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Comprehensive Assessment of the Potential for Efficient District Heating and Cooling and for High-Efficient Cogeneration in Austria

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ABSTRACT

In accordance with the EU Energy Efficiency Directive all Member States have to develop a comprehensive assessment of the potential for high-efficient CHP and efficient district heating and cooling by the end of 2015. This paper describes the approach and methodology used to determine the district heating potentials for Austria. In a first step actual and future heating and cooling demand in the building sector is evaluated using the techno-economic bottom-up model Invert/EE-Lab. Relevant infrastructure probably existing in 2025 is investigated and included into the analysis. Technical potentials for efficient technologies are calculated. After a classification of relevant regions into main and secondary regions a country-level cost-benefit-analysis is performed. The results indicate that there is a reasonable additional potential for district heating by the year 2025 under our central scenario assumptions and within sensitivity scenarios. Only in scenarios with high CO_2-price or low gas price, CHP is an economically efficient solution to supply district heat.

Keywords:

Comprehensive Assessment;
Energy Efficiency Directive;
Efficient District Heating;
High-Efficient Cogeneration;
Potential Analysis;
Austria;
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1. Introduction

Space heating and cooling accounts for almost one third of the final energy use in Austria and plays a central role in achieving energy efficiency targets. 20% of this demand is supplied by district heating whereas the share of combined produced heat for district heating has reduced from more than 70% to 63% within the last 5 years according to national statistics. As part of the EU Energy Efficiency Directive [1] all Member States have to develop a comprehensive assessment of the potential for the use of high-efficient combined heat and power and efficient district heating and cooling by the end of 2015.

In Austria so far there has been no such analysis on national level. Only technical potentials for CHP have been analyzed but mainly from the electricity side and without spatial resolution [2]. On international level different analyses have been carried out in this area but with different focuses and mainly for the Scandinavian countries. For example in [3] boundaries of profitability in sparse district heating systems have been analyzed and in [4] a techno-economic model has been developed to determine easy and fast economical boundaries for district heating. In [5] the role of district heating in future renewable energy systems has been examined based on the case of Denmark. Later in [6] the role of district heating in a future Danish energy system has been

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analyzed combining the use of a heat atlas with national energy system analysis. In [7] the Danish heat atlas is used to provide inputs to energy system models related to expansion of district heating networks. In [8] a GIS based approach is used to determine future district heating potentials in Denmark using an existing heat atlas, which was further developed for high resolution spatial heat planning in [9]. In [10] a methodology to estimate and spatially allocate the heat demand for an assessment of district heating potential in the USA is presented. The Heat Roadmap Europe project calculated the potentials of an alternative heating strategy combining district heating with heat savings [11] and identifying strategic heat synergy regions [12] for Europe. Among others the work from [13] was used to define the criteria suggested by the EED and also contributed to carry out this assessment adding valuable ideas to implement the used approach.

But no one of this works directly applied the suggested criteria and the resulting parameters to carry out a national potential analysis on district heating and CHP. Also no one was particularly designed to fulfill the requirements of the directive giving input to other European countries to assess their potentials.

This comprehensive assessment includes in a first step the evaluation of relevant heating and cooling demand regions. To determine the relevant regions the actual heat demand as well as existing infrastructure and the potential of industrial waste heat, renewable energy and efficient technologies have been identified in a regional resolution. For the defined regions an economic cost-benefit analysis was performed in a second step to calculate the potential for efficient district heating and high-efficient cogeneration as required by the EED. According to the directive a CHP-plant is referred to as high-efficient when the primary energy savings of combined production exceed 10% compared to separated production and a district heating system is referred to as efficient when it uses at least 50% renewable energy, 50% excess heat, 75% CHP-heat or 50% of a combination of these sources.

2. Methodology

In this section the methodology used in the Comprehensive Assessment to determine the potential for efficient district heating and high-efficient CHP is described. The different steps are:

- Evaluating the actual and future heating and cooling demand,
- Investigate relevant in 2025 still existing infrastructure,
- Calculate potentials for efficient technologies to cover heating and cooling demand,
- Determine relevant regions suitable for district heating,
- Perform a cost-benefit analysis of the optimal mix of supply technologies

2.1. Evaluating the actual and future building related heating and cooling demand

To determine relevant heating and cooling demand regions, the demand for space heating, cooling and domestic hot water has to be evaluated on a geographical highly disaggregated level. The actual demand for heating and cooling and two scenarios for the year 2025 are developed using the techno-economic bottom-up model Invert/EE-Lab [14]. Two scenarios for 2025 are developed because the EED suggests a time horizon of 10 years. The energy calculation in Invert/EE-Lab is implemented by a thermodynamic/physical mapping of buildings. The calculation of final heating and cooling energy demand is based on the Austrian Standards which are in line with European standards (EN13790) but includes user behavior to deal with the difference of expected and real heating demand. The regional disaggregation is done by using data about the settlement areas on a 250 × 250m resolution and the population density on a 1 × 1km resolution. The developed algorithm calculates an energy density function allocating the structure of the buildings (amount of units, construction period, type of building, size, heating fuels, etc. at community level; for all 2.380 municipalities; main data sources: [18]) as well as workplaces and employees over tangent-planes to a 50 × 50m grid. Because these calculations on raster elements-basis led to an underestimation of the plot ratio – which is defined as the building floor area to the land area in a given territory – especially of sparsely populated raster elements compared to values in the literature [15, 13] a correction of the plot ratio was done. Evaluations in [15] have shown that typical plot ratios for settlement structures with lowest densities lie around 0.1. Therefore a correction of the plot ratio was done assigning the floor area of raster elements with a plot ratio smaller than 0.05 in three steps to neighboring elements with higher plot ratios where the plot ratio could not rise by more than 75% within each step. Further explanations and effects are shown in [16].

For the future energy demand two scenarios have been developed including a Business-As-Usual Scenario which represents the central scenario of this analysis and a high-efficiency Scenario to conduct some sensitivity analysis. In order to achieve a high level of consistency with other relevant energy scenarios for Austria, the scenarios and assumptions are in accordance with the project "Erstellung von energiewirtschaftlichen Inputparametern und Szenarien zur Erfüllung der Berichtspflichten des Monitoring Mechanisms" (Development of energy-related input parameters and scenarios to meet the requirements of the Monitoring Mechanisms) [17], which was funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The Business-As-Usual Scenario corresponds to the scenario "with existing measures 2015" which assumes that the measures and energy policy frameworks implemented or decided by the beginning of 2014 continue to exist without amplification but also without softening the agreed measures. This refers in particular to the provisions in building regulations, subsidies etc.

The High-Efficiency Scenario used for the sensitivity analysis assumes that an ambitious package of measures is made to increase efficiency, both in buildings and industrial sector.

2.2. Relevant existing infrastructure

The relevant existing infrastructure in terms of existing CHP and power plants and district heating networks is evaluated and included into the cost-benefit analysis without additional investment costs. Existing CHP and power plants are taken from the Platts-Database 2011 and have been updated by a desktop research to include newest information about recent closings. Based on the year of latest investments into these plants and average lifetimes for production units of different fuel-types, the remaining stock of plants for 2025 is evaluated. Existing waste incineration plants are assumed to continue to exist until 2025 independent of their commissioning year arguing that their main purpose is the treatment of waste and not the production of heat.

