Potential for efficient Heat and cold supply

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Summary

This report was written in the course of the IEA HPT Annex 57 and is based on the "comprehensive assessment of the potential for efficient heating and cooling" derived as a requirement to Art. 14 of the Energy Efficiency Directive (Europäisches Parlament 2012) in 2021. The report is based on the findings and work of (Mostafa Fallahnejad et al. 2022).

The report is aligned with the requirements of Art. 14 (1) of the Energy Efficiency Directive (or Annex VIII according to the Commission Delegated Regulation of 4 March 2019 amending Annexes VIII and IX to Directive 2012/27/EU as regards the content of the comprehensive assessments of the potential for efficient heating and cooling), C(2019) 1616 final (Europäische Kommission 2019a) as well as the corresponding recommendations of the Commission (Europäische Kommission 2019b).

The structure of the report is as follows: After an introduction in Chapter 1, Chapter 2 (Part 1 according to Annex VIII of the Energy Efficiency Directive) gives an overview of the heating and cooling demand and supply in Austria. Chapter 3 (Part 2 according to Annex VIII) presents the existing targets, strategies and policy measures in this context (Europäisches Parlament 2012). Chapter 4 analyses the economic potential for efficient heating and cooling supply. Lastly, Chapter 5 summarises potential and planned new strategies and strategic measures to tap the potential for efficient heating and cooling.

This report includes the regionalised representation of the heat demand and the determination of economic potentials in the period until 2030 as well as 2050. This map material as well as background data for the study are provided within the framework of the Austrian Heatmap. This was already created in 2015 as part of the study "Assessment of the potential for the use of high-efficiency CHP and efficient district heating and cooling supply" (Büchele et al. 2015) in a first version and is now being updated with the current data.

The economic potentials for different variants of efficient heating and cooling supply are strongly dependent on future framework conditions such as energy prices, CO_2 prices, whether external costs are considered, and achievable connection rates for district heating. To account for this, a large number of scenarios were calculated. For these variants, possible district heating regions were also explicitly identified geographically.

The basic assumption of the study is that the goal of (net) climate neutrality in Austria will be achieved between 2030 and 2050. This means that fossil energy sources still play a role in determining the economic potential for 2030, but no longer for 2050. For 2050, it is therefore assumed, among other things, that any demand for gas will be provided from renewable sources.

Under these assumptions, the following key statements can be made:

- The decarbonisation of the heating and cooling supply in Austria is possible, but only under some key assumptions and framework conditions, such as extensive efforts to renovate buildings, parallel decarbonisation of electricity generation and the successful integration of industrial waste (/excess) heat accompanied by the decarbonisation of industry.
- The share of district heating depends above all on the connection rate that can be achieved in the district heating regions, which in turn is strongly related to the spatial energy planning framework conditions. Depending on the achievable connection rate, an economic potential for district heating is calculated from about 20% to over 50%.

Concerning the technology mix of district heating supply, the following statements can be made:

- Under the assumptions made in this study, renewable gas does not prove to be a cost-effective option for decarbonising the sector.
- Biomass continues to represent a significant share of the renewable heat supply, both decentralised and in district heating. It can be observed that in the scenarios with low efficiency increases, the pressure on the use of biomass resources would increase very strongly.
- It can be seen that heat pumps play an essential role not only in decentralised applications, but also in district heating.
- The role of thermal power plants and CHPs in a future renewable electricity system was not the focus of this study. In the sense of high fuel utilisation, heat extraction from existing thermal power plants should definitely be strived for. Until 2050, however, the analyses show that gas-fired CHP plants will only be used with relatively low full load hours.
- Large solar thermal plants can be an economically viable option, although there is a strong dependence on the overall structure of the generation portfolio on the one hand, and on the achievable cost reductions on the other - these in turn scale strongly with the size of the plants.
- The use of large thermal storage systems is shown to contribute significantly to the economic operation of the heating networks. At the same time, there are significant uncertainties regarding the associated costs, which depend not least on the exact location.

Model-based analyses, such as those in this study, are always subject to uncertainties. On the one hand, these result from the possible cost development (including the locally existing site-specific conditions, which can lead to deviations in terms of costs), especially regarding large-scale thermal storage and solar thermal energy and the costs for land required for them, as well as deep geothermal (and the associated risks in the development). On the other hand, there are also uncertainties regarding technological developments and the efficiencies and corresponding technology characteristics that can be expected in the future. Furthermore, it is also evident that the interplay of the various renewable district heating technologies in the portfolio, also with the use of heat storage, is complex and strongly depends on the expected district heating demand. The expected heat demand is in turn strongly dependent on the measures concerning building renovation as well as on the achievable connection rates. Since these factors cannot be predicted in the long term, a continuously adapting planning process is required, both on the part of the heating network operators and on the part of policymakers.

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1 Introduction

This report was written in the course of the IEA HPT Annex 57 and is based on the "comprehensive assessment of the potential for efficient heating and cooling" derived as a requirement to Art. 14 of the Energy Efficiency Directive (Europäisches Parlament 2012) in 2021. The report is based on the findings and work of (Mostafa Fallahnejad et al. 2022).

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Already in 2015, the Vienna University of Technology, together with e-think and ecofys, prepared the study "Assessment of the potential for the use of high-efficiency CHP and efficient district heating and cooling supply" (Büchele et al., 2015). In the course of this project, the Austrian Heatmap was also created, which has since been available at www.austrian-heatmap.gv.at. The current study builds on this report from 2015, even though adjustments and a partly different methodological approach were necessary in accordance with the modified and differently structured recommendations for conducting the assessment.

The map material and background data for the study are again provided as part of the Austrian Heatmap.

2 Overview of heating and cooling supply in Austria

This chapter provides an overview of the heating and cooling demand as well as the corresponding supply, both in the base year and in different scenarios until 2030 and 2050. A special focus is on the presentation of the current grid-connected heat supply. The corresponding data according to the recommendations of the Commission (European Commission, 2019b) can be found in Table 1.

2.1.1 Heating and cooling demand and supply in Austria

For the presentation of the useful energy demand for the end-use sectors heating and cooling, the useful energy analysis of Statistics Austria up to 2018 was evaluated (Statistik Austria 2018a). For this purpose, the entire manufacturing sector ("industry"), public and private services, and the entire other economic sectors (both summarized as "trade") as well as private households ("households") were evaluated. In each of the three defined sectors, those areas of useful energy production were taken into account that are relevant for heating and cooling supply (namely "space heating and air conditioning", "steam generation" and "industrial furnaces").

Figure 1 shows the amount of useful energy used for heating and cooling applications in the Austrian industrial sector. It can be seen that in recent years the amount of useful energy required for steam generation and industrial furnaces has been about three times higher than for space heating and air conditioning.

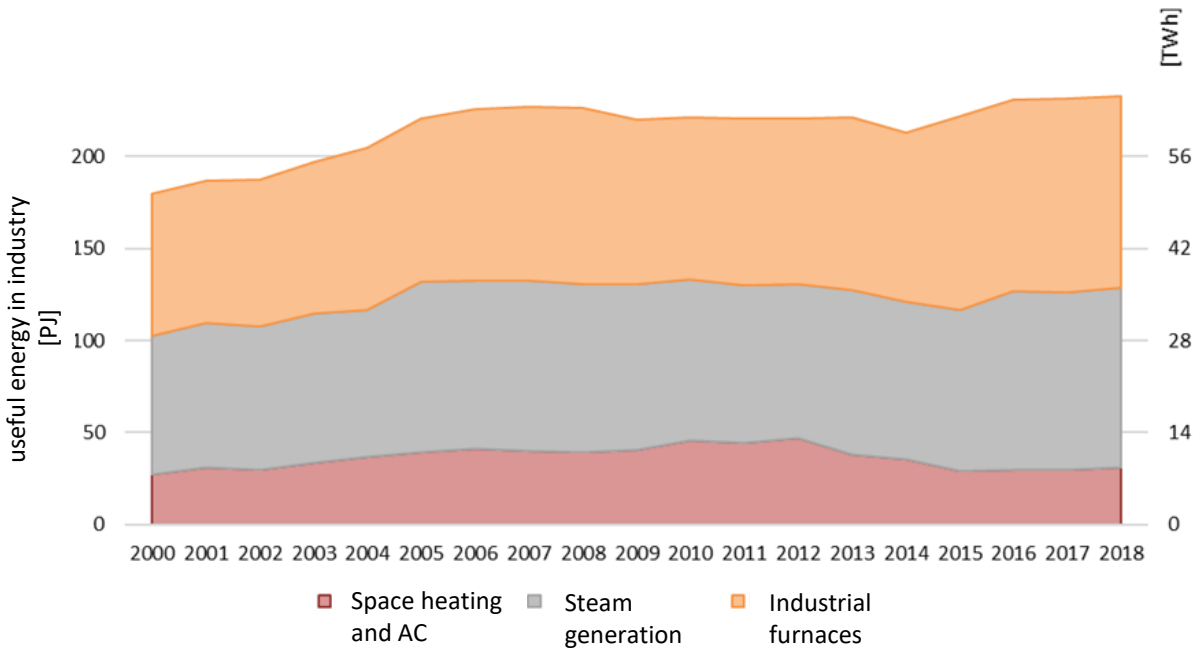

Figure 1: Application of useful energy for heating and cooling applications in the Austrian industrial sector (Source: Useful Energy Analysis Austria (1993 to 2018), Statistics Austria).

Figure 2 shows the amount of useful energy used for heating and cooling applications in the public and private services and agriculture sectors. By far the largest share is accounted for by space heating and

air conditioning. While industrial furnaces in Austrian businesses also account for a significant share of the useful energy demand, steam generation plays a subordinate role.

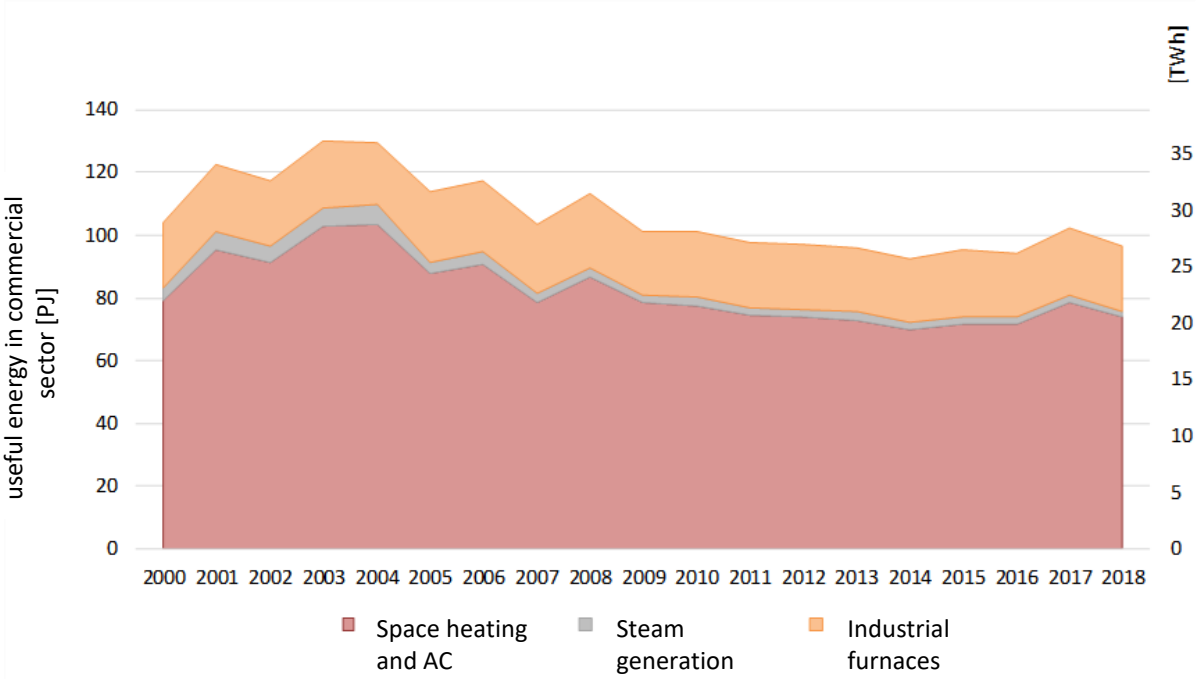

Figure 2: Application of useful energy for heating and cooling applications in the Austrian commercial sector (Source: Useful Energy Analysis Austria (1993 to 2018), Statistics Austria).

The consumption of useful energy in the heating and cooling sector for Austrian households is shown in Figure 3. Thermal energy is used for space heating and air conditioning as well as for cooking purposes (categorized as "industrial ovens" in the useful energy analysis). Steam is not required in Austrian households.

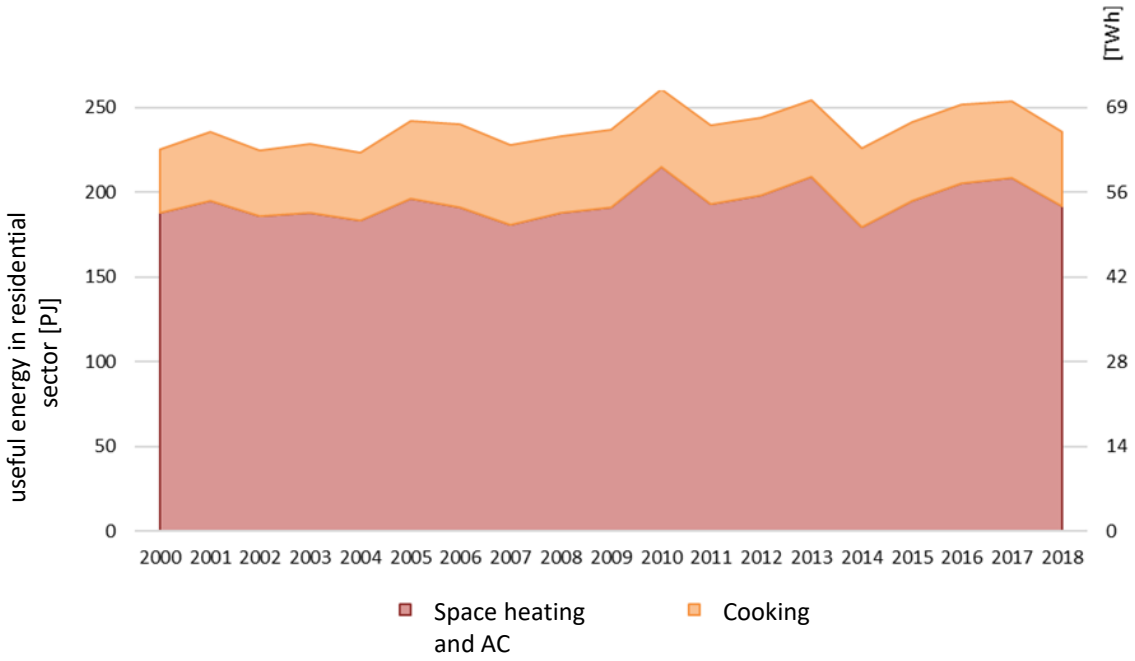

Figure 3: Application of useful energy for heating and cooling applications in Austrian households (Source: Useful Energy Analysis Austria (1993 to 2018), Statistics Austria).

To simplify reporting for the comprehensive assessment of the potential for efficient heating and cooling supply, the European Commission provides a template that is recommended for use (European Commission, 2020a). The reporting of current heating and cooling supply using this template distinguishes between energy provided on-site and energy provided off-site, each of which is further subdivided into sectors (residential, services, industry, and other sectors). Within the sectors, the subdivision is made between fossil fuels and renewable energy (as well as further subdivisions, which are explained in the following description and can be seen in Table 1).

Energy provided on site:

The values for heat-only generators ("heat-only boiler") and for "other technologies" are taken from the current utility energy analysis by Statistics Austria (Statistik Austria 2018a). For "high-efficiency CHP", the assumption was made that it is only directly applied in the industry sector and plays a negligible role in direct application in the residential, service and other sectors. For the industry sector, the values for "high-efficiency CHP" were derived using data from Statistics Austria's total energy balance (Statistik Austria 2018b). For this purpose, the total energy quantities provided by company-owned plants ("UEA") according to the total energy balance were converted to corresponding heat quantities using data from the operating statistics on (electrical) efficiencies of power plants (E-Control 2019). The values for heat pumps are also taken from the total energy balance (Statistik Austria 2018b), whereby the energy quantities from "ambient heat, etc." minus "solar heat" (effectively "ambient heat" and "reaction heat") are included here. The values given for heat pumps are based on the assumption of an average coefficient of performance (COP) for all heat pumps in use (assumption: COP = 3).

Energy provided off-site:

According to the analyses of (Moser, S., Lassacher, S. 2020), the decoupled waste heat in Austria amounts to approx. 1.8 TWh/a. Values for "high-efficiency CHP" and "other technologies" are taken from the total energy balance (Statistik Austria 2018b), where the energy quantities provided by energy supply companies ("EVU") are spent proportionally according to their sectoral distribution in district heating. Since no data are available for the distribution of the fossil and renewable fuels used in different sectors, an aliquot equal distribution was assumed here. Furthermore, since no information is available on the extent to which the waste heat was generated on the basis of renewable energies or fossil fuels, no distinction was made in the following table.

Table 1: Current heating and cooling supply, 2018. Reported according to European Commission template (Sources: own analyses based on (Statistik Austria 2018a), (Statistik Austria 2018b), (E-Control 2019) and (Moser, S., Lassacher, S. 2020))

Energy provided on site			Unit	Value
Residential buildings	Fossile Fuels	exclusive heat generating boiler plants	GWh/a	26 800
		Other technologies	GWh/a	4 739
		High efficient CHP	GWh/a	0
	Renewable Energies	exclusive heat generating boiler plants	GWh/a	18 918
		High efficient CHP	GWh/a	0
		Heatpumps	GWh/a	2 636
		Other technologies	GWh/a	4 073
Service Sector	Fossile Fuels	exclusive heat generating boiler plants	GWh/a	5 441
		Other technologies	GWh/a	4 756
		High efficient CHP	GWh/a	0
	Renewable Energies	exclusive heat generating boiler plants	GWh/a	885
		High efficient CHP	GWh/a	0
		Heatpumps	GWh/a	2 568
		Other technologies	GWh/a	3 564
Industry	Fossile Fuels	exclusive heat generating boiler plants	GWh/a	36 326
		Other technologies	GWh/a	4 234
		High efficient CHP	GWh/a	889
	Renewable Energies	exclusive heat generating boiler plants	GWh/a	17 307
		High efficient CHP	GWh/a	898
		Heatpumps	GWh/a	116
		Other technologies	GWh/a	2 489
Other sectors	Fossile Fuels	exclusive heat generating boiler plants	GWh/a	329
		Other technologies	GWh/a	231
		High efficient CHP	GWh/a	0
	Renewabel Energies	exclusive heat generating boiler plants	GWh/a	1 865
		High efficient CHP	GWh/a	0
		Heatpumps	GWh/a	38
		Other technologies	GWh/a	165

Energy provided off-site				
Residential buildings	Fossile Fuels	High efficient	GWh/a	3 393
		Other technologies	GWh/a	1 249
	Renewabel Energies	High efficient	GWh/a	1 636
		Other technologies	GWh/a	2 865
	Waste heat		GWh/a	813
Service Sector	Fossile Fuels	High efficient	GWh/a	2 865
		Other technologies	GWh/a	1 055
	Renewabel Energies	High efficient	GWh/a	1 382
		Other technologies	GWh/a	2 419
	Waste heat		GWh/a	686
Industry	Fossile Fuels	High efficient	GWh/a	1 206
		Other technologies	GWh/a	444
	Renewabel Energies	High efficient	GWh/a	582
		Other technologies	GWh/a	1 019
	Waste heat		GWh/a	289
Other sectors	Fossile Fuels	High efficient	GWh/a	75
		Other technologies	GWh/a	28
	Renewabel Energies	High efficient	GWh/a	36
		Other technologies	GWh/a	64
	Waste heat		GWh/a	18

2.1.2 Grid-connected supply

This chapter analyzes the development of the Austrian district heating sector and the existing networks up to 2018, if possible. For this purpose, a regionally resolved presentation of the most important heat supply areas in Austria is made. Different network structures and relevant parameters are surveyed and compared. The supply structure of these areas (waste incineration, biomass plants, heating plants and combined heat and power plants according to different energy sources) will be researched and presented.

2.1.2.1 Development of the district heating sector and current status

Data from the total energy balance (Statistik Austria 2018b) show that heating networks have been gaining importance in Austria since the 1970s. In the period between 2005 and 2018, district heating generation in Austria increased by about 40% and follows an overall increasing trend. In the period between 2012 and 2018, a constant trend can be seen. The network losses in the entire district heating sector amount to about 15% on average over the years 2005 to 2018. With the remaining sales volume of about 20 TWh, district heating was able to cover more than 18% of the total heat demand in the residential and services sectors in 2018. In the manufacturing sector, this share was almost 5%, and in agriculture it was also almost 5%. The district heating supply in Figure 4 clearly shows the approximately constant course of the supply from CHP plants and thermal plants (TP) with non-renewable generation and at the same time a significant increase in generation from CHP plants and heating plants based on renewable energy sources.

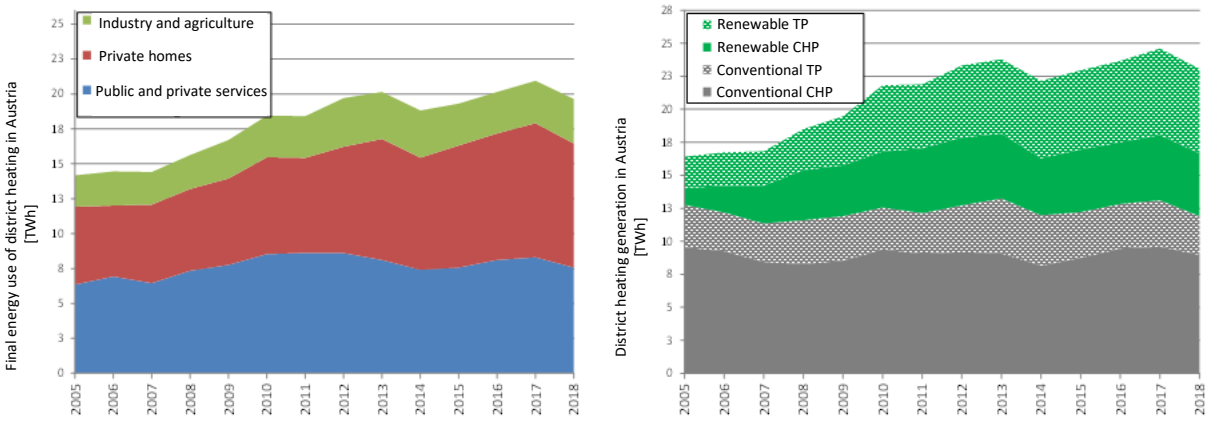

Figure 4: Final energy use and type of uptake of the district heating sector in Austria (Statistik Austria 2018b)

The increase in district heating demand was almost exclusively met on the generation side by the expansion of heating plants and combined heat and power plants using renewable energy sources (mainly biomass). In 2018, wood waste accounted for the largest share of biogenic energy sources at over 88%. The total share of renewable energy sources in district heating generation increased from 22% in 2005 to 48% in 2018. The share of heat generated in CHP plants has always been between 56% and 67%. The generation from the individual energy sources is shown in Figure 5.

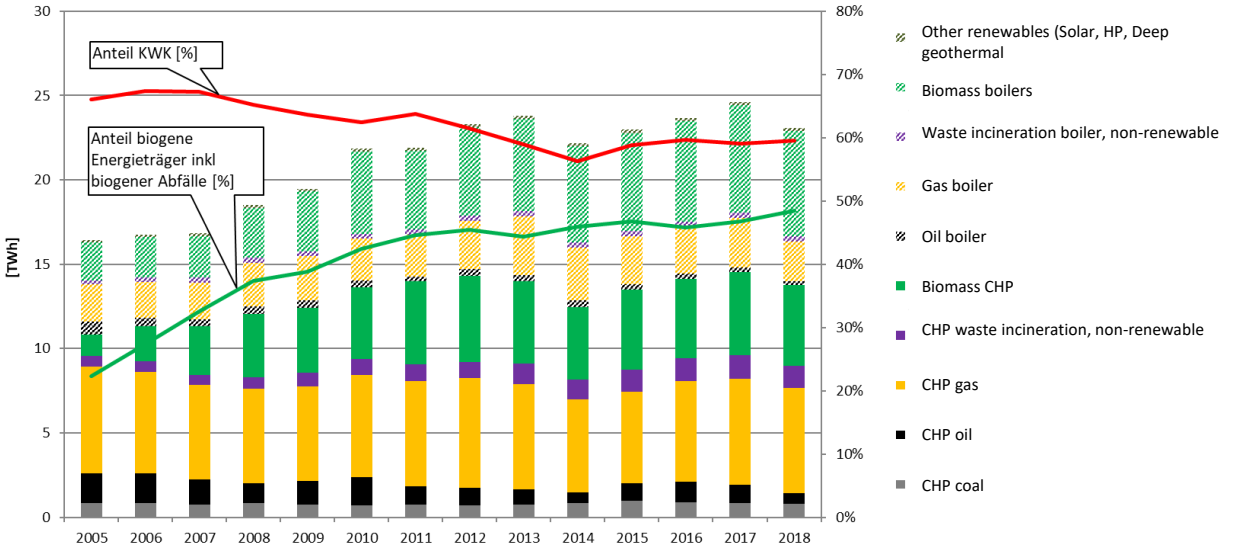

Figure 5 Shares of energy sources in district heating generation (Statistik Austria 2018b)

The current situation of district heating supply for private households is derived from the results of the housing survey in the micro census (Statistik Austria 2019). According to this, more than 1 million of the total of almost 4 million primary residences were supplied with district heating in 2019. This corresponds to a share of 26.7% of Austria's main residences. According to the Austrian Association of Gas and Heat Suppliers (FGW), heat was supplied by heating companies to end customers in a total network of around 5,600 km in 2019 for this purpose (Fachverband Gas Wärme 2020).

