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ASSESSING THE TECHNICAL AND ECONOMIC POTENTIAL OF HIGH EFFICIENT CHP AND EFFICIENT DISTRICT HEATING AND COOLING: THE METHODOLOGY USED FOR THE "COMPREHENSIVE ASSESSMENT" IN AUSTRIA

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1. Introduction

The reduction of greenhouse gas emissions from the energy system is one of the central challenges of the 21st century. This is tried to be achieved by an increased use of renewable energy sources and increasing the efficiency of the energy system. 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 but also in the industrial sector there are relevant potentials for energy reduction.
As part of the EU Energy Efficiency Directive (EED) ("Directive 2012/27/EU of the european parliament") all Member States have to develop a comprehensive assessment of the potential for the use of high-efficient combined heat and power (CHP) and efficient district heating and cooling[1] by the end of 2015.
In a first step relevant heating and cooling demand regions exceeding certain consumption or production thresholds listed in the directive have to be identified and the potential of renewable energy and efficient technologies should be determined for each region. For these regions an economic cost-benefit analysis has to be performed in the second step. This leads to the central questions of the work described in this paper:

1) Is the selection criteria of regions to be analyzed according to the EED (plot ratio[2] >0.3) clear, unambiguous and sufficient?
2) How can significant heating and cooling demand regions be identified and characterized?
3) How do different characteristics of these regions influence the cost-benefit analysis of high-efficient CHP and efficient district heating and cooling opportunities?

2. Methodology

In this section the methodology used in the different steps of the comprehensive assessment is described:

- Evaluating the actual and future heating and cooling demand,
- Investigate relevant existing infrastructure,
- Calculate potentials for efficient technologies,
- Determine relevant regions,
- Perform a cost-benefit analysis

First, a definition of the relevant system boundaries of heating and cooling demand and supply regions is done. These boundaries include the temperature level up to 500°C that can be provided by CHP and the values specified in the directive of at least 20 GWh of annual heating and cooling consumption for industrial zones and a plot ratio of at least 0.3 for the heating demand of municipalities and conurbations.

2.1. Evaluating the actual and future heating and cooling demand

2.1.1. Actual and future building related demand

To determine relevant heating and cooling demand regions, the demand for space heating, cooling and 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-

[1] 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] 'plot ratio' means the ratio of the building floor area to the land area in a given territory ("Directive 2012/27/EU of the European Parliament," 2012)

Lab (Mueller, 2015). The energy calculation is implemented in INVERT/EE-Lab by a thermodynamic/physical mapping of buildings. The calculation of final energy demand is based on the Austrian pre-standard ÖNORM B 8110-5 2007, and the Austrian Standards ÖNORM B 8110-6 2007, ÖNORM H 5055 2008 and ÖNORM H 5056 2007. The systematic user factor is integrated as a difference of the interior temperature from the standard value of 20°C (Müller et al., 2010). The regional disaggregation is done by using data about the settlement areas on a 250x250 m resolution and the population density on a 1x1 km resolution. The developed algorithm allocates 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, GWZ 2001 Statistics Austria) as well as workplaces and employees over tangential areas to a 50x50 m grid. Because the calculations on raster elements-basis led to an underestimation of the plot ratio especially of sparsely populated raster elements compared to values in the literature, 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. As additional criteria the plot ratio of the raster elements was not allowed to increase by more than 75% in every step compared to the calculation without correction. The output of the INVERT/EE-Lab model allows a very broad evaluation of the data. The heat demand was divided into six heat density classes which were merged to five sub-regions for the cost-benefit analysis.

Two demand scenarios up to 2050 have been developed but the values for 2025 will be used for the assessment as suggested by the EED. The two scenarios include a Business-As-Usual (BAU) and a High-Efficiency Scenario (EFF)[3].

The BAU scenario 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. All analyses done in this paper refers to the BAU scenario.

The high efficiency scenario assumes that an ambitious package of measures is made to increase efficiency, both in buildings and industrial sector. It is based on the assumption that coordinated measures to reduce barriers for high-quality building renovation are implemented. This includes, among other things, changes in the laws for ownership and tenancy, in the building regulations, promotion of energy consultancy, building-specific remediation plan etc.

2.1.2. Demand in industrial sector

The industrial energy demand is analyzed using two different methods. On the one hand a characterization of the energy demand for heating and cooling is done on the basis of national statistics. This top-down analysis leads to overall figures of the different industrial branches and allows for a selection of branches to be analyzed in higher detail. On the other hand we estimate the heating and cooling demand for large industrial sites taking part in the Emission Trading System (ETS). This bottom-up analysis leads to estimations of the energy demand for heating and cooling of large industrial plants allowing for plant specific data to be used in the cost-benefit-analysis of industrial CHP. It is furthermore the basis for the subsequent estimation of industrial waste heat potentials linked to their geographical location, which are used in the cost-benefit-analysis of efficient district heating and cooling.

