumption, identification of potentials and drafting of the implementation concept, should also be defined.

In addition, common guidelines should apply, such as the compulsory creation of a heat atlas, as in Hamburg (Bürgschaft der Freien Hansestadt Hamburg, 2018), division into heating supply areas, as in Denmark, the structuring of the heating supply on the basis of renewable energies or the limitation of the use of fossil fuels. To support the municipalities, information and instruments should be made available and methods communicated via the proposed competence centres. There should also be a set of technical rules containing information on possible supply options and generation installations, including the land requirement, efficiency potentials and an assessment of the socio-economic costs. To allow the municipal heat plans to be assessed and support given to the municipalities, the competence centres should be provided with sufficient funds.

If heat plans are drawn up locally, and to guarantee their implementation, the possible actions that municipalities can take should be expanded. It is therefore conceivable that, as in Denmark, the authority of municipalities could be extended with regard to decisions on the use of land, as well as – where permitted by the constitution – their authority to expropriate land, if necessary. With the concrete implementation of the heat plans and adherence to the long-term strategies in mind, municipalities should also be granted the right of approval with regard to the construction of new installations. Municipalities should be given the authority to collect technical data from energy generators, network operators and chimney sweeps to allow appropriate planning. To assist the municipalities with the drafting of the plans, financial support should also be considered (Jochum et al., 2017; Steinbach et al., 2017; Maaß, 2020). Such support could be provided by dividing up the municipal heat planning measure and making support available for individual components. Financial support could also be offered indirectly via the competence centres, which in this way could provide enhanced assistance to the municipalities.

Assessment of measure

<u>Qualitative assessment:</u> The municipal heat planning measure complements existing and future economic incentives by adding a strategic component. The compulsory drafting of a strategic heat plan would constitute a clear commitment to the objectives for buildings set out in the Climate Change Act and would promote its implementation.

Assessment of GHG and primary energy savings: As an accompanying measure, municipal heat planning does not contribute directly to a reduction in greenhouse gas emissions and to primary energy savings.

Impact on the share of high-efficiency cogeneration and renewable energies: Municipal heat plans that provide for the use and expansion of renewable energies and unavoidable waste heat will increase the share of renewable energies used nationally.

The construction of new heating networks will allow increased use of CHP installations. Over the medium term, however, the expansion of renewable energies in existing heating networks could squeeze out fossil-based CHP installations.

Links to national financial programming, cost savings and support measures: Compulsory municipal heat planning will force municipalities to address the issue of the long-term heating supply and, where appropriate, make prompt investments in areas including infrastructure, renovation measures, and information and awareness-raising measures. This in turn will increase the take-up of funding.

Both regulatory and financial incentives are needed to decarbonise the heating supply.

Estimate of budgetary costs: Based on the newly established competence centre for heat planning in Baden-Württemberg, it is assumed that the budgetary costs would be around €2.75 million.

In Baden-Württemberg 103 urban districts are obliged to carry out heat planning. There are 1,100 municipalities in total. The costs are made up of assumed personnel costs, with two employees at the level EG 13 and two at the level EG 14, as well as material costs of €30,000 for these 1,200 municipalities. Scaled to a total of 11,000 municipalities throughout Germany, this results in costs of €2.75 million. (FernUniversität-Hagen (2019); KEA (n.d.); (Zeitung für Kommunalwirtschaft, 2020))

IV.4. Extra-budgetary financing of support programmes, following the example of the Federal Programme for Efficient Heating Networks: heat levy

Description of measure

To ensure the ongoing extra-budgetary financing of heating infrastructure conversion measures, a heat levy on energy sources used to generate heat could be introduced in accordance with the polluter pays principle, in addition to the Fuel Emissions Trading Act (BEHG). Such a levy could have the advantage of creating stable financing opportunities over the long term, which are needed in particular in the area of heating networks. In this respect the question of the parties who are subject to the levy (e.g. the distributors of fossil fuels) and its administrability are just as important as the question of the associated additional burden, the additional complexity and congruence with the BEHG.

As in the case of the BEHG, within the framework of this analysis no duplication with the European Emissions Trading Scheme (ETS) is envisaged, and the levy is applied, on the basis of the CO_2 content, when fossil fuels are placed onto the market. The instrument should apply solely to fossil-based heat generation, in order to finance measures and support mechanisms in the heating sector. The taxation of fuels for material use and use in the transport sector is explicitly not the intention of this instrument.

Over the medium term a switchover of substantial parts of the support regime in the area of buildings and heating is conceivable, in principle. Initially, the measure proposed here focuses on the financing of the Federal Programme for Efficient Heating Networks (BEW, see also the associated measure in Section IV.1), which requires stable, extra-budgetary financing to a greater extent on account of the long investment periods involved. The possibility in principle of making the funding extra-budgetary also needs to be assessed from a State-aid perspective.

It is proposed that the support required for heating networks will be financed in full from all operators of fossil-based heat generators that are not covered by the ETS. The amount needed for the support will increase steadily over the coming years, while the prevalence of fossil-based heat generators in the area of heating will gradually decrease (see Table 46). All in all, this results in a price path that starts at a very low level and then, based on the assumptions made up to 2030, increases to levels similar to the BEHG in 2021.

The figures for the currently assessable funding volume for the BEW from 2021 to 2030 are taken from an ongoing research project (ifeu et al., 2020). These figures are rounded on the basis of the document. The predicted levels of oil and gas demand for buildings are taken from the assessment of the Climate Action Programme in the NECP, which incorporates decisions under the Climate Action Programme over the last twelve months (Kemmler et al., 2020). The CO_2factors of the fuels are taken from the publication '*CO_2-Emissionsfaktoren für fossile Brennstoffe*' ('CO_2 Emission Factors for Fossil Fuels') of the Federal Environment Agency (Juhrich, 2016).

Table 46: Overview of bases for derivation

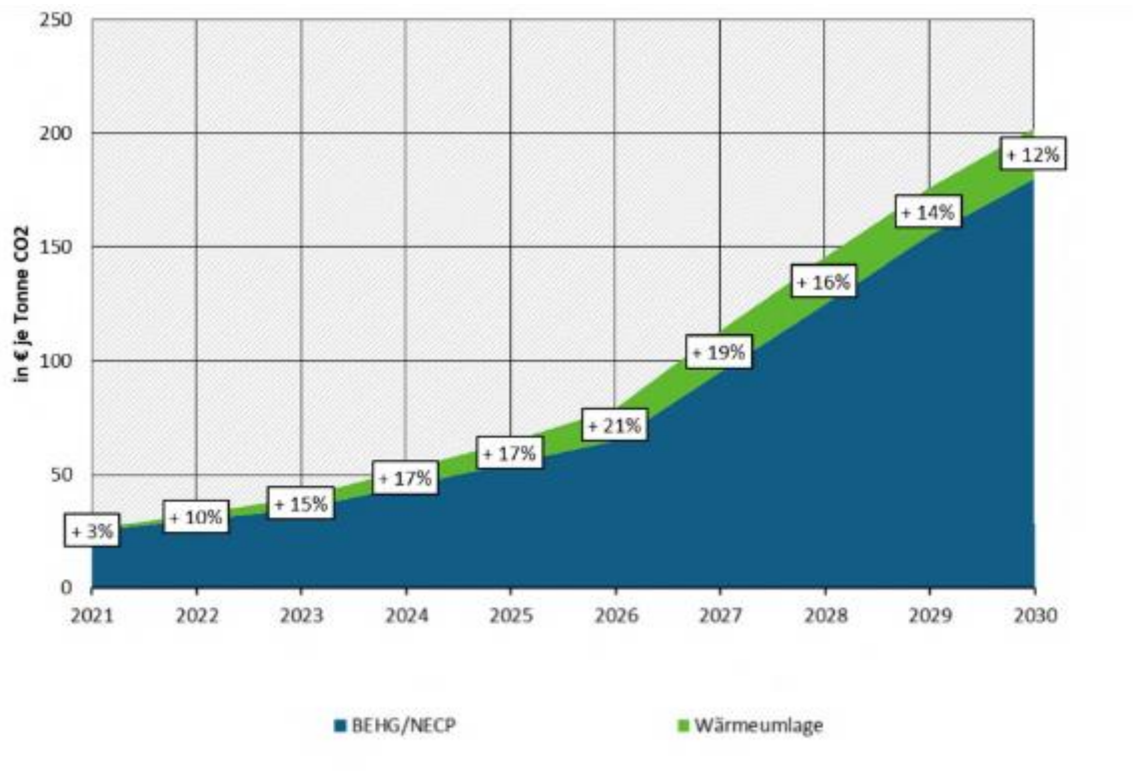
	CO_2 emissions from space heating and hot water in millions of tonnes of CO_2	**Currently predicted funding requirement of the 'Federal Programme for Efficient Heating Networks' in millions of euro**	**Resulting levy in €/t CO_2**	**For comparison: fuel surcharge under the BEHG (up to 2026) and predicted values from the NECP (from 2027) in €/t CO_2**
2021	105	80	1	25
2022	101	300	3	30
2023	97	500	5	35
2024	93	700	8	45
2025	90	850	9	55
2026	86	1,200	14	65
2027	83	1,500	18	95
2028	79	1,600	20	125
2029	76	1,600	21	155
2030	73	1,600	22	180

Assessment of measure

Figure 105 shows the results of the assessment and the comparison with the BEHG in graphical form. Relative to the carbon prices already decided on, or those expected from 2026, the additional charge is small and fluctuates between 3% and 21% of that under the BEHG.

As a secondary effect, there would be a stimulus resulting from the price of fossil fuels, which would influence, on the one hand, short-term energy consumption behaviour and, on the other, long-term investment behaviour in relation to energy-related building renovations and heating systems.

In the section below the extent of the short-term impacts of price stimuli is estimated and the results are ranked. Use is made here of work carried out as part of the project '*Harmonisiertes Monitoring von Energieeinsparungen deutscher Effizienzmaßnahmen sowie kontinuierliche Prüfung/Aktualisierung der prognostizierten Einsparziele der Maßnahmen für das Jahr 2030*' ('Harmonised monitoring of energy savings of German efficiency measures and ongoing examination/updating of predicted savings targets of the measures for 2030') (BfEE 16/2017). In this case, however, the observations focus solely on the heating consumption of private households and (for the time being) only short-term behavioural effects.



in € je Tonne CO2	in € per tonne of CO_2
BEHG/NECP	BEHG/NECP
Wärmeumlage	Heat levy

Source: Kemmler et al. (2020), own calculations (Prognos)

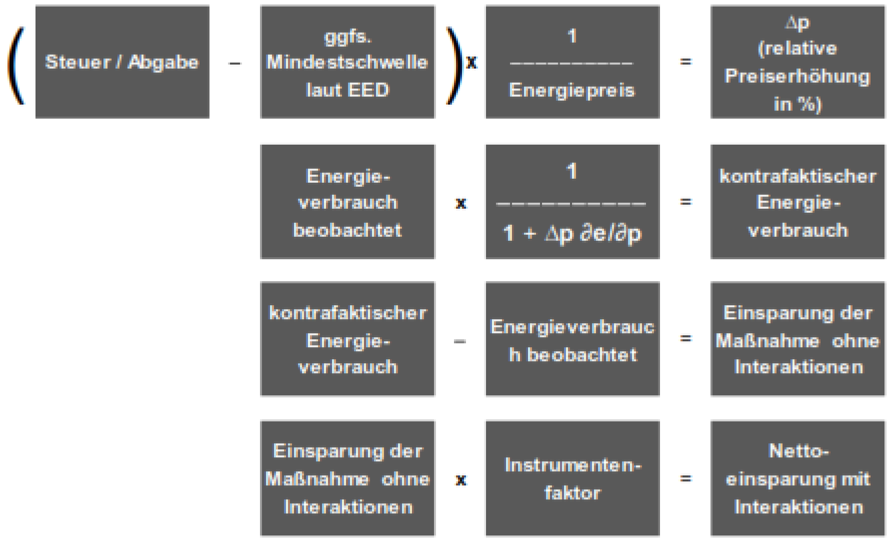
Figure 105: Comparison of the levy under consideration with the price path of the surcharge under the BEHG

Short-term elasticities to estimate the behavioural changes triggered

To determine the impact of the price stimulus on consumption behaviour, an approach involving short-term elasticities is used. Key input variables here are observed energy consumption, the (relative) price increase based on the surcharge applied to the CO_2 tax under the BEW and the assumed short-term price elasticity. This approach involves deriving two energy consumption paths: one path that reflects only the expected development of the price of energy sources up to 2030 and one that also makes assumptions relating to the price increase due to the CO_2 tax. It is assumed that the short-term consumption behaviour of consumers is influenced by the price (this has been modelled using short-term price elasticities) and therefore that energy consumption is lower for the path with the CO_2 tax than in the reference case. The difference is presented as the saving.

Steuer / Abgabe	tax/levy
ggfs. Mindestschwelle laut EED	if applicable, minimum threshold in accordance with EED
Energiepreis	energy price
Δp (relative Preiserhöhung in %)	Δp (relative price increase in %)
Energieverbrauch beobachtet	energy consumption observed
kontrafaktischer Energieverbrauch	counterfactual energy consumption
Einsparung der Maßnahme ohne Interaktionen	saving from measure without interactions
Instrumentenfaktor	instrument factor
Nettoeinsparung mit Interaktionen	net saving with interactions

Figure 106 below provides an overview of the calculation system.



Steuer / Abgabe	tax/levy
ggfs. Mindestschwelle laut EED	if applicable, minimum threshold in accordance with EED
Energiepreis	energy price
Δp (relative Preiserhöhung in %)	Δp (relative price increase in %)
Energieverbrauch beobachtet	energy consumption observed
kontrafaktischer Energieverbrauch	counterfactual energy consumption
Einsparung der Maßnahme ohne Interaktionen	saving from measure without interactions
Instrumentenfaktor	instrument factor
Nettoeinsparung mit Interaktionen	net saving with interactions

Figure 106: Calculation system for price instrument, short-term impact

The values from past notifications of the Federal Government in accordance with Art. 7 of the 2012 EED (Bundesregierung, 2012) and/or from previous National Action Plans on Energy Efficiency are used as short-term price elasticities. These were derived as part of a study by Prognos und GWS (2012) and are broken down by both consumption segment and application. The savings determined in this way are presented in Table 47 below.

Table 47: Behaviour-based final energy savings in the area of residential buildings as a result of budget-neutral financing of the BEW

GWh net	Extra-light fuel oil	Natural gas	Total
2021	28	56	112
2022	112	194	278
2023	167	306	472

GWh net	Extra-light fuel oil	Natural gas	Total
2024	250	444	694
2025	250	472	750
2026	361	722	1,083
2027	444	833	1,278
2028	444	833	1,278
2029	417	806	1,222
2030	417	778	1,194
gross annual final energy saving (GWh/a) in 2030	417	778	1,194
gross cumulative final energy saving (GWh) from 2021 to 2030	2,778	5,556	8,333

Source: own calculations based on Prognos und GWS, (2012)

Combined with the emission factors for natural gas (203 g/kWh) and fuel oil (267 g/kWh), this results in cumulative GHG savings of 1.87 million tonnes of CO_2-eq by 2030. Both energy sources have a primary energy factor of 1.1, which results in an annual primary energy saving of 4.7 PJ/a or 1,314 GWh/a in 2030.

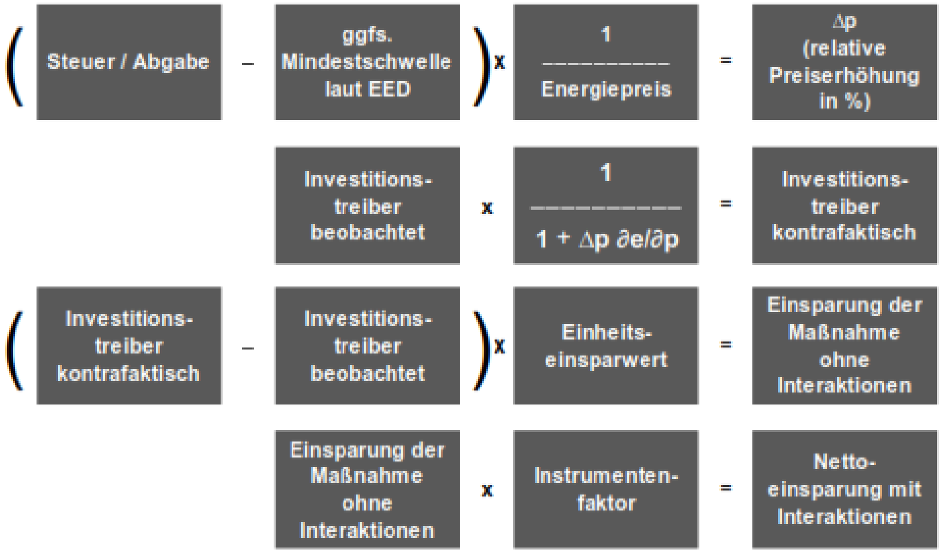
Additional examination of long-term elasticities to estimate investment decisions triggered

A second possible calculation approach makes additional assumptions and statements about investment decisions changed as a result of the CO_2 tax. Here cross-price elasticities are used to link prices to the driver variables describing investment behaviour, in this case relating to full renovation equivalents in the building stock.

As with the first approach, two development paths that are dependent on two different price developments are calculated. In this case, however, instead of energy consumption, statements are derived relating to the driver variables describing investment behaviour. The saving is then determined from the difference in the driver variables, multiplied by a standard saving value.

The savings determined using this approach are in addition to the change in short-term consumption behaviour. This means the savings can be added together. In contrast to short-term behavioural change, the lifetime of the measures examined here is more than 1 year; in accordance with the EU Commission’s recommendations in the guidance notes on Art. 7 of the EED a lifetime of 25 years can be assumed.

The figure below provides an overview of the calculation system.



Steuer / Abgabe	tax/levy
ggfs. Mindestschwelle laut EED	if applicable, minimum threshold in accordance with EED
Energiepreis	energy price
Δp (relative Preiserhöhung in %)	Δp (relative price increase in %)
Investitionstreiber beobachtet	investment drivers observed
Investitionstreiber kontrafaktisch	counterfactual investment drivers
Einheitseinsparwert	standard saving value
Einsparung der Maßnahme ohne Interaktionen	saving from measure without interactions
Instrumentenfaktor	instrument factor
Nettoeinsparung mit Interaktionen	net saving with interactions

Figure 107: Calculation system for price instrument, long-term impact

The savings determined in this way are presented in Table 48 below.

Table 48: Additional final energy savings in the area of residential buildings as a result of budget-neutral financing of the BEW, attributable to changes in investment behaviour regarding energy-efficient renovation of the outer envelope

	Total saving in GWh net
2021	28
2022	28
2023	28
2024	28
2025	28
2026	28
2027	28
2028	56
2029	56
2030	56
net annual final energy saving (PJ/a) in 2030	417
net cumulative final energy saving (PJ) from 2021 to 2030	1,806

Source: own calculations based on Prognos and GWS (2009)

In line with the previous section, the GHG savings are calculated by taking an average emission factor for the heating supply into account, based on the efficiency scenario of the Energy Efficiency Strategy for Buildings (see Table 49). The cumulative savings therefore amount to 0.02 million tonnes of CO_2-eq. With an average primary energy factor of 0.8 the resulting primary energy saving is 1.1 PJ/a or 311 GWh/a.

Table 49: Average emission factor for heat generation in the period under consideration

	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Emission factor (g/kWh)	80	78	75	73	70	67	65	62	59	57

Source: Energy Efficiency Strategy for Buildings and own calculation

Ranking

Assessment of GHG and primary energy savings: Overall, the approach presented here suggests that budget-neutral financing of the BEW results in total savings of 1,583 GWh/a in 2030; of these savings 1,194 GWh/a are behaviour-based savings and 389 GWh/a are savings resulting from changes in investment behaviour regarding the energy-efficient renovation of buildings (renovation of external walls) from 2021 to

2030. The GHG savings amount to a total of 1.9 million tonnes (cumulative from 2021 to 2030).

A (higher) CO_2 tax could generate additional steering effects, although for various reasons these are left out of consideration in this examination. These effects include:

- Incentive to make greater use of heat pumps, heating systems run on renewable energies or district heating.
- Impact in the area of new buildings: increased use of heat pumps and a reduction in the heating demand in new buildings are conceivable.

These effects are not quantified in the present analysis, however.

Impact on the share of high-efficiency cogeneration and renewable energies: The effects on the further development of CHP and the expansion of renewable heat generators also result primarily from the BEHG and BEW and no further effect is expected from the small additional levy.

Links to national financial programming and support measures: For the reasons outlined, the long-term effects could be investment certainty and medium-term independence of the support instruments from the budget. The savings for the public budget can be taken from the funding requirements in column 2 of Table 46. The funds are currently planned in the form of a support programme and would become extra-budgetary as a result of implementing this measure. The effects mentioned would have to be weighed up against the additional administrative burden and the additional complexity of energy pricing associated with the measure. Reducing this complexity is also a political objective that is the subject of much discussion.

Legal assessment

A detailed legal assessment, in particular of the EU and finance-related constitutional framework, is urgently recommended as part of the process of working out this measure. Based on this assessment, which in terms of individual arguments could closely follow other examples (e.g. the *Kohlepfennig* tax used to subsidise the coal industry, the BEHG, etc.), principles could be derived that would serve as valuable guidelines for the further detailed development of the measure. Regarding the proposal described to date, efforts should be made to outline the group being addressed more clearly in order to demonstrate the benefits to and homogeneity of the group. Risks of incompatibility with the constitution could potentially be present, although these could be largely addressed and eliminated by the detailed structuring of the measure. It is primarily the enhanced impact that provides the objective justification for the measure and distinguishes it from the national Fuel Emissions Trading Act. Such a pronounced impact is not anticipated on the basis of, in particular, the current price path up to 2026. Unfortunately, a detailed legal assessment cannot be performed within the framework of this project. If this measure is not pursued for legal reasons, the proposed system would still serve as an example for the restructuring of the system of levies and taxes that is needed overall in the energy sector.

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F. Annex

I. Annex Part I.3

I.1. Data for Part I.3.a

Useful energy

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE111	2,117.22	1,100.37	245.07
DE112	2,082.63	645.46	1,319.56
DE113	2,793.28	749.31	644.98
DE114	1,596.57	451.66	341.02
DE115	2,391.88	633.19	311.72
DE116	2,347.48	613.38	208.67
DE117	537.78	192.95	26.24
DE118	1,927.81	543.51	127.11
DE119	746.83	299.53	217.95
DE11A	1,294.35	585.70	167.47
DE11B	1,004.88	415.54	148.42
DE11C	911.19	281.01	259.22
DE11D	2,129.42	679.35	1,387.29
DE121	340.94	119.72	0.00
DE122	1,178.45	516.10	914.26
DE123	2,634.78	585.42	762.22
DE124	1,319.18	316.77	1,155.82
DE125	630.50	275.02	10.74
DE126	1,145.36	523.47	1,037.29
DE127	1,052.92	286.87	52.03
DE128	2,782.87	612.44	1,437.76
DE129	606.45	212.73	14.88
DE12A	1,109.96	316.81	0.00
DE12B	1,353.50	293.91	74.35
DE12C	925.18	258.03	345.00
DE131	848.41	358.92	244.69
DE132	1,487.40	418.81	180.38
DE133	868.22	241.64	0.00
DE134	2,401.33	658.23	2,617.34
DE135	1,101.41	308.51	152.55
DE136	1,463.24	433.28	63.09
DE137	1,019.36	296.97	0.00
DE138	1,567.71	484.46	792.40
DE139	1,146.85	323.39	450.90
DE13A	1,065.12	323.87	135.12

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE141	1,763.00	532.06	442.86
DE142	1,243.88	368.72	53.06
DE143	1,523.87	416.27	1,698.50
DE144	589.88	296.22	0.00
DE145	1,352.20	442.08	1,509.40
DE146	1,364.26	509.53	833.22
DE147	1,249.09	409.89	0.00
DE148	1,719.57	686.67	1,408.83
DE149	943.52	352.90	192.21
DE211	652.01	285.25	562.07
DE212	5,598.89	2,850.67	1,004.07
DE213	273.75	158.90	0.00
DE214	708.95	263.63	2,448.20
DE215	593.16	293.10	188.02
DE216	656.51	243.76	21.66
DE217	788.75	267.93	0.00
DE218	676.84	232.46	44.16
DE219	923.82	238.52	125.87
DE21A	736.04	281.69	153.58
DE21B	902.26	346.92	58.27
DE21C	985.69	290.92	0.00
DE21D	562.34	236.71	0.00
DE21E	694.84	188.44	107.75
DE21F	594.98	219.79	55.47
DE21G	716.17	223.85	312.34
DE21H	1,501.55	857.43	13.94
DE21I	678.31	174.33	779.45
DE21J	860.80	263.69	1,822.37
DE21K	1,472.27	545.06	1,533.55
DE21L	766.92	237.47	0.00
DE21M	1,144.89	397.22	269.73
DE21N	789.38	270.83	1,235.22
DE221	365.74	184.53	152.12
DE222	333.96	203.36	0.00
DE223	260.04	158.49	221.98
DE224	826.92	300.66	195.23
DE225	802.96	195.69	244.31
DE226	843.90	246.10	847.43
DE227	1,044.99	311.16	268.93
DE228	1,511.88	510.16	75.33

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE229	722.76	181.04	214.72
DE22A	943.97	292.62	120.81
DE22B	779.54	158.04	104.42
DE22C	689.96	219.67	810.93
DE231	261.68	134.34	204.07
DE232	697.26	504.71	572.09
DE233	255.16	153.90	84.97
DE234	812.86	207.98	76.58
DE235	1,186.96	299.84	56.46
DE236	936.92	284.80	793.62
DE237	797.24	209.71	761.04
DE238	1,286.34	296.83	358.12
DE239	1,157.37	363.69	516.41
DE23A	637.31	199.18	356.27
DE241	408.33	223.17	104.26
DE242	400.23	256.03	128.65
DE243	240.82	139.01	0.00
DE244	302.46	153.77	10.99
DE245	1,052.92	185.73	525.07
DE246	880.14	200.04	37.10
DE247	624.32	145.15	57.44
DE248	837.34	175.92	99.87
DE249	842.42	216.79	410.14
DE24A	616.38	136.09	485.86
DE24B	578.38	201.80	85.74
DE24C	522.00	173.01	38.81
DE24D	622.73	208.94	303.35
DE251	260.33	132.74	0.00
DE252	519.84	312.77	0.00
DE253	535.98	197.97	48.96
DE254	2,202.61	1,288.74	611.64
DE255	229.72	69.09	0.00
DE256	1,322.85	345.95	434.86
DE257	879.19	183.00	33.79
DE258	721.83	147.39	110.00
DE259	1,111.94	271.62	67.10
DE25A	751.02	230.03	262.35
DE25B	860.95	238.73	14.83
DE25C	699.66	200.48	356.23
DE261	290.34	160.72	752.84

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE262	290.68	194.44	0.00
DE263	687.62	493.60	42.22
DE264	1,066.82	217.39	1,373.55
DE265	869.01	254.89	0.00
DE266	653.64	199.42	0.00
DE267	672.21	166.94	59.25
DE268	668.68	243.55	386.23
DE269	796.46	185.38	502.28
DE26A	1,044.15	248.41	1,070.82
DE26B	836.23	175.44	49.88
DE26C	1,157.21	208.89	536.69
DE271	1,154.03	651.57	680.43
DE272	235.15	123.02	95.12
DE273	314.99	198.61	67.50
DE274	238.75	123.57	16.08
DE275	853.13	302.43	742.59
DE276	1,494.86	405.90	1,198.04
DE277	692.53	299.73	242.48
DE278	841.24	280.01	176.73
DE279	977.99	322.36	754.94
DE27A	437.45	193.92	48.75
DE27B	971.22	330.16	671.74
DE27C	946.59	359.51	677.54
DE27D	996.12	379.38	1,476.34
DE27E	1,019.22	425.60	274.02
DE300	13,856.62	7,466.06	1,269.30
DE401	377.34	169.24	1,171.20
DE402	471.46	253.63	0.00
DE403	281.31	205.20	79.47
DE404	717.51	445.13	0.00
DE405	1,046.84	402.50	16.63
DE406	1,090.00	359.80	16.78
DE407	867.10	352.89	36.92
DE408	958.69	316.14	949.01
DE409	1,239.35	399.82	1,478.03
DE40A	1,235.51	355.31	896.39
DE40B	756.73	326.45	1,353.47
DE40C	1,094.89	437.65	3,322.91
DE40D	712.92	304.39	2,101.56
DE40E	1,329.50	479.22	275.88

	Useful energy 2018 [GWh]		
	Residential*	Services*	Industry**
DE40F	558.26	216.76	173.44
DE40G	863.35	350.12	347.67
DE40H	1,038.43	447.74	349.67
DE40I	838.16	378.58	480.05
DE501	2,430.18	1,340.84	6,200.12
DE502	511.69	217.69	101.91
DE600	7,028.41	3,607.32	8,971.45
DE711	546.09	450.17	0.22
DE712	2,132.64	1,622.11	212.84
DE713	370.69	186.43	0.00
DE714	1,037.73	530.36	563.72
DE715	1,449.57	442.58	93.60
DE716	1,510.62	413.90	15.21
DE717	1,034.09	461.40	1,893.49
DE718	1,194.70	407.30	10.39
DE719	2,066.33	742.39	365.43
DE71A	1,036.50	373.11	0.00
DE71B	688.51	224.77	0.00
DE71C	1,384.79	444.82	413.36
DE71D	999.26	332.58	0.00
DE71E	1,455.74	526.97	218.23
DE721	1,436.35	623.53	198.98
DE722	1,680.00	623.41	1,381.07
DE723	1,145.47	379.93	327.24
DE724	1,354.55	654.49	1,717.12
DE725	711.06	334.88	624.80
DE731	937.80	603.24	831.44
DE732	1,355.79	716.91	958.17
DE733	834.33	388.96	231.36
DE734	1,575.27	472.57	167.42
DE735	1,220.82	533.08	87.57
DE736	1,108.68	633.18	856.86
DE737	742.63	292.49	204.17
DE803	703.74	362.15	167.86
DE804	381.25	225.70	0.00
DE80J	1,338.10	591.72	80.69
DE80K	1,035.00	439.09	75.16
DE80L	1,154.14	523.95	266.44
DE80M	603.96	185.30	194.21
DE80N	1,178.86	544.42	156.06

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE80O	1,176.75	439.44	546.19
DE911	1,212.86	546.77	320.83
DE912	569.65	303.41	11,877.82
DE913	676.38	251.14	2,641.07
DE914	1,110.06	353.06	329.07
DE916	1,063.11	483.78	623.47
DE917	653.83	217.85	9.62
DE918	995.42	428.89	526.49
DE91A	844.69	264.02	1,812.11
DE91B	735.86	251.55	719.27
DE91C	2,205.52	879.45	1,217.91
DE922	1,324.82	798.23	134.45
DE923	1,101.88	404.58	200.17
DE925	1,764.81	651.84	3,322.93
DE926	580.47	217.74	870.90
DE927	851.16	471.24	1,017.48
DE928	1,111.49	402.65	556.15
DE929	6,419.09	2,242.14	1,857.18
DE931	1,244.13	370.50	0.00
DE932	1,306.84	572.86	44.69
DE933	1,420.02	471.22	86.22
DE934	399.57	230.24	114.25
DE935	998.62	369.99	425.74
DE936	732.45	244.75	0.37
DE937	1,075.40	650.86	745.73
DE938	960.68	444.16	350.71
DE939	1,167.42	487.18	4,224.98
DE93A	674.34	316.79	1,474.45
DE93B	852.21	343.76	202.83
DE941	411.57	119.25	206.90
DE942	286.82	154.38	49.98
DE943	872.81	355.62	0.00
DE944	823.95	428.83	690.71
DE945	386.41	182.28	495.23
DE946	757.27	368.41	770.17
DE947	1,571.84	424.72	26.79
DE948	952.33	732.86	1,167.55
DE949	2,063.45	1,274.93	3,125.69
DE94A	612.94	278.71	1,421.35
DE94B	799.07	422.32	711.61

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DE94C	1,254.35	388.91	63.79
DE94D	818.58	419.64	3,524.80
DE94E	2,433.56	1,137.08	2,891.39
DE94F	869.28	567.11	485.99
DE94G	565.99	292.97	1,452.70
DE94H	451.20	169.39	0.00
DEA11	2,645.28	1,123.73	1,213.30
DEA12	1,930.28	706.51	30,596.57
DEA13	2,586.41	857.34	3,165.45
DEA14	960.48	413.76	4,490.31
DEA15	1,134.73	373.48	110.47
DEA16	729.04	228.60	544.34
DEA17	832.17	262.41	550.78
DEA18	629.76	251.20	216.44
DEA19	758.78	241.88	196.21
DEA1A	1,825.95	715.82	313.51
DEA1B	1,608.70	725.38	1,001.96
DEA1C	2,123.52	768.77	1,783.33
DEA1D	1,945.51	731.37	8,079.69
DEA1E	1,433.68	534.09	235.27
DEA1F	2,164.77	766.27	4,344.25
DEA22	1,382.64	501.34	373.43
DEA23	3,925.77	1,915.26	8,501.70
DEA24	678.07	237.85	604.09
DEA26	1,421.88	571.45	2,278.60
DEA27	2,166.82	573.02	9,207.78
DEA28	1,338.59	393.97	1,372.71
DEA29	1,374.58	322.08	91.80
DEA2A	1,870.04	586.21	222.92
DEA2B	1,656.10	393.39	440.50
DEA2C	2,799.38	716.13	492.70
DEA2D	2,851.74	1,114.12	1,741.14
DEA31	490.79	159.64	0.00
DEA32	1,040.28	398.77	448.80
DEA33	1,440.27	556.39	196.43
DEA34	1,835.61	860.64	391.25
DEA35	1,079.69	341.05	303.24
DEA36	2,871.03	786.95	8,614.06
DEA37	2,409.04	901.03	1,379.62
DEA38	1,380.07	774.10	1,328.31

	Useful energy 2018 [GWh]		
	Residential*	Services*	Industry**
DEA41	1,921.65	804.40	805.23
DEA42	1,842.50	664.30	2,522.39
DEA43	1,693.50	483.21	345.43
DEA44	1,250.38	521.98	570.40
DEA45	2,447.03	777.57	1,656.08
DEA46	1,976.07	679.08	338.62
DEA47	1,909.27	871.15	1,105.03
DEA51	1,576.32	569.93	499.95
DEA52	2,433.02	854.07	1,607.89
DEA53	1,067.68	377.02	1,333.57
DEA54	759.67	278.95	498.53
DEA55	646.81	171.51	321.54
DEA56	1,782.69	538.61	1,147.46
DEA57	2,103.52	942.80	2,796.41
DEA58	2,707.05	1,052.66	1,252.12
DEA59	1,058.44	325.58	137.45
DEA5A	2,088.25	660.93	1,509.47
DEA5B	1,821.84	598.42	2,228.77
DEA5C	1,943.47	562.65	3,935.01
DEB11	615.20	245.92	443.91
DEB12	949.44	218.72	165.51
DEB13	1,074.36	254.43	65.30
DEB14	1,033.94	265.01	618.01
DEB15	776.19	223.00	0.00
DEB17	1,419.61	380.61	1,662.65
DEB18	1,227.10	324.33	508.44
DEB1A	874.00	210.14	385.12
DEB1B	1,619.22	459.92	641.22
DEB1C	561.74	148.16	61.46
DEB1D	856.44	266.05	31.33
DEB21	591.74	237.67	6.23
DEB22	941.81	249.79	388.91
DEB23	898.57	356.18	586.71
DEB24	600.98	168.51	245.71
DEB25	1,121.69	219.61	50.21
DEB31	215.65	64.30	0.00
DEB32	694.58	270.06	119.04
DEB34	673.75	362.37	20,962.10
DEB35	834.23	351.33	793.86
DEB36	320.52	74.53	0.00

	Useful energy 2018 [GWh]		
	Residential*	Services*	Industry**
DEB37	334.53	110.89	0.00
DEB38	228.81	118.20	191.61
DEB39	380.35	118.93	1,258.13
DEB3A	279.71	85.94	0.00
DEB3B	727.24	157.78	88.08
DEB3C	889.83	184.30	785.63
DEB3D	609.24	132.49	680.94
DEB3E	690.00	149.06	858.09
DEB3F	1,059.12	192.07	0.00
DEB3G	699.49	111.09	17.20
DEB3H	1,060.45	273.56	0.00
DEB3I	827.65	131.04	0.00
DEB3J	1,121.50	235.63	588.31
DEB3K	947.50	178.92	0.00
DEC01	2,326.02	693.90	806.12
DEC02	925.18	199.72	240.20
DEC03	1,073.35	221.73	252.70
DEC04	1,670.12	381.82	8,353.95
DEC05	1,187.91	337.03	840.27
DEC06	844.36	174.06	213.44
DED21	2,051.03	1,326.55	608.52
DED2C	1,976.15	809.31	975.40
DED2D	1,929.16	809.14	904.12
DED2E	1,400.78	689.01	1,832.75
DED2F	1,514.21	676.35	500.03
DED41	1,102.00	652.46	99.88
DED42	2,497.13	986.30	291.92
DED43	1,982.11	1,146.97	776.18
DED44	1,662.87	724.67	215.06
DED45	1,663.34	1,069.98	705.13
DED51	1,905.32	1,383.69	264.36
DED52	1,437.35	658.32	4,312.12
DED53	1,029.60	701.11	1,527.10
DEE01	470.54	241.92	0.00
DEE02	931.68	493.02	11.70
DEE03	1,003.55	541.17	13.10
DEE04	641.90	270.14	587.87
DEE05	1,042.55	453.33	314.93
DEE06	570.51	259.99	16.01
DEE07	1,103.42	483.68	2,203.53

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DEE08	1,210.44	523.99	3,024.67
DEE09	1,406.35	584.15	1,542.80
DEE0A	947.82	344.48	287.57
DEE0B	1,116.01	495.03	2,340.42
DEE0C	1,136.10	545.32	4,449.83
DEE0D	697.85	328.45	1,133.24
DEE0E	889.64	350.63	7,057.08
DEF01	389.50	149.75	0.00
DEF02	947.48	407.37	0.00
DEF03	940.50	332.20	24.80
DEF04	388.13	122.41	51.48
DEF05	875.27	216.96	1,083.22
DEF06	1,091.54	212.79	4.60
DEF07	1,041.75	249.62	13.47
DEF08	1,322.60	362.35	341.12
DEF09	1,421.07	325.92	762.54
DEF0A	718.84	146.54	14.40
DEF0B	1,478.63	330.76	17.32
DEF0C	1,220.86	258.79	0.00
DEF0D	1,352.41	344.43	422.57
DEF0E	762.27	207.08	4,532.35
DEF0F	1,227.26	274.31	6.83
DEG01	813.72	437.51	31.60
DEG02	426.93	195.60	18.15
DEG03	391.11	196.63	493.52
DEG04	126.04	60.99	0.00
DEG05	270.17	108.67	3.59
DEG06	449.39	243.08	1,129.94
DEG07	423.62	223.78	31.11
DEG09	502.74	276.61	246.79
DEG0A	450.17	229.41	0.00
DEG0B	734.44	319.80	77.71
DEG0C	558.05	284.60	316.86
DEG0D	380.60	189.09	12.46
DEG0E	391.82	205.73	152.17
DEG0F	501.86	244.77	220.67
DEG0G	443.15	211.33	84.56
DEG0H	257.66	115.89	444.89
DEG0I	635.20	284.98	1,023.77
DEG0J	464.32	228.74	143.14

	Useful energy 2018 [GWh]		
	Residential*	**Services***	**Industry****
DEG0K	551.28	295.36	2,866.23
DEG0L	598.82	289.07	128.68
DEG0M	536.02	217.88	0.00
DEG0N	200.09	76.01	0.00
DEG0P	739.07	307.41	559.46

*space heating and hot water only, **space heating, hot water, air conditioning and process cooling

Final energy

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DE111	2,342.1	1,460.1	633.1	1,281.8	1,158.3	843.5	318.0	261.2	198.6
DE112	2,302.6	1,442.6	605.0	751.9	685.4	499.6	1,794.5	1,445.2	1,057.2
DE113	3,088.0	1,934.5	807.2	872.8	793.7	575.9	940.8	780.2	552.5
DE114	1,765.1	1,085.2	452.8	526.1	468.5	341.1	465.4	392.3	309.6
DE115	2,644.2	1,667.3	702.4	737.6	672.2	489.0	448.2	372.1	282.5
DE116	2,595.1	1,610.2	670.8	714.5	642.7	466.2	298.2	239.4	176.1
DE117	594.7	357.4	151.1	224.8	195.2	140.9	37.3	30.7	23.1
DE118	2,131.3	1,340.5	566.0	633.1	574.6	422.2	182.3	150.7	109.1
DE119	825.9	523.2	224.9	348.9	319.0	238.1	319.3	268.6	206.5
DE11A	1,431.6	916.6	398.2	682.3	630.0	474.4	239.9	205.6	160.5
DE11B	1,111.3	688.5	294.5	484.0	433.3	322.3	211.2	178.7	138.6
DE11C	1,007.4	596.3	247.8	327.3	280.4	203.3	374.5	322.2	255.4
DE11D	2,354.4	1,435.5	602.7	791.3	697.8	511.1	1,979.7	1,626.9	1,157.7
DE121	377.0	233.0	98.4	139.5	125.3	90.5	0.0	0.0	0.0
DE122	1,303.3	781.1	333.2	601.2	522.0	375.5	1,327.9	1,115.1	752.8
DE123	2,912.4	1,855.8	775.2	681.9	628.8	458.5	1,084.1	928.0	732.5
DE124	1,458.3	920.7	384.5	369.0	337.3	245.6	1,627.1	1,342.0	957.1
DE125	697.3	410.9	173.6	320.4	274.2	195.7	14.8	12.0	9.0
DE126	1,266.8	776.6	335.0	609.8	541.2	392.1	1,481.0	1,243.8	859.8
DE127	1,164.0	725.5	304.5	334.2	301.1	220.8	79.1	67.1	53.0
DE128	3,076.1	1,941.1	812.3	713.4	651.4	474.8	1,976.3	1,634.8	1,248.7
DE129	670.6	393.9	164.0	247.8	212.0	150.9	21.8	18.2	14.3
DE12A	1,227.1	756.4	315.5	369.0	330.0	240.3	0.0	0.0	0.0
DE12B	1,496.1	923.9	381.9	342.4	306.2	222.4	109.0	93.2	73.9
DE12C	1,022.8	629.2	261.6	300.6	268.0	194.5	487.7	394.3	278.9
DE131	938.3	573.5	242.9	418.1	372.2	266.6	342.7	275.1	204.7
DE132	1,644.4	1,078.8	458.3	487.9	463.0	341.7	262.1	221.7	154.6
DE133	959.8	619.7	262.6	281.5	262.5	193.0	0.0	0.0	0.0
DE134	2,654.7	1,694.7	716.4	766.7	706.5	517.9	3,978.6	3,366.8	2,587.8

	Final energy [GWh]								
	Residential			**Services**			**Industry**		
	2018	**2030**	**2050**	**2018**	**2030**	**2050**	**2018**	**2030**	**2050**
DE135	1,217.6	730.4	303.0	359.4	311.9	226.3	229.1	190.3	145.2
DE136	1,617.7	977.5	407.3	504.7	442.5	320.1	81.7	68.8	54.8
DE137	1,127.0	683.6	284.6	345.9	303.7	220.7	0.0	0.0	0.0
DE138	1,733.3	1,092.6	460.2	564.3	516.2	375.7	1,195.2	1,010.1	797.3
DE139	1,267.9	795.8	336.2	376.7	341.6	248.6	655.2	554.7	436.5
DE13A	1,177.6	731.6	309.1	377.3	338.7	247.5	198.3	166.2	130.3
DE141	1,949.2	1,217.7	509.9	619.8	561.7	410.6	613.3	500.7	379.0
DE142	1,375.2	856.2	357.1	429.5	388.7	282.1	74.7	61.6	47.6
DE143	1,684.7	1,029.0	427.0	484.9	428.9	311.3	2,442.7	2,086.6	1,642.6
DE144	652.5	400.0	170.7	345.1	307.2	222.7	0.0	0.0	0.0
DE145	1,495.1	947.3	403.1	515.0	470.9	350.4	2,187.0	1,862.7	1,369.0
DE146	1,508.6	962.7	412.8	593.5	546.1	407.3	1,128.7	937.2	732.3
DE147	1,381.1	875.4	371.3	477.5	438.2	321.9	0.0	0.0	0.0
DE148	1,901.6	1,226.3	528.8	799.9	744.5	555.5	1,754.9	1,460.4	1,149.5
DE149	1,043.3	659.7	282.0	411.1	375.4	279.1	289.1	240.6	183.4
DE211	721.1	459.3	196.5	332.3	306.9	224.5	769.6	617.3	448.0
DE212	6,193.3	3,917.7	1,691.8	3,320.6	3,063.5	2,219.0	1,267.1	993.7	726.1
DE213	302.9	196.1	85.8	185.1	174.0	128.8	0.0	0.0	0.0
DE214	783.9	487.9	205.8	307.1	280.3	206.9	3,405.4	3,074.0	2,280.1
DE215	656.1	424.4	183.3	341.4	321.2	237.7	279.7	232.9	178.2
DE216	726.0	471.9	201.2	283.9	269.3	199.1	30.1	24.7	19.1
DE217	872.1	572.4	244.0	312.1	298.1	221.1	0.0	0.0	0.0
DE218	748.4	493.8	210.6	270.8	259.4	191.5	68.0	58.0	46.1
DE219	1,021.3	644.1	267.7	277.8	257.3	189.1	182.8	157.4	124.9
DE21A	813.9	534.0	228.7	328.1	315.4	235.9	181.4	152.1	121.3
DE21B	997.7	651.4	277.5	404.1	387.3	288.3	76.0	64.5	51.2
DE21C	1,089.8	709.5	299.2	338.9	322.2	236.8	0.0	0.0	0.0
DE21D	621.9	393.5	167.1	275.7	255.0	187.3	0.0	0.0	0.0
DE21E	768.2	499.2	209.5	219.5	209.5	154.9	149.2	122.7	94.7
DE21F	657.9	428.6	182.5	256.0	243.5	179.6	80.8	67.9	45.3
DE21G	791.8	501.4	210.8	260.8	241.3	177.3	355.5	295.7	235.3
DE21H	1,661.2	1,114.5	488.7	998.8	980.5	740.5	21.1	18.0	14.3
DE21I	749.9	479.2	200.1	203.1	190.9	141.2	1,064.9	905.7	689.1
DE21J	951.7	617.0	260.8	307.2	289.8	214.0	2,492.6	2,207.8	1,612.2
DE21K	1,628.0	1,058.7	451.2	634.9	601.8	445.8	2,170.4	1,826.6	1,366.9
DE21L	847.9	555.8	235.1	276.6	263.8	193.6	0.0	0.0	0.0
DE21M	1,265.9	795.9	335.1	462.7	426.2	313.7	390.2	325.6	228.6
DE21N	872.8	563.7	238.8	315.5	297.8	220.3	1,761.1	1,476.2	1,007.7
DE221	404.6	262.3	113.6	214.9	202.4	148.9	209.5	169.3	124.1

