A GIS-based Assessment of the District Heating Potential in Europe

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Abstract:

The scarcity of fossil fuels and the climate impact of their combustion are increasingly pressuring problems. The fundamental approach to both of them is the usage of renewable energy sources, accompanied by higher energy efficiency. Cogeneration in district heating (DH) plants allows for more efficient use of primary energy resources and can thus contribute to the solution. This paper presents an assessment of the possible role of DH in Europe until the year 2030. It is based on a newly developed method that allows for the quantification of country-specific DH potentials for different heat demand levels. It relies on a GIS-based analysis of the heat demand in high spatial resolution, which enables the identification of areas suitable for DH. The results suggest that a doubling of today's heat deliveries could be achieved, making DH a feasible option for increased energy efficiency in the heating sector. The discussion of the results includes an assessment of potential limitations to DH such as the lack of central heating installations and the high capital costs of the distribution network.

Keywords: District Heating, Combined Heat and Power

1 Introduction

The efficiency of the fuel use in thermal power stations can be increased by using the excess heat for purposes of district heating (DH) or industrial processes. Today, such combined heat and power plants (CHP) account for approximately 11 % of Europe's total electricity supply, with shares ranging from less than 2 % (Malta, Greece) to more than 40 % (Denmark). Given the possible energy savings and the flexibility of CHP, these shares are expected to increase in the future [1]. According to the International Energy Agency (IEA), CHP can play an important role in the balancing of fluctuations of renewable energies [2].

In this paper, the potentials for an extension of DH in Europe are evaluated. The analysis is performed in three steps: (1) an estimation of the overall demand for useful heat in the residential and commercial sector, (2) a consideration of its spatial distribution and (3) an evaluation of the suitability to supply it with DH. Previous studies argue that there are significant possibilities of an extension of DH in most European countries, however without performing a detailed analysis [3,4]. Germany's DH potentials have been quantified in bottom-up approaches making use of building statistics and satellite data in high spatial resolution [5,6].

2 Data and Methodology

The analysis of the DH potential is conducted in a spatially explicit top-down approach. Using GIS data, the overall heat[1] demand of a country – extracted from national energy balances and scenarios – is allocated according to the population and land use. Taking into account a minimum heat demand density threshold, agglomerations are identified and considered as areas suitable for DH (see scheme in Figure 1).

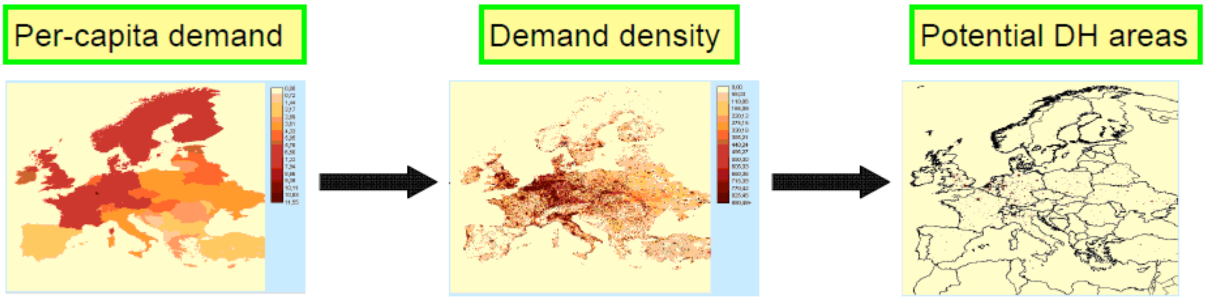

Figure 1: Schematic view of the procedure of the estimation of district heating potentials.

The input data for the spatial distribution of the heat demand is converted to a pixel size of 0.0083° side length, equivalent to a pixel area of between 0.27 km^2 and 0.74 km^2. The analysis of heat demand and DH potentials is done for a total of 40 countries, including all member and candidate countries of the European Union (see Table 5 in the Appendix).

2.1 Heat Demand Analysis

The technological and economic potential for DH in a specific location is primarily defined by the overall heat demand and its allocation. Here, it is assumed that only the heat demand in residential and commercial buildings can be covered by DH systems – industrial heat demand is thus not included. Furthermore, only the heat demand for space heating and hot water is considered, excluding process heat.[2]

The average annual per-capita heat demand in the residential and commercial sector is calculated on the basis of statistics and projections of the total final energy demand. These values are extracted from the *Primes 2009 Baseline* scenario for the years 2005 and 2030.[3] The share of final energy used for purposes of space heating and hot water production is different for each country. Country-specific values for these shares have been collected and estimated by the MAG program at the International Institute for Applied System Analysis (IIASA).[4] It is assumed that they are constant until 2030. The final energy demand for heat is converted into a value of useful energy by taking into account fuel-specific conversion efficiencies (see [8,9]). Detailed data of the fuel shares in the heat generation is only available for the residential space heating and hot water production in some countries.