Figure 6 shows the distribution of the final energy consumption of district heating among the Austrian provinces. The distribution of grid-connected heat supply varies considerably among the individual provinces. It can be seen that almost one third of the total district heating is sold in Vienna, followed by Upper Austria, Lower Austria and Styria. Vorarlberg and Burgenland come last. Vorarlberg and Burgenland also have the lowest sales per capita. The highest per capita sales are in Carinthia and Vienna. However, an upward trend in district heating supply can be observed in all federal provinces.

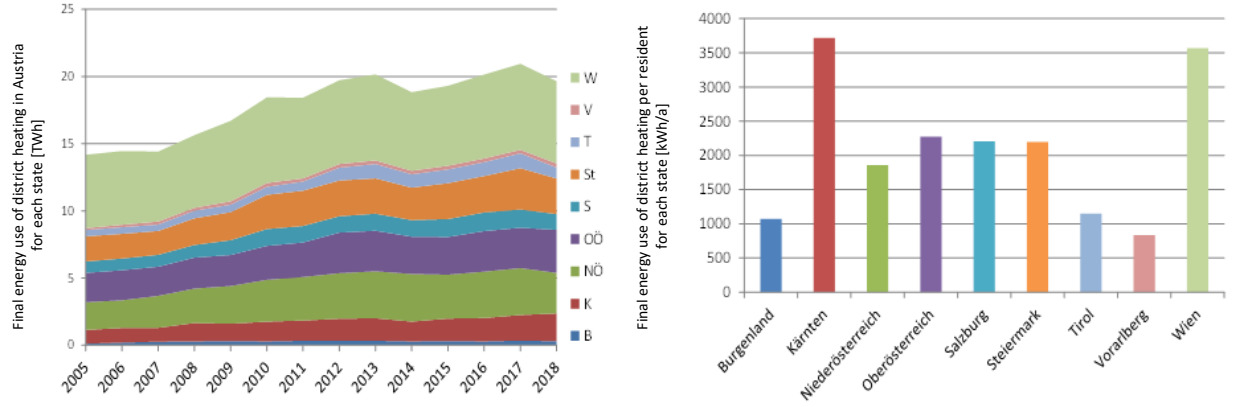

Figure 6 Development and shares of final energy consumption of district heating by federal states (Statistik Austria 2018c)

2.1.2.2 Supply structure of district heating networks (generation plants and companies)

A wide variety of heat sources can be used to supply district heating networks. These range from CHP plants (cogenerated heat) and heating plants to industrial waste heat and the feed-in of solar or geothermal heat by means of heat pumps and direct electric heaters. In principle, district heating in Austria is provided on the basis of the following options:

- Heat from CHP plants of various fuels
- Heat from waste incineration plants
- Heat from heating plants with various fuels
- Industrial waste heat
- Geothermal heat
- Solar thermal heat
- Large-scale heat pumps

Because of these many possibilities, the supply structure of district heating networks varies greatly. In the larger cities, the networks were originally fed mostly by coupled heat generated from the CHP plants of the electricity suppliers. In these large networks, however, heat from biomass or waste incineration also plays a major role, and alternative sources such as industrial waste heat or large heat pumps are increasingly being used. In addition, in the larger cities, boilers are usually needed to cover peak loads and as an outage reserve. In smaller communities, district heating networks are mostly fed by biomass heating plants or biomass CHP.

In 2018, 72 fossil-fired thermal power plants, 472 biogenic-fired thermal power plants, and 23 other thermal power plants (other biogenic, other fuel, and mixed-firing) were in operation in Austria, for the primary purpose of electricity generation. Of these total 567 power plants, almost 90% of the installed electrical capacity of about 7.2 GWel were CHP plants (E-Control 2018).

The 472 biogenic-fired power plants provide an installed electrical capacity of almost 500 MWel. Here, most of the plants not operating as CHP are biogas-fired micro gas turbines or small gas engines for electricity generation. The total thermal capacity of all CHP plants (fossil and biogenic) was more than 8.8 GWth in 2018, generating almost 32 TWh of heat (E-Control 2018). The development of the thermal and electrical outputs of all fossil and biogenic CHP plants in operation since 2005 is shown in Figure 7 (E-Control 2019). This shows that the installed thermal and electrical capacities of CHP plants increased steadily until 2011 and have since declined again slightly. The cumulative capacity of power plants without CHP, on the other hand, has been constantly declining.

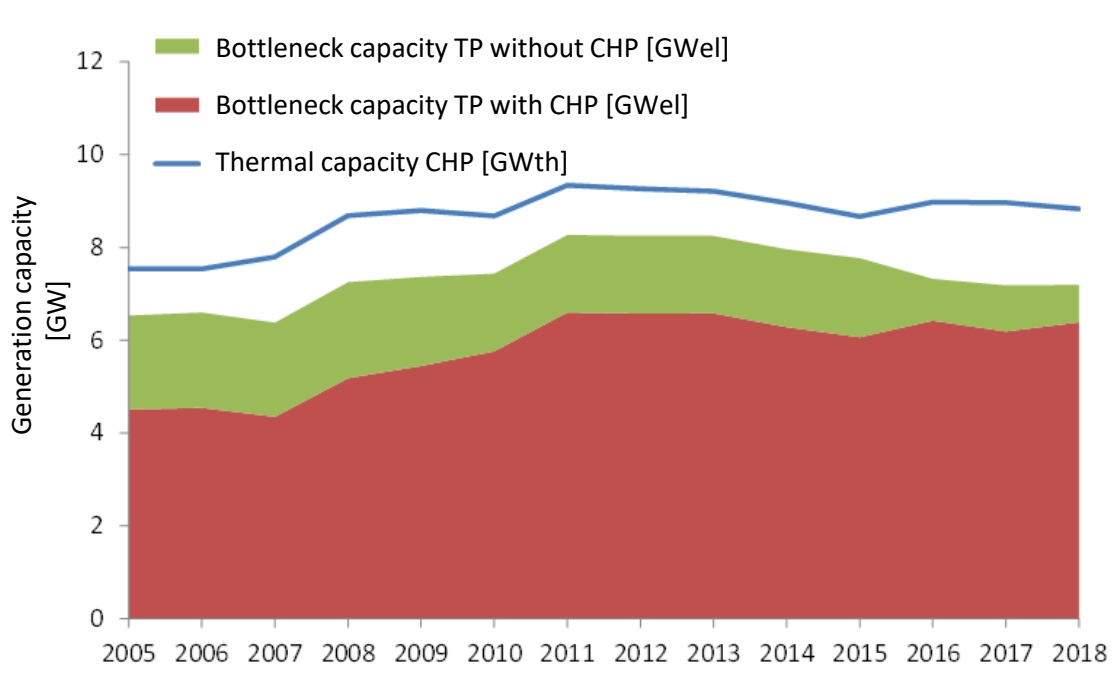

Figure 7: Installed capacity (electric and thermal) of thermal power plants in Austria (E-Control 2019)

In Austria, large heating plants fired by fossil fuels are found almost exclusively in large cities. The majority of all heating plants are smaller heating plants which are supplied with biogenic energy carriers. According to the Biomass Heating Survey 2019 (Haneder 2020), a total of 828 wood chip furnaces with a heat output greater than 1 MWth have been installed since 2000. Based on the average capacity of 2.9 MW, this results in a total capacity of almost 2,400 MWth. For plants of this size, it can almost always be assumed that they are used for feeding into a local or district heating network. Assuming an average service life of about 20 years for these plants, there are currently 870 plants of this size installed with a total capacity of 2,500 MWth.

For the disposal of waste, there are 34 incineration and co-incineration plants in Austria with a capacity exceeding 2 t/h. Of these, 18 plants are assigned to industry, 8 plants to energy utilities, and 8 plants to special municipal or recycling companies (Kellner 2020). In particular, the plants of the municipal and energy supply companies already feed to a large extent into district heating networks. Industrial co-incineration plants mostly serve to generate their own heat for specific processes. Furthermore, there are 26 incineration and co-incineration plants with capacities below 2 t/h which are not discussed in more detail here (Kellner 2020).

Industrial waste heat to an economically usable extent mainly accumulates in energy-intensive industry. If a sufficiently high temperature level and a sufficiently high heat flow are still available after the internal use of the heat, it is advisable to feed this cheaply available energy into a nearby district heating network.

Already today, some large industrial plants feed their waste heat into a district heating network. Particularly for larger networks, this covers part of the base load, since the heat is generated continuously in many processes. Examples of waste heat feeds that have been implemented are:

- KWK der OMV Schwechat speist in das Wiener Fernwärmenetz

- Hrachowina und Henkel Austria speisen in das Wiener Fernwärmenetz
- Stahlwerk Marienhütte speist in das Grazer Fernwärmenetz
- Böhler Edelstahl speist ins Fernwärmenetz Kapfenberg
- Voestalpine Stahl Donawitz speist ins Fernwärmenetz Leoben
- Zementwerk Hofmann Kirchdorf speist ins Fernwärmenetz der Energie AG in Kirchdorf

According to the analyses of (Moser, S., Lassacher, S. 2020) , the decoupled waste heat in Austria amounts to approx. 1.8 TWh/a. However, the temporal fluctuations over the years must be taken into account, which are caused, for example, by a change in production. According to data from *Kommunalkredit Public Consulting GmbH*, the decoupled waste heat from plants that have been subsidized since 2011 amounts to around just over 0.8 TWh/a (KPC 2021). However, these data only include publicly funded projects that have been systematically recorded since 2011. This explains the significant deviations between the researched waste heat quantities. Possible annual fluctuations of the actually fed-in waste heat quantities must also be taken into account in the KPC data. In addition, it is noted that in connection with the calculations carried out within this study the waste heat quantities stated above are not limited to companies within the ETS. In Table 4, the values were given based on (Moser, S., Lassacher, S. 2020).
Geothermal (hydrothermal) uses in Austria are limited to potential areas in Upper Austria and Styria. A total of 12 plants for the use of geothermal energy are available, with eight plants in the Upper Austrian basin and four plants in the Styrian basin. All of the Upper Austrian and at least two of the Styrian geothermal plants are used to generate district heating (Könighofer et al. 2014a). Upper Austria currently has the highest installed thermal capacity from geothermal sources. In total, about 70MWth are provided by seven plants (Lassacher 2018). Figure 8 shows geothermal potential areas in Austria.

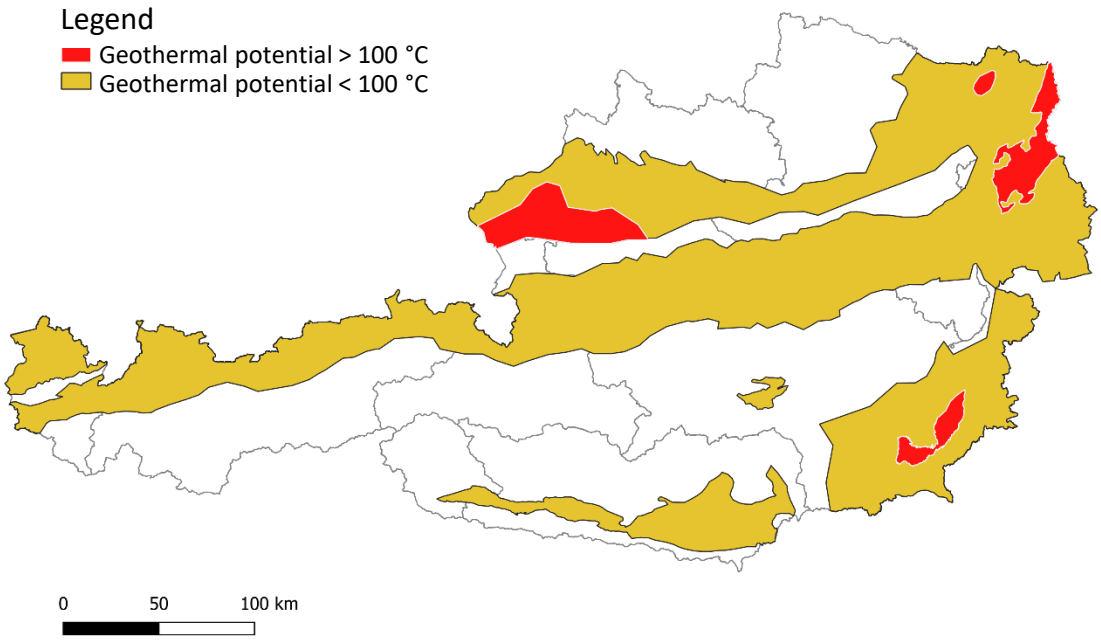

Figure 8: Geothermal potential areas in Austria (source: own figure based on association Geothermal Energy Austria, 2019)

Large-scale solar thermal systems offer the possibility of using solar energy to produce heat for district heating networks. Due to the predominant heat production in the summer months, they are particularly suitable for networks where no cost-effective heat supply is available in summer (e.g., through waste

incineration or waste heat utilization). As of the end of 2019, there were approximately 5.05 million square meters of thermal solar collectors in operation in Austria, corresponding to an installed capacity of 3,535 MWth. The average annual market growth in Austria between 2000 and 2010 was 7%. During this period, the annual installed capacity almost doubled from 117 MWth to 200 MWth. Since 2010, however, market growth has been declining. For the year 2019, a market decline of 8% was recorded. The installed capacity in 2019 is the same as in the early 1990s. Almost all of the installed capacity is used by small residential consumers to produce hot water for their own use (Biermayr et al.). Despite the market decline of solar thermal, which is mainly attributed to the price decline of photovoltaics for the areas of single and multi-family houses, an increasing number of large-scale solar thermal plants have also been built in recent years to support district heating networks. Currently, several large-scale solar thermal plants are integrated into urban district heating systems in Austria. The largest of these plants are listed in Table 2.

Table 2: Large-scale solar thermal systems in Austria (SDH 2017)

Plant	Year	Operator	Location	Area [m²]	Power [kW_{th}]
District heating plant	2006	S.O.L.I.D., AT	Graz	7.750	5.300
Hydroelectric power plant Andritz	2009	S.O.L.I.D., AT	Graz	3.860	2.702
Wels	2011	Elektrizitätswerke Wels, AT	Wels	3.388	2.400
Berliner Ring	2004	S.O.L.I.D., AT	Graz	2.480	1.736
Eibiswald	1997	Nahwärmegen. Eibiswald, AT	Eibiswald	2.450	1.715
Salzburg	2011	GSWB, AT	Salzburg	2.150	1.505
AVL List	2017	S.O.L.I.D., AT	Graz	1.584	1.109
Waldmühle Rodaun	2015	Wien Energie, AT	Kaltenleutgeben	1.500	1.050
Perg	2014	HABAU, AT	Perg	1.420	1.000
Merkur Arena	2002	S.O.L.I.D., AT	Graz	1.407	985
Loeben	2013	Brauerei Göss, AT	Loeben	1.375	963
Villach	2017	Energieinsel Landskron, AT	Villach	1.357	950
Gleinstätten	2006	Nahwärme Gleinstätten, AT	Gleinstätten	1.315	921
Bad Mitterndorf	1997	BIO-SOLAR, AT	Bad Mitterndorf	1.120	784
Wohnen am Lohbach I	1999	Wohnen am Lohbach I, AT	Innsbruck	1.080	756
Sieghartskirchen	2013	Fleischwaren Berger, AT	Sieghartskirchen	1.068	748
Bolaring	2000	Gem. Salzb. Wohn. G.m.b.H., AT	Salzburg	1.056	739
Lodenareal	2009	NEUE HEIMAT TIROL, AT	Innsbruck	1.050	735

2.2 Scenarios for heating and cooling demand

For the estimation of district heating potentials and efficient heat supply, scenarios for the development of space heating and hot water demand are required. These are characterized by renovation, new construction and demolition activities. For the purpose of this study, scenarios were used that are based on the project "Heating demand of small consumers with regard to climate targets 2030 and 2050" in the context of the creation of energy scenarios (Krutzler et al. 2017).

Two scenarios are distinguished: In the "WEM" scenario (with existing measures), it is assumed that the measures already implemented remain in force unchanged. In the "Transition" scenario, a development of final energy demand and final energy use is depicted in which a cross-sectorally consistent overall reduction of Austrian CO2 emissions of 80% compared to 1990 is achieved by 2050. It is emphasized that the "Transition" scenario is thus not in line with the current political requirements, both on the part of the current Austrian government program and on the part of the European Union as well as the Paris Agreement. In chapter 4, which builds on these scenarios, it is therefore assumed that the remaining fossil fuels (mainly natural gas) are provided by renewable gases, while it is assumed that the level of energy demand reduction due to forced building renovation and efficient new construction is sufficient to achieve full decarbonization.

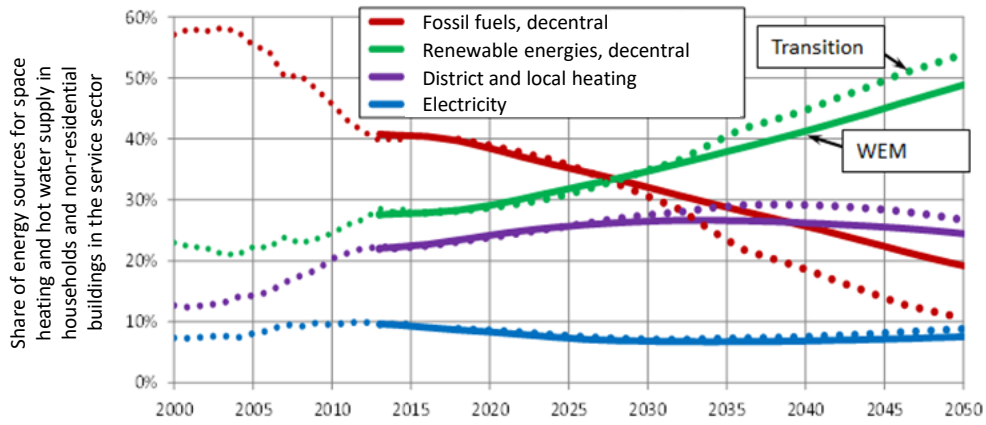

Figure 9: Development of the shares of energy source groups for the heat supply of small consumers in the WEM 2017 and Transition 2017 scenarios (Müller et al. 2017)

While it is possible to reduce the useful energy demand for space heating and hot water by about 50% in the Transition scenario, the reduction in the WEM scenario is only about one third. In Chapter 4, these two scenarios of useful heat demand development are used to determine the economic potential for different individual, decentralized heating systems as well as for district heating under the assumption of a complete decarbonization of the sector - achieved between 2030 and 2050.

Further information on the scenario setting, the policy assumptions, the assumed economic framework conditions, and the renovation and boiler replacement activities implied by the scenarios can be found in (Krutzler et al. 2017).

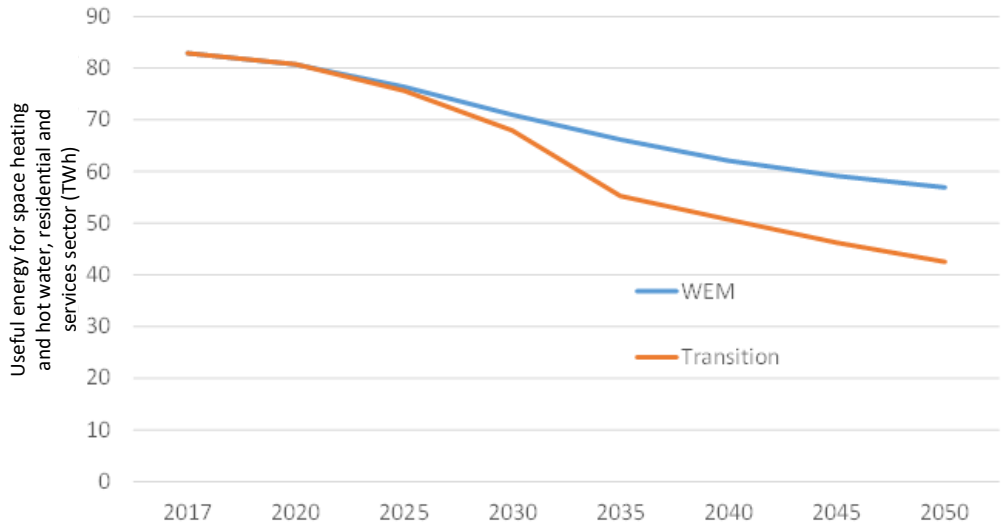

Figure 10: Development of useful energy demand for space heating and hot water in households and the service sector, Austria in the WEM and Transition scenarios

The reporting of the current and projected heating and cooling demand according to the mentioned submission of the European Commission is done by means of information on the final energy demand as well as by information on the useful energy demand.

For the final energy heat demand, the current useful energy analysis of the Federal Statistical Office (Statistik Austria) in Austria was used (Statistik Austria 2018a), which describes the current final energy consumption by useful energy categories. For this purpose, the total energy quantities of all categories relevant for heating demand, namely "space heating and air-conditioning," "steam generation," and "industrial furnaces," were taken into account for residential buildings (private households), services (public and private services), industry (total manufacturing sector), and other sectors (agriculture), respectively.

The data on final energy cooling demand are taken from the results of Heat Roadmap Europe 4 (Heat Roadmap Europe 2017). Here, in the sheet "Aggregation analysis", the section "Shares of type of heat in final heating and cooling by sector" was used for residential buildings, services as well as for industry. Other sectors (namely agriculture) cannot be shown here.

The useful energy heat demand for space heating and hot water is presented on the basis of the WEM or transition scenario described above. The useful energy quantities of the industrial sector were prepared on the basis of scenario data from WIFO (Kratena 2019), whereby the values shown only take into account heat energy ("space heating", "steam generation" and "industrial furnaces"). The final energy quantities determined in this source were converted to useful energy on the basis of assumptions on efficiencies (80%).

Process heating and cooling as well as space cooling is not explicitly considered in the further calculations to determine the economic district heating potential within the scope of this project.

Table 3: Current and projected heating and cooling demand, 2018 and 2017. Reporting as submitted by the European Commission. (Source: own analysis on basis of (Statistik Austria 2018a; Heat Roadmap Europe 2017; Krutzler et al. 2017; Kratena 2019))

				Year					
		Unit	2018(/17)	2025	2030	2035	2040	2045	2050
Heat demand, final energy	Residential buildings	GWh/a	65 397						
	Service sector	GWh/a	24 136						
	Industry	GWh/a	65 587						
	Other sectors	GWh/a	2 730						
Cooling demadn, final energy	Residential buildings	GWh/a	32						
	Service sector	GWh/a	1 821						
	Industry	GWh/a	2 014						
	Other sectors	GWh/a							
Heat demand, useful energy	Residential buildings	GWh/a	53 891	51 304	48 944	46 598	44 366	42 510	40 884
	Residential buildings*	GWh/a	53 791	50 791	46 954	40 372	37 127	34 076	31 202
	Service sector	GWh/a	29 000	25 092	22 041	19 596	17 724	16 646	16 050
	Service sector*	GWh/a	29 003	24 821	20 974	14 906	13 589	12 174	11 343
	Industry	GWh/a	52 971	56 351	58 279	61 162	63 934	65 599	67 278
	Other sectors	GWh/a							

* The scenario developments up to 2050 are based on the WEM scenario, the values marked with an asterisk (*) describe the Transition scenario. As only the space heating and hot water demand in residential and tertiary buildings will be considered in the further course of the study for the calculation of the economic potentials, both scenarios will only be presented for these sectors.