	Final energy [GWh]								
	Residential			**Services**			**Industry**		
	2018	**2030**	**2050**	**2018**	**2030**	**2050**	**2018**	**2030**	**2050**
DE222	369.5	227.4	98.7	236.9	211.6	155.3	0.0	0.0	0.0
DE223	287.7	179.2	77.9	184.6	166.5	122.9	249.4	208.5	167.1
DE224	914.4	564.6	236.4	350.2	318.4	235.6	290.2	244.4	170.1
DE225	887.6	524.4	213.2	228.0	198.6	143.5	344.4	287.5	221.8
DE226	933.0	578.6	241.7	286.7	259.2	189.8	1,188.5	1,046.6	792.2
DE227	1,155.3	739.3	311.4	362.5	338.5	250.7	375.3	312.7	239.0
DE228	1,671.7	1,028.2	431.2	594.3	533.5	391.1	110.2	93.9	73.6
DE229	799.0	471.5	192.0	210.9	184.1	133.6	309.4	260.8	202.9
DE22A	1,043.7	652.7	273.2	340.9	314.2	233.0	171.1	144.4	113.3
DE22B	861.6	524.7	214.4	184.1	165.4	120.8	139.8	119.0	94.4
DE22C	762.8	473.9	198.6	255.9	232.1	170.9	1,133.2	935.9	705.9
DE231	289.5	177.2	75.9	156.5	138.9	101.4	291.6	241.2	185.5
DE232	771.7	498.9	221.2	587.9	552.1	408.9	789.5	649.3	488.8
DE233	282.3	173.7	75.3	179.3	159.8	117.8	123.2	106.1	84.1
DE234	898.6	518.7	211.6	242.3	205.5	148.9	107.5	89.6	69.8
DE235	1,312.1	771.6	315.2	349.3	302.1	218.4	82.3	70.1	55.4
DE236	1,035.9	631.4	262.9	331.7	294.9	215.3	1,103.5	910.0	703.9
DE237	881.3	507.1	206.5	244.3	206.2	148.8	1,095.8	941.5	746.1
DE238	1,421.9	876.4	362.1	345.8	311.4	227.0	392.7	326.0	261.0
DE239	1,279.6	760.3	315.3	423.6	366.7	266.8	745.8	642.0	509.4
DE23A	704.6	404.4	165.8	232.0	195.3	140.9	487.6	405.1	314.9
DE241	451.7	265.3	113.3	260.0	222.0	160.1	121.3	100.1	78.2
DE242	442.9	241.2	102.2	298.2	235.8	168.8	141.2	117.2	93.9
DE243	266.4	153.7	65.4	161.9	135.4	98.1	0.0	0.0	0.0
DE244	334.6	185.3	77.4	179.1	144.4	102.7	15.6	12.9	10.0
DE245	1,163.7	693.3	281.1	216.3	188.2	135.0	757.1	635.1	487.2
DE246	972.9	566.0	229.8	233.0	198.5	142.4	54.1	46.4	36.8
DE247	690.1	396.5	161.0	169.1	142.2	101.9	81.6	69.1	54.3
DE248	925.5	553.0	225.3	204.9	179.1	128.7	144.0	124.1	98.5
DE249	931.3	519.5	209.9	252.5	206.2	147.1	584.5	487.2	350.8
DE24A	681.3	382.6	153.8	158.5	130.2	92.5	702.0	604.5	479.8
DE24B	639.5	360.6	148.0	235.1	194.1	139.9	105.1	86.9	68.3
DE24C	577.2	342.2	141.9	201.5	173.7	125.6	55.6	47.1	36.8
DE24D	688.5	377.3	153.7	243.4	195.1	139.2	432.3	368.8	291.0
DE251	288.0	183.0	78.9	154.6	142.5	104.8	0.0	0.0	0.0
DE252	575.2	353.3	152.7	364.3	324.9	237.1	0.0	0.0	0.0
DE253	592.7	357.9	150.4	230.6	202.7	145.1	68.3	56.3	43.5
DE254	2,436.9	1,511.4	655.5	1,501.2	1,354.5	988.0	869.0	713.6	547.3
DE255	254.0	154.6	64.4	80.5	71.1	51.2	0.0	0.0	0.0

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DE256	1,462.4	863.5	354.1	403.0	349.1	252.7	593.5	492.5	383.2
DE257	971.8	594.1	243.6	213.2	189.9	136.9	53.6	45.5	35.3
DE258	797.9	484.9	199.0	171.7	151.8	109.2	159.5	137.2	108.7
DE259	1,229.2	745.6	307.0	316.4	280.1	202.6	96.1	80.7	62.7
DE25A	830.3	493.7	204.4	268.0	233.4	170.1	369.0	306.0	237.7
DE25B	951.8	581.8	241.6	278.1	247.3	180.1	20.6	17.2	13.3
DE25C	773.5	458.3	188.8	233.5	202.6	146.7	515.2	440.7	347.0
DE261	321.2	191.3	82.8	187.2	161.0	117.2	1,085.1	905.5	614.1
DE262	321.7	182.3	78.2	226.5	186.4	134.4	0.0	0.0	0.0
DE263	761.0	444.5	191.9	575.0	487.9	352.7	45.8	38.1	30.6
DE264	1,179.2	709.4	292.3	253.2	221.1	159.8	2,003.3	1,686.1	1,139.8
DE265	960.8	552.7	226.1	296.9	250.5	180.1	0.0	0.0	0.0
DE266	722.7	412.7	168.7	232.3	195.0	141.0	0.0	0.0	0.0
DE267	743.1	433.2	176.9	194.5	165.5	119.0	77.5	65.3	48.7
DE268	739.4	452.2	190.1	283.7	253.0	185.8	568.1	487.9	387.5
DE269	880.4	526.1	217.4	215.9	187.7	136.0	737.5	627.6	468.8
DE26A	1,154.2	685.5	280.4	289.4	251.2	181.3	1,547.1	1,330.4	1,055.0
DE26B	924.3	532.2	215.4	204.4	171.6	122.8	71.2	60.7	47.9
DE26C	1,279.0	769.1	312.8	243.3	214.5	154.8	582.2	480.3	382.8
DE271	1,276.7	798.4	346.2	759.0	690.4	504.6	969.2	795.3	561.2
DE272	260.1	159.3	68.5	143.3	127.4	93.4	138.5	116.6	78.1
DE273	348.5	209.5	90.7	231.4	202.2	147.5	104.6	89.0	70.7
DE274	264.1	160.2	68.7	143.9	126.6	92.6	25.3	21.5	16.7
DE275	943.3	594.3	251.4	352.3	322.6	238.2	1,031.4	849.1	656.0
DE276	1,652.6	1,026.7	427.5	472.8	428.6	313.1	1,822.8	1,551.3	1,229.1
DE277	765.9	477.5	203.5	349.1	317.6	236.1	288.8	242.7	193.6
DE278	930.1	577.2	241.7	326.2	296.8	219.1	243.3	206.6	162.6
DE279	1,081.3	676.5	284.6	375.5	342.3	251.0	1,068.3	901.8	712.0
DE27A	483.8	301.7	128.2	225.9	206.2	151.5	70.3	59.1	45.3
DE27B	1,073.9	669.8	280.9	384.6	352.5	260.1	827.2	690.0	526.6
DE27C	1,046.8	657.4	277.7	418.8	385.6	286.6	920.7	768.3	550.5
DE27D	1,101.5	674.1	283.9	441.9	394.6	290.6	2,007.4	1,631.5	1,229.6
DE27E	1,127.2	701.0	297.3	495.8	451.5	332.3	320.1	266.7	211.1
DE300	15,328.9	9,626.1	4,187.5	8,696.9	7,961.5	5,751.6	1,560.3	1,267.3	975.5
DE401	417.3	233.2	98.1	197.1	160.1	113.5	1,820.9	1,549.3	1,230.9
DE402	521.5	277.0	115.8	295.4	228.0	159.8	0.0	0.0	0.0
DE403	311.3	163.0	69.6	239.0	181.6	128.5	87.4	72.7	58.3
DE404	793.9	474.3	206.2	518.5	450.3	324.9	0.0	0.0	0.0
DE405	1,157.6	743.8	318.4	468.9	437.9	323.0	24.3	20.9	16.5

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DE406	1,205.2	693.9	287.9	419.1	351.3	253.6	24.2	20.7	16.4
DE407	958.9	504.3	207.1	411.1	312.9	222.3	54.6	46.8	37.1
DE408	1,060.0	704.4	302.1	368.3	355.6	264.7	1,455.4	1,241.1	986.0
DE409	1,370.3	865.1	366.2	465.7	427.2	313.6	2,128.4	1,831.9	1,452.2
DE40A	1,365.9	852.1	357.7	413.9	375.5	273.6	1,374.2	1,166.7	921.5
DE40B	836.9	430.3	176.1	380.3	283.2	199.0	1,874.7	1,690.8	1,257.2
DE40C	1,210.8	727.0	307.6	509.8	444.7	324.2	5,019.0	4,238.3	3,347.4
DE40D	788.4	459.2	194.1	354.6	299.0	216.0	2,857.9	2,348.6	1,816.9
DE40E	1,470.1	989.4	426.6	558.2	544.1	405.8	327.3	275.5	220.2
DE40F	617.3	340.6	141.5	252.5	201.8	143.8	210.3	177.1	141.0
DE40G	954.8	513.6	212.0	407.8	317.5	225.3	501.1	431.7	342.7
DE40H	1,148.5	761.0	331.4	521.6	500.4	374.1	484.9	397.9	304.9
DE40I	927.0	512.4	214.5	441.0	353.6	253.0	685.8	573.0	400.0
DE501	2,688.5	1,638.5	710.6	1,561.9	1,377.8	1,010.8	9,039.9	7,601.3	5,990.9
DE502	565.9	326.1	137.6	253.6	211.8	151.5	142.0	121.7	96.6
DE600	7,774.7	4,819.1	2,076.4	4,202.0	3,790.7	2,733.4	12,038.5	9,972.6	7,697.1
DE711	604.5	370.8	166.4	524.4	464.0	344.8	0.3	0.3	0.2
DE712	2,360.5	1,421.0	635.0	1,889.5	1,644.5	1,208.4	239.0	198.3	158.2
DE713	410.0	250.9	108.7	217.2	192.2	139.8	0.0	0.0	0.0
DE714	1,147.9	716.0	312.3	617.8	557.8	406.9	812.3	691.3	508.8
DE715	1,602.7	998.5	420.5	515.5	465.0	340.8	126.4	106.4	83.1
DE716	1,670.0	1,052.2	442.1	482.1	439.8	322.9	21.4	17.8	13.6
DE717	1,143.7	723.8	313.3	537.5	491.7	366.3	2,595.7	2,083.0	1,512.8
DE718	1,321.0	841.8	358.4	474.4	438.1	320.9	15.2	13.1	10.4
DE719	2,284.9	1,464.3	626.6	864.8	803.9	595.6	528.3	442.5	339.1
DE71A	1,146.1	732.5	313.2	434.6	403.8	298.9	0.0	0.0	0.0
DE71B	761.3	466.9	195.2	261.8	233.1	170.1	0.0	0.0	0.0
DE71C	1,531.1	965.8	412.0	518.2	471.4	345.9	451.2	374.2	299.0
DE71D	1,104.9	696.7	294.7	387.4	354.6	260.3	0.0	0.0	0.0
DE71E	1,609.7	1,038.8	445.8	613.8	572.2	424.6	306.1	243.9	178.3
DE721	1,588.5	941.3	397.1	726.3	628.0	459.3	279.0	236.4	186.5
DE722	1,857.7	1,101.7	461.7	726.2	623.8	455.3	2,068.0	1,761.8	1,394.1
DE723	1,266.5	755.3	315.2	442.6	383.0	278.5	477.3	409.6	324.5
DE724	1,498.3	897.0	381.9	762.4	662.5	487.2	2,294.6	1,930.0	1,532.5
DE725	786.5	459.6	194.8	390.1	330.0	242.2	867.4	712.9	550.2
DE731	1,037.7	598.9	258.2	702.7	588.1	425.9	1,158.2	913.5	655.7
DE732	1,499.8	900.9	386.9	835.1	727.4	537.0	1,366.5	1,149.8	810.9
DE733	922.8	531.9	224.5	453.1	377.8	276.0	353.8	300.8	238.6
DE734	1,741.6	1,015.8	420.5	550.5	465.7	336.6	233.7	190.0	140.2

	Final energy [GWh]								
	Residential			**Services**			**Industry**		
	2018	**2030**	**2050**	**2018**	**2030**	**2050**	**2018**	**2030**	**2050**
DE735	1,350.2	790.3	333.7	621.0	526.0	385.2	118.0	97.0	75.1
DE736	1,226.6	728.6	313.1	737.6	634.7	469.7	1,215.5	998.7	716.2
DE737	821.2	470.3	196.1	340.7	282.8	204.7	293.3	249.0	191.0
DE803	778.5	433.1	183.7	421.8	341.7	240.7	202.2	163.9	125.9
DE804	421.8	227.0	96.1	262.9	205.8	144.7	0.0	0.0	0.0
DE80J	1,479.9	794.6	329.0	689.3	537.5	379.5	106.2	88.8	69.8
DE80K	1,144.6	683.2	289.2	511.5	442.3	320.0	118.2	100.6	78.2
DE80L	1,276.5	725.9	305.7	610.3	502.8	360.3	343.2	260.1	182.4
DE80M	667.7	391.7	162.7	215.9	183.3	131.2	209.9	174.4	140.0
DE80N	1,303.9	722.3	302.9	634.2	508.9	362.9	206.4	155.8	108.1
DE80O	1,301.2	749.8	312.7	511.9	428.1	307.6	748.1	640.9	509.7
DE911	1,341.4	797.1	339.3	636.9	549.4	395.8	423.8	343.5	256.0
DE912	630.2	369.9	161.6	353.4	297.5	222.2	18,271.0	15,522.5	12,318.5
DE913	747.9	437.1	183.5	292.5	247.8	177.2	3,615.7	2,900.0	2,104.9
DE914	1,227.3	727.5	305.1	411.3	353.1	257.1	506.8	430.8	341.3
DE916	1,175.8	668.0	280.9	563.5	464.2	336.0	930.8	795.5	627.6
DE917	722.9	413.6	171.7	253.8	210.4	151.4	13.5	11.3	8.7
DE918	1,100.9	632.3	267.3	499.6	414.5	301.9	742.4	622.4	481.3
DE91A	933.9	553.9	232.2	307.5	263.3	191.6	2,578.6	2,183.0	1,738.2
DE91B	813.6	477.1	200.2	293.0	248.2	180.2	813.1	675.9	537.5
DE91C	2,439.0	1,387.7	580.2	1,024.4	846.4	609.4	1,778.6	1,497.2	1,120.1
DE922	1,465.8	933.8	415.0	929.8	855.0	651.5	166.1	138.1	109.0
DE923	1,218.4	703.9	295.0	471.3	394.1	284.8	283.7	236.0	181.9
DE925	1,951.5	1,128.6	474.4	759.3	635.1	459.5	3,985.4	3,320.4	2,491.0
DE926	641.9	362.2	151.2	253.6	206.9	149.7	1,243.0	1,053.1	821.0
DE927	941.6	590.1	259.8	548.9	496.4	373.5	1,447.9	1,228.0	888.5
DE928	1,229.0	745.8	317.3	469.0	410.9	301.5	737.4	629.6	501.3
DE929	7,097.8	4,268.1	1,800.5	2,611.8	2,280.8	1,641.3	2,662.1	2,244.1	1,748.1
DE931	1,375.5	823.6	345.1	431.6	373.8	271.3	0.0	0.0	0.0
DE932	1,445.3	874.3	377.6	667.3	581.2	432.3	59.4	49.4	38.3
DE933	1,570.1	1,007.1	433.3	548.9	508.0	378.4	94.4	78.5	62.9
DE934	442.1	269.0	118.2	268.2	235.2	176.2	121.4	100.7	80.9
DE935	1,104.3	687.7	293.5	431.0	389.6	286.0	473.0	393.9	315.7
DE936	809.9	494.3	209.5	285.1	251.2	184.1	0.6	0.5	0.4
DE937	1,189.9	761.1	339.4	758.2	697.4	530.0	805.7	668.6	535.9
DE938	1,062.6	652.9	282.9	517.4	458.8	341.3	376.1	312.2	250.7
DE939	1,291.1	826.6	360.1	567.5	523.5	392.7	5,554.5	4,860.1	3,591.8
DE93A	745.9	451.3	195.1	369.0	322.2	238.6	1,702.6	1,407.3	1,115.6
DE93B	942.4	582.7	250.3	400.4	357.8	264.7	220.4	183.3	147.2

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DE941	455.0	271.2	113.3	138.9	119.7	86.5	263.1	219.6	171.4
DE942	317.3	193.8	86.1	179.8	156.9	118.9	66.9	53.2	38.7
DE943	965.2	611.9	261.5	414.2	379.9	278.4	0.0	0.0	0.0
DE944	911.4	555.8	241.8	499.5	439.8	323.6	1,022.9	861.5	618.9
DE945	427.4	233.5	98.7	212.3	167.9	120.1	676.9	611.5	453.2
DE946	837.6	539.7	236.8	429.1	397.6	299.6	871.2	728.7	583.6
DE947	1,737.7	1,066.8	448.4	494.7	439.0	319.1	35.9	29.7	23.1
DE948	1,054.1	690.7	314.8	853.7	803.5	619.1	1,248.2	1,035.2	831.2
DE949	2,283.1	1,474.1	657.9	1,485.1	1,379.7	1,050.4	4,284.1	3,535.1	2,573.4
DE94A	677.9	413.9	178.5	324.7	285.6	212.6	2,052.9	1,727.8	1,171.2
DE94B	884.0	577.1	256.1	491.9	461.5	351.1	796.4	663.2	529.5
DE94C	1,386.8	862.2	365.3	453.0	407.3	299.0	91.5	76.7	56.9
DE94D	905.5	585.1	257.9	488.8	455.0	344.6	4,681.7	4,198.0	3,129.4
DE94E	2,691.6	1,719.7	749.1	1,324.5	1,225.0	916.4	3,932.5	3,320.7	2,601.7
DE94F	961.9	629.6	283.5	660.6	621.4	474.1	632.1	527.4	409.8
DE94G	626.1	379.7	165.4	341.3	297.6	222.8	2,036.1	1,734.3	1,329.9
DE94H	498.9	306.3	131.4	197.3	174.4	128.7	0.0	0.0	0.0
DEA11	2,925.5	1,726.5	736.3	1,309.0	1,122.7	801.1	1,775.5	1,471.6	1,105.7
DEA12	2,134.5	1,224.4	515.3	823.0	684.6	487.4	47,269.5	40,314.6	31,934.1
DEA13	2,859.7	1,646.0	687.4	998.7	835.3	590.2	4,895.2	4,168.2	3,309.7
DEA14	1,062.2	639.2	274.9	482.0	419.0	305.2	5,419.5	4,539.8	3,548.5
DEA15	1,254.6	737.8	308.9	435.0	370.4	264.5	125.7	104.4	83.2
DEA16	806.0	469.5	196.6	266.3	224.6	160.4	838.4	712.9	566.5
DEA17	920.1	534.4	223.0	305.7	257.0	183.2	760.4	688.2	509.4
DEA18	696.4	396.8	165.6	292.6	242.6	172.8	321.9	264.6	198.6
DEA19	838.9	496.6	207.7	281.7	241.9	173.4	306.3	260.5	206.3
DEA1A	2,019.2	1,165.9	488.4	833.8	702.1	498.6	452.6	382.8	299.7
DEA1B	1,779.2	1,116.5	486.5	845.0	761.5	570.3	1,150.0	960.8	769.5
DEA1C	2,348.1	1,412.0	601.6	895.5	777.9	565.2	2,488.5	2,123.1	1,687.0
DEA1D	2,151.3	1,326.4	568.2	851.9	758.2	558.4	11,980.8	10,162.7	7,984.7
DEA1E	1,585.4	978.1	420.6	622.1	551.6	407.7	321.3	271.9	214.8
DEA1F	2,393.7	1,441.1	613.2	892.6	775.1	568.1	6,178.7	5,453.5	4,100.7
DEA22	1,528.9	956.3	409.3	584.0	533.7	378.7	538.7	448.0	345.2
DEA23	4,342.3	2,638.7	1,138.9	2,231.0	1,968.4	1,418.1	11,715.3	10,574.1	7,820.1
DEA24	749.8	453.1	192.4	277.1	242.1	175.1	831.1	752.0	554.7
DEA26	1,572.4	998.3	430.1	665.7	610.5	454.1	2,823.6	2,358.0	1,730.9
DEA27	2,395.4	1,500.9	632.9	667.5	604.8	441.6	12,748.1	11,536.7	8,532.5
DEA28	1,479.9	922.5	386.2	458.9	414.2	302.2	1,875.0	1,573.9	1,117.5
DEA29	1,519.5	950.7	398.6	375.2	338.5	246.8	140.1	119.5	93.4

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	**2030**	**2050**	**2018**	**2030**	**2050**	**2018**	**2030**	**2050**
DEA2A	2,067.6	1,268.9	530.4	682.8	607.7	441.6	334.9	282.7	214.8
DEA2B	1,830.7	1,112.6	462.3	458.2	403.3	290.9	639.4	542.4	385.7
DEA2C	3,094.6	1,967.6	832.3	834.2	772.4	556.1	723.2	617.0	487.7
DEA2D	3,153.6	1,929.1	816.3	1,297.8	1,156.6	839.8	2,450.7	2,077.6	1,634.4
DEA31	542.6	307.2	127.6	186.0	152.2	108.3	0.0	0.0	0.0
DEA32	1,150.4	643.9	269.9	464.5	377.2	267.3	628.3	530.2	391.9
DEA33	1,592.7	944.8	399.5	648.1	557.2	398.8	277.1	231.3	179.3
DEA34	2,030.3	1,271.5	556.8	1,002.5	901.2	676.8	565.5	474.0	351.0
DEA35	1,193.7	745.0	318.2	397.3	356.6	262.8	366.0	308.1	245.8
DEA36	3,174.0	1,821.5	755.2	916.7	760.9	543.0	11,877.2	10,714.1	7,963.4
DEA37	2,663.9	1,662.0	714.1	1,049.6	944.0	700.1	1,776.8	1,507.4	1,199.6
DEA38	1,526.8	957.7	424.8	901.7	811.5	616.3	1,885.0	1,587.3	1,228.0
DEA41	2,125.2	1,269.6	536.2	937.0	813.3	587.7	1,250.1	1,063.7	844.5
DEA42	2,037.4	1,246.8	530.7	773.8	683.0	500.5	3,195.9	2,615.6	2,010.5
DEA43	1,872.3	1,109.7	459.9	562.9	483.8	349.2	435.7	360.3	282.4
DEA44	1,382.8	806.6	340.3	608.0	512.8	374.0	795.3	658.0	509.8
DEA45	2,705.5	1,600.7	665.9	905.8	777.4	561.2	2,178.0	1,784.9	1,377.7
DEA46	2,185.0	1,303.9	549.2	791.0	683.2	495.7	424.2	352.5	276.9
DEA47	2,111.7	1,294.7	556.2	1,014.8	898.6	662.1	1,504.3	1,238.8	952.2
DEA51	1,743.0	993.0	415.7	663.9	548.9	389.1	772.3	657.9	521.3
DEA52	2,690.3	1,576.0	661.9	994.9	845.4	602.0	2,245.0	1,781.5	1,289.0
DEA53	1,180.6	658.2	271.5	439.2	356.8	251.4	2,071.9	1,759.3	1,370.7
DEA54	840.0	500.6	211.5	324.9	279.5	202.0	539.4	447.8	358.8
DEA55	715.0	405.0	167.1	199.8	164.3	115.5	442.3	401.8	295.8
DEA56	1,970.9	1,131.6	471.0	627.4	522.4	373.9	1,749.9	1,472.8	1,149.6
DEA57	2,326.5	1,377.8	583.9	1,098.2	942.4	690.9	3,975.8	3,308.9	2,477.7
DEA58	2,993.6	1,722.5	720.8	1,226.2	1,023.5	738.5	1,893.2	1,612.8	1,272.6
DEA59	1,170.2	684.6	282.6	379.2	321.8	231.2	207.1	174.7	129.1
DEA5A	2,308.8	1,343.3	553.5	769.9	649.9	466.9	2,297.0	1,951.8	1,543.2
DEA5B	2,014.4	1,210.2	509.8	697.1	604.6	439.8	3,111.3	2,656.3	2,098.5
DEA5C	2,148.6	1,276.9	533.2	655.4	563.2	405.3	6,194.4	5,255.0	4,088.3
DEB11	680.3	396.2	167.1	286.5	241.7	172.5	683.8	581.2	453.4
DEB12	1,049.5	628.7	259.1	254.8	221.3	159.1	238.6	205.3	162.7
DEB13	1,187.6	703.7	288.4	296.4	254.4	183.0	93.0	77.6	57.8
DEB14	1,143.0	694.3	289.7	308.7	271.4	196.4	871.7	731.4	558.8
DEB15	858.1	505.7	209.1	259.8	222.6	161.3	0.0	0.0	0.0
DEB17	1,569.4	946.1	394.1	443.4	387.1	281.1	2,472.1	2,085.0	1,490.3
DEB18	1,356.6	815.7	338.6	377.8	328.6	237.4	713.6	632.5	461.3
DEB1A	966.1	570.8	235.4	244.8	209.2	150.3	560.0	480.9	376.3

	Final energy [GWh]								
	Residential			**Services**			**Industry**		
	2018	**2030**	**2050**	**2018**	**2030**	**2050**	**2018**	**2030**	**2050**
DEB1B	1,790.1	1,077.8	447.4	535.7	466.9	338.9	926.3	797.6	633.1
DEB1C	621.0	370.0	153.0	172.6	148.8	107.2	88.6	74.4	57.1
DEB1D	946.9	568.6	237.1	309.9	269.5	195.9	43.5	35.8	27.4
DEB21	654.4	382.9	160.8	276.9	235.2	168.0	9.0	7.7	6.1
DEB22	1,041.2	621.0	257.3	291.0	251.5	181.6	547.7	449.1	339.4
DEB23	993.7	604.0	256.1	414.9	364.9	268.4	654.5	543.5	433.7
DEB24	664.4	392.0	161.9	196.3	167.6	120.9	352.8	303.4	241.0
DEB25	1,239.8	751.8	309.3	255.8	224.5	161.5	69.7	57.2	43.9
DEB31	238.4	145.7	61.6	74.9	66.1	47.7	0.0	0.0	0.0
DEB32	768.1	448.2	187.0	314.6	266.9	190.7	172.5	147.8	116.9
DEB34	745.3	472.5	209.7	422.1	385.2	287.5	28,839.3	26,191.6	19,291.3
DEB35	922.6	553.6	236.0	409.3	355.6	255.2	857.8	712.2	568.2
DEB36	354.3	213.7	88.5	86.8	75.8	54.1	0.0	0.0	0.0
DEB37	369.9	207.2	85.2	129.2	105.2	74.5	0.0	0.0	0.0
DEB38	253.1	158.1	69.0	137.7	124.2	91.3	276.2	238.0	189.0
DEB39	420.5	257.5	108.9	138.5	122.4	88.7	1,735.3	1,570.5	1,158.7
DEB3A	309.2	175.8	72.1	100.1	82.5	58.7	0.0	0.0	0.0
DEB3B	803.9	495.6	207.1	183.8	163.1	118.5	110.5	93.4	74.4
DEB3C	983.6	597.9	247.3	214.7	188.7	136.2	957.1	799.8	604.1
DEB3D	673.4	392.9	160.3	154.3	130.5	93.2	971.8	833.7	662.6
DEB3E	762.7	469.1	196.0	173.6	154.3	112.4	1,202.5	999.6	766.2
DEB3F	1,170.6	676.9	273.6	223.7	188.0	133.5	0.0	0.0	0.0
DEB3G	773.1	433.7	173.3	129.4	105.5	74.2	23.9	19.8	15.3
DEB3H	1,172.3	715.7	297.9	318.7	281.5	203.5	0.0	0.0	0.0
DEB3I	914.7	554.6	228.1	152.6	133.4	95.8	0.0	0.0	0.0
DEB3J	1,239.6	768.1	320.6	274.5	245.5	177.9	811.8	700.1	527.9
DEB3K	1,047.3	591.2	237.5	208.4	170.6	120.7	0.0	0.0	0.0
DEC01	2,571.6	1,459.6	595.7	808.3	668.8	474.0	1,201.6	1,008.8	791.1
DEC02	1,022.7	586.1	237.4	232.6	193.6	137.5	342.9	288.6	224.3
DEC03	1,186.4	659.1	264.2	258.3	208.8	147.1	385.1	326.7	257.3
DEC04	1,846.1	1,054.2	426.9	444.8	369.9	263.6	12,985.6	11,049.5	8,779.0
DEC05	1,313.3	747.0	305.3	392.6	324.1	231.6	1,147.2	962.5	747.2
DEC06	933.3	524.0	210.7	202.8	165.6	117.2	295.4	242.5	187.2
DED21	2,269.6	1,350.3	588.4	1,545.2	1,337.8	967.3	829.3	668.7	501.6
DED2C	2,185.4	1,172.7	481.6	942.7	741.1	525.3	1,154.0	950.4	744.9
DED2D	2,133.5	1,129.0	462.4	942.5	730.0	516.4	1,258.9	1,046.8	812.0
DED2E	1,549.4	920.2	393.1	802.6	692.5	503.5	2,741.7	2,315.0	1,823.0
DED2F	1,674.7	1,011.0	428.9	787.8	693.6	503.7	750.8	638.2	483.7
DED41	1,219.3	636.8	267.9	760.0	577.7	406.0	153.8	130.6	103.4

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DED42	2,761.5	1,450.6	588.6	1,148.9	888.9	627.4	442.6	374.6	285.3
DED43	2,192.9	1,183.0	496.8	1,336.0	1,053.3	754.7	1,120.0	946.4	667.0
DED44	1,839.1	991.8	408.5	844.1	665.4	470.1	288.8	237.3	181.5
DED45	1,840.6	996.2	420.8	1,246.4	992.0	718.5	991.2	822.2	625.0
DED51	2,108.8	1,242.0	545.3	1,611.8	1,380.9	999.0	380.7	315.3	240.8
DED52	1,589.8	966.7	413.0	766.8	677.7	495.6	5,976.0	5,385.4	3,976.3
DED53	1,139.4	682.2	297.0	816.7	714.0	531.1	2,195.0	1,858.2	1,348.1
DEE01	520.5	259.7	107.2	281.8	203.8	142.4	0.0	0.0	0.0
DEE02	1,030.6	547.8	230.2	574.3	444.5	311.9	16.9	14.5	11.5
DEE03	1,110.2	598.3	252.4	630.4	494.0	348.7	18.9	16.3	12.9
DEE04	709.9	393.2	164.5	314.7	252.7	179.8	822.0	682.1	529.6
DEE05	1,153.0	610.1	252.1	528.1	406.8	288.8	454.7	391.6	310.8
DEE06	631.0	360.3	152.5	302.9	250.4	181.3	23.0	19.0	14.7
DEE07	1,220.4	703.4	297.6	563.4	470.0	340.3	2,761.9	2,339.2	1,865.1
DEE08	1,338.7	729.8	304.6	610.4	482.3	343.0	3,928.4	3,423.1	2,638.0
DEE09	1,555.3	849.0	352.2	680.5	539.2	383.1	2,237.2	1,909.1	1,516.0
DEE0A	1,048.1	554.0	226.3	401.3	307.7	216.7	430.2	364.8	288.4
DEE0B	1,234.3	703.7	296.6	576.6	476.4	344.8	3,231.8	2,923.2	2,155.6
DEE0C	1,256.6	681.1	284.8	635.2	498.6	355.9	5,648.2	4,909.8	3,793.4
DEE0D	771.9	411.8	171.4	382.6	295.7	209.7	1,596.3	1,340.7	909.3
DEE0E	983.8	530.8	219.1	408.4	319.5	226.4	9,699.4	8,788.6	6,484.7
DEF01	430.7	260.7	110.3	174.4	153.3	109.9	0.0	0.0	0.0
DEF02	1,047.9	608.6	256.3	474.5	400.8	284.9	0.0	0.0	0.0
DEF03	1,039.9	618.9	259.8	387.0	334.4	239.0	37.1	31.2	24.6
DEF04	429.1	245.8	101.8	142.6	118.4	84.2	59.7	49.6	39.4
DEF05	967.6	573.4	237.6	252.7	217.2	156.9	1,490.2	1,352.3	996.2
DEF06	1,206.5	752.7	312.9	247.9	224.8	162.5	6.4	5.2	4.0
DEF07	1,151.6	691.6	285.7	290.8	253.8	182.1	14.3	11.9	9.5
DEF08	1,462.2	883.5	367.9	422.1	370.6	267.1	380.6	314.9	250.9
DEF09	1,570.8	983.0	411.7	379.7	344.5	249.6	943.5	787.8	578.2
DEF0A	794.6	487.7	201.5	170.7	152.1	109.4	19.9	16.4	12.6
DEF0B	1,634.5	995.4	411.9	385.3	341.6	246.6	23.7	19.0	13.8
DEF0C	1,349.5	822.6	339.8	301.4	267.5	192.7	0.0	0.0	0.0
DEF0D	1,495.0	942.7	396.6	401.2	367.0	267.3	603.1	505.3	388.4
DEF0E	842.7	505.6	211.3	241.2	209.4	151.6	6,367.3	5,648.8	4,299.6
DEF0F	1,356.6	846.5	353.9	319.5	289.3	209.8	9.5	7.8	6.0
DEG01	900.2	508.8	216.9	509.6	418.7	299.0	45.4	38.8	30.6
DEG02	472.2	240.0	98.9	227.8	168.4	116.9	26.2	22.2	17.5
DEG03	432.6	228.7	95.2	229.0	176.0	123.5	709.3	604.7	475.5

	Final energy [GWh]								
	Residential			Services			Industry		
	2018	2030	2050	2018	2030	2050	2018	2030	2050
DEG04	139.4	71.8	29.5	71.0	53.1	37.4	0.0	0.0	0.0
DEG05	298.8	170.7	71.2	126.6	105.2	74.5	5.2	4.5	3.5
DEG06	497.1	278.7	118.0	283.2	229.3	167.7	1,620.7	1,393.6	1,105.4
DEG07	468.6	259.0	109.6	260.7	208.5	150.7	44.8	38.6	30.6
DEG09	556.2	313.3	133.1	322.2	262.1	190.6	362.0	311.0	247.0
DEG0A	498.0	270.0	113.4	267.2	209.3	151.0	0.0	0.0	0.0
DEG0B	812.3	446.8	184.9	372.5	296.7	212.9	112.7	94.9	65.1
DEG0C	617.3	360.0	152.9	331.5	279.8	205.1	398.8	330.0	258.0
DEG0D	421.0	246.9	105.2	220.3	186.4	136.8	17.9	15.4	12.1
DEG0E	433.4	240.7	101.0	239.6	192.8	139.7	220.3	189.5	150.4
DEG0F	555.1	319.8	134.9	285.1	238.5	173.7	323.7	278.0	220.4
DEG0G	490.2	293.0	124.8	246.2	212.7	156.2	92.3	76.7	61.4
DEG0H	285.0	150.1	61.5	135.0	103.2	73.6	638.2	546.4	432.2
DEG0I	702.5	382.4	158.4	332.0	262.0	187.4	1,576.6	1,343.6	1,067.5
DEG0J	513.6	293.1	124.2	266.5	219.6	160.3	210.0	178.9	141.1
DEG0K	609.9	345.9	146.6	344.1	282.2	206.0	4,229.1	3,561.9	2,521.3
DEG0L	662.4	363.2	152.2	336.7	267.3	193.0	175.1	147.5	108.9
DEG0M	592.8	305.1	125.0	253.8	189.3	133.0	0.0	0.0	0.0
DEG0N	221.3	117.0	48.2	88.5	68.1	47.4	0.0	0.0	0.0
DEG0P	817.3	448.1	185.6	358.1	284.2	204.2	846.4	714.6	563.0

I.2. Data for Part I.3.b and Part I.3.c

Table 50: List of identified thermal power plants

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
1	Arzberg 6	Uniper SE	Arzberg	BY	258.3	Cold reserve	Natural gas
2	Barby	Cargill Deutschland GmbH	Barby	ST	20	Operating	Natural gas
3	Bergheim K2/TG2	Martinswerk GmbH	Bergheim	NW	10	Operating	Brown coal
4	Berlin-Charlottenburg GT-6	Vattenfall Europe GmbH	Berlin	BE	68	Operating	Natural gas
5	Bexbach	Steag Power Saar GmbH	Bexbach	SL	780	Operating	Hard coal
6	Biberach 1	Boehringer Ingelheim Pharma GmbH	Biberach	BW	4.1	Operating	Natural gas
7	Biberach 2	Boehringer Ingelheim Pharma GmbH	Biberach	BW	4.3	Operating	Natural gas
8	Biberach 3	Boehringer Ingelheim Pharma GmbH	Biberach	BW	4.1	Operating	Natural gas
9	Bischofferode / Holungen	StW Leipzig	Bischofferode	TH	20	Operating	Solid biomass
10	Sigmundshall 1	K+S KALI GmbH	Bokeloh	NI	4	Operating	Natural gas

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
11	Sigmundshall 2	K+S KALI GmbH	Bokeloh	NI	10	Operating	Natural gas
12	Sigmundshall 3	K+S KALI GmbH	Bokeloh	NI	5	Operating	Natural gas
13	Boxberg R	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Boxberg	SN	675	Operating	Brown coal
14	Kirchmöser	Uniper SE	Branden-burg	BB	207	Operating	Natural gas
15	Bremen-Mittelsbüren (GKB)	Gemeinschaftskraftwerk Bremen GmbH & Co. KG (GKB) / swb Erzeugung GmbH	Bremen	HB	460	Operating	Natural gas
16	Bremen-Mittelsbüren 4	swb Erzeugung GmbH	Bremen	HB	160	Operating	Blast furnace gas
17	Bremen-Mittelsbüren GT 3	swb Erzeugung GmbH	Bremen	HB	88	Operating	Extra-light fuel oil
18	Breuberg/Odenwald	IKW Breuberg GmbH (Pirelli Deutschland GmbH)	Breuberg	HE	11.4	Operating	Natural gas
19	Brokdorf (KBR)	E.ON Kernkraft GmbH	Brokdorf	SH	1,480	Operating	Uranium
20	Brunnenthal-Köditz I	Papierfabrik Carl Macher GmbH	Brunnen-thal	BY	4.8	Operating	Natural gas
21	Brunnenthal-Köditz II	Papierfabrik Carl Macher GmbH	Brunnen-thal	BY	5.2	Operating	Natural gas
22	Brunsbüttel	Sasol Germany GmbH	Brunsbüttel	SH	10	Operating	Natural gas
23	Castrop-Rauxel 2	Evonik New Energies GmbH	Castrop-Rauxel	NW	1	Operating	Natural gas
24	Darmstadt	Entega AG	Darmstadt	HE	100	Grid reserve	Natural gas
25	Darmstadt I	Merck KGaA	Darmstadt	HE	10.6	Operating	Natural gas
26	Dotternhausen 2	Holcim GmbH	Dottern-hausen	BW	8	Operating	Heavy fuel oil
27	Dotternhausen 3	Holcim GmbH	Dottern-hausen	BW	8	Operating	Heavy fuel oil
28	Düsseldorf	StW Düsseldorf AG (SWD AG)	Düsseldorf	NW	10	Operating	Natural gas
29	Düsseldorf-Lausward E (Emil) GT-1	StW Düsseldorf AG (SWD AG)	Düsseldorf	NW	67	Operating	Natural gas
30	Düsseldorf-Lausward E (Emil) GT-2	StW Düsseldorf AG (SWD AG)	Düsseldorf	NW	67	Operating	Natural gas
31	Düsseldorf-Lausward E GT	StW Düsseldorf AG (SWD AG)	Düsseldorf	NW	74	Operating	Extra-light fuel oil
32	Elsdorf	Pfeifer & Langen KG, Zuckerfabrik	Elsdorf	NW	13	Operating	Brown coal
33	Huntorf CAES	Uniper SE	Elsfleth	NI	321	Operating	Natural gas
34	Emden 4 GT	Statkraft Markets GmbH	Emden	NI	50	Operating	Natural gas
35	Grohnde (KWG)	GKK Grohnde GmbH & Co. OHG	Emmerthal	NI	1,430	Operating	Uranium
36	Weisweiler E (4)	RWE Power AG	Eschweiler	NW	363	Operating	Brown coal
37	Weisweiler F (5)	RWE Power AG	Eschweiler	NW	340	Operating	Brown coal
38	Weisweiler G (6) - GT	RWE Generation SE	Eschweiler	NW	274	Cold reserve	Natural gas
39	Weisweiler H (7) - GT	RWE Generation SE	Eschweiler	NW	274	Cold reserve	Natural gas
4	Isar 2 - Essenbach (KKI)	E.ON Kernkraft GmbH	Essenbach	BY	1,485	Operating	Uranium

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
0	(Ohu)						
41	Euskirchen	Pfeifer & Langen KG, Zuckerfabrik	Euskirchen	NW	14.5	Operating	Brown coal
42	Frankfurt / Oder GT	Stadtwerke Frankfurt (Oder) GmbH	Frankfurt / Oder	BB	25	Operating	Natural gas
43	Frimmersdorf Q	RWE Power AG	Frimmers-dorf	NW	310	Security reserve	Brown coal
44	Fulda ('Moritz 3+4')	RhönEnergie Fulda GmbH	Fulda	HE	12	Operating	Diesel
45	Gelsenkirchen-Scholven B	Uniper SE	Gelsenkir-chen	NW	370	Operating	Hard coal
46	Gelsenkirchen-Scholven C	Uniper SE	Gelsenkir-chen	NW	370	Operating	Hard coal
47	Sermuth	envia THERM GmbH	Großbothen Sermuth	SN	17	Operating	Natural gas
48	Großkayna	envia THERM GmbH	Großkayna	ST	129	Operating	Extra-light fuel oil
49	Staudinger 4 (Großkrotzenburg)	Uniper SE	Großkrot-zenburg	HE	637.6	Operating	Natural gas
50	Ingolstadt 3 - Großmehring	Uniper SE	Großmehring	BY	420	Operating	Heavy fuel oil
51	Ingolstadt 4 - Großmehring	Uniper SE	Großmehring	BY	420	Operating	Heavy fuel oil
52	Gundremmingen C (KRB)	Kernkraftwerk Gundremmingen GmbH	Gundremmingen	BY	1,344	Operating	Uranium
53	Hamburg VERA	VERA Klärschlammverbrennung GmbH	Hamburg	HH	12.4	Operating	Natural gas
54	Hamburg	ADM Hamburg AG (Ölmühle)	Hamburg	HH	22.5	Operating	Natural gas
55	Hamburg-Harburg	Nynas GmbH & Co. KG / Deutsche Shell AG	Hamburg	HH	38.3	Operating	Refinery gas
56	Hamm-Uentrop 10	Trianel Power Kraftwerk H.-U. GmbH	Hamm	NW	425	Operating	Natural gas
57	Hamm-Uentrop 20	Trianel Power Kraftwerk H.-U. GmbH	Hamm	NW	425	Operating	Natural gas
58	Westfalen E (Hamm-Uentrop)	RWE Generation SE	Hamm-Uentrop	NW	820	Operating	Hard coal
59	Hausham GT 2	Peißenberger Kraftwerks GmbH (PKG)	Hausham	BY	26.8	Operating	Extra-light fuel oil
60	Hausham GT 3	Peißenberger Kraftwerks GmbH (PKG)	Hausham	BY	26.8	Operating	Extra-light fuel oil
61	Hausham GT 4	Peißenberger Kraftwerks GmbH (PKG)	Hausham	BY	26.8	Operating	Extra-light fuel oil
62	Buschhaus (Helmstedt)	Helmstedter Revier GmbH (MIBRAG)	Helmstedt	NI	405	Security reserve	Brown coal
63	Herdecke H3 (Cuno)	Mark-E AG / Statkraft Markets GmbH	Herdecke	NW	424	Operating	Natural gas
64	Ibbenbüren	RAG Anthrazit Ibbenbüren GmbH	Ibbenbüren	NW	30	Operating	Mine gas
65	Ingolstadt	Audi AG	Ingolstadt	BY	10	Operating	Natural gas
66	Karlsruhe	Stora Ensa Maxau GmbH	Karlsruhe	BW	24.6	Operating	Natural gas
67	Karlsruhe-RDK 6 (West 6)	StW Karlsruhe / EnBW (Rheinhafen)	Karlsruhe	BW	180	Cold reserve	Heavy fuel oil
68	Kirchlengern 2	Energieservice Westfalen-Weser GmbH (EWW)	Kirchlen-gern	NW	23	Operating	Natural gas
69	Kirchlengern 3	Energieservice Westfalen-Weser GmbH (EWW)	Kirchlen-gern	NW	19	Operating	Natural gas

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
70	Kirchlengern 4	Energieservice Westfalen-Weser GmbH (EWW)	Kirchlengern	NW	13	Operating	Natural gas
71	Krefeld GuD (GT)	Cargill Deutschland GmbH	Krefeld	NW	25.8	Operating	Natural gas
72	Krefeld GuD (VM)	Cargill Deutschland GmbH	Krefeld	NW	14	Operating	Natural gas
73	Landesbergen, Robert Frank 4 DT	Statkraft Markets GmbH	Landesbergen	NI	450	Cold reserve	Natural gas
74	Landesbergen, Robert Frank 4 GT	Statkraft Markets GmbH	Landesbergen	NI	60	Operating	Natural gas
75	Leuna GuD-HKW I-1	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	38.3	Operating	Natural gas
76	Leuna GuD-HKW I-2	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	38.3	Operating	Natural gas
77	Leuna GuD-HKW I-3	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	38.3	Operating	Natural gas
78	Leuna GuD-HKW I-5 EKT	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	22.1	Operating	Natural gas
79	Leuna GuD-HKW I-5 KT1	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	25	Operating	Natural gas
80	Leuna GuD-HKW II	envia THERM GmbH / InfraLeuna GmbH	Leuna	ST	56	Operating	Natural gas
81	Emsland-Lingen (KLE)	KKW Lippe-Ems GmbH (RWE / E.ON)	Lingen	NI	1,406	Operating	Uranium
82	Ludwigshafen FHKW T1	Techn. Werke Ludwigshafen AG	Ludwigshafen	RP	1.8	Operating	Natural gas
83	Ludwigshafen FHKW T3	Techn. Werke Ludwigshafen AG	Ludwigshafen	RP	2.8	Operating	Natural gas
84	Ludwigshafen FHKW T4	Techn. Werke Ludwigshafen AG	Ludwigshafen	RP	5	Operating	Natural gas
85	Ludwigshafen I (GT)	Techn. Werke Ludwigshafen AG / Younicos AG / KNS mbH	Ludwigshafen	RP	5	Operating	Natural gas
86	Marbach II	EnBW Kraftwerke AG	Marbach	BW	77.8	Grid reserve	Extra-light fuel oil
87	Marbach III DT	EnBW Kraftwerke AG	Marbach	BW	270	Grid reserve	Extra-light fuel oil
88	Marbach III GT	EnBW Kraftwerke AG	Marbach	BW	90	Grid reserve	Extra-light fuel oil
89	Mayen 2	Moritz J. Weig GmbH	Mayen	RP	3.6	Operating	Natural gas
90	Mühlhausen-Grabe 1	Uniper SE	Mühlhausen-Grabe	TH	5	Operating	Natural gas
91	Mühlhausen-Grabe 2	Uniper SE	Mühlhausen-Grabe	TH	5	Operating	Natural gas
92	Neckarwestheim 2 GKN	EnBW Kernkraft GmbH (EnKK)	Neckarwestheim	BW	1,400	Operating	Uranium
93	Neuhof-Ellers 1	K+S KALI GmbH	Neuhof	TH	5	Operating	Natural gas
94	Neuhof-Ellers 2	K+S KALI GmbH	Neuhof	TH	1.5	Operating	Natural gas
95	Neuhof-Ellers 3	K+S KALI GmbH	Neuhof	TH	4.5	Operating	Natural gas
96	Neurath A - Grevenbroich	RWE Power AG	Neurath	NW	312	Operating	Brown coal
97	Neurath B - Grevenbroich	RWE Power AG	Neurath	NW	312	Operating	Brown coal
98	Neurath C - Grevenbroich	RWE Power AG	Neurath	NW	312	Security reserve	Brown coal
99	Neurath F - Grevenbroich (BoA 2)	RWE Power AG	Neurath	NW	1,100	Operating	Brown coal