The data for existing networks is taken from the last complete national census on the Austrian building stock in 2001 [18]. This data was updated with available data for 2011 on stock of households and dwelling units supplied by district heating on federal states basis. An average growth rate for district heating from 2001–2011 per federal state is calculated and applied for all municipalities within the respective federal state with existing net infrastructure in 2001. After 2001 newly built networks cannot be determined by this approach leading to an overestimation of the share of connected households in municipalities with existing district heating networks and an underestimation of the number of municipalities with district heating networks in 2012 and 2025.

2.3. Technical potentials for high efficient technologies to cover heating and cooling demand

Beside the heat demand and the existing infrastructure, technical potentials play an important role to determine relevant regions for district heating. Only high efficient technologies according to the EED were taken into account. Therefore technical potentials for renewable energy sources as well as for CHP, waste incineration plants and industrial waste heat were identified as follows:

- The potential of gas fired technologies for every region is identified by evaluating the share of the heat demand of the municipality that is situated near existing gas pipelines [14, 16]. Central gas-fired technologies are considered to be unlimited if there is a gas pipeline within 2 km distance. For individual heating technologies the potential is limited to the share of the heat demand within 2 km to an existing pipeline
- The regional potentials for biomass are calculated on basis of the outcomes from the project "Regio Energy" [19]. The energy potential of forestry biomass was used which was calculated on base of the forest inventory 2000/2001 for each Austrian district. The technical potential considers all possible forestal logging independent of the type of use and includes different types of soft- and hardwood and leads to an Austrian-wide technical potential of 31 TWh, taking into account current non-energetic use. This data was used to calculate the technical potentials for forestry biomass for all municipalities per county according to their share of energy demand.

- To estimate the potential of solar thermal power the available rooftops of buildings are considered. The solar thermal potential of the large buildings is classified as suitable for district heating and the potential of the small buildings as suitable for local supply on a municipality basis. Based on an analysis of existing GIS maps for different cities, the roof area suitable for energy purposes on small buildings was estimated to 50% and about 85% for large buildings due to their flat roofs. A factor for row spacing necessary on flat rooftops is included and limits for 1 m^2 of collector per 2.5 m^2 of rooftop. Additional limitations account for 90% availability in rural areas and 65% in inner city areas. These calculations have been done within the SolarGrids Project [16]. Applying an average annual solar yield of 400 kWh/m^2 for integration into a district heating system results in an Austrian-wide technical potential of 21.7 TWh. The assumed annual yield can be achieved by different combinations of collector size and storage size whereas the yield decreases with further exploitation of the potential [16]. This was neglected in this estimation.
- The potential for geothermal energy is used from the project "GeoEnergy2050" [20] wherein municipalities are listed fulfilling a set of technological and economic criteria for the use of geothermal energy for district heating. All municipalities listed under "Geothermal potential for 2020" are assumed to have the potential as it is defined in the set of criteria resulting in a potential of 10 MW of geothermal power for each of these municipalities.
- The potential for heat from waste incineration plants is based on the heat production of operating plants near or within urban areas and accounts for 2 TWh. No additional potential is assumed due to already existing overcapacities.
- The potential for waste heat from industrial production is calculated for industrial sites taking part in the ETS. The energy demand is estimated using a combination of both a bottom up and a top down approach. In the bottom up approach real emission data, energy-input-per-emission factors and efficiencies are used to calculate energy input of industrial sites. The top-down calculations compare these results with national statistics on useful energy demand by fuel and energy category for producing sectors. To calculate potential waste heat amounts, sector specific factors as in [21, 22] are used and applied to the Austrian case. The results are compared with data from existing national and regional waste heat studies. The potential is further split up into two temperature ranges: Temperatures above 100°C, which are suitable for direct use in a district heating network, and temperatures below 100°C, which need a heat pump to increase the temperature level.
- The technical potential for cooling technologies is derived starting from the useful energy needed for cooling calculated within the Invert/EE-Lab model to maintain temperature in all buildings. A diffusion restriction of air-conditioning equipment has to be implemented due to the fact that only a limited share of the total cooling demand is covered. The limitation is also based on the scenarios and assumptions of the project "Erstellung von energiewirtschaftlichen Inputparametern und Szenarien zur Erfüllung der Berichtspflichten des Monitoring Mechanisms" [17] (Development of energy-related input parameters and scenarios to meet the requirements of the Monitoring Mechanisms) wherein the final energy needed for cooling rises from about 500 GWh in 2012 to 858 GWh in 2025. Assuming an average coefficient of performance of 3 for the air conditioning systems the resulting useful energy needed in 2025 for cooling accounts for 2574 GWh. This represents 18.4% of the total useful energy demand for cooling and is set as an average share for all municipalities. For the technical potential of absorption chillers an additional limitation is made. Since the installation of absorption chillers is considered only for buildings with high cooling loads of some MW and full-load-hours around 1000 h, the amount of energy in buildings meeting these criteria is estimated. 80% of the buildings within the building categories shops, hotels, public buildings (health sector, some offices and education) and office buildings that are classified as large in the Invert/EE-Lab model are assumed to meet these criteria. In the category shops 37% are classified as large, in the

hotel industry 38%, 32% in public buildings and 56% in office buildings resulting in a technical potential of 320 MWh of useful energy delivered by absorption chillers in the year 2025.

2.4. Determination of main and secondary regions suitable for district heating

According to the EED relevant heating and cooling demand regions and conurbations are defined by a "plot ratio" of greater than 0.3 where the “plot ratio” is defined as the building floor area to the land area in a given territory. The Guidance Notes on the EED [23] indicate that the suggested plot ratio corresponds to a linear heat density of 2.5 MWh/m when applying a current specific heat demand of 130 kWh/m^2 and the linear heat density is defined as the quota of heat annually sold and the total trench length of the district heating pipe system. Regions fulfilling these parameters are classified as directly feasible for district heating according to expert literature [13]. Therefore these parameters represent the minimum criteria to determine the regions that have to be considered. In the case of Austria this results in only 7 regions with annual demand over 10 GWh covering 17% of the Austrian building related heat demand. Therefore an adapted approach is used diminishing the plot ratio and combining it with heat density and heat demand to obtain a more representative selection of regions in Austria using the Invert/EE-Lab Data:

- Raster elements have to fulfill a minimum energy density of 10 GWh/km^2 instead of 39 GWh/km^2 as the specification in the guidance notes would have resulted in. This reduction was conducted because evaluation showed that in Austria there are 55 regions with densities over 30 GWh/km^2 whereof only 8 fulfill the suggested plot ratio and 20 regions with densities over 45 GWh/km^2 whereof 12 fulfill the suggested plot ratio.
- The plot ratio as the strongest selection criteria was set to 0.25 per raster element and reduced by a factor dependent on the annual heat demand. So raster elements within regions with high energy demand do not have to fulfill a plot ratio of 0.25 but a minimum of 0.1 to be included into the region.
- The heat demand was chosen as a criterion as no district heating will be feasible in areas without a viable heat that can be sold. The value has been set to 10 GWh/a which is half of the demand as it is suggested as threshold for industrial sites.

The algorithm used to determine these areas calculates the spatial distribution of the heat demand considering neighboring raster elements. Raster elements exceeding the minimum threshold of heat density get connected and with increasing heat demand the algorithm bridges greater distances to connect raster elements.