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[1] In contrast to other publications, the term "heat" here and in the following refers to useful energy for purposes of space heating or hot water generation, independent of its primary energy resource.

[2] This is a rather pessimistic assumption. In [5] it is estimated that 30 % of the process heat demand in the commercial sector can be attributed to the hot water consumption (e.g. laundries) and another 30 % to the space heating demand (e.g. nursery), making 60 % of the commercial process heat demand accessible for a DH supply.

[3] Primes is an energy system model developed by the E^{3}M Lab at the National University of Athens. Its results are for example presented in [1]. For countries where no Primes data is available, the IEA World Energy Outlook 2009 is considered [7]. In the following, the term "Primes Scenario (2030)" refers to the projections of the Primes BL2009 scenario (for the year 2030), which has been used as Baseline scenario and data source for this study.

[4] Personal communication with Janusz Cofala, IIASA.

Where no data is available, the overall average of all other countries conversion efficiencies is used. The values derived for the residential sector are also applied to the commercial sector. Divided by the population numbers in 2005 and 2030, per-capita values for both the space heating and the hot water demand in the residential and the commercial sector are obtained.

In order to assess the impact of significant reductions in heat demand on the district heating potential, an ambitious efficiency scenario for 2030 has been considered in addition. In this scenario – which is in the following labeled *Efficiency2030* scenario – the heat demand is modeled as an iterative function of changes in average outside temperature, per-capita living/business area and annual demand for hot water and room heat. Based on the *Primes* heat demand values in the residential and commercial sector for 2005 and the corresponding hot water shares, the per-capita demand is extrapolated until 2030. It is assumed that the reduction in annual Heating Degree Days (HDD) measured between 1980 and 2010 continues until 2030 with a constant rate.[5] The future development of the heated floor area for living and businesses follows the *Primes* scenario and is also kept constant until 2030. The efficiency increase in the use of heat for space heating is assumed to be 2 %/a in the EU15+ and 0.5 %/a in all other countries, whereas the hot water demand decreases by 0.3 %/a in the EU15+ while remaining constant in all other countries.[6]

Some European countries show significant disparities in the climatic conditions of different regions. For this reason, it is assumed that within a country the per-capita heat demand for both space heating and hot water generation is proportional to the HDD. Eurostat data of monthly HDD allows for the calculation of relative per-capita demands on the level of NUTS-2 statistical regions.[7] To assure that the national average value of the residential per-capita demand is not changed, each region's number of HDD is weighted with the regional share in the national population.

Additional to the outside temperature, the annual per-capita heat demand depends on the corresponding housing conditions such as building type, dwelling size, inhabitant number and specific heat demand of the dwelling [5,6]. The lower surface-to-volume ratio of apartment buildings entails a relatively smaller specific space heat demand per square meter. Consequently, it has to be considered that the per-capita heat demand is lower in cities, which are generally dominated by multi-family apartment buildings. Provided that no comprehensive statistics for all the relevant parameters is available, it is assumed that the per-capita heat demand in multi-family buildings is reduced by 20 % in comparison to single family buildings. In order to apply this assumption to the population density data, limits for the presence of the different building types have been defined. For all areas with a population density above 5000 inhabitants per square kilometer it is estimated that all buildings are multi-family homes, whereas areas with a density lower than 300 inhabitants per square kilometer only host single-family buildings. Between those limits, the relative per-capita

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[5] The concept of heating degree days has been developed as an indicator for the outside temperature-dependent amount of energy required for the heating of buildings. For details and data, see Eurostat [10].

[6] EU15+ here and in the following refers to the EU15 plus Norway, Switzerland and Liechtenstein.

[7] NUTS is the abbreviation for the "Nomenclature of Statistical Territorial Units". It is a hierarchical system for dividing up the economic territory of the European Union into smaller units, usually administrative districts within the member countries. For details, see [11]. HDD data can be accessed via [12].

demand increases linearly. This adjustment is only applied to the residential space heating, but not to the commercial heat demand and the residential hot water demand.

The heat demand of a country is not equally allocated over its land area but mostly determined by the location of residential and commercial areas. In order to obtain a heat density map, the per-capita demand values have to be multiplied with a grid that represents the distribution of residential and commercial consumers. For the residential heat demand, the per-capita demand in each grid cell is multiplied with the number of inhabitants of the corresponding cell. The population density map is obtained from the Eurostat population statistics and prospects [12], a population density map provided by the Joint Research Centre [13] and the GRUMP dataset published by the Center for International Earth Science Information Network (CIESIN) at Columbia University [14].