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
100	Neurath G - Grevenbroich (BoA 3)	RWE Power AG	Neurath	NW	1,100	Operating	Brown coal
101	Niederaußem C	RWE Power AG	Niederaußem	NW	335	Operating	Brown coal
102	Niederaußem D	RWE Power AG	Niederaußem	NW	320	Operating	Brown coal
103	Niederaußem E	RWE Power AG	Niederaußem	NW	315	Security reserve	Brown coal
104	Niederaußem F	RWE Power AG	Niederaußem	NW	320	Security reserve	Brown coal
105	Niederaußem H	RWE Power AG	Niederaußem	NW	687	Operating	Brown coal
106	Niederaußem K (BoA 1)	RWE Power AG	Niederaußem	NW	1,012	Operating	Brown coal
107	Franken I-GT (Nürnberg)	Uniper SE	Nuremberg	BY	53	Operating	Natural gas
108	Oberhausen-Holten	Oxea GmbH (Ruhrchemie)	Oberhausen	NW	69	Operating	Natural gas
109	Itzehoe	Uniper SE	Oldendorf	SH	89.6	Operating	Extra-light fuel oil
110	Osnabrück T6	Kämmerer Papierfabrik GmbH	Osnabrück	NI	10	Operating	Brown coal
111	Audorf	Uniper SE	Osterrönfeld	NI	89.6	Operating	Extra-light fuel oil
112	Heyden	Uniper SE	Petershagen	NW	923	Operating	Hard coal
113	Leinau	Vereinigte Wertach-Elektrizitätswerke (VWEW)	Pforzen	BY	13.2	Operating	Diesel
114	Salzwedel	Uniper SE	Salzwedel	ST	10.3	Operating	Landfill gas
115	Sandersdorf	Eco Strom Plus GmbH	Sandersdorf-Brehna	ST	12	Operating	Biomass
116	Sehnde (Bergmannssegen-Hugo DT1)	K+S KALI GmbH	Sehnde	NI	14	Operating	Natural gas
117	Sehnde (Bergmannssegen-Hugo GT2)	K+S KALI GmbH	Sehnde	NI	1	Operating	Natural gas
118	Sipplinger Berg	Bodensee-Wasserversorgung (ZVBWV)	Sipplingen	BW	15.3	Operating	Diesel
119	Stuttgart-Münster GT16	EnBW Kraftwerke AG	Stuttgart	BW	25	Operating	Extra-light fuel oil
120	Stuttgart-Münster GT17	EnBW Kraftwerke AG	Stuttgart	BW	25	Operating	Extra-light fuel oil

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
121	Stuttgart-Münster GT18	EnBW Kraftwerke AG	Stuttgart	BW	25	Operating	Extra-light fuel oil
122	Thyrow A	Lausitz Energie Kraftwerke AG (LEAG)	Trebbin-Thyrow	BB	37	Grid reserve	Natural gas
123	Thyrow B	Lausitz Energie Kraftwerke AG (LEAG)	Trebbin-Thyrow	BB	37	Grid reserve	Natural gas
124	Thyrow C	Lausitz Energie Kraftwerke AG (LEAG)	Trebbin-Thyrow	BB	37	Grid reserve	Natural gas
125	Thyrow D	Lausitz Energie Kraftwerke AG (LEAG)	Trebbin-Thyrow	BB	37	Grid reserve	Natural gas
126	Thyrow E	Lausitz Energie Kraftwerke AG (LEAG)	Trebbin-Thyrow	BB	38	Grid reserve	Natural gas
127	Unterbreizbach DT-2	K+S KALI GmbH	Unterbreizbach	TH	6	Operating	Natural gas
128	Unterbreizbach DT-3	K+S KALI GmbH	Unterbreizbach	TH	13	Operating	Extra-light fuel oil
129	Unterbreizbach GT-1	K+S KALI GmbH	Unterbreizbach	TH	5	Operating	Natural gas
130	Unterbreizbach GT-2	K+S KALI GmbH	Unterbreizbach	TH	5	Operating	Natural gas
131	Pleinting 1	Uniper SE	Vilshofen	BY	300	Cold reserve	Extra-light fuel oil
132	Pleinting 2	Uniper SE	Vilshofen	BY	425	Cold reserve	Extra-light fuel oil
133	Irsching 2	Uniper SE	Vohburg	BY	330	Cold reserve	Extra-light fuel oil
134	Irsching 4 (‘Ulrich Hartmann’)	Uniper SE / Siemens	Vohburg	BY	578	Grid reserve	Natural gas
135	Irsching 5	Uniper SE, N-Ergie, Mainova, Entega AG	Vohburg	BY	876	Grid reserve	Natural gas
136	Walheim 1	EnBW Kraftwerke AG	Walheim	BW	107	Operating	Hard coal
137	Walheim 2	EnBW Kraftwerke AG	Walheim	BW	160	Operating	Hard coal
138	Waltenhofen SKW I	Allgäuer Überlandwerk GmbH	Waltenhofen	BY	26	Operating	Extra-light fuel oil
139	Waltenhofen SKW II	Allgäuer Überlandwerk GmbH	Waltenhofen	BY	12	Operating	Diesel
140	Wedel A	Vattenfall Hamburg Wärme GmbH	Wedel	SH	51	Operating	Extra-light fuel oil
141	Wedel B	Vattenfall Hamburg Wärme GmbH	Wedel	SH	51	Operating	Extra-light fuel oil

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
142	Werdohl-Elverlingsen 1/2	Mark-E AG	Werdohl	NW	220	Security reserve	Natural gas
143	Gersteinwerk F1 GT (Werne)	RWE Power AG	Werne	NW	55	Operating	Natural gas
144	Gersteinwerk F2 DT (Werne)	RWE Power AG	Werne	NW	372	Cold reserve	Natural gas
145	Gersteinwerk G1 GT (Werne)	RWE Power AG	Werne	NW	55	Operating	Natural gas
146	Gersteinwerk G2 DT (Werne)	RWE Power AG	Werne	NW	372	Cold reserve	Natural gas
147	Gersteinwerk I1 GT (Werne)	RWE Power AG	Werne	NW	55	Operating	Natural gas
148	Gersteinwerk I2 DT (Werne)	RWE Power AG	Werne	NW	372	Cold reserve	Natural gas
149	Gersteinwerk K1 (GT) (Werne)	RWE Power AG	Werne	NW	112	Operating	Natural gas
150	Wesseling (Rheinland-Raffinerie Süd) (Kessel 6) D209	Basell Polyolefine GmbH / Shell AG	Wesseling	NW	53	Operating	Natural gas
151	Wesseling (Rheinland-Raffinerie Süd) (Kessel 7)	Basell Polyolefine GmbH / Shell AG	Wesseling	NW	42	Operating	Heavy fuel oil
152	Wesseling (Rheinland-Raffinerie Süd) (Kessel 8)	Basell Polyolefine GmbH / Shell AG	Wesseling	NW	53	Operating	Natural gas
153	Wilhelmshaven	Uniper SE	Wilhelmshaven	NI	788.1	Operating	Hard coal
154	Wilhelmshaven (Rüstersieler Groden)	Riverstone Holdings LLC / BKW FMB Energie / WSW Energie und Wasser AG	Wilhelmshaven	NI	830	Operating	Hard coal
155	Wilhelmshaven GT	Uniper SE	Wilhelmshaven	NI	57.7	Operating	Extra-light fuel oil
156	Worms	Grace GmbH	Worms	RP	12.4	Operating	Natural gas
157	Wuppertal-Barmen 2	WSW Energie und Wasser AG	Wuppertal	NW	61	Operating	Extra-light fuel oil
158	Zolling-Leininger GT-1	Riverstone Holdings LLC	Zolling	BY	25.8	Operating	Extra-light fuel oil
159	Zolling-Leininger GT-2	Riverstone Holdings LLC	Zolling	BY	25.8	Operating	Extra-light fuel oil
	Additional sites on the power plant list of the Federal Network Agency						
	Power plant name	**Operator**	**Location**	**Federal state**	**Capacity in MW electric**	**Operating status**	**Energy source**
160	Heizkraftwerk Altbach/Deizisau	EnBW Energie Baden-Württemberg AG	Altbach	BW	81	Operating	Natural gas
16	Heizkraftwerk Altbach/Deizisau	EnBW Energie Baden-Württemberg AG	Altbach	BW	57	Operating	Natural gas

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Operating status	Energy source
1							
162	Heizkraftwerk Altbach/Deizisau	EnBW Energie Baden-Württemberg AG	Altbach	BW	50	Operating	Natural gas
163	HKW Altenstadt	Heizkraftwerk Altenstadt GmbH & Co. KG	Altenstadt	BY	9.8	Operating	Biomass
164	Notstromdiesel	DS Smith Paper Deutschland GmbH	Aschaffenburg	BY	0.5	Operating	Mineral oil products
165	Bergkamen	STEAG GmbH	Bergkamen	NW	717	Seasonal storage	Hard coal
166	Moabit	Vattenfall Wärme Berlin AG	Berlin	BE	34	Operating	Mineral oil products
167	Farge	ENGIE Deutschland AG	Bremen	HB	350	Operating	Hard coal
168	GT	Stadtwerke Düsseldorf AG	Düsseldorf	NW	86.2	Operating	Mineral oil products
169	BMKW Flörsheim Wicker	MVV Energie AG	Flörsheim Wicker	HE	12.6	Operating	Biomass
170	Enertec Hameln	Enertec Hameln GmbH	Hameln	NI	14.5	Operating	Biomass
171	Heizkraftwerk Heilbronn	EnBW Energie Baden-Württemberg AG	Heilbronn	BW	125	Legally prevented from being decommissioned	Hard coal
172	Heizkraftwerk Heilbronn	EnBW Energie Baden-Württemberg AG	Heilbronn	BW	125	Legally prevented from being decommissioned	Hard coal
173	KWM	Kraftwerk Mehrum GmbH	Hohenhameln OT Mehrum	NI	690	Operating	Hard coal
174	Werk Kalscheuren	Orion Engineered Carbons GmbH	Cologne	NW	26.5	Operating	Other energy sources
175	BMKW Königs Wusterhausen	MVV Energie AG	Königs Wusterhausen	BB	17.1	Operating	Biomass
176	BMKW Mannheim	MVV Energie AG	Mannheim	BW	17.9	Operating	Biomass
177	DKW Nord	Vereinigte Wertach-Elektrizitätswerke GmbH	Mindelheim	BY	11.4	Operating	Mineral oil products
178	Biomasse-HKW	B+S Papenburg Energie GmbH	Papenburg	NI	20	Operating	Biomass

Table 51: List of identified CHP installations

	Power plant name	Operator	Location	Federal state	Capacity in MW electric	Capacity in MW thermal for district heating	Operating status	Energy source
1	Aachen-Melaten	STAWAG Energie GmbH	Aachen	NW	10.1	10.8	Operating	Natural gas
2	Aachen	STAWAG Energie GmbH	Aachen	NW	16	6	Operating	Natural gas

3	Aachen-Seffent	STAWAG Energie GmbH	Aachen	NW	10	0	Oper-ating	Biomass
4	Alfeld (Leine)	SAPPI Papierfabrik Alfeld GmbH	Alfeld (Leine)	NI	20	0	Oper-ating	Natural gas
5	Alfeld (Leine) Block 5	SAPPI Papierfabrik Alfeld GmbH	Alfeld (Leine)	NI	16.8	0	Oper-ating	Solid biomass
6	Altbach/Deizisau HKW 1	EnBW Kraftwerke AG	Altbach	BW	476	280	Grid re-serve	Hard coal
7	Altbach/Deizisau HKW 2 (DT)	EnBW Kraftwerke AG	Altbach	BW	379	280	Oper-ating	Hard coal
8	Altbach/Deizisau 4 (Kombiblock)	EnBW Kraftwerke AG	Altbach	BW	250	180	Cold re-serve	Natural gas
9	Altbach/Deizisau GT C	EnBW Kraftwerke AG	Altbach	BW	95	0	Oper-ating	Natural gas
10	Altbach/Deizisau GT B	EnBW Kraftwerke AG	Altbach	BW	75	0	Oper-ating	Natural gas
11	Altbach/Deizisau GT E	EnBW Kraftwerke AG	Altbach	BW	69	0	Oper-ating	Natural gas
12	Altbach/Deizisau GT A	EnBW Kraftwerke AG	Altbach	BW	66	0	Oper-ating	Natural gas
13	Schongau-Altenstadt	BMHKW Altenstadt GmbH	Altenstadt	BY	11.6	19	Oper-ating	Solid biomass
14	Anklam	Suiker Unie GmbH & Co. KG	Anklam	MV	15.1	0	Oper-ating	Extra-light fuel oil
15	Annweiler	Kartonfabrik Buchmann GmbH	Annweiler	RP	29	0	Oper-ating	Natural gas
16	Arneburg	Zellstoff Stendal GmbH	Arneburg	ST	100	600	Oper-ating	Solid biomass
17	Arneburg	Zellstoff Stendal GmbH	Arneburg	ST	47	0	Oper-ating	Solid biomass
18	Arnsberg	Reno De Medici Arnsberg GmbH	Arnsberg	NW	20.5	0	Oper-ating	Hard coal
19	Aschaffenburg	DS Smith Paper Deutschland GmbH / Aschaffenburger Versorgungs GmbH	Aschaf-fenburg	BY	49	0	Oper-ating	Natural gas
20	Augsburg-Lechhausen	StW Augsburg	Augsburg	BY	30.8	41.3	Oper-ating	Natural gas
21	Augsburg DT	StW Augsburg / UPM GmbH	Augsburg	BY	32	0	Cold re-serve	Natural gas
22	Augsburg T2	StW Augsburg	Augsburg	BY	20.4	0	Oper-ating	Natural gas
23	Bad Kreuznach	Evonik New Energies GmbH / Michelin Reifenwerke	Bad Kreuznach	RP	11.7	0	Oper-ating	Natural gas
24	Grabe	Thüringer Energie AG (TEAG) / Uniper SE	Bad Salzungen	TH	10	57	Oper-ating	Natural gas
25	Baruth	Unitherm Baruth GmbH	Baruth	BB	20	73	Oper-ating	Solid biomass
26	Kassel Baunatal	VW Kraftwerk GmbH	Baunatal	HE	78	85	Oper-ating	Natural gas
27	Beeskow	Sonae Arauco Beeskow GmbH	Beeskow	BB	18.3	66	Oper-ating	Solid biomass
28	Bergheim K1/TG1	Martinswerk GmbH	Bergheim	NW	10	0	Cold re-serve	Brown coal
29	Bergkamen A	Steag GmbH	Bergka-men	NW	780	20	Oper-ating	Hard coal
30	Bergkamen Biomasse-HKW	RWE Innogy Cogen GmbH	Bergka-men	NW	20	20	Oper-ating	Solid biomass
31	Berlin-Mitte HKW GT 1	Vattenfall Europe GmbH	Berlin	BE	178	1,210	Oper-ating	Natural gas
32	Berlin-Klingenberg (Rummelsburg)	Vattenfall Europe GmbH	Berlin	BE	188	590	Oper-ating	Natural gas

33	Berlin-Reuter-West D	Vattenfall Europe Wärme AG	Berlin	BE	300	363	Operating	Hard coal
34	Berlin-Reuter-West E	Vattenfall Europe Wärme AG	Berlin	BE	300	363	Operating	Hard coal
35	Berlin-Lichterfelde	Vattenfall Europe GmbH	Berlin	BE	315	230	Operating	Natural gas
36	Berlin-Charlottenburg GT-4	Vattenfall Europe GmbH	Berlin	BE	73	150	Operating	Natural gas
37	Berlin-Charlottenburg GT-5	Vattenfall Europe GmbH	Berlin	BE	73	150	Operating	Natural gas
38	Berlin-Moabit 1-1 (A)	Vattenfall Europe GmbH	Berlin	BE	100	136	Operating	Hard coal
39	Berlin-Buch 1	Vattenfall Europe GmbH	Berlin	BE	5.3	130	Operating	Natural gas
40	Berlin-Wilmersdorf 3	Vattenfall Europe GmbH	Berlin	BE	96	110	Operating	Extra-light fuel oil
41	Berlin-Wilmersdorf 1	Vattenfall Europe GmbH	Berlin	BE	92	110	Operating	Extra-light fuel oil
42	Berlin-Wilmersdorf 2	Vattenfall Europe GmbH	Berlin	BE	92	110	Operating	Extra-light fuel oil
43	Berlin-Moabit 1-2 (GT 5-7)	Vattenfall Europe GmbH	Berlin	BE	51	104	Operating	Extra-light fuel oil
44	Berlin-Adlershof 1	BTB GmbH	Berlin	BE	14	96	Operating	Natural gas
45	Berlin-Neukölln/Gropiusstadt (Rudow)	Harpen AG / RWE Innogy Cogen GmbH	Berlin	BE	20	66	Operating	Solid biomass
46	Berlin-Köpenick	Vattenfall Europe GmbH	Berlin	BE	11	50	Operating	Natural gas
47	Berlin-Scharnhorststraße	Vattenfall Europe GmbH	Berlin	BE	12	40	Operating	Natural gas
48	Berlin-Neukölln	FHW Neukölln AG	Berlin	BE	10	11.5	Operating	Natural gas
49	Berlin-Adlershof 3	BTB GmbH	Berlin	BE	8	8	Operating	Natural gas
50	Berlin-Mitte HKW GT 2	Vattenfall Europe GmbH	Berlin	BE	178	0	Operating	Natural gas
51	Berlin-Mitte HKW DT	Vattenfall Europe GmbH	Berlin	BE	112	0	Operating	Natural gas
52	Berlin-Wedding	Bayer Pharma AG / Energieversorgung Wedding	Berlin	BE	10	0	Operating	Natural gas
53	Berlin-Buch 2	Vattenfall Europe GmbH	Berlin	BE	7.5	0	Operating	Natural gas
54	Berlin-Adlershof 2	BTB GmbH	Berlin	BE	6.8	0	Operating	Natural gas
55	Bernburg	Solvay Chemicals GmbH	Bernburg	ST	155	232	Operating	Natural gas
56	Bielefeld HKW 1 Schildescher Straße	Stadtwerke Bielefeld GmbH	Bielefeld	NW	28.6	160	Operating	Natural gas
57	Bielefeld-Hillegossen GuD	Stadtwerke Bielefeld GmbH / MPB	Bielefeld	NW	39	0	Operating	Natural gas
58	Bitterfeld Chemiepark	envia THERM GmbH	Bitterfeld	ST	114	110	Operating	Natural gas
59	Blankenstein	Zellstoff- und Papierfabrik Rosenthal GmbH	Blankenstein	TH	57.2	0	Operating	Solid biomass
60	Hiltrop	Stadtwerke Bochum GmbH	Bochum	NW	44	120	Operating	Natural gas
6	Lippendorf S	EnBW Kraftwerke AG	Böhlen	SN	933.6	230	Oper-	Brown

1							ating	coal
62	Lippendorf R	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Böhlen	SN	933.6	230	Operating	Brown coal
63	Bomlitz	EnBW Kraftwerke AG / Dow Wolff Cellulosics GmbH	Bomlitz	NI	22.7	117	Operating	Natural gas
64	Bonn HKW Nord (Karlstraße)	Energie- und Wasserversorgung Bonn/Rhein-Sieg GmbH	Bonn	NW	25	110	Operating	Natural gas
65	Bonn HKW Nord (Karlstraße) GuD	Energie- und Wasserversorgung Bonn/Rhein-Sieg GmbH	Bonn	NW	74	70	Operating	Natural gas
66	Bopfingen	RWE Power AG	Bopfingen	BW	20	0	Operating	Biomass
67	Borken	Borchers Biomassekraftwerk GmbH	Borken	NW	11.4	0	Operating	Biomass
68	Boxberg Q	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Boxberg	SN	907	65	Operating	Brown coal
69	Boxberg N	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Boxberg	SN	500	60	Operating	Brown coal
70	Boxberg P	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Boxberg	SN	500	0	Operating	Brown coal
71	Brandenburg a.d. Havel (Upstallstraße)	StW Brandenburg	Brandenburg	BB	39	80	Operating	Natural gas
72	Braunschweig HKW Mitte	Braunschweiger Versorgungs AG (BS Energy)	Braunschweig	NI	78	330	Operating	Hard coal
73	Braunschweig HKW Nord	Braunschweiger Versorgungs AG (BS Energy)	Braunschweig	NI	26.5	80	Operating	Natural gas
74	Braunschweig HKW Mitte Block 12 (DT)	Braunschweiger Versorgungs AG (BS Energy)	Braunschweig	NI	28.2	67.2	Operating	Natural gas
75	Braunschweig	VW Kraftwerk GmbH	Braunschweig	NI	11	0	Operating	Natural gas
76	Braunschweig HKW Mitte GuD	Braunschweiger Versorgungs AG (BS Energy)	Braunschweig	NI	77		Operating	Natural gas
77	Bremen-Hastedt (HyReK)	swb Erzeugung GmbH	Bremen	HB	15	210	Operating	Battery storage
78	Bremen-Hastedt 15	swb Erzeugung GmbH	Bremen	HB	130	150	Operating	Hard coal
79	Bremen-Hafen 6, (Elfi)	swb Erzeugung GmbH	Bremen	HB	337	39	Operating	Hard coal
80	Bremen-Farge	Riverstone Holdings LLC	Bremen	HB	397	26	Operating	Hard coal
81	Brilon GT	Egger Kraftwerk Brilon GmbH	Brilon	NW	14.7	48	Operating	Natural gas
82	Brilon HKW	Egger Kraftwerk Brilon GmbH	Brilon	NW	19.8	30	Operating	Solid biomass
83	Burghausen 1	Kraftwerk Burghausen GmbH	Burghausen	BY	124	350	Operating	Natural gas
84	Burghausen 2	Kraftwerk Burghausen GmbH	Burghausen	BY	54	0	Operating	Natural gas
85	Calbe	ACR Biokraftwerk Calbe Invest GmbH & Co. KG	Calbe	ST	10.2	0	Operating	Solid biomass
86	Castrop-Rauxel 1	Evonik New Energies GmbH	Castrop-Rauxel	NW	11.4	0	Operating	Natural gas
87	Chemnitz Nord II B/20	eins energie in sachsen GmbH & Co. KG	Chemnitz	SN	67	165	Operating	Brown coal
88	Chemnitz Nord II C/30	eins energie in sachsen GmbH & Co. KG	Chemnitz	SN	100	140	Operating	Brown coal
89	Cottbus	HKW Cottbus GmbH / StW Cottbus	Cottbus	BB	81.7	120	Operating	Pulverised brown coal
90	Darmstadt II	Merck KGaA / 2G Energy	Darmstadt	HE	3.1	3.2	Operating	Natural gas
91	Datteln 4	Uniper SE	Datteln	NW	1,100	380	Test mode	Hard coal

92	Ruselkraftwerk Maxhofen	Kraftwerksgesellschaft Rusel GmbH	Deggen-dorf	BY	25	0	Oper-ating	Diesel
93	Delitzsch	BMK Delitzsch GmbH (Danpower GmbH)	Delitzsch	SN	20	0	Oper-ating	Solid biomass
94	Delitzsch	Knock on Wood GmbH	Delitzsch	SN	20	0	Oper-ating	Solid biomass
95	Dessau GuD	DVV mbH	Dessau	ST	59	258	Oper-ating	Natural gas
96	Dillingen (Dillinger Hütte)	Steag New Energies GmbH / VSE AG / ROGESA	Dillingen	SL	95.5	230	Oper-ating	Blast furnace gas
97	Dingolfing GT1	GHD Bayernwerk Natur GmbH	Dingolfing	BY	7	10	Oper-ating	Natural gas
98	Dingolfing GT2	GHD Bayernwerk Natur GmbH	Dingolfing	BY	7	10	Oper-ating	Natural gas
99	Dormagen (Bayer)	RWE Power AG / Currenta GmbH	Dormagen	NW	597.1	480	Oper-ating	Natural gas
100	Dortmund	Wärme- und Stromerzeugung Dort-mund GmbH (RWE / DEW21)	Dortmund	NW	26.5	300	Oper-ating	Natural gas
101	Dortmund	Deutsche Gasrußwerke GmbH & Co. KG	Dortmund	NW	25	0	Oper-ating	Synthesis gas
102	Dresden Nossener Brücke DT	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	75	455	Oper-ating	Natural gas
103	Dresden-Nord	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	11	70	Oper-ating	Natural gas
104	Dresden Nossener Brücke GT1	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	65		Oper-ating	Natural gas
105	Dresden Nossener Brücke GT2	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	65		Oper-ating	Natural gas
106	Dresden Nossener Brücke GT3	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	65		Oper-ating	Natural gas
107	Dresden Nossener Brücke GT4	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	10		Oper-ating	Natural gas
108	Duisburg-Walsum 9	Steag GmbH	Duisburg	NW	410	295	Oper-ating	Hard coal
109	Duisburg-Wanheim HKW III B	StW Duisburg	Duisburg	NW	245	167	Oper-ating	Natural gas
110	Duisburg-Wanheim HKW III A	StW Duisburg	Duisburg	NW	41	88	Oper-ating	Natural gas
111	Duisburg-Walsum 10	Steag GmbH (51%) / EVN (49%)	Duisburg	NW	790	0	Oper-ating	Hard coal
112	Duisburg-Ruhrort 4 ('Hermann Wenzel')	ThyssenKrupp Stahl AG (TKS)	Duisburg	NW	180	0	Oper-ating	Blast furnace gas
113	Duisburg-Ruhrort 3 ('Hermann Wenzel')	ThyssenKrupp Stahl AG (TKS)	Duisburg	NW	100	0	Oper-ating	Blast furnace gas
114	Duisburg-Ruhrort 2 ('Hermann Wenzel')	ThyssenKrupp Stahl AG (TKS)	Duisburg	NW	64	0	Oper-ating	Blast furnace gas
115	Duisburg-Homberg (HKW Sachtleben)	Venator Materials Corporation	Duisburg	NW	29.5	0	Oper-ating	Pulver-ised brown coal

116	Duisburg	DK Recycling und Roheisen GmbH	Duisburg	NW	22	0	Oper-ating	Blast furnace gas
117	Düren	Metsä Tissue GmbH Düren	Düren	NW	14	0	Oper-ating	Natural gas
118	Düren 4	Papierfabrik Schoellershammer GmbH	Düren	NW	9.9	0	Oper-ating	Brown coal
119	Düren 2	Papierfabrik Schoellershammer GmbH	Düren	NW	3	0	Oper-ating	Natural gas
120	Düsseldorf-Lausward F ('Block Fortuna')	StW Düsseldorf AG (SWD AG)	Düssel-dorf	NW	595	300	Oper-ating	Natural gas
121	Düsseldorf-Lausward E (Emil) DT-1	StW Düsseldorf AG (SWD AG)	Düssel-dorf	NW	324	140	Oper-ating	Natural gas
122	Düsseldorf-Lausward A (Anton)	StW Düsseldorf AG (SWD AG)	Düssel-dorf	NW	114	75	Oper-ating	Natural gas
123	Garath	StW Düsseldorf AG (SWD AG)	Düssel-dorf	NW	11	75	Oper-ating	Natural gas
124	Düsseldorf-Flingern GT	StW Düsseldorf AG (SWD AG)	Düssel-dorf	NW	90	0	Oper-ating	Extra-light fuel oil
125	Düsseldorf-Holthausen	Henkel AG & Co. KGaA	Düssel-dorf	NW	89	0	Oper-ating	Natural gas
126	Düsseldorf	Daimler AG	Düssel-dorf	NW	21.6	0	Oper-ating	Natural gas
127	Eberswalde-Finow	Barnimer Energiegesellschaft GmbH (BEG)	Eberswal-de	BB	20	0	Oper-ating	Solid biomass
128	Ehingen T5	SAPPI Papierfabrik Ehingen GmbH	Ehingen	BW	13.2	0	Oper-ating	Solid biomass
129	Ehingen T3	SAPPI Papierfabrik Ehingen GmbH	Ehingen	BW	8	0	Oper-ating	Solid biomass
130	Ehingen T4	SAPPI Papierfabrik Ehingen GmbH	Ehingen	BW	4	0	Oper-ating	Natural gas
131	Eilenburg	Stora Enso Sachsen GmbH	Eilenburg	SN	47.2	40	Oper-ating	Natural gas
132	Eisenach-Wiesengrund	Adam Opel AG	Eisenach	TH	24	79.5	Oper-ating	Natural gas
133	Eisenach	Eisenacher Versorgungsbetriebe GmbH	Eisenach	TH	10	9	Oper-ating	Natural gas
134	Eisenhüttenstadt	Vulkan Energiewirtschaft Oderbrücke GmbH (Arcelor Mittal Eisenhüttenstadt GmbH)	Eisenhüt-tenstadt	BB	60	80	Oper-ating	Convert-er gas
135	Eisenhüttenstadt ('Block 7')	Vulkan Energiewirtschaft Oderbrücke GmbH	Eisenhüt-tenstadt	BB	56	0	Oper-ating	Convert-er gas
136	Elsterwerda Biomasse	Danpower GmbH	Elster-werda	BB	12.6	12	Oper-ating	Solid biomass
137	Eltmann	Palm Power GmbH & Co. KG (Papierf-abrik)	Eltmann	BY	58	90	Oper-ating	Natural gas

138	Emden BMKW	StW Emden / Statkraft Markets GmbH	Emden	NI	22	30	Oper-ating	Solid biomass
139	Emden 4 DT	Statkraft Markets GmbH	Emden	NI	400	0	Cold re-serve	Natural gas
140	Emlichheim	PN Biomasseheizkraftwerk Emlichheim GmbH / RWE Innogy GmbH	Emlich-heim	NI	23	67	Oper-ating	Solid biomass
141	Emlichheim	BEKW Bioenergiekraftwerk Emsland GmbH / RWE Innogy GmbH	Emlich-heim	NI	13	0	Oper-ating	Solid biomass
142	Erfurt-Ost 1	SWE Energie GmbH	Erfurt	TH	86	224	Oper-ating	Natural gas
143	Erfurt-Iderhoffstr.	SWE Energie GmbH	Erfurt	TH	12	80	Oper-ating	Natural gas
144	Erfurt-Ost 2	SWE Energie GmbH	Erfurt	TH	32.6	47	Oper-ating	Natural gas
145	Erkrath	StW Erkrath	Erkrath	NW	10.2	10.7	Oper-ating	Natural gas
146	Erlangen GuD 1	Erlanger Stadtwerke AG	Erlangen	BY	24	21.1	Oper-ating	Natural gas
147	Erlangen HKW	Erlanger Stadtwerke AG	Erlangen	BY	18	0	Oper-ating	Hard coal
148	Erlangen GT	Erlanger Stadtwerke AG	Erlangen	BY	7.4	0	Oper-ating	Natural gas
149	Weisweiler G (6)	RWE Power AG	Eschweiler	NW	663	91.5	Oper-ating	Brown coal
150	Weisweiler H (7)	RWE Power AG	Eschweiler	NW	656	91.5	Oper-ating	Brown coal
151	Flensburg K12	StW Flensburg	Flensburg	SH	77	75	Oper-ating	Natural gas
152	Flensburg K09	StW Flensburg	Flensburg	SH	36	72	Oper-ating	Hard coal
153	Flensburg K10	StW Flensburg	Flensburg	SH	33	72	Oper-ating	Hard coal
154	Flensburg K11	StW Flensburg	Flensburg	SH	31	72	Oper-ating	Hard coal
155	Flörsheim-Wicker	Biomasse Rhein-Main GmbH / MVV O&M GmbH	Flörsheim	HE	18.9	0	Oper-ating	Solid biomass
156	Frankfurt-West 4	Mainova AG	Frankfurt / M.	HE	100	150	Oper-ating	Natural gas
157	Frankfurt-Niederrad 1 GuD	Mainova AG	Frankfurt / M.	HE	76	120	Oper-ating	Natural gas
158	Frankfurt-West 2	Mainova AG	Frankfurt / M.	HE	72	105	Oper-ating	Hard coal
159	Frankfurt-West 3	Mainova AG	Frankfurt / M.	HE	72	105	Oper-ating	Hard coal

160	Frankfurt Fechenheim	Mainova AG	Frankfurt / M.	HE	12.4	43.6	Oper-ating	Solid biomass
161	Frankfurt-West 5	Mainova AG	Frankfurt / M.	HE	40	0	Oper-ating	Natural gas
162	Frankfurt Fechenheim 1+2	AlessaChemie GmbH / GETEC AG	Frankfurt / M.	HE	20	0	Oper-ating	Pulver-ised brown coal
163	Frankfurt Fechenheim 3	AlessaChemie GmbH / GETEC AG	Frankfurt / M.	HE	20	0	Oper-ating	Natural gas
164	Frankfurt-Griesheim	WeylChem Griesheim GmbH / Getec Heat&Power AG	Frankfurt / M.	HE	19.5	0	Oper-ating	Pulver-ised brown coal
165	Frankfurt / Oder DT	Stadtwerke Frankfurt (Oder) GmbH	Frankfurt / Oder	BB	24	80	Oper-ating	Pulver-ised brown coal
166	Frechen / Wachtberg	RWE Power AG	Frechen	NW	201	251	Oper-ating	Brown coal
167	Freiberg	Stadtwerke Freiberg AG / Freiberger Erdgas GmbH	Freiberg	SN	13.4	9	Oper-ating	Natural gas
168	Freiburg Uni-HKW	Medical Center – University of Freiburg	Freiburg	BW	27	0	Oper-ating	Natural gas
169	Freiburg GuD ('Rhodia')	Wärmeverbundkraftwerk Freiburg GmbH (Solvay Acetow GmbH)	Freiburg i. Br.	BW	67.9	200	Oper-ating	Natural gas
170	Ebersdorf-Friesau	Mercer International Inc. / Klausner Holz Thüringen GmbH	Friesau	TH	13	36.5	Oper-ating	Solid biomass
171	Frimmersdorf P	RWE Power AG	Frimmers dorf	NW	325	30	Secu-rity re-serve	Brown coal
172	Fulda 3	Papierfabrik Adolf Jass GmbH & Co. KG	Fulda	HE	27.4	0	Oper-ating	Natural gas
173	Fulda (3A, 3B, 3C)	RhönEnergie Fulda GmbH	Fulda	HE	12.8	0	Oper-ating	Diesel
174	Fulda 2	Papierfabrik Adolf Jass GmbH & Co. KG	Fulda	HE	8.6	0	Oper-ating	Natural gas
175	Buer FWK	Uniper SE	Gelsenkir-chen	NW	73.9	244	Oper-ating	Hard coal
176	Gelsenkirchen-Ueckendorf (Joarin)	A-TEC Anlagentechnik GmbH	Gelsenkir-chen	NW	10.4	0	Oper-ating	Mine gas
177	Gelsenkirchen-Resse	Emscher Lippe Energie GmbH	Gelsenkir-chen	NW	10.2	0	Oper-ating	Diesel
178	Gendorf / Burg-kirchen II	InfraServ Gendorf	Gendorf	BY	62.9	0	Oper-ating	Natural gas
179	Gendorf / Burg-kirchen I	InfraServ Gendorf	Gendorf	BY	10	0	Oper-ating	Natural gas
18	Gera-Nord (Tinz)	Energieversorgung Gera GmbH / Kraftwerke Gera GmbH / Engie	Gera	TH	22.5	21	Oper-ating	Natural gas

0		Deutschland AG						
181	Gera-Lusan	Energieversorgung Gera GmbH / Kraftwerke Gera GmbH / Engie Deutschland AG	Gera	TH	18	18.4	Oper-ating	Natural gas
182	Göttingen	Uniper SE / University of Göttingen	Göttingen	NI	23	32.8	Oper-ating	Natural gas
183	Greifswald Helmshäger Berg	Stadtwerke Greifswald GmbH	Greifswald	MV	15	27.3	Oper-ating	Natural gas
184	Grenzach-Wyhlen GuD	KGW Kraftwerk GmbH (BASF)	Grenzach-Wyhlen	BW	30	0	Oper-ating	Natural gas
185	Großenkneten	ExxonMobil Production Deutschland GmbH (EMPG)	Großenkneten	NI	30.5	0	Oper-ating	Natural gas
186	Staudinger 5 (Großkrotzen-burg)	Uniper SE	Großkrot-zenburg	HE	553	300	Oper-ating	Hard coal
187	Freienhufen (Großräschen) / HKW Sonne	HKW Sonne GmbH	Großräschen	BB	14	24	Oper-ating	Solid biomass
188	Güstrow-Sarmstorf	Nawaro Bioenergie AG	Güstrow	MV	20	0	Oper-ating	Biomass
189	Gütersloh Mohndruck	StW Gütersloh / Mohndruck GmbH	Gütersloh	NW	23	59	Oper-ating	Natural gas
190	Gütersloh	Pfleiderer Holzwerke AG	Gütersloh	NW	13.3	40	Oper-ating	Solid biomass
191	Hagen-Kabel GuD	Mark-E AG	Hagen	NW	251	108	Oper-ating	Natural gas
192	Hagen-Kabel Bio	Mark-E AG / Stora Enso Kabel GmbH	Hagen	NW	20	86	Oper-ating	Solid biomass
193	Halle-Dieselstraße A	StW Halle GmbH	Halle	ST	49.2	55	Oper-ating	Natural gas
194	Halle-Dieselstraße B	StW Halle GmbH	Halle	ST	49.2	55	Oper-ating	Natural gas
195	Halle-Trotha GuD	Heizkraftwerk Halle-Trotha GmbH	Halle	ST	58.1	50	Oper-ating	Natural gas
196	Hallstadt II	Michelin Reifenwerke	Hallstadt	BY	6.3	12.6	Oper-ating	Natural gas
197	Hallstadt I	Michelin Reifenwerke	Hallstadt	BY	3.8	0	Oper-ating	Natural gas
198	Duisburg-Hamborn 5	ThyssenKrupp Stahl AG (TKS)	Hamborn	NW	240.7	150	Oper-ating	Blast furnace gas
199	Duisburg-Hamborn 4	ThyssenKrupp Stahl AG (TKS)	Hamborn	NW	108	0	Oper-ating	Blast furnace gas
200	Duisburg-Hamborn 3	ThyssenKrupp Stahl AG (TKS)	Hamborn	NW	64	0	Oper-ating	Blast furnace gas
201	Hamburg-Tiefstack HKW	Vattenfall Europe GmbH	Hamburg	HH	205	785	Oper-ating	Hard coal
20	Hamburg-Tiefstack GuD	Vattenfall Europe GmbH	Hamburg	HH	142	170	Oper-ating	Natural gas

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203	Hamburg-Moorburg A	Vattenfall Europe GmbH	Hamburg	HH	827	120	Operating	Hard coal
204	Hamburg-Moorburg B	Vattenfall Europe GmbH	Hamburg	HH	827	120	Operating	Hard coal
205	Hamburg Billbrook (Bio)	Müllverwertung Borsigstraße GmbH	Hamburg	HH	20	63	Operating	Solid biomass
206	Hameln-Afferde Biomasse	Enertec Hameln GmbH	Hameln	NI	20	62	Operating	Solid biomass
207	Hannover-Stöcken 1, GKW	Enercity (StW Hannover), Continental, VWK	Hannover	NI	150	212.5	Operating	Hard coal
208	Hannover-Stöcken 2, GKW	Enercity (StW Hannover), Continental, VWK	Hannover	NI	150	212.5	Operating	Hard coal
209	Hannover-Linden (GKL) DT 1	Enercity (StW Hannover, 90%) / Uniper SE (10%)	Hannover	NI	97	185	Operating	Natural gas
210	Hannover	Exxon Mobil Deutschland GmbH	Hannover	NI	31	0	Operating	Natural gas
211	Hannover-Linden (GKL) GT 1	Enercity (StW Hannover, 90%) / Uniper SE (10%)	Hannover	NI	79		Operating	Natural gas
212	Hannover-Linden (GKL) GT 2	Enercity (StW Hannover, 90%) / Uniper SE (10%)	Hannover	NI	79		Operating	Natural gas
213	Hausham GT 1	Peißenberger Kraftwerks GmbH (PKG)	Hausham	BY	26.8	25	Operating	Extra-light fuel oil
214	Heidelberg University Hospital	RWE Innogy Cogen GmbH	Heidelberg	BW	14.3	197.6	Operating	Natural gas
215	Heidenheim a.d. Brenz HKW 2	IHKW Heidenheim GmbH	Heidenheim	BW	24.3	145	Operating	Natural gas
216	Heidenheim a.d. Brenz HKW 1	IHKW Heidenheim GmbH	Heidenheim	BW	13.7	145	Operating	Natural gas
217	Heilbronn 7	EnBW Kraftwerke AG	Heilbronn	BW	816	550	Operating	Hard coal
218	Heilbronn 3	EnBW Kraftwerke AG	Heilbronn	BW	110	285	Cold reserve	Hard coal
219	Heilbronn 4	EnBW Kraftwerke AG	Heilbronn	BW	110	285	Cold reserve	Hard coal
220	Heilbronn 5	EnBW Kraftwerke AG	Heilbronn	BW	125	28	Operating	Hard coal
221	Heilbronn 6	EnBW Kraftwerke AG	Heilbronn	BW	125	28	Operating	Hard coal
222	Heiligenberg DTKW Prototyp	Rosenkranz GmbH	Heiligenberg	BW	10	0	Operating	Solid biomass
223	Heiligengrabe I	SWISS KRONO GmbH	Heiligengrabe	BB	5	37	Operating	Solid biomass
22	Heiligengrabe II	SWISS KRONO GmbH	Heiligengrabe	BB	19.7	10	Operating	Solid biomass

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225	Heiligengrabe III	SWISS KRONO GmbH	Heiligen-grabe	BB	19.9	0	Oper-ating	Solid biomass
226	Heins-berg/Industriepark Oberbruch	NUON AG	Heinsberg	NW	21	260	Oper-ating	Natural gas
227	Hemmingstedt (Raffinerie Heide)	Raffinerie Heide GmbH	Hem-mingstedt	SH	48.5	0	Oper-ating	Mineral oil products
228	Herbrechtingen	Biomasse-Heizkraftwerk-Herbrechtingen GmbH	Her-brecht-ingen-Giengen	BW	16	25	Oper-ating	Solid biomass
229	Wintershall	K+S KALI GmbH	Heringen	HE	110	299	Oper-ating	Natural gas
230	Herne 4	Steag GmbH / StW Herne	Herne	NW	511	550	Oper-ating	Hard coal
231	Herzberg	Smurfit Kappa Herzberger Papierfabrik GmbH	Herzberg	NI	20	0	Oper-ating	Natural gas
232	Frankfurt-Hoechst B1	InfraServ GmbH Hoechst KG	Höchst	HE	45	284	Oper-ating	Hard coal
233	Frankfurt-Hoechst A	InfraServ GmbH Hoechst KG	Höchst	HE	89	204	Oper-ating	Natural gas
234	Frankfurt-Hoechst C	InfraServ GmbH Hoechst KG	Höchst	HE	105.7	126	Oper-ating	Natural gas
235	Frankfurt-Hoechst B2	InfraServ GmbH Hoechst KG	Höchst	HE	28.2		Oper-ating	Natural gas
236	Mehrum 3 (C)	Kraftwerk Mehrum GmbH (KWM) / Energetický a Průmyslový Holding (EPH)	Hohen-hameln	NI	750	0	Oper-ating	Hard coal
237	Clauen	Nordzucker AG	Hohen-hameln	NI	18.6	0	Oper-ating	Natural gas
238	Horn-Bad Mein-berg	B+T Horn Energie GmbH	Horn-Bad Meinberg	NW	20	94	Oper-ating	Solid biomass
239	Huckingen A	RWE Power AG / Hüttenwerke Krupp Mannesmann GmbH (HKM)	Huckingen	NW	320	34	Oper-ating	Blast furnace gas
240	Huckingen B	RWE Power AG / Hüttenwerke Krupp Mannesmann GmbH (HKM)	Huckingen	NW	320	34	Oper-ating	Blast furnace gas
241	Ville / Berrenrath (Hürth)	RWE Power AG	Hürth	NW	107	0	Oper-ating	Brown coal
242	Goldenberg K1	RWE Power AG	Hürth	NW	47	0	Oper-ating	Brown coal
243	Ibbenbüren	RWE Power AG	Ib-benbüren	NW	838	20	Oper-ating	Hard coal
244	Ingelheim	Boehringer Ingelheim Pharma GmbH & Co. KG	Ingelheim	RP	11	0	Oper-ating	Solid biomass
245	Jena-Süd I	Thüringer Energie AG (TEAG) / Uniper SE	Jena	TH	204	225	Oper-ating	Natural gas

246	Jülich HKW	Pfeifer & Langen KG (Zuckerfabrik Jülich)	Jülich	NW	25	120	Operating	Brown coal
247	Kaiserslautern HKW Karcherstraße	StW Kaiserslautern	Kaiserslautern	RP	15	81	Operating	Hard coal
248	Kaiserslautern HKW Karcherstraße	StW Kaiserslautern	Kaiserslautern	RP	12.5	12	Operating	Natural gas
249	Kalkar-Appeldorn	Pfeifer & Langen KG (Zuckerfabrik Appeldorn)	Kalkar-Appeldorn	NW	11.7	0	Operating	Natural gas
250	Karlsruhe HKW West (Turbine 3)	StW Karlsruhe	Karlsruhe	BW	42	350	Operating	Natural gas
251	Karlsruhe-RDK 8	StW Karlsruhe / EnBW (Rheinhafen)	Karlsruhe	BW	912	220	Operating	Hard coal
252	Karlsruhe-RDK 7 (West 7)	StW Karlsruhe / EnBW (Rheinhafen)	Karlsruhe	BW	550	220	Operating	Hard coal
253	Karlsruhe KW MiRO 1	MiRO Mineralölraffinerie Oberrhein GmbH	Karlsruhe	BW	51	40	Operating	Natural gas
254	Karlsruhe KW MiRO 2	MiRO Mineralölraffinerie Oberrhein GmbH	Karlsruhe	BW	31	40	Operating	Natural gas
255	Karlsruhe-Waldstadt	StW Karlsruhe	Karlsruhe	BW	24	40	Cold reserve	Natural gas
256	Karlsruhe-RDK 4 (West 4s)	StW Karlsruhe / EnBW (Rheinhafen)	Karlsruhe	BW	363	0	Operating	Natural gas
257	Maxau I	Stora Enso Maxau GmbH	Karlsruhe	BW	85	0	Operating	Solid biomass
258	Kassel 2 HKW	Kasseler Fernwärme GmbH	Kassel	HE	38	80	Operating	Brown coal
259	Kassel 1 HKW	Städtische Werke Energie + Wärme GmbH	Kassel	HE	29	45	Operating	Natural gas
260	Kassel-Mittelfeld	Kasseler Fernwärme GmbH	Kassel	HE	12	30	Operating	Solid biomass
261	Kassel 1 HKW - Erweiterung	Städtische Werke Energie + Wärme GmbH	Kassel	HE	30	0	Operating	Natural gas
262	Kempen	StW Kempen GmbH	Kempen	NW	14.4	45	Operating	Natural gas
263	Kiel-Ost	Gemeinschaftskraftwerk Kiel GmbH	Kiel	SH	200	192	Operating	Natural gas
264	Kiel HKW Humboldtstraße (GT 5/6, DT1)	Stadtwerke Kiel AG	Kiel	SH	32	40	Operating	Natural gas
265	Kiel GT 1+2	Stadtwerke Kiel AG	Kiel	SH	11	0	Operating	Natural gas
266	Kiel GT 3+4	Stadtwerke Kiel AG	Kiel	SH	10.4	0	Operating	Natural gas
267	Kirchlengern 1	Energieservice Westfalen-Weser GmbH (EWW)	Kirchlengern	NW	184.5	0	Operating	Natural gas

