HEAT ROADMAP EUROPE 2050

FIRST PRE-STUDY FOR THE EU27

by

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PREFACE

Although the heating and cooling sector is very large in size and already provides low and no-carbon solutions, it has largely been overlooked in all scenarios exploring the energy future towards 2050. The Energy Roadmap 2050 published by the European Commission rightly acknowledges that *renewable heating and cooling is vital to decarbonisation* and that *a cost-optimal policy choice between insulating buildings and systematically using waste-heat* needs to be found. Yet, the Roadmap omits a thorough analysis of the heating and cooling sector.

Against this background, during early 2011, Euroheat & Power, Aalborg University and Halmstad University further discussed the possibility for developing a major European research project called Heat Roadmap Europe, focusing on the future European heat and cooling market and its interactions with other parts of the energy market. In order to prepare for a full project proposal, a pre-study research project was established. The five major purposes of the pre-study were identified as:

- Validation of the proposed research methodology.
- Indication of possible results from a future full research study.
- Early warning information to policy-makers about the quality of official EU energy roadmaps with respect to the expansion of district heating systems.
- Giving an alternative future projection to many all-electric future heat scenarios.
- Information leaflet for tentative partners in a future research consortium concerning Heat Roadmap Europe.

The Aalborg and Halmstad universities have performed this pre-study in cooperation according to a methodology based on energy modelling and mapping of local conditions reflecting the possible future district heating opportunities.

May 2012,

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EXECUTIVE SUMMARY

This pre-study presents the findings concerning a considerable expansion of the district heating sector within the current EU27 member states until 2050. Heat deliveries are presumed to grow by a factor of 2.1 until 2030 and by a factor of 3.3 until 2050.

The current energy policy context is that the latest energy communication from the European Commission (*Energy Roadmap 2050*) contains only a very modest growth in the future for district heating systems and additional industrial heat use from industrial CHP plants. A small increase is foreseen for industrial demands, while heat deliveries to the residential and service sectors are expected to decrease. In total, the heat delivered is expected to increase by less than one per cent per year, giving a total increase of 20% until 2030 and of 40% until 2050.

In this prestudy, more ambitious growth rates are assessed for district heating in the EU27 between 2010 and 2050. The chosen methodology in this pre-study contains a combination of hour-by-hour energy modelling of the EU27 energy system and mapping of local conditions, which is essential for district heating analysis. However, the link between these two actions has not been fully utilised in this pre-study due to the limited working time available: The mapping action has only indicated the input to the energy modelling action.

MAPPING OF LOCAL CONDITIONS

Currently, 60 million EU citizens are served by district heating systems in their daily life. But the existing district heating systems supply only part of the heat demands in the cities they serve. Cities with at least one system have a total population of 140 million inhabitants and approximately 57% of the EU population lives in regions that have at least one district heating system. Hence, more district heat can be delivered in the future by expanding existing district heating systems.

Only less than half of the calorific value of waste incinerated in 414 waste-to-energy plants is recovered as electricity or heat. This gives a driving force for increasing the heat recycling from the existing plants. Further waste-to-energy plants can be implemented, as almost 100 million tonnes of non-recycled waste is deposited in landfills.

One quarter of the European population lives in urban areas that could be reached by geothermal heat through future district heating systems. This includes major cities such as Hamburg, Berlin, Munich, Frankfurt am Main, Hanover, Stuttgart, Aalborg, Groningen, Amsterdam, Rotterdam, Paris, Lyon, Strasbourg, Barcelona, Budapest, and Bratislava.

Other local conditions considered are heat demands in urban areas, thermal power generation for using combined heat and power, biomass availability, and solar district heating.

The vision for the mapping of local conditions is to present the most suitable regions (hot spots) for future expansion of district heating systems by combining information about heat demands with information about available heat sources for each region within the EU27. Due to uncertainties relating to the quality of carbon dioxide emissions reported from various industrial and energy plants in the E-PRTR database, the most interesting hot spots for district heating cannot yet be presented in numbers. However, this major question mark can be eliminated by correcting these current deviations in the database.

In summary, the mapping part of the pre-study indicated that the market shares for district heating for buildings can be increased to 30% in 2030 and 50% in 2050.

ENERGY SYSTEM ANALYSIS FOR 2010

To begin, this pre-study focused on the existing EU27 energy system. A detailed breakdown of the energy consumed for the EU27 is available from the International Energy Agency, which was updated until 2009 at the time this study was being carried out [1, 2]. Therefore, the 2009 EU27 energy balance was used to represent the 2010 reference point in this pre-study. Using an historical year is important since historical data represents the actual operation of the energy system and it is documented in much more detail than forecasted scenarios: hence, the historical data can be used as a baseline for estimating future data which is not available. From the EU27 energy balance from the IEA, it is evident that district heating accounts for approximately 12% of the total residential and services heat demand in 2009. This 2010 historical reference is modelled on an hour-by hour basis in this pre-study using the energy system analysis tool EnergyPLAN.

Using the EnergyPLAN tool, a first draft evaluation of expanding district heating in Europe is carried out in this Heat Roadmap Europe (HRE) pre-study, from the present 12% to first 30% and afterwards to 50% of the heating of buildings. The benefits are illustrated in two steps. Step 1 shows the potential energy efficiency improvements connected to CHP while step 2 shows the additional potential of increasing the use of industrial waste heat, waste incineration, geothermal and solar thermal resources. Both steps are calculated for the present European energy system for the year 2010 as well as for a scenario representing the implementation of current EU27 energy policy until 2050.

According to the IEA EU27 energy balance for 2009, which was used to profile the heating sector in 2010, the 38% (50% minus 12%) of heating for buildings in question is today heated by electric heating or individual boilers burning coal, oil, natural gas or biomass. In step1 these buildings are converted to district heating using the following assumptions:

- Coal, oil and natural gas boilers are replaced accordingly, while no replacement of biomass boilers are assumed. Firstly, biomass boilers are typically outside the reach of district heating and secondly, biomass replaced by district heating may again be used to replace oil and natural gas in other buildings.
- Moreover to simplify the calculations in the pre-study, no electric heating has been replaced, although that can prove to be an important part of the district heating expansion.
- The production of district heating will come partly from *existing* power and CHP plants assuming an average efficiency in the present situation of 32% electric and 52% thermal output and partly from *new* Combined Cycle (CC) CHP plants with an efficiency of 47% electric and 44% thermal output. The CC plants will burn natural gas equivalent to the oil and gas saved in the individual boilers being replaced.

- The share of peak load boilers in all systems is assumed to be on the same level as the existing average of approximately 9-13%. In the case of 50% district heating this means that a small share of large-scale heat pumps in district heating areas will have to be added in order to be able to balance the electricity supply.

The idea of these assumptions is to illustrate the potential energy efficiency improvements using the same amounts of biomass as well as oil plus natural gas. The results are illustrated in **Figure 1**. As can be seen, the expansion of district heating and CHP will decrease the fuel consumption for heating buildings in Europe substantially. Today 12% of heat is supplied by district heating which consumes a little less than 250 TWh/year of fuel, while the remaining individual boilers consume around 3100 TWh/year. The total of approximately 3350 TWh/year will decrease by 40% to around 2000 TWh/year if a 50% district heating share is reached. The fuel used by the boilers to be replaced by district heating if expanded to 50%, is today approximately 1550 TWh/year of coal, oil, and natural gas. In a system with district heating and CHP the fuel consumed by the total energy system will decrease by 1300 TWh/year (see **Figure 2**), meaning that the same heating can be provided with a net use of only 250 TWh/year of fuel. The net use of 250 TWh/year requires the following changes to the system: Fuel for CHP is increased in existing systems by 1360 TWh/year and in new CC-CHP systems by 1560 TWh/year while the electricity from the CHP plants replaces 2670 TWh/year of production from the condensing power plants. In the power and CHP plants, the burning of natural gas is increased by net 1460 TWh/year equivalent to the oil and gas saved in the individual boilers while the net influence on the use of coal is a decrease of 1210 TWh/year.

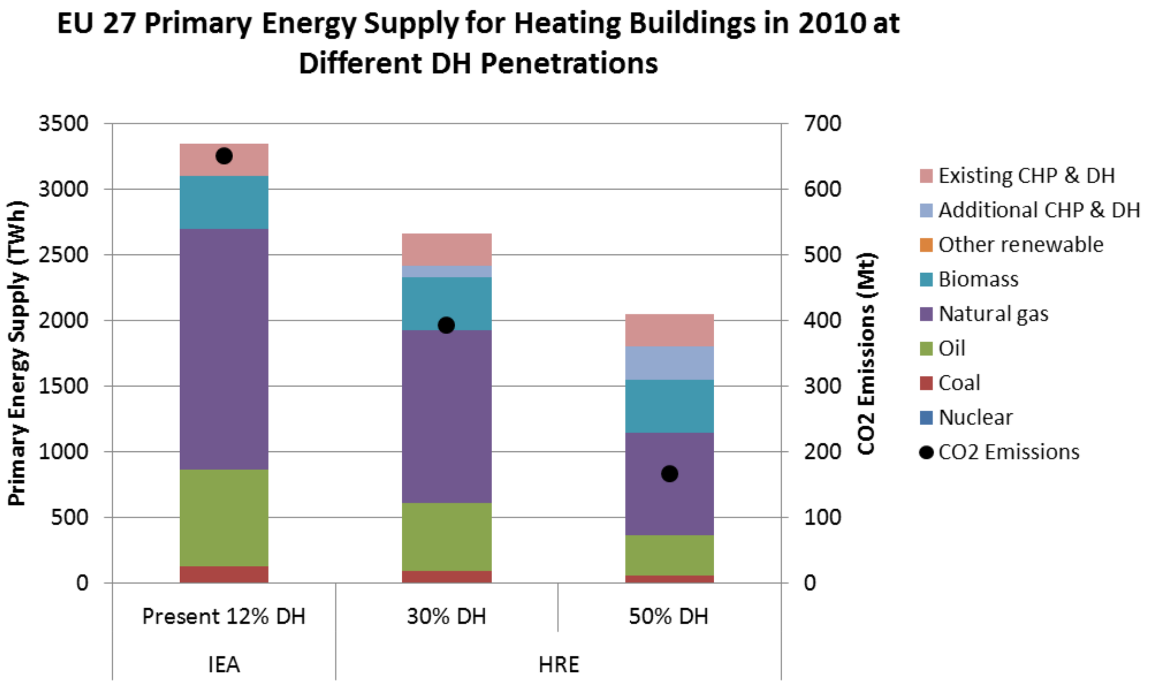

Figure 1: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010 EU27 energy system at present and if district heating and CHP were expanded to 30% or 50%.

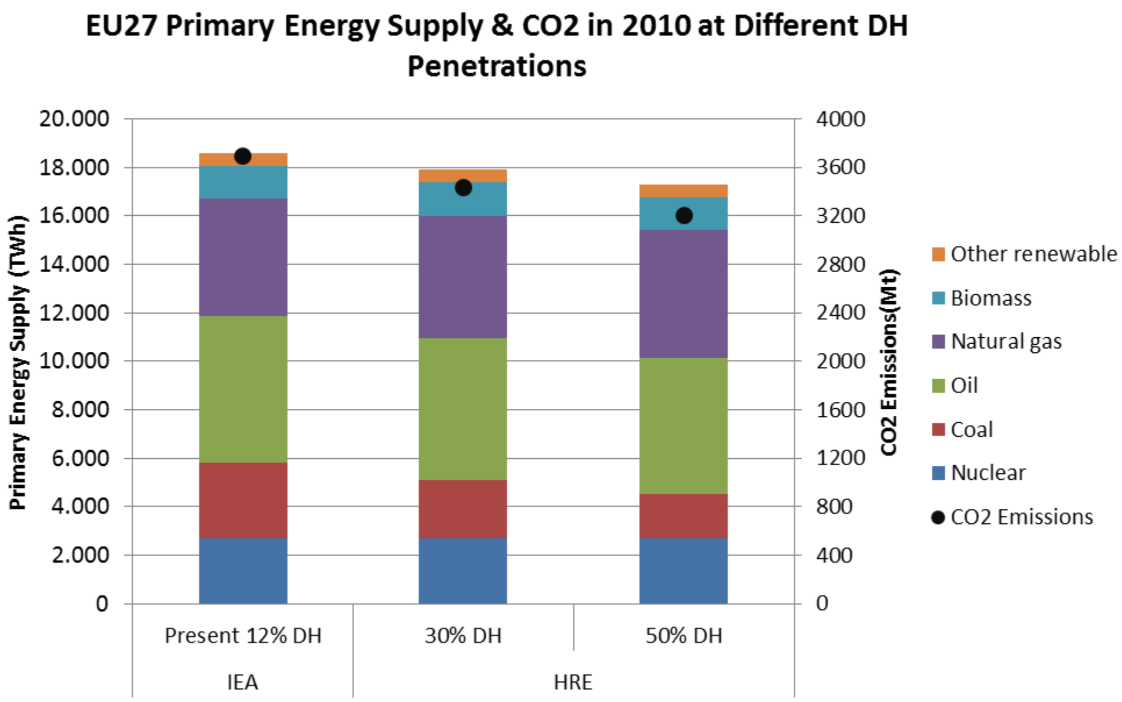

Figure 2: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010 at present and if district heating and CHP were expanded to 30% or 50%.

In total, **Figure 2** indicates that the expansion of district heating will decrease the European primary energy consumption by 7%, fossil fuels by 9%, and the carbon dioxide emissions by 13% while still supplying the exact same energy services. Again it should be noted that the potential for fuel savings is most likely higher than calculated in this pre-study, since there are additional alternatives which could also be implemented. For example, there is also a substantial amount of electric heating in the EU27 energy system which can be converted.

Step 2 illustrates further benefits of district heating by implementing the following investments:

- Increase waste incineration from now 105 to 1198 TWh/year in 2050
- Increasing the use of geothermal heat from now approximately 2 to 111 TWh/year in 2050
- Increase the use of solar thermal heat from now 0.04 to 55.5 TWh/year in 2050
- Increase the use of industrial excess heat from 53 to 219 TWh/year in 2050

The results are shown in **Figure 3**.
Since these investments represent the replacement of fuels rather than efficiency improvements, such benefits will only slightly decrease the primary energy consumption further. However the share of fossil fuels as well as the carbon dioxide emissions will be reduced substantially. If both step 1 and 2 are implemented, then the total fossil fuels in Europe are reduced by 13% and the carbon dioxide emissions by 17%, as illustrated in **Figure** 4.

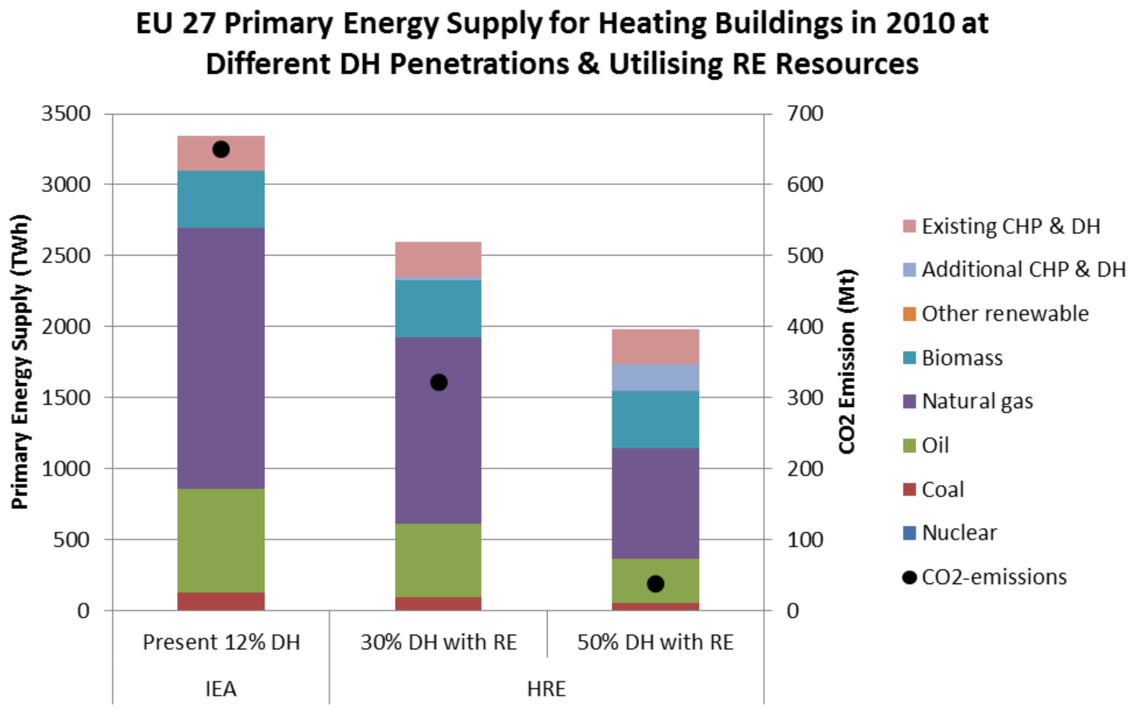

Figure 3: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010 EU27 energy system at present and if district heating and CHP were expanded to 30% or 50%, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

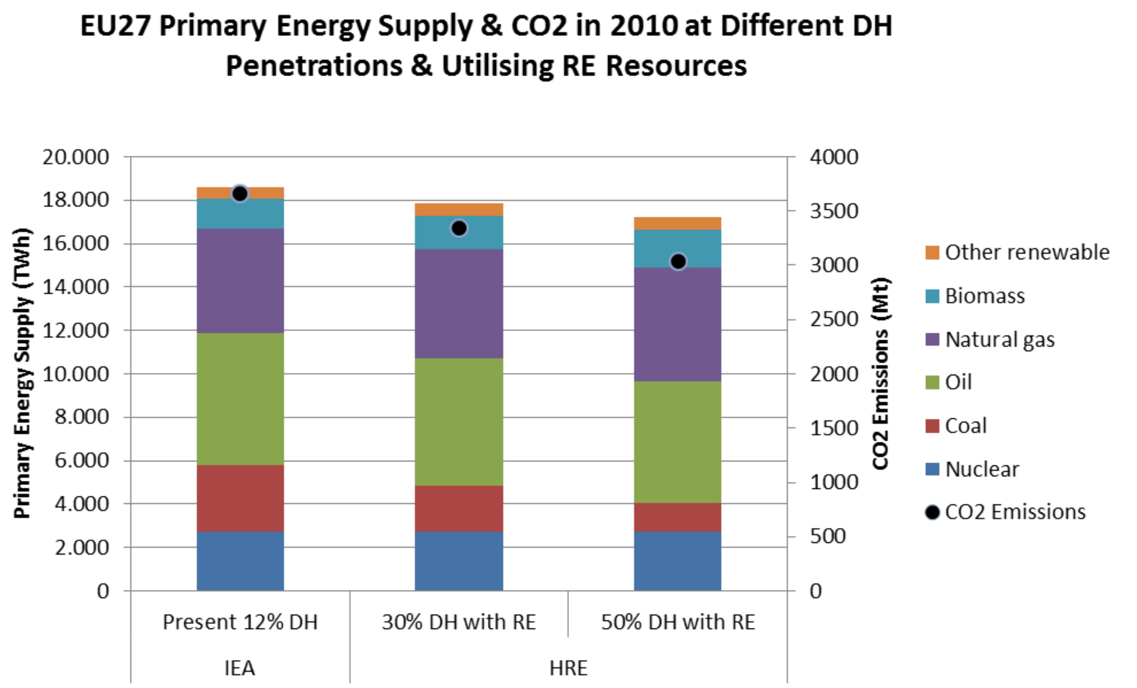

Figure 4: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010 at present and if district heating and CHP were expanded to 30% or 50%, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

REFERENCE SCENARIO FOR 2030 AND 2050

Additional to the above estimation of district heating benefits in the present 2010 EU27 system, the analyses has also been carried out for a reference scenario representing the implementation of current EU27 energy policy until 2050: this is based on the Current Policy Initiatives (EU CPI) scenario in the "*Energy Roadmap 2050*" report. This scenario represents a business-as-usual forecast for the EU27 energy system if existing policies are followed. Some interesting trends included in the EU CPI scenario are the following:

- Nuclear power is gradually reduced during the period to 2030, but subsequently begins to increase back to 2010 levels in 2050 once again.
- The EU 20-20-20 targets for renewable energy, greenhouse gas emissions, and energy savings for 2020 are achieved.
- Existing CHP and Power plants are being replaced with new plants over the years resulting in a gradual increase in the average efficiencies of the European power sector.
- The specific heating demand for buildings is decreased due to energy conservation improvements in the buildings, but the heat demand in industry increases substantially.