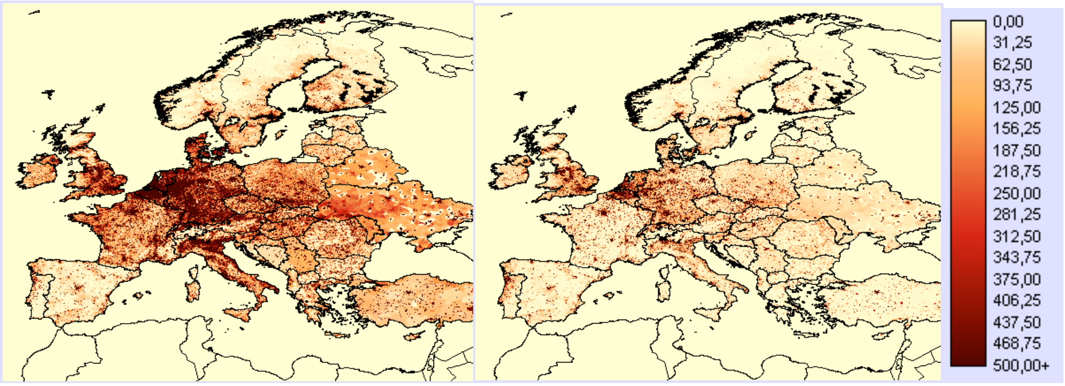

Figure 2: Heat demand in MWh/km²/year in the residential and commercial sector for space heating (left) and hot water (right) calculated for the *Primes* 2005 heat demand values.

The spatial distribution of the commercial heat demand is mostly based on the CORINE land cover (CLC) data set [15].[8] At the time this study was performed, the processing of the CLC 2006 data was only completed for 36 out of 39 countries. For the remaining three countries, the CLC 2000 data has been used. For all countries with CLC data availability, it is assumed that the commercial heat demand is distributed equally over all raster cells that have been assigned to the categories representing continuous urban fabric, discontinuous urban fabric and industrial or commercial units. In countries, where no land use data is available, the commercial heat demand is distributed according to the population.

A closer look on the demand density maps in Figure 2 reveals that the Grump data used for the Non-EU countries in Eastern Europe is not quite precise. It shows a rare population distribution pattern characterized by areas of very low population in the surroundings of major cities and an almost homogenous distribution in rural areas. This affects the results of the analysis of DH potentials, given the decisive role of the heat demand distribution.

2.2 District Heating Potentials

The derived heat demand maps enable the identification of areas with high demand densities. Due to the dominant capital cost of the distribution network, a high heat demand density is crucial for the economic viability of DH systems. The areas suitable for DH are

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[8] The CLC categorizes the use of each raster cell and assigns it to one of 44 different classes, including different kinds of artificial surfaces, agricultural areas, forest and semi natural areas, wetlands and water bodies. It covers EU27, Albania, Bosnia and Herzegovina, Croatia, Iceland, Liechtenstein, the former Yugoslavian Republic of Macedonia, Montenegro, Norway, San Marino, Serbia, Switzerland and Turkey.

defined by the application of a minimum heat demand density threshold value. Generally, the minimum heat demand density for the cost-effectiveness of a DH system depends on a variety of parameters such as the demand profile and the installation costs, and might be different than assumed here. A sensitivity analysis is conducted by taking into consideration different threshold values ranging from 4 GWh/km²/a to 15 GWh/km²/a.

After eliminating all raster cells with a demand density below the selected threshold value, neighboring cells of higher demand are grouped to agglomerations. Whereas in some cases those agglomerations are only composed of one cell, in metropolitan areas they can have sizes of many square kilometers. The number and size of the agglomerations is to high extent influenced by the threshold value applied. For further analysis, each agglomeration is assigned to one or various countries and the annual heat demand, the average heat demand density and the hot water demand are extracted. Those parameters later provide the basis for the attribution of a heat generation system and the estimation of the relative heat distribution costs.

The economic DH potential can be limited by the availability of central heating systems. The difference between central and individual heating system is thereby determined by the availability of a pipe system connecting different rooms of a dwelling to a heat source. In contrast to that, individual heating systems are usually stoves placed in one or various rooms of a dwelling. Depending on the climate and building structure, the share of dwellings equipped with a central heating system differs in between European countries (see Table 5 in the Appendix). In areas where only a small share of dwellings is furnished with a central heating system, DH might not be an economic option, as it would require buildings first to be equipped with a pipe system, which would increase the costs significantly. On the long run, when more and more buildings are refurbished, this limitation looses its importance.