This results in 38 regions which are conurbations with high potential for district heating and will be classified as main regions. These main regions include 109 municipalities and experience a detailed individual evaluation of available technologies and existing infrastructure and the cost benefit analysis will be performed for each of them with individual parameters.

All remaining municipalities that are not part of these main regions got classified as one out of 30 types of so called secondary regions. This classification is done according to different characteristics of the municipalities including climatic aspects, distribution of heat density, existing network infrastructure and the availability of renewable and technologies classified as efficient for district heating according to the EED. For these secondary regions an aggregated evaluation will be performed and the cost benefit analysis will be done on each of the 30 types wherein every type represents the average of all municipalities belonging to this type. For a detailed insight on the classification of the secondary regions see [24].

2.5. Cost Benefit Analysis

The cost benefit analysis is the last step of the comprehensive assessment and is carried out for each of the 38 main regions and for each type of the 30 secondary regions. The cooling demand is considered in a separate economic calculation. The described cost-benefit analysis determines the cost-optimal technology mix for heating and cooling and thus determines the economic potential of each technology for Austria in 2025.

For each region areas with or without existing district heating network are considered separately and the heat demand is divided into five heat density classes. We thus obtain ten so called sub-regions for each region. The examination is performed sequentially starting with the sub-regions with existing district heating network and descending from the highest heat density to the lowest. The following steps are performed per region:

1. For each region the heat demand in the ten sub-regions is determined for 2025 (section 2.1).

2. The technical potential of the considered technologies is determined for each region (see section 2.3).
3. The heat output of grid-connected capacities still existing in 2025 (see section 2.2) is determined and subtracted from the heat demand of regions with existing district heating network
    a. If these capacities are not sufficient to cover the demand, the cost-optimal technology mix according to the calculated merit order (see section 2.5.1) is used to meet the remaining demand. All technologies are included so that local technologies may be the best solution. When a local technology is cheaper than supply by existing capacities this would mean removal or non-use of an existing network. However, in this case no investment costs for the distribution network occur since this is already in place.
    b. If the capacities of the existing grid-connected plants exceed the demand, these capacities are used to meet the demand of the sub-regions without existing network starting with the highest heat density.
4. For each sub-region the demand not covered by the existing capacities is met by applying the cost optimal technology mix. The procedure is as follows:
    a. From the technological merit order including investment, transportation and distribution costs (see section 2.5.1) the most cost effective technology is selected. The grid-connected technologies include a peak load boiler covering the 10% of peak heat demand. In cogeneration plants the share of the peak load boilers may be higher due to the electricity led optimization. In the central scenario the maximum share of the peak load boiler within the main regions accounts for 34% and the average share for all main regions is 12%.
    b. The heat demand has to exceed a fixed minimum plant size. This takes into account that large power plants would be oversized to supply small systems.
    c. When the potential of the most cost-effective technology is exhausted, the second most cost-effective technology is chosen and there is no further potential of the exhausted technology for the other sub-regions.
    d. These steps are repeated until the demand of the subregion is covered.

2.5.1. Costs

The choice of the most cost-effective technology depends on the region, the presence of a district heating network, the expansion potential and limitations on the technical potential.

The costs consist of:

1. Production costs for heating per technology, depending on the load
2. Supply costs for heat transport from the power plant to the distribution grid, depending on distance (relevant only for selected technologies such as geothermal energy or waste heat)
3. Distribution costs for district heating technologies
4. Benefit (income) is generated only by cogeneration power plants in the form of sold electricity (Section 2.5.2)

Production costs:

The calculation of the production costs is done with an economic interest rate of 4%. Variable costs for heat production are calculated per unit and get converted into prices of 2025. The CO_2-certificates price is set to 25 EUR/t_{CO2}. Fuel costs are based on historical prices and assumptions on the price development up to 2025 [25]. They refer solely to the costs of the combustible and do not include taxes due to the socio-economic perspective. Figure 1 shows the relation of the costs schematically.

Network costs for heat transport and heat distribution:

Central heat generating technologies supplying households and service sector (assumed temperature range 60–90°C) have additional costs for heat transport and heat distribution. These costs are calculated on basis of a reference network which has a peak load of 10 MW_{th} and includes residential buildings and service companies. Network losses are assumed to be 10% which is the average value for Austrian district heating systems according to Statistics Austria. Although network losses are highly related to the plot ratio and are therefore higher for lower plot ratios the used losses are representative due to the selection of most prospective regions. The relations for the calculation of the network costs are depicted in Figure 2.

The share of connected consumers per subregion indicates how much of the heat demand of a region

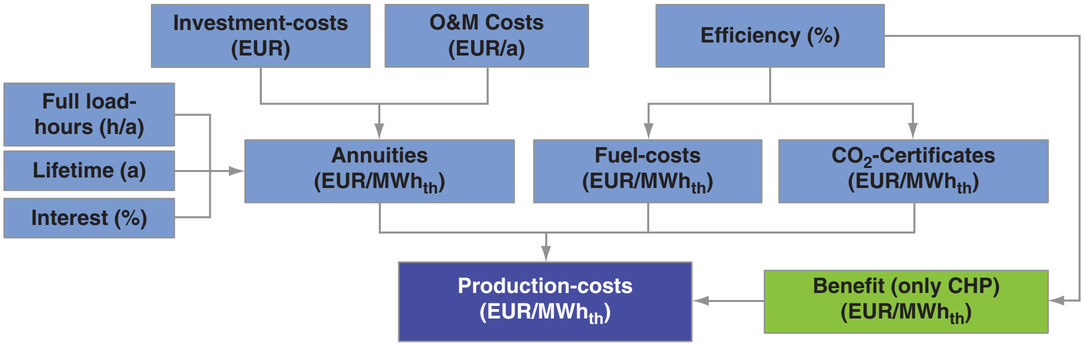

Figure 1: Schematic relations for the production costs

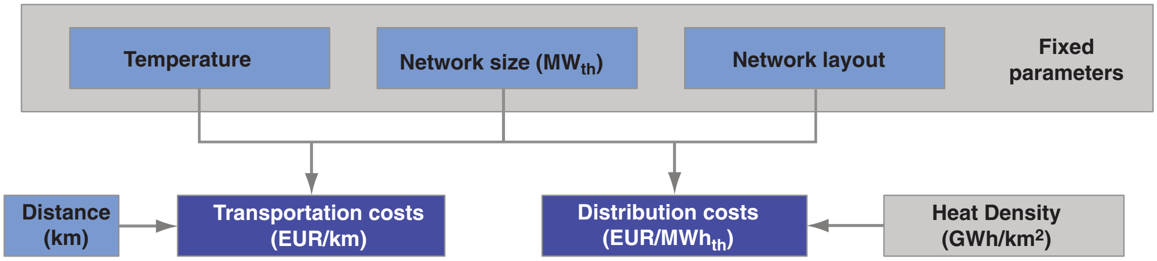

Figure 2: Relations between network costs

potentially can be connected to the network. This share is usually below 100% as individual buildings due to technical restrictions may not be suitable for connection or individual customers can refuse a connection. The connection rate thus directly influences the demand within an area. The technical limitation is set to 90% of the demand not yet supplied by district heating.

The transportation costs are calculated under the assumption of light soil with already installed cables and pipes because the distance between plant and network is usually an area of medium population density. The transportation costs from the power plant to the distribution network add up to 83.5 EUR/km/a and consist of the investment costs for pipe and O&M costs. Pumping costs account for less than 1% and are neglected. Only geothermal plants, waste incineration plants and industrial waste heat have transportation costs because other plants are usually situated near the distribution grid.