ENERGY SYSTEM ANALYSIS FOR 2010, 2030 AND 2050

The results of these analyses are illustrated in **Figure 5** and **Figure 6** with regard to primary energy supply and carbon dioxide emissions. In the diagrams the expansion of district heating is compared to the CPI reference (EP CPI in the graphs refers to the model of the CPI scenario constructed in the EnergyPLAN tool). As can be seen the fuel consumption for heating is expected to decrease in the CPI reference mainly due to energy savings. If district heating is expanded at the same time then substantial fuel savings and carbon dioxide reductions will be achieved due to a combined increase in energy efficiency in electricity and heat production. This is evident in **Figure 7** by the increased use of CHP, surplus heat, and renewable resources in the HRE scenarios.

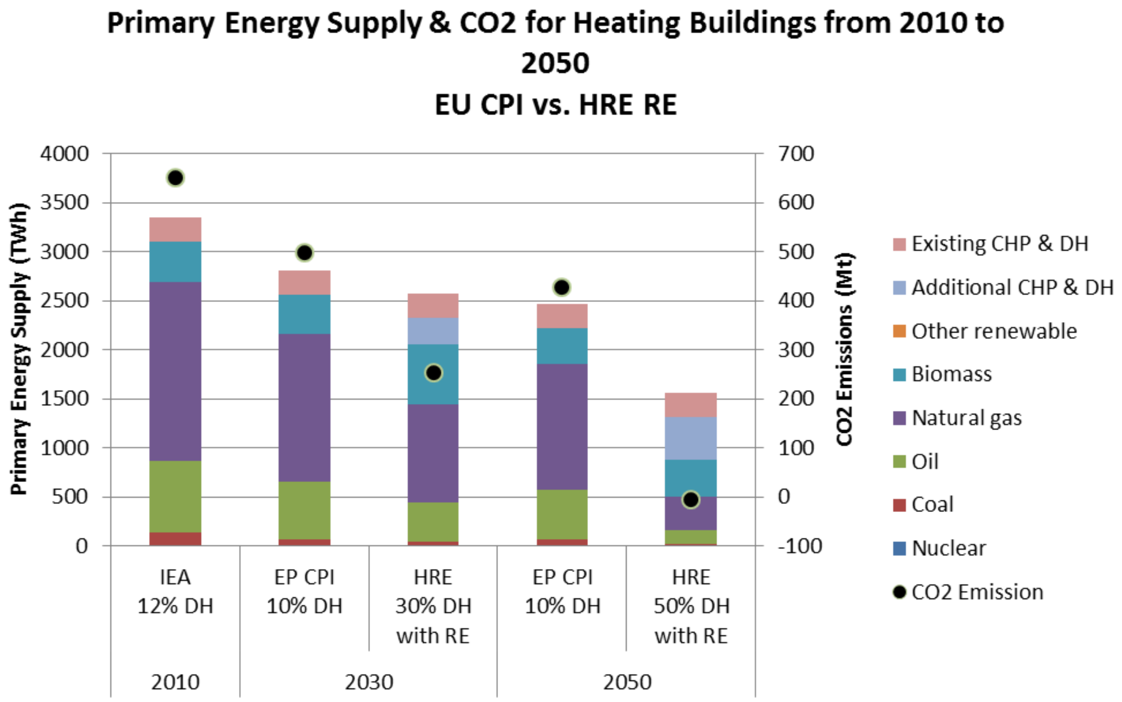

Figure 5: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010, 2030, and 2050 EU27 energy system under a business-as-usual scenario and if district heating and CHP is expanded to 30% in 2030 and to 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

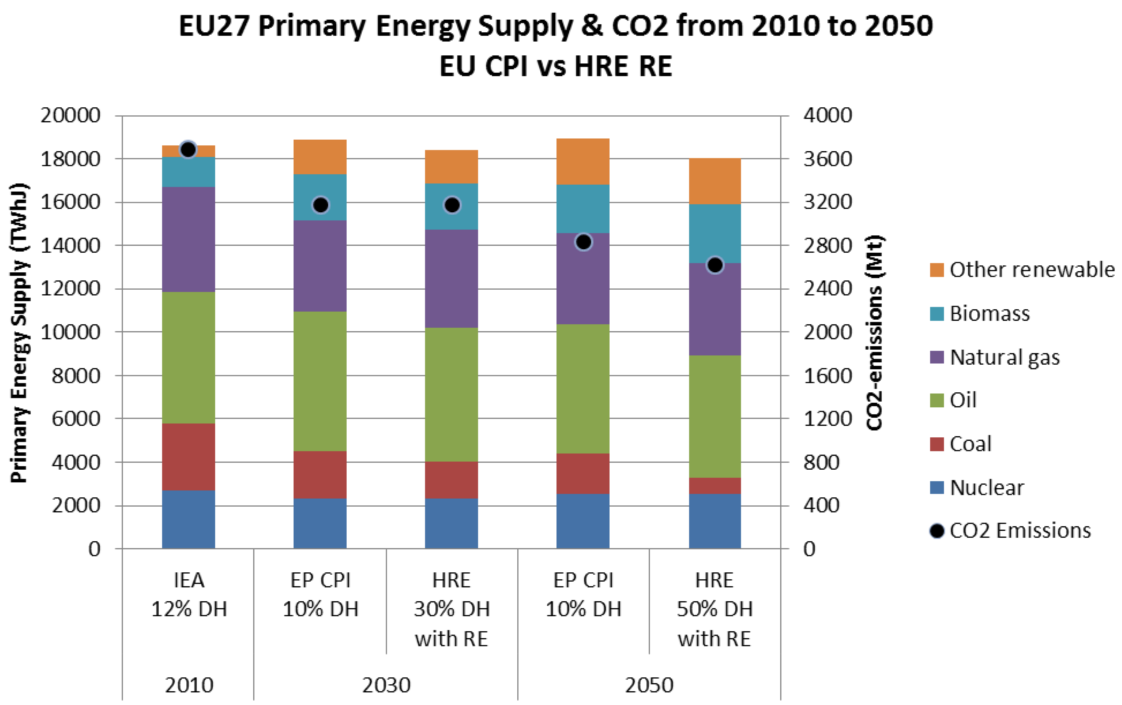

Figure 6: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

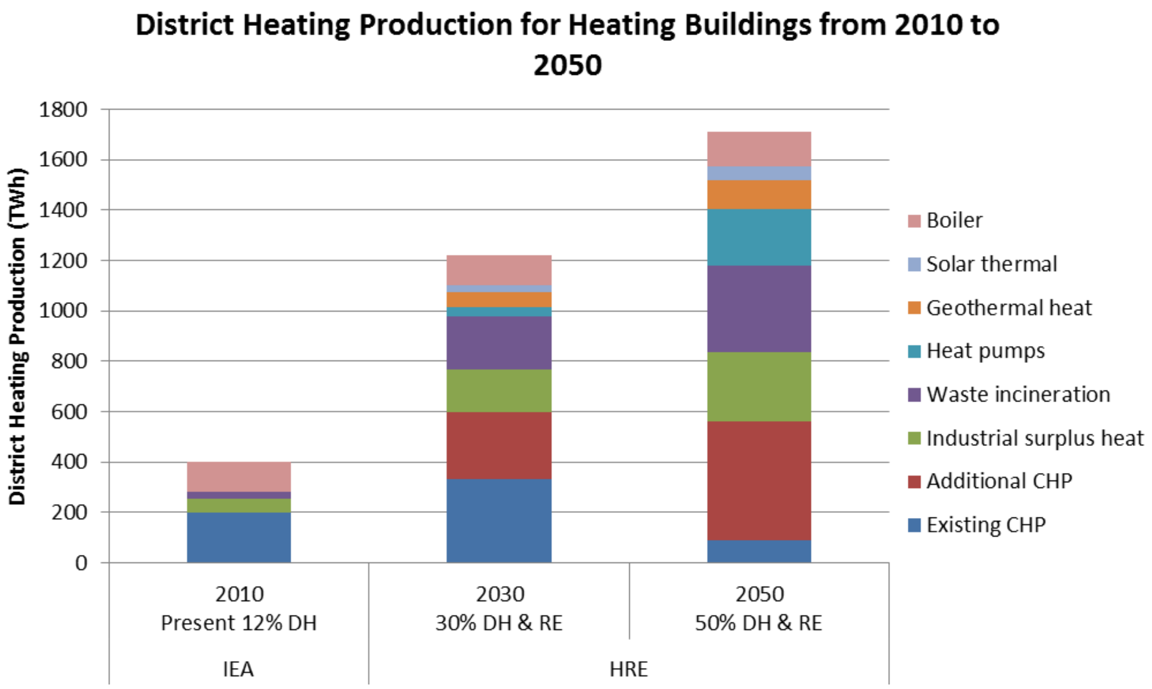

Figure 7: District heating production for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

JOBS AND INVESTMENT COSTS FOR EXPANDING DISTRICT HEATING SYSTEMS.

This pre-study also includes a rough estimate of costs which indicate that, assuming the same fuel prices as forecasted in the *Energy Roadmap 2050* report, the implementation of the district heating expansion scenario will decrease the total costs of heating buildings in Europe by approximately €14 billion/year in 2050, as illustrated in **Figure 8**. Even more importantly, implementing the district heating alternative will transfer money from importing fossil fuels to investments in district heating pipelines, CHP plants, geothermal, solar thermal, industrial waste heat, and waste incineration. Thus a substantial number of jobs will be created in the investment phase. This pre-study only includes a first rough estimate of job creation which is around 8-9 million man years: this equates to approximately 220,000 new jobs on average over the 38 year period from 2013 to 2050. It must however be emphasized that 220,000 jobs is a rough estimate of the minimum number of work places being created and the 220,000 jobs solely arise from the additional investments. The real number will be higher because:

- Multiplier effects of the jobs created are not included.
- Additional jobs are not included to account for the fact that when the energy costs of Europe decrease, European industry will become more competitive.
- Additional jobs from industrial innovation due to the investments in new energy technologies are not included.

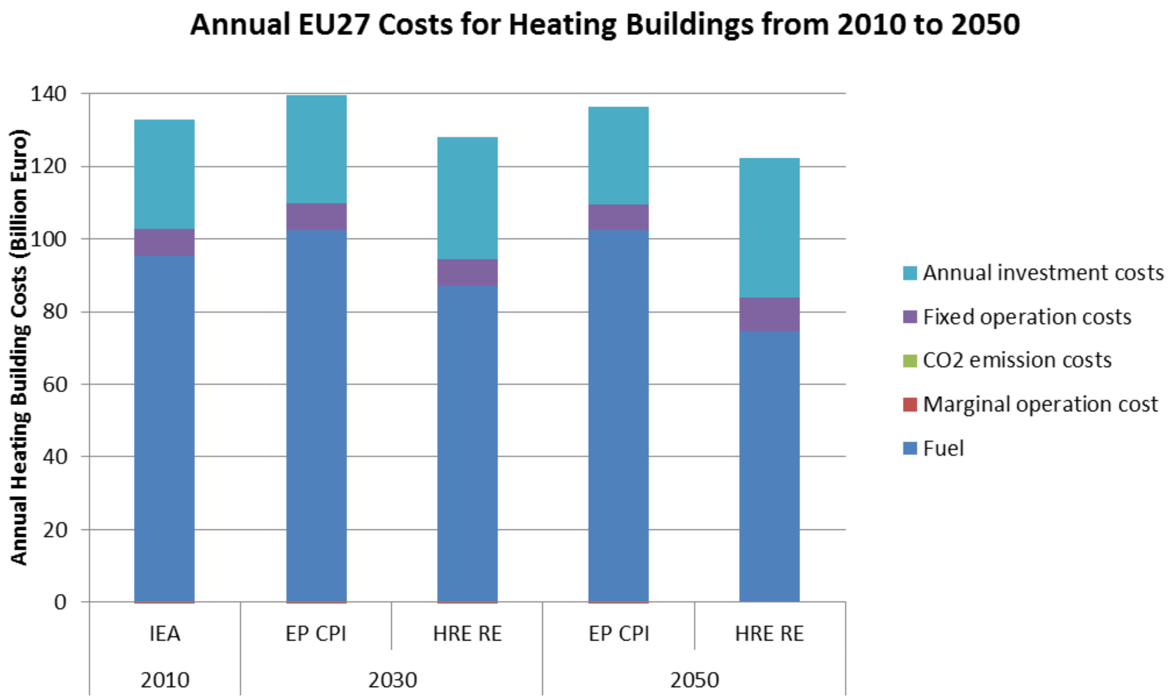

Figure 8: Socio-economic costs for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

CONCLUSIONS

The major findings from this Heat Roadmap Europe pre-study exploring the future district heating possibilities can be summarised by the following eight conclusions:

- The first conclusion is that more district heating in Europe will reduce the energy system costs considerably since local heat recycling and renewable energy use will reduce expensive energy imports, while also increasing the efficiency of both the electricity and heat sectors. The pre-study calculations indicate that the overall annual cost reduction in the heating sector will be about €14 billion by 2050, if more district heating is implemented compared to the Energy Roadmap 2050 CPI reference. This corresponds to a relative cost decrease of 11%. At the current energy import prices, the direct socio-economic payback is estimated to be two to three years for heat distribution pipes put into the ground giving more recycled heat. In addition, there is a balance-of-payment benefit that has not been quantified in this study.

- The second conclusion follows from the first conclusion: Since fossil fuels are substituted with local resources, the reduced primary energy supply from fossil fuels will also give considerably reduced emissions of carbon dioxide for all heat demands served by district heating systems. The reduced energy import will also increase the future security of supply and give more positive balances of foreign exchange.

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- The third conclusion is that more district heating will generate local labour since intensive investments will replace expensive imports of fossil fuels to Europe. An estimate indicates that approximately 8-9 million man-years will be created in Europe during the 40 year period, due to investments in heat recycling, renewable energy supply, and extended and new heat grids. This represents a rough estimate of the minimum number of jobs and should be quantified more thoroughly in the future.

- The fourth conclusion concerns the future European electricity supply system. With a high proportion of variable renewable electricity supply, a smart energy system is crucial so that all sectors can contribute to a balance between supply and demand. One of the proven flexible partners is district heating systems which can provide balancing power in both directions. For example, electric boilers and large heat pumps together with thermal storages can absorb critical excess electricity generation, while combined heat and power plants can actively support the electricity supply system during power deficits. Therefore, district heating can enable higher penetrations of intermittent electricity production on the European electricity grid.

- The fifth conclusion is about the importance of communicating the local possibilities for district heating to urban and regional planners. The planned continuation of this pre-study should contain a creation of an interactive internet tool providing the local conditions for district heating for each administrative region in the EU27.

- The sixth conclusion is about the methodology applied in this pre-study, which is a combination of energy modelling and mapping of the local conditions using a high geographical resolution: The high resolution also recognises future possibilities for local activities managed by local organisations. This methodology is crucial for district heating analysis since the potential for expansion is dependent on local heat resources and demands. Therefore, this methodology should be elaborated in the planned continuation of this pre-study, while also making a tighter connection between the energy modelling part and the local mapping part.

- The seventh conclusion concerns traditional energy modelling based on national energy balances. Their low geographical resolution tends to exclude specific local possibilities. Hereby, they favour generic possibilities available everywhere such as electric and gas alternatives associated to major international energy companies. Hence, these traditional energy tools may only capture some of the alternatives available. Traditional energy tools also tend to work with a low time resolution in their analyses. However, it is important to use a high time resolution to capture the daily variations in the energy system in order to verify the true variability in energy demand and supply, especially in a future energy system with high penetrations of intermittent resources.

- The eighth and final conclusion refers to the availability of data within the current IEA and future Energy Roadmap 2050 reports. At present, there is a lack of detailed data for the heat sector in these energy balances. For example, all fuels consumed by CHP plants are recorded together and not subdivided by condensing mode, extraction mode, and back-pressure mode. In the future, it would be beneficial if the details within these energy balances could be increased for the heat sector. In line with this, we would like to thank the European Commission for providing all of the data possible during the limited timeframe of this study

FINAL RECOMMENDATION

This pre-study has demonstrated the potential increase in energy efficiency and renewable energy consumption associated with district heating, so a full research study is recommended to further elaborate on the methodology applied in this pre-study.