A significant share of DH costs arises from the investment in the pipe network. Installation costs are different between countries, but also within a country, and are depending on the location, geometry, density and structure of the corresponding settlement. Given that for this study no information on the building structure of settlements and country-specific installation costs was available, a simplified method for the economic rating of potential DH areas is applied. It is based on the experience that installation costs are generally higher in densely populated areas, as more efforts for excavation, road shutoff, traffic diversion and piping is required [16]. Using the heat demand density map and the population density map, the number D of inhabitants per MWh of heat consumed per year is calculated for each pixel and agglomeration. Subsequently, the arithmetic mean $\overline{D}$ and the standard deviation σ_D over all agglomerations are determined. Later in the analysis, those values are used for the exclusion of the agglomerations with highest numbers of inhabitants per amount of heat, in order to identify those areas with the higher economic attractiveness for the installation of a DH system. Like this, a village in a cold area with few dwellings but high per-capita demand is favored over a city located in a warmer region with the same total demand but characterized by a high population density and low per-capita demands. In the latter, the installation costs are assumed to be higher, but would have to be apportioned to the same amount of heat.

2.3 Heat Generation Technologies

In order to not only estimate the potential for DH but also the primary energy input and electricity output of the corresponding heat generation technologies, a closer look on the supply side is required. Thus, a CHP unit and a peak boiler are attributed to each agglomeration. Their size is defined by the total heat demand and the base load share of the agglomeration. Whereas the hot water demand (base load) is assumed to be completely provided by the CHP system, the space heating demand is to 30 % covered by the peak boiler. Given the hot water share and the CHP share of the space heating demand, the total amount of heat produced in the CHP unit can be calculated according to equation (1).

$$Q^{CHP} = \frac{Q^{HW} + Q^{SH} \times s^{SH,CHP}}{1 - s^{loss}} \tag{1}$$

$$P_{th}^{ne} = \frac{Q^{CHP}}{N^{FLH}} \tag{2}$$

$$P_{el}^{ne} = P_{th}^{ne} \times \sigma^{CHP} \tag{3}$$

$$W^{CHP} = N^{FLH} \times P_{el}^{ne} \tag{4}$$

Q^{CHP} – Heat generated in CHP
Q^{HW} – Heat demand for hot water
Q^{SH} – Heat demand for space heating
s^{loss} – Heat share lost in the network
$s^{SH,CHP}$ – CHP share in space heating
N^{FLH} – CHP full load hours per year
P_{th}^{ne} – Net thermal capacity
P_{el}^{ne} – Net electric capacity
σ^{CHP} – CHP coefficient
W^{CHP} – Electricity generated in CHP

Table 1: Assumptions for the CHP units [17].

CHP parameter	Value
s^{loss}	0.12
Full Load Hours N^{FLH} [h/a]	3000
σ^{CHP}	0.60

An extension of DH is accompanied by an increase of the electricity generation in CHP units. The installed electrical capacity P_{el}^{ne} of the CHP units and the corresponding electricity generation W^{CHP} can be calculated according to equation (2) to (4). In order to obtain a rough estimate, general assumptions for the heat losses in the distribution network Q^{loss}, CHP full load hours N^{FLH} and the CHP coefficient σ^{CHP} are made and applied to the DH potentials found (see Table 1). In specific systems those values will probably be different, provided their strong dependency on both local climate and technologies used.

3 Results and Discussion

3.1 Heat Demand and Agglomerations

Based on the *Primes* heat demands 2005/2030 and the *Efficiency2030* scenario, the national average per-capita heat demands were obtained. Significant differences both between countries and the projections of the future demand are evident. Apparently the demand values are not only influenced by the climatic conditions, but also by other factors including the architecture and insulation of buildings, the standard of living and energy efficiency policies. Figure 3 shows the average values of the overall heat demand in the residential and commercial sector for selected country groups (see Table 5 in the Appendix). The position, number and characteristics of the demand agglomerations identified on the basis of the heat density maps strongly depend on the selected threshold value. In Table 2 the number and characteristics of the agglomerations found for the *Primes* 2005 heat demand are listed.

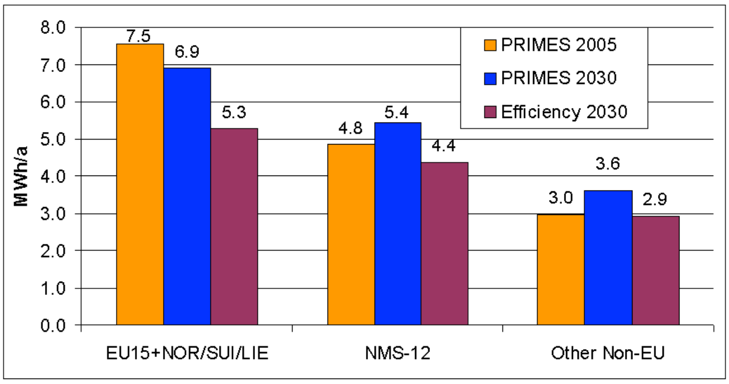

Figure 3: Average per-capita useful heat demand in MWh/a in the different scenarios for selected country groups, including space heating and hot water demand in the residential and commercial sector.[9]

Table 2: Agglomerations for *Primes* 2005 heat demand and different demand density thresholds.