2.3 Waste heat: utilization and potentials

2.3.1 Methodology for calculating waste heat potentials

The industrial waste heat included in the report comprises those production facilities that are subject to the European emissions trading system. For this purpose, all plants were included that appear in the EU Emission Trading System (ETS) Database (Europäische Kommission 2020b) in August 2020. This database contains the annual and plant-specific emissions of all companies that are subject to the ETS. As of August 2020, this database included emission time series from 2008-2019.

As part of the project "Assessment of the potential for the use of high-efficiency cogeneration and efficient district heating and cooling" (Büchele et al. 2015) , which was carried out in 2015 as the first report on Art 14 of the Energy Efficiency Directive, an estimation of the waste heat potential of such plants was already carried out using different methods. On the one hand, the waste heat potentials were determined on the basis of the registered emissions from the ETS - the respective energy input and the corresponding waste heat were calculated via the plant-specific emissions. On the other hand, the waste heat potential was calculated for selected plants on the basis of the respective production volumes.

In order to extrapolate the current waste heat potentials based on the approach from 2015 (Büchele et al. 2015), the change in emissions per plant over time was used. The change in averaged emissions from 2008-2011 (basis of the Austrian Heatmap 2015 calculation) compared to averaged emissions 2016-2019 served as the basis. Based on this change, the waste heat potential was re-estimated. However, this only applies to those plants whose waste heat potential was already estimated in 2015 via the plant-specific emissions. Plants whose waste heat was estimated on the basis of production volumes have been individually reassessed in this study on a case-by-case basis.

The potential for ETS of newly added plants was estimated using the module "User-defined excess heat potentials", which was developed within the HOTMAPS project, based on individual production volumes. In our own research, we also determined whether plants that were subject to the ETS in (Büchele et al. 2015) and are no longer listed in the ETS database still exist or still have waste heat potential. Plants that are neither in 2015 nor currently in the ETS system were not considered (e.g., supermarkets).

2.3.2 Waste heat potential in Austria

The technical waste heat potentials calculated in this study by sector are shown in Fig. 11. The technical potential is to be understood as potential waste heat whose actual development possibilities depend on the individual technical, economic and regulatory framework conditions. Since the calculated values are estimates, they are to be regarded as indications and must be analyzed again in detail when implementing waste heat extraction.

Figure 11 shows that the largest potentials are to be found in the chemical industry, the paper industry, mineral oil processing and the integrated steelworks sector. The integrated steelworks sector refers to the combination of several production stages for the manufacture of steel. The largest waste heat potential is found in the paper industry sector (approx. 5.4 TWh). Looking at the waste heat according to temperature classes, the sectors integrated steel mills, mineral oil processing and the paper industry each have a waste heat potential of approx. 0.5 TWh > 100 °C. The waste heat potential of the integrated steel mills is also lower than that of the paper industry. Lower potentials can also be found in the chemical and cement industries and in aluminum production, as well as in isolated cases in the other sectors. In the temperature class < 100 °C, the chemical industry (approx. 1.4 TWh), the paper industry (approx. 5 TWh), integrated steel mills (approx. 0.3 TWh) and mineral oil processing (approx. 0.7 TWh) show the most comprehensive potentials. For Austria as a whole, the technical waste heat potential amounts to around 10.3 TWh, of which 7.7 TWh are in the temperature range < 100 °C and 2.6 TWh in the temperature range > 100 °C.

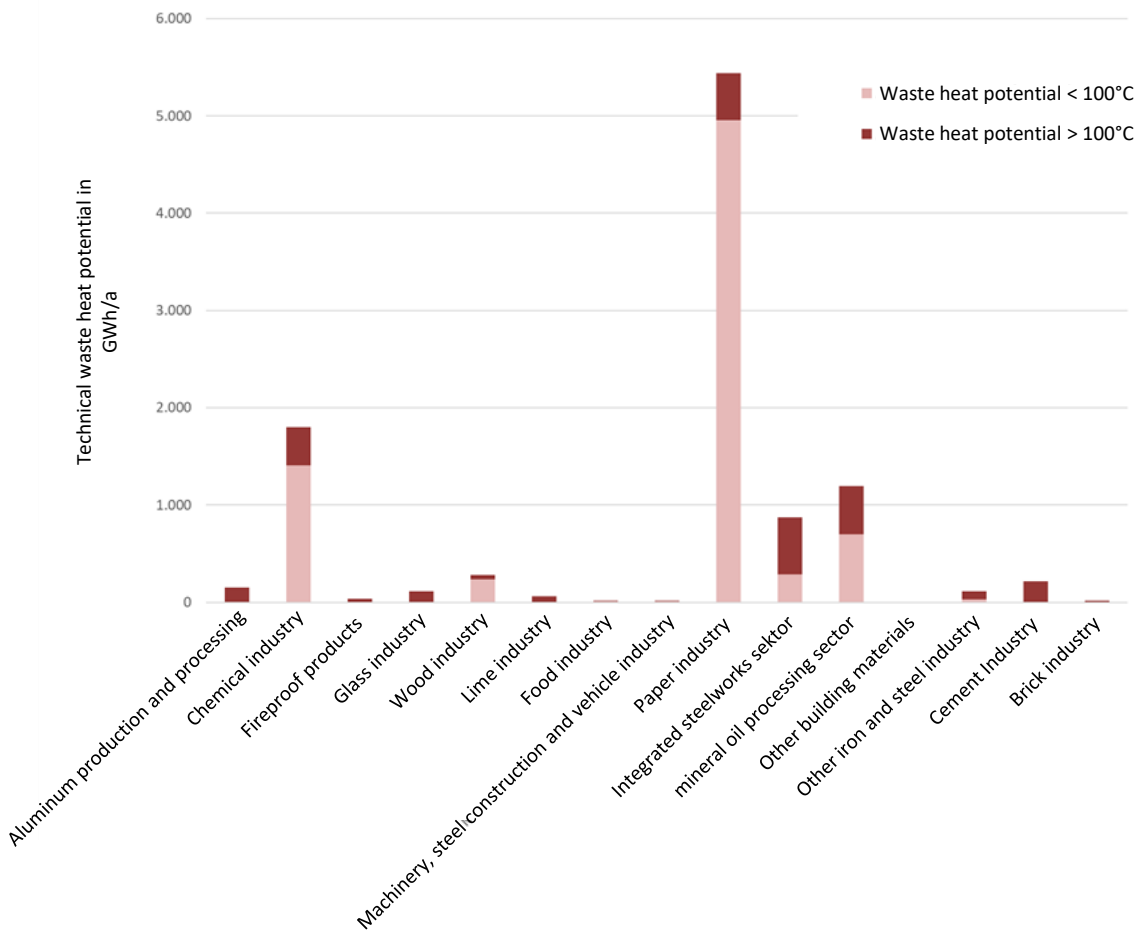

Figure 11: Technical waste heat potential by sector and temperature level (Source: (own calculations), (Büchele et al. 2015)

To determine the available waste heat from thermal power plants and renewable energy plants, their annual electricity generation was calculated on the basis of their rated electrical output and full load hours (E-Control 2018). From this, possible achievable quantities of heat extraction - with corresponding, at least partially heat-controlled operation of the power plants - were estimated. It should be noted here that the interactions on the power system could not be considered in detail.

Waste heat from waste incineration plants is already used to a large extent in Austria. A detailed analysis of possible additional waste heat utilization was not possible within the scope of this study.

Table 4: Determined additional available waste heat, 2018. Reporting in accordance with the submission of the European Commission. (Source: own analysis and research on basis of: (E-Control 2018) (E-Control 2019; Moser, S., Lassacher, S. 2020))

	Threshold	Unit	Value
Thermal power plants	50 MW	GWh/a	3.656
Facilities for the use of renewable energies	20 MW	GWh/a	287
Industrial plants	20 MW	GWh/a	1.806

*The Korneuburg thermal power plant was not taken into account, as it is currently not in continuous operation.

2.4 Map representations

The maps are presented within the framework of the Austrian Heatmap. On the one hand, the heat and cooling density for different scenarios and years (2017, 2030, 2050) is shown there. On the other hand, the map allows the user to display the district heating potentials determined in chapter 4 under different assumptions of connection rates and district heating distribution costs and to read certain core data for these areas.

As additional layers, the Austrian Heatmap provides information on existing heat grids, existing thermal power plants and heating plants as well as industrial waste heat potentials.

3 Goals, strategies and political measures

The currently existing targets, strategies and policy measures in the field of heating and cooling, in particular district heating and cooling, are described below based on the Integrated National Energy and Climate Plan (Bundesministerium für Nachhaltigkeit und Tourismus 2019) and the current government program (Bundeskanzleramt Österreich 2020).

The integrated national energy and climate plan has the following points in which a reference to the heating/cooling sector can be found:

Measures with influence on the target dimension energy efficiency until 2030:

- Increasing the share of efficient renewable energy sources and district heating/cooling for heating, hot water and cooling, including building component activation, active use of hot water tanks and buildings as storage facilities for load balancing and load flexibilization.
- Implementation of Directive 2012/27/EU as amended by Directive 2018/2002/EU, including measures in the buildings sector
- Doubling the renovation rate
- Promotion, regulatory law, identification, and phasing out of counterproductive incentives and subsidies.
- Phasing out fossil liquid fuels

Measures influencing the target dimension of security of energy supply by 2030:

- Investments in district heating network infrastructure
- „The funding priority "heat distribution" includes about 40 projects for feeding waste heat into existing or new local and district heating networks or setting up waste heat distribution networks, which account for a large part of the renewable energy use in this priority."
- Regulatory law, market incentives

Measures with an influence on decarbonization:

- Phasing out fossil liquid fuels: according to the federal government's climate and energy strategy (mission2030), by 2030 around half of the current 700,000 oil-fired heating systems are to be replaced by innovative energy systems based on renewable energy or by efficient district heating (especially based on renewable energy sources). In addition, the aim is to switch existing fossil-fuel boilers that are more than 25 years old to renewable energy sources or district heating from 2025 onward.
- The evaluation of necessary infrastructure measures in the areas of district heating and cooling from renewable energies is being carried out in the course of the current preparation of the Renewable Expansion Act. In addition, an integrated network infrastructure plan is currently being developed.
- Flexibility through intelligent network management (e.g. flexible heating networks)
- Optimization of hybrid low-temperature and anergy networks
- Development of components and systems for heat and cold supply

- As part of the 2019 renovation offensive, the federal government, together with the provinces, offered a funding priority for phasing out fossil-fuel heating systems in residential buildings ("Get out of oil - bonus").

Furthermore, the government program features the following points with regard to the heating/cooling sector:

- Draw up heating strategy: In close cooperation with the federal states, the federal government is developing an Austrian heating strategy with the aim of completely decarbonizing the heating market. This includes promoting local and district heating and improving the spatial planning framework for district heating networks.
- Increase the average renewable share in district heating by at least 1.5 percentage points per year
- Phased plan to phase out oil and coal in the building sector
    - For new construction (from 2020)
    - When changing the heating system (from 2021)
    - mandatory replacement of boilers older than 25 years (as of 2025)
    - Replacement of all boilers no later than 2035
- Analogous to the phased plan for oil and coal, the legal basis for the replacement of gas heating systems will be created:
    - In new construction, no gas boilers/new connections will be permitted after 2025.
    - No further expansion of gas networks for space heating, except for densification within existing networks.
- Roadmap for the gradual unbundling of heating networks

Other measures:

- The Heat and Cold Pipeline Expansion Act is designed to achieve CO2 savings and increase energy efficiency on the basis of investment subsidies. The construction of cooling networks is intended to curb the increase in electricity consumption for air-conditioning and to make cost-effective use of existing heat and waste heat potential, especially in industry.

4 Analysis of the economic potential for efficient heat supply

This chapter presents the analyses of the economic potential for efficient heat supply in Austria. First, the methodology chosen to calculate the economic potential is described, including important assumptions and analyzed scenarios and sensitivities. This is followed by a detailed presentation of the analyses and results of the individual analysis steps, starting with the identification of potentially suitable district heating regions on the basis of the expected distribution costs, the combination of similar regions into region types, the calculation of the costs of heat feed-in into potential district heating networks and the estimation of the costs for object-related supply. Finally, the results of the comparison of the costs for network-related and object-related supply are shown, as well as the economic potentials derived from them.

Due to the clearly predominant share of heat demand in the heating and cooling sector, the analysis of the economic potential is only carried out for heat supply.

4.1 Methodology and chosen scenarios

This chapter describes the methodology for the cost-benefit analysis (CBA) in the context of this study. The methodology is presented, how economic potentials of heat supply from district heating or combined heat and power (CHP) are identified, and which cost components are considered. In addition, the methods for calculating these cost components are presented in detail. This is followed by an overview of the scenario calculations carried out with regard to various cost-relevant input parameters, including a presentation of the parameters selected.

4.1.1 Method

The analysis of the economic potential of efficient heat supply is carried out in the following four steps:

1. identification of regions where district heating could potentially be of interest; this is done on the basis of expected costs for heat distribution according to heat density
2. summary of regions with similar characteristics regarding district heating suitability (previous step) and supply potential resources as well as existing infrastructure to typical regions (region types)
3. calculation of the costs for the heat supply:
    a. rom district heating for different portfolios in the identified region types under different framework conditions.
    b. from decentralized provision in different object types for different technologies and framework conditions
4. identification of the economic potential for efficient district heating and combined heat and power (CHP) by comparing the property-related supply costs and the costs for the supply from

district heating in the identified region types. Aggregation of the potentials in the region types to Austria-wide potentials.

The following Figure 12 shows an overview of the individual steps of this methodology.

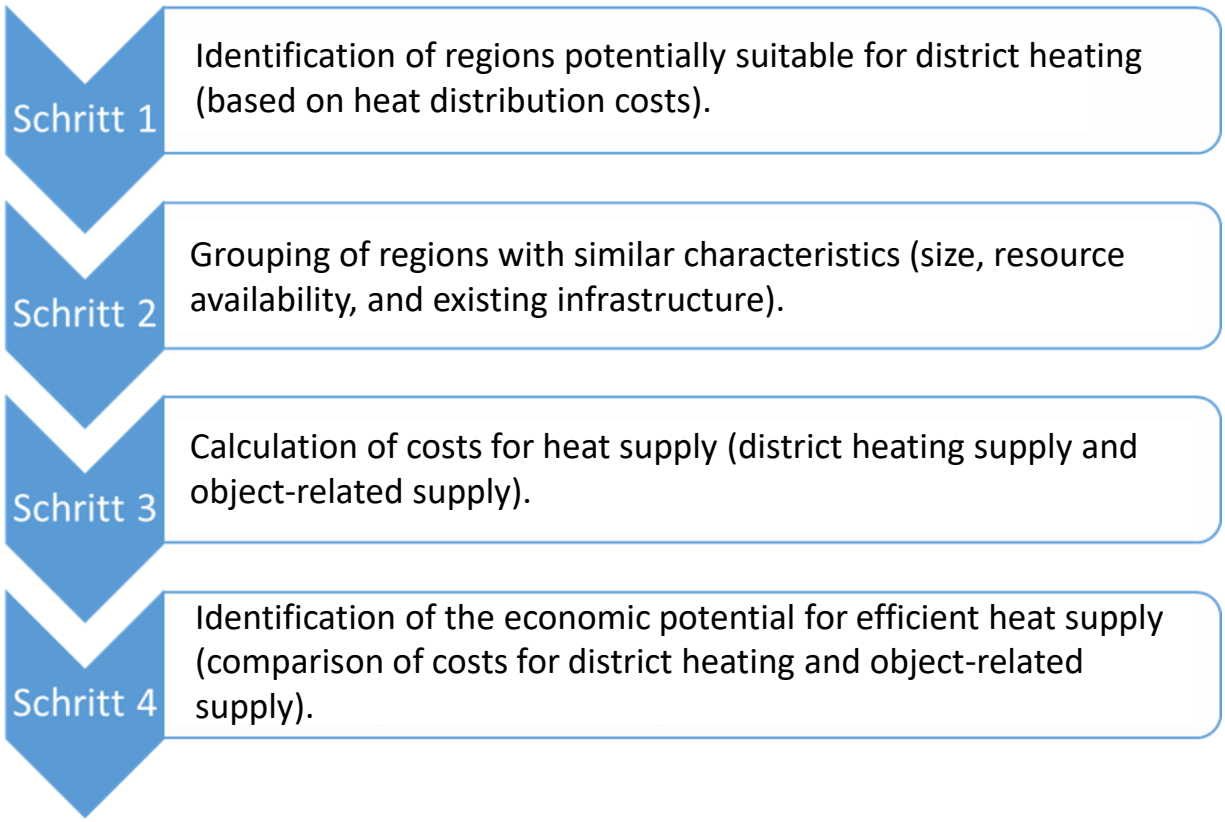

Figure 12: Methodology of cost-benefit analysis (CBA) - step-by-step identification of economic potentials

The methods and assumptions used for these four steps are presented below.

Step 1: Identification of regions where district heating could be potentially interesting

In this first step, heat distribution costs are estimated for each hectare in Austria and average heat distribution costs are calculated for contiguous areas. This is based on the methodology of (Persson, U., Werner, S. 2011) and (Fallahnejad et al. 2018). From the heat demand as well as the built-up area (floor areas), the potential heat supply via a district heating network as well as the capital costs incurred in the process are calculated for each hectare in Austria. Together, these result in potential heat distribution costs for the installation of a district heating network in this hectare. Using defined maximum average heat distribution costs, related areas are then identified that appear potentially suitable for district heating, since the heat distribution costs do not exceed set limits.

The basis for these calculations are the heat demand density maps as well as the development density maps for the years 2030 and 2050, which were created from the WEM and Transition scenarios (see chapter 2.2). Other important input variables are the specific capital costs for the network installation,

the shares of the heat demand in the respective hectare that are covered by district heating (market shares), the limits of the allowable heat distribution costs, and the imputed interest rate. The specific capital costs are taken from (Persson et al. 2019) and 5% is used as the imputed interest rate. Assumptions on market shares as well as thresholds of allowable heat distribution costs are varied in scenarios to show their influence on the size of potential district heating regions.

The result of these calculations are areas that are potentially suitable for the use of district heating under certain assumptions. For each potential district heating area, the heat demand that could be covered by district heating and the average heat distribution costs are calculated.

Further details on the methodology and the results of this step are presented in chapter 4.2.

Step 2: Grouping of regions with similar characteristics into typical regions (region types).

In the second step, regions that are potentially suitable for the use of district heating are now grouped into regions with similar characteristics in terms of size, availability of resources as well as existing infrastructure. First, the following information is identified for each potential district heating region:

- Available potential of industrial waste heat above 100°C, suitable for direct feed into a district heating network by means of heat exchangers
- Available potential of industrial waste heat below 100°C, suitable for feeding into a district heating network by means of a heat pump
- Available potential for deep geothermal energy (Könighofer et al. 2014b)
- Size of any existing river as a potential heat source for heat pumps. (Umweltbundesamt 2020)
- Availability of gas network infrastructure (Müller et al. 2017) and (Büchele et al. 2015) based on (E-Control 2008)
- District heating network already in place or not (Büchele et al. 2015)

The four largest identified district heating regions are then separated from all potential regions. These will be considered separately in further analyses. Specifically, these are the cities of Vienna, Graz, Linz and Salzburg. All other regions are now grouped into six typical regions using cluster analysis. For this purpose, the methodology of the minimum "mathematical distance" between selected parameters is used. The parameters used in this analysis are the data listed above.

The results of this step are presented in chapter 4.3.

Step 3: Calculation of the cost of heat supply

In a next step, the costs for the provision of heat are calculated. On the one hand, the costs of providing heat in district heating systems are calculated, and on the other hand, the costs of providing heat directly in the objects to be supplied. To identify the economic potentials for efficient district heating supply, these costs are then compared with each other. The following Figure 13 shows an overview of the different cost components that are taken into account, as well as an overview of the scenarios that are calculated.

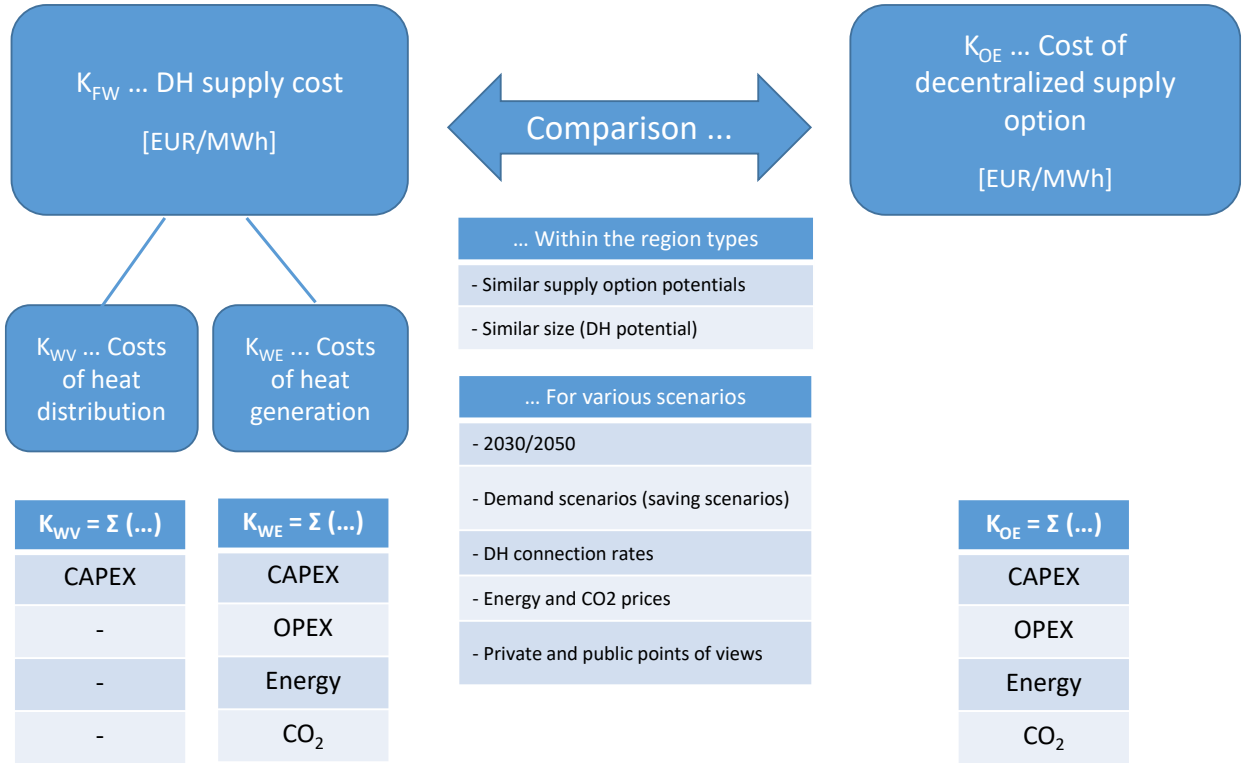

Figure 13: Methodology of the Cost-Benefit Analysis (CBA) - Overview of Cost Components and Scenarios

On the district heating supply side, the costs for heat distribution and the costs for heat feed-in are taken into account. The former have already been calculated in step 1 of the CBA for the various regions potentially suitable for district heating. These costs represent the annotated capital costs for the network infrastructure.

The costs of heat injection into the potential district heating networks are now calculated for the typical regions identified in Step 2. This allows technology portfolios to be applied and calculated in this step according to the availability of resources and infrastructure in each region.

For each typical district heating region, the costs of heat injection are now calculated for different scenarios using a dispatch model. The dispatch model minimizes the running annual costs of the use of a defined power plant park, taking into account hourly changing parameters such as heat demand, supply potential, electricity prices, temperatures in the grid and in potential heat sources. The dispatch model, which was developed within the EU Horizon 2020 project Hotmaps, is used for this purpose. The model allows, among other things, to take into account the dependence of the efficiencies of heat pumps on the changing temperatures in the heat sources and in the networks (upstream) over the year.

A detailed compilation of the calculated scenarios with respect to technology portfolios and heat demands can be found together with the presentation and description of the results in chapter 4.4.

The costs of the object-related heat supply are also calculated with a model, which was developed within the EU Horizon 2020 project Hotmaps. It calculates the necessary installed capacity of the supply system based on the annual heat demand in an object and then for this the costs of heat supply for different technologies or technology combinations. Furthermore, it allows the calculation of reference

costs of object-related heat supply by defining the technology mix in the different buildings. Figure 14 shows this procedure and the necessary parameters and selected scenarios.