To calculate the energy demand of the industrial plants taking part in the ETS we use two different methods: industrial sectors that are heterogeneous in the goods produced and its energy demand per unit of production are calculated based on production quantities on-site and energy demand per unit produced values. We used mainly information provided by environmental reports of the different plants and enterprises and sectoral studies on energy demand and production characteristics. For heterogeneous sectors as well as for plants where no information on production quantities could be found we calculate the energy demand based on its real emission values listed in the ETS combined with emission per energy demand values gained from the national inventory report.

2.2. Relevant existing infrastructure

The relevant existing infrastructure in terms of existing plants and district heating networks is investigated to include them into the cost-benefit analysis. Existing plants are taken from the Platts-Database 2011and have been updated to include newest information about recent closings. Based on the year of last change of the plants and average lifetimes for the different fuel-types the remaining plants for 2025 are evaluated. Waste incineration

[3] In order to achieve a high level of consistency with other relevant energy scenarios, the assumptions made here are taken from 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), which is currently funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The scenario presented here as "BAU" corresponds to the scenario "with existing measures 2015” (Müller and Kranzl, 2015).

plants are assumed to continue to exist. That means their investment costs are not considered in the cost-benefit analysis arguing that their main purpose is the treatment of waste and not the production of heat.

Existing district heating networks are assumed to continue to exist until 2025 due to their long lifetime and the fact that large infrastructures like networks are renovated bit by bit. The Data for existing networks is taken from the last complete national census on the Austrian building stock in 2001. This Data is updated with available Data for 2011 on stock of households and dwelling units supplied by district heating on federal states basis. Therefore an average growth rate per federal state is calculated which is applied for all municipalities with existing net infrastructure by 2001 in that state. New 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. Furthermore there are no data about number and type of buildings connected to district heating networks and the classification on size of district heating system has to be done on the 2001 data. This data shows that in 325 Austrian municipalities more than 5% of the building stock were connected to a district heating network and in 822 municipalities between 0.5 and 5% of the buildings were connected.

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

Beside the heat demand and existing infrastructure technical potentials play an important role to determine relevant regions for district heating. Only high efficient technologies according to the EED are taken into account. Therefore technical potentials for renewable energy sources as well as for CHP, waste incineration plants and industrial waste heat are evaluated. To determine the regional potentials technical approaches like the suitable roof area for solar thermal collectors, the availability of natural gas within a certain distance or existing waste capacities for incineration plants are used. The technical potentials are identified as follows:

- The potential of gas fired technologies for every region is identified by evaluating the heat demand of the region that lies within a certain distance to existing gas pipelines. Central gas-fired technologies are considered to be unlimited if there is a pipeline within 2 km distance and the potential for individual heating technologies is limited to the heat demand within 2 km to an existing pipeline
- Due to regional differences in availability of biomass and the options for biomass transport between regions and countries these potentials are considered to be unlimited in a first model run
- To estimate the potential of solar thermal power the available rooftops of buildings are considered. 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 1m² of collector per 2.5m² of rooftop. Additional limitations account for 90% availability in rural areas and 65% in inner city areas. Half of the rooftops are classified as “very suitable” and half as “suitable”. 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
- The potential for geothermal energy is used from the existing project “GeoEnergy2050” (Könighofer et al., 2014) wherein municipalities are shown fulfilling different criteria for the use of geothermal energy.
- The potential for heat from waste incineration plants is based on the heat production of operating plants. 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 emission trading system (ETS) using emission factors and efficiencies to calculate their energy input and sector specific factors to calculate potential waste heat. The results are compared with data from existing national and regional waste heat studies. The potential is further split up in 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 maximum potential for cooling technologies results from a diffusion limitation of air-conditioning equipment due to the fact that the calculated cooling demand refers to the useful energy needed to maintain temperature in all buildings. As for the heat demand scenarios the assumptions accord to the project „Erstellung von energiewirtschaftlichen Inputparametern und Szenarien zur Erfüllung der Berichtspflichten des Monitoring Mechanisms“ (Müller and Kranzl, 2015) (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 2.574 GWh. This demand is set in relation with the total useful energy demand for cooling and represents 18.4%. This is set as average share to determine the cooling potential for every municipality. 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 and full load hours around 1.000h, the amount of energy present in buildings meeting these criteria is tried to be estimated. 80% of the buildings within the building categories shops, hotels, public buildings (health sector, some offices, education) and office buildings

classified as large in the INVERT/EE-Lab model, are assumed to meet these criteria. In the category shops 37% probably have these high full load hours, in the hotel industry its 38%, 32% in public buildings and 56% in office buildings.