Heat density threshold	Total number of agglomerations	Average agglomeration area	Total heat demand	Average heat density
4 GWh/km²/a	27766	6.84 km²	2075 GWh/a	5.8 GWh/km²/a
7 GWh/km²/a	12796	8.11 km²	1625 GWh/a	9.7 GWh/km²/a
15GWh/km²/a	4207	8.84 km²	955 GWh/a	19.1 GWh/km²/a

In comparison to the demand density in existing DH systems, the threshold values used for the identification of agglomerations are chosen relatively low. This assumption is made due to two characteristics of the heat demand density map, being the general tendency to underestimate the demand and the blurring of the demand in smaller settlements. Whereas the first effect is caused by the limitation to the residential and commercial sector and the negligence of all process heat demand, the latter is attributed to the spatial resolution of the data used. Particularly in small but dense settlings, the demand density can be much higher than found in the GIS approach used here. This arises from the fact that the population possibly living in an area of few hectares is attributed to one or even more pixel of a size up to almost 1 km², irregularly reducing the demand density. As a consequence, the heat demand density especially of smaller villages is underestimated, which causes them not to be identified as potential DH areas by the method used here. One has to keep in mind that the heat demand density in a small area that is actually supplied by district heat can be much higher than the assumed thresholds. No assessment of the demand distribution within a pixel can be done.

3.2 District Heating Potentials for Different Demand Levels

The DH potential is defined by the overall heat demand in the agglomerations. One decisive factor for its magnitude is the heat demand per person. Figure 4 illustrates how the DH potential differs according to the heat demand level. The corresponding heat consumption is shown in Figure 3. For a first assessment of the geographic location of the DH potentials, a separation between three country groups is made. The largest potential can be found in the EU15+ countries. This can be easily explained by recalling the higher population number and density, as well as the superior per-capita heat demands of those countries. The light blue

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[9] NMS-12 stands for the so-called “New Member States” which entered the EU between 2004 and 2007.

bar shows the amount of district heat that was delivered in 2005 [9]. It seems that in the NMS-12 no more DH potentials are present, the same being the case for some countries in northern Europe, as can be seen in Table 6 in the Appendix.

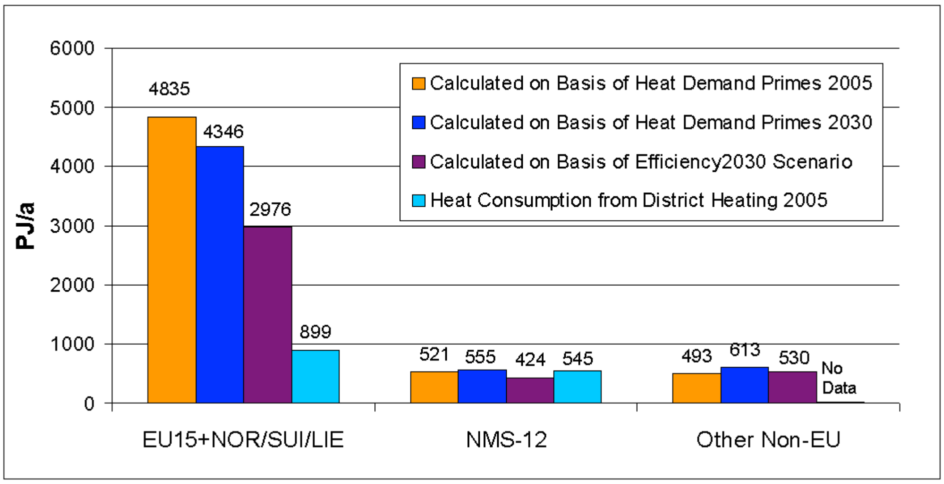

Figure 4: DH potentials in PJ/a in comparison to the current DH supply applying the 7 GWh/km²/a threshold to different demand levels

The potential determined by this method very much depends on the selection of the threshold value used for the identification of DH areas. Figure 5 compares the results for three different thresholds, always taking into account the same per-capita heat demand values. Not surprisingly, the potential is diminished when a higher threshold value is considered.