TABLE OF CONTENTS

NOMENCLATURE

Abbreviation	**Description**
CC	Combined Cycle
CEEP	Critical Excess Electricity Production
CEWEP	Confederation of European Waste-to-Energy Plants, located in Brussels.
CHP	Combined Heat and Power
CORINE	The European land cover surveying system.
CPI	Current Policy Initiatives, future energy system scenario in the EC communication *Energy Roadmap 2050*.
DH	District Heating
EC	European Commission
EEA	European Environment Agency, located in Copenhagen.
EnergyPLAN (EP)	The energy system analysis tool used in the pre-study.
EP CPI scenario	A model of EU CPI scenario in the EnergyPLAN tool to validate the EU CPI reference from the *Energy Roadmap 2050* report.
EU	European Union
EU CPI scenario	The future energy system scenario called Current Policy Initiatives (CPI) from the *Energy Roadmap 2050* communication. This scenario was chosen as the reference scenario in this pre-study.
HRE	Heat Roadmap Europe, a label for a planned research project initiated by this pre-study.
HRE scenario	The first step in the future energy system scenario developed within this pre-study. It only includes the efficiency improvements due to increased CHP with district heating. This scenario is benchmarked against the EU CPI scenario.
HRE RE scenario	The second step in the future energy system scenario developed within this pre-study. It includes both energy efficiency improvements and the utilisation of additional renewable energy resources due to the implementation of district heating.
IEA	International Energy Agency, located in Paris.
IEA 2010	The historical reference scenario used in this pre-study. The most recent EU27 energy balance available from the IEA is for 2009, so this was used to represent the 2010 reference scenario, which is called IEA 2010.
ISWA	International Solid Waste Association, located in Vienna.
NUTS	Nomenclature of Statistical Territorial Units, defined by Eurostat.
NUTS3	The third level of the European NUTS system defining the national administrative regions.
PES	Primary Energy Supply
PP	Power Plants
PRIMES	The energy systems model used for energy modelling in the EC communication *Energy Roadmap 2050.*
RE	Renewable energy
WTE	Waste-to-energy, label for defining waste incineration plants with energy recovery

1. INTRODUCTION

1.1 CURRENT HEAT MARKET CONTEXT

The current heat market for residential and service sector buildings within EU27 is about 3200 TWh/year according to **Figure 9**. The market share for district heating in this heat market for buildings is 12%, giving heat deliveries of about 380 TWh/year. District heat is also used for low-temperature heat demands in the industry. These heat deliveries are about 230 TWh/year. These two major customer groups add up to the total volume of heat sold from district heating systems to about 610 TWh/year. Further 220 TWh/year is delivered from industrial CHP plants to industrial demands. Hence, the total turnover in the EU27 heat balance for final consumption amounts to about 830 TWh/year. The exact division between district heating systems and industrial CHP plants is very diffuse in international heat statistics. Hereby, it is also difficult to identify the real extent of district heating in EU27, but the simple division estimated above will be used in this pre-study.

Currently, the heat market for buildings is dominated by two thirds of heat supply from fossil fuels according to **Figure 9**. This gives a future opportunity for district heating to expand by substituting fossil fuels in order to reduce primary energy supply and carbon dioxide emissions. This expansion can be fulfilled by expanding heat recycling and renewable energy use in existing and new district heating systems. A proper assessment by energy modelling is still missing for this possible expansion for the whole EU27. However, some assessments have been performed for some countries and cities. One country example is the two Varmeplan Danmark reports for Denmark [48, 49] and one city example is the renewable plan for the Munich district heating system [50], introducing geothermal heat as the future base load.

The main purpose with this pre-study is to pave the road for a proper assessment of a future expansion of district heating within EU27. The focus is on more heat deliveries to the residential and service sector buildings.

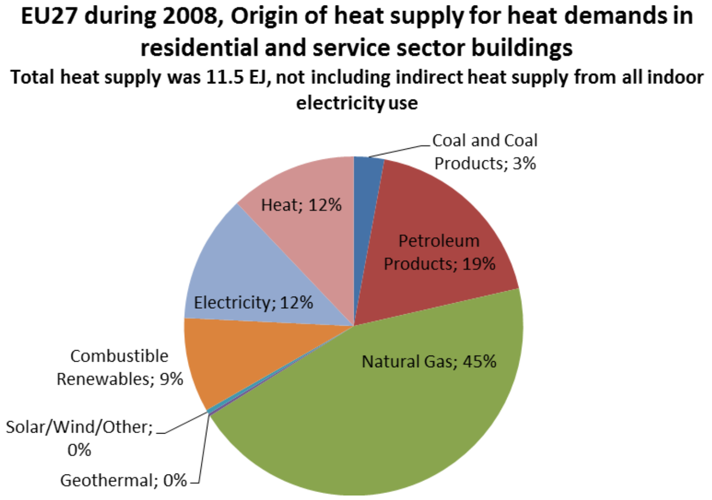

Figure 9: Composition of the origin for heat supply to residential and service sector buildings in EU27 during 2008. Labels refer to the standard commodity groups used in the IEA energy balances. Heat denotes mainly heat from district heating systems. Data sources: IEA energy balances for 2008 complemented with some external estimation. One EJ is 10^{18} Joule, equivalent to 1 million TJ or 278 TWh.

1.2 CURRENT EU ENERGY POLICY CONTEXT

The European Union does not have a specific energy policy or directive concerning district heating. However, the specific directives for combined heat and power, industrial emissions, emissions trading, energy performance in buildings, renewable energy, waste management, energy taxation and energy efficiency (forthcoming) are examples of the EU regulatory framework for district heating.

The latest projection within the EU energy policy context concerning future heat deliveries from district heating systems and industrial CHP plants is the specific *Energy Roadmap 2050* communication [3], published in December 2011. This communication followed the more general communication from March 2011 called *A Roadmap for moving to a competitive low carbon economy in 2050* [51]. However, the description of the heat sector is not complete in this future projection, since the complete energy balance for the whole heat sector is missing in the corresponding impact assessment report [40].

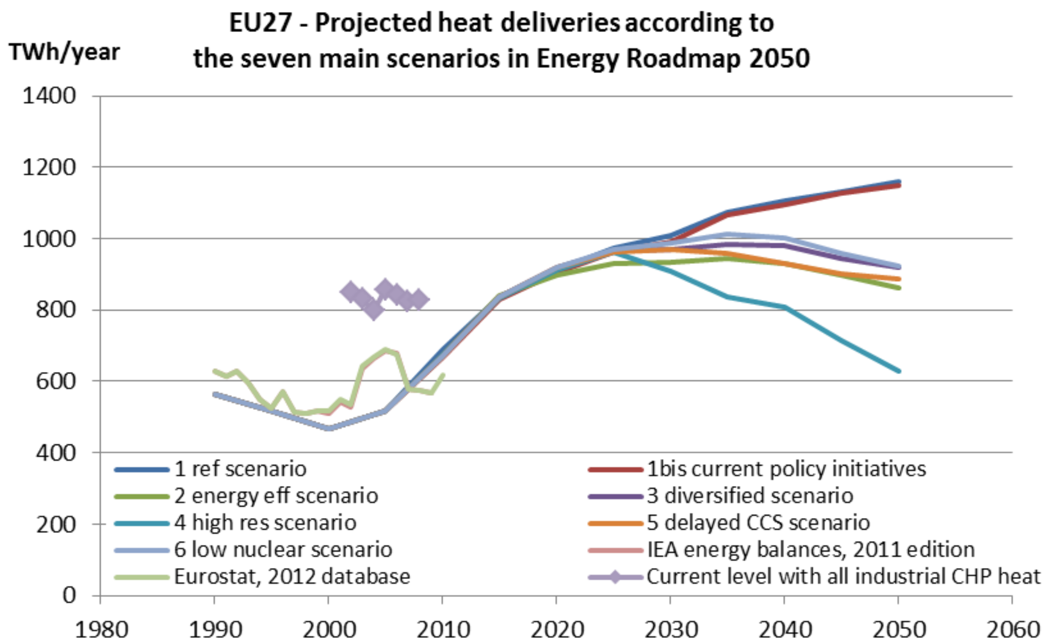

Figure 10: Expected heat deliveries for each of the seven main scenarios in the *Energy Roadmap 2050* communication [40] compared to available heat statistics from Eurostat and IEA for the recent years. We have estimated the current total use level by adding some missing heat deliveries from industrial CHP plants to industrial purposes in the current statistics. This addition has been made in order to reduce the confusion created by the current routines for international heat statistics.

The development of the heat deliveries in each of the seven scenarios elaborated in *Energy Roadmap 2050* is presented in Figure 10. The diagram is somewhat confusing with respect to the future development. The first years in the projection lack some heat deliveries from industrial CHP plants to industrial purposes since they are based on existing heat statistics lacking these heat deliveries. On the other hand, the energy modelling from 2015 and onwards includes all CHP heat deliveries. Hereby, the diagram gives a false optimistic view of the real expected development. Therefore, we have added our own estimations of the total heat deliveries for the period of 2002-2008, estimated with additional input from the specific Eurostat statistical reports concerning CHP heat generation in EU27. The average of these years amounts to about 830 TWh/year, the same level earlier identified in the preceding sub-section about the heat market context.

The expected development becomes then an increase with almost 20% until 2030 and with almost 40% until 2050 in the *Energy Roadmap 2050* reference scenario, indicating an annual expansion rate lower than 1% per year. However, this expansion is unevenly distributed among the two major customer groups. Heat deliveries to industrial purposes are expected to increase with 48% until 2030 and with 87% until 2050, while heat deliveries to residential and service sector buildings are expected to decrease with 13% until 2030 and with 22% until 2050.

Two questions arise directly from analysing the projection of the heat deliveries in *Energy Roadmap 2050*: Have local synergy options been considered at all? To what extent have substitution of electricity and gas use by excess heat recovery been conceived?

The conclusion is then that the European Commission does not foresee any radical expansion of the heat deliveries from district heating systems and industrial CHP plants in the future. Since all decarbonisation scenarios give lower heat deliveries than in the reference scenario, the European Commission has not identified district heating and industrial CHP as a major future decarbonisation tool within the energy system. Hence, *Energy Roadmap 2050* has not estimated the outcome from a radical expansion of European district heating systems.

A major explanation for the absence of a scenario with more district heating in the *Energy Roadmap 2050* communication is that the PRIMES model have been used for the energy system analysis. As we have identified from studying the background references for Annex II, the PRIMES model do no aggregate local conditions and possibilities relevant for expanding district heating systems. The PRIMES model is also a market equilibrium solution based on current energy technologies. Then by its nature, the model favours business-as-usual scenarios, giving fewer possibilities for radical technological changes.

1.3 OUR BASIC METHODOLOGY

For this pre-study, we have used a methodology based on a combination of energy modelling and mapping of local conditions reflecting the possible future district heating opportunities. This approach is not completely new. The same methodology was used in the Heat Plan Denmark (Varmeplan Danmark) project [48, 49] with a very high geographical resolution for the mapping of local conditions.

The link between the energy modelling part and the mapping part is rather weak in this pre-study. The aim with a planned full study is to explore how this link can be stronger. The mapping part is only used as an indicator of how intensive an expansion of district heating can be in 2030 and 2050.

The main target area for the analysis is the aggregated area of the European Union with 27 member states (EU27). Since the mapping of local conditions concerns all countries within the European Union; the mapping information can be used for separate analyses for each country.

1.4 ENERGY SYSTEMS ANALYSIS TOOL: ENERGYPLAN

EnergyPLAN was deemed suitable as an energy system analysis tool for this pre-study. EnergyPLAN has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark [3]. Approximately ten versions of EnergyPLAN have been created and it has been downloaded by more than 1200 people. The current version can be downloaded for free from [4] while the training period required can take a few days up to a month, depending on the level of complexity required.

EnergyPLAN is a user-friendly tool designed in a series of tab sheets and programmed in Delphi Pascal. The main purpose of the tool is to assist the design of national or regional energy planning strategies by simulating the entire energy-system: this includes heat and electricity supplies as well as the transport and industrial sectors. All thermal, renewable, storage/conversion, transport, and costs (with the option of additional costs) can be modelled by EnergyPLAN. It is a deterministic input/output tool and general inputs are demands, renewable energy sources, energy station capacities, costs, and a number of different regulation strategies for import/export and excess electricity production. Outputs are energy balances and resulting annual productions, fuel consumption, import/export of electricity, and total costs including income from the exchange of electricity. The energy system is modelled on an hourly basis over a period of one year, which ensures that the system can be operated reliable even with high penetrations of intermittent renewable energy. In the programming, any procedures which would increase the calculation time have been avoided, and the computation of one year requires only a few seconds on a normal computer. Finally, EnergyPLAN optimises the operation of a given system as opposed to tools which optimise investments in the system.

Previously, EnergyPLAN has been used to analyse the large-scale integration of wind [5] as well as optimal combinations of renewable energy sources [6], management of surplus electricity [7], the integration of wind power using Vehicle-to-Grid electric-vehicles [8], the implementation of small-scale CHP [9], integrated systems and local energy markets [10], renewable energy strategies for sustainable development [11], the use of waste for energy purposes [12], the potential of fuel cells and electrolysers in future energy-systems [13, 14], the potential of thermoelectric generation (TEG) in thermal energy-systems [15], and the effect of energy storage [16], with specific work on compressed-air energy storage [17, 18] and thermal energy storage [3, 5, 19]. In addition, EnergyPLAN was used to analyse the potential of CHP and renewable energy in Estonia, Germany, Poland, Spain, and the UK [20]. EnergyPLAN has been used to simulate a 100% renewable energy-system for the island of Mljet in Croatia [21] as well as the countries of Ireland [22] and Denmark [23, 24]. Other publications can be seen on the EnergyPLAN website [4], while an overview of the work completed using EnergyPLAN is available in [25] and a comparison with other tools is available in [26].

1.5 MAPPING LOCAL CONDITIONS

A major setback in standard generic energy modelling is that national conditions constitute the basis for analysis. By such an approach, energy assets, demands, and distribution structures are viewed from an aggregated perspective not permitting insight into unique local circumstances and conditions. Such perspectives may be well suited when considering cross-border technologies and energy carriers, e.g. electricity and gas grids, since such commodity flows are integrated and visible in international energy statistics. But, for analyses aiming to include genuinely local technologies, e.g. district heating and cooling systems, such perspectives generally tend to be too blunt to detect and capture synergy options strictly limited to the local dimension.

The ambitious European targets to increase energy efficiency in future power and heat distribution and use acts as a force to address local conditions in a more systematic and thorough sense than previously elaborated. The main reason for this is simply that only local conditions disclose obtainable synergies between local heat assets and prevailing heat demands. Only at the local level, the excess heat from various activities and sources can be utilised by recovery and distribution in district heating systems. For this reason, one fundamental idea for the planned Heat Roadmap Europe Project is to deliberately break-up national boundaries and use local conditions as a foundation for the analysis, as it strives to identify, map, and quantify feasible and cost-effective synergy locations in Europe.

For this purpose, we have used the NUTS3 regions defined by Eurostat as primary level of analysis for mapping local conditions in order to get relevant input to the energy modelling. These administrative regions are available for 34 European countries with 1461 defined regions. The 27 Member States of the European Union consists of 1303 NUTS3 regions, see Figure 11. However, the population in each NUTS3 region varies considerably according to **Figure 12**. About 90 NUTS3 regions have more than one million inhabitants. By using these predefined administrative regions, other statistical variables are easily available from the Eurostat databases.

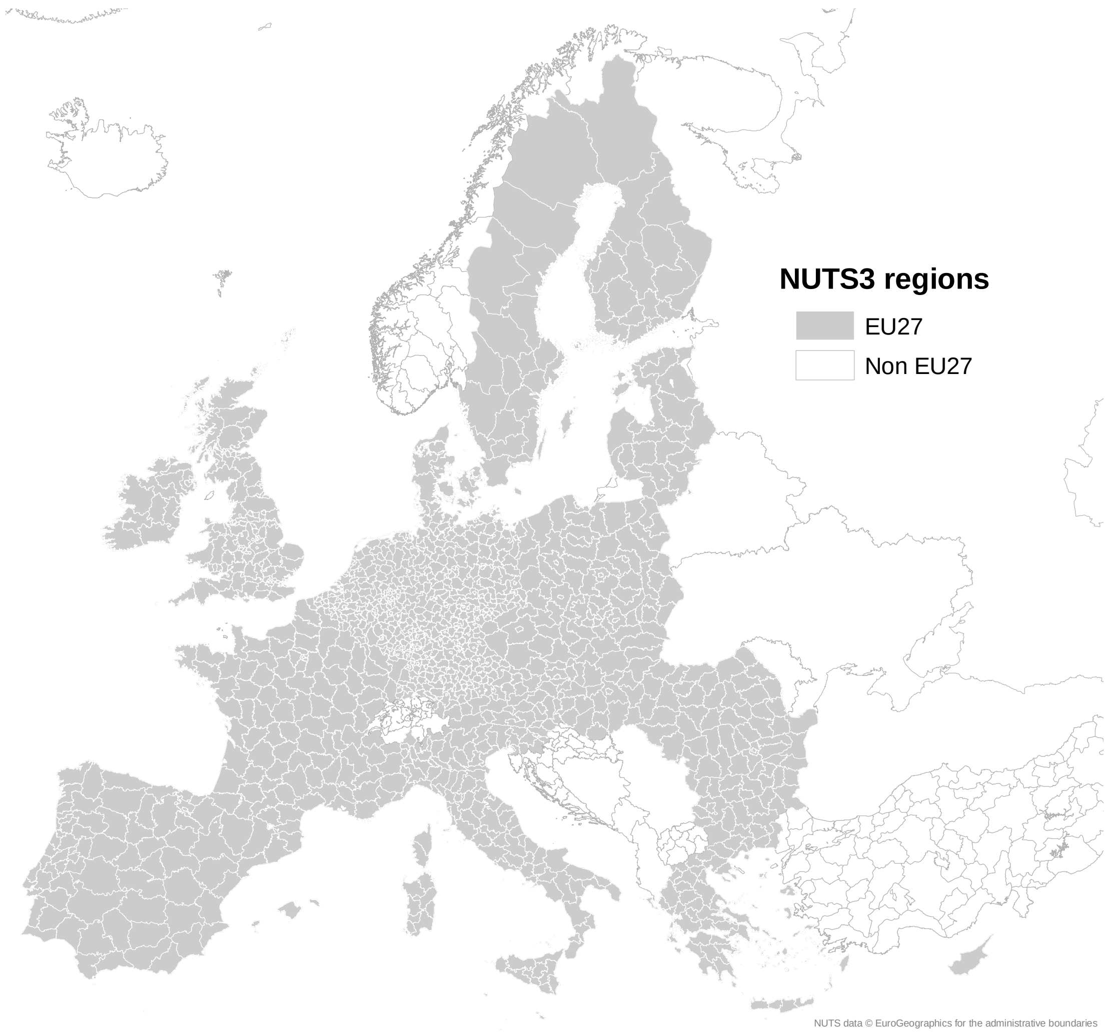

Figure 11: The NUTS3 regions of Europe, of which 1303 are located within the EU27.