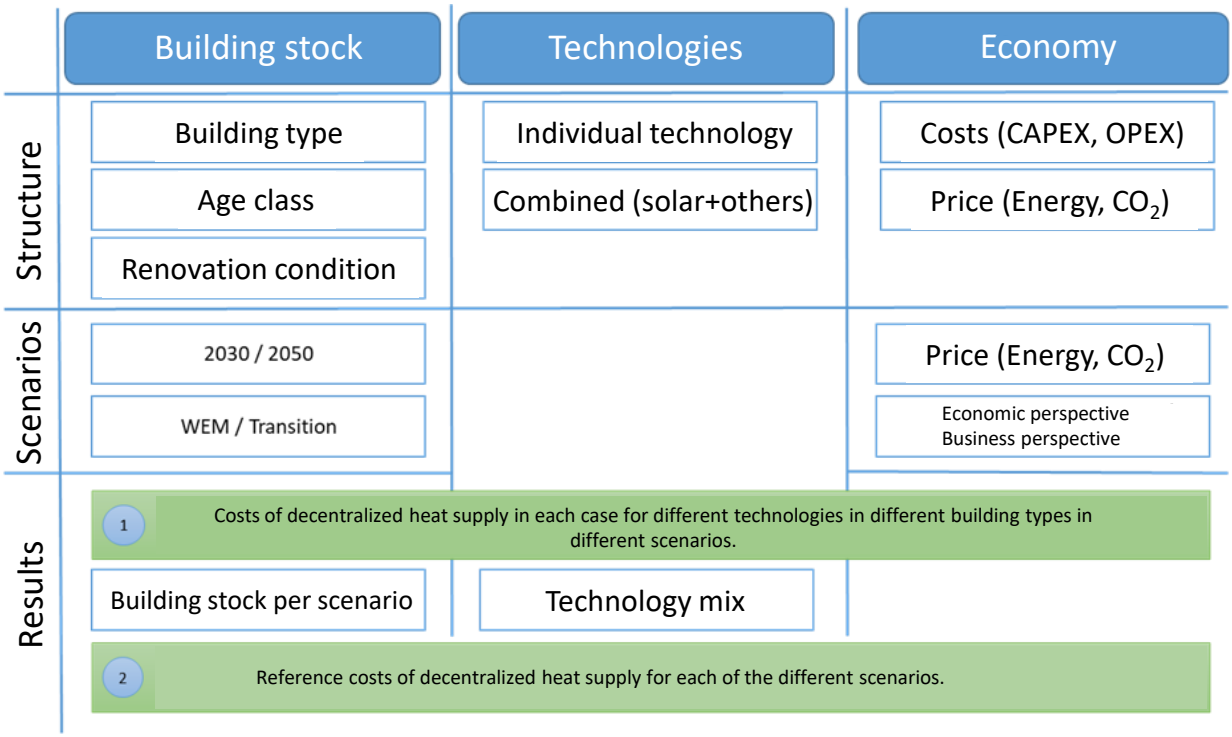

Figure 14: Calculation of costs and scenarios for object-related heat supply

The costs of the object-related heat supply are calculated for different technologies in different typical buildings (single-family houses, multi-family houses, office buildings, etc.) from different construction periods (building age classes). The renovation status of the buildings and the composition of the building stock are taken into account, as they result from the scenarios for the development of the heat demand in the buildings according to scenario WEM and Transition (see also chapter 2.2). For the calculations a module is used, which was developed within the Horizon 2020 project Hotmaps. The module developed in Hotmaps is connected to the Invert/EE-Lab model in this project in order to automatically access central input and output data from the WEM and Transition scenarios.

The results of the calculations for object-related heat supply are presented in chapter 4.5.

Step 4: Identification of the economic potential for efficient district heating and combined heat and power (CHP) generation.

In a final step, the results of the previous steps are now used to identify economic potentials for the use of district heating and CHP. The comparison of heat supply costs from district heating (heat injection + heat distribution) and from object-related options in a region type for a specific set of scenario settings then decides on the economic viability of meeting the respective heat demand from district heating or object-related options. If the cost of providing heat from district heating is lower in a region type in a specific set of scenario settings, the economic viability of meeting the respective heat demand from district heating or object-related options is determined. The sum of the heat supply from the different technologies in all areas of the region type is then the economic potential per technology. This also includes the economic potential for CHP in district heating. Figure 15 illustrates this principle.

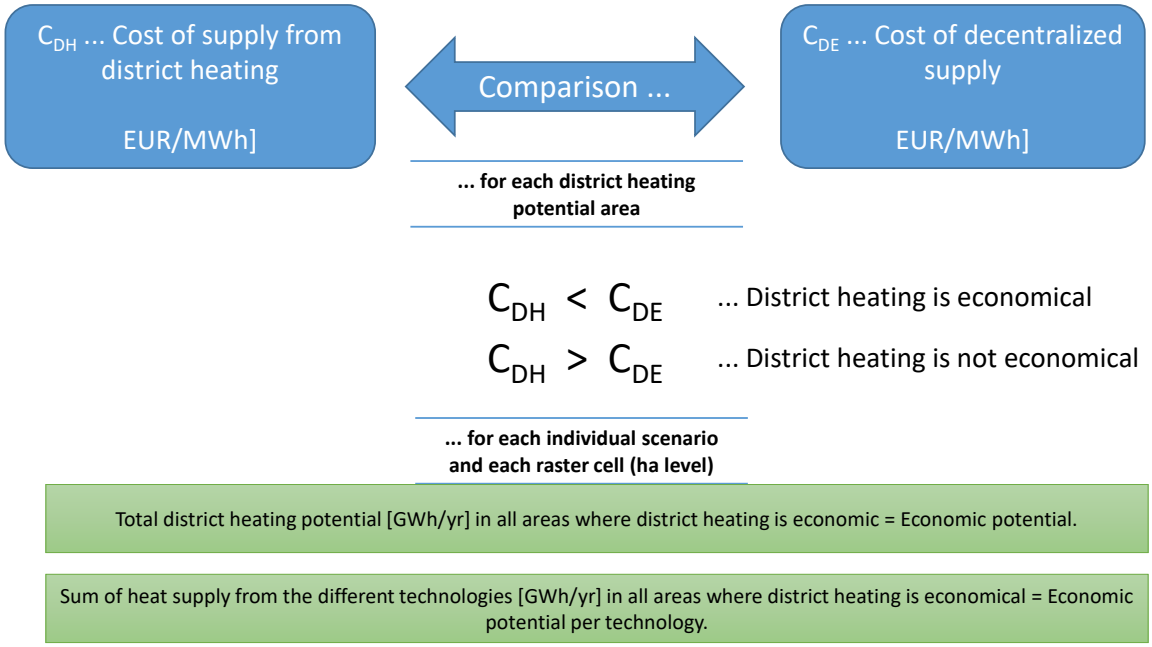

Figure 15: Methodology of cost-benefit analysis (CBA) - identification of economic potential.

The results of this step, and thus the final results of the cost-benefit analysis (CBA), are presented in Section 4.6.

4.1.2 Overview of calculated scenarios and central input data

This chapter provides an overview of the scenarios and the parameters varied in the CBA in the context of this study, as well as key input data for the different steps in the CBA as explained in the previous chapter.

The following tables show the selected scenario variations for the identification of potentially district heating suitable regions (Table 5), in the district heating uptake (Table 6) as well as in the calculation of the object-related heat supply (Table 7).

Table 5: Overview of the selected scenarios in the identification of regions potentially suitable for district heating.

Name	Number	Description
Point in time	2	2030 / 2050
heat demand development	2	WEM and Transition
Market share of district heating in areas potentially supplied with district heating	2	45% vs. 90%
Maximum allowable average heat distribution costs	4	20, 30, 40 and 50 EUR/MWh
Total	32	

Table 6: Overview of the selected scenarios in district heat generation

Name	Number	Description
Cluster	10	4 specific regions (Vienna, Graz, Linz, Salzburg) 6 typical regions (demand / supply potential) For each cluster: • Temperatures (Air, Water, hear sources) • Radiation • Load profile • Resource availability
Point in time	2	2030 / 2050
Economic view	2	Economic / Business
Heat demand	4	Two demand scenarios each per point in time
Energy and CO_2 price	2	Low vs. high prices
Technology portfolios	3	A: BAU predominantly gas B: Alternative 1: Gas with renewables and waste heat C: Alternative 2: Predominantly renewables and waste heat, hardly any gas
Total	480	

Table 7: Overview of the selected scenarios for calculating the reference costs of object-related heat supply

Name	Number	Description
Building stock and demand development	2	Composition of the building stock from 20 different building categories for residential and non-residential buildings, and 11-13 different building age classes per building category. Building stock and demand trends are taken from the WEM and Transition scenarios. Costs and energy source requirements are calculated for individual buildings and excerpted in the results. For the calculation of the reference costs of object-related supply, the costs are weighted according to the composition of the stock.
Point in time	2	2030 / 2050
Economic view	2	Business / Economic
Energy and CO_2 prices	2	Low vs. high prices
Technology portfolios	1	One technology distribution each in the different building types per time and heat demand scenario
Total	16	

Further details on selected input parameter combinations as well as the results of the scenario calculations in the individual areas / steps are presented in the following chapters 4.2, 4.3, 4.4 and 4.5. Related scenario variants from the different areas are then used in the identification of economic potentials. These are presented in chapter 4.6.

Central input parameters for the cost-benefit analysis (CBA) are energy carrier prices, CO2 prices, emission factors, external costs as well as depreciation periods and interest rates. Two approaches are distinguished in all calculations:

- **Economic perspective**: no taxes are taken into account, but external costs are considered; the interest rate is 2% and the depreciation period corresponds to the technical lifetime of the infrastructures.
- **Business perspective**: taxes and CO2 prices are taken into account, but no external costs; the interest rate used is 4% and the depreciation period corresponds to the technical lifetime of the inf-rastructures

Table 8 below describes the key assumptions and data sources on prices and CO2 emissions for this study. The following tables show the parameters selected on this basis for prices, external costs and emission factors for the various energy sources in the different application areas (district heating, private households and services) for the years 2030 and 2050.

Table 8: Assumptions and data sources on prices and CO2 emissions

Energieträger	Annahmen	Datenquellen
Electricity	Hourly wholesale market prices for Austria in two scenarios with different assumptions regarding technology focus and regulatory framework, both scenarios follow an EU decarbonization path until 2050, in Austria there are no net emissions already in 2030. The two scenarios: Common EU-wide vision vs. localized solutions	Calculations with the Enertile model (Fraunhofer ISI 2020) within the framework of the project (SET-Nav 2020). A description of the scenarios can be found in (Sensfuß 2019). Feedback from experts and stakeholders
Gas	Share of green gas (synthetic gas & biogas) in the natural gas grid in 2030 at 6%, in 2050 at 100%. 2030 predominantly biomethane in green gas, 2050 predominantly H2 and PtG. Details on green gas assumptions can be found in Table 20 in the Appendix.	(Agora, V., Agora, E. 2018) (Lambert 2018) (Prognos AG 2020) (Thrän 2014) (Lux, B., Pfluger, B. 2020) (Brändle, G., Schönfisch, M., Schulte, S. 2020) Feedback from experts and stakeholders
Oil	Declining demand for oil => stable, low prices; no more oil for heat supply (2050)	(SET-Nav 2020) and (Sensfuß 2019) Feedback von Experten und Stakeholdern
Biomas	Price stabilization in the low-price scenario, moderater price increase in the high-price scenario; Biomass assumed to be CO2 neutral	Own analyses based on, (IEA 2018) (Biermayr et al.) Feedback from experts and stakeholders
Waste	Waste costs 0 - 5 EUR/MWh Specific emissions reduce by 20% by 2050	Assumptions Feedback from experts and stakeholders
Industrial waste heat	Waste heat costs 5 - 20 EUR/MWh, depending on quality and price scenario For low temperatures a heat pump is needed	Experience Feedback from experts and stakeholders
CO_2	From the same model and scenario as electricity prices (2030: 81-120 EUR/t; 2050: 183-296 EUR/t). External costs CO2 emissions: 300 EUR/t (only in the economic calculations).	(Fraunhofer ISI 2020) within the framework of the project (SET-Nav 2020). Details can be found in (Sensfuß 2019). Feedback from experts and stakeholders

Table 9: Prices, CO2 factors and external costs for the different energy sources in 2030.

2030										
Energy carrier	Low Price					High price				
	Taxes and charges		Emission factor	CO_2 price	External costs	Taxes and charges		Emission factor	CO_2 price	External costs
	With	without				With	without			
	EUR/MWh	EUR/MWh	tCO_2/MWh	EUR/tCO_2	EUR/tCO_2	EUR/MWh	EUR/MWh	tCO_2/MWh	EUR/tCO_2	EUR/tCO_2
Use of the district heating										
Electricity	56	73	0.008	81	300	67.1	84.1	0.012	121.1	300
Natural Gas	29.6	33.6	0.2	81	300	38.2	42.2	0.2	121.1	300
Biogas/ Syngas	68.2	82.2	0.002	81	300	93.2	97.2	0.003	121.1	300
Heating oil	48.4	53.4	0.266	81	300	62.9	68	0.266	121.1	300
Wood chips	18.6	18.6	-	81	300	21.7	21.7	-	121.1	300
waste	-	-	0.13	81	300	5	5	0.13	121.1	300
Waste heat <100°C	5	5	-	81	300	10	10	-	121.1	300
Waste heat >100°C	15	15	-	81	300	20	20	-	121.1	300
Use in residential sector										
Electricity	136.5	199.7	0.008	-	300	147.6	213.1	0.012	-	300
Natural Gas	59.6	80.5	0.2	-	300	68.2	90.9	0.2	-	300
Biogas/ Syngas	98.2	126.8	0.002	-	300	123.2	156.8	0.003	-	300
Heating oil	55.7	72.8	0.266	-	300	70.2	90.2	0.266	-	300
Wood logs	31.7	38	-	-	300	39.2	47	-	-	300
Pellets	53.3	63.9	-	-	300	62.2	74.7		-	300
Use in service sector										
Electricity	136.5	166.5	0.008	-	300	147.6	177.6	0.012	-	300
Natural Gas	59.6	67	0.2	-	300	68.2	75.7	0.2	-	300
Biogas/ Syngas	98.2	105.6	0.002	-	300	123.2	130.6	0.003	-	300
Heating oil	55.7	60.7	0.266	-	300	70.2	75.2	0.266	-	300
Wood chips	25.2	25.2	-	-	300	31.2	31.2	-	-	300
Pellets	53.3	53.3	-	-	300	62.2	62.2	-	-	300

Table 10: Prices, CO2 factors and external costs for the different energy sources in 2050.

2030										
Energy carrier	Low Price					High price				
	Taxes and charges		Emission factor	CO_2 price	External costs	Taxes and charges		Emission factor	CO_2 price	External costs
	With	without				With	without			
	EUR/MWh	EUR/MWh	tCO_2/MWh	EUR/tCO_2	EUR/tCO_2	EUR/MWh	EUR/MWh	tCO_2/MWh	EUR/tCO_2	EUR/tCO_2
Use of the district heating										
Electricity	88.7	105.7	0.002	183	300	127.5	144.5	0.009	296	300
Natural Gas	31.9	35.9	0.2	183	300	41.2	45.2	0.2	296	300
Biogas/ Syngas	88.7	92.7	0.003	183	300	128.7	132.7	0.011	296	300
Heating oil	42.5	47.5	0.266	183	300	55.3	60.3	0.266	296	300
Wood chips	17.9	17.9	-	183	300	28.4	28.4	-	296	300
waste	-	-	0.104	183	300	5	5	0.104	296	300
Waste heat <100°C	5	5	-	183	300	10	10	-	296	300
Waste heat >100°C	15	15	-	183	300	20	20	-	296	300
Use in residential sector										
Electricity	169.2	239.1	0.002	-	300	207.9	285.5	0.009	-	300
Natural Gas	61.9	83.2	0.2	-	300	71.2	94.5	0.2	-	300
Biogas/ Syngas	118.7	151.4	0.003	-	300	158.7	199.4	0.011	-	300
Heating oil	49.8	65.7	0.266	-	300	62.5	81	0.266	-	300
Wood logs	32.3	38.7	-	-	300	51.2	61.4	-	-	300
Pellets	51.2	61.5	-	-	300	81.3	97.6		-	300
Use in service sector										
Electricity	169.2	199.2	0.002	-	300	207.9	237.9	0.009	-	300
Natural Gas	61.9	69.3	0.2	-	300	71.2	78.7	0.2	-	300
Biogas/ Syngas	118.7	126.1	0.003	-	300	158.7	166.1	0.011	-	300
Heating oil	49.8	54.8	0.266	-	300	62.5	67.5	0.266	-	300
Wood chips	25.6	25.6	-	-	300	40.7	40.7	-	-	300
Pellets	51.2	51.2	-	-	300	81.3	81.3	-	-	300

4.2 Potentially suitable regions for district heating based on heat distribution costs

As shown in the previous chapter, areas potentially suitable for district heating are identified by the expected heat distribution costs. The heat distribution costs are calculated on the basis of heat density, building density, investment costs and market shares of district heating in potential areas. Potentially suitable areas are then identified by defining maximum allowable heat distribution costs in related areas.

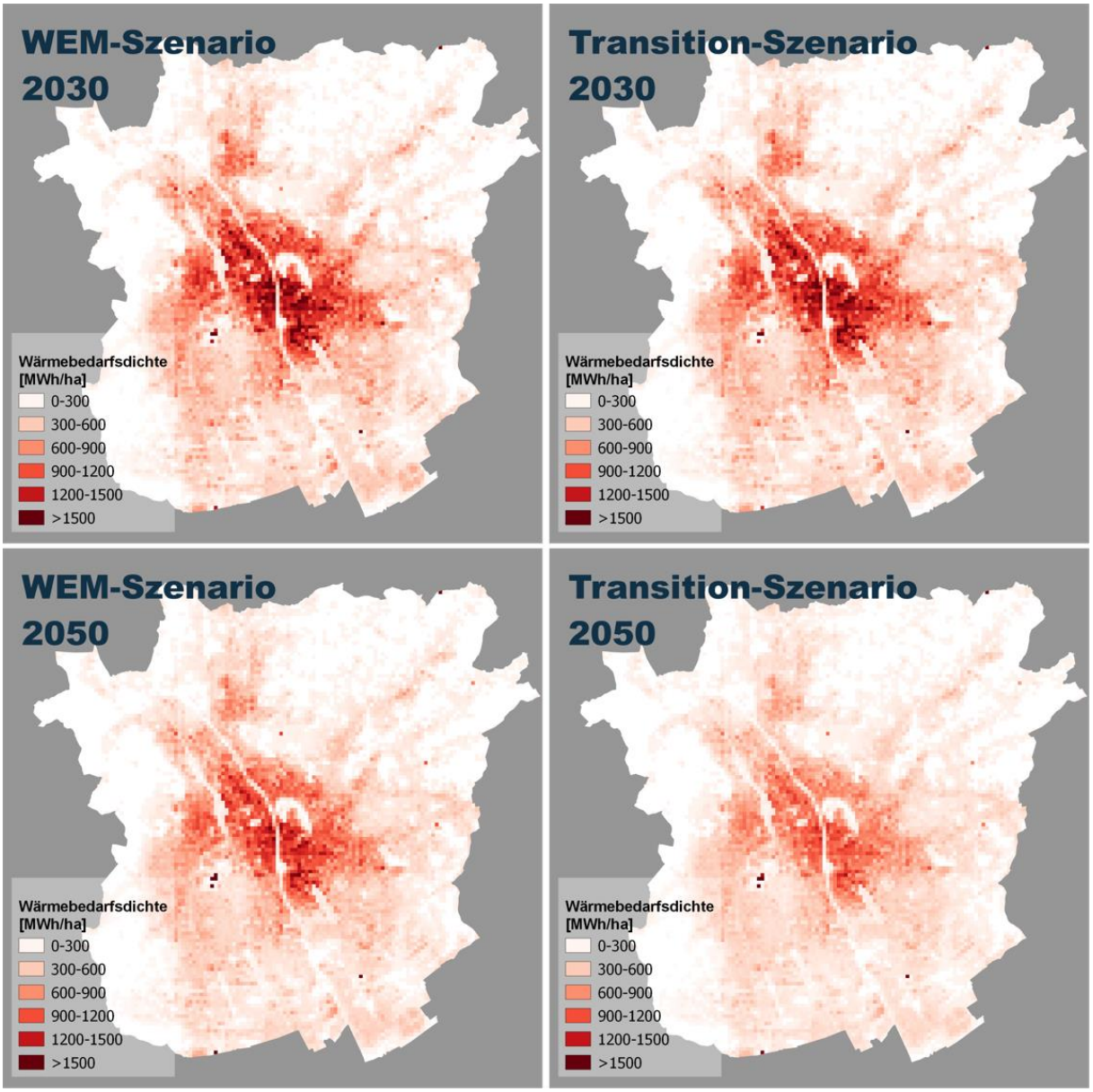

Figure 16: Distribution of heat demand densities in the city of Graz in the two heat demand development scenarios (WEM & Transition) for the years 2030 and 2050.

The calculations are based on heat demand densities and building densities from the scenarios in chapter 2.2. Figure 16 shows the heat demand densities in the city of Graz for the two scenarios WEM and Transition for the years 2030 and 2050.

The Figure 16 clearly shows that the heat demand densities differ significantly in the different scenarios and time points. For 2050 in particular, it is clear that the reduction in demand is much greater in the Transition scenario than in the WEM scenario.

The cost of heat distribution is now calculated for each individual hectare. This is done using the following formula (from Persson et al., 2019).

$$C_{d,T} = \frac{C_{1,T} + C_{2,T} \cdot d_a}{n \cdot \frac{Q_T}{L} \cdot \sum_{t=0}^{n} (1+r)^{-t}}$$

$$d_a = 0.0486 \cdot \ln(Q_T/L) + 0.0007 \qquad [m]$$

$$w = A_L/L = \begin{cases} 137.5e + 5 & [m] \quad 0 < e \leq 0.4 \\ 60 & [m] \quad e > 0.4 \end{cases}$$

T	Timing of the investment
Inv_T	Annualized DC distribution network costs per average heat supplied [€/GJ].
L	Route length [m]
$C_{1,T}$	Construction costs constant [€/m], here 212 €/m
$C_{2,T}$	Construction costs factor [€/m²], here 4 464 €/m²
d_a	Average pipe diameter [m]
n	The amortization period, in this case 30 years
Q_T	Annual heat supply [GJ]
Q_T/L	Heat supply per route length [GJ/m].
r	Imputed interest rate, here 5%
w	Effective width [m]
A_L	Land area, here 1ha

Areas potentially suitable for district heating are now calculated for the following scenarios:

- Demand development: WEM vs. transition scenario
- Dates: 2030 und 2050
- Market share of district heating in potential district heating areas: 45% vs. 90%
- Maximum permissible average distribution costs: 20, 30, 40 and 50 EUR/MWh

In addition to the maximum permissible average distribution costs, a minimum potential of 10 GWh/yr was defined as a further criterion for the suitability of an area for the use of district heating.

In total, the variation of the different parameters results in 32 scenario combinations. The following Figure 17 shows as a result of the calculation the extension and location of potential district heating areas for the combination with consistently advantageous parameters, i.e. the largest possible extension of district heating potential areas according to the chosen approach.

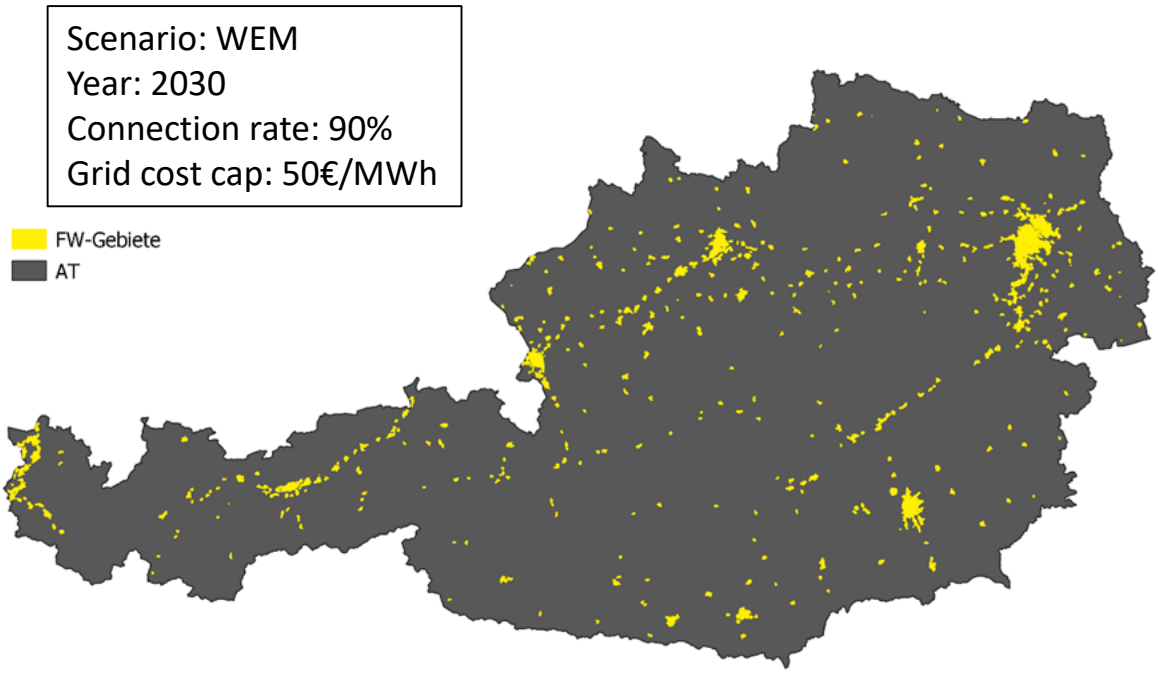

Figure 17: Regions potentially suitable for use of district heating - scenario with consistently favorable assumptions for the year 2030 (and thus largest possible expansion).