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

The combination of the demand with the existing potentials for renewable energy and efficient technologies as well as the existing supply systems leads to an identification of relevant heating and cooling demand and supply regions. The threshold of 0.3 for the plot ratio as it is suggested in the EED, results in only 7 regions with annual demand over 10 GWh which have to be considered in Austria covering only 17% of the Austrian building related heat demand. Therefore an adapted approach is used combining the plot ratio, the heat density and the heat demand to obtain a more comprehensive selection of regions using the INVERT/EE-Lab Data:

- The heat demand was chosen as a criteria as after first evaluations only 7 regions excessed 10 GWh/a but another 10 regions showed a demand of less than 10 GWh/a and no district heating will be feasible in areas without a viable heat to be sold. The criteria has been set to half of the demand of 20 GWh/a as it is suggested for industrial sites that have to be considered in the comprehensive assessment.
- The energy density per raster element was reduced to 10 GWh/km² as the specification in the interpretative notes would have led to a density of 39 GWh/km² and the evaluation showed that in Austria there are 55 regions with densities over 30 GWh/km² (whereof only 8 fulfill the suggested plot ratio) and 20 regions with densities over 45 GWh/km² (whereof 12 fulfill the suggested plot ratio) exceeding the annual demand of 10 GWh/km².
- The plot ratio turned out to be the hardest criteria and was set to 0.25 and even reduced by a factor dependent on the annual heat demand so that regions with high energy demand do not have to fulfill the plot ratio of 0.25 but a minimum of 0.1.

The algorithm used to determine areas suitable for district heating calculates the spatial distribution of heat demand considering the neighboring raster elements. Raster elements exceeding the minimum threshold of heat density get connected whereat with increasing heat demand the algorithm bridges greater distances to connect raster elements. It was assumed that at a certain heat density municipal boundaries formed a passable barrier for connection but not so for province borders.

The chosen heat density threshold of 10 GWh/km² led to 690 areas of connected 250x250 m grid elements meeting these criteria in Austria. For these areas the reduced plot ratio of 0.25 and the minimum annual heat demand of 10 GWh were applied. The resulting 38 potentially municipality-crossing regions are conurbations with high potential for district heating and will furthermore be called main regions. These main regions experience a detailed individual evaluation of available technologies and existing infrastructure and the cost benefit analysis will be performed for each of them.

All remaining municipalities that are not part of these main regions get 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 efficient technologies. 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 (Büchele et al., 2015)

2.5. Cost Benefit Analysis

The cost benefit analysis is the last step of the comprehensive assessment which is carried out separately for the different temperature levels. Beside the cooling demand which is considered in a separate economic calculation, the supply and demand are divided into two temperature ranges: the range 60-90 ° C for residential and commercial demand and supply, and the range from 100 ° C to 500 ° C providing the industrial sector with steam. According to the Energy Efficiency Directive “the purpose of preparing a cost-benefit analyses in relation to measures for promoting efficiency in heating and cooling […] is to provide a decision base for qualified prioritization of limited resources at society level”. 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.

The determination of the cost optimal technology mix is done for all 38 main and 30 secondary regions. 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 following steps are performed per region:

1. For each region the heat demand in the ten sub-regions is determined. 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
2. The technical potential of the considered technologies is determined for each region (see section 2.3).

3. The output of existing grid-connected capacities determined for 2025 according to their technical lifetime (see section 2.2) is 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 is determined to meet the remaining requirements. In this case all technologies are included so that local technologies may be the best solution. 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 top 10% of peak heat demand. In cogeneration plants the share of the peak load boilers may be higher due to the electricity led optimization.
    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 subregions.
    d. These steps are repeated until the demand of the subregion is covered.

Based on this approach, the most cost-effective technology mix for all subregions and the share of efficient district heating and CHP is determined. The potentials for all municipalities classified as secondary regions are determined for the 30 different types and scaled according to the number of municipalities per type.
The potential for local CHP is carried out afterwards and calculates the part of the heat demand without potential for district heating that can be met by local CHP according to the merit order of all local technologies. The analysis is done by applying load profiles for different objects and establishing the merit order of all local technologies. Existing installations are not considered for local technologies.

2.5.1. Costs

As stated in Section 2.2 existing grid-connected technologies that will—based on their average technical lifetime—continue to exist in 2025 are included in the analysis. The remaining demand is covered by the most cost-effective technology until it reaches its technical potential or the demand is met. The choice of most cost-effective technology depends on the region and the existence of a district heating network, the expansion potential and limitations on the technical potential.
The costs consist of:

1. Production costs for heating / cooling 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

Benefit (income) is generated only by cogeneration power plants

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 (Müller und Kranzl, 2013), Figure 1 shows the relation of the costs schematically.