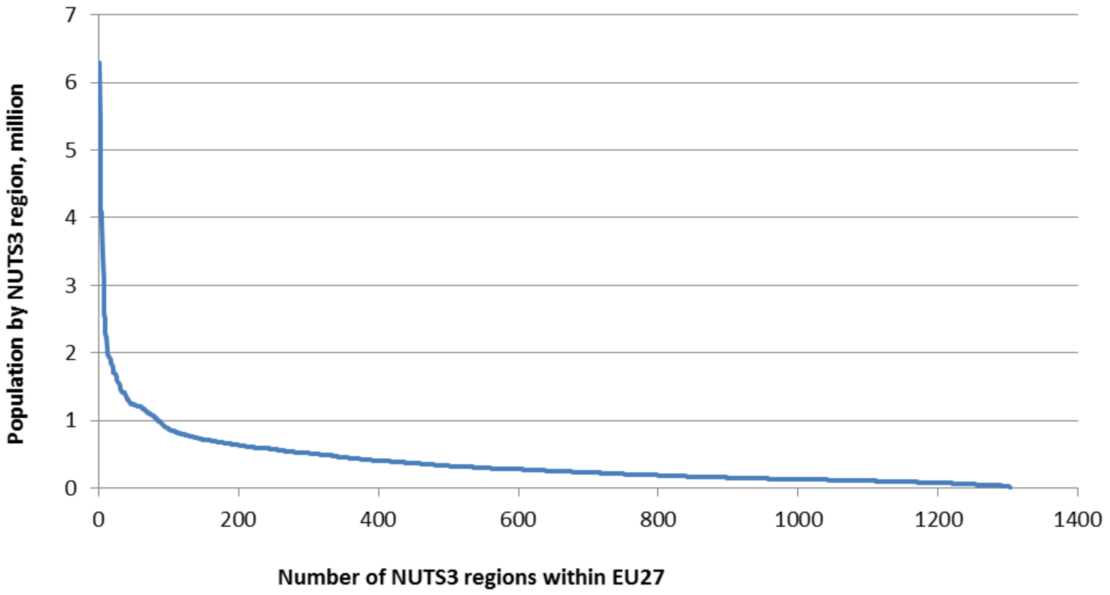

Figure 12: The distribution of the population in each NUTS3 region.

2. REFERENCE SCENARIO FOR 2010, 2030 AND 2050

2.1 CHOICE OF REFERENCE SCENARIO

Before evaluating an alternative energy roadmap for Europe based on district heating, a reference scenario needs to be defined. This reference scenario should represent a business-as-usual development which alternative scenarios can be benchmarked against. To begin, a review of other energy strategies was carried out to identify a suitable reference scenario for this study.

Firstly, it was evident that the most detailed historical breakdown of the EU27 energy system is created by the International Energy Agency (IEA) in their annual energy balances reports [1, 2]. At the time this project was being completed, the most recent energy balance available from the IEA for the EU27 was based on the year 2009. Hence, the year 2009 is used in this study as the 2010 reference energy system. The IEA data acts as a crucial baseline in this study, since the detailed breakdown of the EU27 energy system available for 2009 can act as a guideline when making assumptions for the energy balances in forecasted years. Since the IEA do not create forecasted energy balances, a separate energy balance needed to be identified as the reference for the future years.

A brief description of some of the most recent reports regarding low or zero carbon emission goals for future years is seen in Annex I. This also includes the role of district heating in each of the reports. Most of the reports state that combined heat & power (CHP) and/or district heating are important, but fail to quantify to which extent these options can be used to move towards a low or zero carbon emission energy system. In the few reports where it is more than just briefly mentioned, it still is not included as a major role. The reason for neglecting CHP may not be a lack of relying on the technology, but the absence of suitable models to include it. In the Energy Roadmap communication [27] from the European Commission, the following statement is seen:

> "*An analysis of more ambitious energy efficiency measures and cost-optimal policy is required. Energy efficiency has to follow its economic potential. This includes questions on to what extent urban and spatial planning can contribute to saving energy in the medium and long term; how to find the cost-optimal policy choice between insulating buildings to use less heating and cooling and systematically using the waste heat of electricity generation in combined heat and power plants*."

This quote clearly reflects the need for an energy scenario which includes smart electricity and heat grids, storages, CHP, and district heating to an extent that can elucidate the full potential of these technologies. To neglect this unresolved significant part of the energy solution might result in unnecessary costs for decarbonising the European energy system or even a failure in reaching the emission goals for the European Union.

The EC published in March 2011 *A Roadmap for moving to a competitive low carbon economy in 2050* [51], which analysed cost-effective ways of reducing greenhouse gas emissions. It was intended to act a basis for developing sector specific initiatives and roadmaps such as the *Energy Roadmap 2050* which was published in its final version in December 2011. After completing the review of existing energy strategies, the Current Policy Initiatives (CPI) scenario from the *Energy*

Roadmap 2050 report was deemed the most suitable forecast for this study. The report is the latest of the documents described in Annex I and the CPI scenario includes the current European energy policies. It represents an update of another scenario (called "Reference scenario") in the same report which means that besides the EU 2020 targets for renewable energy sources and greenhouse gas reductions as well as the Emissions Trading Scheme Directive, the CPI scenario includes the latest developments in energy prices, energy taxation, efficiencies, infrastructure and policy (such as Germany's decision on a phase-out of nuclear power and Italy cancelling their nuclear programme, although the report does assume that the amount of level of nuclear plants in the EU27 will increase again to the current level after decreasing towards 2030).

The CPI scenario is based on the assumption that there will be no changes in European energy policies beyond the publication of the report. It is described not as a forecast but a projection of what will happen if the market forces at all times determines the energy solution in the present economic, technological and political situation[1]. The PRIMES model – which is described in Annex II – was used to develop the projections in *Energy Roadmap 2050*.

Another key reason for choosing the *Energy Roadmap 2050* is that this is the research which EU policy is based on: it is the European Commission's own prediction of the future energy system in Europe. However the EU27 energy balances available for the CPI scenario are not as detailed as the IEA 2009 EU27 energy balance. Hence, the IEA energy balance can act as a proxy when detailed assumptions are necessary for the scenarios in this study.

To summarise, three years will be considered in this pre-study: 2010, 2030, and 2050. The IEA EU27 energy balance for 2009 will be used to create the 2010 reference, while the CPI scenario from *Energy Roadmap 2050* will be used to create the business-as-usual forecasts for 2030 and 2050. These forecasts will be referred to as *EP CPI 2030* and *EP CPI 2050* respectively.

Finally, there are two key differences between the scenarios in the *Energy Roadmap 2050* and this pre-study. The first key difference is the energy tool utilised: in the *Energy Roadmap 2050* report, the PRIMES tool was used to develop the forecasts for the EU27 along with individual forecasts for each of the member states. PRIMES use a market equilibrium tool, which operates using a five year time-step over a duration time of 50 years. Hence, it is a combination of macro-economic forecasts with technical restrictions on the energy system, where the primary goal is to establish how various policies will influence the evolution of the energy system being considered. The focus in this pre-study is different and hence, a different energy tool is utilised.

In this pre-study, the aim is not to establish forecasts, but instead to perform a detailed technical analysis of the EU27 energy system to establish the role district heating based on hourly calculations over a duration time of one year. Therefore, the optimisation will be based on technical performance instead of market conditions and the operation of the system will be evaluated on an hourly basis. The evaluation of heating systems and the interaction between wind power, nuclear, CHP plants and heat pumps requires an hourly resolution to evaluate the high

[1] Average growth rate is assumed to be 1.7% p.a. The oil price is 106 US$/barrel in 2030 and 127 US$/barrel in 2050 (in year 2008 dollars). This is higher than the IEA Technology Perspectives where the expectations for the economic growth are 3.1% p.a. on an average between 2007 and 2050.

level of interaction between the electricity, heat, and transport sectors in a future smart energy system. Such systems cannot be analysed with resolutions that do not reflect the intermittent resources and their connection with the demands. For these reasons the analysis tool called EnergyPLAN (EP), which has been described in detail in section 1.4, will be used in this pre-study for both the reference forecasts (henceforth referred to as *EP CPI*) and the Heat Roadmap Europe scenario.

The second key difference between the *Energy Roadmap 2050* report and this pre-study is the resolution considered when defining the district heating alternatives. The approach in this pre-study has been to analyse specific local conditions within the EU27 member states to assess the overall EU27 potential for district heating. This has been performed using a detailed database of existing district heating networks, heat loads, and potential heat supplies along with some mapping tools to see how they fit together.

2.2 FINAL ENERGY CONSUMPTION WITH CURRENT EU POLICIES

As outlined in **Figure 13**, the energy consumed in industry increases the most from 2010 to 2050, while the residential, services, and agricultural sectors either decrease or show negligible growth. The transport sector increases slightly between 2010 and 2030, but subsequently decreases between 2030 and 2050. It is important to note here that the decrease in transport energy consumption between 2030 and 2050 may not reflect a decrease in transport demand. For example, there is a large increase in more efficient transport technologies between 2030 and 2050, specifically in relation to electric vehicles which increase by 220% over this period. Hence, although the energy demand for transport reduces, the overall transport demand may not. Quantifying this would require a more detailed assessment of the transport sector, similar to the analysis completed in the CEESA project [28].

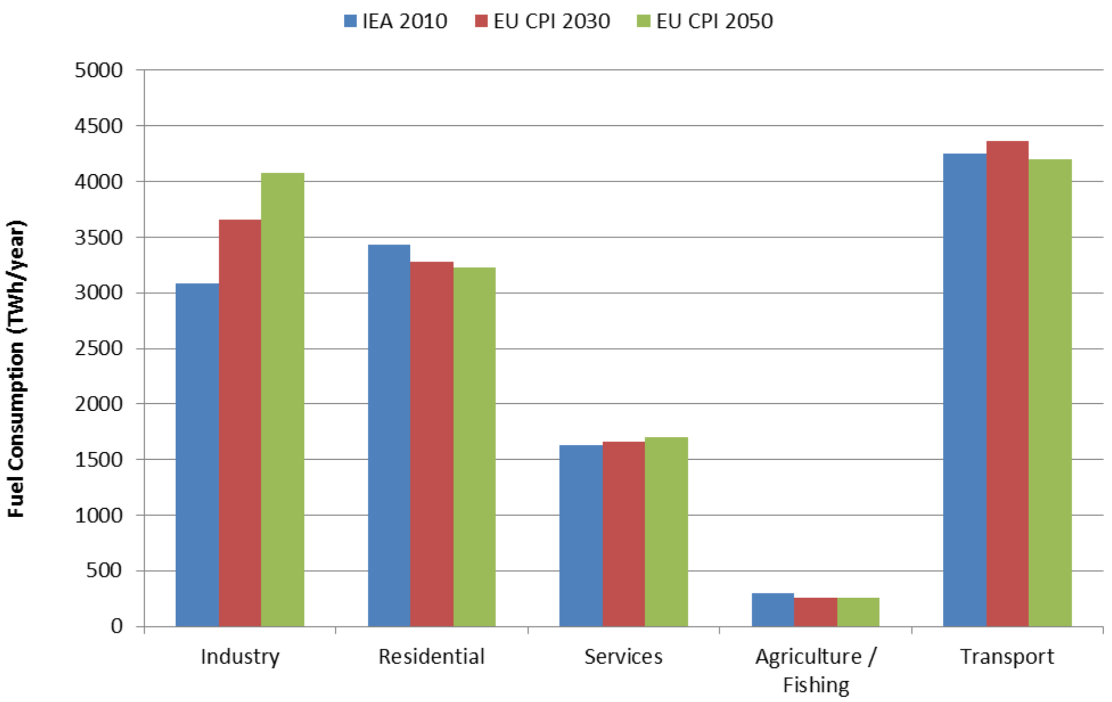

Figure 13: Final energy consumption by sector in the reference scenarios for 2010, 2030, and 2050.

In relation to fuel, the total energy consumption is divided by fuel in Figure 14. Here it is evident that electricity consumption increases by approximately 20% from 2010 to 2030 and by approximately another 20% between 2030 and 2050. The largest reductions are in oil and gas, which suggests that conventional thermal combustion technologies (such as boilers) are replaced by electricity. Other interesting trends include a relatively large increase in solar thermal, biomass/waste, biofuels, and heat.

However, as outlined in **Figure 15** and earlier presented in section 1.2, the increase in heat consumption is entirely related to industry and not to the residential or services sectors. Once again this suggests that low-temperature district heating applications (which is primarily space heating) are not utilised, but instead individual oil and gas boilers are replaced with electricity. This demonstrates the importance of this study, which will focus specifically on the role of low-temperature district heating in the future EU27 energy system.

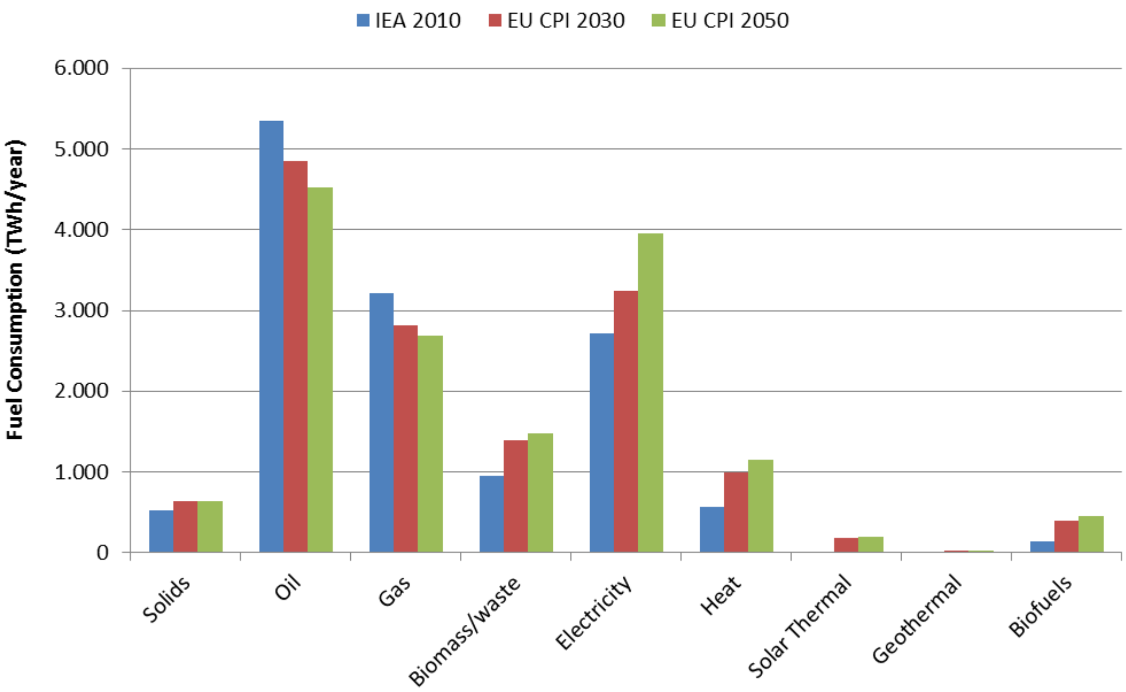

Figure 14: Final energy consumption by fuel in the reference scenarios for 2010, 2030, and 2050.

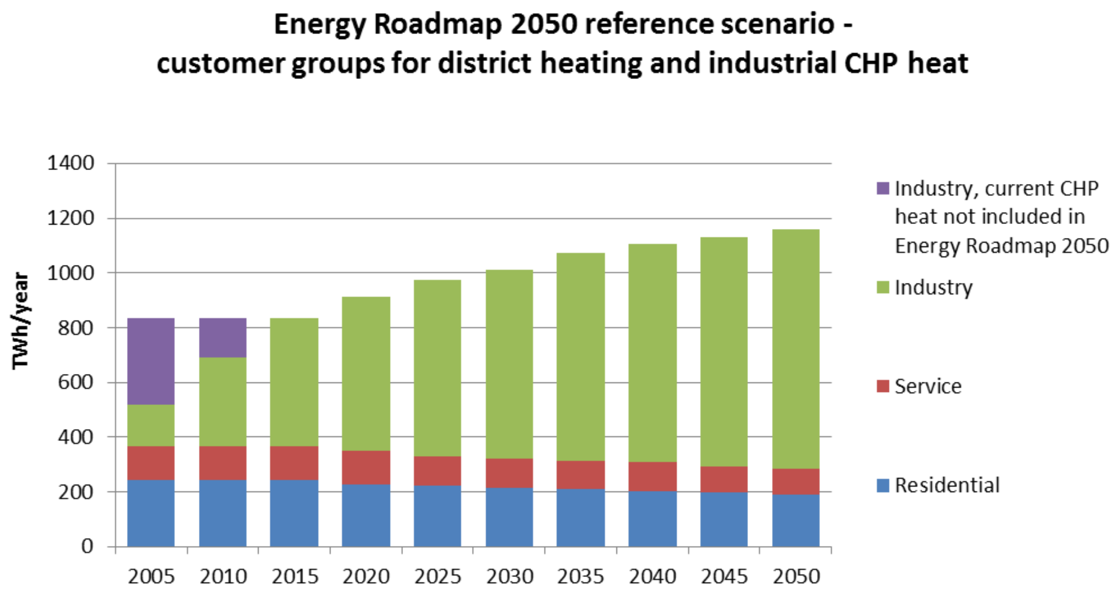

Figure 15: Expected customer groups for district heating and industrial CHP heat in the *Energy Roadmap 2050* reference scenario. Source: [40]. We have added the current deliveries of industrial CHP heat to industrial for 2005 and 2010 missing in the *Energy Roadmap 2050* impact assessment.

2.3 MODELLING THE REFERENCE SCENARIOS IN ENERGYPLAN

After profiling the reference energy scenarios using the statistics from the IEA and the *Energy Roadmap 2050* project, these years then needed to be modelled in the EnergyPLAN tool. While doing so, a number of key assumptions were made in relation to the heating sector. Firstly and most significantly, profiling the growth in industrial CHP proved very difficult within the timeframe of this study. This was primarily due to the different methodologies and lack of data for industrial CHP fuel consumption, electricity production, onsite heat consumption, and heat sold. For example, the IEA energy balance does not outline the heat consumed onsite for industrial CHP, but instead this is documented within the final energy consumption of industry. In contrast, the data from the *Energy Roadmap 2050* documents all fuel consumed by industrial CHP together with non-industrial CHP fuel consumption. Hence, these datasets had to be treated differently when profiling industrial CHP in the different years.

Also, in this study only district heating for the residential and services sectors is considered, so all fuel consumed for district heating relating to industry was removed from the district heating simulations and documented separately as an industry fuel consumption. Since two separate datasets were being used, both with limited data and different documentation methodologies, this process also required a number of assumptions relating to CHP efficiencies and fuel mixes.

In addition, no data was obtained during this study in relation to the electricity and heat sold by industrial CHP to the electric and district heating grids respectively. However, these statistics were available in the IEA energy balance for 2009 and hence, it was assumed that both the electricity produced and heat consumed would increase proportionally with the total final heat demand for industry outlined in **Figure 15**. As a result, industrial CHP produces approximately 10% of total electricity production in 2050.

Since industrial CHP increased, so did the heat sold to district heating grids by industry. However, not all of this heat is used by the residential and services sectors for low-temperature district heating applications since some of this heat is used by industry. It was not possible to establish from any statistics available what proportion of this heat is reused in industrial processes and hence, it was assumed that industry consumed same proportion of the total heat demand that industry made up. In other words, industry reused the same proportion of heat that it represented in **Figure 15**.

Another important assumption in the pre-study relates to centralised power plants (PP) and CHP. In the statistics, the fuel consumption recorded under CHP includes the fuel consumed by CHP plants operating in condensing power plant (PP) mode. As a result, the total efficiency for CHP is unrealistically low: for example, in 2009 the heat efficiency of CHP would be approximately 20% if all fuel documented under CHP was allocated as fuel consumed during CHP mode, whereas typically the heat efficiency of CHP is approximately 50%. This assumption was verified when the IEA energy balance for Denmark was analysed: here all fuel for power plants was recorded as CHP even though they often operate in PP mode only. Hence, to divide the fuels recorded under CHP into fuels for CHP in PP mode and fuels for CHP in CHP mode, 50% heat efficiency was assumed for CHP plants to estimate their total fuel consumption and the remainder was allocated to PP mode.