The following Figure 18 shows the potential district heating area Vienna and surroundings. Depending on the scenario combination, this results in a more or less large area potentially suitable for district heating. The assumed market shares of district heating and the maximum permissible heat distribution costs have a major influence on the result.

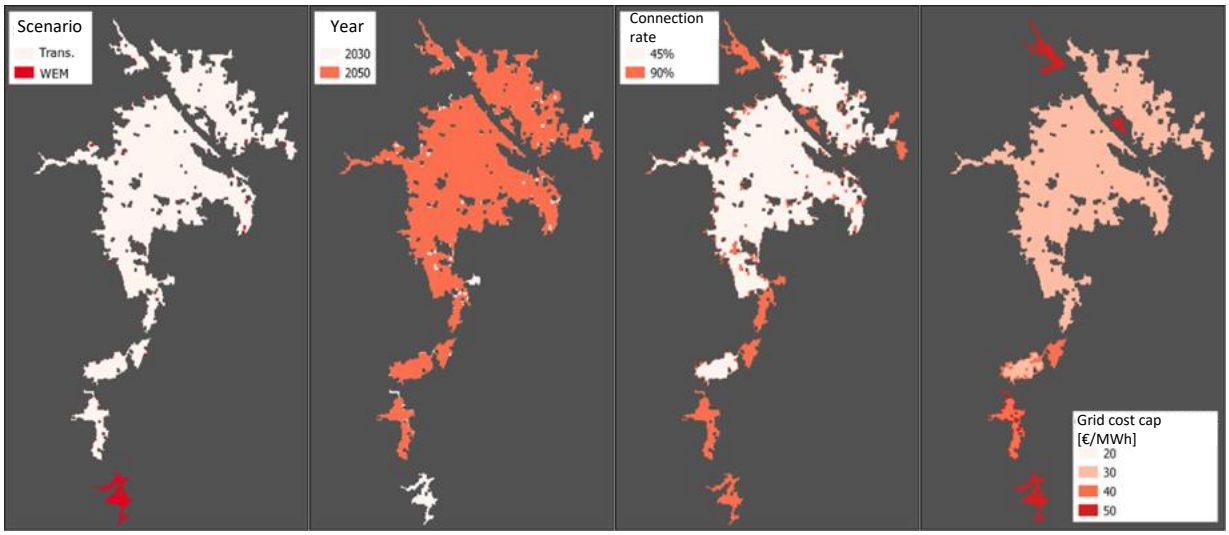

Figure 18: Sensitivity of the expansion of areas potentially suitable for district heating to the different scenario parameters (from left to right: demand development, timing, market share of district heating, maximum allowable distribution costs).

4.3 Identification of typical district heating regions

For the regions identified in the last step as potentially suitable for the use of district heating, typical regions are now identified. First, the four largest regions are singled out. These will be considered individually in the further analyses. These regions are:

- Vienna
- Linz
- Graz
- Salzburg

The remaining regions determined in the previous chapter, which are potentially suitable for district heating due to the distribution costs, are linked in the next step with the respective available potentials for heat generation in order to determine district heating regions with a typical supply structure based on this. The determined regions, which are potentially suitable due to the distribution costs, are not limited to the municipal boundaries, but depending on the scenario and maximum permitted distribution network costs, larger or smaller areas could be supplied.

The number and extent of regions that are potentially suitable for district heating (in addition to the four large, individually considered regions) on the basis of distribution costs varies greatly between 12 and 442 depending on the scenario (demand development, market share of district heating, year, maximum permissible distribution costs, see also Table 5). In the following, the potentials available within the region boundaries are assigned to these potential regions according to the extent per scenario.

From all potential regions across all scenarios, unique combinations of available resource potentials (typical expression of resource potentials) are then determined and these 593 unique combinations of resource potentials are classified into six typical regions.

The following availabilities of heat potentials were used to determine the typical regions:

- Availability of high-temperature waste heat above 100°C (suitable for direct feed into a district heating network by means of a heat exchanger)
- Availability of low-temperature waste heat below 100°C (suitable for feeding into a district heating network by means of a heat pump)
- Potential for deep geothermal energy (Könighofer et al. 2014b)
- Size of any existing river as a potential heat source for heat pumps. (Umweltbundesamt 2020)
- Availability of gas grid infrastructure (Müller et al. 2017) and (Büchele et al. 2015) based on (E-Control 2008))
- Existing district heating network (Büchele et al. 2015)

The following Figure 19 shows the distribution of these potentials and availabilities across Austria.

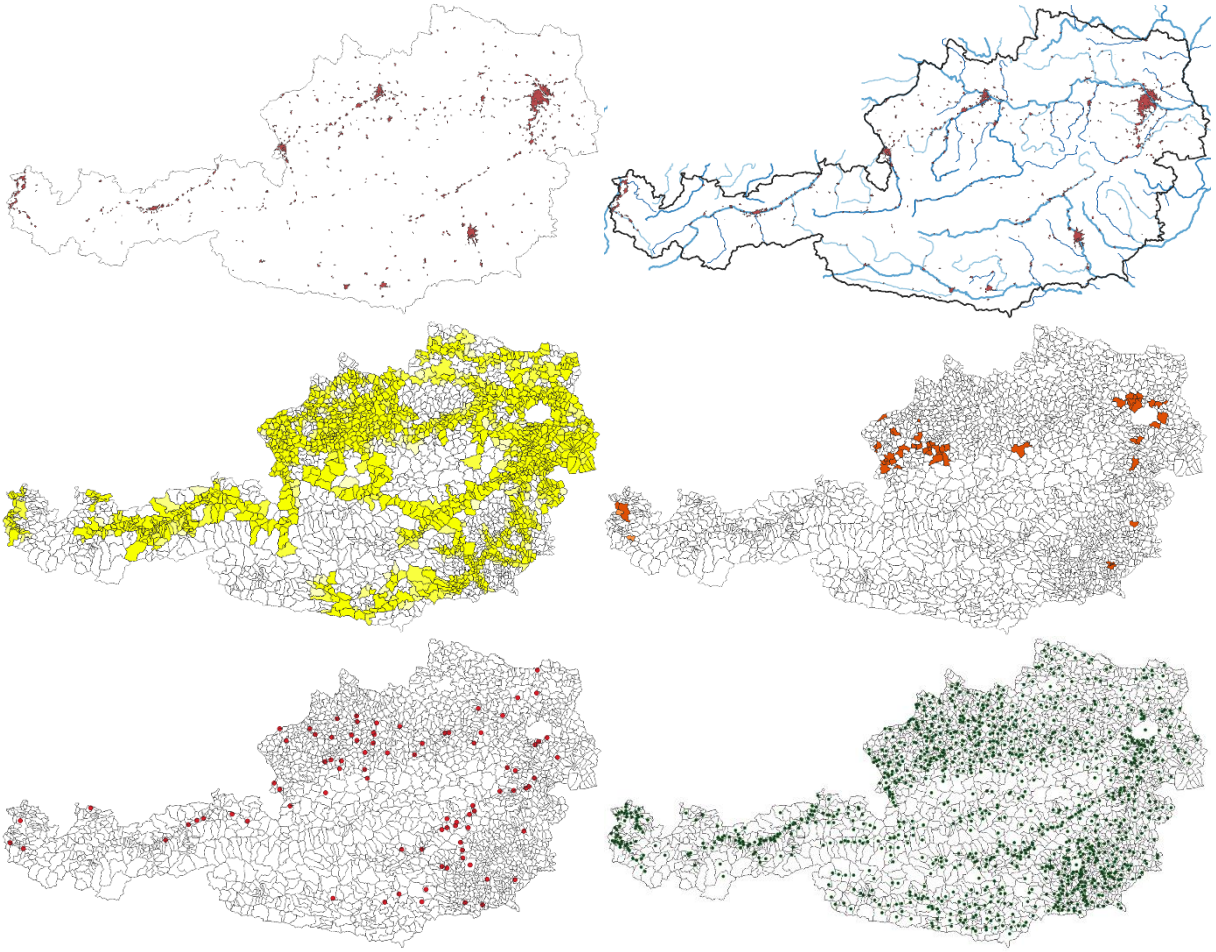

Figure 19: Areas potentially suitable for district heating (top left), rivers (top right), gas grid infrastructure (middle left), geothermal potential (middle right), potential for industrial waste heat (bottom left), existing district heating grids (bottom right) and their distribution across Austria

The allocation of the individual regions to the six types and thus also the threshold values for the allocation is determined by an algorithm which groups together regions with the minimum "thematic distance" between the selected parameters (i.e. regions which are most similar in the existing heat potentials) and groups them step by step. Figure 20 shows an example of the result of this grouping. The horizontal line here shows the section for the division into the six typical regions.

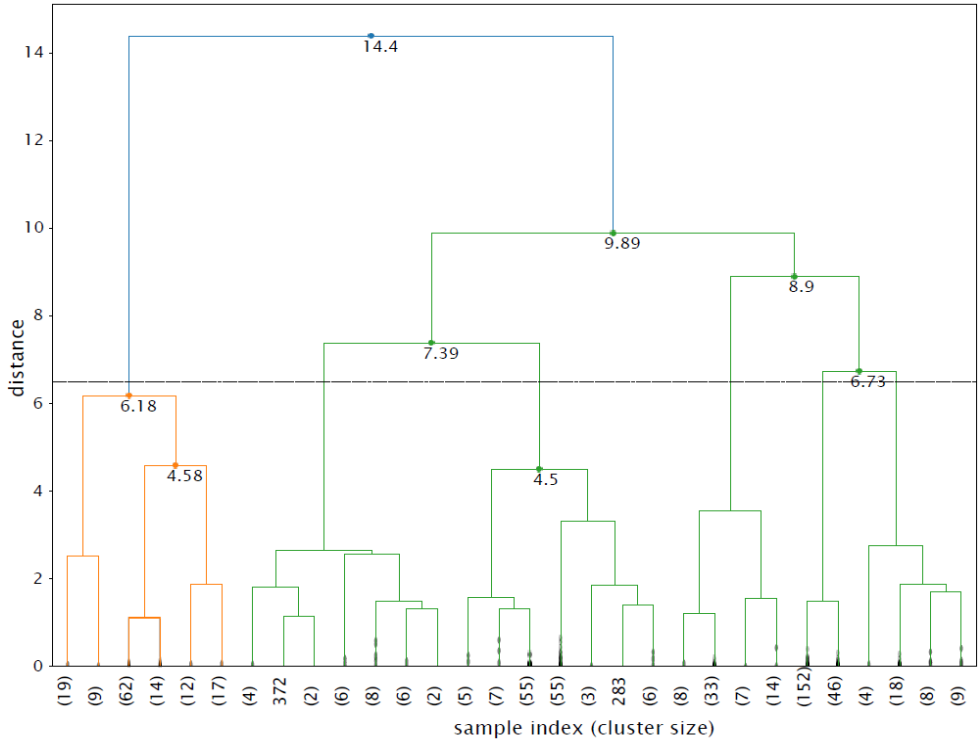

Figure 20: Grouping of all regions potentially suitable for district heating based on their resource availability into different numbers of different regions - the horizontal line shows the average for the classification of the six typical regions in this study.

In Figure 21, the resource availability is shown graphically for all regions potentially suitable for district heating (with the exception of the four largest, which are analyzed individually). 0 means that no potential or no infrastructure is available, 1 means that infrastructure is available or a correspondingly high resource potential is available. The figure shows that in most of the regions potentially suitable for district heating, a gas network is available and in a large part of the regions a more or less large district heating network already exists. Furthermore, it can be seen that the different resources tend to occur in different regions. I.e. in regions with potential for deep geothermal energy there is usually no industrial waste heat potential and no rivers. In regions where there are large rivers, there is hardly any waste heat or deep geothermal energy.

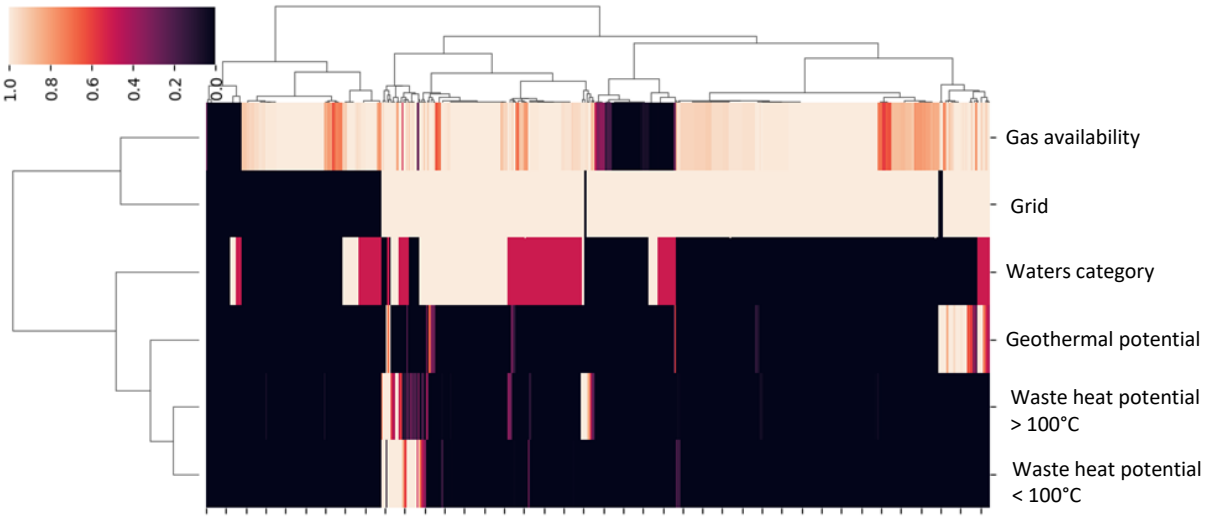

Figure 21: Visualization of resource availability in the regions potentially suitable for district heating - 0 corresponds to "Not available" and 1 corresponds to "Potential 100% available".

These characteristics result in the 6 selected region types for the further investigations. The following Table 11 summarizes the characteristics of these regions qualitatively.

Table 11: Qualitative presentation of the six identified region types and their characteristics in terms of resource availability.

	Existing grid	Gas availability	High temperature waste heat availability	Low temperature waste heat availability	Geothermal potential	Water potential
Type 5: Region without grid, but with existing gas network	No	Yes	No	No	No	Low
Type 6: Region with existing grid without gas infrastructure	Yes	No	No	No	No	Low
Type 7: Region with existing grid, gas infrastructure and high potential for water heat pumps	Yes	Yes	No	No	No	High
Type 8: Region with existing grid, gas infrastructure and geothermal potential	Yes	Yes	No	No	Yes	No
Type 9: Region with existing grid, gas infrastructure and waste heat potential	Yes	Yes	Yes	Yes	No	Low
Type 10: Region with existing grid and gas infrastructure	Yes	Yes	No	No	No	No

Table 12 below shows the details regarding the number and sizes of regions across the different scenarios. The more advantageous a scenario is for district heating deployment, the more regions are potentially suitable for deployment and the higher the values on number and heat demand in the table. Advantageous scenario parameters are high future heat demand, high market shares of district heating in district heating regions, and high maximum allowed heat distribution costs. In the table it can be seen that there is a very high bandwidth for the number and heat demand in all region types due to the variation of the parameters mentioned. To account for this range of potential heat demands, the subsequent calculations in each region type calculate the costs of district heating supply for four different district heating demands for both 2030 and 2050. In the subsequent allocation of the costs of district heating supply to the identified areas, the most similar sizes of the district heating demands are then used in each case.

Table 12: Number and size of regions for the six types of regions identified.

	Number of regions per scenario (min - max) [-]	Heat demand of regions for each scenario (min - max) [GWh]	Sum of heat demand of regions for each scenario (min - max) [GWh]
Type 5: Region without existing grid but with gas infrastructure	2 - 90	10 - 136	54 – 1,670
Type 6: Region with existing grid without gas infrastructure	5 - 195	10 - 675	290 – 9,200
Type 7: Region with existing grid, gas infrastructure and high potential for water heat pumps	2 - 66	10 – 1,100	48 – 5,200
Type 8: Region with existing grid, gas infrastructure and geothermal potential	1 - 43	10 - 50	13 - 750
Type 9: Region with existing grid, gas infrastructure and waste heat potential	1 - 23	10 - 150	40 - 990
Type 10: Region with existing grid and gas infrastructure	0 - 24	0 - 320	0 – 1,400

4.4 Costs of different district heating supply portfolios in the region types

According to the methodology described in chapter 4.1, the mode of action of different district heating supply portfolios was simulated for the (typical) district heating regions identified in chapter 4.3 in order to identify economically favorable technology portfolios on the one hand and to determine the heat production costs of district heating supply on the other hand.

Therefore, the results of two regions are described in more detail in this section. For this purpose, the portfolios for a region with a high potential for river heat pumps and for a region with a high waste heat potential are defined and exemplary results are discussed afterwards.

The following Table 13 describes the construction logic of the portfolios for the region with a high potential for river heat pumps.

Table 13: Logic and basic assumptions for the creation of district heating generation portfolios for the example of cluster 7.

Cluster 7 Region with existing grid, gas infrastructure and high potential for river heat pumps				
Portfolio 1				
Short description	90% gas, the rest is covered by river HP and air HP			
Demand scenario	Very little	Small	Medium	Large
Detaiedl description	80% gas, rest air HP	strong expansion of the air HP strong expansion of river HP (air HP maximized)	Strong expansion of Gas Grid → 80% Gas Strong expansion of river HP (river HP maximized)	Expansion of Gas → 90% Gas
Portfolio 2				
Short description	60% Gas, rest is covered by river HP, air HP, waste water HP and Biomass			
Demand scenario	Very little	Small	Medium	Large
Detailed description	60% air HP 40% Gas	Strong expansion of river HP Air HP is maximized Biomass CHP is maximited	Strong expansion of Gas River HP is maximized Waste water HP is maximized	Strong expansion of Gas Light expansion of waste water HP
Portfolio 3				
Short description	30% Gas and 40% river HP + electric heater and 15% air HP, rest is covered by waste water HP and Biomass			
Demand scenario	Very little	Small	Medium	Large
Detailed description	90% Air HP Rest covered by Gas	Strong expansion of Air HP	Very strong expansion of river HP+electric heater Strong expansion of river HP Expansion of Biomass CHP, solar thermal Light expansion of air HP (Air HP, Waste water HP and Biomass are maximized)	Strong expansion of Gas strong expansion of river HP and electric heater

The specific values for the installed capacities of the individual technologies are defined in the Table 14 below (in MWth).

Table 14: Overview of district heating generation portfolios (MWth) for the Cluster 7 example.

Demand scenario	40 GWh	150 GWh	400 GWh	750 GWh	40 GWh	150 GWh	400 GWh	750 GWh	40 GWh	150 GWh	400 GWh	750 GWh
District heating generation [MWh]	40 000	150 000	400 000	750 000	40 000	150 000	400 000	750 000	40 000	150 000	400 000	750 000
Peak load [MW]	13.3	49.7	132.6	248.7	13.3	49.7	132.6	248.7	13.3	48.7	132.6	248.7
Minimum load [MW]	0.8	3	7.9	14.9	0.8	3	7.9	14.9	0.8	3	7.9	14.9
Portfolio	Portfolio 1	Portfolio 1	Portfolio 1	Portfolio 1	Portfolio 2	Portfolio 2	Portfolio 2	Portfolio 2	Portfolio 3	Portfolio 3	Portfolio 3	Portfolio 3
MVA	-	-	-	-	-	-	-	-	-	-	-	-
Geothermal energy	-	-	-	-	-	-	-	-	-	-	-	-
Waste heat HP	-	-	-	-	-	-	-	-	-	-	-	-
Direct waste heat	-	-	-	-	-	-	-	-	-	-	-	-
River HP	-	15	25	25	-	20	75	75	-	-	75	120
Air HP	4	25	25	25	9	25	25	25	13	50	60	60
Waste water HP	-	-	-	-	-	-	20	25	-	-	35	35
Biomass CHP	-	-	-	-	-	10	10	10	-	-	10	10
Biomass TP	-	-	-	-	-	-	-	-	-	-	-	-
Solar thermal	-	-	-	-	-	-	-	-	-	-	10	10
Electrical heater	-	-	-	-	-	-	-	-	-	-	10	40
Gasturbine	-	-	-	100	-	-	-	65	-	-	-	35
Gas combined cycle	-	-	-	-	-	-	-	-	-	-	-	-
Gas TP	10	11	90	124	5	5	45	95	1	1	10	55
Storage	12.8MW @ 2.7GWH	48.1MW @ 10GWH	128.2MW @ 26.7 GWH	240.4MW @ 50GWH	12.8MW @ 2.7GWH	48.1MW @ 10GWH	128.2MW @ 26.7GWH	240.4MWH @ 50GWH	12.8MW @ 2.7GWH	48.1MW @ 26.7GWH	128.2MW @ 26.7GWH	240.4MW @ 50GWH
Storage size	33 tm^3	123 tm^3	330 tm^3	617 tm^3	33 tm^3	123 tm^3	330 tm^3	617 tm^3	33 tm^3	123 tm^3	330 tm^3	617 tm^3

The next Table 15 describes the construction logic of the portfolios for the region with a high waste heat potential.

Table 15: Logic and basic assumptions for the creation of district heating generation portfolios for the example of cluster 9.

Cluster 9 Region with existing grid, gas infrastructure and waste heat potential				
Portfolio 1				
Short description	75% gas, 20% waste heat and air HP			
Demand scenario	Very little	Small	Medium	Large
Detaiedl description	80% gas, rest air HP	Direct waste heat is maximized Expansion of waste heat HP Light expansion of air HP (gas share at 20%)	Strong expansion of Gas Expansion of waste heat HP to maximum	Strong expansion of Gas
Portfolio 2				
Short description	10% Gas and 30% waste heat and the rest is covered by Air HP, waste water HP, Biomass and river HP + electric heater			
Demand scenario	Very little	Small	Medium	Large
Detailed description	10% Gas 50% Biomass 40% Air HP	Direct waste heat is maximized Expansion of waste heat HP	Maximum expansion of Biomass Expansion of waste heat HP Strong expansion of air HP River HP is maximized	Strong expansion of waste heat HP Strong expansion of air HP Strong expansion of river HP + electric heater Light expansion of Gas
Portfolio 3				
Short description	30% Gas and 40% river HP + electric heater and 15% air HP, rest is covered by waste water HP and Biomass			
Demand scenario	Very little	Small	Medium	Large
Detailed description	70% waste heat HP 30% LWP	Direct waste heat is maximized Expansion of waste water HP	Maximal expansion of waste water HP Strong expansion of waste heat HP Light expansion of air HP	Strong expansion of waste heat HP Strong expansion of air HP Light expansion of river HP

The defined values for the installed capacities of the individual technologies are defined in the Table 16 below (MWth in each case).

Table 16: Overview of district heating generation portfolios (MWth) for the example of cluster 9.