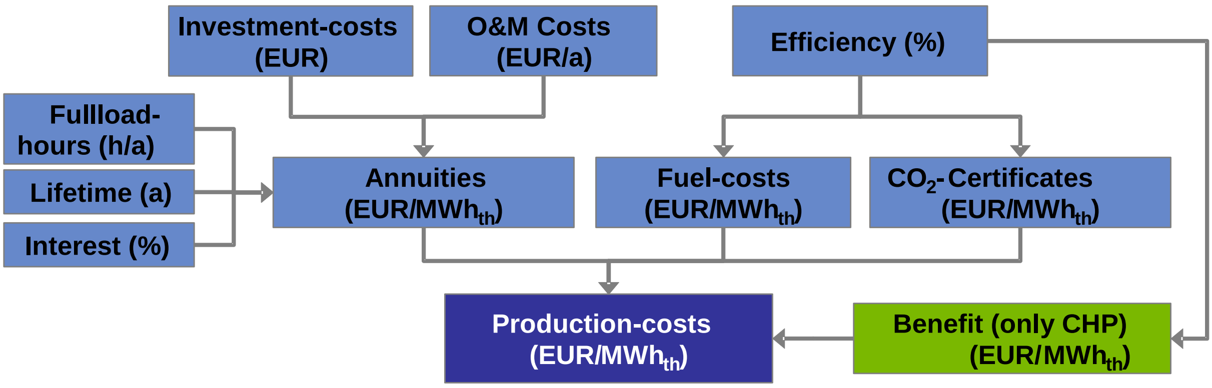

Figure 1: Schematic relations for the production costs

Network costs for heat transport and heat distribution

Central heat generating technologies supplying households and service sector (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 MWth and includes residential buildings and service companies. 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 can potentially 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 and the technical limitation is set to 90% of the demand.

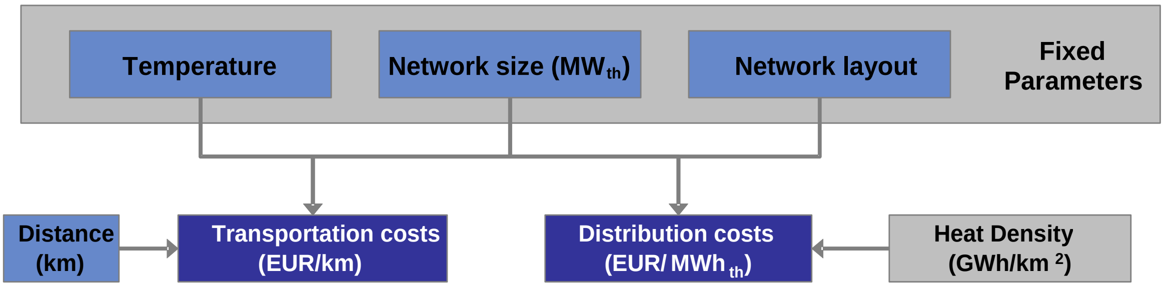

Figure 2: Relations between network costs

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 a few of the technologies have transportation costs because the plants are often situated near the distribution grid. Industrial heat supply (temperature range 100–500 ° C) is assumed to be without transportation costs because the heat usually is produced in-house.

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 MWth) the network capacity leads to larger variation in distribution costs. Therefore different 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 five heat densities considering sparsely populated rural and densely populated urban areas. The heat demand for each region was determined for five different heat density classes and the economic potential is examined separately:

- 0–10 GWh / km²,
- 10–20 GWh / km²,

- 20–35 GWh / km²,
- 35–60 GWh / km²
- 60 GWh / km².

2.5.2. Generated income

Revenues in the electricity market, which have an important impact on the competitiveness of CHP technologies, 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.
Gas-fired power plants (CCGT and GT) are operated in combination with a peak load boiler. This is on the one hand used to cover the peak load and on the other hand used as a back-up technology in times of low electricity prices. The capacity of the peak load boiler is dimensioned to cover the 10% of peak demand resulting in around 60% of the total installed capacity. At full power the CCGT plant is operating at around 45% electrical and about 36% thermal efficiency. If the thermal power is completely reduced (0% efficiency), the electrical efficiency increases to around 52%. Gas turbine power plants (GT) have a fixed relation between thermal and electrical output and the remaining heat is unused at a low heat demand. Waste incineration plants and biomass fueled cogeneration plants usually are not electricity-led and therefore their revenue is calculated using an average annual electricity price for the incineration plant and an average electricity price when applying a heat led operation mode for the biomass CHP.

2.5.3. Economics of cooling alternatives

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

1) via local compression chillers (air conditioning),
2) via local absorption chillers using heat of a district heating network or
3) via 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 (May-September) 90% of the installed heat capacity can be used for absorption chillers. 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 depenedent 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.