The final significant assumption relating to the modelling concerns the various plant efficiencies. Using the detailed breakdown in the IEA EU27 2009 energy balance, the efficiency of different units could be estimated: for example, the power plant efficiency was estimated at approximately 39%. In the 2030 and 2050 scenarios, the efficiency of PP is progressively increased by 3% and 6% respectively, to account for technological developments. A detailed breakdown of the data used and how it was interpreted is available in Annex III, while an overview of the key results is provided below.

2.4 VERIFICATION OF THE EU CPI SCENARIO

Based on these assumptions, the reference scenarios for 2010, 2030, and 2050, could be modelled in the EnergyPLAN tool for this HRE study. As displayed in **Figure 16**, the resulting simulations in EnergyPLAN were very similar for 2010: the primary energy supply (PES) is only 0.5% larger in the EP IEA scenario than in the IEA statistics. For 030, the EU CPI scenario is the same, but as displayed in **Figure 16**, for 2050 there is a concerning difference since the PES is 2.7% larger in the EP CPI scenario than in the EU CPI statistics. Hence, this warranted a further investigation.

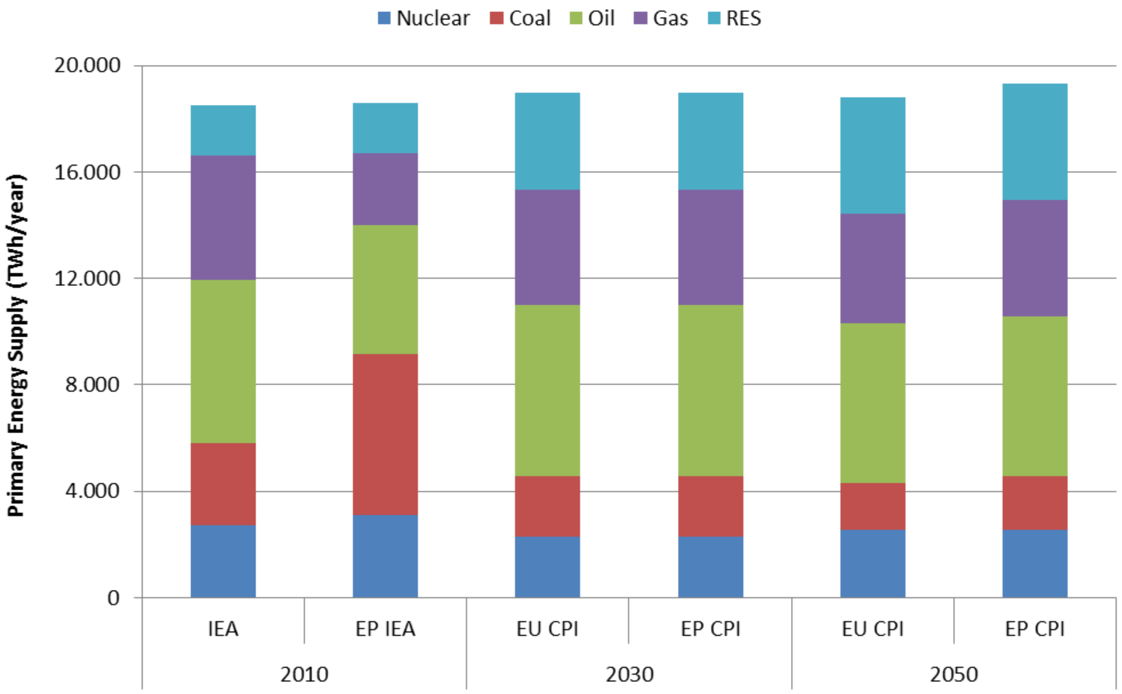

Figure 16: Primary energy supply by fuel in the reference scenarios according to the statistics and the EnergyPLAN models.

From the hourly simulations in the EnergyPLAN tool for the EU CPI scenario, it is evident that the difference in 2050 is most likely caused by the critical excess electricity production (CEEP). CEEP is the amount of intermittent renewable electricity which is produced, but cannot be used for a variety of reasons such as grid stabilisation issues, supply exceeding demand, or a lack of flexibility (demand and supply side) within the energy system. In the 2050 EP CPI simulation, there is approximately 220 TWh of CEEP and no imports required. This outlines the benefits of Energy Plan's hourly modelling, since it indicates that the 2050 EU CPI scenario is not technically feasible unless 220 TWh of CEEP is created: this is approximately 5% of the total electricity production and 20% of total wind production.

Since renewable energy is not providing this electricity in the EP CPI scenario, it must be produced by other power plant units. Based on the assumed power plant efficiency in the analysis of 48.5%, the extra fuel required is approximately 455 TWh (see the 2050 dataset in Annex III). When the relatively small losses created due to pumped hydroelectric energy storage are also considered, then the total additional fuel required from power plants is approximately 484 TWh, which is very similar to the extra fuel demand recorded in the simulation of 510 TWh (see the 2050 dataset in Annex III). The remaining difference of 25 TWh is small enough to be caused by modelling differences. As a result, it seems that the hourly analysis in EnergyPLAN has uncovered some balancing issues in the electricity sector within the EU CPI scenario, so the EU27 energy system could require more flexibility if the intermittent renewable energy targets forecasted are to be realised.

In summary, the 2010 and 2030 EP CPI reference models are very similar to the statistics, with a maximum difference of approximately 0.5%. The 2050 EP CPI reference is different and after analysing the hourly operation of the system, the most likely cause of this is the additional 222 TWh of CEEP in the energy system. This CEEP is most likely due to large amount of non-adjustable base load combined with a large proportion of intermittent renewable energy production in the 2050 EU CPI scenario, but this could not be evaluated in detail in the timeframe of this study. More details about the EP CPI reference models are presented later, when they are compared to the district heating alternatives.

Finally, it is important to recognise the role of the EP CPI reference models created in this section. These simply act as the baseline to which the district heating scenarios are compared and so the district heating alternatives will not benefit from the CEEP differences outlined here. However, to ensure that this is the case, the new district heating alternatives in this pre-study will be modelled in both the historical 2010 energy system as well as the forecasted EU CPI scenarios for 2030 and 2050.

3. HRE SCENARIO FOR 2030 AND 2050

This section contains mainly the mapping of local conditions relevant for the expansion of district heating systems. It ends with the positions used as input to the EnergyPLAN model in the HRE scenario.

3.1 CURRENT DISTRICT HEATING SYSTEMS AND THEIR LOCATIONS

District heating systems can to be found all over Europe today, but levels of expansion differ significantly between EU27 Member States. While occupying dominating national heat market shares between 40-60% in some Scandinavian and Baltic Member States, district heating systems cover currently 12% of the European heat market for buildings in the residential and service sector. The corresponding market share for the industrial sector is about 9% [39]. The European district heating systems have networks containing distribution pipes with a total trench length of almost 200,000 km. Total revenues for heat sold are about €30 billion per year.

Since district heating mainly is an urban occurrence, due to the dependency on concentrated heat demands for feasible heat distribution, it is relevant to express levels of expansion in terms of urban heat market shares. As a European average, district heat constitute about 15% of current urban heat markets, while these fractions can reach as high as above 90% in some cities with mature district heating systems.

The spread and dissemination of European district heating technology can be seen in Figure 17, where each red dot marks a city with at least one district heating system in operation. The map is based on the current content in the Halmstad University District Heating and Cooling Database. Some current numbers from the database are summarised in Table 1. The database is not complete, since about 6000 district heating systems currently operate in Europe, of which 5400 are located within EU27. The deficit consists mainly of small systems in Germany, France and Poland.

This overview shows that it is possible to track NUTS3 regions which have existing experience of district heating systems in operation. An expansion of existing systems in these regions should be possible.

Table 1: Overview of numbers of district heating systems in Europe according to the current content of the Halmstad University DHC database.

	All Europe	EU27	Population concerned within EU27, million	Proportion of population concerned within EU27
Number of systems	4174	3549	60	12%
in cities and towns over 5000 inhabitants	2779	2431		
Number of cities concerned	3482	3070	140	28%
- in cities and towns over 5000 inhabitants	2428	2161		
Number of NUTS3 regions concerned	658	599	287	57%
Total number of NUTS 3 areas	1461	1303	500	100%

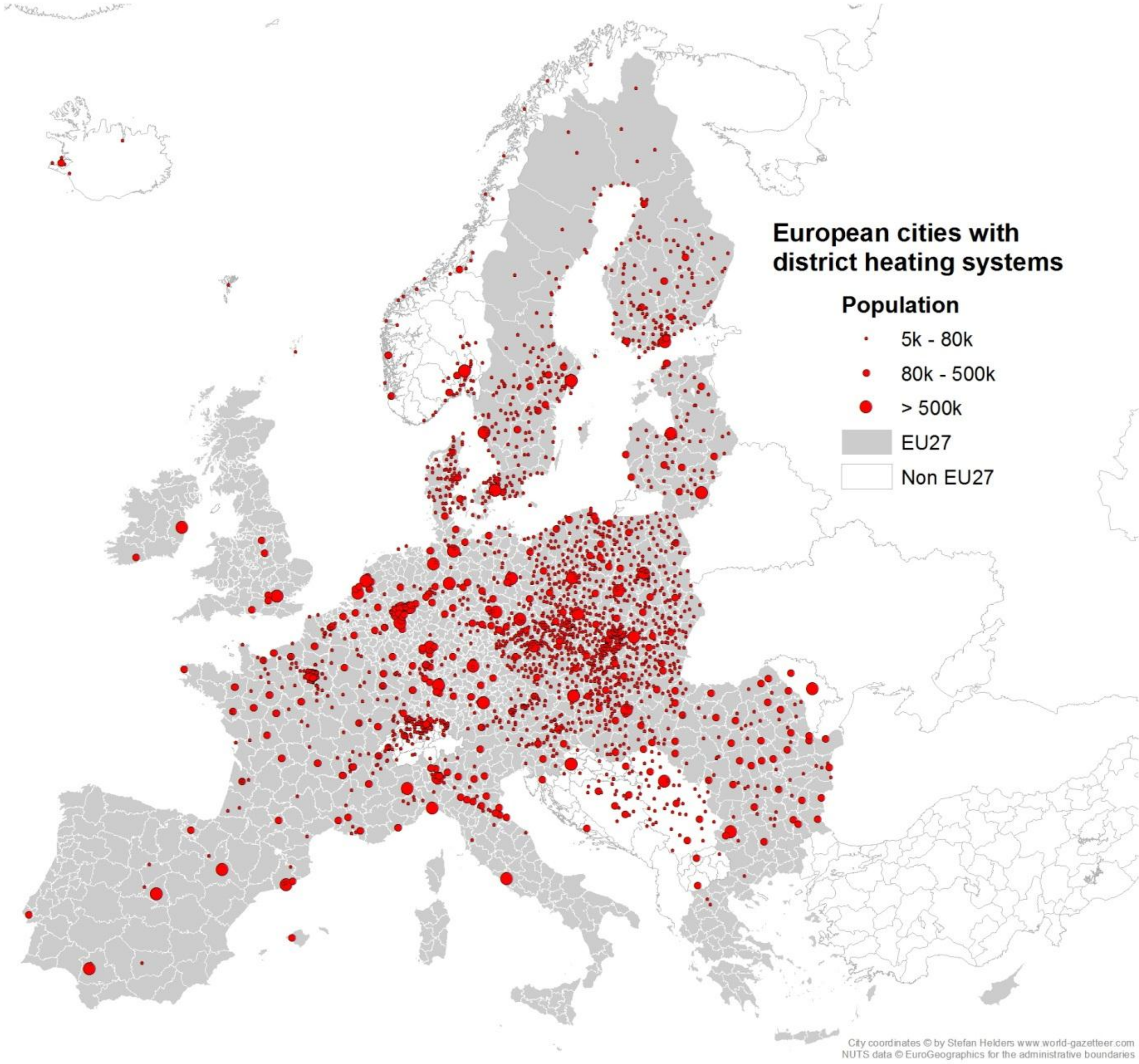

Figure 17: District heating systems in Europe by city size and for cities having more than 5000 inhabitants. The map shows 2428 cities with 2779 systems. Source: Halmstad University DHC Database.

3.2 URBAN AREAS WITH HEAT DEMANDS

A key parameter in the project is to produce reliable assessments of low temperature heat demands for space heating and domestic hot water preparation in each NUTS3 region, since these heat demands constitute the main target for district heat distribution. Low temperature heat demands for space heating and domestic hot water preparation in residential and service sectors can be estimated for each NUTS3 region from average specific heat demands unique for each EU27 Member State, by subsequently relating these to total population counts within each NUTS3 region in respective Member State. To distinguish further the share of NUTS3 region residential and service sector heat demands that constitute a basis for district heat distribution, the project will exploit the features of the European CORINE 2000 GIS database to reveal the concentration of heat demands in urban areas. In this database, the European land area is defined according to different land cover types, and hence, it is possible to identify the proportion of urban areas within each NUTS3 region. An excerpt from this database is presented in Figure 18, showing the land cover types in Belgium. An overview of these proportions is presented in Annex IV in **Figure 38**.

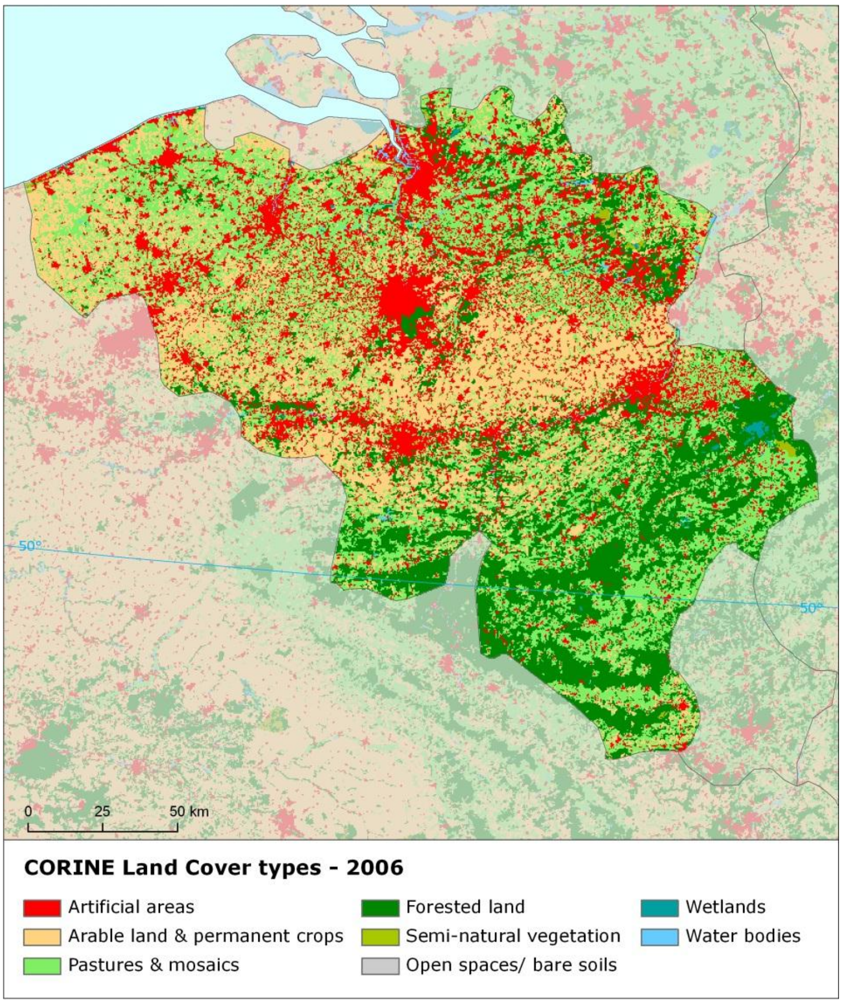

Figure 18: The land cover types for Belgium as an example from the CORINE database.

In 2010, about 73% of all 502 million EU27 residents lived in urban areas, according to United Nations World Urbanization Prospects [37], indicating that the major part of residential and service sector low temperature heat demands are located in urban and city areas. This condition is in itself a strong argument for increased use of district heating in Europe. The forecast for the future indicate further that urban population fractions in EU27 will continue to increase and are estimated to be 75% in 2020 and 84% in 2050. Although, it should be noted that such aggregated estimates for the entire EU27 are to be considered as indicative only. The reason for this being that no harmonised definition of "urban area" currently is available, why Member States employ national definitions.

In the extension of this project, as the results will be disseminated to regional energy planners and local authorities, the features of the European CORINE 2000 GIS database will provide additional benefit. Information on land cover types and - especially - urban tissue distribution will be important when sub-penetrating the NUTS3 region level to out-line feasible distribution distances from available heat sources to existing and future district heating systems. By thus offering spatial guidance and geographical support when identifying and analysing European synergy opportunities and locations, the European CORINE 2000 GIS database constitute a corner-stone in the tool-package of the project. Specific urban areas are also available in the EU Urban Atlas program.

3.3 CURRENT EXCESS AND RENEWABLE HEAT STREAMS BY REGIONS

In the Ecoheatcool study [30], the future possible heat resources from combined heat & power, waste-to-energy, heat recycling of industrial excess heat, geothermal heat, and biomass was quantified on an aggregated level for 32 European countries. Those findings can be summarised as:

- Approximately 17% of all residual heat from thermal power generation was recycled into district heating systems or used directly for industrial demands
- Only 1% of the European biomass potential was used in district heating systems for urban heat demands
- Approximately 7% of the calorific value of non-recycled waste was utilised as heat in district heating systems
- Only 3% of the direct available industrial excess heat was recycled into district heating systems
- Less than 0.001% of the geothermal resources suitable for direct use was utilised in district heating systems

Hence, there is no shortage of available heat resources in short and medium term. The Heat Roadmap Europe project aims at finding the locations for these future heat resources in order to facilitate an expansion of district heating in Europe.

To provide an alternative projection of future European heat supply in contrast to the generic model approach of the *Energy Roadmap 2050*, key parameters to identify in the Heat Roadmap Europe project will be the availability of alternative local heat resources and current excess heat streams. Thus using a bottom-up approach to include local conditions, the project aims at establishing balances between demands (local heat demands in residential and service sectors) and sources (available local excess heat and renewables) in each NUTS3 region.

In combination with spatial information and geographical data for each locality and activity, the project aims at finding regions with exceptional good conditions for establishing new and expanding existing district heating systems. However, the idea of using GIS based spatial planning for finding district heating opportunities is not new. This approach was used in Sweden in 2003 in order to identify more aggregated heat loads for higher utilisation of industrial excess heat and combined heat and power [41]. A similar project in the UK gathered information about industrial heat loads [42]. The knowledge gained in that project is now available as interactive Internet maps for the CHP development [43] and the recently released National Heat Map [44]. A similar approach has also been used to give an overview of the European power plant infrastructure [45]. Hence, both information availabilities and presentation methods have made it possible to leave national energy balances in favour of local energy balances in future energy modelling.