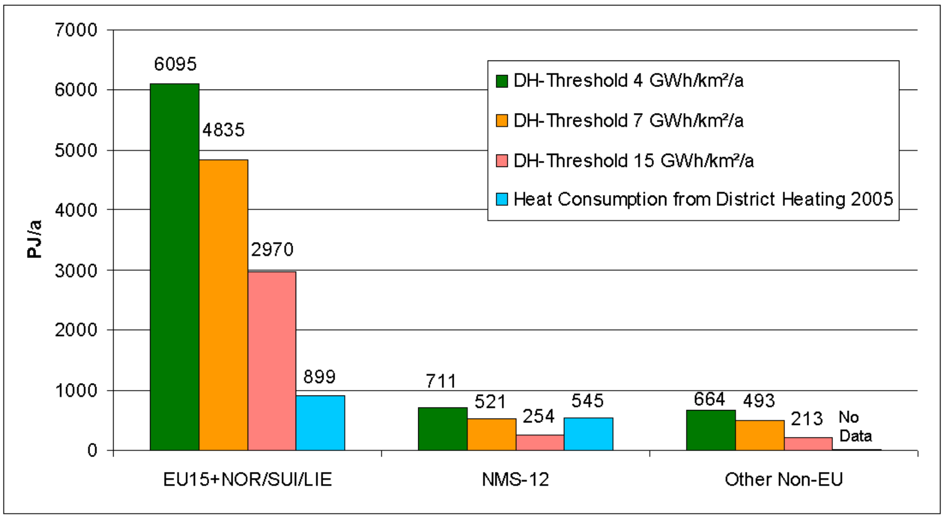

Figure 5: DH potentials in PJ/a for the Primes 2005 heat demand using different thresholds for the identification of agglomerations.

Even for the lowest threshold value used here, the DH supply in 2005 exceeds the potentials in some countries. This is the case for Bulgaria, Denmark, Estonia, Finland, Lithuania, Slovakia and Sweden. Possible explanations of this phenomenon are at hand and different according to the country: in the Nordic countries, district heating is already widely used not only in cities, but also in smaller villages. For the reasons of limited spatial resolution discussed earlier, it is likely that the demand density in smaller villages appears lower than it is, causing them to remain below the threshold that is set. In the eastern European countries it might be the case that the assumption of a relatively low per-capita demand in cities is not valid. Additionally it is possible that the demand density is indeed lower than the smallest threshold value. Independent of the weaknesses of the method used in this study, it is also conceivable that the quality of the data used – being the population distribution, the total energy demand, the share of final energy used for heating purposes or the district heating statistics – is insufficient.

3.3 Limitations to the use of District Heating

In this paragraph, possible economic limitations to the use of DH are discussed. One element considered is the availability of central heating system. Its impact is analyzed by reducing the heat supplied to the agglomerations according to the share of dwellings without a central heating system. The resulting reduction of the potential can be seen in Figure 6 and Table 6 in the Appendix. It is important to keep in mind that no information about the location of the dwellings lacking a central heating system is available: in the extreme cases, they could be all inside or outside the agglomerations identified. Consequently, the impact of this parameter can be smaller or bigger in reality.

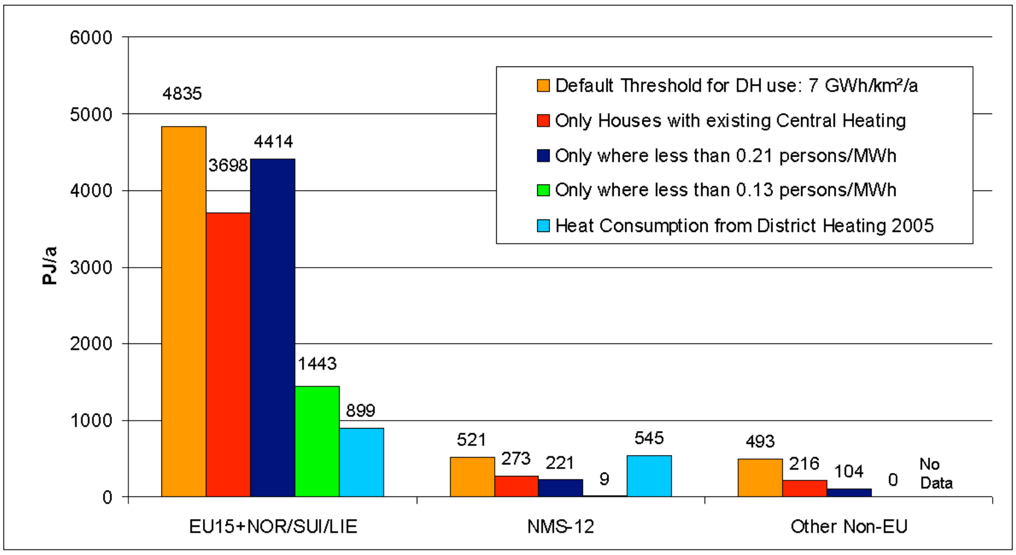

Figure 6: DH potentials in PJ/a for the Primes 2005 heat demand using different limitations.