2.5.4. Industrial heat demand

District heating in general is only applicable to cover very low shares of industrial heat demand due to the high temperatures needed in many processes. Therefore only the economic potential for cogeneration in the industry is estimated in this analysis. The economic potential for industrial cogeneration is calculated for the large industrial plants identified in the demand analysis on the basis of ETS data. For sectors that are poorly represented in the ETS but important in terms of temperature demand between 100 and 500°C the energy demand as well as the economic potential for the use of CHP is calculated based on typical plant sizes.
To determine the economic feasibility of CHP in these plants the resulting annual costs for the use of CHP are compared to the costs resulting from the use of a reference technology. For each of the plant types a reference technology is defined representing the currently most used technology in this sector.

3. Results

In this section the main results of the different steps of the comprehensive assessment are described but the focus lies on the discussion of the used approach for the comprehensive assessment. As the analysis still is in progress not all results are final.

3.1. Heating and cooling demand

3.1.1. Building related energy demand

Figure 3 shows the major outcomes of the evaluation of the building related heating demand. The scenario shows the development of the demand for the different building classes in the Busines-As-Usual scenario for 2010 to 2050. The demand in this scenario drops from about 100 TWh in 2010 to about 55 TWh in 2050. More than two third of the demand occurs within residential buildings. The division of the heat demand into six different heat density classes is shown for 2025 – the year for which the Cost-Benefit-Analysis is done.

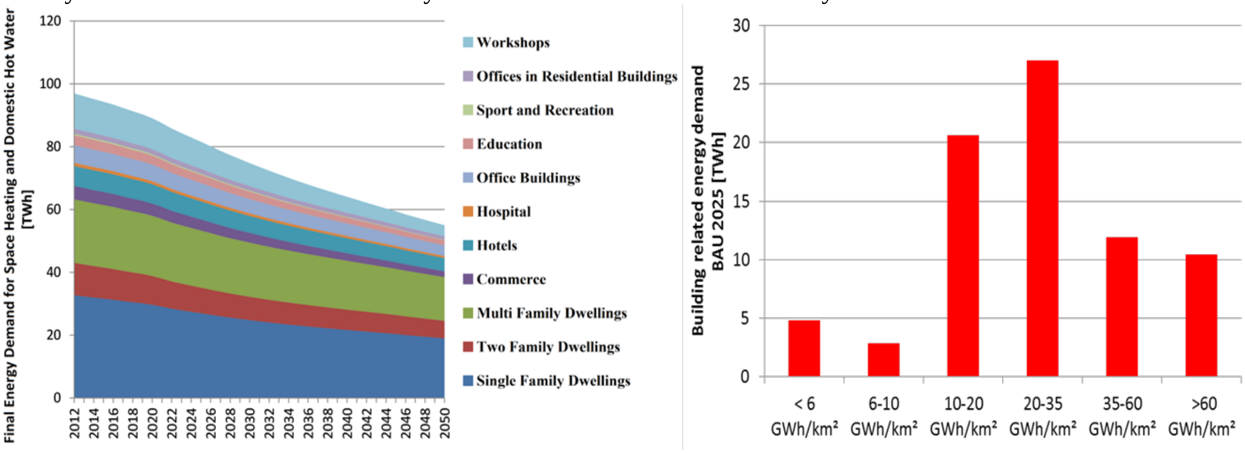

Figure 3: BAU demand scenario and distribution into heat density classes of the Austrian heat demand

The Austrian map in Figure 4 shows the spatial distribution of the demand for space heating and hot water. The urban agglomerations with their high energy demand can be seen as well as the mountainous regions without demand. The detail of Vienna and its buildings gives an imagination on the resolution of the heat demand data.