Current excess and renewable heat streams are found mainly in thermal power generation, waste-to-energy incineration facilities, energy intensive industrial processes, geothermal fields, biomass availabilities, and annual solar irradiancies. An overview is given below with respect to available information sources about their locations with respect to NUTS3 regions.

3.3.1 COMBINED HEAT AND POWER

The possibility of combined heat and power is based on the need of thermal power generation in the European power balance. Recycling of heat from these plants will reduce their heat losses to the environment and substitute the current use of fossil fuels for space heating and hot water preparation in buildings. The locations of major thermal power stations using fuel combustion are presented in Annex IV in **Figure 40**. However, many of these installations already operate as combined heat and power plants.

3.3.2 WASTE-TO-ENERGY (WTE)

Waste incineration with energy recovery belongs to the fourth recovery step of the waste management hierarchy after prevention, re-use, and recycling in the Waste Framework Directive. The primary purpose with waste incineration is to avoid the environmental problems associated with landfills, the fifth and final step in the waste management hierarchy. As presented in **Figure 19**, the use of landfills is still very extensive for municipal solid waste in many EU Member States, since 92 million tonnes of municipal solid waste reached landfills during 2010 according to [46]. Also industrial waste streams are available for waste incineration. Less than half of the current waste supplied to the Swedish WTE plants is municipal solid waste.

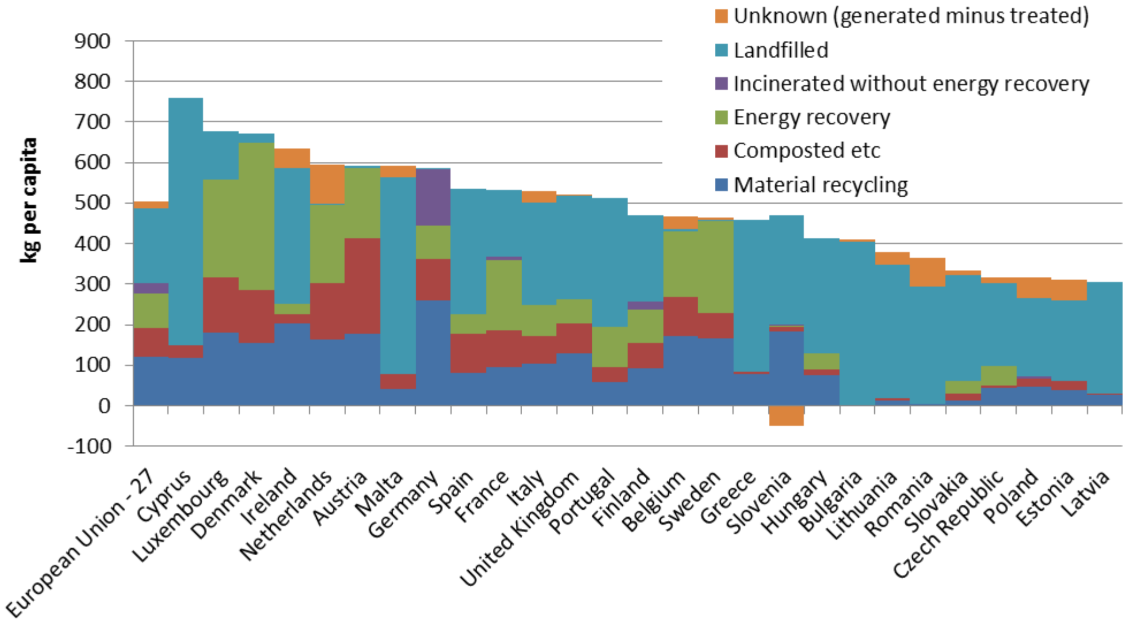

Figure 19: Distribution of municipal solid waste treatment in EU27 Member States during 2010 according to the waste hierarchy order categories. Source: [46].

The locations of the 414 WTE plants currently operating within EU27 are presented in Annex IV in **Figure 41**. These plants receive about 65 million tonnes of waste per year, representing a calorific heat value of between 180 and 200 TWh. Currently, less than half of this calorific heat value is recovered as electricity and heat. During 2009, only 45 TWh heat was recycled from these European WTE plants according to the Eurostat heat balance.

Hence, more heat can be recycled from WTE plants, both from better utilisation of existing plants and establishment of new WTE plants.

3.3.3 INDUSTRIAL EXCESS HEAT

Industrial excess heat is normally recycled from five typical energy intensive industrial sub-sectors (chemical/petrochemical; iron and steel; non-ferrous metals; non-metallic minerals; and pulp and paper production) and oil refineries. Current recycling of industrial excess heat is difficult to discover since it is not reported in international energy statistics. The only bodies that report these heat streams are national district heating associations gathering own national statistics. An overview of these heat streams is presented in [39] for 2008: 0.3 TWh in France, 4.9 TWh in Sweden, 0.8 TWh in Denmark, 0.9 TWh in Germany, and 0.03 TWh in Italy. These volumes add up to 6.9 TWh for the whole EU27. But this estimation is probably an underestimation, since the situation in many other countries is unknown.

The locations for major industrial plants having excess heat are presented in Annex IV in Figure 42. Many of these plants are located near to urban areas giving the possibility of transferring the excess heat to heat consumers in district heating systems.

3.3.4 GEOTHERMAL HEAT

European Geothermal Energy Council (EGEC) reported recently [47] that 212 district heating systems in Europe use partly input from geothermal heat. According to Eurostat energy statistics, systems in Belgium, Denmark, Germany, Lithuania, Hungary, Austria, and Slovakia utilised 0.7 TWh during 2009. But systems also appear in France, Poland, Romania, and United Kingdom. The French systems used 0.8 TWh during 2009 according the national SNCU statistics. About thirty of them are situated in the Paris region. New major geothermal projects are implemented in Paris in France, Den Haag in Netherlands, and Vienna in Austria. EGEC foresees an expansion in many countries until 2014 according to Figure 20.

The geothermal conditions vary by location in Europe. The estimated temperatures at a depth of 2000 metres are presented by NUTS3 region in Annex IV in Figure 43. By joining population statistics with Figure 43, we can conclude that 4 % of the EU27 population live in NUTS3 regions with geothermal temperatures above 200ºC. The corresponding population proportions are 8 % for temperatures between 100 and 200ºC and 19% for temperatures between 60 and 100ºC. With an urban population of 73%, the proportion of the EU27 population that can be reached with a geothermal district heating systems is about 26%. These areas include major cities as Aalborg, Hamburg, Berlin, Munich, Frankfurt am Main, Hanover, Stuttgart, Groningen, Amsterdam, Rotterdam, Paris, Lyon, Strasbourg, Madrid, Barcelona, Budapest, and Bratislava.

3.3.5 BIOMASS

Biomass is currently used as original energy source in many European district heating systems. Fuel sources are mainly forestry and agricultural waste. According to the Eurostat heat balance for 2009, 67 TWh heat with biomass origin was supplied into district heating systems. Sweden had a lead position with an input of 24 TWh, while other significant supply appeared in Austria, Denmark, and Finland.

The long term demand of biomass for pulp & paper and other community resource demands will certainly be serious competitors for the overall biomass resource. However, in typical forestry areas, the availability of forestry wood waste can be sufficient for local district heating systems. A map-based overview of the European forestry areas is presented in Annex IV in **Figure 44**.

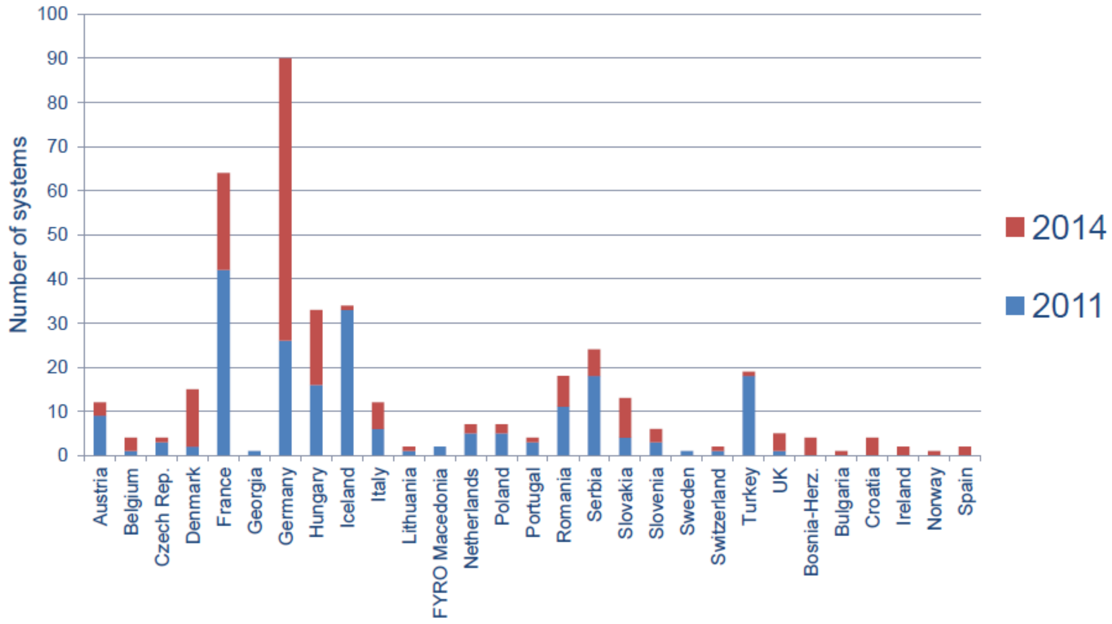

Figure 20: Number of geothermal district heating systems in Europe by country: Firstly as existing systems in 2011 and secondly as planned additions for 2014. Source: [47].

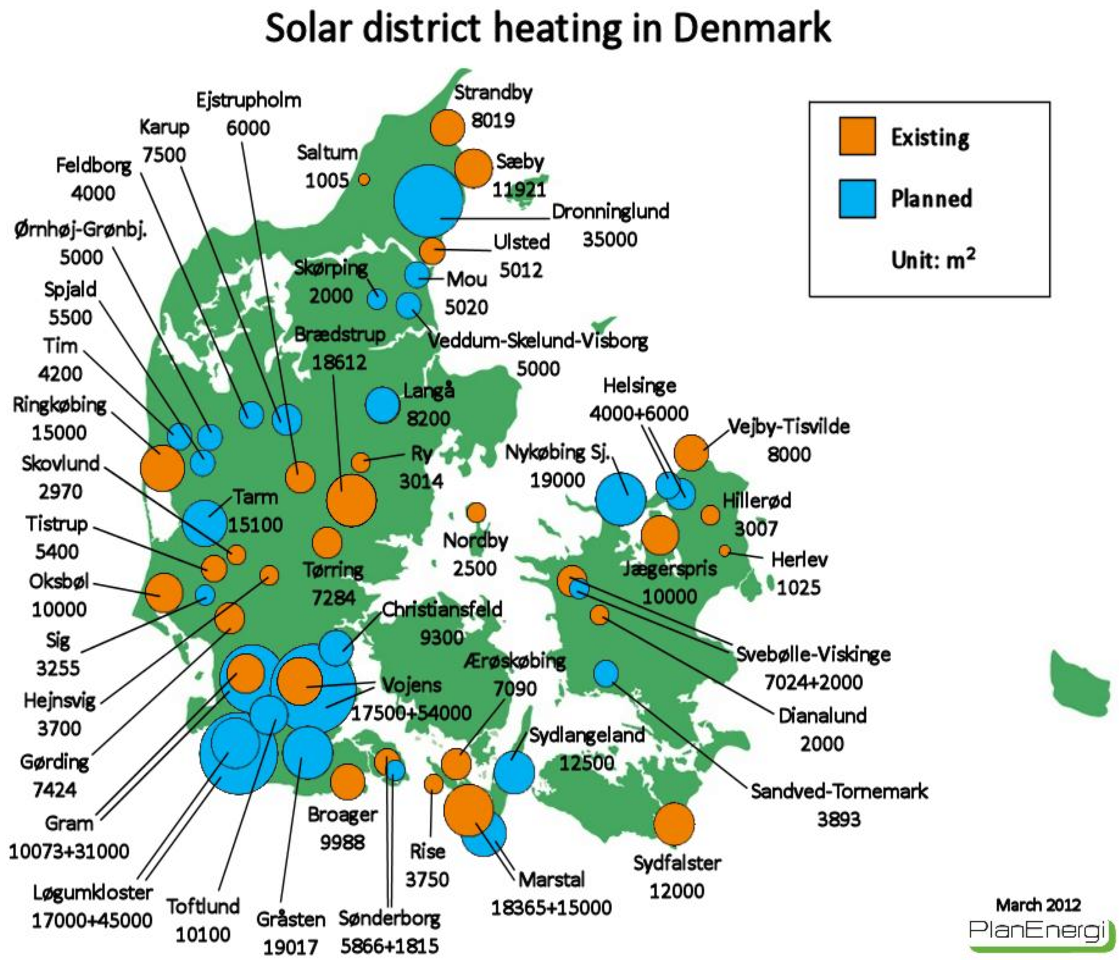

Figure 21: Overview of existing and planned solar collector fields connected to district heating systems in Denmark. Source: PlanEnergi.

3.3.6 SOLAR HEAT

Some solar thermal installations in conjunction to district heating systems appear in Denmark, Germany, Austria, and Sweden. Denmark had a lead position with a solar heat supply of 0.03 TWh during 2009 according to the Eurostat heat balance. Denmark has also seen an increasing interest in more installations according to Figure 21. This large Danish interest has given lower installations cost for large solar collector fields, giving the possibility for other countries to benefit from this trend.

The regional conditions for solar district heating depends on the location in Europe, since the global solar irradiation is about twice in Southern Europe compared to Northern Europe. The global irradiation for optimal angle by NUTS3 region is presented in Annex IV in Figure 45.

3.3.7 CONCLUSION WITH RESPECT TO AVAILABLE LOCAL HEAT RESOURCES

The main conclusion from this sub-section is that it should be possible to gather a future matrix of various local heat resources as columns and NUTS3 regions as rows from available information sources. Hereby, the local conditions for expansion of district heating can be estimated for each NUTS3 region with respect to heat sources.

3.4 POSSIBLE EXTENSIONS OF DISTRICT HEATING SYSTEMS

As presented in Figure 17, district heating is widely used in Europe today, although typically at moderate expansion levels. But, the wide presence of district heating systems today acts in favour of future extensions of existing systems, since it is a greater leap to introduce a completely new technology than it is to extend and expand an existing one. Technology know-how, component manufacturers, and business models are already present in many EU27 Member States, why possible extensions of current district heating systems are to be considered achievable from a pure practical point of view.

Additionally, from an economic point of view, it has been established in a recent work [38] that urban district heating can threefold at competitive and directly feasible conditions from current urban heat market shares of approximately 20% up to market shares of 60%! In this work, focusing on city areas in France, Germany, the Netherlands, and Belgium, the current average urban district heating heat market share (21%) was slightly higher than the EU27 average (15%), indicating that average European extension possibilities are greater still. The main study result from [38] is depicted in **Figure 22**, where it can be seen that beneficial extension possibilities up to 60% urban district heating heat market shares are equally present in all four studied Member States. This high level of district heating extension further corresponds to a marginal distribution capital costs of only 2.1 €/GJ (7.6 €/MWh).

One of several important aspects of the methodology in [38] is that it utilises local conditions, e.g. population and heat densities on sub-city levels, to produce the resulting estimates of specific investment costs for district heat distribution. By this methodology feature, high resolution modelling of feasible extensions or new establishments of district heating systems can be performed for unique city districts, where the concentration of residential and service sector heat demands are taken into account for each assessment.

In conjunction with information from the Eurostat Urban Audit, the European CORINE 2000 GIS database (mentioned in section 3.2), and other relevant data sources, modelling of specific investment costs for district heating systems are made possible by this methodology.

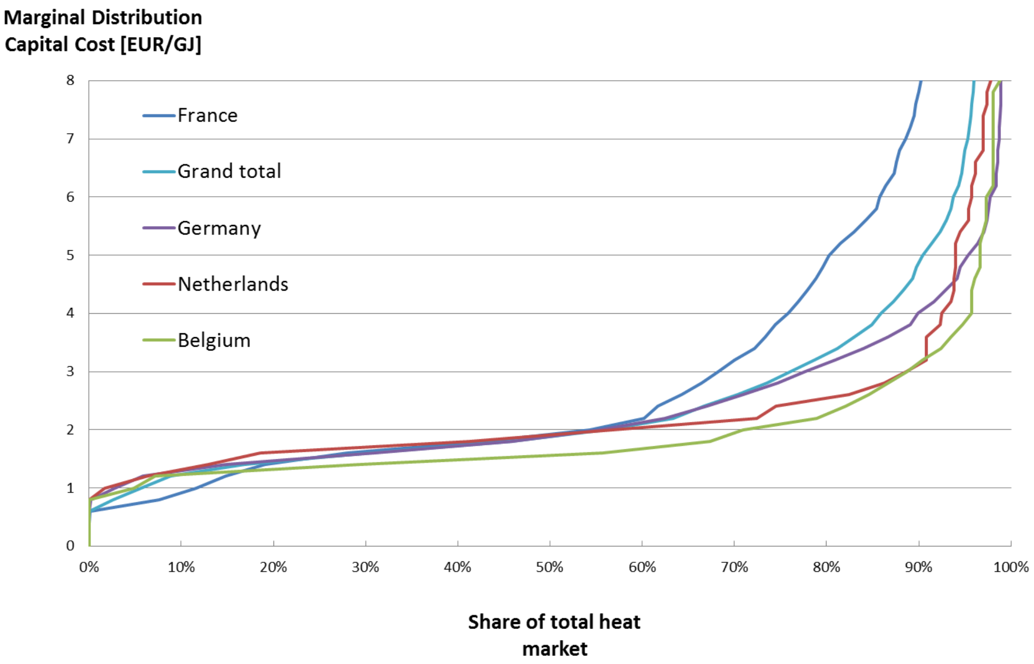

Figure 22: Current marginal distribution capital cost levels and corresponding urban district heating heat market shares in four studied European countries in 2008 [38].