An analysis of the distribution costs as a function of the heat density and network capacity has shown that the distribution costs are highly dependent on the heat density, but only in small networks (1 MW$_{th}$) the network capacity leads to larger variation in distribution costs. Therefore different distribution costs are used only as a function of the heat density of the subregions and other specific local characteristics. Local factors that influence the distribution costs are:

- presence of an existing district heating network,
- average heat density,
- full-load hours of the load profile and share of connected costumers

The calculation is performed under the assumption of a depreciation time for the network of 30 years, an interest rate of 4% and a network temperature of 90°C with a temperature difference of 25 K between flow and return.

The calculation of the distribution costs differentiates the following five heat densities considering sparsely populated rural and densely populated urban areas:

- 0–10 GWh/km^2, (49.2 €/MWh)
- 10–20 GWh/km^2, (35.1 €/MWh)
- 20–35 GWh/km^2, (30.0 €/MWh)
- 35–60 GWh/km^2, (26.6 €/MWh)
- >60 GWh/km^2, (24.1 €/MWh)

2.5.2. Generated revenues

Revenues of CHP plants from the electricity market are determined using an electricity led operation based on a future hourly price curve. This hourly electricity price is used to determine the plant dispatch dependent on heat demand and price of electricity. A price curve for the year 2025 is used with an average electricity price of

47.2 EUR/MWh and adapted to the fuel prices and CO_2 certificate costs assumed here. The electricity price curve is based on a detailed operational electricity market model, which determines the cost-optimal operation for given power plants and a given share of renewable energy in the total electricity market area.

2.5.3. Sensitivity analysis

To evaluate the influence of different parameters and to establish a range of possible results some sensitivity analysis are conducted. The sensitivities include following variations:

- High CO_2 price of 100 EUR/t_{CO2} (instead of 25 EUR/t_{CO2})
- Low gas price of 20 EUR/MWh (instead of 32.6 EUR/MWh)
- High gas price of 40 EUR/MWh
- Low connection rate of 45% (instead of 90%)
- High-Efficiency-Scenario in reduction of building-related demand for heating and hot water

2.5.4. Economics of cooling alternatives

The cooling demand can be met by three different ways considered in this analysis:

1) Local compression chillers (air conditioning),
2) Local absorption chillers using heat of a district heating network or
3) Central absorption chillers in conjunction with a separately installed district cooling network

The latter option is highly dependent on local conditions and therefore not suitable for an analysis based on a general approach. For all regions with district heating potential a cost comparison between compression and absorption chillers is carried out taking into account the technical potential. It is assumed that during the cooling period (1st May – 30th September according to Austrian standard) 90% of the installed heat capacity can be used for absorption chillers because the average heat load in the cooling period - mainly domestic hot water preparation – accounts for an average of 10% of the installed heat capacity in all main regions. The cost comparison of compression and absorption chillers is done using a typical cooling load profile for office buildings. Absorption chillers are installed with peak-load compression chillers with a power ratio of 40:60 corresponding to a peak load of 10% of cooling demand and full load hours for the base-load absorption chillers of approximately 1000 hours. The fuel costs of the absorption chillers consist of the used electricity as well as the used heat produced within the district heating network and are therefore dependent on the mix of technologies. "Must-run" technologies such as waste incineration plants and industrial waste heat have heat production costs of zero, for the remaining technologies an average price for heat is calculated. The fuel costs of compression chillers are based solely on the electricity consumed for cooling and the efficiency.

3. Results

In this section the main results of the different steps of the comprehensive assessment are described.

3.1. Building related heating demand

Figure 3 and Figure 4 show the major outcomes of the evaluation of the building related demand for heating and hot water with the Invert/EE-Lab model. The scenario shows the development of the demand for the different building classes in the central Business-As-Usual scenario from 2012 to 2050. The demand in this scenario drops from 97 TWh in 2012 to 77 TWh in 2025 and to 55 TWh in 2050. More than two third of the demand occurs within residential buildings. Figure 4 shows the division of the heat demand into different heat density classes for 2025 – the year for which the Cost-Benefit-Analysis is done.

3.2. Determination of main- and secondary regions suitable for district heating

The methodology described in section 2.4 led to 38 main regions with high heat densities and high heat demand where district heating can play a central role. These regions include 109 municipalities accounting for 40% (31 TWh) of the building related heat demand in Austria. The annual demand of these main regions varies from about 10 GWh in the smallest region to more than 15 TWh in the biggest region. About one third of the energy demand in the main regions lies in areas with energy densities above 60 GWh/km^2 wherein the Vienna region accounts for 90% of this amount. The 2nd third of the energy lies in areas with densities between 35 and 60 GWh/km^2 and the last third in areas with energy densities below 35 GWh/km^2. Vienna is the only region in Austria with more than 50% of the heat demand in densities higher than 60 GWh/km^2. Figure 5 shows the heat densities, the red-bordered main regions and in the pie chart their share on the building related heat demand

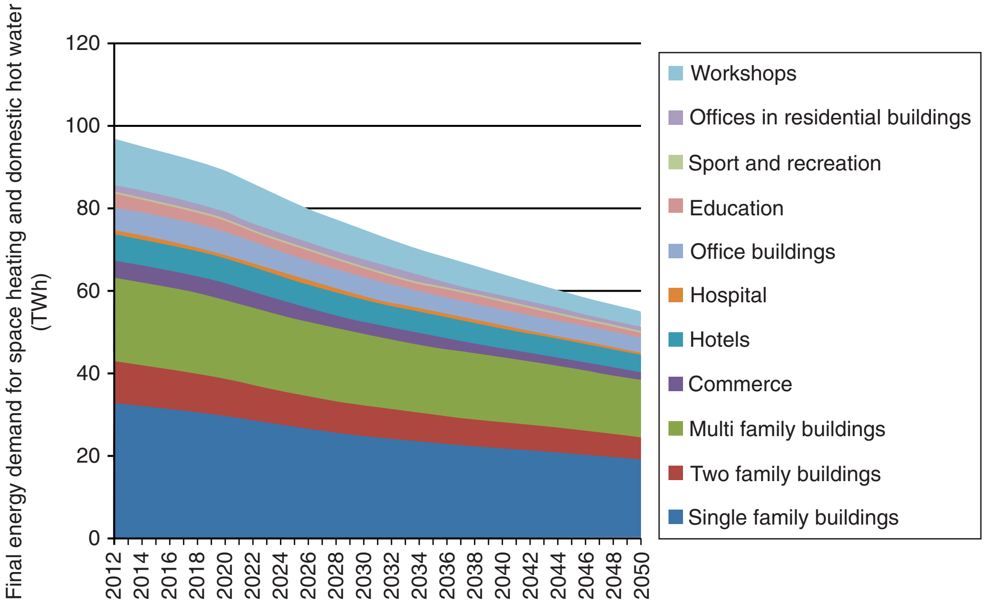

Figure 3: BAU scenario for building related energy demand in Austria for different building classes