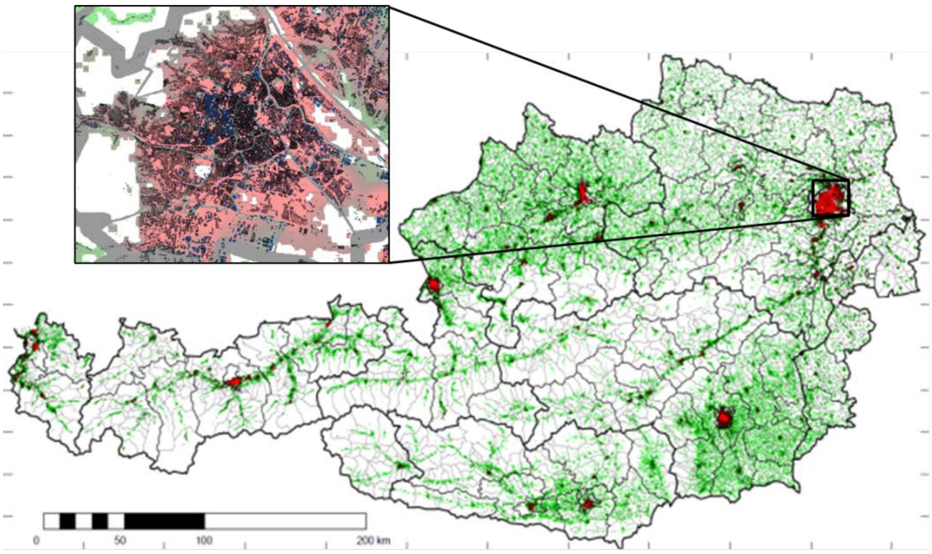

Figure 4: Spatial distribution of the Austrian heat demand

3.1.2. Industrial heat demand

Figure 5 shows a breakdown of the energy demand in the manufacturing sector in Austria. The heating and cooling demand is shown separately for space heating and hot water, steam production, heat in furnaces and cooling. The values for the heating and cooling demand thereby are given in terms of useful energy. Furthermore the figure shows the fuel demand for other uses than heating and cooling as well as the total electricity demand (which is partly also used for heating and cooling). The figure shows that sectors with relevant steam demand in Austria are the pulp and paper production (9.5 TWh/a), chemical and petrochemical industry (3.2 TWh/a), wood and wood products (2.3 TWh/a) and the production of food and beverages (2.1 TWh/a). We can furthermore see that all of the stated sectors also show relevant electricity demand on-site although with different ratios between electricity and steam demand. Also a split up of the existing demand into different temperature level is shown based on the data of various German studies applied on the Austrian sectors (Nast 2010, Wagner 2002, Eikmeier 2005 and Hofer, 1995). It shows that almost 65% of industrial heat demand accrues at temperatures between 30 and 500°C with the largest share of 27% in the range between 100 and 500°C.

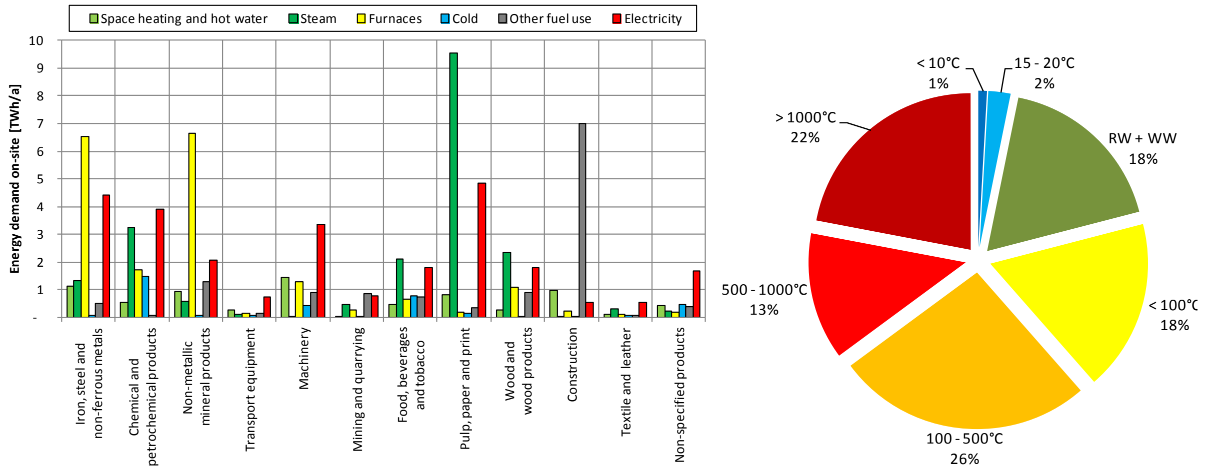

Figure 5: Sectoral energy demand in industrie and its temperature ranges

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

The methodology described in section 2.4 leads to the mentioned 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% of the building related heat demand in Austria. The annual demand of these main regions in 2025 varies between the regions from about 10 GWh to more than 15 TWh. About one-third of this energy lies in areas with energy densities above 60 GWh/km² 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/km² and the last third in areas with energy densities below 35 GWh/km². Vienna is the only region in Austria in which more than 50% of the heat demand lies in areas with a density higher than 60 GWh/km². Figure 6 shows these main regions and their share on the building related heat demand 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. The distribution of the demand of the main regions and of Vienna into the six different heat density classes can be seen in the column chart.