Demand scenario	20 GWh	60 GWh	120 GWh	260 GWh	20 GWh	60 GWh	120 GWh	260 GWh	20 GWh	60 GWh	120 GWh	260 GWh
District heating generation [MWh]	20 000	60 000	120 000	260 000	20 000	60 000	120 000	260 000	20 000	60 000	120 000	260 000
Peak load [MW]	7.1	21.2	42.4	91.9	7.1	21.2	42.4	91.9	7.1	21.2	42.4	91.9
Minimum load [MW]	0.4	1.1	2.1	4.6	0.4	1.1	2.1	4.6	0.4	1.1	2.1	4.6
Portfolio	Portfolio 1	Portfolio 1	Portfolio 1	Portfolio 1	Portfolio 2	Portfolio 2	Portfolio 2	Portfolio 2	Portfolio 3	Portfolio 3	Portfolio 3	Portfolio 3
MVA	-	-	-	-	-	-	-	-	-	-	-	-
Geothermal energy	-	-	-	-	-	-	-	-	-	-	-	-
Waste heat HP	-	4	9	9	-	5	9	19	5	5	16	45
Direct waste heat	-	9	9	9	-	9	9	9	-	9	9	9
River HP	-	-	-	-	-	-	-	-	-	-	-	-
Air HP	2	3	9	9	3	3	9	18	3	3	9	20
Waste water HP	-	-	-	-	-	-	9	9	-	5	9	9
Biomass CHP	-	-	-	-	4	4	9	9	-	-	-	-
Biomass TP	-	-	-	-	-	-	-	-	-	-	-	-
Solar thermal	-	-	-	-	-	-	-	-	-	-	-	-
Electrical heater	-	-	-	-	-	-	-	35	-	-	-	-
Gasturbine	-	-	-	28	1	1	1	9	-	-	-	-
Gas combined cycle	-	-	-	-	-	-	-	-	-	-	-	-
Gas TP	6	6	19	40	-	-	-	-	-	-	-	-
Storage	6.4MW @ 1.3GWH	29.2MW @ 4GWH	38.5MW @ 8GWH	83.3MW @ 17.3GWH	6.4MW @ 1.3GWH	19.2MW @ 4GWH	38.5MW @ 8GWH	83.3MWH @ 17.3GWH	6.4MW @ 1.3GWH	19.2MW @ 4GWH	38.5MW @ 4GWH	83.3MW @ 17.3GWH
Storage size	16 tm^3	49 tm^3	99 tm^3	213 tm^3	16 tm^3	49 tm^3	99 tm^3	213 tm^3	16 tm^3	49 tm^3	99 tm^3	213 tm^3

In the following, an excerpt of the result of three generation portfolios under two district heating demand scenarios for the year 2030 and 2050 as well as under high and low prices and under operational and economic framework conditions is presented for the district heating region with

high potential for river heat pumps. It can be seen (Figure 22) that under the assumption of moderate district heating demand, portfolio 2 has the lowest heat production costs, while in the case of high demand, portfolio 3 proves to be the most favorable in terms of heat production costs.

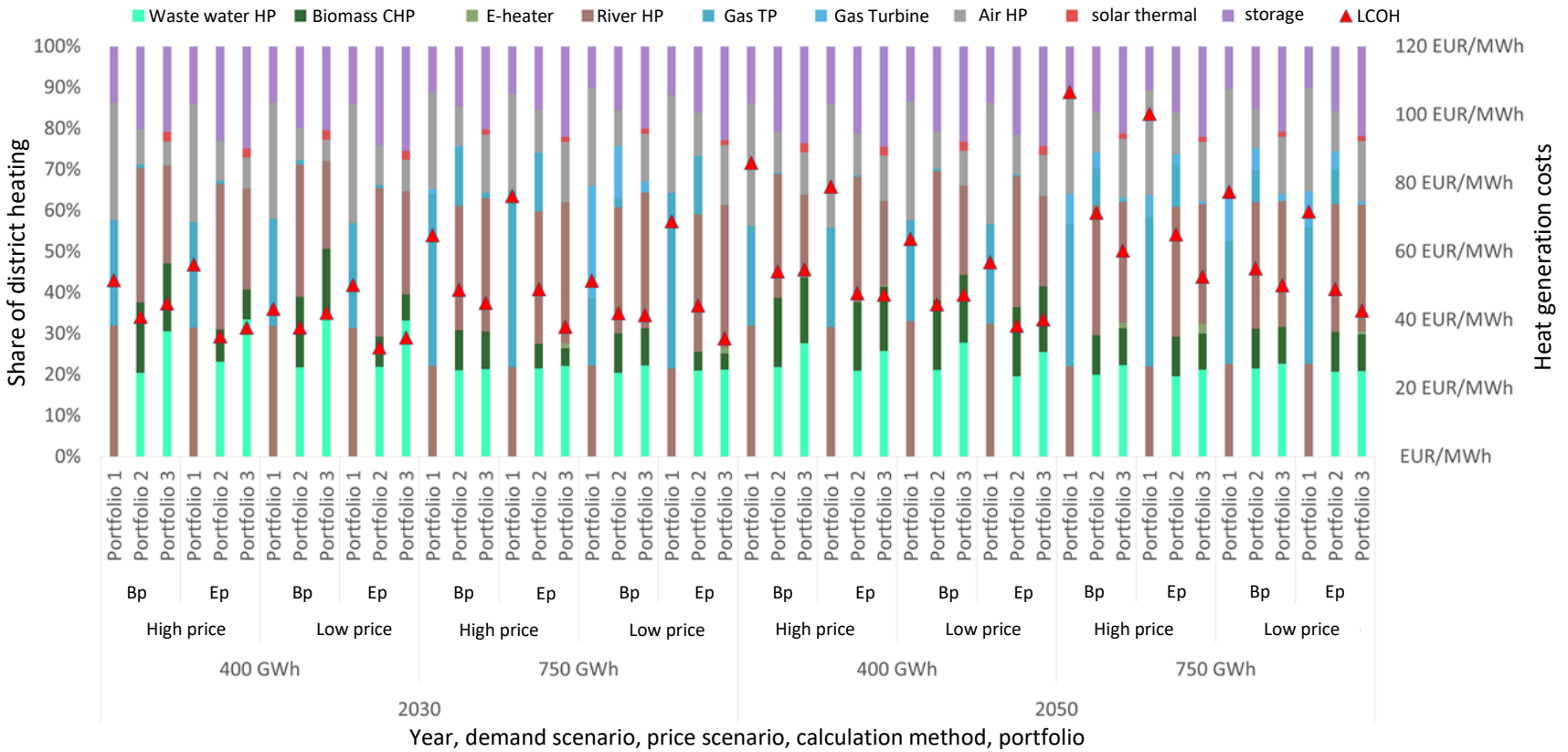

Figure 22: Share of different technologies in district heating generation and the resulting heat production costs for the case of cluster 7 (Bp...Buisness perspective, Ep...Economic perspective).

The Figure 23 below shows an excerpt of the results for the region with high waste heat potential. The graph shows the share of technologies in district heating generation per portfolio for two demand scenarios, for the year 2030 and 2050, as well as under high and low prices and under

operational and economic conditions. It can be observed that the portfolio 3 is the most favorable for the high demand scenario. Furthermore, it can be identified that for the medium demand scenario in 2030 it is more economical to expand gas instead of the biomass plant. However, this changes in 2050.

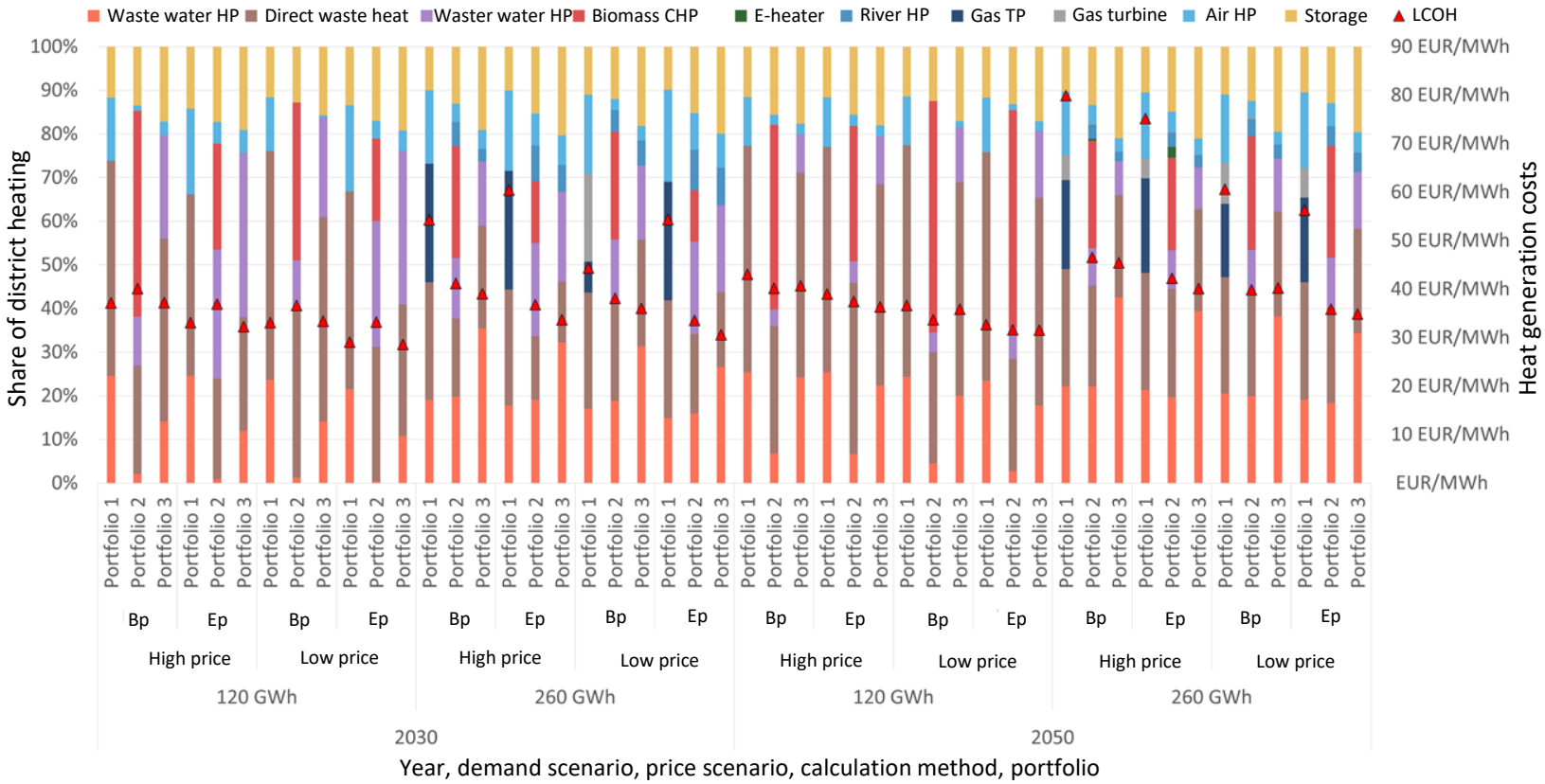

Figure 23: Share of different technologies in district heating generation as well as the resulting heat production costs for the case of cluster 9 (Bp...Buisness perspective, Ep... Economic perspective).

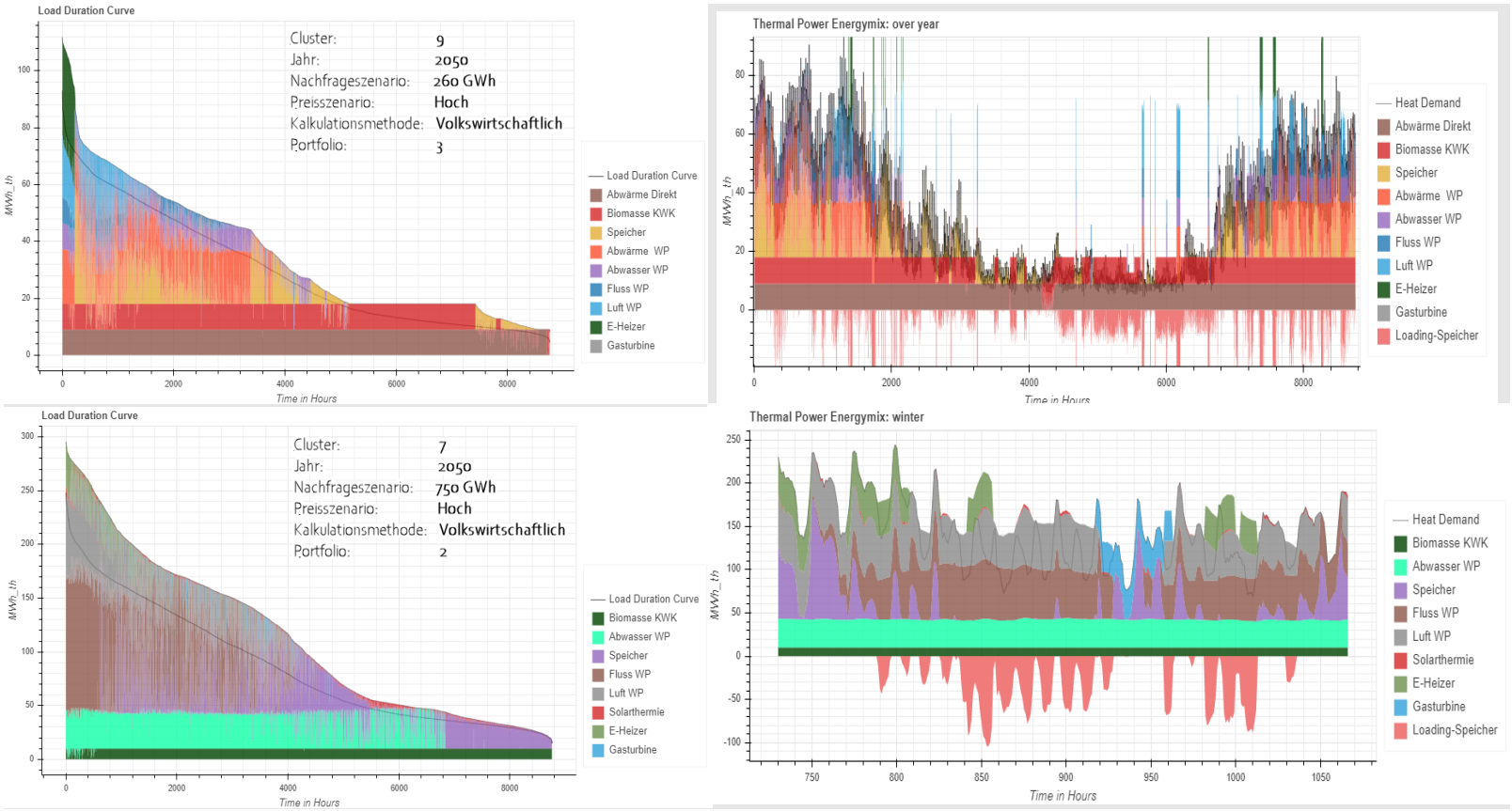

Figure 24: Plot of hourly simulation results for example scenarios from cluster 7 (bottom, heating season) and cluster 9 (top, full year).

In the course of determining the economic potential for the comparison with decentralized supply, the most favorable portfolio is always used.

The heat production costs are determined on the basis of an hourly cost minimization of the technology deployment. A selected result is shown in Figure 24, which shows the hourly use of the technologies for the two regions investigated.

Based on these results, the heat distribution costs for each individual region are added to the district heating generation costs on the basis of the analyses in chapter 4.2 in order to arrive at the region-specific costs of district heating supply.

4.5 Costs of object-related heat supply

To calculate the economic potential of district heating, the costs of district heating supply in all identified potentially suitable regions are compared with reference costs for object-related heat supply. As shown in chapter 4.1.1, the costs of heat supply are calculated directly in the objects / buildings for different typical buildings, different supply technologies and different scenario variants with the model Invert/EE-Lab. For the most part, existing scenarios and underlying data and assumptions from the project "Heat demand of small consumers with regard to climate targets 2030 and 2050" in the context of the creation of energy scenarios (Krutzler et al. 2017) are used (see chapter 2.2). For the two scenarios WEM and Transition, the following data are adopted for the analyses presented here for the years 2030 and 2050: the development of the building structure (demolition and new construction of different building types) and their thermal properties (type and prevalence of renovation measures in different building types) as well as the costs and efficiencies of heat supply technologies. Energy carrier prices as well as CO2 emission factors are adjusted to the assumptions in the present study (see Table 9 and Table 10). In a first step, the costs of heat supply (Levelized Costs of Heat in EUR/MWh) are calculated for all different typical buildings using different supply technologies and scenario variants in the years 2030 and 2050. The following two figures show the results of these calculations for two typical buildings, which have relevant shares in the Austrian building stock: Figure 25 shows the results for single-family houses built between 1990 and 1999, and Figure 26 shows the results for office buildings built between 1946 and 1969.

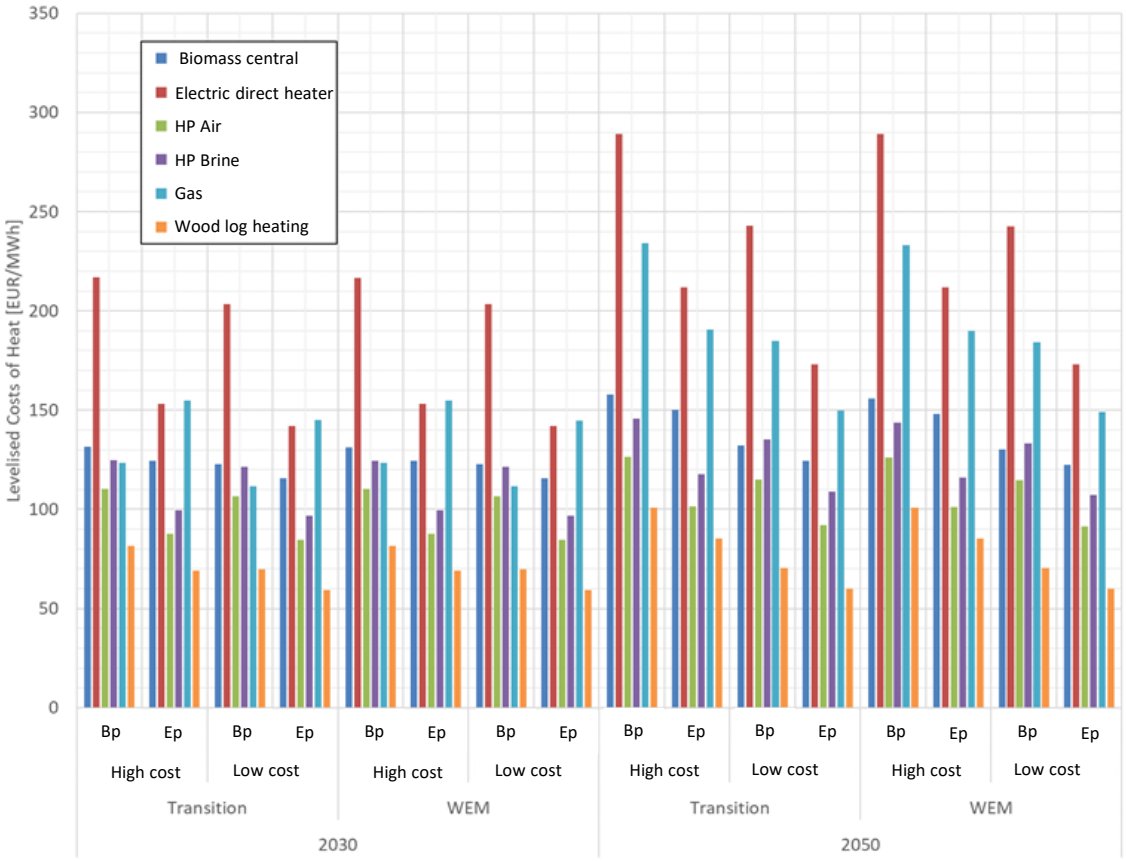

Figure 25: Levelized Costs of Heat (LCOH) in the different scenarios for different technologies in single-family houses built between 1990 and 1999 (Bp...Buisness perspective, Ep...Economic perspective)

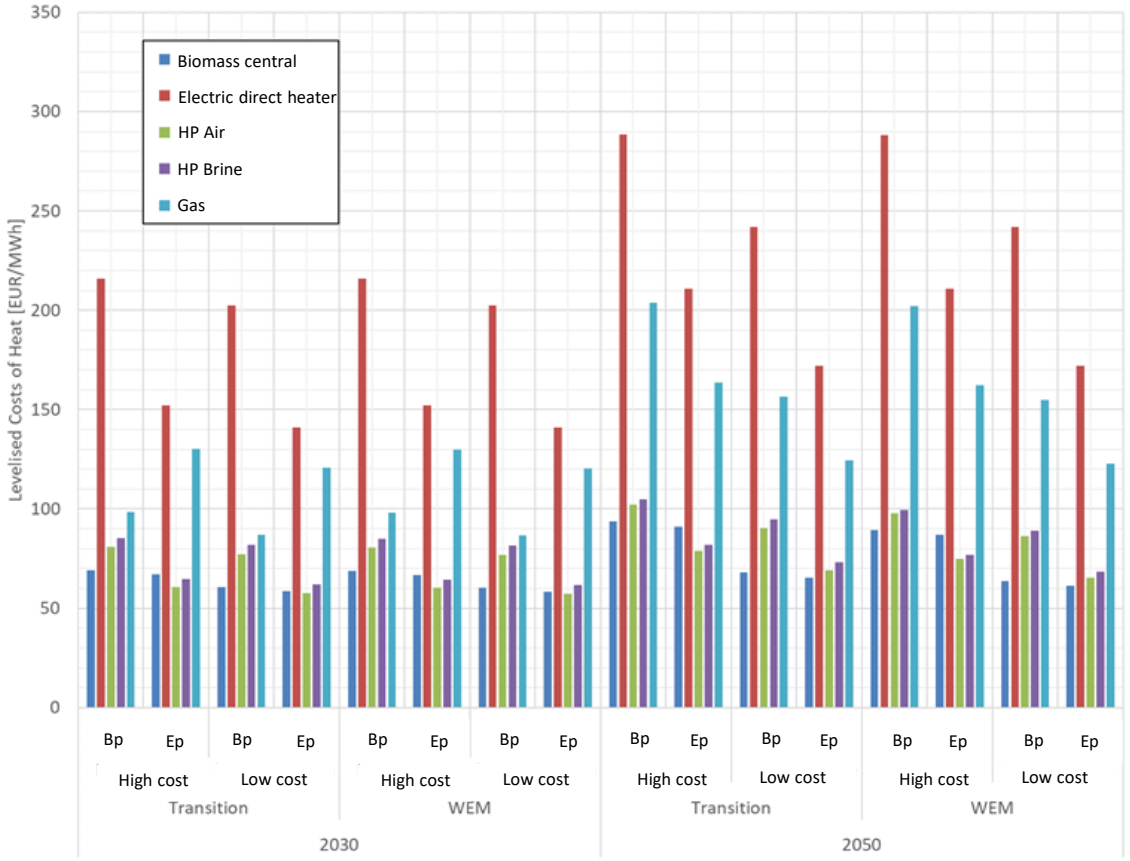

Figure 26: Levelized Costs of Heat (LCOH) in the different scenarios for different technologies in large office buildings built between 1946 and 1969.

The figures show that direct electric heaters are the most expensive heat supply option in both single-family homes and office buildings. This is due to the high prices of energy sources. The second most expensive option is gas heating. Both these technologies are significantly more expensive than heat pumps or biomass in all scenarios, except in the BW calculations for 2030. In the VW calculations, it is assumed that external costs arise for CO2 emissions. This leads to significantly higher LCOHs for gas supply in the 2030 calculations compared to the BW calculations. In 2050, gas supply is expensive because only biogas and synthetic gas are used. However, this also means that there will be virtually no more CO2 emissions. Basically, the costs in the BW calculations are higher than in the VW calculations, because the VW calculations do not take taxes into account. The figures also show that the heat supply via heat pumps causes similar costs as the supply via central biomass boilers. The cheapest alternative is logwood heating, which is only an option for small buildings like single family houses.

Based on the calculated costs for different technologies in the different typical buildings, the reference costs for the object-related heat supply in the different scenarios are calculated in a subsequent step. For this purpose, the costs of heat supply in all typical buildings are weighted by all different technology variants according to their occurrence in the respective underlying scenario (WEM or Transition). For this purpose, the distribution of the areas of typical buildings is taken directly from the respective scenario and year, the distribution of the technologies used is slightly adjusted: since reference costs are to be calculated for a purely object-related heat supply, the shares of the demands covered by

district heating from the underlying scenario are distributed among the different object-related technology options. The following Table 17 shows the technology distribution used for calculating the reference costs in the different development scenarios and years.

Table 17: Average distribution of technologies used to calculate reference costs for object-related heat supply (based on (Krutzler et al. 2017))

	WEM		Transition	
	2030	2050	2030	2050
Gas	35%	11%	35%	9%
Oil	19%	0%	18%	0%
Logs	13%	20%	13%	15%
Biomass - Automatic	12%	26%	12%	27%
Power direct heater	9%	7%	9%	7%
HP - Brine	8%	19%	8%	21%
HP - Air	5%	18%	5%	22%

*Log heating systems are only considered in single-family houses, for all other building types the share of wood logs is taken into account for biomass automatics

Figure 27 shows the calculated reference costs of the object-related heat supply for the different scenarios. This results in LCOH between 93.5 EUR/MWh (WEM, VW, 2050, low prices) and 143.5 EUR/MWh (Trans, BW, 2050, high prices). For 2030, the reference costs in the VW scenarios are higher than in the corresponding BW scenarios, for 2050 it is the other way around. This is due to the fact that in the VW calculations, costs are applied for emitted CO2, whereas in the BW calculations it is assumed that no CO2 price has to be paid in the object-related provision. In 2030, there are still relevant CO2 emissions in the use of gas and oil, in 2050, oil is no longer used and also in the gas network, only biogas and synthetic gas are used and thus almost no CO2 emissions occur here. In principle, the reference costs in the VW calculations are lower in this case, since taxes are not taken into account. There are significant differences in the reference costs between high and low price levels, while the differences between the developments in the WEM and Trans scenarios are significantly smaller.