268	Klein Wanzleben	Nordzucker AG	Klein Wanzleb-en	ST	24	0	Oper-ating	Natural gas
269	Köln-Niehl II	RheinEnergie AG	Cologne	NW	421	370	Oper-ating	Natural gas
270	Köln-Niehl III	RheinEnergie AG	Cologne	NW	453	265	Oper-ating	Natural gas
271	Köln-Godorf (Rheinland-Raffinerie Nord)	Shell Deutschland Oil GmbH	Cologne	NW	215	235	Oper-ating	HVR, natural gas
272	Köln-Merkenich 4	RheinEnergie AG	Cologne	NW	18	90	Oper-ating	Natural gas
273	Köln-Merkenich GuD	RheinEnergie AG	Cologne	NW	110	80	Oper-ating	Natural gas
274	Köln-Merkenich 6	RheinEnergie AG	Cologne	NW	85	78	Oper-ating	Brown coal
275	Köln Südstadt	RheinEnergie AG	Cologne	NW	37	75	Oper-ating	Natural gas
276	Köln-Merheim I	RheinEnergie AG	Cologne	NW	17	29	Oper-ating	Natural gas
277	Köln T31	Ineos Manufacturing Deutschland GmbH	Cologne	NW	35	0	Oper-ating	Mineral oil products
278	Köln T21	Ineos Manufacturing Deutschland GmbH	Cologne	NW	20.5	0	Oper-ating	Mineral oil products
279	Köln T22	Ineos Manufacturing Deutschland GmbH	Cologne	NW	20.5	0	Oper-ating	Mineral oil products
280	Köln T23	Ineos Manufacturing Deutschland GmbH	Cologne	NW	20.5	0	Oper-ating	Mineral oil products
281	Köln T24	Ineos Manufacturing Deutschland GmbH	Cologne	NW	10	0	Oper-ating	Mineral oil products
282	Knapsack - Hürth I	Statkraft Markets GmbH	Cologne-Hürth	NW	812	0	Oper-ating	Natural gas
283	Knapsack - Hürth II	Statkraft Markets GmbH	Cologne-Hürth	NW	450	0	Oper-ating	Natural gas
284	Königs Wuster-hausen	MVV O&M GmbH	Königs Wuster-hausen	BB	20	54.6	Oper-ating	Solid biomass
285	Königsbrunn	Lechwerke AG	Königs-brunn	BY	10.6	8	Oper-ating	Natural gas
286	Könnern	Pfeifer & Langen KG (Diamant Zucker KG)	Könnern	ST	29	149.6	Oper-ating	Brown coal
287	Kösching	BinderHolz Deutschland GmbH	Kösching	BY	15.1	35	Oper-ating	Solid biomass
288	Kösching	Gunvor Raffinerie Ingolstadt GmbH	Kösching	BY	24	0	Oper-ating	Refinery gas
289	Uckermark	ENERTRAG AG	Krackow	BB	21	0	Oper-ating	Solid biomass

290	Klarsee	Geno Bioenergie GmbH & Co. KG	Krackow	MV	20	0	Oper-ating	Biomass
291	Penkun-Klarsee	Nawaro Bioenergie Park Klarsee GmbH	Krackow	MV	20	0	Oper-ating	Biomass
292	Krefeld-Uerdingen N 230	Currenta GmbH & Co. OHG	Krefeld	NW	116	460	Oper-ating	Hard coal
293	Krefeld-Uerdingen L 57	Currenta GmbH & Co. OHG	Krefeld	NW	27	155	Oper-ating	Hard coal
294	Krefeld	SWK Energie GmbH	Krefeld	NW	13	0	Oper-ating	Natural gas
295	Kriebstein-Kriebethal	Kübler & Niethammer Papierfabrik Kriebstein AG	Kriebstein	SN	12.8	0	Oper-ating	Natural gas
296	Kühbach-Unterbernbach	Anton Heggenstaller GmbH	Kühbach	BY	12.2	0	Oper-ating	Solid biomass
297	Lachendorf 1	Drewsen Spezialpapiere GmbH & Co. KG	Lachendorf	NI	13.3	0	Oper-ating	Natural gas
298	Lachendorf 2	Drewsen Spezialpapiere GmbH & Co. KG	Lachendorf	NI	9	0	Oper-ating	Solid biomass
299	Lage	Pfeifer & Langen KG (Zuckerfabrik Lage)	Lage	NW	10.2	0	Oper-ating	Heavy fuel oil
300	Landesbergen, Robert Frank 5 (Bio)	BMKW Landesbergen GmbH	Landes-bergen	NI	22	30	Oper-ating	Solid biomass
301	Landshut III (BMW-Werk)	Bayerische Motorenwerke AG	Landshut	BY	7.2	5.4	Oper-ating	Natural gas
302	Landshut I (BMW-Werk)	Bayerische Motorenwerke AG	Landshut	BY	2.8	2.7	Oper-ating	Natural gas
303	Landshut II (BMW-Werk)	Bayerische Motorenwerke AG	Landshut	BY	2.7	2.4	Oper-ating	Natural gas
304	Leipzig-Nord DT 1	StW Leipzig	Leipzig	SN	46	200	Oper-ating	Natural gas
305	Leipzig-Nord GT 1	StW Leipzig	Leipzig	SN	64		Oper-ating	Natural gas
306	Leipzig-Nord GT 2	StW Leipzig	Leipzig	SN	64		Oper-ating	Natural gas
307	Lemgo GuD (HKW West)	StW Lemgo	Lemgo	NW	13.1	14.8	Oper-ating	Natural gas
308	Lemgo Bruchweg (HKW Mitte)	StW Lemgo	Lemgo	NW	11.3	2.5	Oper-ating	Natural gas
309	Leppersdorf	Sachsenmilch AG (Müller Sachsen GmbH)	Leppers-dorf	SN	36	0	Oper-ating	Natural gas
310	Leuna	Raffinerie-Kraftwerks-Betriebs GmbH	Leuna	ST	162	208	Oper-ating	Refinery gas
311	Leuna GuD-HKW I-4	InfraLeuna GmbH / TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	ST	16	0	Oper-ating	Natural gas

312	Leverkusen G15 Nord - K2	Currenta GmbH & Co. OHG	Leverkus-en	NW	25.1	555	Oper-ating	Natural gas
313	Leverkusen X50	Currenta GmbH & Co. OHG	Leverkus-en	NW	29	156	Oper-ating	Natural gas
314	Leverkusen	KRONOS Titan GmbH	Leverkus-en	NW	14.9	0	Oper-ating	Natural gas
315	Leverkusen G15 Nord - K4	Currenta GmbH & Co. OHG	Leverkus-en	NW	31		Oper-ating	Natural gas
316	Leverkusen G15 Nord - K3	Currenta GmbH & Co. OHG	Leverkus-en	NW	25.1		Oper-ating	Natural gas
317	Leverkusen G22 Süd - WSK 1	Currenta GmbH & Co. OHG	Leverkus-en	NW	13.4		Oper-ating	Hard coal
318	Leverkusen G22 Süd - WSK 2	Currenta GmbH & Co. OHG	Leverkus-en	NW	13.4		Oper-ating	Hard coal
319	Liebenscheid (Siegerland Flu-ghafen)	BHKW Siegerland GmbH & Co. KG	Lie-benscheid	RP	20	20	Oper-ating	Solid biomass
320	Emsland D (Lin-gen) DT	RWE Power AG	Lingen	NI	326	50	Oper-ating	Natural gas
321	Emsland B (Lin-gen) DT	RWE Power AG	Lingen	NI	372	37	Oper-ating	Natural gas
322	Emsland C (Lin-gen) DT	RWE Power AG	Lingen	NI	372	37	Oper-ating	Natural gas
323	Emsland D (Lin-gen) GT 1	RWE Power AG	Lingen	NI	281	0	Oper-ating	Natural gas
324	Emsland D (Lin-gen) GT 2	RWE Power AG	Lingen	NI	281	0	Oper-ating	Natural gas
325	Lingen	BP Europa SE	Lingen	NI	68	0	Oper-ating	Natural gas
326	Emsland B (Lin-gen) GT 1	RWE Power AG	Lingen	NI	58	0	Oper-ating	Natural gas
327	Emsland B (Lin-gen) GT 2	RWE Power AG	Lingen	NI	58	0	Oper-ating	Natural gas
328	Emsland C (Lin-gen) GT 1	RWE Power AG	Lingen	NI	58	0	Oper-ating	Natural gas
329	Emsland C (Lin-gen) GT 2	RWE Power AG	Lingen	NI	58	0	Oper-ating	Natural gas
330	Lubmin (Lubminer Heide)	Industriekraftwerke Greifswald GmbH (E.ON Energy Projects / WINGAS AG)	Lubmin	MV	39	47	Oper-ating	Natural gas
331	Ludwigshafen-Mitte GuD	BASF SE	Ludwigs-hafen	RP	510	540	Oper-ating	Natural gas
332	Ludwigshafen-Süd	BASF SE	Ludwigs-hafen	RP	410	420	Oper-ating	Natural gas
333	Ludwigshafen-Nord	BASF SE	Ludwigs-hafen	RP	127	280	Oper-ating	Natural gas

334	Ludwigshafen FHKW T2	Techn. Werke Ludwigshafen AG	Ludwigs-hafen	RP	13.8	40	Oper-ating	Natural gas
335	Ludwigshafen Industriepark Süd 1	MVV Energie AG	Ludwigs-hafen	RP	12.5	40	Oper-ating	Natural gas
336	Ludwigshafen FHKW T5	Techn. Werke Ludwigshafen AG	Ludwigs-hafen	RP	10	30	Oper-ating	Natural gas
337	Ludwigshafen Industriepark Süd 2	MVV Energie AG	Ludwigs-hafen	RP	12.9	21	Oper-ating	Natural gas
338	Ludwigshafen-Mitte GT	BASF SE	Ludwigs-hafen	RP	48	0	Oper-ating	Natural gas
339	Lünen, Biomasse-HKW	BMK Biomassekraftwerk Lünen GmbH	Lünen	NW	20	67	Oper-ating	Solid biomass
340	Lünen-Stummhafen	Trianel Kohlekraftwerk Lünen GmbH (Steag)	Lünen	NW	820	35	Oper-ating	Hard coal
341	Mainz-Wiesbaden 3-1	Kraftwerke Mainz-Wiesbaden AG	Mainz	RP	417	115	Oper-ating	Natural gas
342	Mainz-Wiesbaden 2-1	Kraftwerke Mainz-Wiesbaden AG	Mainz	RP	350	45	Oper-ating	Natural gas
343	Malchin	envia THERM GmbH	Malchin	MV	10.6	17	Oper-ating	Solid biomass
344	Mannheim 9	Großkraftwerk Mannheim AG (GKM AG)	Mann-heim	BW	911	500	Oper-ating	Hard coal
345	Mannheim 8	Großkraftwerk Mannheim AG (GKM AG)	Mann-heim	BW	480	500	Oper-ating	Hard coal
346	Mannheim 7	Großkraftwerk Mannheim AG (GKM AG)	Mann-heim	BW	475	500	Oper-ating	Hard coal
347	Mannheim - Roche Diagnostic	Roche Diagnostics GmbH / EnBW / Energie- und Medienversorgung Sandhofer Straße GmbH & Co. KG	Mann-heim	BW	20	22	Oper-ating	Natural gas
348	Mannheim BMKW - Friesen-heimer Insel	MVV O&M GmbH	Mann-heim	BW	20	20	Oper-ating	Solid biomass
349	Mannheim 6	Großkraftwerk Mannheim AG (GKM AG)	Mann-heim	BW	280	0	Oper-ating	Hard coal
350	Mannheim	SCA Hygiene Products GmbH	Mann-heim	BW	19.9	0	Oper-ating	Solid biomass
351	Marl I-5	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	74.9	262	Oper-ating	Hard coal
352	Marl I-4	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	61	199	Oper-ating	Hard coal
353	Marl III-312	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	79	195	Oper-ating	Natural gas
354	Marl III-311	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	71	195	Oper-ating	Natural gas
355	Marl II-3	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	62	100	Oper-ating	Natural gas

356	Marl III 310	Infracor GmbH / Evonik Degussa GmbH	Marl	NW	36	0	Oper-ating	Natural gas
357	Mayen 1	Moritz J. Weig GmbH	Mayen	RP	42	0	Oper-ating	Natural gas
358	Mindelheim	Vereinigte Wertach-Elektrizitätswerke (VWEW)	Mindel-heim	BY	11.4	0	Oper-ating	Diesel
359	Moers	INEOS Solvents Germany GmbH	Moers	NW	24	0	Oper-ating	Natural gas
360	Moritzburg 1	Energieversorgungscenter Dresden-Wilschdorf GmbH & Co. KG (EVC)	Moritz-burg	SN	35.1	62.1	Oper-ating	Natural gas
361	Moritzburg 2	Zweite Energieversorgungscenter Dresden-Wilschdorf/Reichenberg GmbH & Co. KG (EVC)	Moritz-burg	SN	35	0	Oper-ating	Natural gas
362	Brottewitz	Südzucker AG	Mühl-berg/Elbe	BB	26	0	Oper-ating	Brown coal
363	München-Süd GuD 2 (DT60)	SWM Services GmbH	Munich	BY	139	463	Oper-ating	Natural gas
364	München-Süd GuD 1 (DT1)	SWM Services GmbH	Munich	BY	82.7	255	Oper-ating	Natural gas
365	München-Freimann GT 1	SWM Services GmbH	Munich	BY	53.1	62.5	Oper-ating	Natural gas
366	München-Freimann GT 2	SWM Services GmbH	Munich	BY	53.1	62.5	Oper-ating	Natural gas
367	München Airport 1-7	Flughafen München GmbH	Munich	BY	11.2	12.6	Oper-ating	Natural gas
368	München Airport 8-9	Flughafen München GmbH	Munich	BY	7.4	9.2	Oper-ating	Natural gas
369	München Airport ('Energiezentrale 2016')	Flughafen München GmbH	Munich	BY	18	0	Oper-ating	Natural gas
370	München-Süd GuD 2 (GT60)	SWM Services GmbH	Munich	BY	139		Oper-ating	Natural gas
371	München-Süd GuD 2 (GT62)	SWM Services GmbH	Munich	BY	139		Oper-ating	Natural gas
372	München-Süd GuD 1 (GT2)	SWM Services GmbH	Munich	BY	98.9		Oper-ating	Natural gas
373	München-Süd GuD 1 (GT3)	SWM Services GmbH	Munich	BY	98.9		Oper-ating	Natural gas
374	Münster/Hafen I	StW Münster	Münster	NW	104	120	Oper-ating	Natural gas
375	Neubrandenburg	StW Neubrandenburg	Neubran-denburg	MV	77	90	Oper-ating	Natural gas
376	Neumarkt	Pfleiderer Holzwerke AG	Neumarkt	BY	19.9	41.5	Oper-ating	Solid biomass
377	Neumünster HKW/TEV (T3/5)	SWN StW Neumünster GmbH	Neumün-ster	SH	53.4	230	Oper-ating	Hard coal

378	Neumünster HKW/TEV (T6)	SWN StW Neumünster GmbH	Neumün-ster	SH	25	0	Oper-ating	Diesel
379	Neurath D - Grevenbroich	RWE Power AG	Neurath	NW	644	4.5	Oper-ating	Brown coal
380	Neurath E - Grevenbroich	RWE Power AG	Neurath	NW	644	4.5	Oper-ating	Brown coal
381	Neuss	Hummel Energie Systeme GmbH	Neuss	NW	11.1	11.1	Oper-ating	Biomass
382	Neuss	FS-Karton GmbH	Neuss	NW	22	0	Oper-ating	Natural gas
383	Neustadt a.d. Donau	Bayernoil Raffineriegesellschaft mbH	Neustadt a.d. Donau	BY	25.8	0	Oper-ating	Natural gas
384	Nidda	Glatfelter Ober-Schmitten GmbH	Nidda	HE	10.6	11	Oper-ating	Natural gas
385	Niederaußem G	RWE Power AG	Niederauß em	NW	687	245	Oper-ating	Brown coal
386	Niederaußem Fortuna-Nord	RWE Power AG	Niederauß em	NW	93	0	Oper-ating	Brown coal
387	Nordenham	Kronos Titan GmbH	Norden-ham	NI	17.1	0	Oper-ating	Natural gas
388	Nordstemmen	Nordzucker AG	Nord-stemmen	NI	36	0	Oper-ating	Natural gas
389	Nortrup GT1	Delkeskamp Verpackungswerke GmbH	Nortrup	NI	4.8	0	Oper-ating	Natural gas
390	Nortrup GT3	Delkeskamp Verpackungswerke GmbH	Nortrup	NI	4.7	0	Oper-ating	Natural gas
391	Nortrup GT2	Delkeskamp Verpackungswerke GmbH	Nortrup	NI	4.3	0	Oper-ating	Natural gas
392	Nortrup GT4	Delkeskamp Verpackungswerke GmbH	Nortrup	NI	4.3	0	Oper-ating	Natural gas
393	Nürnberg - HKW Sandreuth 1	N-ERGIE AG	Nurem-berg	BY	112.5	160	Oper-ating	Natural gas
394	Nürnberg - HKW Sandreuth 2	N-ERGIE AG	Nurem-berg	BY	112.5	160	Oper-ating	Natural gas
395	Franken I-1 (Nürnberg)	Uniper SE	Nurem-berg	BY	395	30	Oper-ating	Natural gas
396	Nürnberg GT5+6	Prinovis GmbH & Co. KG	Nurem-berg	BY	9.2	0	Oper-ating	Natural gas
397	Nürnberg GT3	Prinovis GmbH & Co. KG	Nurem-berg	BY	5.2	0	Oper-ating	Natural gas
398	Nürnberg GT4	Prinovis GmbH & Co. KG	Nurem-berg	BY	5.2	0	Oper-ating	Natural gas
399	Nürnberg GT1	Prinovis GmbH & Co. KG	Nurem-berg	BY	4.3	0	Oper-ating	Natural gas

400	Nürnberg GT2	Prinovis GmbH & Co. KG	Nuremberg	BY	4.3	0	Operating	Natural gas
401	Franken I-2 (Nürnberg)	Uniper SE	Nuremberg	BY	448		Operating	Natural gas
402	Oberhausen II (Sterkrade)	Energieversorgung Oberhausen AG	Oberhausen	NW	25	250	Operating	Natural gas
403	Oberhausen I	Energieversorgung Oberhausen AG	Oberhausen	NW	26	0	Operating	Natural gas
404	Oberkirch	Papierfabrik August Koehler SE	Oberkirch	BW	20	0	Operating	Hard coal
405	Obernburg DT	Kraftwerk Obernburg GmbH (KWO)	Obernburg	BY	44.5	112	Operating	Natural gas
406	Obernburg GT	Kraftwerk Obernburg GmbH (KWO)	Obernburg	BY	65.5		Operating	Natural gas
407	Oberrot	EnBW Klenk Holzenergie GmbH	Oberrot	BW	18.8	40	Operating	Solid biomass
408	Offstein	Südzucker AG	Obrigheim	RP	31	0	Operating	Natural gas
409	Obrigheim (Offstein)	Südzucker AG	Obrigheim /Pfalz	RP	26	42	Operating	Natural gas
410	Oerlinghausen 1	StW Oerlinghausen	Oerlinghausen	NW	8.3	0	Operating	Natural gas
411	Oerlinghausen 2	StW Oerlinghausen	Oerlinghausen	NW	4.8	0	Operating	Natural gas
412	Offenbach Andréstraße	Energieversorgung Offenbach AG (EVO)	Offenbach	HE	60	100	Operating	Hard coal
413	Osnabrück T5	Kämmerer Papierfabrik GmbH	Osnabrück	NI	10.5	0	Operating	Heavy fuel oil
414	Osnabrück T4	Kämmerer Papierfabrik GmbH	Osnabrück	NI	10	0	Operating	Heavy fuel oil
415	Ottersberg	Benas GmbH	Ottersberg	NI	11.4	0	Operating	Biomass
416	Papenburg	B+S Papenburg Energie GmbH	Papenburg	NI	20	0	Operating	Solid biomass
417	Jänschwalde A	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Operating	Brown coal
418	Jänschwalde B	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Operating	Brown coal
419	Jänschwalde C	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Operating	Brown coal
420	Jänschwalde D	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Operating	Brown coal
421	Jänschwalde E	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Security re-	Brown coal

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422	Jänschwalde F	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Peitz	BB	535	76.3	Security reserve	Brown coal
423	Pforzheim 2 Spitzenlastkessel	HKW Pforzheim GmbH (74.9% StW Pforzheim / 25.1% Thüga)	Pforzheim	BW	11.1	60	Operating	Natural gas
424	Pforzheim 2 GuD	HKW Pforzheim GmbH (74.9% StW Pforzheim / 25.1% Thüga)	Pforzheim	BW	41.9	47.5	Operating	Natural gas
425	Pforzheim 2 HKW	HKW Pforzheim GmbH (74.9% StW Pforzheim / 25.1% Thüga)	Pforzheim	BW	29.7	42	Operating	Hard coal
426	Pforzheim 2 Biomasse	HKW Pforzheim GmbH (74.9% StW Pforzheim / 25.1% Thüga)	Pforzheim	BW	13.3	25	Operating	Solid biomass
427	Philippsthal - Hattorf 2	K+S KALI GmbH / Uniper SE	Philippsthal	HE	32	60	Operating	Natural gas
428	Philippsthal - Hattorf 1	K+S KALI GmbH	Philippsthal	HE	36	0	Operating	Natural gas
429	Plattling	Kraftwerk Plattling GmbH/ Daimler AG	Plattling	BY	125	150	Operating	Natural gas
430	Potsdam-Süd	Energie und Wasser Potsdam GmbH	Potsdam	BB	88	275	Operating	Natural gas
431	Quierschied-Weiher 3	Steag Power Saar GmbH	Quierschied	SL	724	30	Grid reserve	Hard coal
432	Ramstein Airbase	Fernwärmeversorgung Flugplatz Ramstein GmbH (FFR)	Ramstein	RP	14	13.2	Operating	Natural gas
433	Raubling GuD	HBB Heizkraftwerk Bauernfeind Betreiberges. mbh	Raubling	BY	27.6	70	Operating	Natural gas
434	Recklinghausen Biomasse-HKW	Ökotech Sundermann GmbH	Recklinghausen	NW	16.5	50	Operating	Solid biomass
435	Recklinghausen	Betr.-Ges.	Recklinghausen	NW	14	0.6	Operating	Natural gas
436	Regensburg I	Bayerische Motorenwerke AG	Regensburg	BY	10.8	0	Operating	Natural gas
437	Regensburg II	Bayerische Motorenwerke AG	Regensburg	BY	2.8	0	Operating	Natural gas
438	Reutlingen	FairEnergie GmbH	Reutlingen	BW	10.1	11.9	Operating	Natural gas
439	Rheinberg DT	Solvay Chemicals GmbH	Rheinberg	NW	79	0	Operating	Hard coal
440	Rheinberg GT 1+2	Solvay Chemicals GmbH	Rheinberg	NW	54	0	Operating	Natural gas
441	Rheinberg GT 3	Solvay Chemicals GmbH	Rheinberg	NW	6	0	Operating	Natural gas
442	Rheinfelden	Evonik Degussa GmbH	Rheinfelden	BW	20	0	Operating	Natural gas

443	Rosenheim GT 4 (Schönfeldstraße)	StW Rosenheim	Rosenheim	BY	10.4	9.5	Operating	Natural gas
444	Rosenheim GT 1-3	StW Rosenheim	Rosenheim	BY	10	0	Operating	Natural gas
445	Rostock	KNG Kraftwerks- und Netzgesellschaft Rostock	Rostock	MV	553	150	Operating	Hard coal
446	Rostock-Marienehe I-III	StW Rostock AG	Rostock	MV	114	120	Operating	Natural gas
447	Rudolstadt-Schwarza	Energie- u. Medienversorgung Schwarza GmbH	Rudolstadt	TH	40	202	Operating	Natural gas
448	Rüsselsheim	Energieversorgung Opel OHG (KEO)	Rüsselsheim	HE	113.9	88	Operating	Natural gas
449	Saarbrücken-Römerbrücke DT	Energie SaarLorLux (ESLL)	Saarbrücken	SL	90	235	Operating	Hard coal
450	Saarbrücken-Römerbrücke GT	Energie SaarLorLux (ESLL)	Saarbrücken	SL	42	187	Operating	Natural gas
451	Saarbrücken HKW Süd	VVS GmbH / StW Saarbrücken	Saarbrücken	SL	42.5	34	Operating	Natural gas
452	Saarlouis	Steag New Energies GmbH / Ford-Werke GmbH	Saarlouis	SL	22	20	Operating	Natural gas
453	Saerbeck 1 (Bioenergiepark)	Energie für Saerbeck eG	Saerbeck	NW	1.1	1	Operating	Biomass
454	Salzgitter-Hallendorf 1	Salzgitter Flachstahl GmbH	Salzgitter	NI	110	0	Operating	Converter gas
455	Salzgitter-Hallendorf 2	Salzgitter Flachstahl GmbH	Salzgitter	NI	110	0	Operating	Converter gas
456	Salzgitter-Hallendorf AB	Salzgitter Flachstahl GmbH	Salzgitter	NI	105	0	Operating	Converter gas
457	Salzgitter-Hallendorf HO A	Salzgitter Flachstahl GmbH	Salzgitter	NI	12	0	Operating	Converter gas
458	Salzwedel	Avacon AG	Salzwedel	ST	10	6	Operating	Natural gas
459	Schkopau A	Uniper SE / Saale Energie GmbH	Schkopau	ST	490	100	Operating	Brown coal
460	Schkopau B	Uniper SE / Saale Energie GmbH	Schkopau	ST	490	100	Operating	Brown coal
461	Schongau HKW 3 Neu	UPM-Kymmene GmbH & Co. KG	Schongau	BY	84	0	Operating	Natural gas
462	Schongau DKW	UPM-Kymmene GmbH & Co. KG	Schongau	BY	46.5	0	Grid reserve	Natural gas
463	Schwarzheide	BASF Schwarzheide AG	Schwarzheide	BB	124	209	Operating	Natural gas
464	Schwedt 1	PCK Raffinerie GmbH	Schwedt	BB	117	132	Operating	Oil residue

465	Schwedt-Vierraden	UPM-Kymmene GmbH & Co. KG / Leipa Georg Leinfelder GmbH	Schwedt	BB	13.3	54	Operating	Solid biomass
466	Schwedt	MVV Energie AG	Schwedt	BB	12.4	25	Operating	Solid biomass
467	Schwedt 2	PCK Raffinerie GmbH	Schwedt	BB	117		Operating	Oil residue
468	Schwedt 4	PCK Raffinerie GmbH	Schwedt	BB	75		Operating	Oil residue
469	Schwedt 6	PCK Raffinerie GmbH	Schwedt	BB	36.5		Operating	Oil residue
470	Schwedt 5	PCK Raffinerie GmbH	Schwedt	BB	30		Operating	Oil residue
471	Schweinfurt 1	GKS Gemeinschaftskraftwerk Schweinfurt GmbH	Schweinfurt	BY	29	60	Operating	Hard coal
472	Schwerin-Süd	StW Schwerin	Schwerin	MV	54.5	60	Operating	Natural gas
473	Schwerin-Lankow	StW Schwerin	Schwerin	MV	24.1	31.6	Operating	Natural gas
474	Amsdorf	ROMONTA GmbH	Seegebiet Mansfelder Land	ST	54.8	189	Operating	Brown coal
475	Sindelfingen 1	Daimler AG	Sindelfingen	BW	71	60	Operating	Natural gas
476	Sindelfingen 2	Daimler AG	Sindelfingen	BW	31	42	Operating	Natural gas
477	Schwarze Pumpe A	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Spremberg	BB	800	60	Operating	Brown coal
478	Schwarze Pumpe B	Lausitz Energie Kraftwerke AG (LEAG) (EPH / PPF Investments)	Spremberg	BB	800	60	Operating	Brown coal
479	Schwarze Pumpe	Vattenfall Europe GmbH	Spremberg	BB	40	0	Operating	Natural gas
480	St. Wendel 1+2	Fresenius Medical Care Deutschland GmbH	St. Wendel	SL	15.6	0	Operating	Natural gas
481	Bützfleth (Stade) 1-3	Dow Deutschland Anlagengesellschaft mbH	Stade	NI	173	0	Operating	Natural gas
482	Bützfleth (Stade) GT1/2	Aluminium Oxid Stade GmbH (AOS)	Stade	NI	30.7	0	Operating	Natural gas
483	Stapelfeld	HanseWerk Natur GmbH	Stapelfeld	SH	10	9.7	Operating	Natural gas
484	Staßfurt 1 u. 2	CIECH Energy Deutschland GmbH	Staßfurt	ST	125	160	Operating	Natural gas
485	Steinitz	Engie Deutschland AG	Steinitz	ST	11.4	0	Operating	Natural gas
486	Stendal	StW Stendal / VASA Kraftwerke-Pool GmbH	Stendal	ST	13.5	13.5	Operating	Natural gas

487	Stephanskirchen I	Hamberger Industriewerke GmbH	Stephan-skirchen	BY	7.6	27	Oper-ating	Solid biomass
488	Stephanskirchen II	Hamberger Industriewerke GmbH	Stephan-skirchen	BY	6.3	0	Oper-ating	Solid biomass
489	Stockstadt I	SAPPI Stockstadt GmbH	Stockstadt	BY	26	0	Oper-ating	Hard coal
490	Stockstadt II	SAPPI Stockstadt GmbH	Stockstadt	BY	18.9	0	Oper-ating	Solid biomass
491	Stuttgart-Münster DT12	EnBW Kraftwerke AG	Stuttgart	BW	48.2	447	Oper-ating	Hard coal
492	Stuttgart-Gaisburg HKW 3	EnBW Kraftwerke AG	Stuttgart	BW	31.2	205	Oper-ating	Natural gas
493	Stuttgart-Pfaffenwald 40	University of Stuttgart	Stuttgart	BW	13.5	92.7	Oper-ating	Natural gas
494	Stuttgart-Münster DT15	EnBW Kraftwerke AG	Stuttgart	BW	48.2		Oper-ating	Hard coal
495	Stuttgart-Pfaffenwald 60	University of Stuttgart	Stuttgart	BW	12.8		Oper-ating	Natural gas
496	Stuttgart-Pfaffenwald 50	University of Stuttgart	Stuttgart	BW	12.5		Oper-ating	Natural gas
497	Sulzberg Au	Allgäuer Überlandwerk GmbH	Sulzberg	BY	18		Oper-ating	Natural gas
498	Tacherting-Schalchen	BioMa Energie AG	Tachert-ing	BY	20	100	Oper-ating	Biomass
499	Deuben	MIBRAG IKW GmbH	Teuchern	ST	86	100	Oper-ating	Brown coal
500	Torgau	Holzindustrie Torgau OHG	Torgau	SN	10.6	0	Oper-ating	Solid biomass
501	Trebsen	Papierfabrik Julius Schulte GmbH & Co. KG / Getec heat & power AG	Treb-sen/Mulde	SN	10	0	Oper-ating	Natural gas
502	Tübingen GKK	StW Tübingen	Tübingen	BW	10	27.1	Oper-ating	Natural gas
503	Tübingen Obere Viehweide	StW Tübingen	Tübingen	BW	14	12.1	Oper-ating	Natural gas
504	Uelzen	Nordzucker AG	Uelzen	NI	47.1	0	Oper-ating	Hard coal
505	Ulm (Magi-russtraße)	Fernwärme Ulm GmbH	Ulm	BW	27	294	Oper-ating	Hard coal
506	München-Nord 2	SWM Services GmbH	Unter-föhring	BY	365	550	Oper-ating	Hard coal
507	Varel	Papier- u. Kartonfabrik Varel GmbH & Co. KG	Varel	NI	58.1	0	Oper-ating	Natural gas
508	Irsching 3	Uniper SE	Vohburg	BY	440	25	Grid re-serve	Natural gas

509	Völklingen-Fenne MKV	Steag Power Saar GmbH	Völklingen -Fenne	SL	233	210	Oper-ating	Hard coal
510	Völklingen-Fenne HKV	Steag Power Saar GmbH	Völklingen -Fenne	SL	233	185	Oper-ating	Hard coal
511	Völklingen Fenne MHK (1-14)	Mingas-Power GmbH (Steag New Energies GmbH)	Völklingen -Fenne	SL	42.7	42.7	Oper-ating	Mine gas
512	Wählitz	MIBRAG IKW GmbH	Wählitz	ST	37.4	40	Oper-ating	Brown coal
513	Walheim GT D	EnBW Kraftwerke AG	Walheim	BW	143	0	Oper-ating	Extra-light fuel oil
514	Wasserburg (Reitmehring)	Molkerei Meggle Wasserburg GmbH & Co. KG / Uniper SE	Wasser-burg	BY	15.5	33.5	Oper-ating	Natural gas
515	Wedel 1	Vattenfall Europe GmbH	Wedel	SH	151	423	Oper-ating	Hard coal
516	Wedel 2	Vattenfall Europe GmbH	Wedel	SH	138.7		Oper-ating	Hard coal
517	Weißenborn	Felix Schöller Spezialpapiere GmbH	Weißen-born	SN	14	0	Oper-ating	Natural gas
518	Wesseling (Rhein-land-Raffinerie Süd) (Kessel 5)	Basell Polyolefine GmbH / Shell AG	Wesseling	NW	20	0	Oper-ating	Brown coal
519	Wiesbaden-Biebrich 2	InfraServ Wiesbaden GmbH	Wiesba-den	HE	7	42	Oper-ating	Solid biomass
520	Wiesbaden-Biebrich (Dycker-hoffbruch)	ESWE BioEnergie AG	Wiesba-den	HE	10.5	24	Oper-ating	Solid biomass
521	Wiesbaden-Biebrich 1	InfraServ Wiesbaden GmbH	Wiesba-den	HE	25	0	Oper-ating	Natural gas
522	Wiesbaden (In-dustriepark Kalle Albert)	InfraServ Wiesbaden GmbH	Wiesba-den	HE	20	0	Oper-ating	Natural gas
523	Wismar	EGGER Holzwerkstoffe Wismar GmbH & Co. KG	Wismar	MV	10	0	Oper-ating	Natural gas
524	Lutherstadt Wittenberg-Piesteritz Chemiepark	StW Leipzig	Witten-berg	ST	20	11.3	Oper-ating	Solid biomass
525	Witzenhausen	SCA Deutschland GmbH / B+T Energie GmbH	Witzen-hausen	HE	13.2	0	Oper-ating	Natural gas
526	Wolfen	envia THERM GmbH	Wolfen	ST	40	0	Oper-ating	Natural gas
527	Wolfsburg Nord A	VW Kraftwerk GmbH	Wolfsburg	NI	70	377.5	Oper-ating	Hard coal
528	Wolfsburg Nord B	VW Kraftwerk GmbH	Wolfsburg	NI	70	377.5	Oper-ating	Hard coal
529	Wolfsburg West 10	VW Kraftwerk GmbH	Wolfsburg	NI	153	130	Oper-ating	Hard coal
53	Wolfsburg West 20	VW Kraftwerk GmbH	Wolfsburg	NI	153	130	Oper-ating	Hard coal

0								
531	Worms	Röhm GmbH	Worms	RP	11	90	Oper-ating	Refinery gas
532	Wörth	Palm Power GmbH & Co. KG	Wörth	RP	62	55	Oper-ating	Natural gas
533	Wörth	Daimler AG (Mercedes-Benz-Werk Wörth)	Wörth	RP	13.3	11.4	Oper-ating	Natural gas
534	Wunsiedel-Holenbrunn	WUN Pellets GmbH	Wunsiedel	BY	13.5	15.6	Oper-ating	Natural gas
535	Wuppertal-Barmen 1	WSW Energie und Wasser AG	Wupper-tal	NW	85	80	Oper-ating	Natural gas
536	Würzburg GuD I (GT I)	Heizkraftwerk Würzburg GmbH	Würzburg	BY	46	125	Oper-ating	Natural gas
537	Würzburg GuD II (TS II)	Heizkraftwerk Würzburg GmbH	Würzburg	BY	26	90	Oper-ating	Natural gas
538	Würzburg GuD I (GT II)	Heizkraftwerk Würzburg GmbH	Würzburg	BY	31		Oper-ating	Natural gas
539	Würzburg GuD II (TS III)	Heizkraftwerk Würzburg GmbH	Würzburg	BY	24		Oper-ating	Natural gas
540	Zeitz	Südzucker AG Mannheim	Zeitz	ST	23.3	0	Oper-ating	Brown coal
541	Zeitz	Südzucker AG Mannheim	Zeitz	ST	23.3	0	Oper-ating	Mineral oil products
542	Zeitz	Südzucker Bioethanol GmbH (Crop Energies)	Zeitz	ST	20	0	Oper-ating	Brown coal
543	Zielitz DT	K+S KALI GmbH	Zielitz	ST	31	0	Oper-ating	Natural gas
544	Zielitz GT 1	K+S KALI GmbH	Zielitz	ST	10	0	Oper-ating	Natural gas
545	Zielitz GuD 1	K+S KALI GmbH	Zielitz	ST	5	0	Oper-ating	Natural gas
546	Zielitz GuD 2	K+S KALI GmbH	Zielitz	ST	5	0	Oper-ating	Natural gas
547	Zielitz GT 2	K+S KALI GmbH	Zielitz	ST	1.5	0	Oper-ating	Natural gas
548	Zolling-Leininger 5	Riverstone Holdings LLC	Zolling	BY	474	150	Oper-ating	Hard coal
549	Zolling-Leininger	Biomasseheizkraftwerk Zolling GmbH / Engie Deutschland AG	Zolling	BY	20	30	Oper-ating	Solid biomass
550	Zülpich	Smurfit Kappa Zülpich Papier	Zülpich	NW	19.5	0	Oper-ating	Natural gas
551	Zülpich GT 1	Smurfit Kappa Zülpich Papier	Zülpich	NW	5.5	0	Oper-ating	Natural gas
55	Zülpich GT 2	Smurfit Kappa Zülpich Papier	Zülpich	NW	5.5	0	Oper-ating	Natural gas

2								
553	Zülpich GT 3	Smurfit Kappa Zülpich Papier	Zülpich	NW	5.5	0	Operating	Natural gas
554	Zwickau	Volkswagen Sachsen GmbH	Zwickau	SN	12.9	12	Operating	Natural gas
Additional sites on the power plant list of the Federal Network Agency								
	Power plant name	**Operator**	**Location**	**Federal state**	**Capacity in MW electric**	**Capacity in MW thermal for district heating**	**Operating status**	**Energy source**
556	KWK-Anlage Neukochen	Papierfabrik Palm GmbH & Co. KG	Aalen	BW	15		Operating	Natural gas
557	KWK-Anlage Barby	Cargill Deutschland GmbH	Barby	ST	17.8		Operating	Natural gas
558	Lippendorf	Lausitz Energie Kraftwerke AG	Böhlen	SN	875		Operating	Brown coal
559	Industriekraftwerk Breuberg	Pirelli Deutschland GmbH	Breuberg	HE	11.4		Operating	Natural gas
560	HKW Chemnitz Nord II	eins - energie in sachsen GmbH & Co. KG	Chemnitz	SN	90.8		Operating	Brown coal
561	HKW Dresden-Nossener Brücke	DREWAG Stadtwerke Dresden GmbH	Dresden	SN	260		Operating	Natural gas
562	P&L Werk Euskirchen	Pfeifer & Langen GmbH & Co. KG	Euskirchen	NW	14.5		Operating	Brown coal
563	HKW West M5	Mainova AG	Frankfurt am Main	HE	38.7		Operating	Natural gas
564	Dampfturbine 5	Mainova AG	Frankfurt am Main	HE	38.7		Operating	Natural gas
565	HKW Tinz	ENGIE Deutschland GmbH	Gera	TH	22.05		Operating	Natural gas
566	Energiezentrum Mohn Media	Mohn Media Mohndruck GmbH	Gütersloh	NW	25		Operating	Natural gas
567	HKW Halle Trotha	EVH GmbH	Halle	ST	97		Operating	Natural gas
568	HKW Halle Trotha	Heizkraftwerk Halle-Trotha GmbH	Halle	ST	56.14		Operating	Natural gas
569	Heizkraftwerk	ADM Hamburg Aktiengesellschaft	Hamburg	HH	22.5		Operating	Natural gas
570	HKW Jena	TEAG Thüringer Energie AG	Jena	TH	182		Operating	Natural gas
571	KWK-Anlage Krefeld DT	Cargill Deutschland GmbH	Krefeld	NW	25.8		Operating	Natural gas
572	KWK-Anlage Krefeld VM	Cargill Deutschland GmbH	Krefeld	NW	14		Operating	Natural gas
57	Emsland	RWE Generation SE	Lingen	NI	887		Operating	Natural gas

3								
574	Emsland	RWE Generation SE	Lingen	NI	359		Operating	Natural gas
575	Emsland	RWE Generation SE	Lingen	NI	359		Operating	Natural gas
576	Emsland	RWE Generation SE	Lingen	NI	116		Operating	Natural gas
577	Emsland	RWE Generation SE	Lingen	NI	116		Operating	Natural gas
578	Werk 1.5	BMW AG	Munich	BY	13.6		Operating	Natural gas
579	Werk 1.1	BMW AG	Munich	BY	13.5		Operating	Natural gas
580	Heizkraftwerk Hafen	Stadtwerke Münster GmbH	Münster	NW	104.14		Operating	Natural gas
581	Oxea GmbH	OXEA Produktion GmbH & Co.KG	Oberhausen	NW	38		Operating	Other energy sources
582	Turbine 5	KÄMMERER Energie GmbH	Osnabrück	NI	9.8		Operating	Multiple energy sources
583	Turbine 4	KÄMMERER Energie GmbH	Osnabrück	NI	9.5		Operating	Multiple energy sources
584	Gasmotor 5	Stadtwerke Rosenheim GmbH & Co. KG	Rosenheim	BY	4.3		Operating	Natural gas
585	HKW 3 Stuttgart-Gaisburg	EnBW Energie Baden-Württemberg AG	Stuttgart	BW	29.15		Operating	Natural gas
586	HKW Bohrhügel	Stadtwerke Suhl/Zella-Mehlis GmbH	Suhl	TH	13.5		Operating	Natural gas
587	BHKW Obere Viehweide	Stadtwerke Tübingen GmbH	Tübingen	BW	13.4		Operating	Natural gas
588	Unterbreizbach	K+S AG	Unterbreizbach	TH	20		Operating	Natural gas
589	Sigmundshall	K+S AG	Wunstorf	NI	11		Operating	Natural gas

Table 52: List of identified waste incineration plants

	Plant type	Municipality	Commissioned	Energy output	RTI [MW]	Capacity [Mg/a]
1	WIP	Augsburg	1994	CHP	75	255,000
2	WIP	Bamberg	1978	CHP	53	145,000
3	WIP	Berlin	1967	CHP		550,000
4	WIP	Bielefeld	1981	CHP	180	400,000
5	WIP	Böblingen	1999	CHP	58	157,000
6	WIP	Bonn	1992	CHP	86	315,000
7	WIP	Bremen	1969	CHP	221	550,000
8	WIP	Bremerhaven	1977	CHP		401,500
9	WIP	Burgkirchen	1994	CHP		230,000
10	WIP	Coburg	1988	CHP	53.4	142,000
11	WIP	Darmstadt	1967	CHP	77	212,000
12	WIP	Düsseldorf	1965	CHP	137	450,000
13	WIP	Emlichheim (Laar)	2008	Electricity		454,176
14	WIP	Essen	1987	CHP		745,000
15	WIP	Frankfurt	1965	CHP		525,300
16	WIP	Freiburg | Eschbach	2005	CHP	61.1	185,000
17	WIP	Göppingen	1975	CHP	57.75	157,680
18	WIP	Hagen	1966	CHP		144,000
19	WIP	Hamburg MVB	1994	CHP	116	320,000
20	WIP	Hamburg MVR	1999	CHP	120	320,000
21	WIP	Hameln	1977	CHP	141	300,000
22	WIP	Hamm	1985	CHP		295,000
23	WIP	Hannover	2005	Electricity	105	280,000
24	WIP	Helmstedt | Buschhaus	1998	Electricity	172.5	525,000
25	WIP	Herten	1982	CHP	208.4	600,000
26	WIP	Ingolstadt	1977	CHP	99	255,000
27	WIP	Iserlohn	1970	CHP	102	295,000
28	WIP	Kamp-Lintfort	1997	CHP	99	270,000
29	WIP	Kassel	1968	CHP	30.8	200,000
30	WIP	Kempten	1996	CHP	52	160,000
31	WIP	Kiel	1996	CHP	43.75	140,000
32	WIP	Cologne	1998	CHP	241	780,000
33	WIP	Krefeld	1975	CHP	162	375,000
34	WIP	Lauta	2004	CHP	87	225,000
35	WIP	Leuna	2005	CHP	152.78	420,000
36	WIP	Leverkusen	1970	CHP	83.69	280,320
37	WIP	Ludwigshafen	1967	CHP	86.7	210,000
38	WIP	Ludwigslust	2005	Electricity	16	50,000
39	WIP	Magdeburg | Rothensee	2006	CHP	267	650,000
40	WIP	Mainz	2004	CHP		350,000
41	WIP	Mannheim	1965	CHP	263	650,000
42	WIP	Munich	1983	CHP	172	685,000