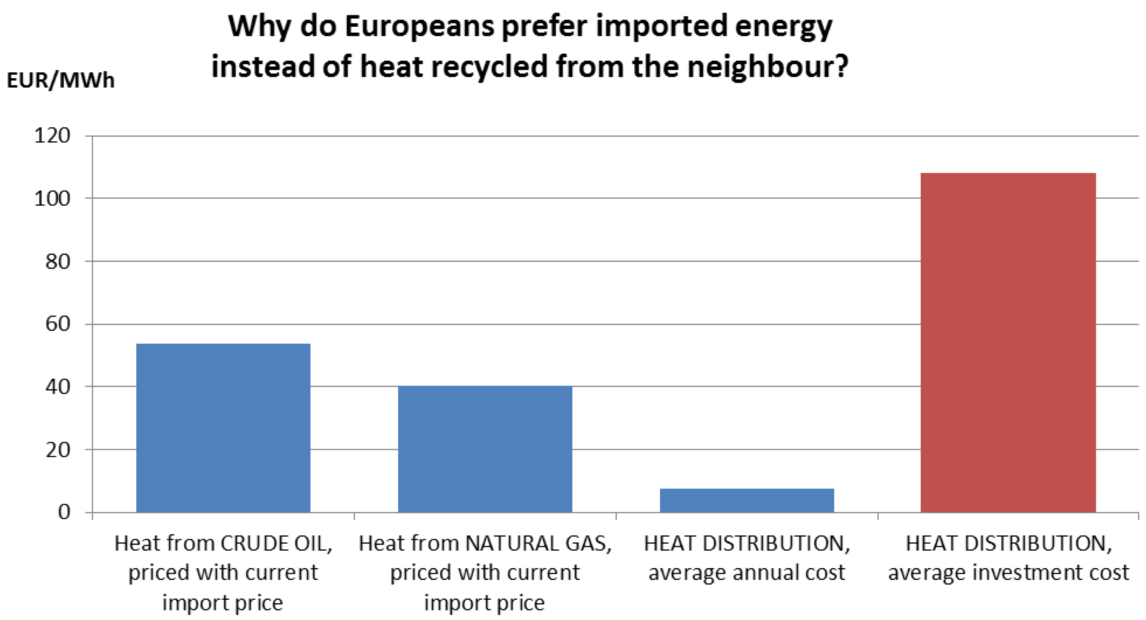

Figure 23: The simple socio-economic comparison between current import prices of fossil fuels and the heat distribution cost for connecting heat surpluses with heat demands. Current import price of crude oil has been set to 110 US$ per barrel.

It is worthwhile to linger for a moment on the suggested average annual cost of 2.1 €/GJ (7.6 €/MWh) for feasible and competitive urban district heat distribution from this work. This specific investment cost represents a high level of European district heating extension and it can be compared to the current cost of heat from oil and natural gas. Given the current crude oil price for import to EU27 (April 2012) of 110 US$/barrel, the corresponding heat costs for imported crude oil and natural gas are presented in Figure 23. These import costs are substituted, when heat are recycled into district heating systems. The annual average cost for heat distribution according to [38] is included as the third bar in Figure 23. Hence, this cost for connecting heat sources with heat demands is much lower than the substituted costs, giving a very profitable situation. When comparing the investment cost for heat distribution with the substituted costs, the socio-economic payback becomes only 2-3 years.

3.5 MOST PROMISING NUTS3 REGIONS (HOT SPOTS)

The main objective in the full Heat Roadmap Europe project will be to outline and map synergy opportunities within the European NUTS3 regions with respect to local heat resources and excess heat recovery in district heating systems. In essence, this objective will be pursued by combining data on current district heating systems and available heat resources with low temperature heat demands in residential and service sectors, hereby identifying European heat 'hot spots' for further analysis and evaluation. The key questions to be answered in this analysis are:

- Which European NUTS3 regions or agglomerations of NUTS3 regions have large volumes of low temperature heat demands in residential and service sectors?
- Which European NUTS3 regions or agglomerations of NUTS3 regions have large volumes of excess heat and local heat resources?
- At acceptable investment cost levels for district heating systems, how much excess heat and local heat resources in identified NUTS3 regions will be recoverable and possible to utilise?
- What is the magnitude of fossil fuel substitution by this excess heat recovery and local heat resource utilisation, and what are the resulting reductions in greenhouse gas emissions

Several methodology issues are present in this part of the project and initial pre-study work has been to define the concept of excess heat hot spots. A first step was to establish a straight forward ratio concept describing the fraction of existing excess heat in a NUTS3 region by the total volume of residential and service sectors low temperature heat demands in this NUTS3 region:

$$Excess\ heat\ ratio\ = \frac{Existing\ excess\ heat}{Low\ temperature\ heat\ demands}$$

In the planned full project, existing excess heat, including excess heat from large combustion installations, waste-to-energy facilities, and energy intensive industrial activities (including fuel supply and refineries), is thought to be divided by all low temperature heat demands for space and tap water heating in any given NUTS3 region to produce the excess heat ratio. Since, during the pre-study, not all collected input data from these activities were found reliable, the excess heat ratio map in Figure 24 is established on the basis of excess heat from energy intensive industrial activities only (including fuel supply and refineries). As an example still, this map shows that excess heat ratios within the 1303 EU27 NUTS3 regions very well may escalate beyond one and above, indicating that existing volumes of industrial excess heat are larger than total volumes of low temperature heat demands in residential and service sectors.

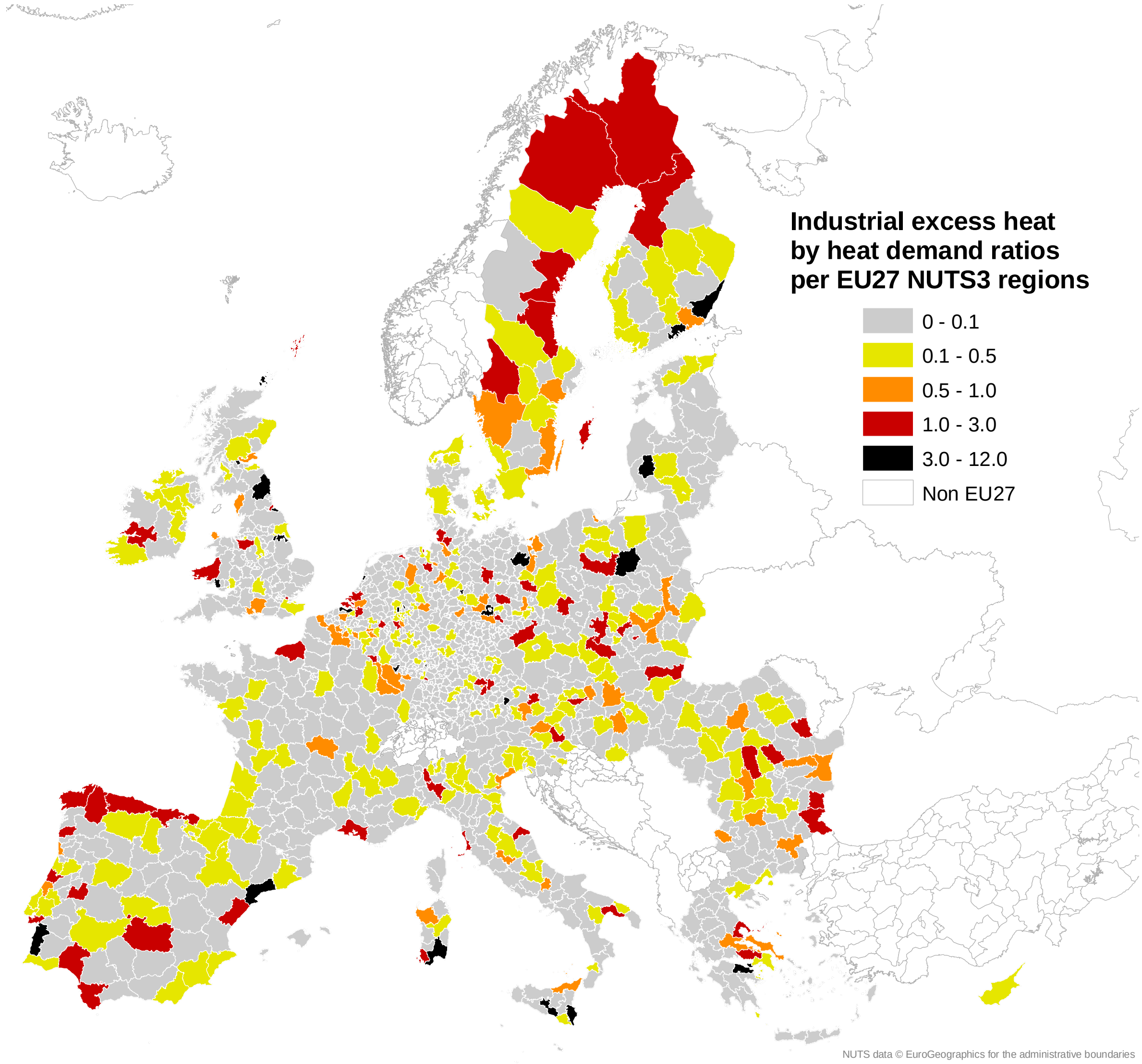

Figure 24: NUTS3 regions with respect to industrial excess heat by heat demand ratios.

But, by this concept design no distinction is made regarding the actual magnitude of neither existing excess heat nor low temperature heat demands. Hence, the excess heat ratio may reach high values in sparsely populated areas where only moderate volumes of existing excess heat are present. Since the main purpose by using the excess heat ratio is to identify densely populated areas with existing and available excess heat, the pre-study work has subsequently continued by developing and analysing measures by which the excess heat ratio concept can be adjusted to take into account the population and heat density of each NUTS3 region.

In this continued work, an excess heat hot spot has been defined as an area in which favourable conditions for the establishment of district heating may exist: adequate heat demands, low investment costs in infrastructure as well as sufficient heat potentials from waste incineration, thermal power plants, and industry. An excess heat hot spot is furthermore defined by its neighbourhood and how well neighbouring areas are suitable as heat sources or sinks to be connected with each other. Hence, the clustering of similar NUTS3 regions as well as the distance-defined characteristics of large-scale district heat developments has to be included in an excess heat hot spot analysis.

A second analysis for further reference thus charts the density of urban areas as a general measure of agglomerated heat markets. Using the European CORINE 2000 GIS database data of the urban tissue, a continuous density map has been prepared using a Kernel function (which includes a weight proportional to the square root of distance) and the ground area of CORINE 2000 polygons weighted with a factor 1.5 for dense, continuous urban areas, and 0.5 for industrial areas compared to non-continuous urban areas. A search radius of 50 km has been applied, in which all weighted areas are summarised. The resulting map, see Figure 25, shows areas with a density above what has been assumed a suitable threshold. It becomes imminent how urban areas are interconnected in Europe.

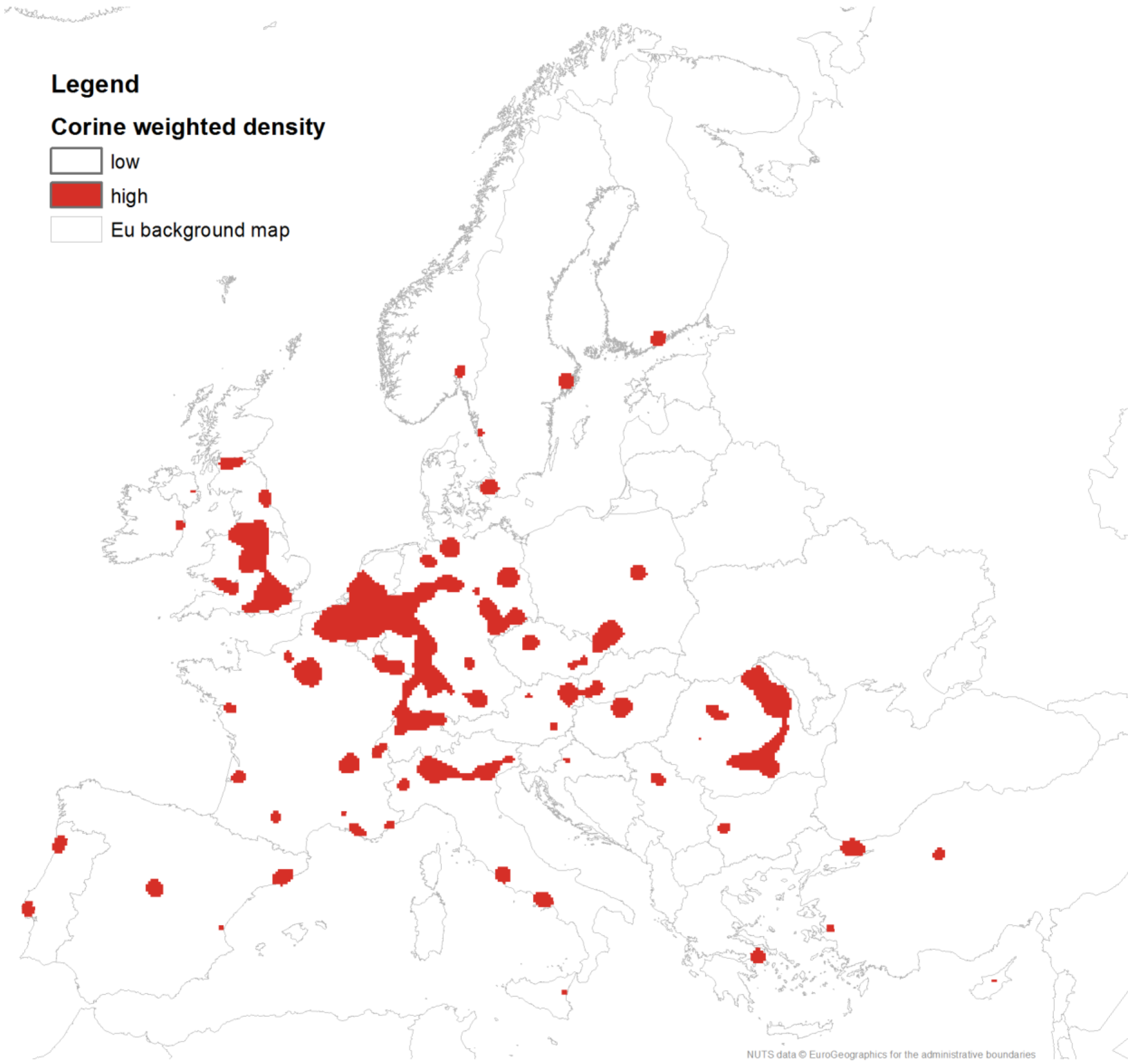

Figure 25: Weighted Kernel density of urban areas by CORINE 2000 polygons. The high density areas are likely candidates for district heating regardless heat demand or supply.

In this pre-study, an analysis was also carried out as an experiment to chart areas in Europe which may be excess heat hot spots for activities aiming at the development of district heating. First a series of spatial statistics was carried out for the mapping of conditions for district heating on the NUTS3 region level mentioned above. Using the Anselin Local Moran's I (pronounced as the letter i) method, using heat demand density as a set of weighted features, statistically significant "hot spots", "cold spots", and spatial outliers were found. The analysis was performed for a fixed distance of 50 km, and resulted in the identification of areas where the surrounding NUTS3 regions have similar heat density values (either high values or low values). The resulting map can be seen in Figure 26. Some few interesting areas can be identified around the bigger cities of England, some highly populated areas of Germany, and in Paris and its neighbourhood, as well as Copenhagen. It shows that the method is highly sensitive to the size of NUTS3 regions.

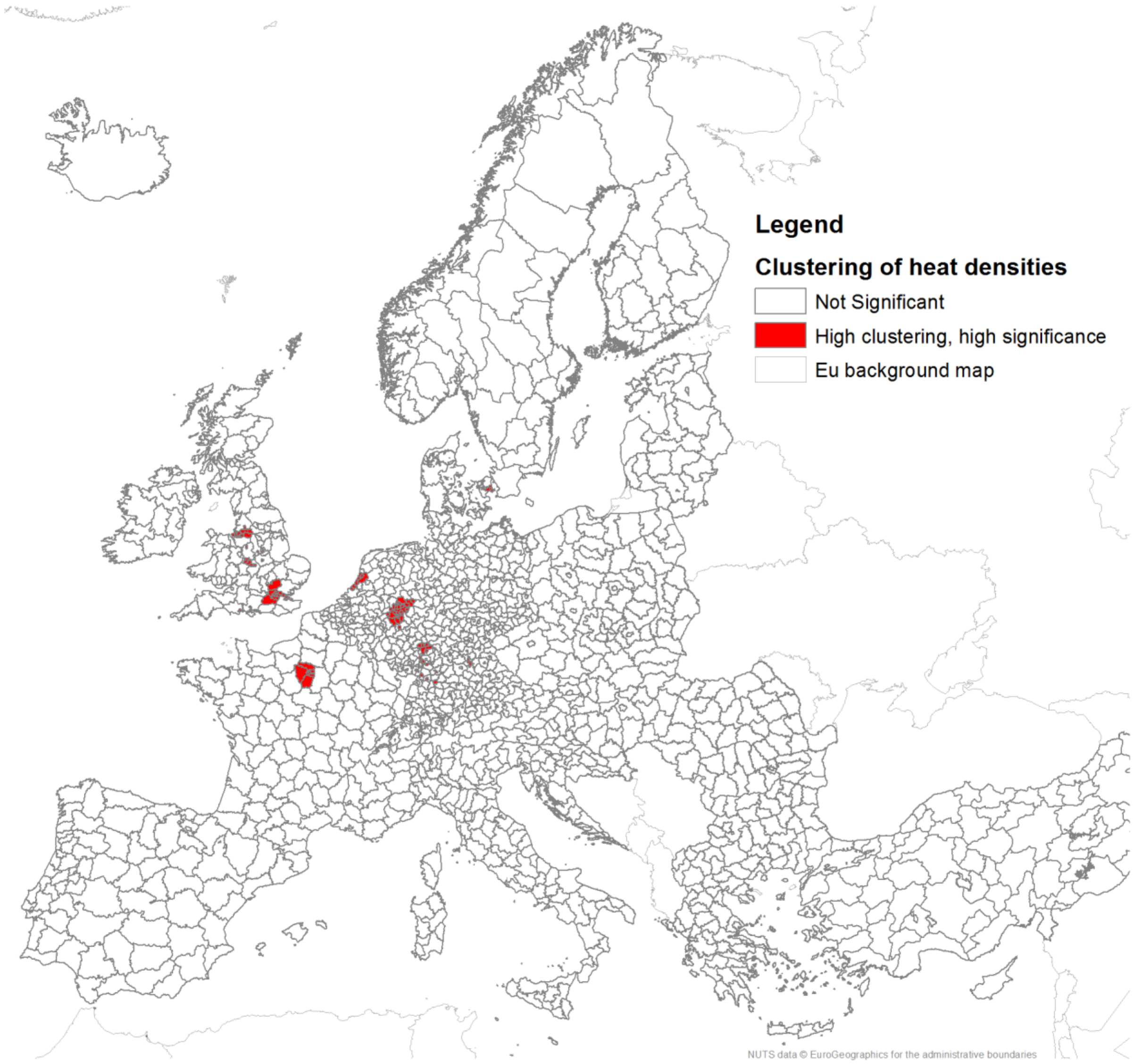

Figure 26: A cluster analysis using the Anselin Local Moran's I method with a fixed distance of 50 km reveals areas with similarly high heat demand densities, which form clusters of statistical significance around a few high density areas.