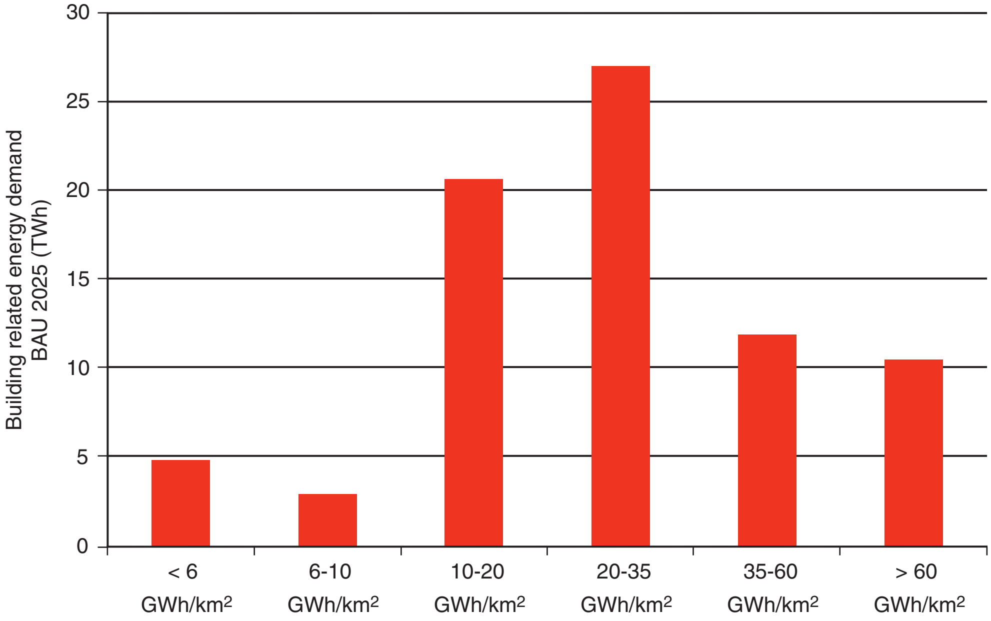

Figure 4: Distribution of the Austrian building related heat demand of 78 TWh for 2025 into heat density classes

in Austria. The main region Vienna (with its conurbations) accounts for 20% of the Austrian demand and for 50% of the demand of the 38 main regions.

Municipalities with lower heat densities where mainly local technologies are the most economical alternative are clustered as secondary regions according to climatic aspects, distribution of heat density, existing network infrastructure and the availability of geothermal or industrial waste heat. Further explanation of the methodology is described in [24]. The assignment of the 2367 remaining municipalities to the 30 types of secondary regions is depicted in Figure 6. In only 25 of these municipalities more than 50% of the demand lies in densities higher than 35 MWh/km^2 but in 700

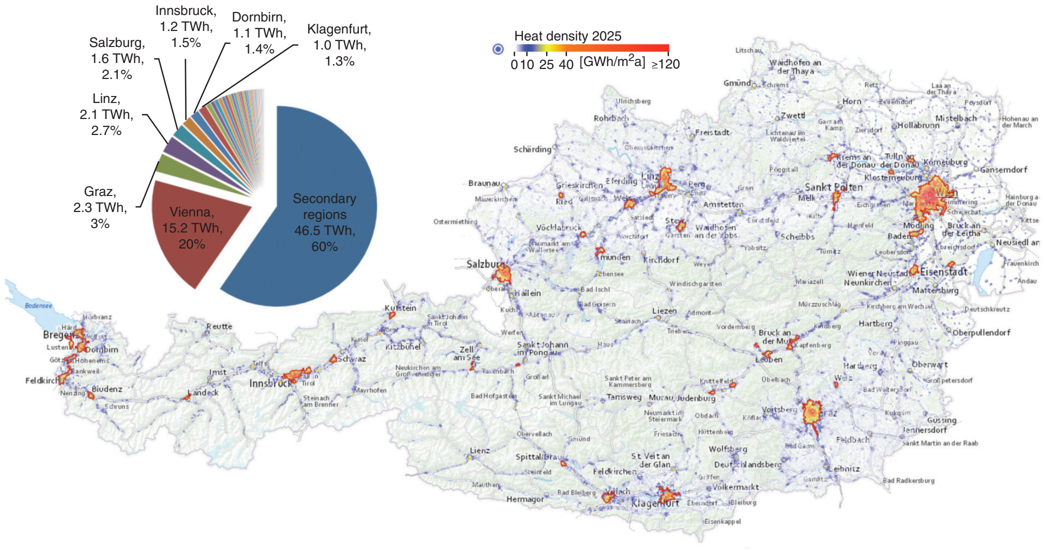

Figure 5: Main regions suitable for district heating in Austria and their share of the total building related heat demand

Figure 6: Assignment of Austrian municipalities to types of secondary regions

municipalities more than 50% of the demand lies in densities below 10 MWh/km^2.

3.3. Technical potentials for district heating

To calculate the technical potential for district heating it was assumed that the share of connected households can rise up to 90% of the heat demand in sub-regions with heat densities of more than 10 GWh/km^2. According to this calculation there is a technical potential of 63 TWh including 13 TWh already supplied by existing infrastructure. This represents a market share of 81% of the total demand of 78 TWh. As reference a reduced technical potential was calculated applying a connection rate of 45% in sub-regions with heat densities higher than 20 GWh/km^2. This calculation results in a reduced technical potential of slightly over 22 TWh including the existing supply and representing a share of 28%. Figure 7 shows the heat demand split up into the different heat density classes, the full- and the reduced technical potential for district heating and the share of demand supplied by existing grids in 2025 for the seven biggest main regions and summed up for the other regions. In some regions the reduced technical potential is smaller than the demand supplied by existing infrastructure in 2025. This indicates that whether there is existing infrastructure in areas with heat densities lower than 20 GWh/km^2 or that some denser areas already have connection rates of more than 45%.

3.4. Technical potentials for district cooling

As stated in section 2.3 the maximum potential for the cooling technologies results from a diffusion-limitation of air-conditioning equipment and an assumption on the share of energy within buildings meeting criteria for the installation of absorption chillers. For 2025 almost 2.6 TWh were identified as technical potential for