43	WIP	Neunkirchen	1969	CHP	55.6	150,000
44	WIP	Neustadt	1984	CHP		56,000
45	WIP	Nuremberg	2001	CHP	105	230,000
46	WIP	Oberhausen | Niederhein	1972	CHP	267	700,000
47	WIP	Offenbach	1970	CHP	84.3	250,000
48	WIP	Olching | Geiselbullach	1975	CHP		120,000
49	WIP	Pirmasens	1998	CHP		180,000
50	WIP	Rosenheim	1964	CHP	27.7	100,000
51	WIP	Salzbergen	2004	CHP	47	130,000
52	WIP	Schwandorf	1982	CHP	205	450,000
53	WIP	Schweinfurt	1994	CHP	62.4	196,806
54	WIP	Solingen	1969	CHP	63	175,000
55	WIP	Stapelfeld	1979	CHP	58.2	350,000
56	WIP	Staßfurt	2007	CHP	111	380,000
57	WIP	Stuttgart	1965	CHP	192.6	420,000
58	WIP	Tornesch-Ahrenlohe	1974	CHP	29	80,000
59	WIP	Ulm	1997	CHP		165,000
60	WIP	Velsen | Saarbrücken	1997	Electricity	83.3	255,000
61	WIP	Weißenhorn	1991	Electricity	48	116,000
62	WIP	Weisweiler | Eschweiler	1996	CHP		360,000
63	WIP	Wuppertal	1976	CHP	186	400,000
64	WIP	Würzburg	1984	CHP		219,000
65	WIP	Zella-Mehlis	2008	CHP	60	160,000
66	WIP	Zorbau	2005	CHP	75	338,000
67	RDF plant	Amsdorf	2004	CHP		120,000
68	RDF plant	Andernach	2008	CHP		114,000
69	RDF plant	Bernburg	2009	CHP	214	552,000
70	RDF plant	Bitterfeld-Wolfen	2010	CHP	56	130,000
71	RDF plant	Bremen Blumenthal	2005	CHP	31	60,000
72	RDF plant	Bremen MKK	2009	CHP	110	330,000
73	RDF plant	Eisenhüttenstadt	2011	CHP	150	340,000
74	RDF plant	Erfurt Ost	2006	CHP	26	63,900
75	RDF plant	Essen	2010	CHP	12	26,500
76	RDF plant	Frankfurt (T2C)	2012	CHP		700,000
77	RDF plant	Gersthofen | Augsburg	2009	CHP	35	90,000
78	RDF plant	Giessen	2009	CHP	10	25,000
79	RDF plant	Glückstadt	2009	CHP		250,000
80	RDF plant	Großräschen	2008	CHP	102	258,750
81	RDF plant	Hagenow	2009	CHP	35	80,000
82	RDF plant	Heringen	2010	CHP	117	297,600
83	RDF plant	Hürth | Knapsack	2008	CHP	130	320,000
84	RDF plant	Korbach	2008	CHP	36	75,000
85	RDF plant	Lünen	1982	CHP		165,000
86	RDF plant	Meuselwitz-Lucka	2005			50,000

87	RDF plant	Minden	2002	CHP	15	35,000
88	RDF plant	Neumünster	2005	CHP	83	150,000
89	RDF plant	Pforzheim	1990	CHP		50,000
90	RDF plant	Premnitz	2001	CHP	106	270,000
91	RDF plant	Rostock	2010	CHP	87	230,000
92	RDF plant	Rudolstadt | Pößneck | Schwarza	2007	Steam	29	80,000
93	RDF plant	Rüdersdorf	2008	Electricity	110	226,000
94	RDF plant	Schwedt	2011	CHP		442,000
95	RDF plant	Spremberg | Schwarze Pumpe	2012	CHP	110	240,000
96	RDF plant	Stavenhagen	2007	CHP	49	90,000
97	RDF plant	Weener | Leer	2008	CHP		120,000
98	RDF plant	Witzenhausen	2009	CHP	124	330,000

Table 53: List of identified geothermal installations

	Name	Federal state	Operating status	Geothermal capacity share MWth	Total MWth	Total MWel
1	München-Sendling	Bavaria	Construction	50		
2	Grünwald (Laufzorn)	Bavaria	Operating	40	73	4.3
3	Taufkirchen	Bavaria	Operating	40	40	4.3
4	Unterhaching	Bavaria	Operating	38	83	
5	Kirchweidach	Bavaria	Operating	30.6	30.6	0.68
6	Holzkirchen	Bavaria	Operating	24	24	3.6
7	Pullach	Bavaria	Operating	16	33.5	
8	Waldkraiburg	Bavaria	Operating	14	18.5	
9	Freiham	Bavaria	Operating	13	78	
10	München Riem	Bavaria	Operating	13	51	
11	Traunreut	Bavaria	Operating	12	13.9	5.5
12	Unterföhring II	Bavaria	Operating	11.3	31.3	
13	Aschheim	Bavaria	Operating	10.7	44.5	
14	Erding	Bavaria	Operating	10.2	48.8	
15	Unterföhring	Bavaria	Operating	10	30	
16	Poing	Bavaria	Operating	9	39	
17	Simbach-Braunau	Bavaria	Operating	9	46.2	
18	Unterschleißheim	Bavaria	Operating	8	33.4	
19	Garching	Bavaria	Operating	7.95	27.95	
20	Ismaning	Bavaria	Operating	7.2	22	
21	Garching a.d. Alz (I)	Bavaria	Construction	6.2		3.5
22	Bruchsal	Baden-Württemberg	Operating	5.7		0.44
23	Landau in der Pfalz	Rhineland-Palatinate	Operating	5	33	1.8

24	Neustadt-Glewe	Mecklenburg-Western Pomerania	Operating	4	14	
25	Sauerlach	Bavaria	Operating	4	4	5
26	Neuruppin	Brandenburg	Operating	2.1		
27	Straubing	Bavaria	Operating	2.1	7.33	
28	Gräfelfing	Bavaria	Planning			
29	Schwerin	Mecklenburg-Western Pomerania	Construction			
30	Pfullendorf	Baden-Württemberg	Operating			
31	Rupertiwinkel	Bavaria	Planning			
32	Neubrandenburg	Mecklenburg-Western Pomerania	Operating			
	Total			403.05	826.98	29.12

Table 54: List of identified solar thermal installations

	Location	Federal state	Operating status	Collector area m²	Capacity kW	Heat store m³
1	Ludwigsburg	Baden-Württemberg	Realisation/planning	14,800	9,600	2,000
2	Senftenberg	Brandenburg	Operating	8,300	5,800	
3	Bernburg	Saxony-Anhalt	Realisation/planning	8,603	5,600	
4	Crailsheim	Baden-Württemberg	Operating	7,500	5,110	37,500
5	Neckarsulm	Baden-Württemberg	Operating	5,670	3,969	
6	Halle	Saxony-Anhalt	Operating	5,091	3,300	
7	Potsdam	Brandenburg	Operating	5,000	3,100	
8	Friedrichshafen	Baden-Württemberg	Operating	4,050	2,835	
9	Hamburg-Bramfeld	Hamburg	Operating	3,000	2,100	
10	Schluchsee	Baden-Württemberg	Realisation/planning	3,000	2,068	
11	Mengsberg	Hessen	Operating	2,950	2,033	300
12	Munich	Bavaria	Operating	2,900	2,030	
	Total			70,864	47,545	

Table 55: List of identified power-to-heat installations

	Operator	Location	Operating status	MWel	MWth
1	Vattenfall	Berlin	Operating	120	108
2	EnBW	Stuttgart	Operating	100	90
3	EnBW	Heilbronn	Operating	60	54
4	Uniper	Herne	Operating	60	54
5	N-ERGIE	Nuremberg	Operating	50	45
6	Wärme Hamburg GmbH	Hamburg	Operating	45	40.5
7	DREWAG - Stadtwerke Dresden	Dresden	Operating	40	36
8	Stadtwerke Flensburg	Flensburg	Operating	30	27
9	Stadtwerke Kiel	Kiel	Operating	30	27
10	Stadtwerke Neubrandenburg / 50Hertz	Neubrandenburg	Construction	30	27

11	Stadtwerke Münster	Münster	Operating	22	19.8
12	EEW Premnitz	Premnitz	Operating	20	18
13	Energie und Wasser Potsdam	Potsdam	Operating	20	18
14	Stadtwerke Bielefeld	Bielefeld	Operating	20	18
15	Stadtwerke Neumünster i.V.m. Enerstorage	Neumünster	Operating	20	18
16	STEAG GmbH	Völkingen Fenne	Operating	20	18
17	swb	Bremen	Operating	18	16.2
18	ENRO Ludwigsfelde	Ludwigsfelde	Operating	15	13.5
19	Stadtwerke Schwerin	Schwerin	Operating	15	13.5
20	Zielitz	Zielitz	Operating	15	13.5
21	Energieversorgung Offenbach	Offenbach am Main	Operating	10	9
22	FHW Neukölln AG	Berlin	Operating	10	9
23	Heizkraftwerke Mainz	Mainz	Operating	10	9
24	Stadtwerke Augsburg	Augsburg	Operating	10	9
25	Stadtwerke München	Munich	Operating	10	9
26	Techn. Werke Ludwigshafen	Ludwigshafen	Operating	10	9
27	VVS Saarbrücken	Saarbrücken	Operating	10	9
28	Südzucker, Standort Zeitz	Zeitz	Operating	10	9
29	Mainova	Frankfurt	Operating	8	7.2
30	BioEnergie Taufkirchen	Taufkirchen	Operating	6.1	5.49
31	Avacon Natur	Salzwedel	Operating	6	5.4
32	BTB Berlin	Berlin	Operating	6	5.4
33	Kraftwerke Dessau	Dessau	Operating	5	4.5
34	Kraftwerke Philippsburg	Philippsburg	Operating	5	4.5
35	Stadtwerke Detmold	Detmold	Operating	5	4.5
36	Stadtwerke Lemgo	Lemgo	Operating	5	4.5
37	Stadtwerke Tübingen	Tübingen	Operating	5	4.5
38	Vattenfall	Berlin	Operating	5	4.5
39	Stadtwerke Jena	Jena	Operating	4	3.6
40	Stadtwerke Lübeck	Lübeck	Operating	2.5	2.25
41	Stadtwerke Norderstedt	Norderstedt	Operating	2.4	2.16
	Total			895	805.5

II. Annex Part II.1

Table 56: Indicative contribution to the national energy efficiency target

Title of measure, strategy or objective	**Notification no**	**Cumulative final energy saving 2021–2030**
Carbon pricing in the heating and transport sectors	M16	198 TWh
Federal support for energy advice on residential and non-residential buildings of municipalities / non-profit organisations	M21	7.5 TWh
Federal support for energy advice in small and medium-sized enterprises	M22	13.7 TWh
National efficiency label for old heating systems	M27	5.2 TWh
Building Energy Act	M10, M11	168 TWh
Federal Support for Efficient Buildings	M03	84.8 TWh
Tax support for energy-efficient renovation of buildings	M18	35.3 TWh
Support for serial renovation	M07	3.1 TWh
Accelerated implementation of measures resulting from energy audit and energy management systems	M14	5.3 TWh
SME Initiative Energy Transition and Climate Protection	M24	2.8 TWh
Federal support for energy efficiency in the economy	M01, M02	149 TWh
Energy and Electricity Tax Act	M15	159 TWj

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

III. Annex Part II.2

Table 57: Policies and measures under the decarbonisation dimension

Title	Brief description
Climate Action Plan 2050	The Climate Action Plan 2050 brings together the principles and goals of the climate policy and maps out the road to a largely greenhouse-gas-neutral Germany by 2050. It provides specific details of Germany's existing climate protection target for 2050 and the agreed interim targets, and it describes measures to implement the Paris Agreement. The Federal Cabinet adopted the Climate Action Plan 2050 on 14 November 2016
Climate Action Programme 2030	With the Climate Action Programme 2030, Germany is pursuing the specified climate protection targets with a broad package of measures comprising innovations, funding, legal standards and requirements, and with a greenhouse gas pricing scheme. The Climate Action Programme 2030 was adopted in October 2019. The individual measures are now being implemented step by step with legislation and support programmes.
Federal Climate Change Act (3.1.1.i.1.)	Germany has legally enshrined its target for GHG reduction by 2030 in the Federal Climate Change Act. Greenhouse gas emissions are to be reduced by at least 55% by 2030. Germany has also made a commitment to pursue greenhouse gas neutrality by 2050 as a long-term goal. In 2025, annual emission levels will be set for further periods after 2030. These must be in line with the law's climate protection objectives and with European requirements. To this end, the law sets out annual emission levels for the sectors of energy, industry, transport, buildings and agriculture.
Carbon pricing in the heating and transport sectors (3.1.1.i.2. and 3.2.iv.1.)	With the Fuel Emissions Trading Act (BEHG), a national Emissions Trading Scheme is being introduced from 2021 for sectors that are not covered by the European Emissions Trading Scheme, creating the basis for carbon pricing in these sectors. In the heating sector, the system covers the emissions from heat generation in the buildings sector and energy and industrial installations outside the European Emissions Trading Scheme. In the first 2 years, the main fuels will be included first: petrol, gas oil, fuel oil, natural gas and LPG.
Support programme to expand landfill aeration and optimise gas capture (3.1.1.i.12.)	The support programme to expand landfill aeration and optimise gas capture directs funding at the core measures of landfill aeration, in which the methane that is otherwise produced is converted into carbon dioxide based on biogenic carbon in a greenhouse-gas-neutral manner, and the optimisation of gas capture.
'Climate Action 2050' information campaign (3.1.1.i.13.)	As part of the campaign, an information portal will be provided to inform citizens and companies about ways in which they can act on climate change. In addition, a comprehensive information campaign will be launched across all relevant media with information explaining the climate action policy in a manner tailored to the target group.
Minimum price in EU emissions trading (3.1.1.ii.1.)	Germany will collaborate closely with the European Commission to introduce a pan-European certificate trading scheme for all sectors. As a first step, the existing European Emissions Trading Scheme is to be supplemented with a moderate European minimum price.
European Climate Initiative (3.1.1.ii.2.)	The European Climate Initiative was launched to boost cooperation and the sharing of experiences across borders in relation to greenhouse gas reduction at non-governmental level. This initiative funds projects that support the exchange of good practice between sub-national players, civil society, business and the scientific community.
Meseberg Climate Working Group (3.1.1.ii.3.)	With the Meseberg Declaration, Germany and France agreed to set up a high-level cross-departmental climate working group. The Climate Working Group supports the implementation of the Paris Agreement. This includes the development of common views on the energy transition, on sustainable financing instruments and on economic incentives, including aspects of carbon pricing.
National Climate Initiative	The National Climate Initiative (NCI) initiates and funds numerous climate action pro-

Title	Brief description
(3.1.1.iii.1.)	jects. Its programmes and projects cover a wide range of climate protection activities. With the development of long-term strategies, support for professional climate protection management and investment funding, the NCI helps to embed climate action locally. The main target groups for the NCI are municipalities, the business community, consumers, schools and other educational establishments.
Development and implementation of a sustainable finance strategy (3.1.1.iii.2.)	The reason for developing a sustainable finance strategy is to further develop Germany into a hub for sustainable finance, to support discussion and implementation processes at national, European and global level, and to contribute to structured and integrated stakeholder dialogue.
Further development of the KfW into a transformative investment bank (3.1.1.iii.3.)	The Kreditanstalt für Wiederaufbau (KfW) is being further developed as a sustainable investment bank to support the transformation of sectors of the economy and the financial market for a greenhouse-gas-neutral future. Practical implementation proposals are made in keeping with the sustainable finance strategy, within the framework of the KfW's equity base and in line with the KfW's strategic objectives. At the same time, appropriate transformation processes in multilateral development banks are promoted through its influence on the competent bodies of those banks.
Green Federal Government securities (3.1.1.iii.4.)	In future, the Federal Government will issue green Federal Government securities in the context of the sustainable finance strategy to be developed, thereby supporting the development of sustainable financial markets. Issuing such securities will create transparency about the Federal Government's green spending.
Further development and comprehensive modernisation of combined heat and power (3.1.2.i.8.)	Combined heat and power (CHP) will be funded in a manner that is compatible with the expansion of renewable energies on the electricity and heat side. Modern CHP systems incorporating heat from renewable energies and using the waste heat potential will replace fossil-fuel-based CHP installations in the future, secure the electricity and heat supply and support the integration of renewable energies through a flexible and system-based approach. CHP funding will be developed further and extended until 2030.
Investments in storage technology (3.1.2.iii.2.)	In the Coalition Agreement of the 19th legislative period, the Federal Government has set out its intention to invest in storage technologies and smart marketing concepts in order to continue to ensure security of supply in all parts of Germany and to keep system costs and costs under the Renewable Energy Sources Act (EEG) as low as possible.
KfW Renewable Energies Programme (3.1.2.iii.3.)	This programme serves to provide long-term low-interest finance for measures designed to use renewable energies to generate electricity and to generate both electricity and heat in combined heat and power installations and for measures designed to integrate renewable energies into the energy system. Up to 100% of the eligible investment costs are financed, with a ceiling of €50 million per project.
Regulatory framework for the development of Renewable Energy Communities (3.1.2.v.6.)	Renewable Energy Communities offer great potential for the successful expansion of renewable energies at national and European level. Germany has also created a regulatory framework for Renewable Energy Communities to support and drive the development of such communities. So far, the key aspects of this regulatory framework are as follows. Access to Renewable Energy Communities is open to end consumers in Germany in a non-discriminatory manner, and the same can be said for access by Renewable Energy Communities to existing funding schemes. In addition, Germany has given particular priority to community-run energy companies in calls for proposals for funding in the field of onshore wind energy. The Federal Government is examining whether changes are necessary to transpose Directive (EU) 2018/2001 within the existing regulatory framework.
Heating Network Systems 4.0 (3.1.2.vi.1.)	Through the Heating Network Systems 4.0 support programme, systemic support has been introduced for the first time in Germany in the area of heating infrastructure, supporting not only individual technologies and components, but also complete systems. This support programme has been amended and will continue until at least 2030.
Increasing conversion of heating networks to re-	This measure involves supplementing the Heating Network Systems 4.0 support programme with a heating network transformation programme, which is intended to help

Title	Brief description
newable energies and unavoidable waste heat (3.1.2.vi.2.)	decarbonise existing heating networks. The following are accompanying measures or measures that support the transformation towards low-carbon heating: levy-based, market-economy-oriented funding, carbon pricing, any necessary adjustment of the legal framework for the expansion and optimisation of heating networks with a high renewable energy component, and accompanying stakeholder dialogue on 'heating networks in the context of the heating transition'.
Use of Biomass for Energy Production support programme (3.1.2.vii.1.)	This support programme provides, most notably, for the promotion of practical solutions of a demonstration and pilot nature that help boost the flexibility of electricity and heat generation from biomass. Biomass residue and waste potentials should be exploited, in particular, to improve energy sustainability in heating and electricity.
Renewable Raw Materials support programme (3.1.2.vii.2.)	This programme aims to fund research, development and demonstration projects relating to the use of renewable raw materials for energy production. Alongside research and development projects, the focus is especially on practical procedural and process optimisations of a demonstration and pilot nature.
National transposition of EU Directive 2003/87 by means of the Greenhouse Gas Emissions Trading Act (3.1.3.i.1.)	National strategies and measures to achieve the objectives of the Climate Action Plan 2050 in the sectors of the European Emissions Trading Scheme (ETS) reduce CO_2 emissions effectively across the EU if unused emissions certificates do not lead to emissions in other Member States (waterbed effect). Whether and for how long such a waterbed effect exists depends partly on the impact with the Market Stability Reserve (MSR) in the ETS.
Sector coupling (3.1.3.ii.1.)	The direct use of electricity from renewable energies enables the exploitation of efficiency potentials and a reduction in the use of fossil fuels. Even with applications where other options to reduce GHGs are difficult to implement through the direct use of electricity, electricity-based technologies that use renewable energies are an important option for achieving energy and climate goals. Sector coupling is the object of a wide range of support measures, projects and programmes (see other dimensions).
Peer review process within the framework of the G20 (3.1.3.iv.1.)	In 2009, the G20 members agreed to abolish inefficient subsidies for fossil fuels in the medium term. To implement this, the countries signed up to a voluntary peer review process. In September 2016, Germany submitted a report on the relevant German subsidies.
Federal Government's subsidy report (3.1.3.iv.2.)	Every 2 years, as part of the subsidy reporting, all subsidies are subjected to a regular sustainability impact assessment. The long-term economic, ecological and social effects of the respective subsidy are examined, for example in relation to economic prosperity and provision for the future, climate protection and resource conservation, or employment protection, and the results are documented in the subsidy report.
Comprehensive evaluation of tax advantages (3.1.3.iv.3.)	A total of 33 tax advantages listed in the subsidy report have undergone a systematic evaluation within the framework of a research appraisal, especially with regard to the achievement of objectives, efficiency, instrumental suitability and, for the first time, their sustainability. The results of the appraisal are now being reviewed in terms of the need for action and optimisation of the individual measures.
Phasing-out of grants for coal (3.1.3.iv.4.)	The most important measure currently being undertaken in Germany to reduce subsidies for fossil fuels is the phasing-out of grants to fund coal. Subsidies relating to the sale of domestic coal were paid for the last time in 2018 and coal mining then ended. Subsequent shutdown measures will continue to be subsidised until the end of 2022.

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

Table 58: Policies and measures under the energy efficiency dimension

Title	Brief description
Energy Efficiency Strategy 2050 (3.2.i.1.)	The cross-sector Energy Efficiency Strategy 2050 (EffSTRA) defines key objectives and instruments for the further development of energy efficiency policy. It defines an energy efficiency target for 2030 and a package of measures aimed at reducing primary energy

Title	Brief description
	consumption in Germany. The strategy also launches a broad-based dialogue process on the development of a long-term roadmap for halving primary energy consumption by 2050.
National Action Plan on Energy Efficiency 2.0 (3.2.i.2.)	The National Action Plan on Energy Efficiency (NAPEE) defines urgent measures and further working processes for achieving the national efficiency and climate protection targets. The cornerstones of energy efficiency policy are: stepping up energy efficiency in buildings, industry, trade, commerce and services, establishing energy efficiency as an investment and business model, and increasing individual responsibility for energy efficiency. The NAPEE measures have been revised and transferred to a NAPEE 2.0 in order to address a possible gap in the achievement of the efficiency targets with an effective set of measures.
Efficiency First (3.2.i.3.)	Across all sectors, the supreme principle is Efficiency First. From the Federal Government's point of view, the first priority is a significant and permanent reduction in energy demand, the second is the direct use of renewable energies in all sectors where possible, and the third is the efficient use of electricity from renewable sources for heating, transport and industry in the context of sector coupling.
Long-Term Renovation Strategy (3.2.ii.)	According to Article 2a of the EU Directive on the energy performance of buildings, the Federal Government must submit a Long-Term Renovation Strategy (LTRS) to the European Commission. With this LTRS, every Member State should produce a roadmap containing measures and nationally defined measurable progress indicators for achieving the long-term climate objectives and also identify pathways and incentives for renovation of the national building stock. In August 2020, Germany published its LTRS to support the renovation of the national stock of public and private residential and non-residential buildings, including policies and measures to fund comprehensive cost-effective renovations and policies and measures targeting the worst-performing segments of the national building stock.
PR campaign 'Germany Does It Efficiently' (3.2.ii.1.)	As part of the BMWi information campaign 'Germany Does It Efficiently', information will in future be given in an even more specialised and targeted manner.
Independent advice from Verbraucherzentrale Bundesverband e. V. (Federation of German Consumer Organisations) (3.2.ii.2. and 3.2.iv.9.)	Initial and short consultations are supported financially and provided in the form of independent advice from the Verbraucherzentrale Bundesverband e. V. (vzbv). These nationwide consultations are intended to help break down prejudice and barriers to energy-efficient renovation measures and the use of renewable energies. They are also a low-threshold entry point for building-related advice.
Federal support for energy advice on residential buildings (3.2.ii.3. and 3.2.iv.10.)	The federal support for energy advice on residential buildings (EBW) is aimed at owners of residential buildings. As part of the advice, a qualified energy consultant examines the entire property and draws up a comprehensive energy advisory report (including an individual renovation roadmap). Alongside the potential for saving energy, the report estimates possibilities for using renewable energies and the investment that this would require, and sets out the savings on heating costs and CO_2. In specific terms, the energy advice has been boosted by the following measures: increase in funding with a grant of up to 80% (previously 60%), modernisation recommendations through subsidised energy advice for the preparation of an energy performance certificate, energy advice linked to ambient air quality measurements by qualified chimney sweeps and other qualified advice (e.g. heating replacement).
Federal support for energy advice on non-residential buildings of municipalities / non-profit organisations (EBK) (3.2.ii.4. and 3.2.iv.11.)	The federal support for energy advice on non-residential buildings of municipalities / non-profit organisations (EBK) has been assisting municipalities, municipal companies and non-profit organisations with the energy-efficient renovation of their building stock and the erection of new energy-efficient buildings since 2016. Thanks to qualified and subsidised energy advice, the owners of these buildings gain a good overview of where in their buildings most energy is wasted, what investments make economic sense, what savings potential they have and how to avoid bad investments. The concept of the individual renovation roadmap that is already part of the energy advice on residential buildings is to be developed further for municipal buildings as a next step. Municipalities

Title	Brief description
	will therefore also fulfil their obligation to set an example in the public sector.
Federal support for energy advice in small and medium-sized enterprises (3.2.ii.5. and 3.2.iv.12.)	Within the federal support for energy advice in small and medium-sized enterprises (EBM), renovation concepts are funded for the commercial buildings of small and medium-sized companies. Energy vulnerabilities within the company are investigated and a company tour is conducted. An in-depth energy analysis is carried out, which contains clear information on potential savings and a concrete action plan. As part of the funding strategy, the intention is to merge and align the EBM and EBK support programmes as companies and municipalities often have very similar advisory needs. At the same time, this will provide the necessary scope for targeted differentiation.
National efficiency label for old heating systems (3.2.ii.6.)	With the efficiency label for old heating systems, installers (since 2016) and district chimney sweeps (since 2017) have been awarding the efficiency label in stages, starting with the oldest boilers. The aim of this measure is to increase the rate of replacement of old heating appliances by 20% to 3.7% per year and to encourage energy savings by replacing the boiler. A total of around 13 million boilers are to be labelled over 7 years.
Building Energy Act (3.2.ii.7.)	The Building Energy Act (GEG) creates a new, uniform and coordinated set of rules on the energy requirements for new and existing buildings and on the use of renewable energies for the supply of heating and cooling to buildings. To this end, the separate regulations on building energy efficiency (EnEG, EnEV) and on the use of heat from renewable energies (EEWärmeG) have been merged and standardised. With the GEG, the rules on nearly zero-energy buildings are integrated into the standardised energy saving legislation. As far as buildings are concerned, the energy requirements for new and existing buildings will be reviewed in 2023, rules on the installation of oil heating systems will be presented from 2026, and advice for the buyer or owner in the event of the sale or major renovation of a single or two-family house will be embedded.
CO_2 building renovation programme of the Federal Government (3.2.ii.8.)	This programme has been in existence since 2006 and provides support, via the 'Energy-Efficient Construction and Renovation' (EBS) programmes administered by the KfW, for energy-efficient renovations and the highly efficient new construction of residential and non-residential buildings, as well as individual renovation measures in the area of energy efficiency, with a view to implementing the long-term renovation strategy for buildings. It is the support instrument with the highest volume in the area of efficiency. This support takes the form of low-interest loans in conjunction with either repayment grants or investment grants. Applications can be submitted by private house/apartment owners, housing owners' associations, housing companies and cooperatives, developers and businesses, private and municipal companies, and municipalities and non-profit organisations. In January 2020, within the CO_2 building renovation programme, the support rates for the renovation of residential and non-residential buildings and the support quotas for highly energy-efficient new residential construction projects were increased by ten percentage points.
Market Incentive Programme (3.2.ii.9.)	The Market Incentive Programme (MAP) supports renewable energy installations for heating and cooling, as well as certain heat stores and local heating networks, in both residential and non-residential buildings. This funding is almost exclusively available to installations in existing buildings, while installations in new buildings qualify only in exceptional cases. The programme offers two funding streams. For smaller installations, investment grants are provided via the Federal Office for Economic Affairs and Export Control (BAFA). Installations that are eligible for this grant are solar collector systems, biomass plants, efficient heat pumps and, since January 2020, gas hybrid heating systems with renewable energies integrated to provide a portion of the heating. In the case of larger installations the Federal Government awards grants, within the framework of the KfW programme 'Renewable Energies – Premium', for the repayment of a portion of low-interest KfW loans. This funding stream is open to large-scale solar thermal installations, biomass heating (and power) plants, large-scale efficient heat pumps, biogas pipelines, deep geothermal plants, local heating networks for heat from renewable energies and large heat storage facilities for heat from renewable energies.

Title	Brief description
	In January 2020 the MAP switched from the previous system of providing a fixed amount of support to proportionate financing and support rates were raised by ten percentage points. In order to increase the rate of replacement of oil heating systems, a 'replacement premium' with a funding percentage of up to 45% was integrated into the BAFA component of the MAP. The aim of this premium is to provide an attractive incentive for all heating systems currently using fuel oil to be switched to renewable heat or efficient hybrid gas heating systems with renewable energies integrated to provide a portion of the heating.
Energy Efficiency Incentive Programme (3.2.ii.10.)	The Energy Efficiency Incentive Programme (APEE) boosts the funding under the Market Incentive Programme with additional resources. The APEE is also funding the market introduction of stationary fuel cell heating systems in new and existing buildings. This support takes the form of a grant for stationary fuel cell heating systems with an electrical output of 0.25 to 5.0 kilowatts via the KfW programme 'Energy-efficient construction and renovation – fuel cell grant'.
Support programme for heating optimisation (3.2.ii.11.)	The support programme for heating optimisation is intended to create incentives to replace inefficient heating and hot water circulation pumps with high-efficiency pumps and to optimise existing heating systems by means of hydraulic balancing. The support amounts to up to 30% of the net investment costs. The programme serves as a gateway to the implementation of more comprehensive measures to increase energy efficiency in buildings.
Federal Support for Efficient Buildings (3.2.ii.12.)	Under the revamped Federal Support for Efficient Buildings (BEG) the existing investment support programmes in the area of buildings are being brought together under a single, comprehensive and modernised support offering and their content has been optimised. The following measures are being merged: • Market Incentive Programme (MAP), • Energy-Efficient Construction and Renovation (EBS), • Energy Efficiency Incentive Programme (APEE), • Heating Optimisation (HZO). This makes the funding much more targeted, attractive and even more focused on more ambitious measures, and it substantially simplifies the application procedures. A single application is sufficient for the funding of efficiency measures and renewable energies in renovation or construction projects. Within the BEG, including KfW funding, it is ensured that the investments of other eligible parties can be funded by grants. Implementation of the new BEG is expected to take place in 2020.
Tax support for energy-efficient renovation of buildings (3.2.ii.13.)	Tax support for energy-efficient renovation of buildings was introduced as a key measure in the buildings sector on 1 January 2020. This new instrument complements the existing funding framework for buildings and can be used as an alternative to the investment funding programmes. A tax deduction ensures that as many residential building owners as possible benefit from the measure. Funding is provided for individual renovation measures involving owner-occupied housing which are also considered eligible under the existing building support programmes. A total of 20% of the investment costs can be funded. Funding takes the form of a tax deduction spread over 3 years.
Support for serial renovation (3.2.ii.14.)	The serial renovation approaches developed as part of the pilot projects carried out will be put into practice using a newly launched support programme, with the aim of supporting the industrial pre-production of façade and roof elements and standardised installation of building systems, including the supply of self-generated electricity, in conjunction with new investment and contract models. The aim is to realise high-quality building renovations within shorter time frames.
Energy-efficient urban redevelopment (3.2.ii.15.)	The energy-efficient urban redevelopment programme helps conceive and fund extensive measures in the neighbourhood relating to the energy efficiency of buildings and supply infrastructure. The programme was continued as planned in 2020, and new funding measures were developed and existing ones were enhanced. The grant scheme, in particular, now takes greater account of environmentally friendly mobility

Title	Brief description
	concepts, inter-municipal concepts, heating network planning measures in the concepts and in redevelopment management activity, and concepts relating to mixed neighbourhoods.
Expansion of support programmes for heating networks, heat stores and cross-building investments (3.2.ii.16.)	The Federal Government is planning to bundle support programmes for heating networks, heat stores and cross-building investments that supply buildings, installations or processes with heating or cooling from renewable energies into one new funding pillar.
Further development of the Future of Construction innovation programme (3.2.ii.17.)	The Future of Construction innovation programme actively funds climate protection, energy and resource efficiency, affordable construction, quality of design in the construction (urban planning) context and the management of demographic change. The emphasis is placed on knowledge building and knowledge transfer in relation to technical, architectural and organisational innovations. The innovation programme continues the Future of Construction research initiative launched in 2006.
Energy Transition Construction (3.2.ii.18.)	The Energy Transition Construction research initiative brings together the broad range of research funding topics in the buildings sector and serves to improve the realisation of energy innovations through targeted research communication. It is a core element of the 7th energy research programme and interweaves the content of the research fields of energy-optimised and climate-neutral buildings, energy transition in the neighbourhood, heating and cooling supply, thermal energy storage and the funding initiative for energy efficiency in buildings (EnEff.Gebäude.2050). This funding initiative funds lighthouse projects that, using innovative technologies and concepts, demonstrate solutions for climate-neutral buildings and neighbourhoods that have a broad impact, driving forward market introduction or widespread implementation.
Example-setting role of federal buildings (3.2.ii.19. and 3.2.iv.4.)	Federal Government buildings must set an example in terms of energy efficiency, climate protection and sustainable construction for the entire building stock and demonstrate that climate policy objectives can be achieved in harmony with the cost-effectiveness and functionality of construction measures. New Federal Government buildings are to meet at least EH 40 from 2022 onwards. Similar objectives are to be developed for special uses. As a second step, mandatory renovation targets for 2030 and 2050 are also specified for the existing Federal Government building stock in this decree. To this end, it will be necessary for all new major renovation and modernisation projects to be based on at least the EH 55 standard from a date yet to be defined. Similar objectives must be developed for special buildings, and exceptional situations (listed buildings, etc.) must be taken into account.
Further development of urban development support (3.2.ii.20.)	The urban development support (StBauF) is the Federal Government's most successful urban development policy instrument. Since 1971, the Federal Government and *Länder* Programme (BLP) has been helping cities and communities to eliminate shortcomings in urban development, thereby strengthening them as business and residential locations for the long term. As part of this, strategies also have to be conceived for solving the challenges of climate change. Therefore, climate protection measures and measures for adapting to climate change were also addressed better during the further development of urban development support in 2020. These will be a mandatory requirement for funding in future and will also be eligible for all sub-programmes of urban development support.
Support for advice on energy-saving contracting within the framework of the EBK (3.2.iii.1.)	As part of the advisory programme relating to energy advice for the non-residential buildings of municipalities / non-profit organisations, a contracting cheque (up to 80% of the net consultancy fee) is provided for municipalities and non-profit organisations. A qualified energy consultant examines whether and how the measures proposed in a previous energy audit (also funded) or consultation (renovation roadmap) can be implemented using an appropriate contracting model. The aim is to draw the attention of municipalities to the often unfamiliar possibilities of different contracting models, encouraging greater use of energy-saving contracting in particular.

Title	Brief description
Federal Government / federal state dialogue on contracting (3.2.iii.2.)	The project will provide a platform for intensive dialogue on energy-saving contracting between representatives of the Federal Government and the federal states. The project aims to remove barriers to the implementation of energy-saving contracting and to build up regional expertise in this area.
Model projects for energy-saving contracting (3.2.iii.3.)	The dialogue between the Federal Government and the federal states in relation to energy-saving contracting (ESC) also involves funding for the practical implementation of around 10–15 ambitious energy-saving contracting model projects in representative properties in municipalities and at federal state level, with the aim of providing a model for the potential of contracting and thus prompting the establishment of a functioning ESC market in Germany.
Information on model contracts and guidelines (3.2.iii.4.)	The website of the Federal Office for Energy Efficiency (BfEE) provides information on contracting model contracts and guidelines on energy-saving contracting available free of charge. This includes offers specifically aimed at public properties or municipalities.
Energy-efficiency and resource-efficiency networks of municipalities (3.2.iii.5.)	Under this support programme, municipalities can join forces to form a network in order to improve their energy and/or resource efficiency. Together they can identify and implement savings opportunities through the support of a network team.
EU Ecodesign Directive – expansion of minimum standards (3.2.iv.2.)	The minimum standards for certain product groups are being expanded in order to regulate the level of efficiency of technologies. The further development of instruments in the direction of a system-based approach is also being encouraged for suitable product groups. Interdisciplinary technologies are particularly relevant for industry.
Ambitious standards for energy label and ecodesign (3.2.iv.3.)	The Federal Government will continue to call for ambitious standards in the European negotiations on product regulations for energy label and ecodesign and, in its dealings with the European Commission, it will press for the inclusion of additional product groups in the regulations.
Energy-efficient procurement by public institutions (3.2.iv.5.)	The biggest consumer of goods and services in Germany is the public sector. In recent years, regulations and laws have been enacted that require and support energy-efficient procurement. The Regulation governing the Award of Public Contracts (VgV), which must be respected by all public contracting authorities in Europe-wide calls for tenders, stipulates, for example, that the highest energy efficiency performance level and, if available, the highest energy efficiency class should be demanded if energy-related goods are procured or if they are essential for the performance of a service. Energy efficiency must also be taken into account as an evaluation criterion when determining the most cost-effective tender. For the award of construction contracts, the VgV contains a provision with the same content for construction. The Federal Office for Energy Efficiency also publishes lists of energy efficiency criteria for various product categories as a supplementary aid for contracting authorities.
Accelerated implementation of measures resulting from energy audit and energy management systems (3.2.iv.6.)	Large companies (non-SMEs) are obliged to carry out energy audits. If companies have introduced an energy management system (EMS) or environmental management system, they are exempt from this obligation. The amendment to the Energy Services Act (EDL-G) introduces mandatory online reporting on the execution of the energy audit. In return, companies receive a management overview, which not only gives them an overall view of their audit report, but also contains helpful further information and examples of best practice.
Support for energy management systems (3.2.iv.7.)	The ‘Federal support for energy efficiency in the economy’ programme funds the acquisition and installation of measuring and control technology and sensors for the monitoring and efficient control of energy flows for integration into an energy management system. Also funded are the acquisition and installation of energy management software and software training for staff by third parties. In addition, the energy advice for SMEs includes subsidised advice on the introduction and maintenance of an energy management system in SMEs.
Supplier list of the Federal Office for Energy Efficiency	The Federal Office for Energy Efficiency maintains a free public list of suppliers of energy services, energy audits and other energy efficiency measures operating throughout

Title	Brief description
(3.2.iv.8.)	Germany. End customers can use the list to search for suppliers of certain energy efficiency services in their local area and compare the suppliers based on various criteria. Suppliers can use the supplier list to present their portfolio of energy services.
SME Initiative Energy Transition and Climate Protection (3.2.iv.13.)	The aim of the SME Initiative Energy Transition and Climate Protection is to familiarise small and medium-sized enterprises with topics relating to energy efficiency improvements and reductions in greenhouse gas emissions. As part of this initiative, trade-specific materials are created for these topics and supplied to the companies. In addition, professional experience relating to practical energy topics is to be exchanged through the organisation of regular energy efficiency get-togethers.
Further development of efficiency networks (3.2.iv.17.)	The establishment of energy efficiency networks is to be promoted. To this end, the Energy Efficiency Networks Initiative will be continued. The aim is to increase the transfer of know-how between companies.
Advice and information (3.2.iv.19.)	Alongside the topic of energy efficiency, companies are to be offered information and advice on the development and exploitation of innovations with a focus on resource efficiency and substitution. The advice should build on the already existing offerings of the Centre for Resource Efficiency and, where possible, be combined with advice on energy efficiency.
Support (3.2.iv.20.)	Financial resources are needed, especially to enable companies to make more comprehensive investments in integrating and boosting resource efficiency within and along the value chains through digitisation and Industry 4.0. This funding is to focus on the use of resource-efficient processes and materials and on resource substitution for lightweight construction.
Further and vocational training (3.2.iv.21.)	Employees require special training to stimulate innovation and to ensure that investments are realised in a suitable manner. This training should build on existing offerings. Advice can be obtained from the established pool of qualified consultants all over Germany.
Energy tax advantages (3.2.iv.22.)	The Federal Government will examine, on a case-by-case basis, to what extent the existing energy tax advantages for fossil fuels can be more closely aligned with the climate policy objectives of the Federal Government.
Communication on energy efficiency (3.2.iv.23.)	The ‘Germany Does It Efficiently’ communication and engagement campaign is being continued and developed further. The emphasis is increasingly being shifted away from general public relations work towards specialist communication and targeted consumer education. The aim is to increase the engagement of energy consumers through a more needs-based and direct approach where possible. In addition, continuous communication throughout Germany on energy transition topics in general and efficiency topics in particular will ensure that consumers receive general information and that this issue maintains a presence in the public domain. The responsible ministries are in charge of communicating the Energy Efficiency Strategy 2050 and any monitoring within the framework of general energy transition communication and the individual measures.
Information and Competence Centre for Sustainable Construction (3.2.iv.24.)	The Information and Competence Centre for Sustainable Construction (IKzB) promotes the transfer of knowledge and dialogue with society as a whole regarding the future of energy-efficient construction.
Franco-German Energy Platform (3.2.vii.1.)	The Franco-German Energy Platform operated by the German Energy Agency (Dena) and the French Agency for Ecological Transition (ADEME) includes two efficiency projects. These projects target, firstly, the preparation and international exchange of best practice in the field of building renovation and, secondly, collaboration to promote energy efficiency in industry. The Franco-German Energy Platform is funded by grants from the BMWi.
Energy Efficiency and Heat from Renewable Energy	With the Energy Efficiency and Heat from Renewable Energy support strategy a comprehensive concept has been devised for funding reform. Advisory and investment

Title	Brief description
support strategy (3.2.viii.1.)	funding programmes relating to energy efficiency and heat from renewable energies are important for the achievement of climate targets. The Federal Government has set aside funding amounting to approximately €4.3 billion a year on average for the next 4 years for such programmes. To boost the effectiveness, efficiency and quality of service of these support programmes, a concept containing recommendations for action relating to the fundamental reorganisation of the programmes was presented in May 2017. These recommendations will be implemented systematically by 2021.
Federal support for energy efficiency in the economy (3.2.viii.2.)	As part of the support strategy, the existing six support programmes for efficiency improvements in the economy have been evaluated and consolidated. The existing funding instruments have been scrutinised, proven elements adopted and necessary optimisations made to increase both the effectiveness and the efficiency of the support. In future, the funding of investments in plant and process optimisation and in renewable process heat technology will be bundled into two programmes: 1. Traditional grants under the 'Federal support for energy efficiency and process heat from renewable energy in the economy – grant and loan' programme with the following modules: Module 1: interdisciplinary technologies; Module 2: process heat from renewable energy; Module 3: measuring and control technology, sensors and energy management software; Module 4: energy-related optimisation of plants and processes; 2. Competitive funding under the 'Federal support for energy efficiency and process heat from renewable energy in the economy – funding competition' programme.
Support for mini-cogeneration plants (3.2.viii.3.)	Until the end of 2020, cogeneration plants up to 20 kW that provide energy in residential and non-residential buildings particularly efficiently will be funded.
Asset Class Energy Efficiency (3.2.viii.4.)	The Asset Class Energy Efficiency (ACE) project develops solutions that make energy efficiency measures more attractive to external financial backers. It tackles the core implementation problems for energy efficiency investments and devises an asset class for energy efficiency. This particularly involves due diligence relating to the standardised evaluation of specific energy efficiency measures, the bundling of energy efficiency projects in order to achieve larger investment volumes, and proposals for adapting the federal funding structure. The devised results and project tools are to be validated in practice and developed further during a second stage so that they become even more widely used.
Energy and Electricity Tax Act (3.2.viii.5.)	Tax relief for the manufacturing sector is intended to prevent companies that compete internationally from being disadvantaged due to high energy levies. In addition to general tax relief of 25% for manufacturing companies and a tax cap with relief of up to 90% for energy-intensive companies, there are also full tax breaks for certain energy-intensive and electricity-intensive processes. The tax cap is only granted if the company operates an energy or environmental management system and the manufacturing industry as a whole achieves the annual target for reducing energy intensity. All the aforementioned tax advantages have been evaluated in terms of their target achievement and necessity. The results are currently being assessed.

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

Table 59: Policies and measures under the energy security dimension

Title	Brief description
Security of supply for residential customers (3.3.i.1.)	Under the Energy Industry Act (EnWG), transmission system operators (TSOs) and distribution system operators (DSOs) must ensure security of supply for residential customers in the measures they take. In particular, if there is a risk of congestion in the gas supply, the network must be operated and capacities, including transit capacities, allocated and planned in such a way that the security of supply for residential custom-

Title	Brief description
	ers is maintained for as long as possible.
Provision of information (3.3.i.2.)	To ensure the gas supply, the TSOs and DSOs are obliged under the EnWG to provide the necessary information to any other operator of gas supply networks that are connected to their own network. The same obligation applies to operators of storage systems.
Bi-directional capacity (3.3.i.3.)	The TSOs are responsible for the creation of permanent bi-directional capacity for gas flows in all cross-border interconnections (in accordance with the European Regulation concerning measures to safeguard the security of gas supply). They must collaborate on this with their neighbouring TSO. Of the 29 border crossing points in total, seven border points currently have bi-directional physical gas flow capacities. These capacities are available permanently.
(Natural gas) storage facilities (3.3.i.4.)	The availability of sufficient storage capacity with a high withdrawal rate is critical to the protection of natural gas supply, especially in the event of supply bottlenecks, and the coverage of seasonal fluctuations in consumption. Underground storage facilities are currently operated commercially in Germany at 51 locations. They are spread almost all over Germany, with a regional concentration in the north-west due to the geological conditions. In line with their obligations to ensure supply, responsibility for the use of commercial storage facilities lies with the traders, who must hold sufficient quantities in the underground storage facilities to safeguard supply to their customers, especially over the cold period and in the event of unexpected supply disruptions.
Gas prevention plan (3.3.i.5.)	The measures to maintain and improve the security of supply in Germany are described in the gas prevention plan. This must be drawn up in accordance with Articles 8 and 9 of the European Regulation concerning measures to safeguard the security of gas supply. The gas prevention plan is based on the results of the risk analysis. This risk analysis is carried out in Germany by the Federal Network Agency together with the BMWi and with support from the gas industry. The prevention plan sets out measures to prevent a natural gas supply bottleneck; these measures meet the infrastructure and supply standard, reduce the likelihood of supply crises occurring, prevent regional supply bottlenecks and increase the ability to withstand supply crises.
'Gas 2030' dialogue process (3.3.i.6.)	The future role of gaseous energy sources (fossil and renewable) up to 2030 is being discussed with stakeholders from business and society within the Gas 2030 dialogue process. A report containing the initial findings was presented in October 2019. The dialogue process has shown that natural gas will remain an important component of the energy supply system in the short and medium term.
Future role of renewable gases and National Hydrogen Strategy (3.3.i.7.)	Hydrogen technologies and alternative energy sources based on them are an integral component of the energy transition and contribute to its success. Germany has adopted a National Hydrogen Strategy, which incorporates an action plan for boosting the market uptake of hydrogen technologies.
Energy Security Act – Natural Gas (3.3.i.8.)	The instruments available under the Energy Security Act (EnSiG), in combination with the Regulation on the Security of the Gas Supply in a Supply Crisis (GasSV), are only used in an emergency to ensure that the essential need for natural gas is met in the event of an immediate risk or disruption to the supply of natural gas, where this risk or disruption cannot be eliminated, or cannot be eliminated promptly or only through disproportionate means, using market-based measures. Essential needs also include the need to fulfil public tasks and meet international obligations defined in the EnSiG. The instruments of the EnSiG will become effective if the Federal Government establishes, by means of a legal regulation, that a risk or disruption to the energy supply exists.
Regulation on the Security of the Gas Supply in a Supply Crisis (GasSV) (3.3.i.9.)	The GasSV regulates the transfer of the gas load distribution to the relevant government authorities on the basis of the EnSiG in an emergency only. If the emergency is established by the Federal Government by means of a legal regulation pursuant to the EnSiG, the Federal Network Agency can issue orders as the load distributor and intervene in the market if such intervention is in the national interest, if electricity and gas concerns must be balanced or if gas storage facilities and other gas supply facilities of national importance must be used.