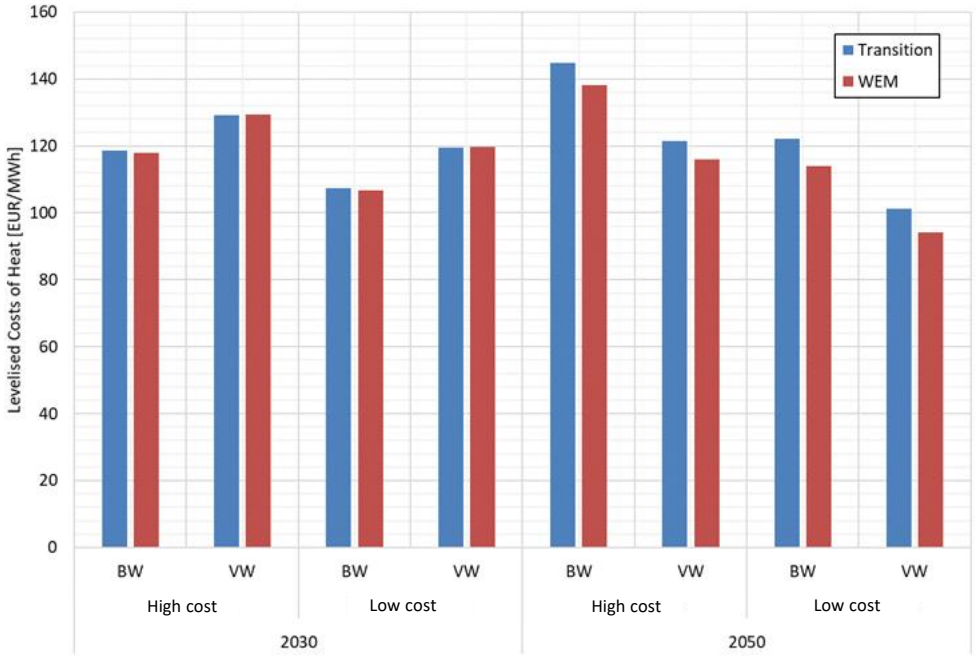

Figure 27: Reference costs for object-related heat supply in the various scenarios

4.6 Results of the cost-benefit analysis

The economic potential of district heating supply as well as the respective resulting economic energy carrier quantities in district heating result from the comparison of the costs of pipeline-bound district heating supply with those of object-related heat supply in the respective region under consideration.

Figure 28 shows this comparison of the LCOH for object-related supply as well as for district heating supply in the different potentially suitable regions for different scenario variants in the year 2030, Figure 29 for the year 2050.

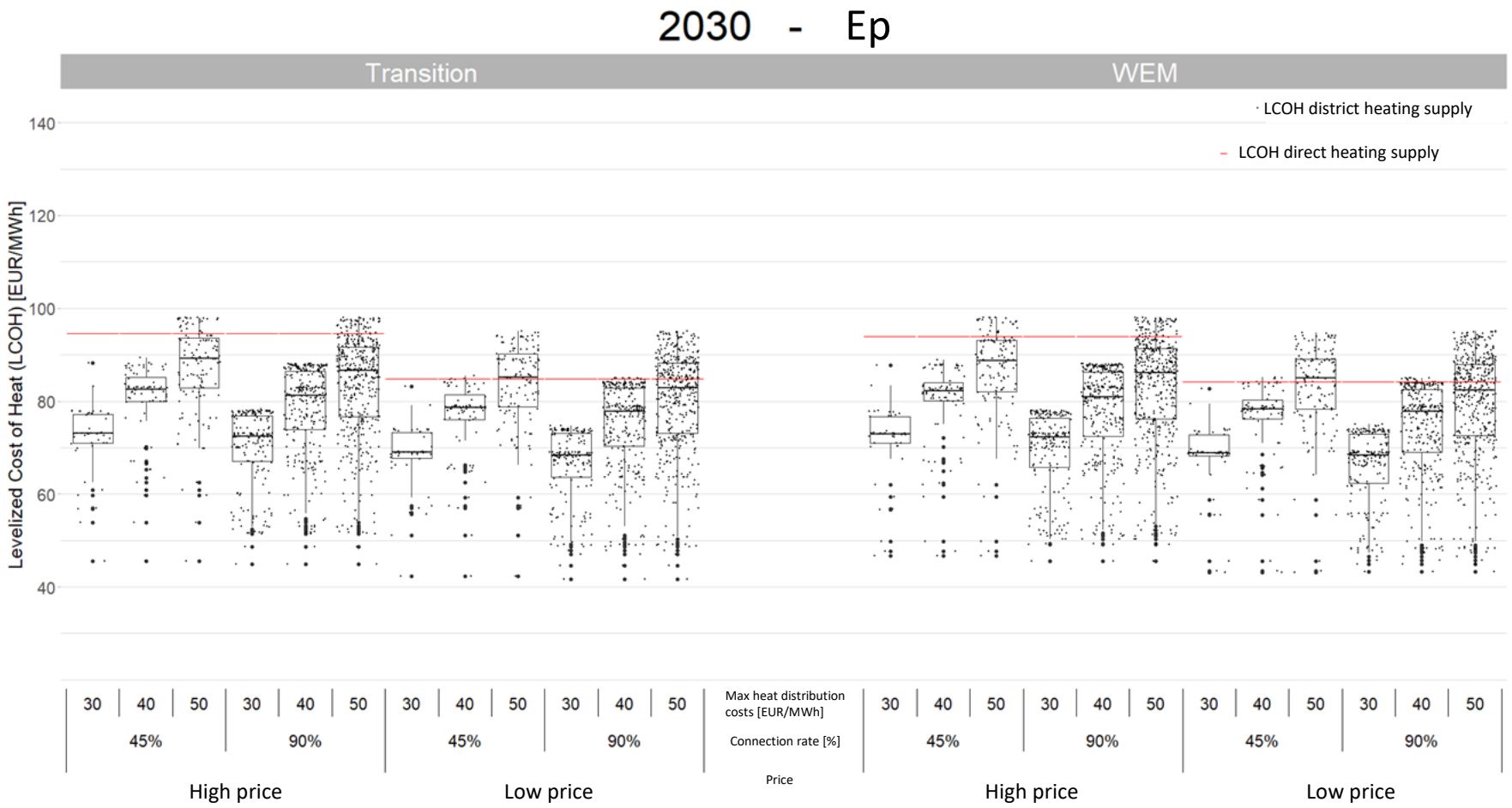

Figure 28: Comparison of costs (LCOH) of property-based heat supply (red line) and costs (LCOH) of district heating supply (boxplot and point clouds) for different scenario variants in 2030, macroeconomic perspective.

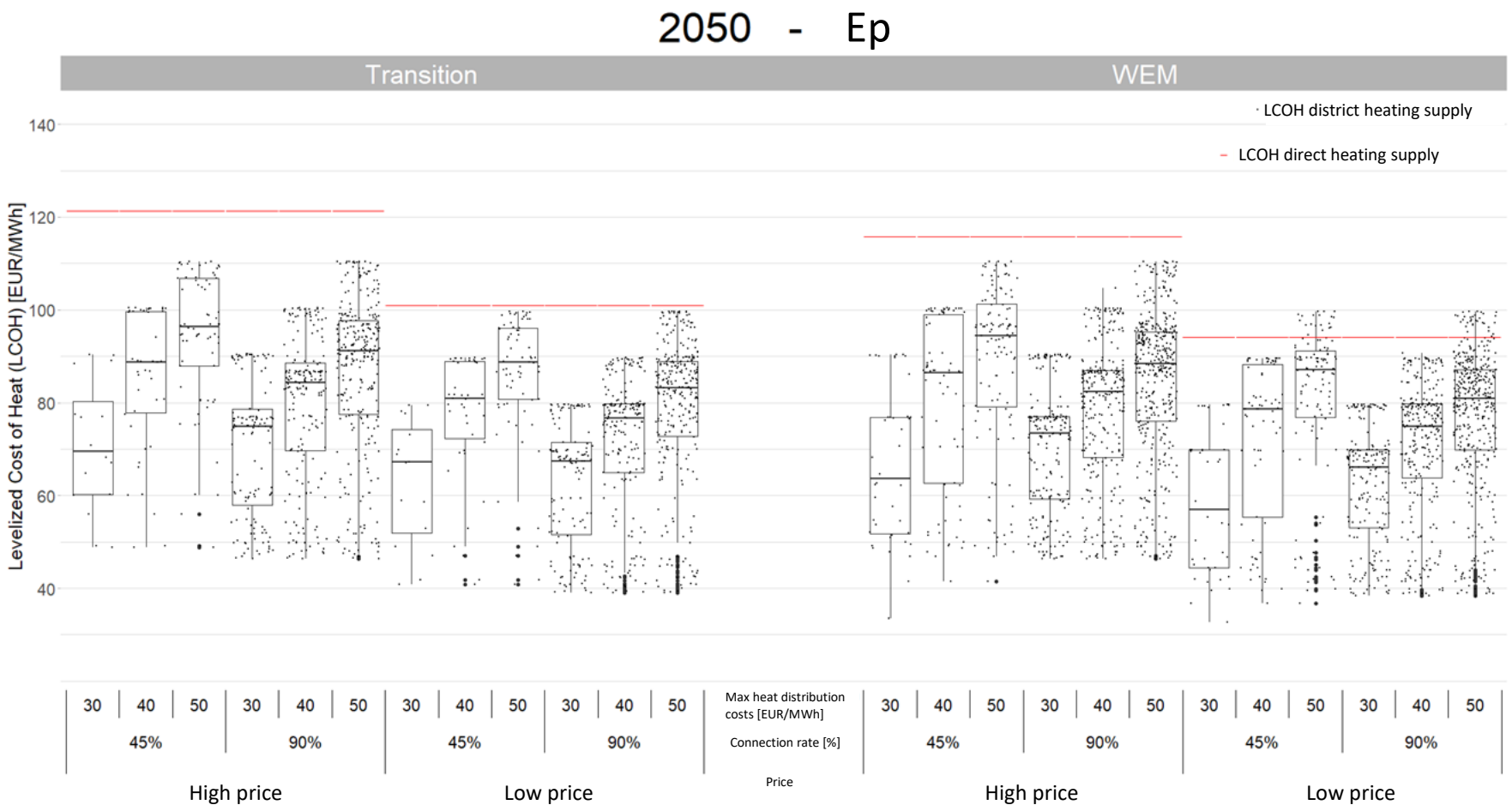

Figure 29: Comparison of costs (LCOH) of property-based heat supply (red line) and costs (LCOH) of district heating supply (boxplot and point clouds) for different scenario variants in 2050, macroeconomic perspective.

It can clearly be observed that under the selected scenarios (and thus also taking into account the underlying regions in which the respective heat production costs can be achieved), district heating has a high economic efficiency for the 2050 scenario, especially under the assumption of a high energy price level. It must be taken into account that the mix of decentralized technologies according to the WEM or transition scenarios described above was assumed constant for all calculated variants. For the year 2030, there is a somewhat lower economic efficiency under the framework conditions and assumptions made, i.e., there are more regions in which decentralized technology proves to be more favorable than heat supply via heat grids.

The following two figures (Figure 30 and Figure 31) show the district heating regions that are not economical in the respective scenario.

The following relationships can be seen in the figure:

- The higher the maximum permitted distribution network costs in the identification of potentially suitable district heating regions (chapter 4.2), the higher the proportion of these regions that drop out again in the comparison between costs related to the object and costs of district heating provision. This is logical, since with higher permitted maximum distribution network costs, significantly more regions also appear potentially suitable for district heating.
- At low prices, more regions are uneconomical than at high prices; this is due to the fact that the influence of prices on the object-related supply is higher than on the district heating supply, since a relevant share of the district heating supply costs is due to the heat distribution.
- It can be seen that the average size of non-economic areas is well below 50 GWh/yr in almost all scenarios in 2050. In 2030, in the scenarios with high maximum distribution network costs, even significantly larger areas are ultimately uneconomic.

The following figures (Figure 30 and Figure 31) show the economic potential of district heating supply in the different calculated scenarios for the years 2030 and 2050.

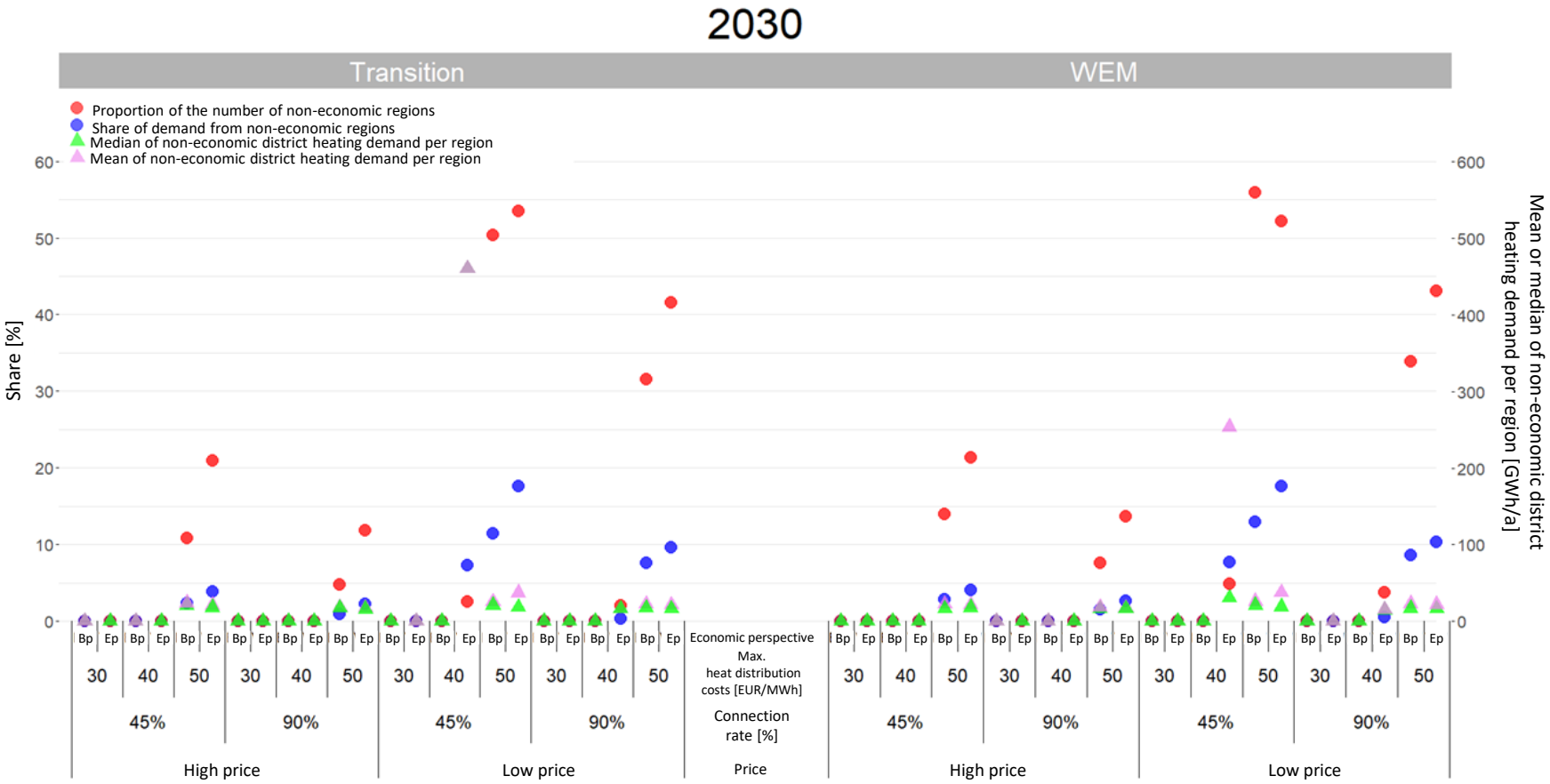

Figure 30: Share of non-economic district heating areas (number and demand) and average size of non-economic areas (median, mean), 2030.

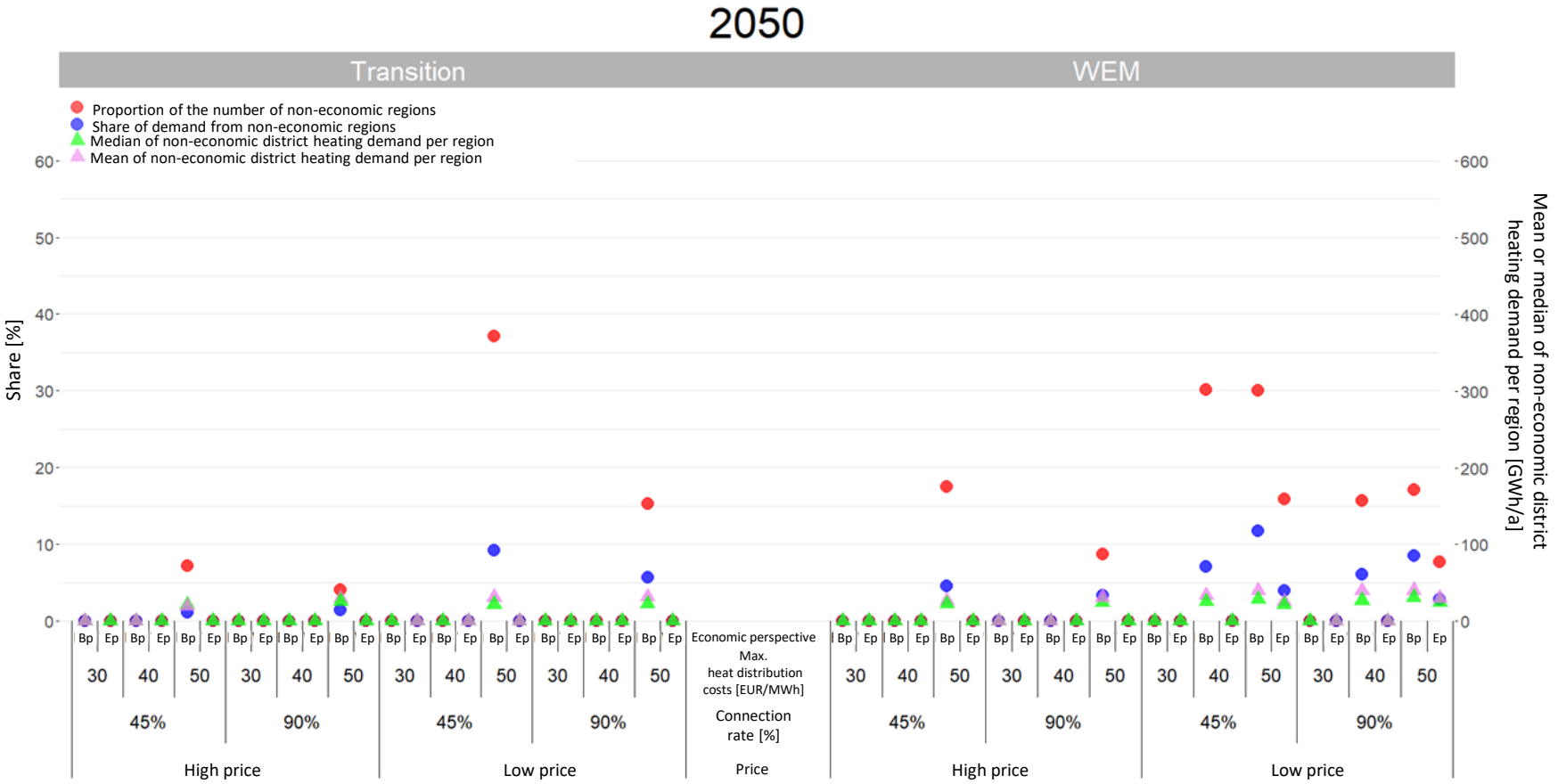

Figure 31: Share of non-economic district heating areas (number and demand) and average size of non-economic areas (median, mean), 2050.

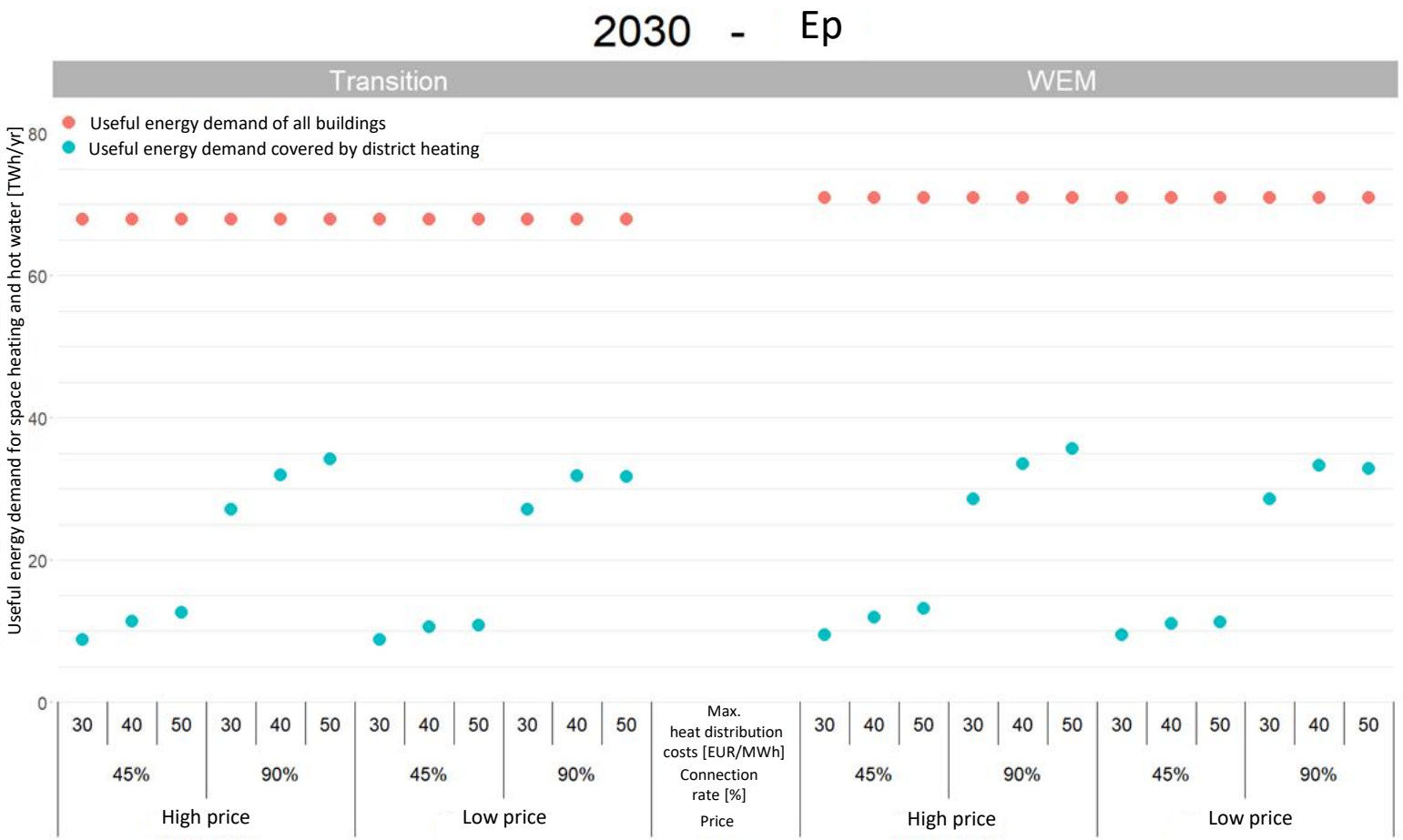

Figure 32: Economic potentials of district heating in the different scenarios calculated, economic perspective, 2030.