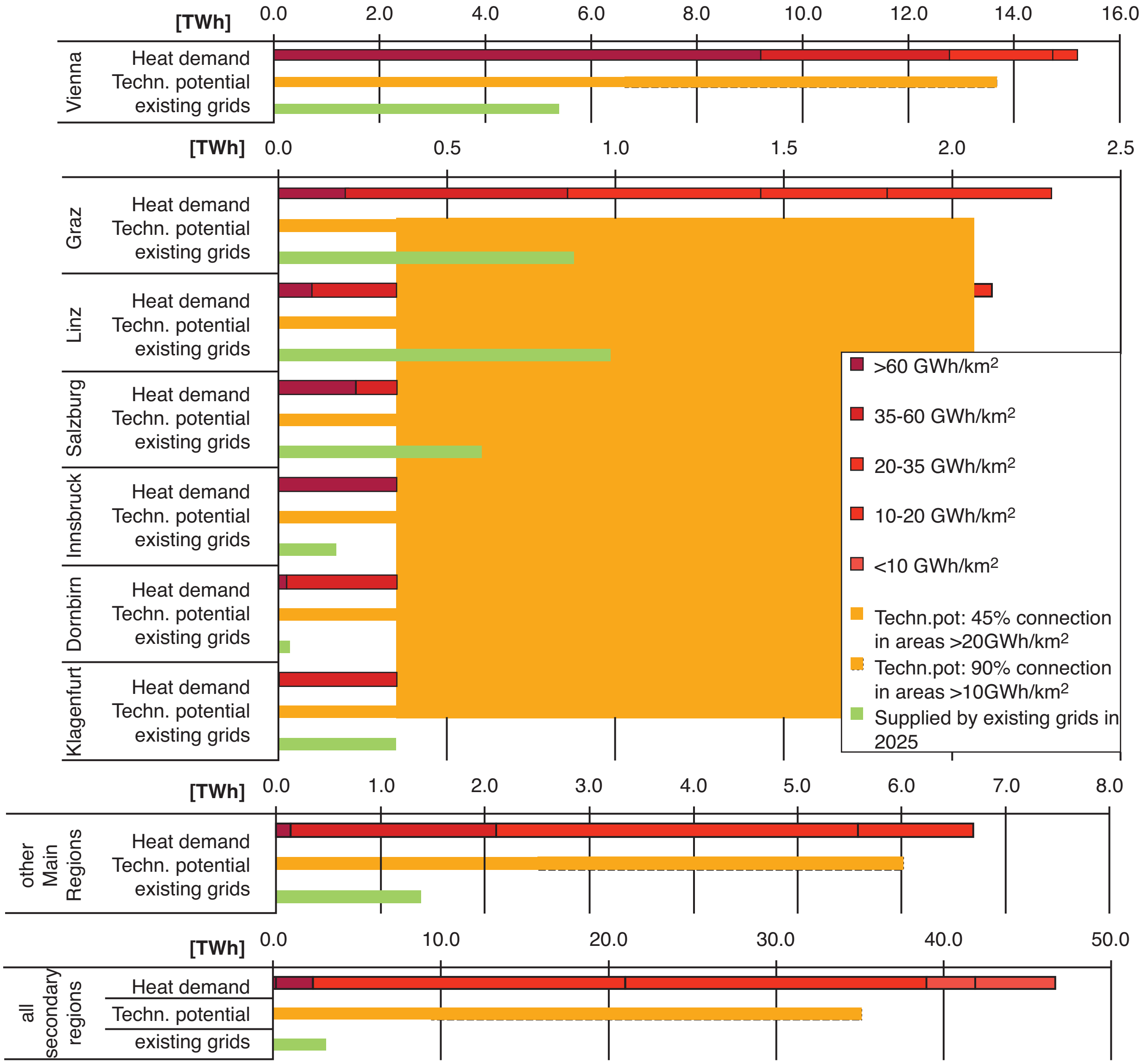

Figure 7: Heat demand, technical potentials for district heating and share of demand supplied by existing grids in 2025

cooling technologies and about 320 MWh as suitable for the application of absorption chillers. Therefore 12% of the cooling demand is suitable for absorption chillers. Figure 8 shows the cooling demand and the share fulfilling the criteria for the application of absorption chillers in 2025 for the seven biggest main regions and summed up for the other regions.

3.5. Technical potentials for CHP

Although there are no technical restrictions for CHP plants in terms of availability, a calculation of the technical potential for heat from CHP is done considering the heat demand suitable for district heating. Using the technical potentials for district heating as starting point, the potential of CHP is calculated arising from the demand profiles when covering the 10% peak energy with a peak load gas boiler as done for the cost-benefit analysis. Assuming a heat-led operation mode the CHP plants achieve 4.300 to 5.600 full load hours in the different regions. The resulting technical potential for CHP in existing district heating networks in Austria accounts for 10.5 TWh representing 13% of the heat demand of 78 TWh. It would rise to 57 TWh representing 73% of the heat demand when establishing the whole potential for district heating. The reduced potential accounts for 21 TWh representing 27% of the heat demand. Figure 9 shows these technical potentials for the different heat density classes and the technical potential within existing district heating networks when the demand is solely met by CHP.

3.6. Cost Benefit Analysis and economical potentials

As stated in Section 2.5 an individual merit order was established for each region and applied to determine the economic potentials. Although the merit order depends on available technology, heat density, distance and applicable full load hours it can be generally stated that in the central scenario the cheapest technologies in terms of heat generation costs are industrial waste heat, geothermal heat, heat from waste incineration and biomass if available. When no one of these technologies is available central gas boilers are the most cost effective technology under stated conditions, cheaper than the analyzed CHP technologies. This will be further discussed in the conclusions section. Figure 10 shows different economic potentials for the biggest main regions and aggregated for the other regions. The dark blue bar shows the demand covered by existing capacities, the light green bar the additional economical potential for district heating and the red bar the share that is not economical feasible for district heating. The dark green bar shows the regions where the economic potential for district heating is efficient according to the EED. For the secondary regions no existing production capacities where considered and therefore the dark grey bar shows the efficient economic potential including the part that may be produced by existing capacities and the light grey bar the economic potential that is not efficient according to the EED.

Figure 11 shows the economic potential for CHP to supply district heat in 2025 for the seven biggest main regions and aggregated for the other main and secondary regions. It can be seen that there is no additional potential for CHP but all heat is produced by existing plants. This is discussed in the conclusions section.

As stated in Section 2.5.3 different sensitivity analysis have been done to evaluate the most important