Title	Brief description
	Orders under Section 1 of the GasSV may concern the following measures and instructions: • increased gas storage, substitution of natural gas with petroleum, substitution of natural gas with other • fuels, use of electricity that is not generated with gas, restriction of electricity production in • gas-fired power plants, increase in the production level of natural gas, regulation of heating of • public buildings, restriction of cross-border gas flows, enforced use of • stocks of alternative fuels and other instructions for end consumers, • large consumers or industrial customers.
Possible measures within the framework of orders pursuant to Section 1 of the GasSV (3.3.i.10.)	Orders under the GasSV may concern the following measures and instructions: increased gas storage, substitution of natural gas with petroleum, substitution of natural gas with other fuels, use of electricity that is not generated with gas, restriction of electricity production in gas-fired power plants, increase in the production level of natural gas, regulation of heating of public buildings, restriction of cross-border gas flows, enforced use of stocks of alternative fuels and other instructions for end consumers, large consumers or industrial customers.
Gas emergency plan (3.3.i.12.)	The measures listed above to remedy or mitigate the consequences of a disruption to the natural gas supply are described in the gas emergency plan for the Federal Republic of Germany.
Energy Security Act – Petroleum (3.3.i.13.)	The scope of the Energy Security Act (EnSiG) covers petroleum and petroleum products. Stipulations relating to the production, transport, storage, distribution and purchase of energy sources, including mineral oil, may be issued by legal regulation. In particular, any measures that restrict consumption may be arranged, e.g, from speed limits or driving bans through to possible rationing of the mineral oil supply. In the event of oil supply disruptions that market participants cannot absorb on their own, or cannot do so in the short term, the release of oil reserves under the Petroleum Stockholding Act (ErdölBevG) is the first and primary instrument.
Petroleum Stockholding Act (3.3.i.14.)	Since 1966, there has been a legal obligation in Germany to maintain a stock of petroleum and petroleum products. This was introduced with the aim of securing the energy supply against at least short-term interruptions to the flow of petroleum imports in view of the growing dependency on such imports. The Petroleum Stockholding Act (ErdölBevG) has been amended several times since then, not least because of European requirements and international developments. The German National Petroleum Stockpiling Agency (EBV) was set up under the law as a federal public corporation headquartered in Hamburg and placed in charge of the stockpiling. In the event of a supply crisis, the BMWi will issue a release order for the EBV's stocks to compensate for the loss of supply.
Mineral Oil Data Act (3.3.i.15.)	The Mineral Oil Data Act (MinÖlDatG) provides the legal basis for the collection of mineral oil data from all the major companies trading in mineral oil. The mineral oil data form the basis for the regular monitoring of the German mineral oil supply, but also for emergency measures. To this end, the BAFA collects mineral oil data on imports and exports, stocks and domestic sales of crude oil and mineral oil products from the reporting companies on a monthly basis.
Fuel Oil Supply Restrictions Regulation (3.3.i.18.)	The Fuel Oil Supply Restrictions Regulation (HeizölLBV) regulates any possible rationing of light fuel oil on the basis of a reference quantity for a previous period. The basis for this is the Energy Security Act and the Federal Government's finding that the energy supply has been disrupted.
Mineral Oil Equalisation Regulation (3.3.i.19.)	The Mineral Oil Equalisation Regulation (MinölAV) enables an equalisation of supply between over-supplied and under-supplied companies in the oil industry. The aim is to maintain market structures as far as possible and to supply the mineral oil at market prices. The regulation may be applied accordingly to fulfil international obligations under the International Energy Programme of the International Energy Agency. The legal

Title	Brief description
	basis is the Energy Security Act and the Federal Government's finding that the energy supply has been disrupted.
Mineral Oil Management Regulation (3.3.i.20.)	The Mineral Oil Management Regulation (MinölBewV) regulates a possible rationing of motor and heating fuels and their production, distribution and use for the benefit of the population and the armed forces.
National Emergency Strategy Organisation (3.3.i.21.)	The National Emergency Strategy Organisation (NESO) brings together the authorities, institutions and companies that, in the event of an oil crisis, are actively involved in assessing it, deciding on response measures and implementing such measures. The NESO is sustained by close collaboration between the authorities and businesses, including their associations. The NESO manual, which contains crisis management instructions, has just been revised.
Solidarity between EU Member States within the framework of the SoS Regulation (3.3.i.11. and 3.3.ii.1.)	In the context of crisis preparedness, regional structures will be tremendously important in the future alongside national structures. With the revised European Regulation concerning measures to safeguard the security of gas supply, provisions on solidarity among EU Member States have been introduced for the first time at European level to ensure the security of gas supply in extreme situations. Germany is pursuing the goal of developing a solidarity mechanism that will enable rapid and effective support for distressed Member States in a gas supply crisis. The contribution of market-based measures to combat a gas crisis is to be strengthened in order to exploit the potential for voluntary demand-side responses by market participants in crisis management as much as possible. The development of a robust compensation scheme is intended to ensure planning security and transparency for Member States seeking solidarity and for the market players concerned. An intensive exchange with neighbouring countries in the development of the solidarity mechanism is of primary importance for Germany so that the requirements resulting from the respective national legal framework can be identified and considered.
Gas Coordination Group (3.3.ii.2.)	In line with the European Regulation concerning measures to safeguard the security of gas supply, the Gas Coordination Group serves as a platform for all security-of-supply matters. It is to be used in the event of a disruption to the supply of natural gas.
Prevention and emergency plan consultations (3.3.ii.3.)	Within the framework of crisis preparedness under the SOS Regulation, not only will national risk analyses be required in the future, but also national risk prevention plans and national risk emergency plans. Corresponding consultations will be conducted with the competent authorities of all neighbouring EU countries, plus Italy, Sweden, Switzerland and Slovakia.
Pentalateral Gas Forum (3.3.ii.5.)	Since 2009, the five countries of Belgium, Luxembourg, the Netherlands, France and Germany have been engaged in dialogue about safeguarding gas supply and about topical gas issues. The Netherlands had already announced years ago that it would reduce funding for low-caloric gas or L-gas. As a result, exports of L-gas to Belgium, France and Germany would also be reduced. For this reason, market space conversions, in which gas appliances are converted to higher-caloric gas, have been initiated in France, Belgium and Germany.
Cooperation in regional groups within the framework of the trans-European energy networks – gas (3.3.ii.6.)	In the area of gas infrastructure and within the framework of the Trans-European Networks for Energy (TEN-E) regional groups, there are four priority energy infrastructure corridors in which Germany is listed as a concerned Member State and therefore as a member of the corresponding regional group. These include the Baltic Energy Market Interconnection Plan (BEMIP) in gas, the North South Interconnection (NSI) East Gas, the NSI West Gas and the Southern Gas Corridor.
Cooperation in regional groups within the framework of the trans-European energy networks – oil (3.3.ii.7.)	In the area of oil infrastructure and within the framework of the TEN-E regional groups, there is also an energy infrastructure corridor for oil, the Oil Supply Connections in Central Eastern Europe (OSC), in which Germany is involved as a member.
Annual Coordinating Meet-	Within the framework of the Annual Coordinating Meeting of Entity Stockholders

Title	Brief description
ing of Entity Stockholders (3.3.ii.8.)	(ACOMES), petroleum stockpile associations are organised. These get together once a year to discuss concrete, specific topics and new developments.

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

Table 60: Policies and measures under the internal energy market dimension

Title	Brief description
Fee-based incentives and incentive regulation (3.4.2.i.6.)	The aim of the incentive regulation is to encourage network operators to behave in a competitive manner and to prevent excessive returns ('monopolistic returns'). The regulatory framework provides that network operators can only use network charges to refinance costs that would be incurred with efficient network management. The incentive regulation therefore targets cost efficiency among electricity and gas network operators as monopoly suppliers and a limitation of the network costs in the interests of all industrial, commercial and residential customers.
Network development plan – gas (3.4.2.i.7.)	Under the EnWG, the TSOs are obliged to work together to devise the network development plan every 2 years. This must include all the effective network technology measures necessary to optimise, strengthen and expand the network as required, to ensure security of supply and to operate the network safely and reliably over the next 10 years. The DSOs provide the information required for this. This plan becomes binding for the TSOs once it has been examined by the Federal Network Agency.
Monitoring of gas network expansion projects (3.4.2.i.8.)	With regard to the expansion of the gas pipeline infrastructure, the TSOs have an obligation under the EnWG to draw up an implementation report every 2 years. This report must contain information on the state of implementation of the most recently published Network Development Plan and the relevant reasons and possible impact in respect of any delays in the implementation of individual projects contained in the plan, e.g. in terms of the provision of capacities. The Federal Network Agency reviews and publishes the implementation report and gives all actual and potential network users the opportunity to comment.
Gradual reduction and phase-out of coal-fired electricity generation based on the recommendations of the Commission on Growth, Structural Change and Employment (3.4.3.i.1.)	At the beginning of 2019 the Commission on Growth, Structural Change and Employment (KWSB) presented extensive recommendations relating to how the gradual phase-out of coal-fired electricity generation could be implemented and financed in a socially acceptable way in accordance with the climate targets. The installed generation capacity from coal-fired power plants is to be reduced steadily such that the output of the power plants in the market is around 15 GW of brown coal and 15 GW of hard coal in 2022, no more than 9 GW of brown coal and 8 GW of hard coal in 2030, and 0 GW by the end of 2038 at the latest.
Sector coupling (3.4.3.i.2.)	Sector coupling, i.e. the efficient, direct and indirect use of electricity from renewable energies, is to be promoted in order to replace fossil fuels in the areas of heating, industry and transport. To this end, steps should be taken to examine how barriers to sector coupling could be removed. This will be supported by programmes and demonstration projects, such as for cost-effective and quickly realisable options to expand the charging infrastructure or efficient heating networks that use renewable energies.
Utilisation Before Limitation measure (3.4.3.ii.7.)	Under the Utilisation Before Limitation measure, CHP installations undertake, pursuant to the EnWG, to reduce the feed-in of CHP electricity vis-à-vis the transmission system operators in network expansion areas that are particularly vulnerable to bottlenecks if a bottleneck occurs in the transmission network and to generate the necessary heating using a power-to-heat (PtH) installation.
Flexible CHP installations as a transitional technology (3.4.3.ii.8.)	From today's perspective, new and modernised CHP installations can make an important contribution to reducing greenhouse gas emissions by 2030 and also play a role after that. To do this, they must cut emissions in the electricity and heating market and respond flexibly to the fluctuating feed-in of renewable energies. The BMWi wants to create pilot projects for CHP installations and is therefore soliciting projects for innova-

Title	Brief description
	tive CHP systems.
Protection of energy consumers (3.4.3.iv.1.)	There are a variety of measures to protect consumers in Germany. For example, the existing transparency requirements are worth mentioning here, as is the opportunity for consumers to call the energy ombudsman *Schlichtungsstelle Energie* to resolve disputes regarding connection to the supply network, energy supply and energy measurement out of court if necessary. In addition, since July 2017, the nationwide energy market watchdog *Marktwächter Energie* has been funded by the Federal Ministry of Justice and Consumer Protection.
Basic and auxiliary supply concept (3.4.3.iv.2.)	The existing basic and auxiliary supply concept is designed to protect residential customers. This ensures that, in principle, every residential customer has a legal right to be supplied with electricity or natural gas by the respective utility company on the basis of its published general conditions and general prices. The basic and auxiliary supply of electricity and/or gas to residential customers is regulated by law under the Basic Electricity Supply Regulation (StromGVV) and the Basic Gas Supply Regulation (GasGVV).
Changes to housing allowance, tenancy law and energy law (3.4.3.iv.5.)	To avoid social hardship resulting from rising heating costs (due to carbon pricing), housing allowance recipients will be supported by a 10% increase in the housing allowance budget. Changes to tenancy law and energy law will also be examined that provide for the limited passing on of carbon pricing. This will lead to a double incentive effect: it should encourage tenants to act in an energy-efficient way and landlords to invest in climate-friendly heating systems and/or energy-efficient renovations.
Transfer payments (3.4.3.iv.6.)	Increased energy costs are already taken into account with transfer payments according to established procedures.
Accompanying structural policy measures in connection with the gradual reduction and phase-out of coal-fired electricity generation (3.4.3.iv.7.)	At the beginning of 2019 the Commission on Growth, Structural Change and Employment (KWSB) presented extensive recommendations relating to how the gradual phase-out of coal-fired electricity generation could be implemented and financed in a socially acceptable way in accordance with the climate targets. The installed generation capacity from coal-fired power plants is to be reduced steadily such that the output of the power plants in the market is around 15 GW of brown coal and 15 GW of hard coal in 2022, no more than 9 GW of brown coal and 8 GW of hard coal in 2030, and 0 GW by the end of 2038 at the latest. The KWSB's recommendations include a social consensus on how coal can be phased out by 2038 at the latest. In May 2019, the cornerstones for the implementation of the KWSB's structural policy recommendations were adopted by the Federal Cabinet. In August 2019, the Federal Cabinet adopted the bill for a Structural Reinforcement Act for Mining Regions (StStG). This Structural Reinforcement Act is another important step towards enabling funds to be channelled and concrete projects to be realised. To support the structural change, the brown coal regions will receive financial assistance of up to €14 billion for particularly significant investments up to 2038.
Market master data register (3.4.3.v.3.)	The market master data register of the Federal Network Agency collects the master data of all grid-based energy supply installations in the electricity and gas markets in Germany and of market players in the form of a uniform online database. The legal basis for the market master data register is the Market Master Data Register Regulation (MaStRV).
Smart Meters Operation Act (3.4.3.v.4.)	In Germany, the Smart Meters Operation Act (MsbG) has formed the legal framework for the installation and operation of smart metering systems to measure electricity and gas consumption since 2016. The MsbG prescribes the roll-out of devices with a certificate from the Federal Office for Information Security that guarantees IT security and privacy by design.
Smart Border Initiative (3.4.3.vi.4.)	Within the framework of the Franco-German Energy Platform, the energy agencies Dena, on the German side, and ADEME, on the French side, are working on the implementation of a project designed to showcase system integration in the form of a cross-border Smart Grid. The aim of this Smart Border Initiative is, in particular, to optimise the management of the distribution networks in the Saarland-Lothringen region using a virtual management tool and a new physical connection at distribution network

Title	Brief description
	level. The planned Smart Grid ('Module 1') will also have interfaces and additional modules in the area of electromobility ('Module 2') and heating / energy efficiency ('Module 3').

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

Table 61: Policies and measures under the research, innovation and competitiveness dimension

Title	Brief description
7th Energy Research Programme of the Federal Government (3.5.i.1. and 3.5.iii.1.)	The 7th Energy Research Programme of the Federal Government was adopted by the Federal Cabinet in September 2018. The programme covers five main topics: (1) Energy transition in the consumption sectors: buildings and neighbourhoods, industry, trade, commerce, services, mobility and transport. In accordance with the 'efficiency first' principle, the project support focuses on efficient energy use and reducing consumption. (2) Energy generation: alongside the main topics of wind and solar energy, other renewable energy generation technologies and low-emission thermal power plants play an important role. (3) System integration: here the focus is placed on grids, storage facilities and sector coupling as new research areas. As part of the planned National Hydrogen Strategy, the Federal Government will also focus on energy research. The efficient and economical storage of renewable energies is a key research objective. (4) Cross-system research topics: these include energy systems analysis, energy-relevant aspects of digitisation, resource efficiency, CO_2 technologies and materials research, as well as social aspects. (5) Nuclear safety research is conducted against the background of withdrawal from the use of nuclear energy. Improving and accelerating the technology and innovation transfer is a particular focus of this programme. With this in mind, 'energy transition living labs' are being set up and financially supported as a new pillar of research funding.
Finance and climate protection (3.5.i.3.)	This measure is all about building the competence of a strong and action-capable research community in Germany in the field of finance and climate protection. Building on the BMBF funding measure 'Economics of Climate Change', topical issues and debates will be taken up and concrete topics and research questions will be identified in a joint process involving science, real economy, financial economy and politics. These will then be addressed using BMBF funding in broad-based research associations and accompanying networking and dialogue activities in the medium to long term. This measure is to be realised in a staggered manner in various components.
Future of Construction initiative's model project for experimental construction (3.5.i.6.)	The Future of Construction research funding has been supplemented with a model project for experimental construction. Technical, architectural and organisational innovations for future-oriented and affordable construction will be tested in practice and their incorporation into general planning and construction practice will be supported. In addition to the Energy Transition Construction research initiative and the 'energy transition living labs' measure, the model project for experimental construction extends the focus to the entire life cycle of buildings and to topics like resource and space efficiency, sufficiency, generational equity, and environmental and health protection.
'Solar Construction / Energy-Efficient City' support initiative (3.5.i.7.)	As part of the 'Solar Construction / Energy-Efficient City' research initiative, the BMWi and BMBF are funding the energy transition in buildings and neighbourhoods. The focus here is on the efficient, systemic, cross-sectoral supply of energy to neighbourhoods on the basis of renewable energies. The lighthouse projects address areas with existing stock, renovations and new constructions. This initiative, launched in mid-2017, has a funding volume totalling €120 million.
EU ETS Innovation Fund:	As part of the European Emissions Trading Scheme, the NER300 programme has

Title	Brief description
further development of the NER300 programme (3.5.i.11.)	existed since 2011; this funds investments in innovative low-carbon demonstration projects in the energy industry. The funding budget is fed by the sale of 300 million EU ETS certificates. The focus of the funding within the NER300 programme is on innovative renewable energy technologies and on carbon capture and storage technology (CCS). The existing programme is being developed further.
Smart Energy Showcases – Digital Agenda for the Energy Transition (3.5.i.13.)	With the Smart Energy Showcases – Digital Agenda for the Energy Transition (SINTEG) programme, solutions to the technical, economic and regulatory challenges of the energy transition are being developed and demonstrated in five large model regions with over 300 companies and other players. The focus is particularly on safe and efficient procedures with mass market capability, innovative technologies and market mechanisms for flexible and smart networks and markets.
Energy Transition Digitisation Act (3.5.i.14.)	The Energy Transition Digitisation Act (GDEW) offers a suitable basis for cross-sector digitisation. To implement this Act, necessary additional measures are being taken, primarily the further development of technical standards and the regulatory framework, e.g. to ensure better integration of renewable energies and flexible loads into the grid.
Greater involvement of start-ups in energy research (3.5.i.16.)	Start-ups often play a crucial role in the development of innovative ideas and solutions to problems. However, the traditional instruments and mechanisms of project funding are hardly tailored to these players. Therefore, the aim is to target start-ups better with new and adapted funding formats within the 7th Energy Research Programme and to increase their involvement in all areas of energy research. To this end, existing barriers are gradually being dismantled: firstly by extending the content of the programme to non-technical innovations related to new technology, and secondly by adapting and accelerating the administrative procedures, by adopting new and more agile project sections and by having a research network networking platform for start-ups.
Digital Innovation Hub for Climate (3.5.i.19.)	This measure involves the initiation and financing of a Digital Innovation Hub for Climate. It focuses on networking between industry, science and politics and on strengthening application-oriented research and development in the area of climate action through exchange regarding digital innovations, the use of digital technologies in climate protection and the development of business models.
Strategic energy technology plan (3.5.ii.1.)	Within the framework of the European strategic energy technology plan (EU SET Plan), Germany is actively involved in the further development of European energy research. Representatives from Germany take part in the working groups on particular topics and formulate strategies for further cooperation on various technologies. The results of the relevant working groups are incorporated into the design and further development of the national funding priorities and have been taken into account in the creation of the 7th energy research programme. The research topics of the SET Plan are addressed in European collaboration, partly via the ‘Berlin Model’ of separate funding applications to the respective national funding bodies and, if appropriate, via joint funding notices.
European Research Area Cofund (3.5.ii.2.)	Germany is pursuing several collaboration projects within the European Research Area (ERA-NET) Cofund, a funding instrument under Horizon 2020 to support partnerships between funding institutions. The specific objective is the strategic coordination of national programmes with the implementation of a joint call for proposals for funding for transnational research and innovation projects. In the area of energy, collaboration projects are currently underway that relate to carbon capture, utilisation and storage (CCUS), geothermal energy, networks and renewable energies.
Greco-German Research Cooperation and Funding of Upcoming Researchers (3.5.ii.5.)	Energy research is one of several pillars of research collaboration between Germany and Greece and has been or will be addressed within the framework of two consecutive bilateral funding notices. Funding is available for projects for the generation, storage and efficient use of renewable energy and for sustainable and efficient heating and cooling.
Franco-German Fellowship Programme (3.5.ii.6.)	With the Make Our Planet Great Again – German Research Initiative (MOPGA–GRI) Fellowship Programme, the Federal Government has established a support programme in parallel to the French initiative of the same name. The aim of the measure is to give renowned researchers and promising junior researchers from abroad the opportunity to

Title	Brief description
	conduct research at German universities and research institutions. Energy research is a particular focus of the initiative, alongside climate and earth system research.
Franco-German Research Funding for a Sustainable European Energy Supply (3.5.ii.7.)	In accordance with the decision by the 19th Franco-German Ministerial Council, a bilateral funding notice was published relating to energy conversion and storage and smart grids. Through joint research projects, innovations have been developed since October 2019 for efficient, affordable and environmentally friendly energy supply based on renewable energies for France, Germany and Europe. Alongside technical aspects, the projects also address the economic and social challenges of the energy transition in Europe within a systemic approach.
EU framework programme for research and innovation – Horizon 2020 (3.5.iii.2.)	No other country is as heavily involved in the EU Framework Programme for Research and Innovation – Horizon 2020 as Germany. Via the National Contact Point for Energy, it supports the participation of German researchers in consortia and their application for EU funding. The information and advisory activities of the National Contact Point help players from the worlds of research and industry to make appropriate use of the comprehensive and complex opportunities of Horizon 2020 relating to energy issues.
'SME-innovative' research funding initiative (3.5.iii.5.)	With SME-innovative, the BMBF offers small and medium-sized enterprises (SMEs) at the forefront of technological progress the opportunity to compete successfully in the market with new products and processes relating to climate action and energy efficiency. This funding initiative is used by SMEs spread throughout Germany. In view of the increased relevance of the topic of climate protection, a concrete reference to the Climate Action Plan 2050 has been added to the revised funding rules in order to engage SMEs even more strongly with this topic.

Source: Federal Ministry for Economic Affairs and Energy (BMWi) (2020)

IV. Annex Part III – Framework data

The **costs of the microeconomic benefits** are determined using a dynamic investment calculation based on the net present value method or the equivalent annual cost method. This results in equivalent total annual costs for the alternative scenarios, which are made up of the equivalent annual cost of the capital-related payment on plants and networks, the operating costs and the energy costs. With regard to the useful heating and cooling supplied, the generation costs are determined. Electricity from electricity-generating technologies is recorded as revenue by calculating the value of the feed-in tariff or electricity purchases avoided, unless such electricity is used within the technological system for heating and cooling. The imputed interest rate used for calculating the net present value and for discounting the increase in energy and costs takes account, at the microeconomic level, of the risk and profit margins from the investor's point of view.

The **benefits at the microeconomic level** are, in particular, the supply of heating, cooling and electricity. In addition, local environmental and health aspects resulting from a reduction in air pollutants or noise emissions can be taken into account.

Just like at the microeconomic level, the **macroeconomic costs** are calculated methodically using the net present value method or the equivalent annual cost method. The calculation includes the economic input data minus any financial subsidies and taxes on sales and energy. In addition, the level of the imputed interest rate is set using a *social discount rate*.

One of the **most important benefits** of using efficient and renewable heating and cooling is the avoidance of environmental damage. The share of environmental damage not included by actors in the economic calculation is referred to as external environmental damage or external costs. The external costs therefore only include negative external effects, which are not internalised by the market. Annex VIII to the EED sets out the external costs both on the cost side and on the benefit side as avoided external costs.

The impact on **jobs** is estimated using the calculated investments and the avoided or additional energy costs under the baseline and alternative scenarios. The impact of the alternative scenarios on the evolution of the gross domestic product and on jobs results from the change on the demand side and from substitution effects between different products. On the supply side, the changes in investments affect the total factor productivity and capital stock. This project does not include its own modelling of these relationships with a macroeconomic model. Instead, it relies on existing studies of the impact of investments on jobs and of the impact on jobs in heating and cooling, as identified with the involvement of researchers. A quantitative estimate of the job effects can therefore be made based on the difference between the baseline scenario and the alternative scenarios. Specific job effects with regard to additional investments in the technological systems are used, as are those due to additional consumption through avoided energy costs. As no comprehensive macroeconomic modelling is carried out here, the results are to be understood as indicative. To this end, the increased and reduced investments are initially allocated to the sectors. For the apportionment of the investments in heating and cooling technologies to the sectors in line with value creation, a transfer module is used that has been applied in previous studies. The specific impact of increased and reduced investments on jobs by sector is also deduced from existing studies.

As an indicator of **energy security**, the avoided or additional energy imports are referenced. For this purpose, the energy sources used are assessed under the scenarios with the share of their import to Germany or Europe.

The extent to which the **competitiveness of companies** can be increased under the alternative scenarios with a greater diffusion of innovative heating and cooling technologies can only be assessed qualitatively within the study. As indicators of competitiveness, the literature assesses the reduction in specific heat generation costs and the market structure via the *Herfindahl-Hirschmann Index* as a measure of market concentration. The potential reduction in the average heat generation costs of individual technologies is mainly derived from technical progress and economies of scale still to be achieved through market growth. The technological systems relevant to the alternative scenarios are discussed qualitatively in the cost-benefit analysis with regard to their innovativeness and potential economies of scale. An assessment of the possible market concentration of companies is possible in an ex-post evaluation based on the observed market structure. **However, this indicator can only be discussed in general terms** for the assessment of the baseline and alternative scenarios.

Framework data

The economic framework data are taken from the framework data paper of the Impact Assessment, as far as possible. The framework data defined in this have been agreed by the responsible departments of the BMWi and BMU and form the basis for the scenario analyses within the NECP and policy scenarios IX or the projection report of the Federal Government. The agreed framework data are documented in a working paper (Öko-Institut et al., 2018) or in an update to the price basis within the 2019 projection report (Repenning et al., 2018). The economic framework data are taken from the framework data paper of the Impact Assessment, as far as possible. The framework data defined in this have been agreed by the responsible departments of the BMWi and BMU and form the basis for the scenario analyses within the NECP and policy scenarios IX or the projection report of the Federal Government. The agreed framework data are documented in a working paper (Öko-Institut et al., 2018) or in an update to the price basis within the 2019 projection report (Repenning et al., 2018).

As no comprehensive scenario modelling is carried out within the scope of this project, the macroeconomic and demographic framework data of the NECP are assumed to be accurate. Therefore, only the framework data and sensitivity parameters that are relevant to an assessment of the alternative scenarios or technological systems are presented below. In particular, a distinction must be made between the microeconomic perspective of different investors (households, energy suppliers, industry) and the macroeconomic perspective. The economic and energy-related framework data include:

- Development of primary energy prices
- Development of prices for greenhouse gas emission allowances (EUA) in the EU ETS
- Development of carbon prices of the national Emissions Trading Scheme from 2026
- Development of retail prices
- Imputed interest rates from a macroeconomic and a microeconomic perspective

The techno-economic properties of the heating and cooling technologies in the technological systems are presented separately in an Excel file in the form of technology profiles. The relevant parameters include:

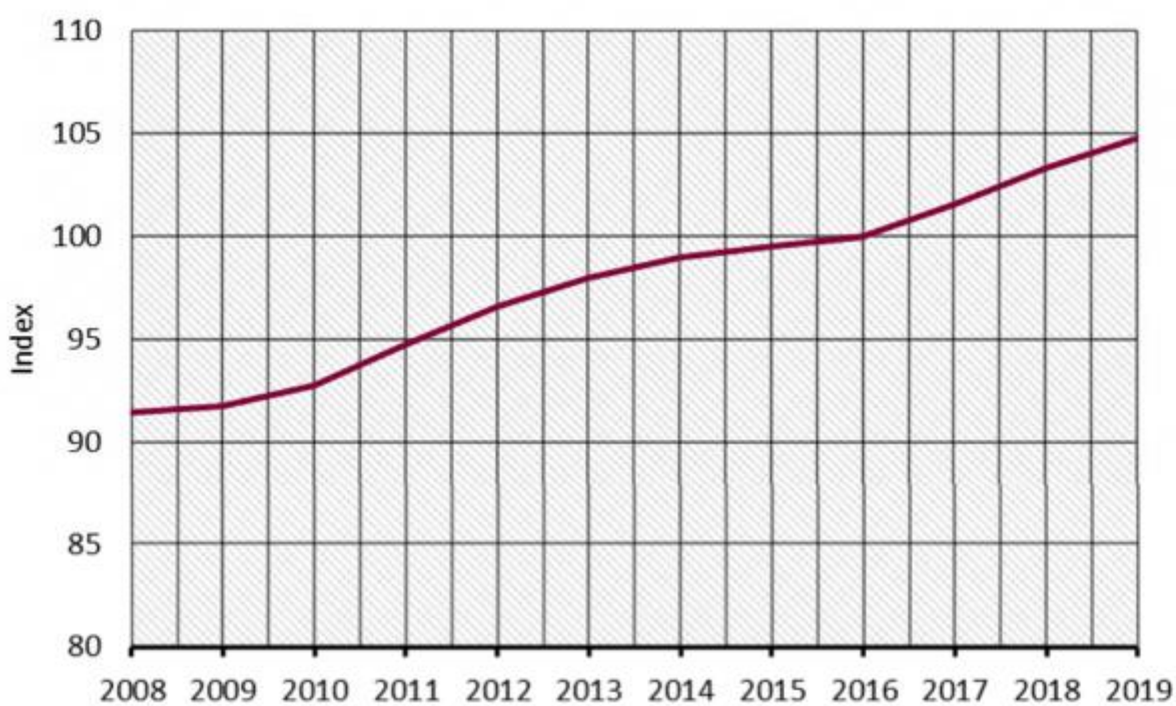
- Brief description of the technology
- Energy source
- Specific investments depending on the installed capacity
- Thermal output range
- Average annual efficiencies
- Technological learning rates

IV.1. Development of energy prices

Base year and price basis

The year 2018 is defined as the base year for the *Comprehensive assessment of the potential for efficient heating and cooling* within the parallel project for the BfEE. In terms of energy statistics and energy use assessments, 2018 represents the latest available data, and this is particularly relevant to Part 1 of the report.

As the price basis for the economic data, the year 2016 is proposed as this also underpins the calculations of the NECP scenario. For the conversion of the nominal prices to a real price basis, the 'cost of living' price index is used (BMWi, 2019).



Source: BMWi energy data

Figure 108: Cost of living price index for conversion to the real price basis

Projection of primary energy and carbon prices

<u>Development of primary energy prices</u>

Table 62 shows the development of primary fossil energy prices as a cross-border price according to the agreed framework data of the Impact Assessment. The increase in retail prices is determined on the basis of this development[62].

Table 62: Development of primary fossil energy prices

€(2016)/GJ	2020	2025	2030	2035	2040	2045	2050
Natural gas	7.7	8.4	9.1	9.7	10.0	10.3	10.5
Brent crude oil	13.2	15	16.5	17.2	17.8	18.5	19.1

Source: Repenning et al., 2018

Development of prices for greenhouse gas emission allowances

Table 63 shows the development of the certificate prices for European Union Allowances (EUA) from the agreed framework data. These are based on the recommendations of the European Commission relating to the preparation of projections under the *Monitoring Mechanism Regulation* (Repenning et al., 2018). The prices of the 2018 Commission Recommendation have not changed since the last Commission Recommendation in 2016 and therefore no longer fully reflect the actual evolution of the main framework conditions. As a result of the recent reform of the EU ETS, the EUA prices already reached an average level of €24.7 in 2019, thereby already exceeding the price assumptions of the recommendation for 2025. The short-term price effect of the reform is therefore significantly underestimated. The COVID-19 pandemic caused prices to fall again initially to around €20 until May 2020. Further price developments are subject to uncertainties. A particularly major driver is the design of the measures relating to the EU ETS within the framework of the European Green Deal (EGD). To address these uncertainties, sensitivity calculations are carried out in which the resulting energy prices are changed within certain margins in order to see the effect of higher or lower prices on the results.

Table 63: Development of prices for EUA

€(2016)/EUA	2020	2025	2030	2035	2040	2045	2050
ET certificate prices	15.65	23.47	34.94	43.81	52.16	73.02	93.88

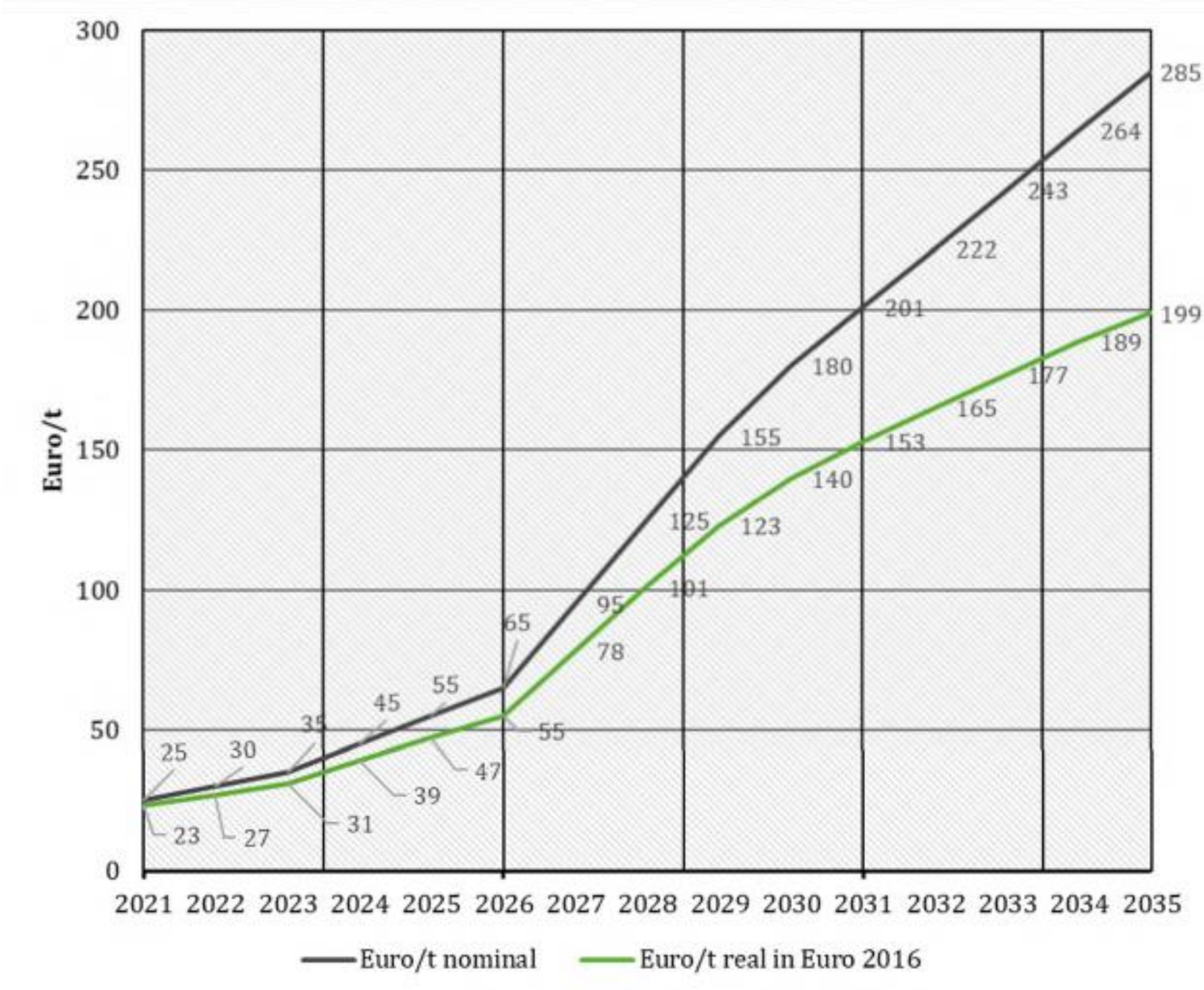
Source: Repenning et al. (2018), Kemmler et al. (2020)

Development of carbon pricing in the national Emissions Trading Scheme (nETS)

With the adoption of the Climate Action Programme 2030, the Federal Government has decided on carbon pricing for the buildings and transport sectors (Bundesregierung, 2019b). Certificates are sold to the distributors of fuels, increasing the prices of fossil fuels. Some of the revenue is used to simultaneously reduce electricity prices by lowering the levy under the Renewable Energy Sources Act (EEG). The national Emissions Trading Scheme will start in 2021 with a fixed price system, which will be raised gradually from €25/t to €55/t in 2025. A price corridor of €55/t

[62] The current coronavirus developments may have a long-term impact on the evolution of energy prices. As our calculations refer to the NECP, the energy prices of the NECP are also used for the cost-benefit analysis. In addition, robust forecasts have yet to be made in relation to such impact. Over the course of the assessments, discussions can be held regarding whether corresponding variations should be carried out within the sensitivity analyses.

to €65/t is earmarked for 2026. For the development from 2026 onwards, the assumptions of the NECP scenarios are used, which are presented in Figure 109.



Source: PROGNOS input data set in Kemmler et al. (2020)

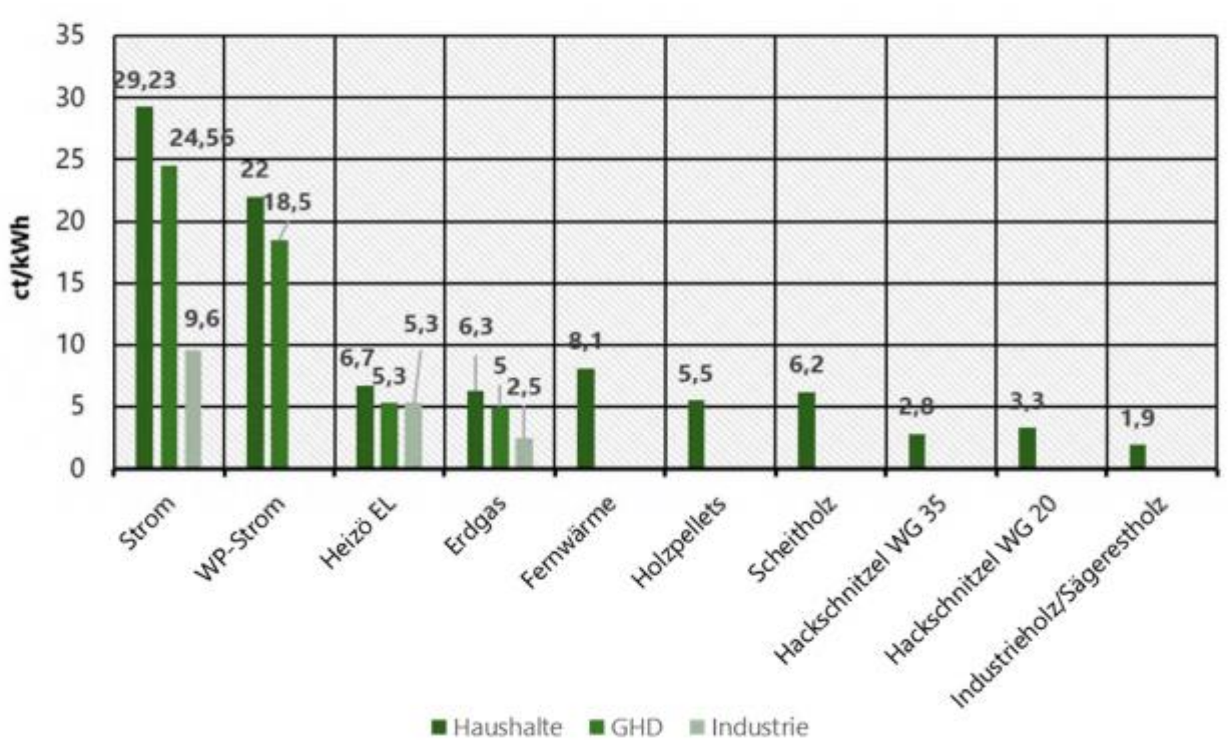
Figure 109: Assumed development of carbon pricing in the national Emissions Trading Scheme

Projections of retail prices

For energy prices at retail level, the actual market prices for 2018 are used as the basis. For the development up to 2050, the price rises are derived from the illustrated development of the primary energy prices, taking into account the additional burden or relief due to changed political price components (carbon pricing).

Energy prices for the base year

Figure 110 shows the energy prices for 2018 as the base year. At the microeconomic level, the prices are calculated taking into account the corresponding energy price increases with the assessment of the individual technological systems for the respective investors.



Strom	Electricity
WP-Strom	Electric HP
Heizö EL	EL fuel oil
Erdgas	Natural gas
Fernwärme	District heating
Holzpellets	Wood pellets
Scheitholz	Firewood
Hackschnitzel WG 35	Wood chips MC 35
Hackschnitzel WG 20	Wood chips MC 20
Industrieholz/Sägerestholz	Industrial wood / sawmill waste
Haushalte	Households
GHD	TCS
Industrie	Industry

Source: BMWi, 2019; C.A.R.M.E.N., 2015; C.A.R.M.E.N., 2020; TFZ, 2020, own calculation as part of the projection report

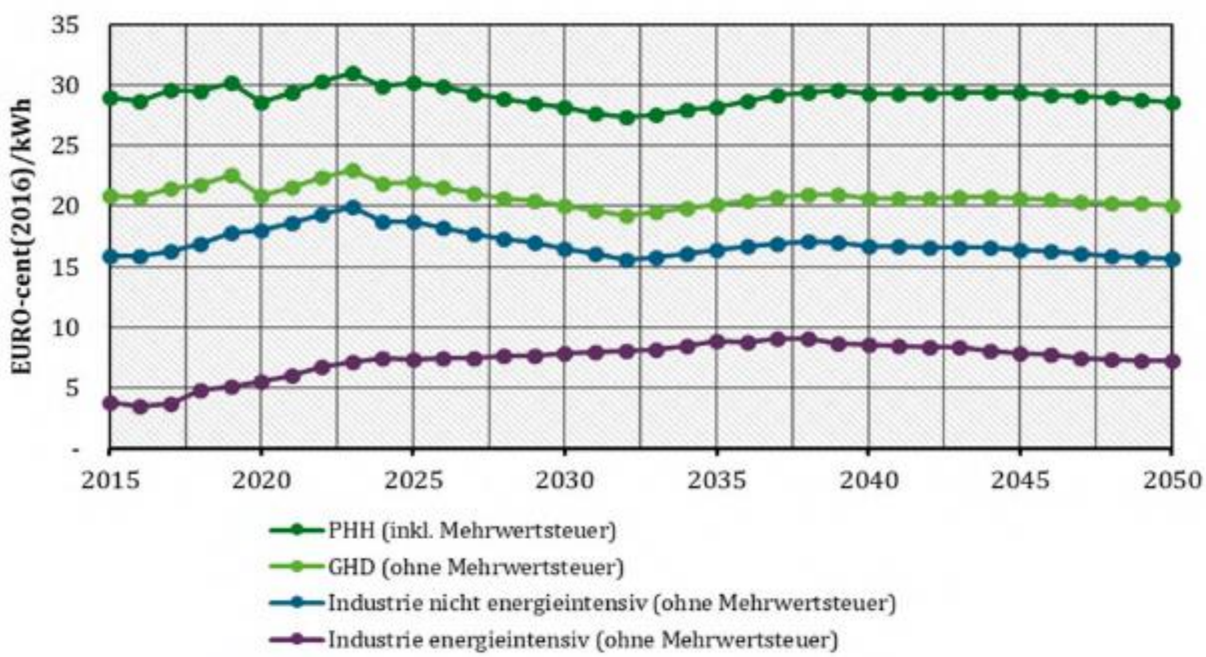
*Heat pump tariff corresponds to regular electricity tariff minus network charges

Figure 110: Energy prices of households in 2018 based on real 2016 prices

At the macroeconomic level, prices are calculated without taxes and levies. For this purpose, energy and electricity taxes are excluded. For households, VAT must also be deducted.

Development of retail prices

Figure 111 shows the development of electricity prices at retail price levels, as incorporated into the modelling of the NECP scenarios on the basis of the agreed framework data.



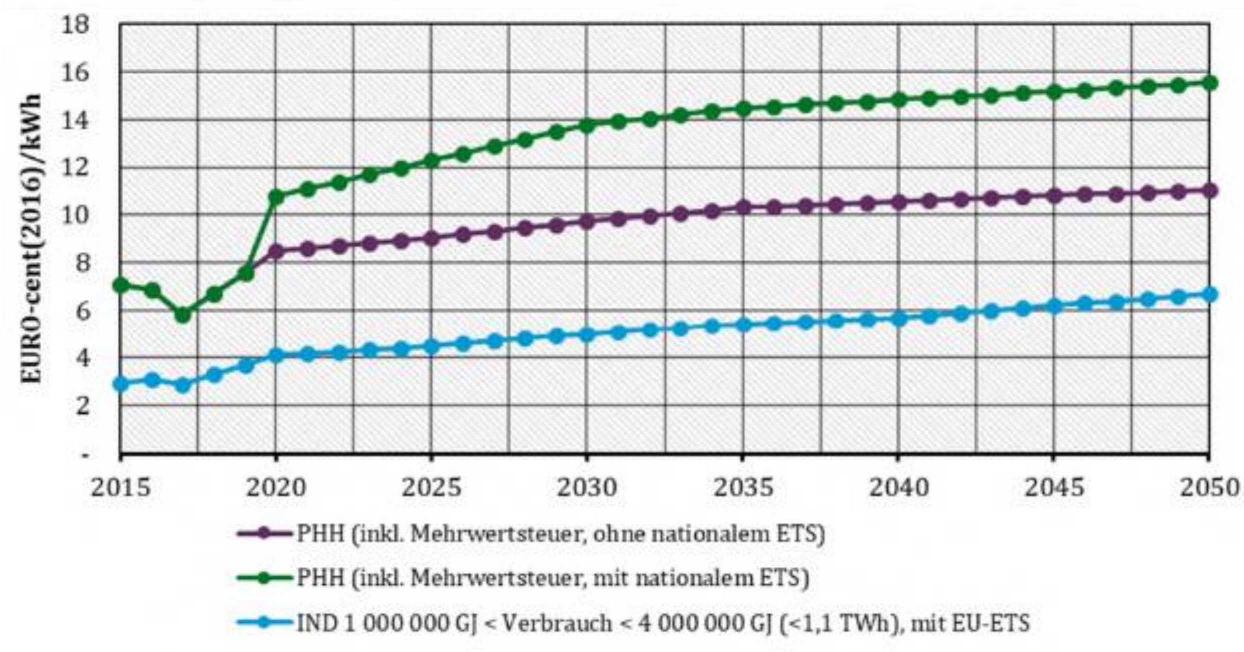
PHH (inkl. Mehrwertsteuer)	PHH (incl. VAT)
GHD (ohne Mehrwertsteuer)	TCS (excl. VAT)
Industrie nicht energieintensiv (ohne Mehrwertsteuer)	Non-energy-intensive industry (excl. VAT)
Industrie energieintensiv (ohne Mehrwertsteuer)	Energy-intensive industry (excl. VAT)

Source: PROGNOS input data set in Kemmler et al. (2020)

Figure 111: Development of electricity retail prices from the NECP Climate Action Programme scenario

Figure 112 shows the assumed development of retail prices for gas. For households, this development is also presented without carbon pricing from the national ETS. The prices take account of the withdrawal from coal in accordance with the Coal Phase-Out Act (KAG) and the depletion of the EEG levy[63].