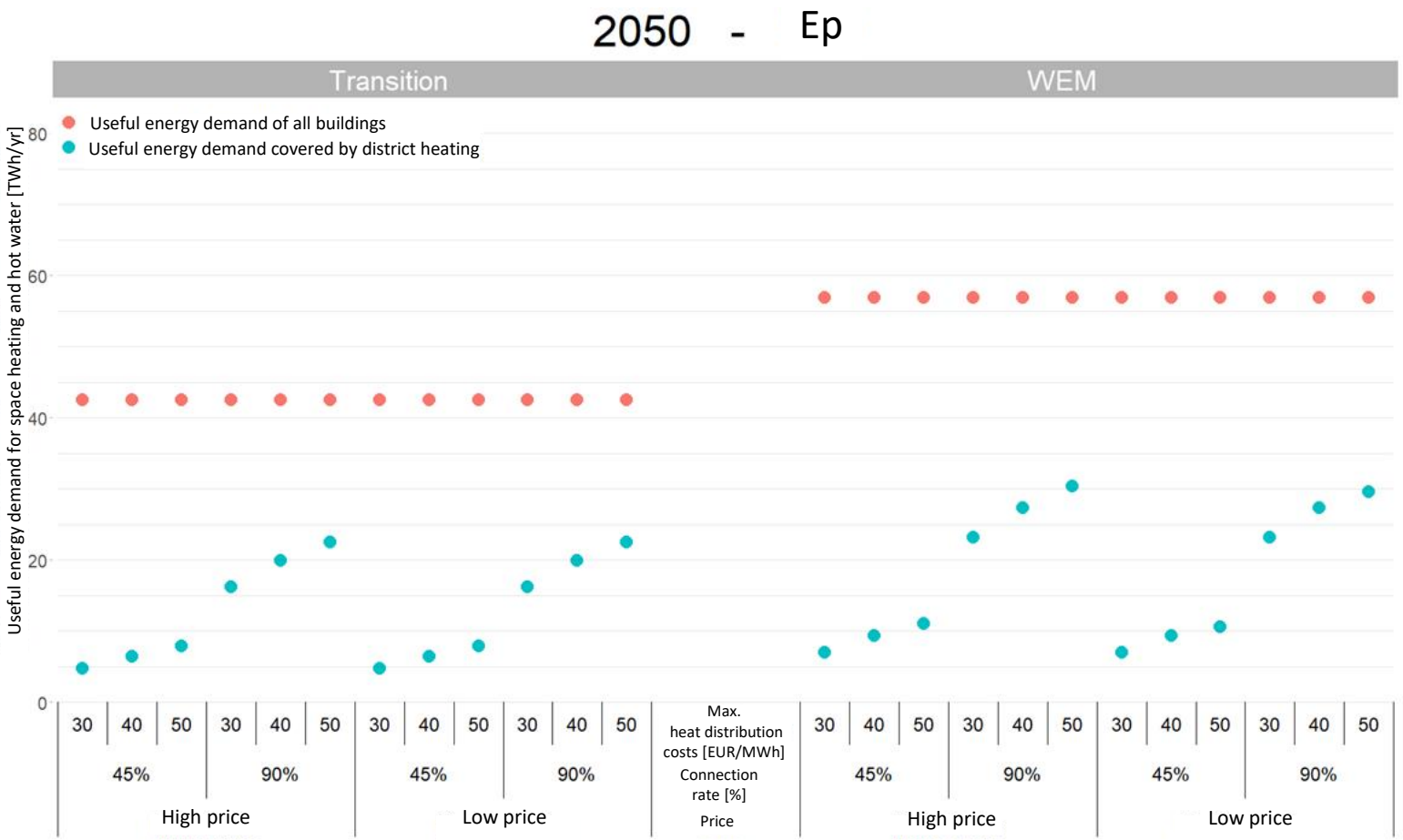

Figure 33: Economic potentials of district heating in the different scenarios calculated, economic perspective, 2050.

Figure 32 and Figure 33 show a strong dependence of the economic potentials on the assumed connection rates (45 vs. 90%). Also relevant is the dependence on the maximum permissible distribution network costs (30, 40 or 50 EUR/MWh). Furthermore, there are differences between economic and business considerations, especially higher max. distribution network costs (for Trans only at 50 EUR/MWh and low prices, for WEM also at 40 EUR/MWh at low prices); in areas with high distribution network costs, the costs of district heating exceed those of property-related provision due to the VAT incurred on the total district heating costs. The differences between the assumptions on prices are minimal in terms of the impact on the economic potential of district heating.

Figure 34 and Figure 35 show the energy carrier mix for the provision of space heating and hot water in the different scenario options for 2030 and 2050. In the figures, both the energy carriers used in the object-related provision (shaded areas) and the energy carriers used in district heating are shown. The figure shows the results of the different scenarios for the two years 2030 and 2050 side by side.

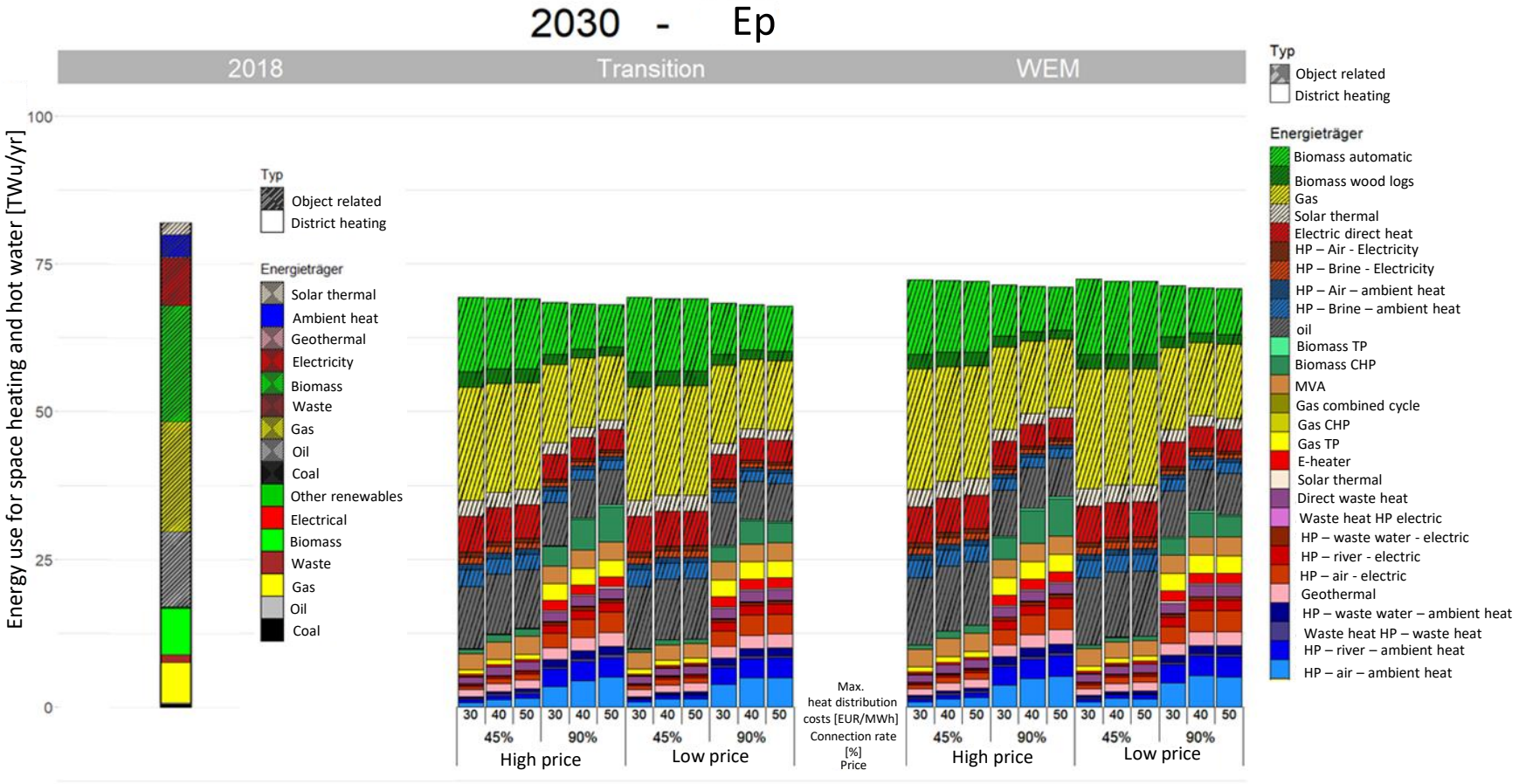

Figure 34: Use of energy sources for the provision of space heating and hot water in the different scenarios in 2030 for the economic analysis

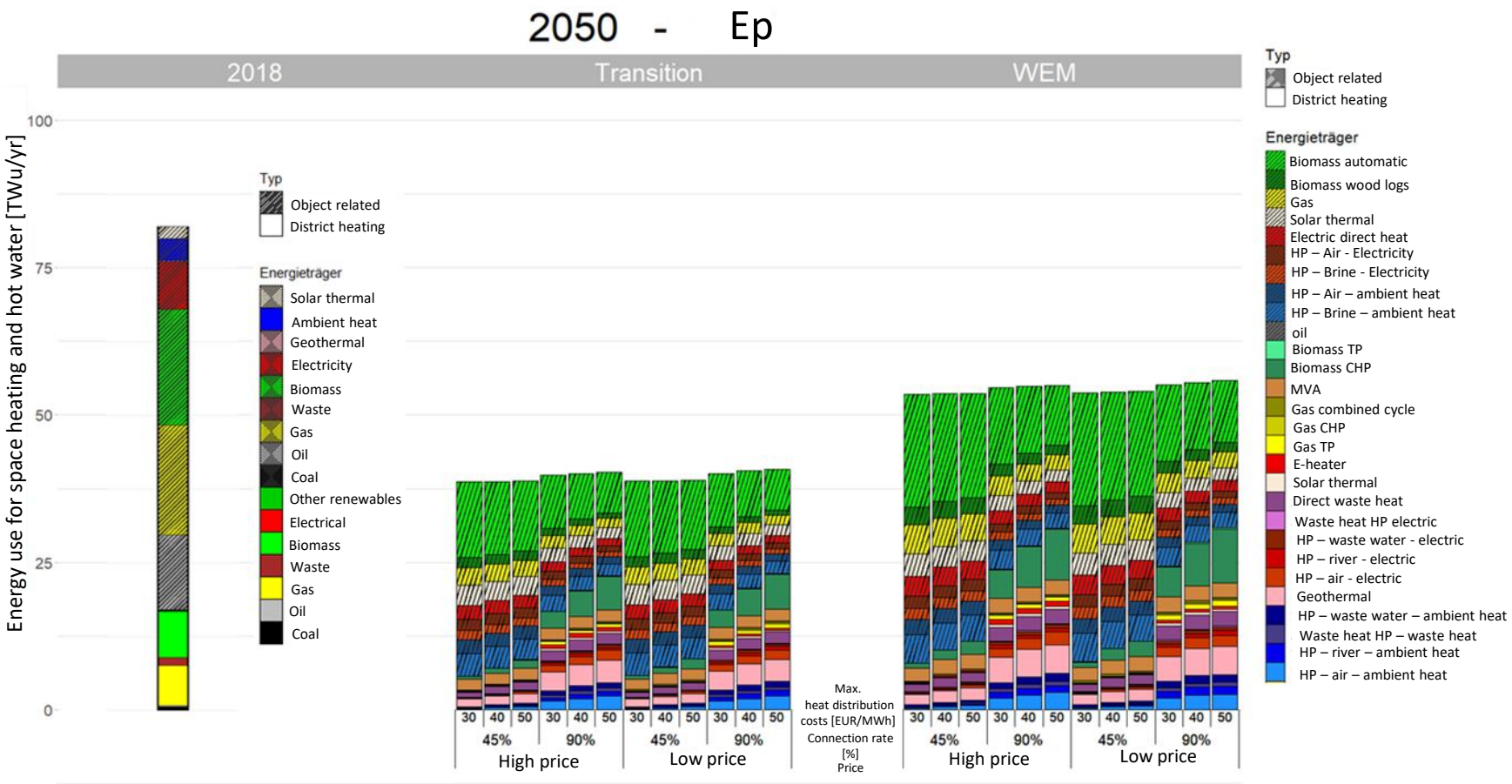

Figure 35: Use of energy sources for the provision of space heating and hot water in the different scenarios in 2050 for the economic analysis

Differences in the coverage of the heat demand between WEM and Transition scenario become apparent, which result from the different levels of demand. More relevant, however, is the distinction between the variants 45% and 90% connection rate. If a higher connection rate can be achieved (e.g. through a stringent energy planning policy), a significantly higher share of the heat demand can be covered for district heating. As a result, a higher share of geothermal or waste heat utilization is also possible, and the **relevance** of **large-scale heat pumps also increases**.

The modeling results in a slightly higher energy input in the scenarios with high district heating shares. This results from the distribution losses in the district heating networks. However, the higher energy input does not mean a lower, but on the contrary a higher overall efficiency in heat supply, since in many cases higher shares of available potentials of waste heat, geothermal energy, waste or river heat can be used. These could not be used in an object-related provision.

While the distribution between centralized and decentralized heat provision is distinct between the scenarios, the energy source mix between the scenarios (connection rates, max. distribution costs, energy source prices, WEM/Trans) remains relatively robust. This suggests that these parameters do not fundamentally change the selection of economic portfolios and technologies in the aggregate of all region types across Austria, and thus the basic statements exhibit a certain robustness. Nevertheless, existing uncertainties are discussed in the following chapter.

Table 18: Economic potential of the efficient and renewable technologies for heating and cooling identified in the cost-benefit analysis. Report according to submission of the European Commission (sources: own analyses) - value ranges according to the respective scenario variants included.

Year 2030	Transition		WEM	
	Bp	Ep	Bp	Ep
	GWh/yr	GWh/yr	GWh/yr	GWh/yr
Industrial waste heat	1 504-3 206	1 366-2 376	1 704-3 314	1 518-2 407
Industrial waste cold	-	-	-	-
Waste incineration	2 914-3 493	2 553-3 043	3 193-3 607	2 640-3 143
High efficiency CHP	1 120-5 463	0-0	1 162-5 661	0-0
Renewable energies				
Deep geothermal energy	1 147-2 417	1 140-2 383	1 187-2 511	1 180-2 477
Biomass	17 059-20 298	13 384-16 758	17 088-20 940	13 693-16 786
Solar thermal	69-142	69-266	72-150	72-279
Other renewables *	2 621-3 771	2 449-3 475	3 987-5 915	3 691-5 538
Heat pumps	4 389-8 501	4 689-9 050	5 245-10 477	5 656-11 142
Year 2050	Transition		WEM	
	Bp	Ep	Bp	Ep
	GWh/yr	GWh/yr	GWh/yr	GWh/yr
Industrial waste heat	1 504-3 206	873-2 598	1 325-3 377	1 325-3 399
Industrial waste cold	-	-	-	-
Waste incineration	1 761-2 098	1 745-1 978	2 287.2 667	2 266-2 501
High efficiency CHP	262-617	191-446	335-785	244-565
Renewable energies				
Deep geothermal energy	1 376-3 765	1 372-3 784	1 768-4 864	1 762-4 879
Biomass	14 670-17 462	14 514-17 376	21 818-25 988	21 554-25 570
Solar thermal	40-334	45-357	57-443	63-487
Other renewables *	2 621-3 771	2 449-3 475	3 987-5 915	3 691-5 538
Heat pumps	4 389-8 501	4 689-9 050	5 245-10 477	5 656-11 142

*Total renewable gas (incl. synthetic gas)

4.7 Discussion and conclusions

The content of this work is to assess the economic potential for energy efficient and renewable heating and cooling supply in accordance with existing energy and climate policy objectives, as defined in the framework of the reporting obligation to Art. 14 of the Energy Efficiency Directive and to be carried out at regular intervals. One of these objectives is the target of CO2 neutrality, which was defined in the current government program for the year 2040 and which also results from the Paris Agreement as well as the current European developments, in particular the European Green Deal.

The intention of the analyses was not to carry out detailed planning or analyses for individual heating networks or to develop concrete recommendations for the design of the legal and political framework for the expansion of renewable energies. Nor is it the intention to develop feasibility studies for the

implementation of concrete technologies in individual heating networks or even to provide a basis for investment decisions for individual heating networks.

The basic assumption is therefore that the goal of (net) climate neutrality in Austria will be achieved between 2030 and 2050. This means that fossil energy sources still play a role in determining the economic potential for 2030, but no longer for 2050. For 2050, it is therefore assumed, among other things, that the eventual demand for gas will be met by renewables.

Under these conditions, the following key statements emerge:

- Decarbonization of the heating and cooling supply in Austria is possible, but only under some key assumptions and framework conditions.
    - Extensive efforts are needed to refurbish buildings: These are the basic prerequisite, e.g., for an efficient use of heat pumps, as well as for a moderate demand for resources to cover the remaining heat demand. In particular, building renovation and the associated reduction of required temperature levels for space heating is also a prerequisite for the further development of heat grids in the direction of the fourth generation (even if this aspect could not be explicitly addressed in the context of this study).
    - Another prerequisite for the decarbonization of the space heating and hot water sector is the decarbonization of the electricity supply as well. Heat pumps are a relevant technology in covering the heat demand and therefore also require a renewable electricity supply in order to classify them as a fully decarbonized option.
    - The integration of waste heat from industry represents a significant resource. In order to be able to classify this as renewable, the decarbonization of industry also represents an essential pillar of the decarbonization of district heating.
- The share of district heating depends above all on the connection rate that can be achieved in the district heating regions. Depending on this, an economic potential of district heating of about 20% to over 50% is calculated.
- Technology mix district heating::
    - Under the assumptions made in this study about the potential composition of renewable gas and the underlying cost price, renewable gas generally does not prove to be a cost-effective option for decarbonizing the sector. The cost of renewable gas will depend on, among other things, the level of demand from different sectors. Since renewable gas is expected to be more difficult to substitute in other sectors (e.g., industry) than, for example, for space heating and domestic hot water, higher demand for low-temperature heat also means higher costs of using renewable gas in industry.
    - Biomass continues to represent a significant share of renewable heat uptake, both decentralized and in district heating. Above all, it can be seen that in the scenarios with low efficiency increase, the pressure on resource utilization of biomass would increase very strongly. The achievability of decarbonization in these scenarios is therefore more questionable than in those with high renovation efforts. The amount of biomass resources that will ultimately be available for the heating sector will depend heavily on demand in other sectors, such as industry. This issue was not part of this study and therefore could not be discussed and analyzed comprehensively.
    - It can be seen that heat pumps play an essential role not only in decentralized applications, but also in district heating. Their efficiency depends both on the development of regionally available heat sources, but also on the development of temperature levels in the heat networks. Seasonal fluctuations in heat source temperatures, such as those of rivers and outside air, were taken into account in the use of heat pumps. This results in some cases in a significantly reduced use of these technologies in the coldest periods

of the year, whereby in these cases the heat storage systems then also play a significant role.

- The role of thermal power plants and CHPs in a future renewable electricity system was not the focus of this study. In the sense of high fuel efficiency, heat extraction from existing thermal power plants should definitely be strived for. By 2050, however, our analyses indicate that gas-fired thermal power plants will only be used with relatively low full load hours - under the premise that only renewable gas will be used.
- arge-scale solar thermal plants can be an economically viable option, but are highly dependent on the overall structure of the generation portfolio on the one hand, and on the achievable costs on the other - which in turn scale strongly with the size of the plants.
- It can be concluded that the use of large thermal storage systems contributes significantly to an economical operation of the heating networks. At the same time, there are significant uncertainties regarding the associated costs, which depend not least on the exact location.

Model analyses such as those in this study are always subject to uncertainties. On the one hand, there are uncertainties regarding the possible cost development (as well as the locally existing specific site conditions, which can lead to deviations with regard to the costs), especially with regard to large-scale thermal storage and solar thermal energy and the required land costs, deep geothermal energy (and the associated risks in the development). On the other hand, there are also uncertainties regarding technological developments and the efficiencies and corresponding technology characteristics that can be expected in the future. Furthermore, the interplay of the different renewable district heating technologies in the portfolio, even with the use of heat storage, is complex and strongly dependent on the expected district heating demand. The expected heat demand is in turn strongly dependent on the measures in the field of building renovation as well as on the achievable connection rates. Since these factors cannot be predicted in the long term, a continuously adapting planning process is required, both on the part of the heat network operators and on the part of policymakers.

As with any model-based analysis, there are certain system limitations of the analysis that have an impact on the results and their significance. When interpreting the results, it is therefore crucial to consider the following aspects:

- There are numerous barriers with regard to the feasibility of the scenarios described and the potentials identified, even if they prove to be economical. These include deadlines that must be met when planning major infrastructure projects. In the past, this has been particularly evident for the development of waste heat potentials. The development of these potentials, which have been identified as economic, therefore nevertheless require the necessary political framework conditions, without which implementation is to be classified as unlikely.
- Some of the portfolios described have costs at very similar levels. In line with the logic of the chosen approach, the most favorable potentials were identified in each case. However, there are uncertainties regarding the preference of the specific technology portfolios and the mix of renewable and efficient potentials for heat supply. What can be considered a robust result, however, is that renewable gas cannot be considered among the favorable options for decarbonizing the space heating and hot water sector.

- n-1 and n-2 security in district heating generation capacities, respectively, were not fully taken into account. This also applies, among others, to the use of industrial waste heat. The authors estimate the effect of this assumption on the results of the study to be small.
- Existing heat networks were not explicitly considered. This can be seen as a conservative assumption regarding the existing district heating potential.
- The focus of the study was on the heat sector. The role of CHP was therefore also considered from the perspective of the heat sector. What role CHP plants will play from the perspective of the electricity system in 2030 and 2050 in Austria was not the focus of this study.
- In the present study, the possible future lowering of temperature levels in heating networks was not considered. However, such a lowering is definitely aspired and propagated and analyzed in relevant studies. In particular, the thermal renovation of buildings supports a reduction of supply temperatures, which in turn facilitates the feed-in of low-temperature waste heat or solar thermal energy. Lowering temperature levels would also have positive effects on district heating potentials, but these could not be quantified in detail within the scope of this study.
- he exogenous configuration of the different district heating generation portfolios is a further limitation of the methodological approach, as it restricts the variety of solutions. However, by varying assumptions and consulting with some district heating companies, a high degree of realism could be achieved.
- As mentioned above, it was assumed in this analysis that waste heat is CO2-neutral. The definition of waste heat according to the Renewable Energy Directive was not the focus of this study.

5 Potential new strategies and strategic measures

According to the Delegated Regulation (EU) 2019/826 of the European Commission, an overview of "new legislative and other strategic measures (8) aimed at unlocking the economic potential identified as above" is provided at this point.

Since the economic potential of district heating can only be exploited with climate target-compliant operation, a higher share of renewable energy or waste heat in the district heating or cooling systems is required. According to the draft bill, applicants for subsidies under the Heat and Cooling Pipeline Expansion Act (WKLG) are therefore to be required to submit a conversion plan for their existing network when submitting a subsidy application, in which they must explain how they intend to achieve a share of up to 80% of renewable energy in the district heating or cooling supply by 2030 (decarbonization path).

In this context, the applicants should describe the necessary measures for the conversion and the time schedule of the conversion and quantify the expected greenhouse gas (GHG) savings. The conversion plans are to be the basis for a step-by-step renovation of the networks, taking into account the municipal heating planning. An exception to this obligation is provided for renewable energy communities for local heating networks, as these are by definition 100% based on renewable energy sources and therefore the submission of a decarbonization path is unnecessary.

In addition, according to the draft of the WKLG, the ranking of incoming applications for funding is to be based on an ecological criterion. In the future, the share of renewable energy in the energy mix of the district heating or district cooling system will be used as the decisive ranking criterion.

6 Annex

6.1 Literaturverzeichnis

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6.4 Assumptions and data for calculation

Table 19: Techno-economic data of various district heating generation technologies.

Name	thermal efficiency	Electric efficiency	Investment-costs (EUR/MW_th)	OPEX fixed (EUR/(MW*a))	Lifetime [a]
MVA	0,70	0,12	1.800.000	27.000	20
Geothermal HP	15,00	-	820.000	50.000	30
Waste heat HP	5,50	-	570.000	2.000	25
Diect waste heat	1,00	-	250.000	7.500	30
River HP	3,10	-	380.000	4.000	25
Air HP	2,50	-	760.000	2.000	25
Waste water HP	3,60	-	380.000	4.000	25
Biomass CHP	0,74	0,11	900.000	45.000	20
Biomass TP	0,85	-	470.000	14.100	20
Solar thermal	1,00	-	785.000	3.900	20
Electric heating	0,99	-	180.000	2.000	20
Gas CHP	0,47	0,33	585.000	23.400	25
Gas combined cycle	0,36	0,45	1.357.000	52.200	25
Gas TP	0,92	-	100.000	3.700	35

Table 20: Assumptions on the composition and corresponding supply costs of green gas in 2030 and 2050 (see Table 8 for sources and further information)

Low price	2030		2050	
	Share [%]	Cost [EUR/MWh]	Share [%]	Cost [EUR/MWh]
PtG	5%	150,0	40%	110,0
H2	15%	80,0	40%	70,0
Biomehtane	80%	60,0	20%	80,0
Total		67,5		88,0

High price	2030		2050	
	Share [%]	Cost [EUR/MWh]	Share [%]	Cost [EUR/MWh]
PtG	5%	210,0	40%	170,0
H2	15%	120,0	40%	100,0
Biomehtane	80%	80,0	20%	100,0
Total		92,5		128,0