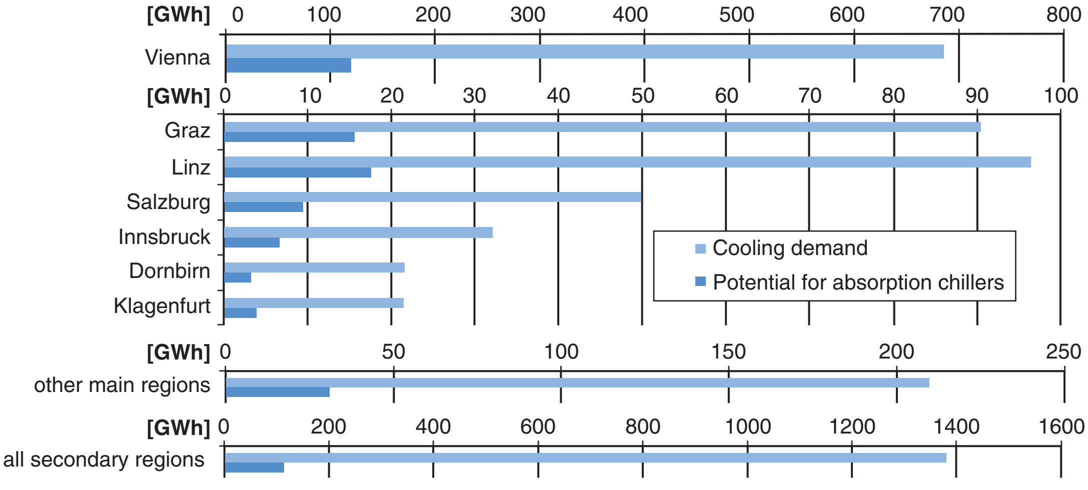

Figure 8: Cooling demand and technical potential for absorption chiller

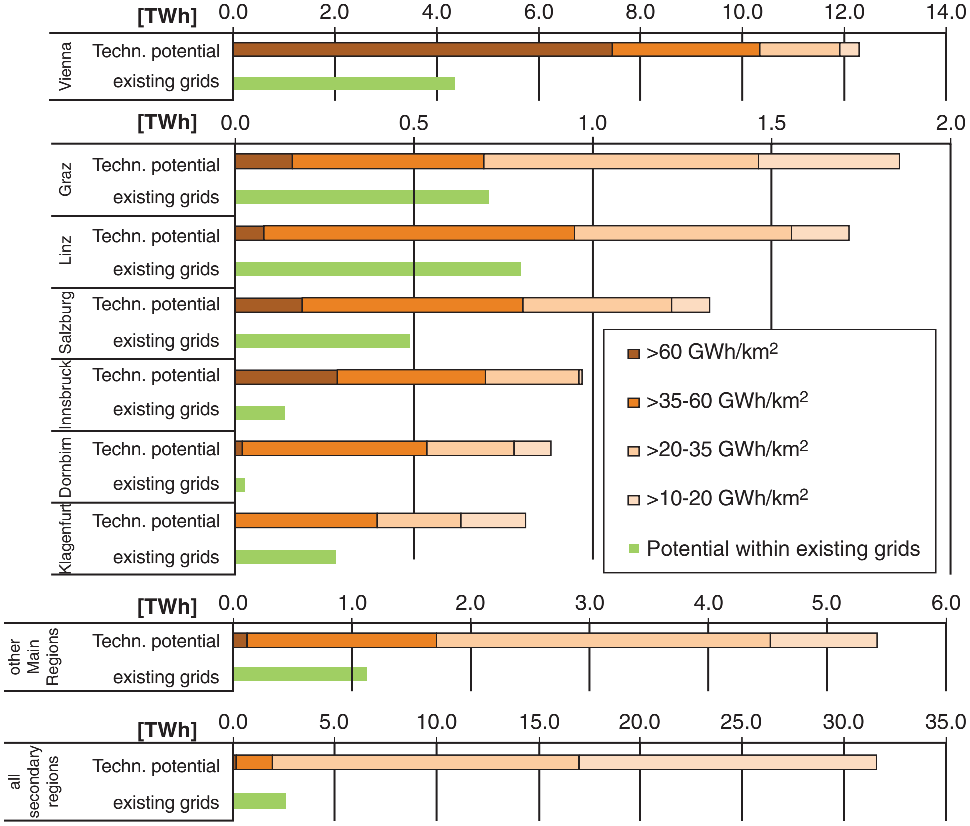

Figure 9: Technical potentials for heat from CHP within existing district heating grids (2025) and when applying the whole technical potential for district heating

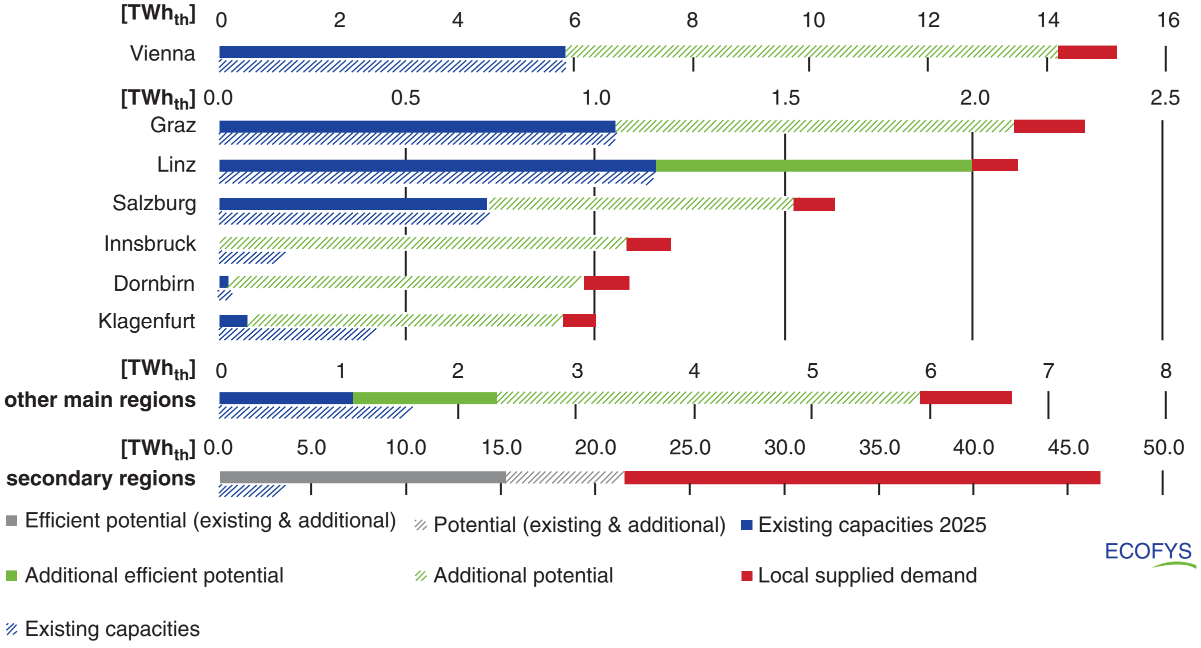

Figure 10: Economical potentials for district heating for the biggest main regions and aggregated for the other regions in 2025

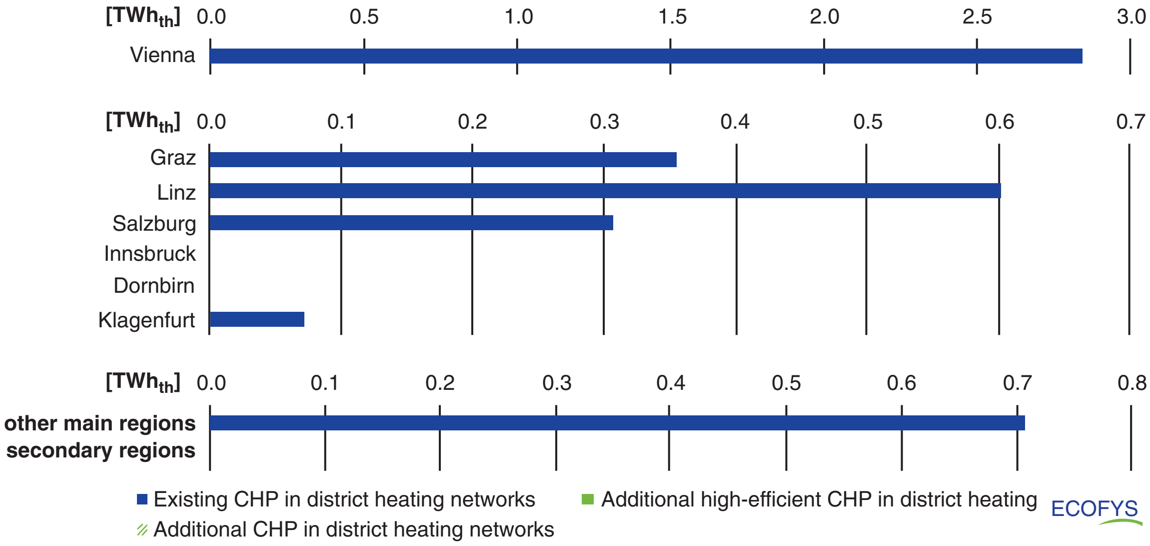

Figure 11: Potentials for CHP for the biggest main regions and aggregated for the other regions for the BAU Scenario 2025

parameters influencing the results. The left column of each scenario in Figure 12 shows the outcomes for the economic district heating potential and the right columns the outcomes for the economic CHP potentials.