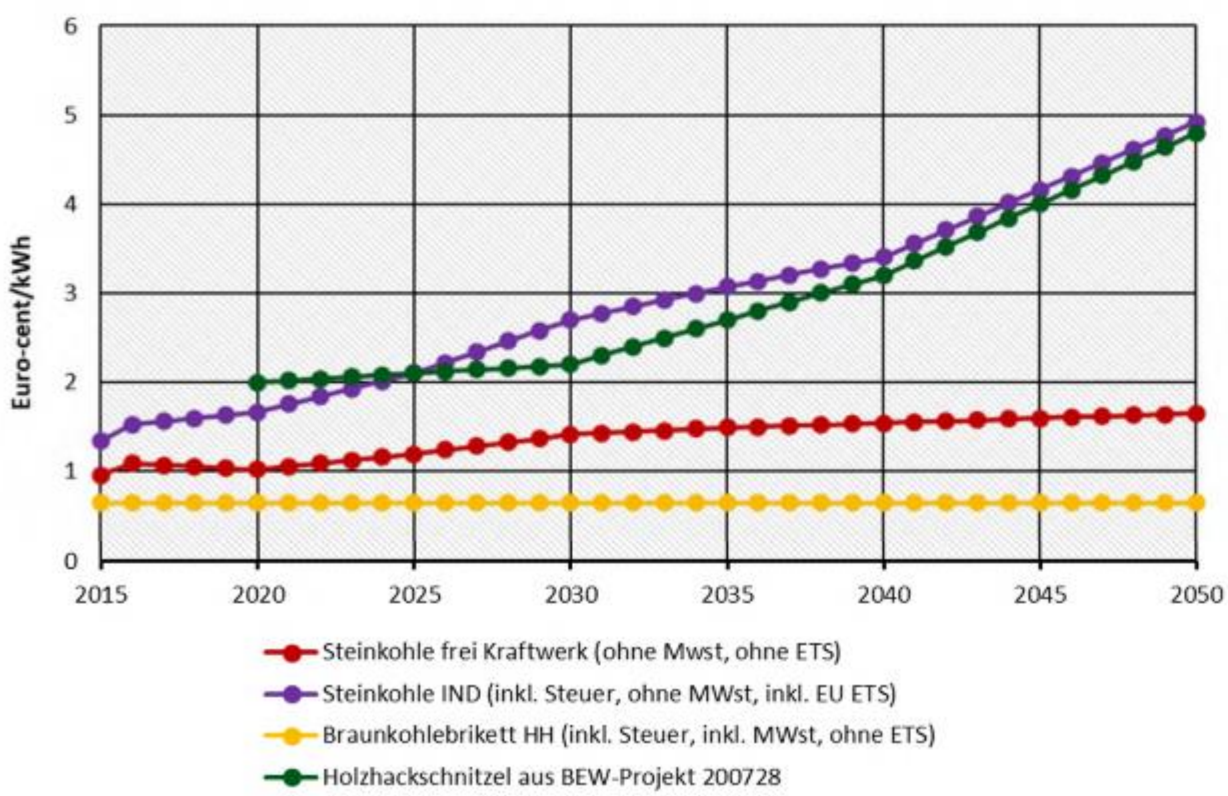
[63] The coronavirus stimulus package is not taken into account due to the timing of the analyses.



PHH (inkl. Mehrwertsteuer, ohne nationalem ETS)	PHH (incl. VAT, excl. national ETS)
PHH (inkl. Mehrwertsteuer, mit nationalem ETS)	PHH (incl. VAT, with national ETS)
IND 1 000 000 GJ < Verbrauch < 4 000 000 GJ (<1,1 TWh), mit EU-ETS	IND 1,000,000 GJ < consumption < 4,000,000 GJ (<1.1 TWh), with EU ETS

Source: PROGNOS input data set in Kemmler et al. (2020)

Figure 112: Development of gas retail prices from the NECP Climate Action Programme scenario



Steinkohle frei Kraftwerk (ohne Mwst, ohne ETS)	Hard coal DDP power plant (excl. VAT, excl. ETS)
Steinkohle IND (inkl. Steuer, ohne MWst, inkl. EU ETS)	Hard coal IND (incl. taxes, excl. VAT, incl. EU ETS)
Braunkohlebrikett HH (inkl. Steuer, inkl. MWst, ohne ETS)	Brown coal briquette HH (incl. taxes, incl. VAT, excl. ETS)
Holzhackschnitzel aus BEW-Projekt 200728	Wood chips from BEW Project 200728

Source: PROGNOS input data set in Kemmler et al. (2020); Federal Programme for Efficient Heating Networks (BEW, not yet published)

Figure 113: Development of prices for solid fuels (coal and wood chips)

IV.2. Macroeconomic and microeconomic discount rate

Macroeconomic perspective

For the macroeconomic perspective, a real **discount rate of 2%** is proposed, which is also defined in the agreed framework data paper for the Impact Assessment as the interest rate for the societal perspective.

This is based on the ‘Economic Valuation of Environmental Damage – Methodological Convention 2.0 for Estimates of Environmental Costs’ of the UBA (UBA, 2012). A distinction is made between short periods up to 20 years and intergenerational periods. Short periods are valued at 3%, while long periods are valued at 1.5%. The defined social discount rate is used for periods with a greater focus on the long-term perspective, which thereby reflects the time preference of a macroeconomic or societal assessment.

Microeconomic perspective

For the microeconomic perspective, a distinction is made, in line with the definition in the guidelines, between investment in *on-sitegeneration technologies* in the areas of residential buildings (households), services and industry and investment in *off-site generation* (energy industry). In contrast to the macroeconomic view, the microeconomic discount rate may include the following aspects (Steinbach & Staniaszek, 2015):

Individual time preference of the investor

- Opportunity costs
- Market price for capital (capital costs)
- Assessment of investment risk

The Comprehensive Assessment of Heating and Cooling from 2014 uses the following discount rates in the cost-benefit analysis (Wünsch et al., 2014):

- Households: 6%
- TCS: 8%
- Industry: 12%

These interest rates seem very high from today's perspective in light of the low cost of funds and low interest rates for alternative investment options. Therefore, even at present, opportunity costs or the market price for raising capital are not the key factors for the level of the discount rates. In addition, the investment in heating and cooling installations is usually a replacement investment that is made because the existing supply system has failed or reached the end of its service life. The alternative of not investing is normally not an option as heating or cooling is a requirement. A flat-rate risk premium is also not relevant for this type of investment as the demand for heating or cooling already exists and will continue to exist in the future. In this respect, the individual time preference of the investor in particular is the decisive aspect for the differentiation of the microeconomic discount rate. The time preference rate indicates the extent to which current consumption is assessed against future consumption. This is therefore a measure of the marginal return expectations for an investment, as foregoing consumption today due to an investment brings future returns. If the rate of return on an investment is higher than the individual time preference rate, the investment is worthwhile from the investor's point of view.

The discount rate for decentralised generation installations in residential buildings (households) is derived on the basis of a period of 20 years, which is the typical service life of technical building equipment. Based on the UBA's methodological convention, **a discount rate of 3%** can be set for this purpose (UBA, 2012). However, a lower discount rate may also be justified in view of the low interest rate level. For example, the 10-year average of the current yield on fixed-income securities is around 1.5% (Deutsche Bundesbank, 2020).

In commerce and industry, on the other hand, higher interest rates are to be expected as, especially in industry, the individual time preference is characterised by shorter payback periods in the assessment of investments. Therefore, an interest rate of **8% is proposed** for industry. For trade, commerce and services, a wide range can be expected in reality in terms of the individual time preference, as this varies according to company size, sector and ownership structure. A discount rate **of 4.5% is proposed** for the cost-benefit analysis.

Long time horizons for investments are to be expected in the energy industry and especially for investments in the infrastructure of heating networks and corresponding generation installations. In the assessment of generation installations in heating networks, the literature uses a real imputed interest rate of 4% (ASUE, 2018; Infrastruktur & Umwelt, 2015; Pehnt et al., 2017). Another approach is offered by the permissible return on equity for electricity and gas network operators as determined by the Federal Network Agency in accordance with the Electricity Network Charges Regulation (StromNEV) and the Gas Network Charges Regulation (GasNEV). The basis for this is a risk-free base interest rate derived from the 10-year average of current yields on fixed-income securities, a risk premium (3.15%) and a corporation tax factor (BNetzA, 2017). In the third regulatory period (2018 to 2022), the pre-tax regulated equity yield rate for new investments is therefore 6.91%. On this basis, with an adjustment for inflation, a real **discount rate of 5.5%** is proposed for investments by actors in the energy industry.

Table 64: Discount rates for the microeconomic assessment of the cost-benefit analysis

Sector	**Discount rate**
Decentralised on-site generation	
Residential buildings (households)	3%
Services (TCS)	4.5%
Industry	8%

Sector	**Discount rate**
Off-site generation	
Heating/cooling networks and generation installations (energy industry)	5.5%

IV.3. Assessment of climate damage

Climate damage is assessed at the cost rates defined in the UBA's 'Methodological Convention 3.0 for the Assessment of Environmental Costs' (Matthey & Bünger, 2019). For the assessment of climate damage, a distinction is made according to the time preference rate, which leads to different cost rates. In line with the UBA's recommendation, the time preference rate of 1% is assumed, with which the climate costs for 2016 are valued at €180/t of CO_2eq.[64] These rise to €240/t of CO_2eq by 2050.

As part of this project, alternative scenarios in communities are compared with a reference development in the 2030 target and 2050 outlook. For the assessment of climate damage, the cumulative GHG savings are quantified over the service life of the alternative supply systems compared to the reference. Since expansion modelling involving transformation pathways is not carried out, a year-by-year allocation of avoided GHG emissions is also not possible. The alternative scenarios examined in the 2030 target will be installed between 2020 and 2030. However, over the service life of the installations, GHG savings will also be realised up to 2050 and beyond. Therefore, for the cost rate to be applied, the mean of the values proposed in (Matthey & Bünger, 2019) for 2030 and 2050 is used, which amounts to €222.5/t of CO_2eq.

[64] Real price based on 2016 prices

V. Annex Part III – Technology profiles

The following profiles for heating network technologies are being developed as part of the *Comprehensive assessment of the potential for efficient heating and cooling*:

Heating network technologies:

6. Tank boiler heating plant with natural gas and oil
7. Water-tube boiler heating plant with natural gas, oil, biomass, biogas, waste
8. Resistance boiler and electrode boiler heating plant
9. Direct and indirect use of geothermal energy
10. Solar thermal energy, flat-plate collectors and evacuated-tube collectors
11. Compression, gas and absorption heat pumps
12. CHP steam turbine
13. CHP gas turbine
14. Gas and biogas engine (cogeneration plant)
15. Fuel cell: polymer electrolyte membrane (PEM) fuel cell and solid oxide fuel cell (SOFC)
16. Waste heat: tube bundle heat exchanger and plate heat exchanger
17. Heating networks: stub line and operating costs
18. Heat store: tank thermal energy storage (TTES), pit thermal energy storage (PTES), aquifer thermal energy storage (ATES)
19. District heating building transfer stations

Decentralised technologies

20. Gas-fired condensing boiler
21. Oil-fired condensing boiler
22. Pellet boiler
23. Brine/water heat pump
24. Air/water heat pump
25. Decentralised solar thermal energy

The technology data set out below for each technology includes, in particular, data regarding:

26. Economic parameters (investment, maintenance and operating costs, energy prices and taxes)
27. Technical parameters (output, efficiency, full load hours, service life)
28. Ecological properties (emissions, primary energy demand)

V.1. Tank boiler heating plant

Table 65: Technology profile for tank boiler heating plant

1.1	**Technology**	**Heating plant**
1.2	**Technical term**	**Tank boiler**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	These boilers are divided into a sheath section for the hot exhaust gas and the pipe section in which the water used in the district heating network is heated or evaporated into steam. Based on the temperature of the exhaust gases, these boilers can be further divided into two groups: conventional technology (exhaust gases > 150 °C) and condensing technology (exhaust gases < 55 °C). The condensing technology is approximately 10% more efficient.
1.5	**Field of application / structure**	Tank boilers are highly available in the range of 1 to 20 MW. The most commonly used fuels are natural gas and oil.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	80	300	110	[1]	
2.2	Spec. investments (2030)	€k/MW_{th}	50	250	110	[1]	
2.3	Spec. investments (2050)	€k/MW_{th}	50	250	110	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x)=0.17*x^(-0.15)				

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW_{th}	1	5	3	[1]	
3.2	Fixed costs (2030)	€k/MW_{th}	1	5	3	[1]	
3.3	Fixed costs (2050)	€k/MW_{th}	1	5	2	[1]	
3.4	Variable costs	€/MWh	0.5				

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	25	30	25	[1]	
4.2	Depreciation periods	a			15	[12]	Reference: 3.1.1
4.3	Efficiency thermal	%	85	98	93	[1]	Based on the calorific value

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.2. Water-tube boiler heating plant

Table 66: Technology profile for water-tube boiler heating plant

1.1	**Technology**	**Heating plant**
1.2	**Technical term**	**Water-tube boiler**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	The basic definition of a water-tube boiler is that water in tubes is heated by hot gases or is evaporated into steam.
1.5	**Field of application / structure**	Water-tube boilers are also used for higher thermal outputs of over 20 MWth and, given that there are many different types, these boilers can be designed for almost any fuel or burner system.

	Investment costs	Unit	Low	High	Typical	Sources	Note
2.1	Spec. investments (today)	€k/MW_{th}	50	600	220	[1]	
2.2	Spec. investments (2030)	€k/MW_{th}	50	600	200	[1]	
2.3	Spec. investments (2050)	€k/MW_{th}	50	600	180	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x)=0.27*x^(-0.20)			[1]	Fuel: Natural gas
2.4	Cost function	€m/MW_{th}	Invest(x)=0.28*x^(-0.20)			[1]	Fuel: Biogas
2.4	Cost function	€m/MW_{th}	Invest(x)=0.32*x^(-0.20)			[1]	Fuel: Oil
2.4	Cost function	€m/MW_{th}	Invest(x)=0.8*x^(-0.20)			[1]	Fuel: Biomass
2.4	Cost function	€m/MW_{th}	Invest(x)=1.33*x^(-0.20)			[1]	Fuel: Waste

	Operating costs	Unit	Low	High	Typical	Sources	Note
3.1	Fixed costs (today)	€k/MW_{th}	1	20	4	[1]	
3.2	Fixed costs (2030)	€k/MW_{th}	1	20	4	[1]	
3.3	Fixed costs (2050)	€k/MW_{th}	1	15	3	[1]	
3.4	Variable costs	€/MWh	0.2			[1]	

	Property	Unit	Low	High	Typical	Sources	Note
4.1	Technical service life	a	25	50	35	[1]	
4.2	Depreciation periods	a			15	[12]	Reference: 3.1.1
4.3	Efficiency thermal	%	85	96	87	[1]	Fuel: Natural gas
4.4	Efficiency thermal	%	75	93	78	[1]	Fuel: Biogas
4.5	Efficiency thermal	%	75	95	81	[1]	Fuel: Oil
4.6	Efficiency thermal	%	75	95	84	[1]	Fuel: Biomass
4.7	Efficiency thermal	%	75	95	81	[1]	Fuel: Waste

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.3. Electrode and resistance boiler heating plant

Table 67: Technology profile for electrode and resistance boiler heating plant

1.1	**Technology**	**Heating plant**
1.2	**Technical term**	**Electrode and resistance boiler**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	Electric boilers use electrical energy directly to generate thermal energy. Either electric resistance boilers or electrode boilers are used in district heating.
1.5	**Field of application / structure**	Typically, electric resistance boilers are used for small and medium-sized applications, from several kW through to 15 MW. Electrode boilers range from 10 MW to 50 MW.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	60	200	120	[1]	
2.2	Spec. investments (2030)	€k/MW_{th}	60	200	120	[1]	
2.3	Spec. investments (2050)	€k/MW_{th}	60	200	120	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x)=0.20*x^(-0.20)			[1]	

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW_{th}	0.3	0.7	0.5	[1]	
3.2	Fixed costs (2030)	€k/MW_{th}	0.3	0.7	0.5	[1]	
3.3	Fixed costs (2050)	€k/MW_{th}	0.3	0.7	0.5	[1]	
3.4	Variable costs	€/MWh	0.2				

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	20	20	[1]	
4.2	Depreciation period	a			15	[12]	Reference: 3.1.1 / 3.1.9
4.3	Efficiency thermal	%	96	99	98	[1]	

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.4. Geothermal energy

The dynamic Excel tool developed as part of the project can be provided by the project team on request.

V.5. Centralised solar thermal energy

Table 68: Technology profile for centralised solar thermal energy

1.1	**Technology**	**Solar thermal energy**
1.2	**Technical term**	**Flat-plate collector or tube collector**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	The absorber, installed in the collector, converts sunlight into heat. The coating of the absorber plate ensures that a lot of heat is absorbed. Thermal insulation covering the back and sides prevents heat loss. Heat is transported from the collector via the solar fluid (usually water mixed with anti-freeze). Tube collectors have lower heat losses than flat-plate collectors. The absorber surface is located in several vacuum tubes, thereby significantly reducing the heat loss. Several little tubes are connected to the collector circuit via a manifold on the frame of the tube collector.
1.5	**Field of application / structure**	The collector surfaces are installed on free-field sites or integrated into building rooftops. Such installations are called large-scale solar thermal installations. There are different variants: solar-assisted local heating for solar pre-heating, solar-assisted local heating with short-term heat storage and solar-assisted local heating with seasonal heat storage.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€/m2	290	560	430	[1]	
2.2	Spec. investments (2030)	€/m2	270	500	380	[1]	
2.3	Spec. investments (2050)	€/m2	260	450	360	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x)=0.661*x^(-0.165)			[1]	Flat-plate collector
2.5	Cost function	€m/MW_{th}	Invest(x)=0.978*x^(-0.15)			[1]	Tube collector

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€/m2	0.7	3.1	1.8	[1]	
3.2	Fixed costs (2030)	€/m2	0.6	2.6	1.5	[1]	
3.3	Fixed costs (2050)	€/m2	0.6	2.1	1.2	[1]	
3.4	Variable costs	€/MWh					

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	35	25	[1]	
4.2	Depreciation period	a			10	[12]	Reference: 3.1.7
4.3	Efficiency thermal	%	33	43	34	[1]	Flat-plate collector
4.4	Efficiency thermal	%	37	46	37	[1]	Tube collector

5.1	Technological dynamic and/or technological potential	Potential for cutting costs exists, especially in the system (standardisation, project planning, installation, etc.).

V.6. Centralised air/water heat pump

Table 69: Technology profile for centralised air/water heat pump

1.1	**Technology**	**Air/water heat pumps (HP) 3 MW to 10 MW**
1.2	**Technical term**	**Air/water compression heat pump**
1.3	**Centralised or decentralised supply**	**Centralised integration into heating network**
1.4	**Brief description**	A heat pump draws heat from the air; this heat is raised to a desired temperature level and then transferred to inside the building or the heating network. The heat is transferred from the heat source with the help of a refrigerant that vaporises even at low temperatures. A compressor increases the pressure of the refrigerant, thereby heating the refrigerant. The energy then continues to the heating system, and the refrigerant cools down and becomes a liquid again. Electricity, gas or waste heat can be used as the driving energy.
1.5	**Field of application / structure**	With the present technology, large-scale heat pumps currently achieve supply temperatures of about 80 °C. In many cases, this maximum supply temperature is too low for integration into conventional district heating networks. During the winter months, the supply temperatures in district heating networks are generally above 100 °C.

	Specific investment costs	**Unit**	**1 MW**	**3 MW**	**10 MW**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MWth	1,400	950	860	[15]	Price basis is 2015
	Of which for plant and materials	€k/MWth	1,100	760	680		
	Of which for installation	€k/MWth	260	170	140		
	Of which for grid connection	€k/MWth	30	20	20		
2.2	Spec. investments (2030)	€k/MWth	1,300	860	760	[15]	Price basis is 2015
	Of which for plant and materials	€k/MWth	1,000	680	610		
	Of which for installation	€k/MWth	240	150	140		
	Of which for grid connection	€k/MWth	30	20	20		
2.3	Spec. investments (2050)	€k/MWth	1,300	860	760	[15]	Price basis is 2015
2.4	Cost function	€m/MWth	a*ln(x)+b	a	b		Derived from values shown
		€m/MWth		-231.97	1,332.99		
Comment			Valid for 1 MW to 10 MW				

	Operating costs	**Unit**	**1 MW**	**3 MW**	**10 MW**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MWth	2	2	2	[15]	
3.2	Fixed costs (2030)	€k/MWth	2	2	2	[15]	
3.3	Fixed costs (2050)	€k/MWth	2	2	2	[15]	
3.4	Variable costs	€/MWh	2.7	2.2	2.2	[15]	Compression HP
3.5	Start-up costs	€/MW/Start	10	10	10		

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	25	25	25	[15]	

4.2	Depreciation period	a	14	14	14	[12]	Reference: 3.1.8
4.3	Lorenz process efficiency 2020	%	47	53	60	[15]	
4.4	Lorenz process efficiency 2050	%	51	58	62	[15]	
4.5	COP 2020	%	275	311	352		See 6.1. With district heating supply 85 / return 45, heat source 9 °C, DeltaT = 4 °C
4.5	COP 2050	%	299	340	363		

5.1	Technological dynamic and/or technological potential	Increase in efficiency The expected improvement in the efficiency of large-scale air source heat pumps in the range of 1 MW to 10 MW is represented technologically by the increase in 'Lorenz efficiency' by 2050 (see 4.3, 4.4). This efficiency is based on installed and planned systems installed in heating networks, especially in Denmark and Finland. As the overall efficiency depends on the heat sink temperatures, a further increase in the COP can also be expected in future by lowering the average heating network temperatures. The reduction from supply 85 / return 45 to supply 60 / return 35, while maintaining the technological efficiency of the 1 MW heat pump, leads to a rise in the COP from 2.78 to 4.01. Lowering of investment costs Compression heat pumps have the potential to reduce costs. Ideally, in future, the investment costs could be closer to those of equipment for industrial refrigeration. Compression heat pumps on a large scale come from industrial refrigeration technology, using the same principles and many of the same components. However, heat pumps need a higher working pressure, which means that some of the main components require specification and limit the output range. Large-scale heat pumps for high supply temperatures are still rare, so the production volume of certain components is low. Most large-scale heat pumps that are installed in Europe and, in particular, Denmark and Finland as the market leaders are custom-made and always require a considerable technical outlay. This is largely due to the fact that the application is still relatively new. As more and more installations are built, it is expected that the technical processes will be systematised and calculation tools will be developed to ensure quick specification and construction.

6.1	Further comments: calculation of the COP	Larger installations achieve higher efficiency due to the use of more complex system components. With regard to heat pumps with air as a heat source, the smaller installations (1 MW) typically consist of air coolers based on glycol and a single condenser, while larger installations (10 MW) use direct evaporators, multiple condensation stages and more efficient components. For this reason it is possible to achieve higher efficiency levels than those indicated for smaller installations. In practice, however, the investment costs generally outweigh the benefits. With larger installations, optimisation is more profitable. To calculate the COP of the heat pump accurately, the respective field of application must be included. Here, the supply and return temperatures (Tin, sink, Tout, sink) of the heating network and the temperature of the heat source (Tin, source), and the reduction of these temperatures by the heat pump (Tout, source = Tin, source - delta T), are particularly important. The theoretical COP can be calculated as a 'Carnot COP' or 'Lorenz COP', which relates the mechanical work to temperature differences in electricity generation, refrigeration technology and heat pump technology. Carnot considers a single cooling circuit with a condenser and an evaporator and relates the mechanical work to the difference in temperature between the condenser and the evaporator. The Lorenz calculation method is preferred for 'staggered' Carnot cycles in which the heating and/or cooling take place over several steps, which is the case in district heating with a temperature rise of 30-50 K. With such high temperature rises, a heat pump system typically includes several condensers in a series, so the system consists of several Rankine cycles. The Lorenz cycle is preferred over the Carnot cycle in this context as it involves more steps in the cycle. The real COP of the heat pump results from the theoretical Lorenz COP multiplied by the 'Lorenz' efficiency of the respective heat pump.

V.7. Lake source heat pump

Table 70: Technology profile for lake source heat pump

1.1	**Technology**	**Lake source heat pumps (HP) 3 MW to 10 MW**
1.2	**Technical term**	**Water/water compression heat pump**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	A heat pump draws heat from the ground, air or water; this heat is raised to a desired temperature level and then transferred to inside the building or the heating network. The heat is transferred from the heat source with the help of a refrigerant that vaporises even at low temperatures. A compressor increases the pressure of the refrigerant, thereby heating the refrigerant. The energy then continues to the heating system, and the refrigerant cools down and becomes a liquid again. Electricity, gas or waste heat can be used as the driving energy.
1.5	**Field of application / structure**	With the present technology, large-scale heat pumps currently achieve supply temperatures of about 80 °C. In many cases, this maximum supply temperature is too low for integration into conventional district heating networks. During the winter months, the supply temperatures in district heating networks are often over 100 °C. The temperatures presented here relate to a lake source heat pump. In Scandinavia, this heat pump is used particularly with seawater. In Germany, there are initial plans in place for lake source heat pumps in artificial lakes created in former brown coal mining areas.

	Specific investment costs	**Unit**	**20 MW**			**Sources**	**Note**
2.1	Spec. investments (2020)	€k/MWth	480			[15]	Investment in 2020 – price basis is 2015
	Of which for plant and materials	€k/MWth	400				
	Of which for installation	€k/MWth	70				
	Of which for grid connection	€k/MWth	10				
2.2	Spec. investments (2030)	€k/MWth	380			[15]	Price basis is 2015
	Of which for plant and materials	€k/MWth	320				
	Of which for installation	€k/MWth	60				
	Of which for grid connection	€k/MWth	10				
2.3	Spec. investments (2050)	€k/MWth	380			[15]	Price basis is 2015

	Operating costs	**Unit**	**20**			**Sources**	**Note**
3.1	Fixed costs (today)	€k/MWth	4			[15]	
3.2	Fixed costs (2030)	€k/MWth	4			[15]	
3.3	Fixed costs (2050)	€k/MWth	4			[15]	
3.4	Variable costs	€/MWh	1.2			[15]	
3.5	Start-up costs	€/MW/Start	10			[15]	

	Property	**Unit**	**20**			**Sources**	**Note**
4.1	Technical service life	a	25			[15]	
4.	Depreciation period	a	14			[12]	Reference: 3.1.8

2							
4.3	Lorenz process efficiency 2020	%	63			[15]	
4.4	Lorenz process efficiency 2050	%	65	170	150	[1]	
4.5	COP 2020		340.2				See 6.1. With district heating supply 85 / return 45, heat source 4°C, DeltaT = 10°C
4.5	COP 2050		351				

5.1	Technological dynamic and/or technological potential	**Increase in efficiency** The expected improvement in the efficiency of large-scale air source heat pumps in the range of 1 MW to 10 MW is represented technologically by the increase in 'Lorenz efficiency' by 2050 (see 4.3, 4.4). This efficiency is based on installed and planned systems installed in heating networks, especially in Denmark and Finland. As the overall efficiency depends on the heat sink temperatures, a further increase in the COP can also be expected in future by lowering the average heating network temperatures. The reduction from supply 85 / return 45 to supply 60 / return 35, while maintaining the technological efficiency of the 1 MW heat pump, leads to a rise in the COP from 278 to 401. **Lowering of investment costs** Compression heat pumps have the potential to reduce costs. Ideally, in future, the investment costs could be closer to those of equipment for industrial refrigeration. Compression heat pumps on a large scale come from industrial refrigeration technology, using the same principles and many of the same components. However, heat pumps need a higher working pressure, which means that some of the main components require specification and limit the output range. Large-scale heat pumps for high supply temperatures are still rare, so the production volume of certain components is low. Most large-scale heat pumps that are installed in Europe and, in particular, Denmark and Finland as the market leaders are custom-made and always require a considerable technical outlay. This is largely due to the fact that the application is still relatively new. As more and more installations are built, it is expected that the technical processes will be systematised and calculation tools will be developed to ensure quick specification and construction.

V.8. Waste heat heat pump

Table 71: Technology profile for waste heat heat pump

1.1	**Technology**	**Waste heat heat pumps (HP) 3 MW to 10 MW**
1.2	**Technical term**	**Compression heat pump for the use of industrial waste heat**
1.3	**Centralised or decentralised supply**	**Centralised integration into heating network**
1.4	**Brief description**	A heat pump draws heat from the ground, air or water; this heat is raised to a desired temperature level and then transferred to inside the building or the heating network. The heat is transferred from the heat source with the help of a refrigerant that vaporises even at low temperatures. A compressor increases the pressure of the refrigerant, thereby heating the refrigerant. The energy then continues to the heating system, and the refrigerant cools down and becomes a liquid again. Electricity, gas or waste heat can be used as the driving energy.
1.5	**Field of application / structure**	With the present technology, large-scale heat pumps currently achieve supply temperatures of about 80 °C. In many cases, this maximum supply temperature is too low for integration into conventional district heating networks. During the winter months, the supply temperatures in district heating networks are generally above 100 °C.

	Specific investment costs	**Unit**	**1 MW**	**3 MW**	**10 MW**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	1,240	860	670	[15]	Investment in 2020 – price basis is 2015
	Of which for plant and materials	€k/MW_{th}	950	680	535		
	Of which for installation	€k/MW_{th}	260	160	125		
	Of which for grid connection	€k/MW_{th}	30	20	10		
2.2	Spec. investments (2030)	€k/MW_{th}	1,140	760	570	[15]	Price basis is 2015
	Of which for plant and materials	€k/MW_{th}	860	605	460		
	Of which for installation	€k/MW_{th}	250	135	100		
	Of which for grid connection	€k/MW_{th}	30	20	10		
2.3	Spec. investments (2050)	€k/MW_{th}	1,140	860		[15]	Price basis is 2015
2.4	Cost function (2020)	€m/MW_{th}	a*ln(x)+b	a	b		Derived from values shown
		€m/MW_{th}		-255	1,219		
	Comment		Valid for 1 MW to 10 MW				

	Operating costs	**Unit**	**1 MW**	**3 MW**	**10 MW**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW_{th}	2	2	2	[15]	
3.2	Fixed costs (2030)	€k/MW_{th}	2	2	2	[15]	
3.3	Fixed costs (2050)	€k/MW_{th}	2	2	2	[15]	
3.4	Variable costs	€/MWh	2.7	2.2	2.2	[15]	Compression HP
3.5	Start-up costs	€/MW/Start	10	10	10		

	Property	**Unit**	**1 MW**	**3 MW**	**10 MW**	**Sources**	**Note**
4.1	Technical service life	a	25	25	25	[1]	
4.2	Depreciation period	a	14	14	14	[12]	Reference: 3.1.8
4.3	Lorenz process efficiency 2020	%	40	45	50	[15]	
4.4	Lorenz process efficiency 2050	%	44	49	54	[15]	

4.5	COP 2020	%	303	341	379		See 6.1. With district heating supply 85 / return 45, heat source 25°C, DeltaT = 10°C
4.5	COP 2050	%	333	371	409		

5.1	Technological dynamic and/or technological potential	**Increase in efficiency** The expected improvement in the efficiency of large-scale air source heat pumps in the range of 1 MW to 10 MW is represented technologically by the increase in 'Lorenz efficiency' by 2050 (see 4.3, 4.4). This efficiency is based on installed and planned systems installed in heating networks, especially in Denmark and Finland. As the overall efficiency depends on the heat sink temperatures, a further increase in the COP can also be expected in future by lowering the average heating network temperatures. The reduction from supply 85 / return 45 to supply 60 / return 35, while maintaining the technological efficiency of the 1 MW heat pump, leads to a rise in the COP from 278 to 401. **Lowering of investment costs** Compression heat pumps have the potential to reduce costs. Ideally, in future, the investment costs could be closer to those of equipment for industrial refrigeration. Compression heat pumps on a large scale come from industrial refrigeration technology, using the same principles and many of the same components. However, heat pumps need a higher working pressure, which means that some of the main components require specification and limit the output range. Large-scale heat pumps for high supply temperatures are still rare, so the production volume of certain components is low. Most large-scale heat pumps that are installed in Europe and, in particular, Denmark and Finland as the market leaders are custom-made and always require a considerable technical outlay. This is largely due to the fact that the application is still relatively new. As more and more installations are built, it is expected that the technical processes will be systematised and calculation tools will be developed to ensure quick specification and construction.

6.1	Further comments:	Larger installations achieve higher efficiency due to the use of more complex system components. In practice, however, the investment costs generally outweigh the benefits. With larger installations, optimisation is more profitable. To calculate the COP of the heat pump accurately, the respective field of application must be included. Here, the supply and return temperatures (Tin, sink, Tout, sink) of the heating network and the temperature of the heat source (Tin, source), and the reduction of these temperatures by the heat pump (Tout, source = Tin, source - delta T), are particularly important. The theoretical COP can be calculated as a 'Carnot COP' or 'Lorenz COP', which relates the mechanical work to temperature differences in electricity generation, refrigeration technology and heat pump technology. Carnot considers a single cooling circuit with a condenser and an evaporator and relates the mechanical work to the difference in temperature between the condenser and the evaporator. The Lorenz calculation method is preferred for 'staggered' Carnot cycles in which the heating and/or cooling take place over several steps, which is the case in district heating with a temperature rise of 30-50 K. With such high temperature rises, a heat pump system typically includes several condensers in a series, so the system consists of several Rankine cycles. The Lorenz cycle is preferred over the Carnot cycle in this context as it involves more steps in the cycle. The real COP of the heat pump results from the theoretical Lorenz COP multiplied by the 'Lorenz' efficiency of the respective heat pump.

V.9. CHP installations: steam turbine

Table 72: Technology profile for CHP installation: steam turbine

1.1	**Technology**	**CHP installations**
1.2	**Technical term**	**Steam turbines**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	With combined heat and power installations, heat and electricity are generated in parallel. Different fuels (liquid, solid, gaseous, fossil and renewable) can be used for operation. In biomass CHP, wood is used as a fuel in the form of pellets, wood chips or scrap wood from the wood-processing industry. These installations generally involve steam turbines.
1.5	**Field of application / structure**	Between 20 MWth and 250 MWth (sub-critical steam state).

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	900	8,900	1,700	[1]	
2.2	Spec. investments (2030)	€k/MW_{th}	850	8,500	1,600	[1]	
2.3	Spec. investments (2050)	€k/MW_{th}	800	8,000	1,400	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x) = 4.59*(x)^(-0.20)			[1]	Fuel: Natural gas
2.5	Cost function	€m/MW_{th}	Invest(x) = 5.31*(x)^(-0.20)			[1]	Fuel: Oil
2.6	Cost function	€m/MW_{th}	Invest(x) = 10*(x)^(-0.25)			[1]	Fuel: Biomass
2.7	Cost function	€m/MW_{th}	Invest(x) = 2.17*(x)^(-0.10)			[1]	Fuel: Coal
2.8	Cost function	€m/MW_{th}	Invest(x) = 20*(x)^(-0.30)			[1]	Fuel: Waste

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW_{th}	5	268	9/50/200	[1]	Natural gas, oil/biomass, coal/waste
3.2	Fixed costs (2030)	€k/MW_{th}	5	257	9/40/190	[1]	Natural gas, oil/biomass, coal/waste
3.3	Fixed costs (2050)	€k/MW_{th}	5	246	7/30/180	[1]	Natural gas, oil/biomass, coal/waste
3.4	Variable costs	€/MWh	1.0			[1]	

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	25	40	30	[1]	
4.2	Depreciation period	a			19	[12]	Reference: 3.1.2
4.3	Efficiency thermal (natural gas)	%	71	73	72	[1]	Fuel utilisation allocated to district heating
4.4	Efficiency thermal (oil)	%	71	73	72	[1]	
4.5	Efficiency thermal (biomass)	%	70	73	71	[1]	
4.6	Efficiency thermal (coal)	%	66	70	68	[1]	
4.7	Efficiency thermal (waste)	%	76	78	77	[1]	

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.10. CHP installations: gas turbine

Table 73: Technology profile for CHP installation: gas turbine

1.1	**Technology**	**CHP installations**
1.2	**Technical term**	**Gas turbines**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	A gas turbine is a thermal engine. In the combustion chamber of a gas turbine, air drawn in is compressed and then mixed with a fuel. This mixture is ignited and combusted. This creates a hot gas with a temperature of up to 1,500 degrees; a connected turbine section converts this thermal energy into kinetic energy / motion. A generator produces electrical energy from this. Various liquid or gaseous fuels are used as combustibles, particularly natural gas. When used in a cogeneration plant, the heat is extracted from the turbine as hot steam and then transferred via heat exchangers to a distribution system / heating network. In a combined-cycle power plant, both principles are combined. The gas turbine produces the heat required for the downstream waste heat boiler, which in turn generates the steam needed for the steam turbine.
1.5	**Field of application / structure**	Small gas turbines have a capacity of 0.5–30 MWel or 1–50 MWth. Medium-sized gas turbines have a capacity of 30–250 MWel or 50–300 MWth, and large gas turbines have a capacity of > 250 MWel or > 300 MWth. The capacity of turbines in a combined-cycle power plant is 50–500 MWel or 50–500 MWth. The applications are very diverse (municipalities, public utilities, energy operators and industries with high energy demands).

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	370	1,300	800	[1]	
2.2	Spec. investments (2030)	€k/MW_{th}	350	1,200	800	[1]	
2.3	Spec. investments (2050)	€k/MW_{th}	310	1,200	800	[1]	
2.4	Cost function	€m/MW_{th}	Invest(x) = 3.05(x)^(-0.35)			[1]	Small gas turbine
2.5	Cost function	€m/MW_{th}	Invest(x) = 1.64(x)^(-0.25)			[1]	Medium-sized gas turbine
2.6	Cost function	€m/MW_{th}	Invest(x) = 0.94(x)^(-0.15)			[1]	Large gas turbine
2.7	Cost function	€m/MW_{th}	Invest(x) = 3.75(x)^(-0.2)			[1]	Combined-cycle gas turbine

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW_{th}	4	14	6	[1]	
3.2	Fixed costs (2030)	€k/MW_{th}	4	12	5	[1]	
3.3	Fixed costs (2050)	€k/MW_{th}	3	11	5	[1]	
3.4	Variable costs	€/MWh	8.0			[1]	Small gas turbine
3.5	Variable costs	€/MWh	7.0			[1]	Medium-sized gas turbine
3.6	Variable costs	€/MWh	5.0			[1]	Large and combined-cycle gas turbine

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	25	40	35	[1]	
4.2	Depreciation period	a			19	[12]	Reference: 3.1.2

4.3	Efficiency thermal	%	50	65	60	[1]	Fuel utilisation allocated to district heating

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.11. CHP installation: cogeneration plants

Table 74: Technology profile for CHP installation: cogeneration plants

1.1	**Technology**	**CHP installations**
1.2	**Technical term**	**Cogeneration plants**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	A cogeneration plant is a modular installation for generating electrical energy and heat. A cogeneration plant essentially consists of an internal combustion engine, a synchronous generator and a heat exchanger. As a result, the cogeneration plant can be operated with oil, gas, fuel oil or biogas. The gas engines can be operated with different gases, such as natural gas, shale gas, mine gas, biogas, landfill gas, sewage treatment plant gas and synthesis gas.
1.5	**Field of application / structure**	Stationary gas engines are used in CHP installations and gas heat pumps. The fields of application are varied. According to the main report by the Energy Efficiency Association for Heating, Cooling and CHP (AGFW) in 2018, of the 1,400 CHP installations connected to a district heating network, 1,218 are cogeneration plants.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW$_{th}$	500	1,200	700	[1]	
2.2	Spec. investments (2030)	€k/MW$_{th}$	450	1,100	600	[1]	
2.3	Spec. investments (2050)	€k/MW$_{th}$	400	1,100	600	[1]	
2.4	Cost function	€m/MW$_{th}$	Invest(x) = 1.11(x)^(-0.3)			[1]	Gas engine
2.5	Cost function	€m/MW$_{th}$	Invest(x) = 1.27(x)^(-0.3)			[1]	Biogas engine

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW$_{th}$	7	12	9	[1]	
3.2	Fixed costs (2030)	€k/MW$_{th}$	7	12	9	[1]	
3.3	Fixed costs (2050)	€k/MW$_{th}$	7	12	9	[1]	
3.4	Variable costs	€/MWh	7.0			[1]	Gas engine
3.5	Variable costs	€/MWh	13.0			[1]	Biogas engine

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	30	25	[1]	
4.2	Depreciation period	a			10	[12]	Reference: 3.1.4
4.3	Efficiency thermal	%	45	57	50	[1]	Fuel utilisation allocated to district heating

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

6.1	Further comments:	In principle, cogeneration plants can be in operation for more than 20 years. The service life of a cogeneration plant depends on many factors, such as supply and return temperatures, number of starts/stops, how the installation runs, and the quality of the mainte-

		nance. As a general rule, the operating life of internal combustion engines is set at 15 years (VDI Guideline 2067). After 30,000 to 60,000 operating hours, the engine is due for a basic overhaul. The cogeneration plant will then achieve the same number of operating hours again. Some installations replace the engine as the central element of the cogeneration plant several times. So, in practice, there are installations that operate for more than 20–25 years.

V.12. Fuel cell

Table 75: Technology profile for fuel cell

1.1	**Technology**	**Fuel cell**
1.2	**Technical term**	**Polymer electrolyte membrane (PEM) fuel cell and solid oxide fuel cell (SOFC)**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	Proton exchange membrane fuel cells (also known as polymer electrolyte membrane fuel cells) are low-temperature fuel cells (70–90 °C). At the heart of these fuel cells is a very thin plastic membrane. PEM fuel cells have a high dynamic response, i.e. electricity and heat are generated flexibly without long start-up phases. SOFCs are high-temperature fuel cells. The solid electrolyte (oxide ceramic) conducts hydrogen ions from an operating temperature of 650 °C (up to 1,000 °C). The electrical energy and heat generated can supply a household with electricity and heat (via heat exchangers). Hydrogen can be produced using a variety of processes. Thermochemical processes use heat and chemical reactions to release hydrogen from organic materials such as fossil fuels and biomass. Water (H2O) can be split into hydrogen (H2) and oxygen (O2) by electrolysis or solar energy. Microorganisms such as bacteria and algae can produce hydrogen through biological processes.
1.5	**Field of application / structure**	Demonstration, pilot, practice and research projects are currently underway in Germany. Fuel cells are used in household supply, cogeneration plants and electricity generation.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW$_{th}$	6,000	20,000	13,000	[1]	
2.2	Spec. investments (2030)	€k/MW$_{th}$	3,000	15,000	9,000	[1]	
2.3	Spec. investments (2050)	€k/MW$_{th}$	1,500	10,000	4,000	[1]	
2.4	Cost function	€m/MW$_{th}$	N/A				PEM
2.5	Cost function	€m/MW$_{th}$	N/A				SOFC

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW$_{th}$	N/A	N/A	N/A		
3.2	Fixed costs (2030)	€k/MW$_{th}$	N/A	N/A	N/A		
3.3	Fixed costs (2050)	€k/MW$_{th}$	N/A	N/A	N/A		
3.4	Variable costs	€/MWh	100 (today); 60 (2030); 20 (2050)			[1]	PEM
3.5	Variable costs	€/MWh	50 (today); 30 (2030); 10 (2050)			[1]	SOFC

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	3	8	5	[1]	
4.2	Depreciation period	a			N/A		
4.3	Efficiency thermal	%			52	[1]	PEM (peak thermal load)
4.4	Efficiency thermal	%			32	[1]	SOFC (peak thermal load)

5.	Technological dynamic and/or techno-	The growth rates (CAGR) for PEM are 57% for the 2020–2030 period and 8% for 2030–2050

1	logical potential	(Germany scenario range minimum_80%). The IEA is projecting a 60% reduction in investment costs by 2050. The investment costs for SOFC cogeneration plants are expected to fall by up to 80% by 2050. This forecast is based on a cost study for the manufacture of solid oxide fuel cell power systems by the Pacific Northwest National Laboratory in 2013, which was prepared for the U.S. Department of Energy.

V.13. Waste heat

Table 76: Technology profile for waste heat

1.1	**Technology**	**Waste heat**
1.2	**Technical term**	**Plate heat exchanger (PHE) and tube bundle heat exchanger**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	Plate heat exchangers are made up of several plates with a gap between them, through which the heat transfer media flow. Plate heat exchangers (PHEs) are available in a wide variety of shapes and materials. Depending on the model, the plates are soldered or welded or are held together by clamping screws. Tube bundle heat exchangers consist of a large number of mostly thin tubes that share the flow of the heat transfer medium. The tubes are usually bundled together and routed through a container, through which the second heat transfer medium flows.
1.5	**Field of application / structure**	Due to its design, the plate heat exchanger offers considerable flexibility (application temperatures up to 900 °C for welded tube plates) and a very wide application range (from 2 kW to 400 MW). Tube bundle heat exchangers have very good heat transfer properties, especially with liquid/liquid applications, though gaseous media can also be used. Due to their shape, they can be designed to be very pressure-resistant. The application range is between 2 kW and 20 MW with application temperatures up to 300 °C.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW$_{th}$	200	800	400	[5], [6], [22]	
2.2	Spec. investments (2030)	€k/MW$_{th}$	190	790	390		
2.3	Spec. investments (2050)	€k/MW$_{th}$	180	780	380		
2.4	Cost function	€/m2	Invest(x)=420*(x)^(-0.011)			[5], [6], [22]	
Comment			ΔT = 20 °C ; heat transfer coefficient = 700 W/m2K (water-forced convection)				

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW$_{th}$	4	16	8	[6]	2% of investment costs
3.2	Fixed costs (2030)	€k/MW$_{th}$	3.8	15.8	7.8		
3.3	Fixed costs (2050)	€k/MW$_{th}$	3.6	15.6	7.6		
3.4	Variable costs	€/MWh	15 to 20			[22]	
Comment			1.5–3% of the investment costs can also be expected for the power consumption of the fan, the circulation pump and the repair and maintenance costs. Repair and maintenance costs (usually 1.5–2% of the investment costs per year, with exhaust gas heat utilisation approximately 2–3%).				

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	30	25		Estimate
4.2	Depreciation period	a			15	[12]	Reference: 3.1.14
4.3	Efficiency thermal	%	70	95	90	[6]	
Comment			The technical service life depends very much on the nature and quality of the media used in the heat exchanger, e.g. the use of waste heat from exhaust gas can lead to corrosion.				

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.14. Heating network

Table 77: Technology profile for heating networks

1.1	**Technology**	**Heating network**
1.2	**Technical term**	**District heating / local heating**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	District heating is heating of any origin that is supplied commercially for a fee on the basis of a contract with the help of a carrier medium (usually heating water or steam); the supply of such heating does not fulfil own ancillary obligations under tenancy law. All forms of heating supply are subject to the Regulation governing the general conditions for the supply of district heating (AVBFernwärmeV). (Definition according to the AGFW, Topp 2009)
1.5	**Field of application / structure**	Although there are no other definitions beyond the term district heating, heating networks can be further differentiated in terms of their temperature, network topology or consumer structure. Historically, heating networks were originally set up as steam networks, as the high temperatures allowed the provision of large demand volumes. These are often referred to as first-generation heating networks. Since 1930, in particular, the emphasis has been on establishing hot water heating networks in which the heating water is pressurised and has a temperature of > 100 °C (second-generation networks) or the temperature is just below 100 °C (third-generation networks). Future-proof networks are low-temperature networks with a temperature level up to 70 °C. These networks are also often referred to as LowEx networks. (Definition according to Lund 2014) When it comes to smaller networks in small and medium-sized towns or communities where heat is distributed only over a comparatively short distance, these are also often referred to as local heating networks. From a technical point of view, the networks can be designed as radial, ring or meshed; this is mainly influenced by urban conditions, such as the road layout or the spatial arrangement of the houses. For smaller and medium-sized district heating networks, radial networks are preferred as they have the shortest pipe length. Meshed networks allow maximum reliability due to redundancies, but they are also associated with high investment (Dötsch et al., 1998).