Furthermore, the effect of a rating of potential DH areas according to their relative heat distribution costs is analyzed. Here, two different limits have been used, representing the exclusion of all agglomerations with a person per MWh ratio *D* higher than the average or higher than the average plus one standard deviation $D > \overline{D} + \sigma_D$. This assessment is done for the *Primes* heat demand in 2005 and the agglomerations resulting from the application of the 7 GWh/km²/a threshold. The corresponding values are $\overline{D}$ = 0.13 and σ_D = 0.08. Figure 6 shows that the potentials in the country groups are affected differently by this limitation. Whereas in the EU15+ only the lower limit causes a significant decrease in the potential, in other parts of Europe already the higher limit reduces the potential to less than half of its original value.

3.4 District Heating Potential of Selected Countries

This section provides a detailed assessment of the DH potential in four selected countries: Germany, Hungary, Ireland and Spain. Four scenarios are considered and compared to a Baseline case representing the previsions of the *Primes* scenario. They all make use of the 7 GWh/km²/a demand density threshold, but differ in the heat demand and the limitations to DH use (see Table 3).

Table 3: Scenario data for the national DH potentials

Parameter	Baseline	Primes_MaxPot	Primes_Limit1	Primes_Limit2	Eff2030_MaxPot
Year	2030	2030	2030	2030	2030
Heat demand	Primes	Primes	Primes	Primes	Efficiency2030
Density Threshold	-	7 GWh/km²/a	7 GWh/km²/a	7 GWh/km²/a	7 GWh/km²/a
Agglomerations excluded	-	None	$D > \overline{D} + \sigma_D$	$D > \overline{D}$	None

The results of the scenario analysis in terms of DH potentials and corresponding shares of DH in the total amount of useful heat are shown in Figure 7 and Figure 8. They illustrate that the potentials are significantly higher than the DH use envisioned for 2030 in the *Primes* Baseline scenario. In that scenario, the heat supply from DH in Germany and Hungary is expected to grow only marginally, in Ireland and Spain no DH is installed at all. In contrast, the analysis shows that in Germany an extension of DH to – depending on the scenario – between 1.5 and 4.5 times today's heat deliveries appears feasible. For Hungary instead, the potential is limited to approximately the double of the 2005 value. Also in Ireland and Spain – both countries almost without any DH to date – substantial potentials are identified. In Spain, their access might however be hindered by comparatively high network installation costs. As the per-capita demand is lower than in the other countries considered, the application of the rating of agglomeration reduces the potentials to a much higher extent.

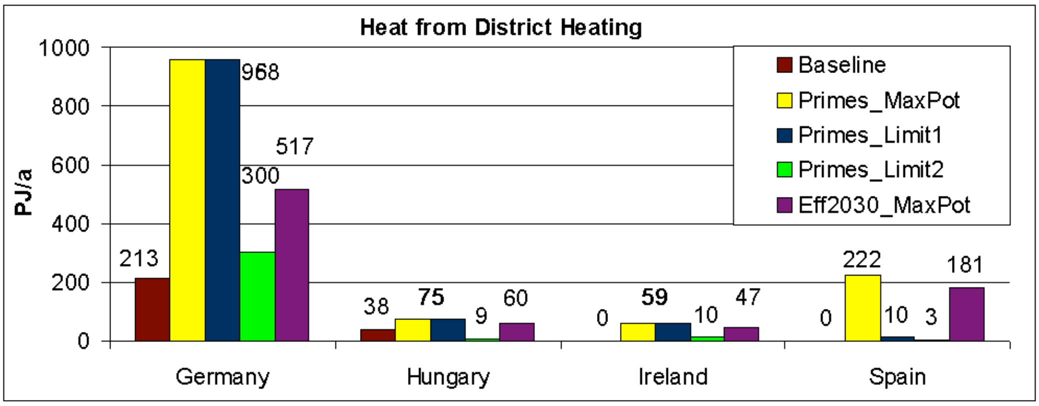

Figure 7: DH potential in PJ/a for the different scenarios in selected countries compared to the 2030 DH use in the Primes Baseline.

Figure 8 provides an idea of the DH share in the overall demand of useful heat for space heating and hot water generation in the residential and commercial sector. It can be seen that without the consideration of the rating of agglomerations according to the population density, in all selected countries DH could reach a major share of up to 45 % in residential and commercial heat supply. The fact that for Hungary its value is lower can be explained by the smaller share of the overall population living in densely populated areas [12].