4. Conclusions and discussion

Both, technical and economic potentials show notable additional potential for district heating in Austria depending on the assumed conditions. The central scenario shows a total economic potential for district heating of 52 TWh accounting for 67% of the Austrian heat demand Although the merit order depends on available technology, heat density, distance and applicable full load hours it can be generally stated that in the central scenario the cheapest technologies in terms of heat generation costs are industrial waste heat, geothermal heat, heat from waste incineration and biomass if available. When no one of these technologies is available central gas boilers are the most cost effective technology under stated conditions, cheaper than the analyzed CHP technologies and cheaper than the cheapest local technology in almost all urban regions. In the central scenario with a connection rate of 90% district heating often is economical feasible down to heat densities of 10-20 GWh/km^2. But when applying a low connection rate of only 45% the sensitivity analysis shows a high sensitivity and a big drop in economic potential to 20 TWh accounting for only 26% of the heat demand. This is of great interest because with low connection rates the distribution costs increase and district heating gets more expensive than individual supply. Therefore the assumed connection rate of 90% is not achievable under free market conditions and even the assumed low connection rate of 45% is hard to achieve when different technologies are competing as it is in Austria and district heating has to deal with high upfront costs to establish a dense network and connect enough costumers. A solution to guarantee high connection rates is comprehensive energy planning to identify regions where district heating is economical feasible and then find a way that costumers have to or want to connect and benefit from the advantages. Furthermore it can be seen that in most main regions the economic potential is not effective according to the EED. This is because the potentials for industrial waste heat, geothermal heat, waste incineration and even biomass is limited and it is supplied mainly by fossil energy carriers in terms of a natural gas boiler as the most economical alternative. In the secondary regions there is a higher share of efficient potential due to the higher availability of biomass compared to the main regions. Another major outcome of this analysis was, that – although there is a high technical potential – under stated conditions there is no additional economic potential for gas fired CHP but all combined produced heat comes from existing plants because the actual electricity price is too low to invest into and run new CHP plants. Only in the scenario with low gas price or high CO$_2$ price of 100 EUR/t$_{CO2}$ new CHP plants are

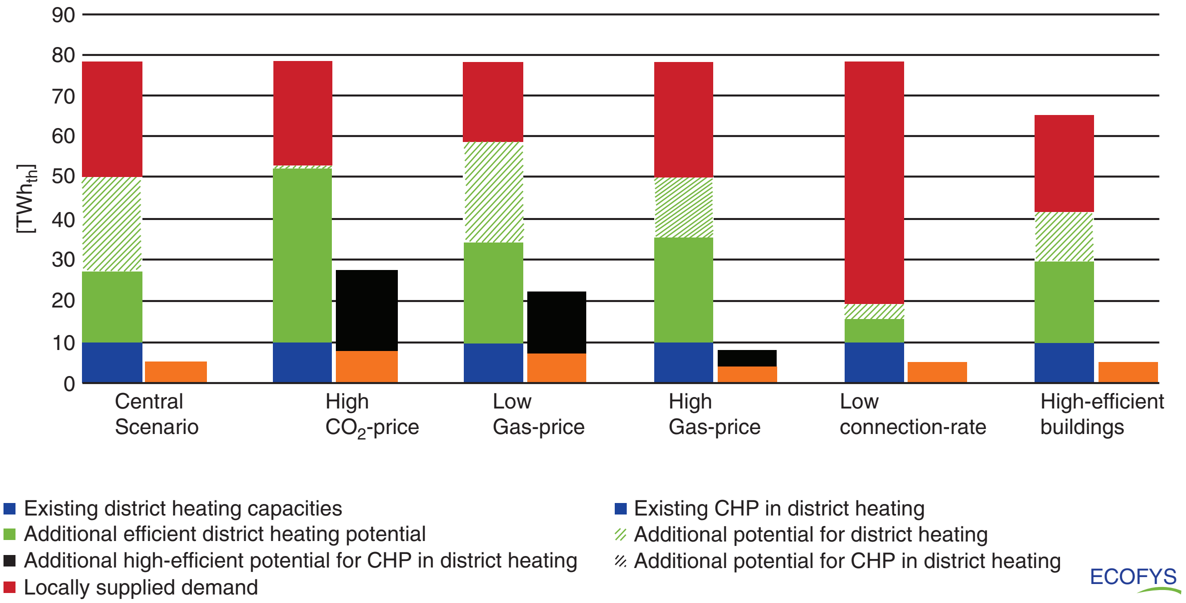

Figure 12: Results of the sensitivity analysis for the district heating and CHP potential for Austria in 2025

economically feasible. Main reasons for this are the low and not internalized costs for carbon and the resulting low revenues on the electricity market. A solution to make renewable and effective technologies more competitive against fossil based solutions would be to find a way to include external costs of extraction, use and long term effects of fossil fuels into their price.

Within this assessment an adapted approach was used because the proposed steps given in the EED showed some lack of clarity in the definition of the regions to be considered. The used term "plot ratio" is defined as the ratio of the building floor area in a given territory but without specifying the given territory. Therefore the term plot ratio applies mainly for inner and outer city areas where city planning can define the land area but shows some disadvantages in sparsely populated areas as there is no clear definition of the corresponding land area per building. Thus, different approaches can lead to notable differences in the calculated plot ratio especially in outer city areas. But also using the plot ratio as unique criteria to determine feasible heating and cooling demand regions may be too simple. The additional definitions in the corresponding Guidance Notes [23] – indicating that the suggested plot ratio corresponds to a linear heat density of 2.5 MWh/m when applying a current specific heat demand of 130 kWh/m^2 – are all directly interconnected and therefore lead to the same areas to be considered. This is why in this comprehensive assessment a combination of energy density per raster element, the plot ratio of raster elements and the total heat demand of connected areas are used to create a balanced set of criteria to select high-potential regions. Beside the evaluation of the main regions, the performed comprehensive assessment includes the characterization of all remaining municipalities as secondary regions to estimate technical and economic potentials for regions not classified as high-potential regions. This gives the opportunity to find a balance between looking in detail at regions with expected high potential, but also evaluating if there may be potential in other regions. Also the same Cost-Benefit-Analysis can be performed for all main and secondary regions only differing in cost structure according to the available technologies and the characteristics of the heat demand in each region.

Still the used approach to identify the main regions and also the criteria for classification of municipalities into secondary regions is just one option and does only consider the characteristics of the Austrian building stock and the parameters were chosen according to the results given by the Invert/EE-Lab Model. As Austria is a small country with only a few bigger cities the suggested criteria in the EED seem too general and too restrictive. However, other countries may have other structures and therefore the criteria used in this assessment may lead to too many or not representative regions when applied to other countries.

In general assessments on national level only allow for a certain degree of detail and especially regional characteristics do influence the results on cost-effective potentials substantially. So some tradeoffs had to be made to combine a detailed look at the main regions with an aggregated look at the secondary regions: Network costs were calculated for one reference network with a set of fixed parameters for all regions, costs for integration of industrial waste heat were calculated on an average base, only one temperature level of district heating networks was considered and also network expansion costs were calculated on base of average prices for pipes and laying.

The Cost-Benefit-Analysis based on classification of different demand and supply regions allow for a first estimation of the potentials of these regions and to determine whether they are suitable for district heating or the use of CHP. But this does not replace detailed feasibility studies for the individual regions with identified potentials. Local analysis should always take into account as much regional characteristics as possible and investment planning always has to be done on a small scale level.

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