	Investment costs	Unit	Low	High	Typical	Sources	Note
2.1	Spec. investments (today)	€/m	200	1,800	700	[14]	
2.2	Spec. investments (2030)	€/m	200	1,800	700	[14]	
2.3	Spec. investments (2050)	€/m	200	1,800	700	[14]	

	Operating costs	Unit	Low	High	Typical	Sources	Note
3.1	Fixed costs (today)	€/m	4	36	14	[14]	Empirical value: In general, the annual operating costs can be assumed to be 2% of the investment.
3.2	Fixed costs (2030)	€/m	4	36	14	[14]	
3.3	Fixed costs (2050)	€/m	4	36	14	[14]	
3.4	Variable costs	€/MWh					

	Property	Unit	Low	High	Typical	Sources	Note
4.1	Technical service life	a	30	70	50		Estimate based on expert discussions
4.2	Depreciation period	a			25	[13]	Reference: 3.2.1 Pipe laid in a duct
4.3	Depreciation period	a			20	[13]	Reference: 3.2.2 Buried pipe
4.4	Efficiency thermal	%	N/A				
Comment			The pipe systems and operating temperatures used have a significant influence on the service life of the infrastructure. At a continuous operating temperature below 115 °C, a service life of at least 50 years is achieved. (DIN EN 253)				

5.1	Technological dynamic and/or technological potential	No major technological advances with an impact on the above properties are anticipated. However, as the energy transition progresses, it can be expected that the networks will have to be transformed. This will mean a lowering of the temperature due to a reduction in consumption on the customer side and, if necessary, an adjustment of the required nominal diameters.

V.15. Heat store

Table 78: Technology profile for heat store

1.1	**Technology**	**Heat store**
1.2	**Technical term**	**Tank thermal energy storage (TTES), pit thermal energy storage (PTES), aquifer thermal energy storage (ATES) and borehole thermal energy storage (BTES)**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	The most commonly used heat stores are large steel tanks (TTES), which are usually used as daily stores. The main parameters for the design of TTES systems are the pressure and temperature of the storage medium. PTES systems are usually built without a solid structure. They mainly involve local excavations and are furnished with a heat-insulating cover and a waterproof membrane. Water or gravel/sand/rock combined with water can be used as the heat medium. With the storage of hot and/or cold water in natural aquifers (ATES), heat is exchanged directly via vertical wells, typically one central well and a number of peripheral wells. In the case of borehole thermal energy storage (BTES), excess heat during the warm summer months is stored in the ground or in natural layers of rock via a borehole and used again during the cold autumn and winter months if needed.
1.5	**Field of application / structure**	TTES systems are located in the vicinity of large production facilities and can also be used for pressure maintenance in the district heating network. If it is necessary to store heat over several months or if the number of steel tanks becomes too high due to few storage cycles, and thus too expensive, seasonal stores or pit thermal energy storage (PTES) and borehole thermal energy storage (BTES) systems are an option. ATES systems close to the surface (depth of 20–300 m) are used in combination with heat pumps for the temperature ranges of comfort heating. In the case of deep aquifers (depth of over 1000 m), the fields of application for large-scale applications depend greatly on the properties of the aquifer. Water at this depth may already have a temperature of over 50 °C.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW$_{th}$	72	4,000	430	[1]	
2.2	Spec. investments (2030)	€k/MW$_{th}$	72	3,750	380	[1]	
2.3	Spec. investments (2050)	€k/MW$_{th}$	72	3,500	340	[1]	
2.4	Cost function	€/m^3	Invest(x)=3,488.7 * (x)^(-0.311)			[1], [23]	Tank thermal energy storage (TTES)
2.5	Cost function	€/m^3	Invest(x)=1,900 * (x)^(-0.33)			[1], [23]	Pit thermal energy storage (PTES)
2.6	Cost function	€/m^3	Invest(x)=9,744 * (x)^(-0.57)			[1], [23]	Aquifer thermal energy storage (ATES)
2.7	Cost function	€/m^3	Invest(x)=2,500 * (x)^(-0.35)				Borehole thermal energy storage (BTES)

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€k/MW$_{th}$	0.02	4.8	0.05/4.0/1.2	[1]	TTES/PTES/ATES/BTES
3.2	Fixed costs (2030)	€k/MW$_{th}$	0.02	4.15	0.05/3.6/1.2	[1]	TTES/PTES/ATES/BTES

3.3	Fixed costs (2050)	€k/MW$_{th}$	0.02	3.7	0.05/3.2/1.2	[1]	TTES/PTES/ATES/BTES
3.4	Variable costs	€/MWh					
Comment			The actual operating and maintenance costs of solar-assisted local heating installations with seasonal heat storage are similar to those of other conventional local heating installations [23]. The operating and maintenance costs are considered to be 0.25% and 1% of investment costs respectively.				

	Property	Unit	Low	High	Typical	Sources	Note
4.1	Technical service life	a	20	50	30	[1]	
4.2	Depreciation period	a			20	[12]	Reference: 2.7.5
4.3	Efficiency thermal	%	91	96	92	[1]	Tank thermal energy storage (TTES)
4.4	Efficiency thermal	%	50	90	80	[1]	Pit thermal energy storage (PTES)
4.5	Efficiency thermal	%	40	60	50	[1]	Aquifer thermal energy storage (ATES)
4.6	Efficiency thermal	%	60	70	65	[24]	Borehole thermal energy storage (BTES)

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production. Significant development potential lies in increased standardisation of work processes and in the development of high-temperature-resistant covers (PTES) at market prices, which can be seen as an improvement on existing designs.

V.16. District heating building transfer station

Table 79: Technology profile for district heating transfer station

1.1	**Technology**	**Transfer station**
1.2	**Technical term**	**District heating transfer station**
1.3	**Centralised or decentralised supply**	**Centralised integration**
1.4	**Brief description**	The transfer station is the link between the building connection pipe and the heating unit inside the building. It serves to transfer the heat to the central unit as contractually agreed, e.g. with regard to pressure, temperature and volumetric flow rate.
1.5	**Field of application / structure**	Small transfer stations are available as standard products in the output range of 10 kW to 500 kW. These can be designed for direct or indirect connection to one or more heating circuits. The temperature and pressure of the primary network determine whether a station should be operated directly or indirectly. Large transfer stations are available in the output range of 500 kW to 20 MW. These transfer stations are used for apartment blocks / industrial purposes.

	Investment costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
2.1	Spec. investments (today)	€k/MW_{th}	35 / 85	210 /150	100 / 76	[1]	Small / large
2.2	Spec. investments (2030)	€k/MW_{th}	35 / 85	210 / 140	98 / 73	[1]	Small / large
2.3	Spec. investments (2050)	€k/MW_{th}	35 / 80	200 / 130	95 / 70	[1]	Small / large
2.4	Cost function	€/kWth	Invest(x)=545.47 * (x)^(-0.468)			[19]	10–500 kW
2.5	Cost function	€/kWth	N/A				Over 500 kW

	Operating costs	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
3.1	Fixed costs (today)	€/MW_{th}	100 /300	150 / 700	125 / 500	[1]	Small / large
3.2	Fixed costs (2030)	€/MW_{th}	100 /300	150 / 700	125 / 500	[1]	Small / large
3.3	Fixed costs (2050)	€/MW_{th}	100 /300	150 / 700	125 / 500	[1]	Small / large
3.4	Variable costs	€/MWh					

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	30	20	[1]	
4.2	Depreciation period	a			20	[13]	Reference: 3.2.5
4.3	Efficiency thermal	%	93	99	95	[1]	Small
4.4	Efficiency thermal	%	95	100	98	[1]	Large

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is well established and production costs are expected to fall only moderately in the future due to improved production.

V.17. Decentralised gas-fired condensing boiler

Table 80: Technology profile for decentralised gas-fired condensing boiler

1.1	**Technology**	**Gas-fired condensing boiler**
1.2	**Technical term**	**Condensing technology**
1.3	**Centralised or decentralised supply**	**Decentralised integration**
1.4	**Brief description**	A gas-fired condensing boiler generates heat from the combustion of natural gas. Through the use of condensing technology, energy is also extracted from the condensed combustion gases, increasing the efficiency of the fuel used by around 11% compared to low-temperature gas boilers. To exploit the condensing effect, the exhaust gas must be cooled to below the dew point of approximately 56 °C. The return temperature in the heat distribution system must be significantly lower than this value.
1.5	**Field of application / structure**	Condensing installations are usually used for heating purposes and involve oil and gas combustion. This is the standard boiler for replacing outdated boilers in existing buildings and for installation in new buildings.

	Specific investment costs [€/kW]	**50 kW**	**35 kW**	**20 kW**	**10 kW**	**m**	**b**	**Operating costs (€/kWth)**	**Cost reduction by 2050**	**Efficiency / APC**	**Source**
	Gas-fired condensing boiler	167	195	300	544	2,934	-0.75	20	0%	0.95	[7]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a			18	[7]	
4.2	Efficiency thermal	%	95%	101%	98%	[20]	

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is established and production costs are not expected to fall significantly in the future due to improved production and optimisation. There is potential for optimisation of operation, ideally automatically, so that the condensing effect is actually used in operation.

V.18. Decentralised oil-fired condensing boiler

Table 81: Technology profile for decentralised oil-fired condensing boiler

1.1	**Technology**	**Oil-fired condensing boiler**
1.2	**Technical term**	**Condensing technology**
1.3	**Centralised or decentralised supply**	**Decentralised integration**
1.4	**Brief description**	An oil-fired condensing boiler generates heat from the combustion of oil. Through the use of condensing technology, energy is also extracted from the condensed combustion gases, increasing the efficiency of the fuel used by around 6% compared to low-temperature fuel oil boilers. To exploit the condensing effect, the exhaust gas must be cooled to below the dew point of approximately 47 °C. The return temperature in the heat distribution system must be significantly lower than this value.
1.5	**Field of application / structure**	Condensing installations are usually used for heating purposes and involve oil and gas combustion. This is the standard boiler to date for replacing outdated fuel oil boilers in existing buildings.

	Specific investment costs [€/kW]	**50 kW**	**35 kW**	**20 kW**	**10 kW**	**m**	**b**	**Operating costs (€/kWth)**	**Cost reduction by 2050**	**Efficiency / APC**	**Source**
	Pellet boiler	317	387	584	848	3,628	-0.62	30	0%	0.95	[7]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a			20	[20]	Assumptions based on those in [20]
4.2	Efficiency thermal	%	0.95	0.97	0.96	[7]	

5.1	Technological dynamic and/or technological potential	No technological advances with an impact on the above properties are anticipated. The technology is established and production costs are not expected to fall significantly in the future due to improved production and optimisation. There is potential for optimisation of operation, ideally automatically, so that the condensing effect is actually used in operation.

V.19. Decentralised condensing pellet boiler

Table 82: Technology profile for decentralised pellet boiler

1.1	**Technology**	**Pellet boiler**
1.2	**Technical term**	**Wood pellet central heating boiler**
1.3	**Centralised or decentralised supply**	**Decentralised integration**
1.4	**Brief description**	Pellet boilers generate heat through the combustion of organic material such as wood pellets and straw pellets. Wood pellets are usually used as the fuel for central heating boilers in buildings. Some boilers use condensing technology.
1.5	**Field of application / structure**	Pellet boilers are used as central heating systems particularly in single and two-family houses, but they are also suitable for apartment blocks or small non-residential buildings.

	Specific investment costs [€/kW]	**50 kW**	**35 kW**	**20 kW**	**10 kW**	**m**	**b**	**Operating costs (€/kWth)**	**Cost reduction by 2050**	**Efficiency / APC**	**Source**
	Pellet boiler	380	500	980	1,200	7,421	-0.77	42	15%	0.90	[8]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a			15	[7]	
4.2	Efficiency thermal	%			101%	[20]	

5.1	Technological dynamic and/or technological potential	Today's small combustion systems have achieved a high level of technological maturity and reliable operation. This is reflected in the complex combustion air controls and the efficiency levels measured, which are consistently above 90% in tests [10]. Development potential lies in the wider application of condensing technology (like with gas- and oil-fired boilers) and in the reduction of air pollutant emissions.

V.20. Decentralised brine/water heat pump

Table 83: Technology profile for decentralised brine/water heat pump

1.1	**Technology**	**Brine/water HP**
1.2	**Technical term**	**Brine heat pump**
1.3	**Centralised or decentralised supply**	**Decentralised integration**
1.4	**Brief description**	Heat pumps use electrical energy and heat from low-temperature heat sources to produce heat at a higher temperature. The temperature is raised using compression. In the case of ground source heat pumps, the heat transfer fluid (usually brine) flows through a geothermal heat collector or a borehole heat exchanger. In the brine heat pump the heat source is the ground. Efficient operation is achieved at low heat distribution supply temperatures of 35 °C; this is realised with underfloor and surface heating systems in new buildings and renovated existing buildings. In existing buildings, heat pumps are recommended if a supply temperature of below 50 °C can be achieved [11].
1.5	**Field of application / structure**	Typically, heat pumps are used to provide hot water, space heating and space cooling in residential and non-residential buildings.

	Specific investment costs [€/kW]	**50 kW**	**35 kW**	**20 kW**	**10 kW**	**m**	**b**	**Operating costs (€/kWth)**	**Cost reduction by 2050**	**Efficiency / APC**	**Full load hours**	**Source**
	Brine/water HP	1,593	1,773	2,099	2,586	5,173	-0.30	15	15%	4.25	1,950	[7.24]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	15	30	25	[1]	
4.2	APC calculated supply/return 35 °C/28 °C	%	430	550	490	[8]	Monovalent design, heat source temperature of 2 °C for boreholes and 0 °C for geothermal collectors and heating circuit supply/return = 35 °C/28 °C
4.3	APC calculated supply/return 55 °C/47 °C	%	370	460	430	[8]	Monovalent design, heat source temperature of 2 °C for boreholes and 0 °C for geothermal collectors and heating circuit supply/return = 35 °C/28 °C
4.4	APC measured existing buildings	%	320	460	370	[10]	
4.5	APC measured new buildings (underfloor heating)		220	520	380	[21]	

5.1	Technological dynamic and/or technological potential	Electrically powered heat pumps have achieved a high level of technical maturity. Further developments are particularly targeting the following points according to [10]: Refrigerant: Further development/adaptation of components for the introduction of new refrigerants with low global warming potential and zero ozone depletion potential, which are not subject to Regulation (EU) No 517/2014 on the phase-down of F gases. These new refrigerants are predominantly unsaturated partly fluorinated hydrocarbons (HFOs), which in turn, unlike natural refrigerants, cause other environmental problems (persistent degradation products, resource-critical input material); Further system development: Increasing use of power control (inverter-controlled). Further development of bivalent heat pump systems: Concepts for the operation of separate appliances and development of hybrid appliances; Fields of application: Elaboration of solutions for apartment blocks, especially for water heating. The focus here is on high supply temperatures. Expansion of the range of more powerful heat pumps, e.g. for supplying heat to neighbourhoods and hospitals or for providing process heat for industry.

6.1	Further comments:	The drilling costs are included in the investment costs.

V.21. Decentralised air/water heat pump

Table 84: Technology profile for decentralised air/water heat pump

1. 1	**Technology**	**Air/water HP**
1. 2	**Technical term**	**Air source heat pump**
1. 3	**Centralised or decentralised supply**	**Decentralised integration**
1. 4	**Brief description**	Heat pumps use electrical energy and heat from low-temperature heat sources to produce heat at a higher temperature. The temperature is raised using compression. The heat pump draws heat from the ground, air or water; this heat is raised to a desired temperature level and then transferred to inside the building or the heating network. The heat source of the air source heat pump is external air. Efficient operation is achieved at low heat distribution supply temperatures of 35 °C; this is realised with underfloor and surface heating systems in new buildings and renovated existing buildings. In existing buildings, heat pumps are recommended if a supply temperature of below 50 °C can be achieved [11].
1. 5	**Field of application / structure**	Typically, heat pumps are used to provide hot water, space heating and space cooling in residential and non-residential buildings.

	Specific investment costs [€/kW]	**50 kW**	**35 kW**	**20 kW**	**10 kW**	**m**	**b**	**Operating costs (€/kWth)**	**Cost reduction by 2050**	**Efficiency / APC**	**Full load hours**	**Source**
	Air/water HP	885	985	1,166	1,436	2,871	-0.30	17	15%	3.60	1,950	[7,8]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4. 1	Technical service life	a	15	30	25	[1]	
4. 2	APC determined supply/return 35 °C/28 °C	%	350	480	430	[8]	Mono-energetic, heat source temperature of 2 °C and heating circuit supply/return = 35 °C/28 °C
4. 3	APC determined supply/return 55 °C/47 °C	%	300	420	360	[8]	Mono-energetic, heat source temperature of 2 °C and heating circuit supply/return = 35 °C/28 °C
4. 4	APC measured existing buildings	%	270	370	310	[10]	
4. 5	APC measured new buildings (underfloor heating)		180	420	310	[21]	

5. 1	Technological dynamic and/or technological potential	Electrically powered heat pumps have achieved a high level of technical maturity. Further developments are particularly targeting the following points according to [10]: Refrigerant: Further development/adaptation of components for the introduction of new refrigerants with low global warming potential and zero ozone depletion potential, which are not subject to Regulation (EU) No 517/2014 on the phase-down of F gases. These new refrigerants are predominantly unsaturated partly fluorinated hydrocarbons (HFOs), which in turn, unlike natural refrigerants, cause other environmental problems (persistent degradation products, resource-critical input material); Noise emissions: Reduction of noise emissions in air/water heat pump units in which one of the main sources of sound is the fan. There are also further developments in the field of compressor technology. The noise emissions of the compressor itself are being reduced, and the decoupling from the pipe system and housing is being improved; Further system development: Air/water heat pumps already predominantly have power control, and increasing use of this technology is to be expected. Further development of bivalent heat pump systems: Concepts for the operation of separate appliances and development of hybrid appliances.

V.22. Decentralised solar thermal energy

Table 85: Technology profile for decentralised solar thermal energy

1.1	**Technology**	**Solar thermal energy**
1.2	**Technical term**	**Solar thermal energy (ST), thermal solar installation**
1.3	**Centralised or decentralised supply**	**Decentralised integration**
1.4	**Brief description**	The absorber, installed in the collector, converts sunlight into heat. The coating of the absorber plate ensures that a lot of heat is absorbed. Thermal insulation covering the back and sides prevents heat loss. Heat is transported from the collector via the solar fluid (usually water mixed with antifreeze). Evacuated-tube collectors have lower heat losses than flat-plate collectors. The absorber surface is located in several vacuum tubes, thereby significantly reducing the heat loss. Several little tubes are connected to the collector circuit via a manifold on the frame of the tube collector.
1.5	**Field of application / structure**	Solar thermal installations are typically used in new and existing single and two-family houses. However, they are also suitable for use in apartment blocks with appropriate roof surfaces and in non-residential buildings with a corresponding demand for hot water.

	Specific investment costs [€/m²]	**50 m²**	**35 m²**	**20 m²**	**10 m²**	**m**	**b**	**Operating costs (€/kWh)**	**Cost reduction by 2050**	**Yield (MWh/m²*a)**	**Source**
	Solar thermal energy		595	690	765	1,221	0		0	350	[8]

	Property	**Unit**	**Low**	**High**	**Typical**	**Sources**	**Note**
4.1	Technical service life	a	20	35	25	[1]	
4.2	Efficiency thermal	%	33	43	34	[1]	Flat-plate collector
4.3	Efficiency thermal	%	37	46	37	[1]	Tube collector

5.1	Technological dynamic and/or technological potential	The technology is mature and has been around for many years. Technical developments can be expected in detailed aspects such as integrated control technology, and in the combination of photovoltaics and solar thermal energy. In 2018, a novel photovoltaic-thermal (PVT) collector of this kind was launched on the market. The market for decentralised solar thermal installations has been declining for years.

V.23. Sources for technology profiles

No	Reference
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No	Reference
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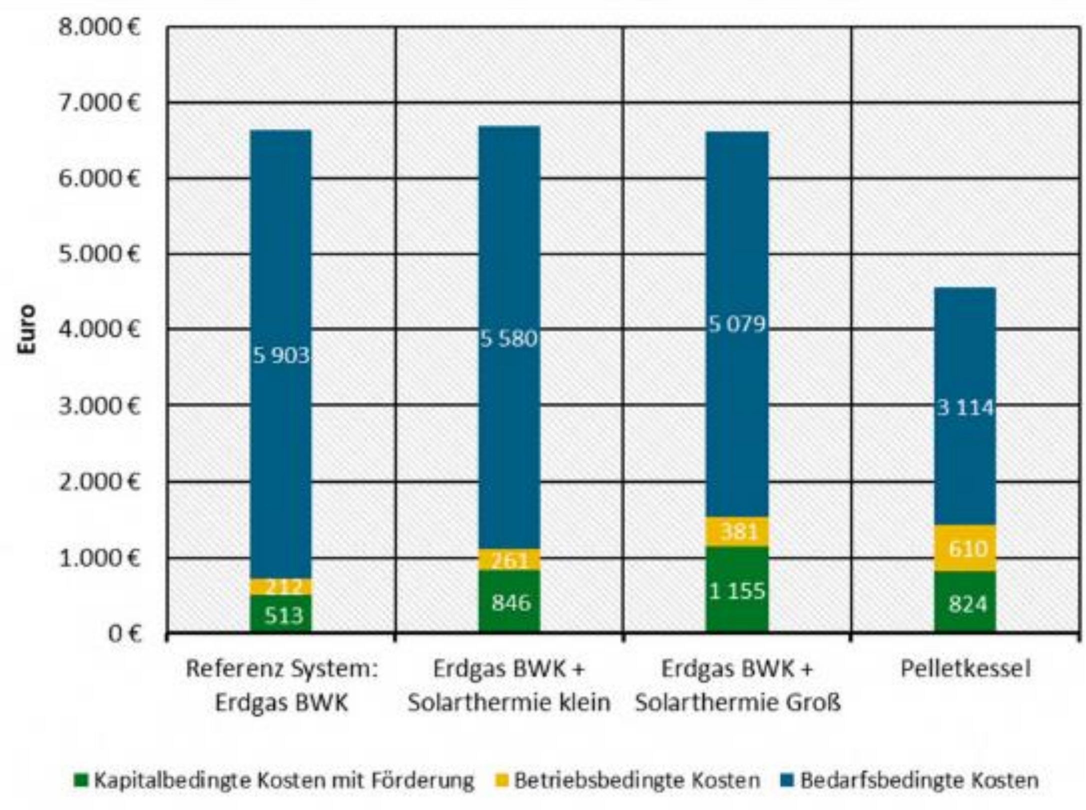
VI. Annex Part III – Decentralised supply options

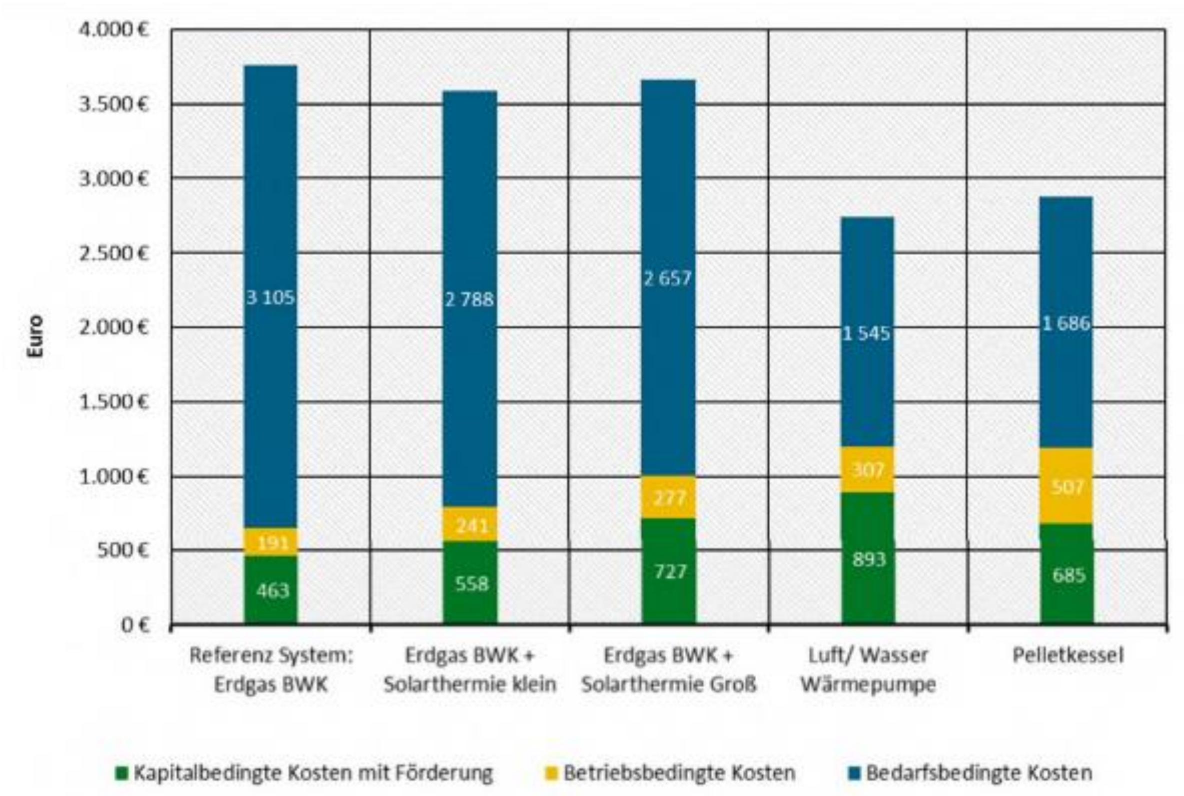
VI.1. Equivalent total annual costs for SFH non-renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Erdgas BWK + Solarthermie klein	Gas-fired CB + small solar thermal
Erdgas BWK + Solarthermie Groß	Gas-fired CB + large solar thermal
Pelletkessel	Pellet boiler
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten	Demand-related costs

Figure 114: Equivalent total annual costs for SFH non-renovated

VI.2. Equivalent total annual costs for SFH renovated

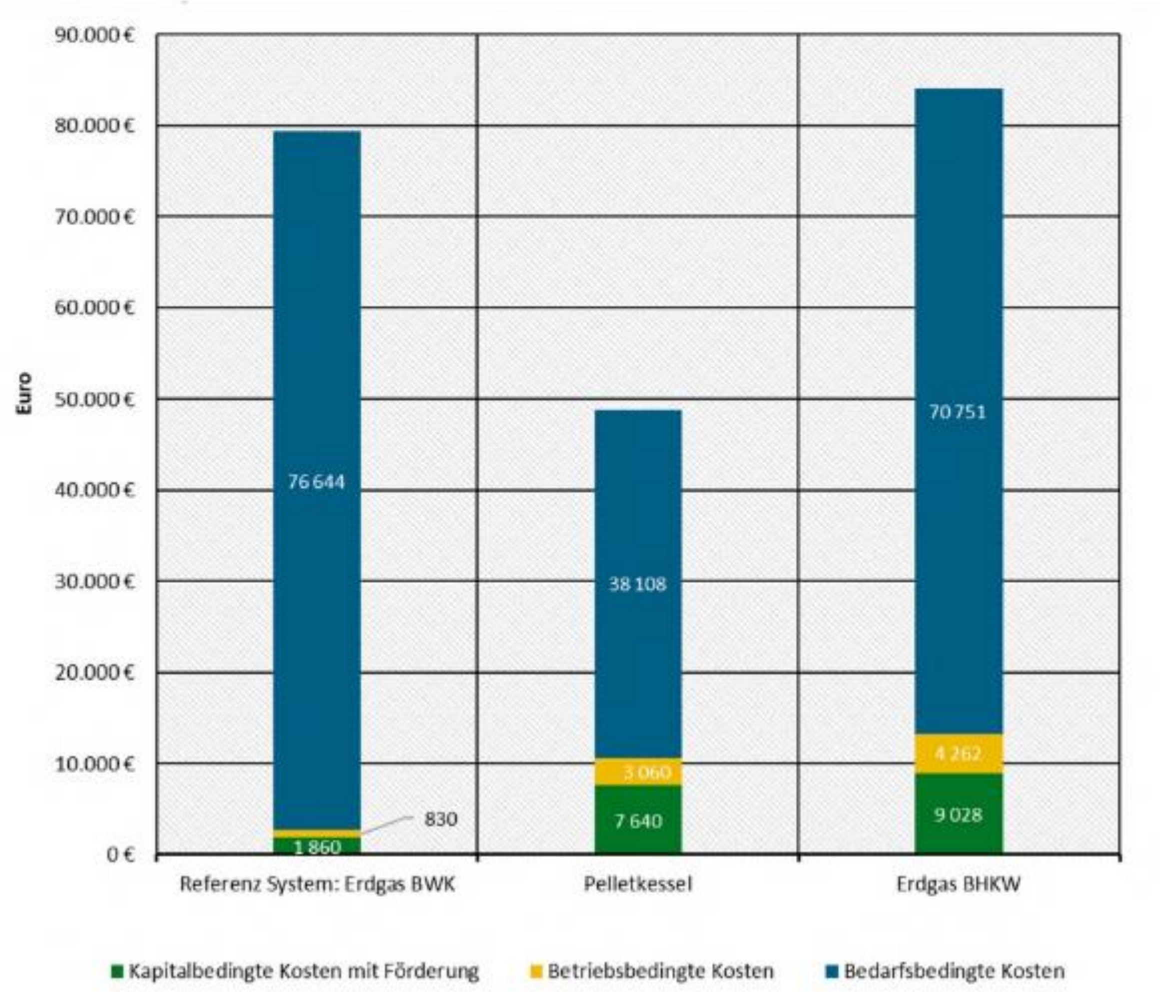


Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Erdgas BWK + Solarthermie klein	Gas-fired CB + small solar thermal
Erdgas BWK + Solarthermie Groß	Gas-fired CB + large solar thermal
Luft/Wasser Wärmepumpe	Air/water heat pump
Pelletkessel	Pellet boiler
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten	Demand-related costs

Figure 115: Equivalent total annual costs for SFH renovated

VI.3. Equivalent total annual costs for AB non-renovated

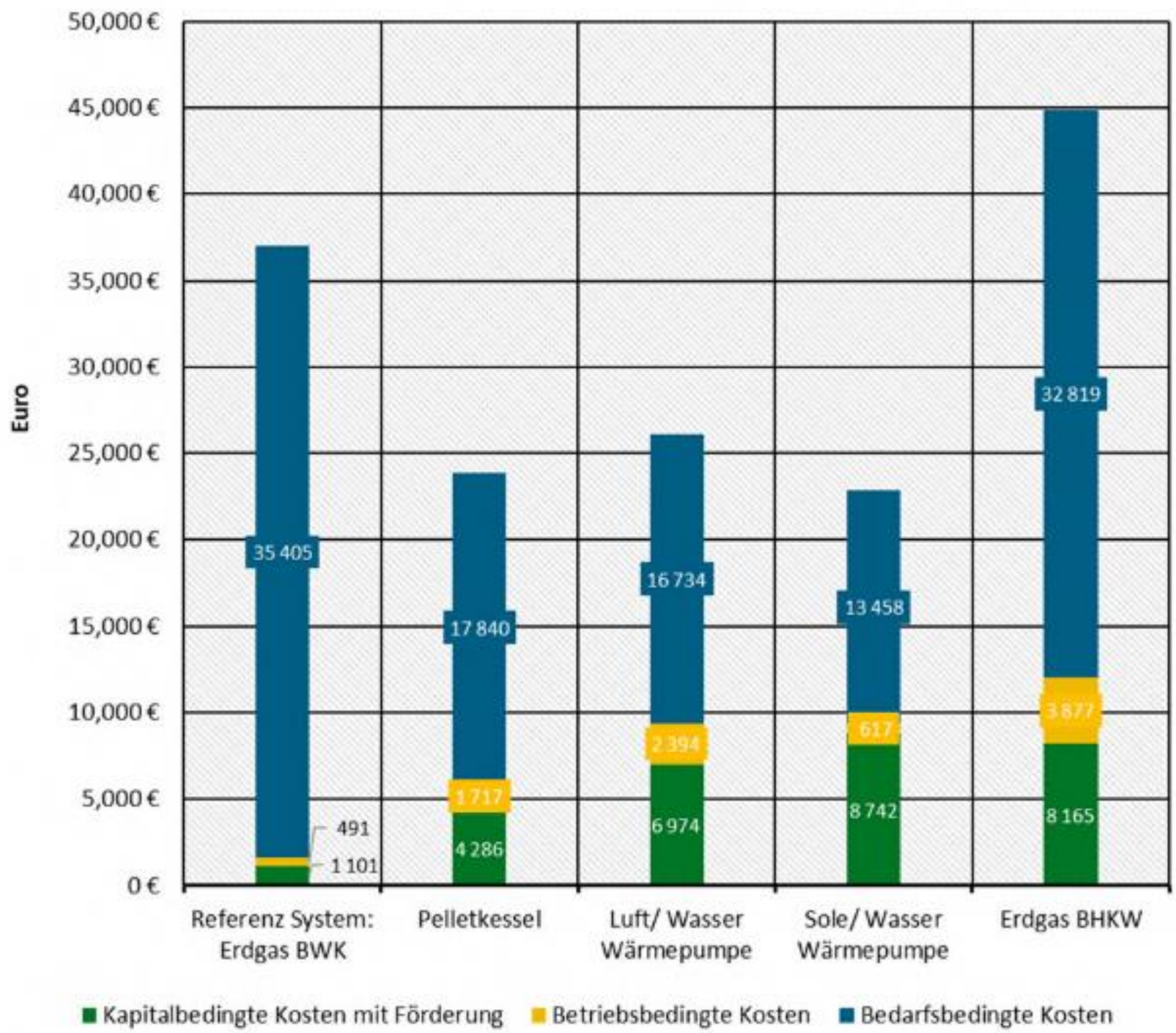
In the same way as Figure 78, this figure presents the equivalent total annual costs for non-renovated apartment blocks in euro. A bar chart clearly shows that demand-related costs and/or energy costs account for the largest share. Capital-related and operating costs are generally low, though higher with renewable energies. The gas-fired condensing boiler reference system has energy costs of €76,644, capital-related costs of €1,860 and operating costs of €830. The natural gas cogeneration plant has energy costs of €38,108, capital-related costs of €7,640 and operating costs of €3,060. The pellet boiler has energy costs of €70,751, capital-related costs of €9,028 and operating costs of €4,262.



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Pelletkessel	Pellet boiler
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten	Demand-related costs

Figure 116: Equivalent total annual costs for AB non-renovated

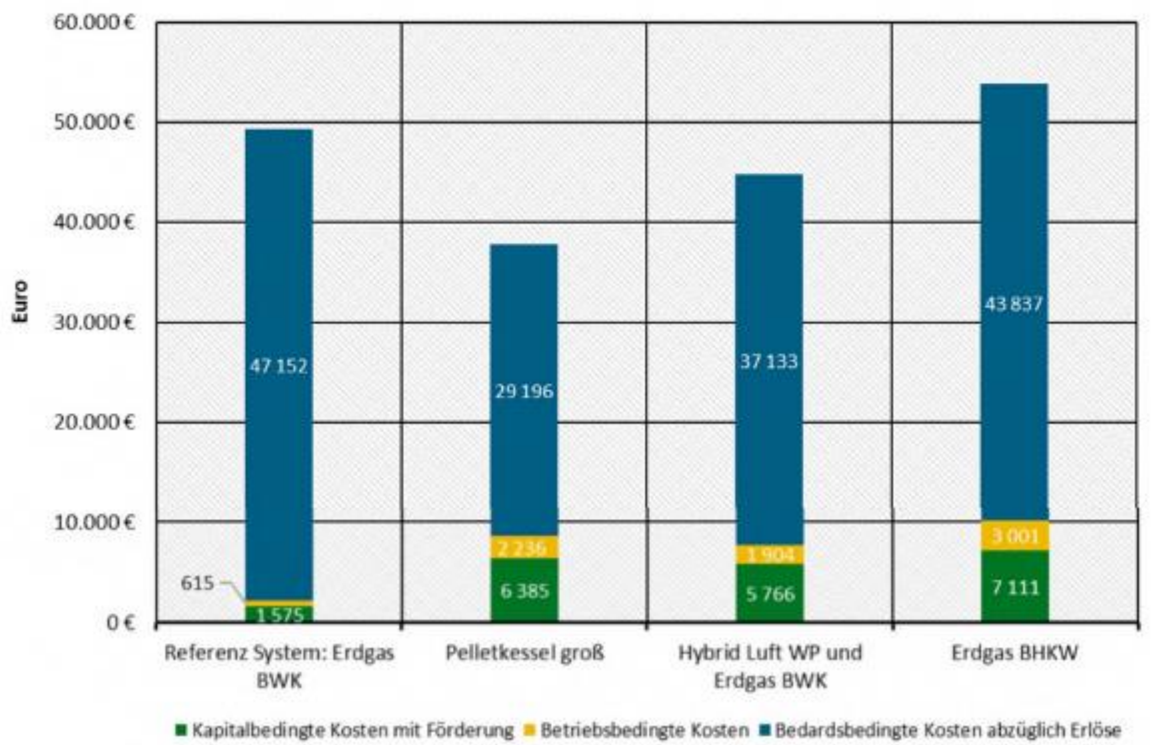
VI.4. Equivalent total annual costs for AB renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Pelletkessel	Pellet boiler
Luft/Wasser Wärmepumpe	Air/water heat pump
Sole/Wasser Wärmepumpe	Brine/water heat pump
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten	Demand-related costs

Figure 117: Equivalent total annual costs for AB renovated

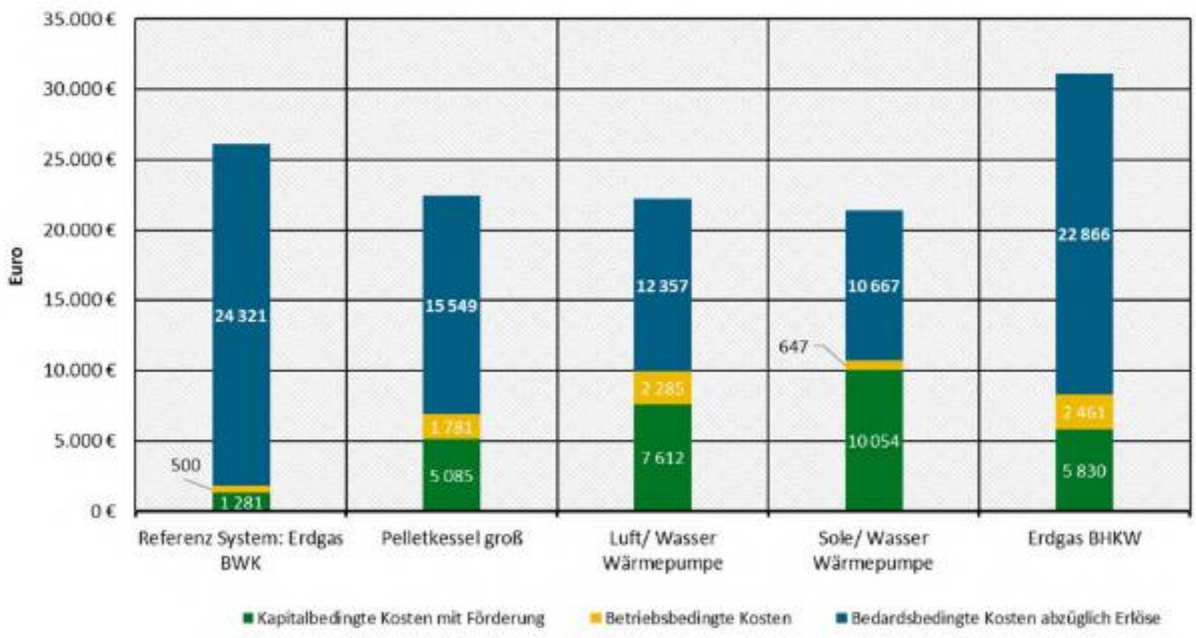
VI.5. Equivalent total annual costs for office buildings non-renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Pelletkessel groß	Large pellet boiler
Hybrid Luft WP und Erdgas BWK	Hybrid air source HP and gas-fired CB
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten abzüglich Erlöse	Demand-related costs minus proceeds

Figure 118: Equivalent total annual costs for office buildings non-renovated

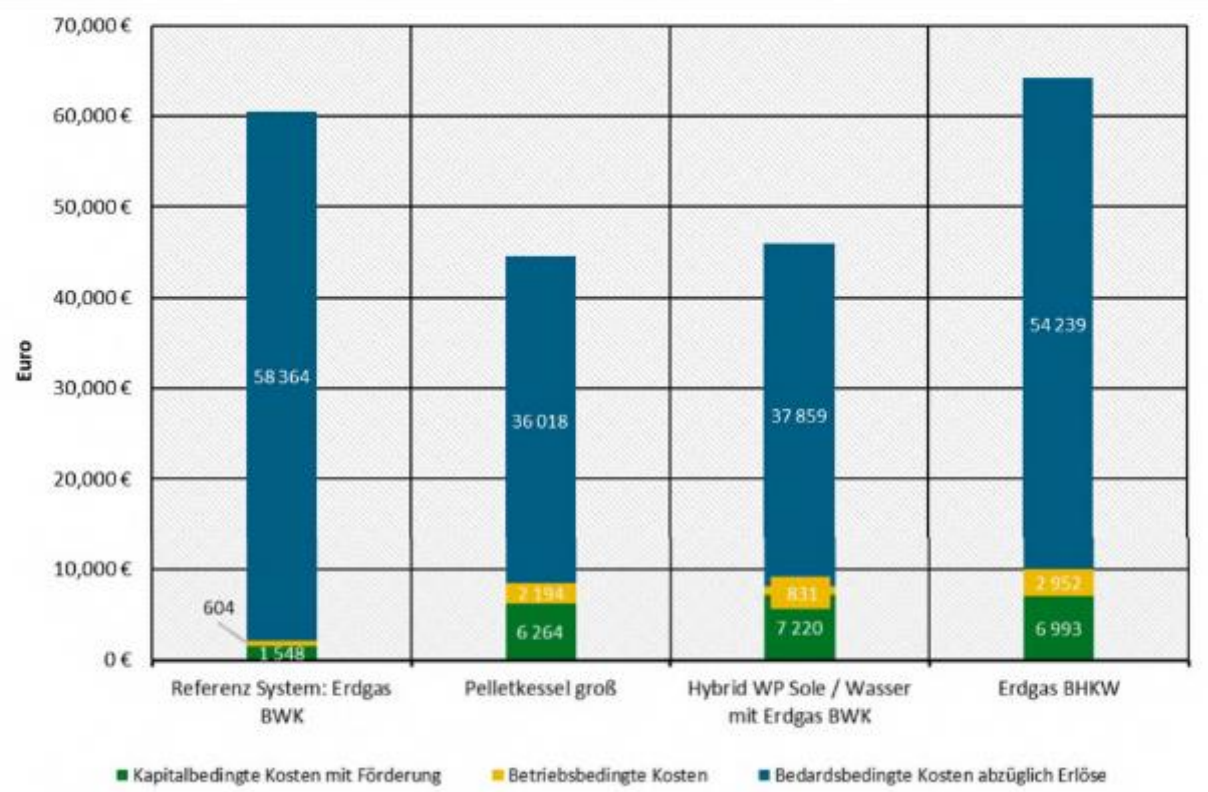
VI.6. Equivalent total annual costs for office buildings renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Pelletkessel groß	Large pellet boiler
Luft/Wasser Wärmepumpe	Air/water heat pump
Sole/Wasser Wärmepumpe	Brine/water heat pump
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten abzüglich Erlöse	Demand-related costs minus proceeds

Figure 119: Equivalent total annual costs for office buildings renovated

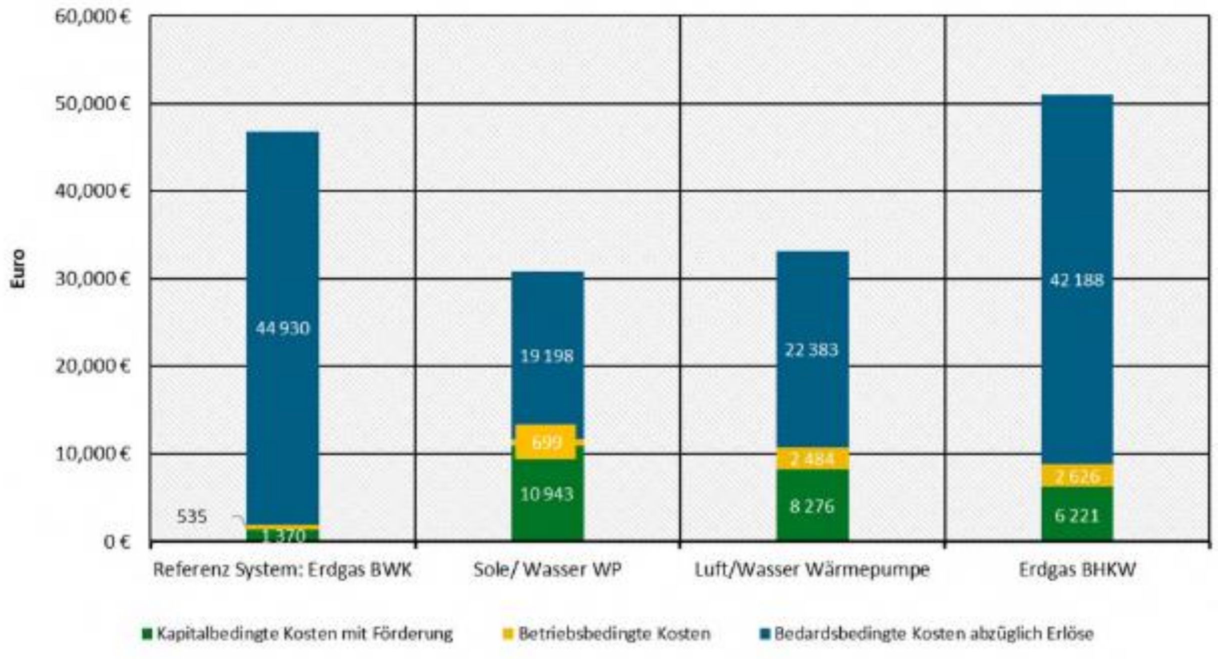
VI.7. Equivalent total annual costs for retail buildings non-renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Pelletkessel groß	Large pellet boiler
Hybrid WP Sole / Wasser mit Erdgas BWK	Hybrid brine/water HP with gas-fired CB
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten abzüglich Erlöse	Demand-related costs minus proceeds

Figure 120: Equivalent total annual costs for retail buildings non-renovated

VI.8. Equivalent total annual costs for retail buildings renovated



Referenz System: Erdgas BWK	Reference system: Gas-fired CB
Sole/Wasser WP	Brine/water HP
Luft/Wasser Wärmepumpe	Air/water heat pump
Erdgas BHKW	Natural gas cogeneration plant
Kapitalbedingte Kosten mit Förderung	Capital-related costs with subsidy
Betriebsbedingte Kosten	Operating costs
Bedarfsbedingte Kosten abzüglich Erlöse	Demand-related costs minus proceeds

Figure 121: Equivalent total annual costs for retail buildings renovated