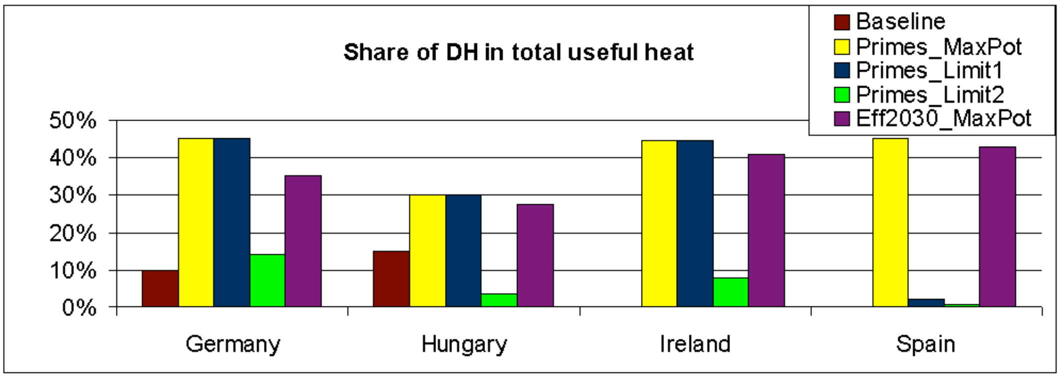

Figure 8: DH Share in total useful heat corresponding to the potentials in 2030

3.5 Estimation of the Corresponding Installed Electrical Capacities

With the calculated DH potentials, also the electrical capacities and electricity generation of the corresponding CHP units can be estimated. This is done for the four selected countries and the scenarios “Primes_MaxPot” and “Eff2030_MaxPot”. Table 4 summarizes the results and provides some benchmarks for the potentially achievable quantities. Comparison to the 2008 values shows the increase in both installed capacity and generated electricity in all countries in both scenarios. Assuming the exploitation of all available potentials, CHP would afford major shares not only of the heat but also the electricity demand of the countries accounted for. However, the parameters shown in Table 4 depend to a high extent not only on the DH scenario, but also on the assumptions made for the full load hours and the CHP coefficient (see Table 1).

Table 4: Electrical capacities and generated electricity of CHP units in 2008 and scenarios for 2030 [18,19]

	2008		Primes_MaxPot		Eff2030_MaxPot	
Country	**P_{EL} [GW]**	**W_{CHP} [TWh]**	**P_{EL} [GW]**	**W_{CHP} [TWh]**	**P_{EL} [GW]**	**W_{CHP} [TWh]**
Germany	22.0[10]	53.8	44.7	134.1	24.1	72.4
Hungary	2.1	8.1	3.5	10.5	2.8	8.4
Ireland	0	0	2.9	8.7	2.3	6.9
Spain	0	0	11.2	33.6	9.1	27.4

4 Conclusion and Outlook

The analysis reveals that potentials for an extension of DH exist in most European countries. Their extent depends on a variety of factors such as the current use of DH, the demand for heat, its spatial distribution, and the demand density threshold applied. The countries with the greatest potentials in absolute numbers are Germany, France, Belgium, the Netherlands and the United Kingdom. Given their high degree of urbanization, DH could supply up to 50 % of the residential and commercial demand for space heating and hot water generation in those countries. Today, in most of those countries the share of DH is below 10 %. With regard to more radical energy efficiency policies in the building sector, it is shown that even for a per-capita space heating demand reduction rate of 2 % per year, a considerable potential for DH remains.

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[10] Includes industrial CHP units

With the method used, also in southern Europe significant DH potentials are identified. In contrast to central Europe, they are however almost only found in major cities with sufficiently high population densities. Whether their exploitation is economically feasible does strongly depend on the installation costs for the DH network. Excluding the potentials found in areas with low per-capita heat demand and high population density, only a small share of the original value remains.

For some countries in northern and eastern Europe, the potentials found are smaller than the heat currently supplied from DH. The reasons for this discrepancy are identified and related to the characteristics of the method and uncertainty in the input data. It has been found that due to the limited spatial resolution, DH potentials in smaller communities could not be quantified. Consequently, it can be assumed that the potentials might be even higher than those found here. In contrast to that, the DH potential might – in addition to the cost aspects discussed – be negatively affected by the competition with an expansion of natural gas networks. Usually it is not reasonable that buildings are connected to both a heat and a gas network.

Considering the vast potentials for DH identified in this paper, an extension of the CHP use in Europe appears feasible. Whether it also is cost-effective, does to a high extent depend on the heat distribution costs. The efficiency advantage can give CHP an important position in Europe’s future energy system. Whether large amounts of CHP electricity and heat could enable the integration of high shares of fluctuating renewable energies into the system needs to be analyzed further, especially concerning the options for a more flexible operation of the CHP system achieved by implementing thermal storages and district cooling. Additionally, the interaction with renewable heating options such as solar district heating, electric heating from surplus wind energy and geothermal heat requires further research. The results presented here provide the basis for a profound economic analysis of the possible future role of shiftable loads and CHP units with thermal storages in Europe’s energy system, which will be carried out with a linear optimization model. There, also the temporal resolution of the heat demand will be considered, as the pattern of the annual heat demand profile influences the full load hours of the CHP system and its share in the total heat supplied.

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