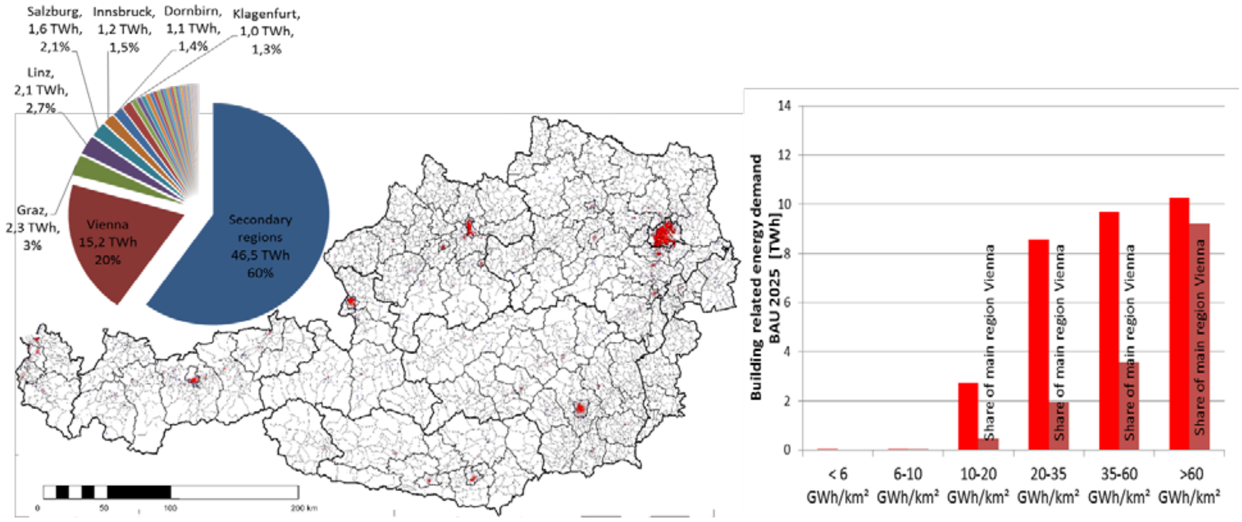

Figure 6: Main regions suitable for district heating in Austria and their heating demand

Municipalities with lower heat densities where mainly local technologies are the most economical alternative, are classified as secondary regions according to the methodology described in (Büchele et al., 2015). The assignment of the 2.367 remaining municipalities to the 30 types of secondary regions is depicted in Figure 7. The distribution of the heat demand into the six heat density classes shows that within the secondary regions just a little amount occurs in the highest density classes. In only 25 municipalities more than 50% of the demand lies in the two density classes higher than 35 MWh/km² but in 700 municipalities more than 50% of the demand lies in the two lowest density classes below 10 MWh/km².

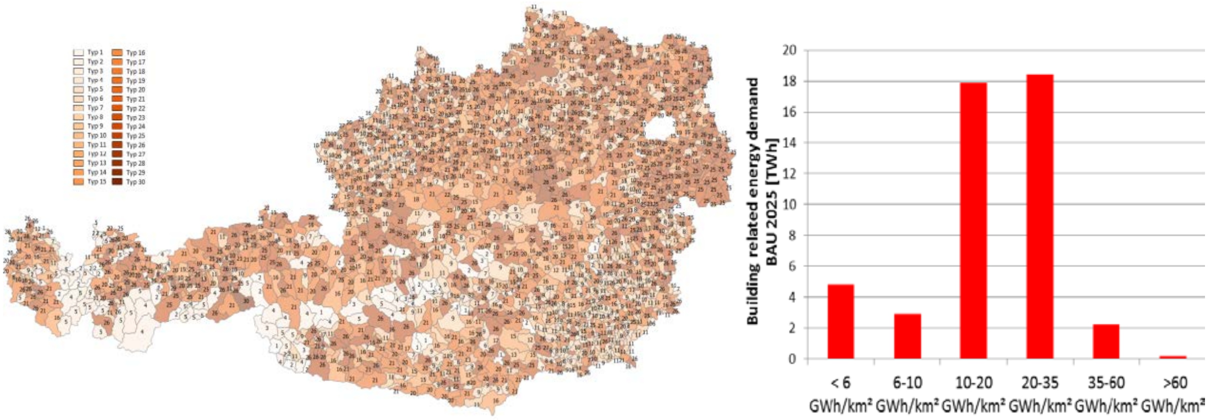

Figure 7: Assignment of Austrian municipalities to types of secondory regions and their heat demand distribution

3.2. Technical potentials

The calculations on the technical potentials for district heating showed that in all of the main regions there is still a significant potential to enlarge the district heating network. For this calculation it was assumed that the share of connected households can rise up to 90% of the heat demand as it is used for the cost-benefit analysis. According to this calculation there would be a technical potential of 17 TWh additional to the existing 11 TWh. But it has to be kept in mind that this would mean a total supply with district heating at a connection rate of 90% of households.

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. From a total need of 6,5 TWh of useful energy for cooling in 2025 within all main regions about 1,2 TWh were identified as technical potential for cooling technologies and just about 200 MWh as suitable for the application of absorption chillers.

Although there are no technical restrictions for CHP plants in terms of availability a calculation of the technical potential for CHP is done considering the heat demand suitable for district heating. Using the technical potentials for district heating as starting point the amount 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 when the peak energy is supplied by the gas boiler. The resulting potential for CHP in existing district heating networks in Austria accounts for 9,3 TWh and would rise up to 62,5 TWh when establishing the whole potential for district heating and the all of the demand would be met just by CHP.

3.3. Cost Benefit Analysis and economical potentials

First calculations on the distribution costs for the different energy densities gave total costs of about 21 €/MW$_{th}$ for district heating networks in areas of more than 60 GW/km². These costs include investment costs of about 16 €/MW$_{th}$ and O&M costs of about 5 €/MW$_{th}$. In areas with less than 10 GW/km² the total costs reach 41 €/MW$_{th}$ consisting of 31.5 €/MW$_{th}$ for the network infrastructure and 9.5 €/MW$_{th}$ for the O&M.

The first results on the cost benefit analysis show that there is potential for district heating in the main regions as well as in the secondary regions in Austria. Within the main regions there could be an additional economic potential for district heating of about 7-8 TWh.

Sensitivity analyses on the first calculations have shown that especially the share of households connected to the district heating grid, has a significant influence on the potential for district heating. This means that additional potential mainly is due to increasing the share of connected households in (sub)regions with already existing district heating network.

The economic potential for local CHP in the residential sector seems to be very limited with significantly less than 1 TWh within all main regions and no economic potential within the secondary regions.

The calculations for the potential for the industrial CHP still have to be done. Same for the economic potentials for the cooling options although first calculations show higher costs for the combination of absorption chillers with compression chillers then for compression chillers only.

4. Conclusions and discussion

Answering the three initially posted questions

1) Is the selection criteria of regions to be analyzed according to the EED (plot ratio >0.3) clear, unambiguous and sufficient?
2) How can significant heating and cooling demand regions be identified and characterized?
3) How do different characteristics of these regions influence the cost-benefit analysis of high-efficient CHP and efficient district heating and cooling opportunities

it can be said that the selection criteria suggested in the Energy Directive to determine areas to be analyzed are not fully clear. 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 different approaches can lead to notable differences in the plot ratio for almost the same area. Also using the plot ratio as unique criteria to determine feasible heating and cooling demand regions may be too simple. Although the specification in the corresponding interpretative notes, indicating that the suggested plot ratio corresponds to a linear heat density[4] of 2.5 MWh/m emerging from a current specific heat demand of 130 kWh/m², illustrates that also other criteria can be important, the used interconnection between these criteria leads to the selection of just as few areas in Austria. According to expert literature regions fulfilling these criteria are directly feasible for district heating and therefore a Cost-Benefit-Analysis should always deliver cost-effective potential but excluding regions that do not fulfill these criteria but may also have economical potential.

The combination of energy density per raster element, plot ratio and energy demand used in this work to determine the main regions for district heating, tries to find a balance between different parameters to select high-potential regions with softer criteria than suggested. Beside the evaluation of the main regions this work includes the characterization of all remaining municipalities as secondary regions to estimate technical and economic potentials for the regions not classified as high-potential regions. And as the first results have shown, there still is economic potential in some secondary regions. This indicates that even in regions not classified as high potential regions there can be economic potential if certain factors like a cheap source of heat is available.

But 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 reflect 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 big cities the suggested criteria in the EED seem too general and too restrictive. There are many existing district heating systems in smaller Austrian cities which according to the EED do not have to be considered in the comprehensive assessment and therefore wouldn’t be included. However, other countries may have other structures and therefore the criteria used in this work may lead to too much or not representative regions.

Fact is that national assessments only allow for a certain degree of detail and different regional characteristics do influence the results on cost-effective potentials substantially. The classification into main and secondary regions tries to combine two different ways of calculations. High potential regions can be looked at in detail in terms of existing infrastructure, technical potentials and characteristics of heat demand, and secondary regions get evaluated in an aggregated manner each represented by a typical average municipality. So the detailed look just has to be done for an amount of regions that is manageable but regions not classified as high-potential regions are not neglected. Also the same Cost-Benefit-Analysis can be done for all main and secondary regions just differing in cost structure according to the available technologies and the characteristics of the heat demand of each region. The main problem in conducting a Cost-Benefit-Analysis on regional base but for the whole national territory is the lack of detailed cost data.

As local characteristics determine the costs to a large extent, big varieties occur between the different regions and trade-offs had to be made to be able to apply the Cost-Benefit-Analysis for all regions. So the network costs of district heating technologies are calculated on one reference network size with fixed parameters for all regions. To respect different costs for expansion and distribution in areas with different heat densities the heat demand was divided into five heat density classes and individual distribution costs were calculated depending on the heat density. The division tries to represent differences in the cost structure within the regions on a sub-regional basis although heat densities are not a continuous function and the calculated density depends on the included area. Also it is hard to estimate which share of energy actually supplied by district heating lies in which heat density class or sub-region respectively.

The Cost-Benefit-Analysis based on classification of the 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. 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 very small scale level.

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[4] Linear heat density is the quota of heat annually sold and the total trench length of the district heating pipe system

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