A similar analysis to identify clusters of NUTS3 regions with similar heat demand densities is the Getis-Ord Gi* (pronounced G-i-star) method for excess heat hot spot analysis. This method may tell where features with either high or low values of heat demand cluster spatially, i.e. where there are similar conditions for the development of district heating. As statistically significant hot spots, those areas are identified where features will have a high value and be surrounded by other features with high values as well. The Getis-Ord Gi* tool returns a chart, Figure 27, which shows a more differentiated picture than by cluster analysis, in which also the neighbouring NUTS3 regions are included. The hot spots found are basically the same.

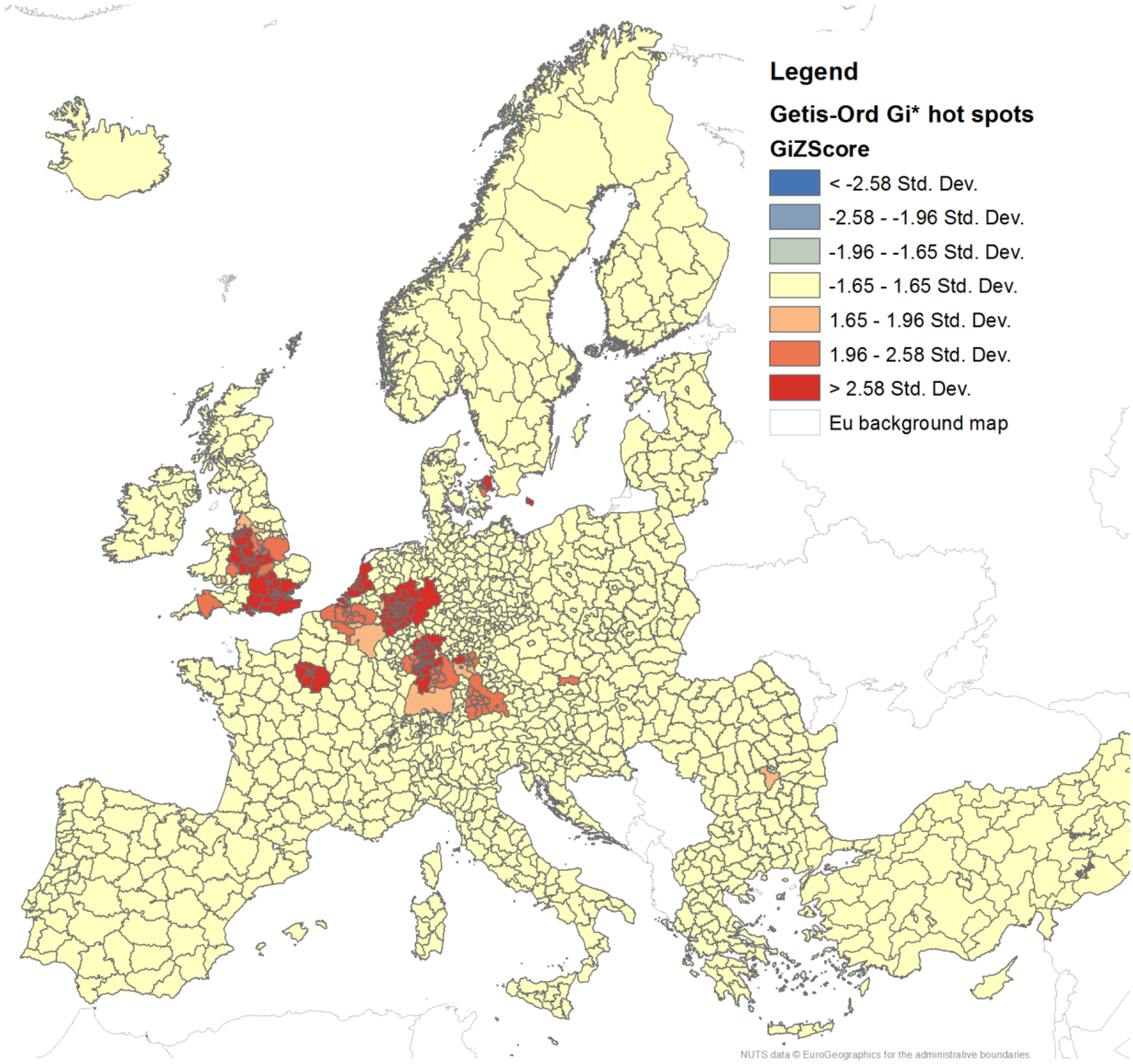

Figure 27: The Getis-Ord Gi* hot spot analysis reveals a similar but more differentiated picture of hot spots based on the heat demand density of NUTS3 regions.

Multi-criteria models offer a different type of analysis where a series of input criteria are based on scaled and graded measures, which individually describe suitability. The criteria are weighted into a composite suitability map, which then contains the weighted criteria. This way a series of parameters can be included in a suitability map, which otherwise are difficult to compare in a quantitative manner.

It was assumed that for the successful installation of a district heating system, four conditions must be met to a certain degree: sufficient heat demand density; sufficient heat supply including excess heat, geothermal or solar heat; as well as an adequate agglomeration of similar areas in clusters.

The resulting map, see Figure 28, is highly sensitive to the chosen scaling and weighting, hence subject to debate and further analysis. Multi-criteria modelling allows for highly complex representations of the input parameters to such analysis and is a powerful tool for the exploration of likely district heating areas. It may be combined with economic and energy system data for increased credibility.

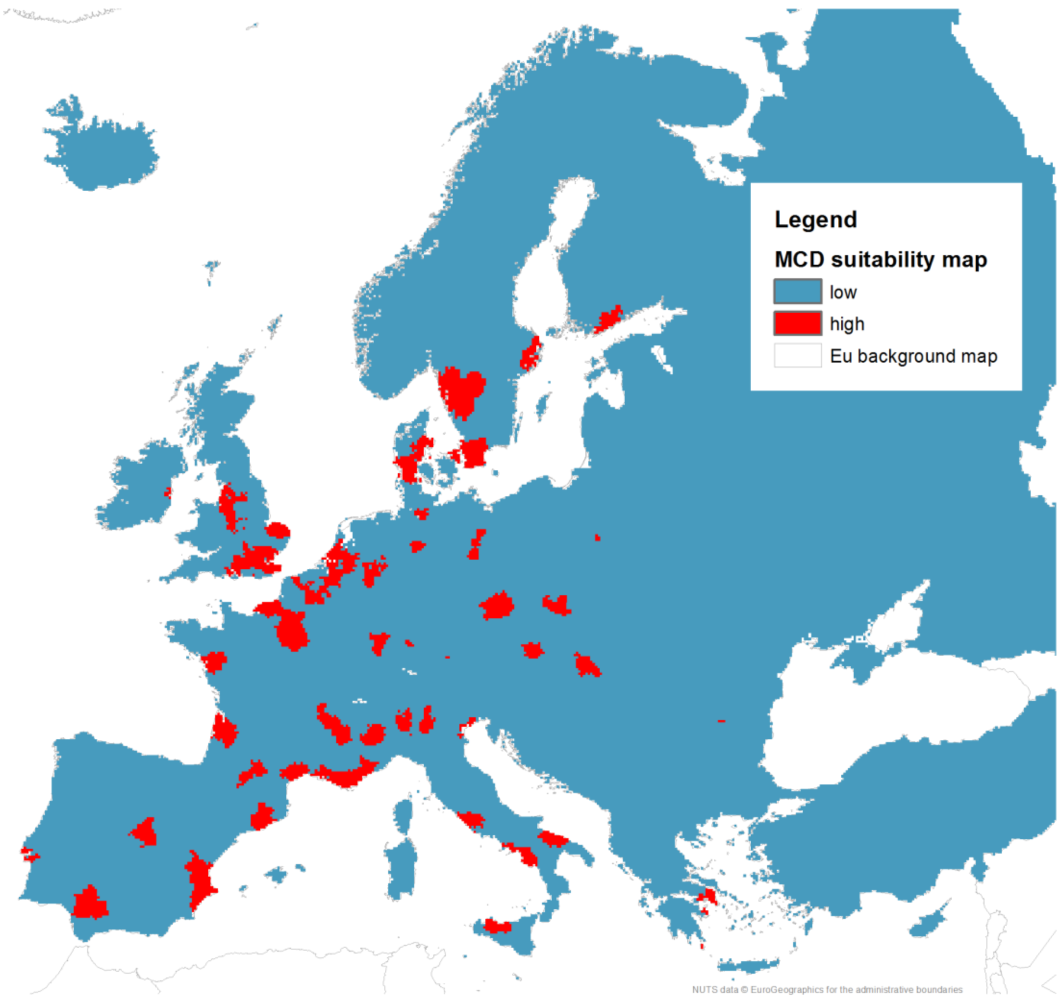

Figure 28: A sample of a hot spot analysis by means of multi-criteria modelling, which includes urban tissue, heat density, Getis-Ord Gi* "hot spot" z-score, industrial excess heat, geothermal potential as well as solar heating potential.

To conclude, the pre-study work has considered several methods by which to identify and evaluate NUTS3 regions as excess heat hot spots for future district heating developments. Although the pre-study was not able to collect all input data to complete such analysis with the required degree of detail and credibility at this stage, the work has resulted in an exploration of methods to be used in the subsequent full excess heat hot spot analysis. In short, the methodological sequence to identify beneficial NUTS3 regions where heat synergy opportunities are present and favourable, consist of the following steps:

- Identification of NUTS3 region excess heat hot spots by use of excess heat ratios, weighted by e.g. population and heat densities and supported by multi-criteria modelling and CORINE 2000 urban tissue information
- In-depth analyses of identified NUTS3 excess heat hot spot regions to locate low temperature heat demand concentrations and assess distances to available excess heat sources and local heat resources
- Estimations of investment costs for extensions of present and/or establishment of new district heating systems that will utilise available excess heat sources and local heat resources for heat distribution to residential and service sector buildings
- Quantification of possible excess heat recovery and local heat resource utilisation by NUTS3 regions, and magnitude estimates of substituted fossil fuels currently used for heating purposes per NUTS3 region.

3.6 THE MAIN ALTERATION OF THE HRE SCENARIO COMPARED TO THE EU CPI SCENARIO

The amounts of heat delivered for end use in the two scenarios analysed are presented in Figure 29. The main alteration in the HRE scenario is the amounts of heat delivered to buildings, since the deliveries to industrial purposes is the same. The assumed market shares for district heating were set to 30% in 2030 and 50% in 2050. The assumptions were based on indications from the mapping part previously presented in this section.

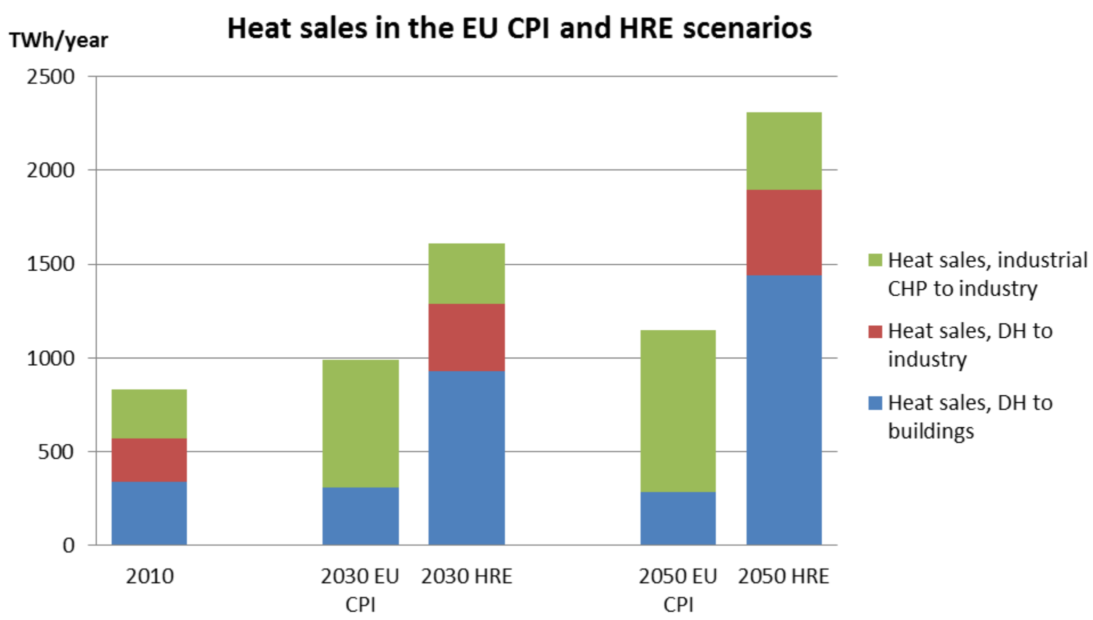

Figure 29: Estimated heat sales in the Heat Roadmap Europe scenario compared to the EU CPI scenario.

4. ENERGY SYSTEM ANALYSIS OF THE HRE SCENARIO

The district heating alternatives relate to the residential and services sectors only, which means they require the replacement of conventional boilers with district heating. Based on the analysis in section 3, two district heating alternatives were considered: one where district heating represents 30% of the heat demand in the residential and services sectors and another where is represents 50%. Both of these scenarios were modelled in the 2010 reference scenario, while in the forecasted EU CPI scenarios, it was assumed that there would be 30% district heating in 2030 and 50% in 2050.

Since district heating will replace urban boilers, it was assumed that the district heating would replace oil, gas, and coal boilers based on the proportion of the heat demand they served in the IEA 2010 reference. Biomass boilers were not replaced since they are typically outside the reach of district heating and since biomass replaced by district heating may again be used to replace oil and natural gas in other buildings. Moreover no changes have been made to electric heating.

The production of district heating will come partly from existing power and CHP plants assuming an average efficiency in the present situation of 32% electric and 52% thermal output and partly from new Combined Cycle CHP plants with an efficiency of 47% electric and 44% thermal output. The CC plants will burn natural gas equivalent to the oil and gas saved in the individual boilers being replaced.

The CHP and boiler capacities are increased in the alternatives until the system operates in a similar way to the operation to the current system. In numerical terms, this means the CHP capacity was adjusted until the peak boilers provided approximately 9-13% of the heat demand. Note that in the 50% district heating alternative, this means that a small share of large-scale heat pumps has to be added in order to be able to balance the electricity supply. The boiler capacity was assumed to be 20% larger than the maximum heat demand and the thermal storage capacity was assumed to equal eight days of average district heating consumption.

Moreover the new CHP plants will be able to replace future power stations. The systems have been adjusted so that the reserve power capacity in all systems will be 30% additional to the peak production on the power plants.

Using the hourly EnergyPLAN reference models (and not the data from the statistics) discussed in section 2, the district heating alternatives outlined in section 3, and these assumptions, the implications of district heating are quantified here in terms of PES and carbon dioxide emissions.

4.1 DISTRICT HEATING IN 2010

In this section, the implications of district heating are quantified for the IEA 2010 reference scenario with 30% and 50% district heating in the residential and service sectors. The benefits are illustrated in two steps. Step 1 shows the potential energy efficiency improvements connected to CHP while step 2 shows the additional potential of increasing the use of industrial waste heat, waste incineration, geothermal and solar thermal resources. The idea of these assumptions is to illustrate the potential energy efficiency improvements using the same amounts of biomass as well as oil plus natural gas.

The results for step 1 are illustrated in Figure 30. As can be seen the expansion of district heating and CHP will be able to decrease the fuel consumption for heating the buildings in Europe substantially. Today 12% is district heating consuming a little less than 250 TWh/year of fuels while the remaining individual boilers consume around 3,100 TWh/year. The total of approximately 3,350 TWh/year will decrease by 40% to around 2,000 TWh/year. The fuel used by the boilers to be replaced by district heating if expanded to 50%, is today approximately 1,550 TWh/year of coal, oil and natural gas. In a system with District heating and CHP the fuel consumption of the total system will be decreased by 1,300 TWh/year meaning that the same heating can be provided with a use of only net 250 TWh/year of fuel. The net use of 250 TWh/year requires the following changes to the system: Fuel for CHP is increased in existing systems by 1,360 TWh/year and in new CC-CHP systems by 1,560 TWh/year while the electricity from the CHP plants replace production on the power plants of 2,670 TWh/year. In the power and CHP plants the burning of natural gas is increased by net 1,460 TWh/year equivalents to the oil and gas saved in the individual boilers while the net influence on the use of coal is a decrease of 1,210 TWh/year.

In total the expansion of district heating will decrease the European primary energy consumption by 7%, fossil fuels by 9% and the carbon dioxide emission by 13% supplying exactly the same energy services as illustrated in **Figure 31**.

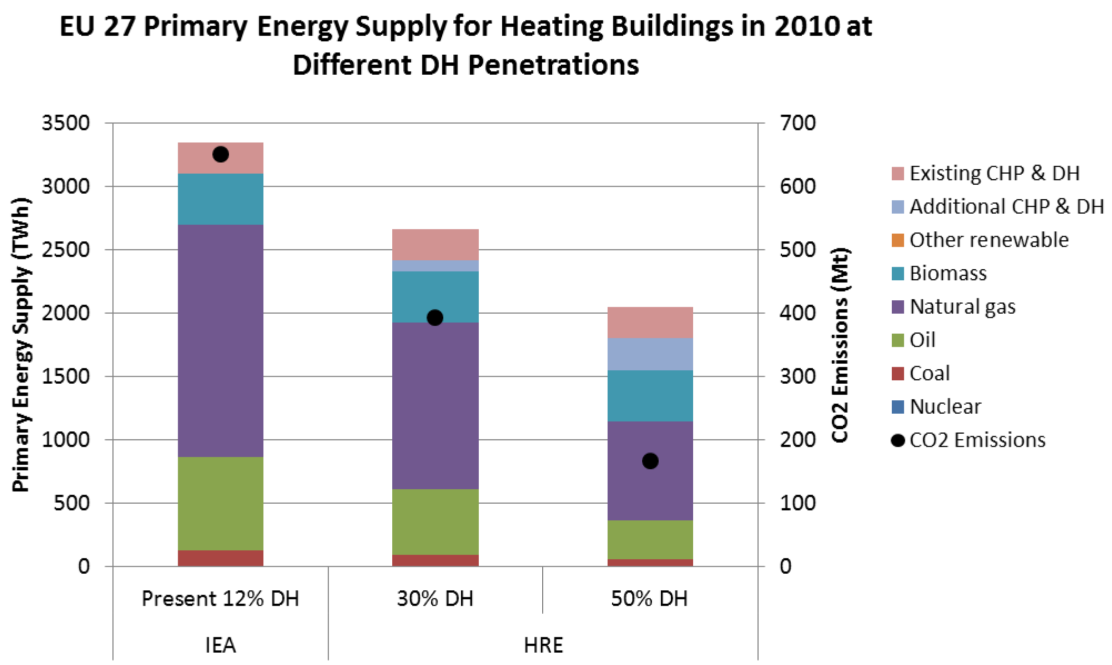

Figure 30: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010 EU27 energy system at present and if district heating and CHP were expanded to 30% or 50%.

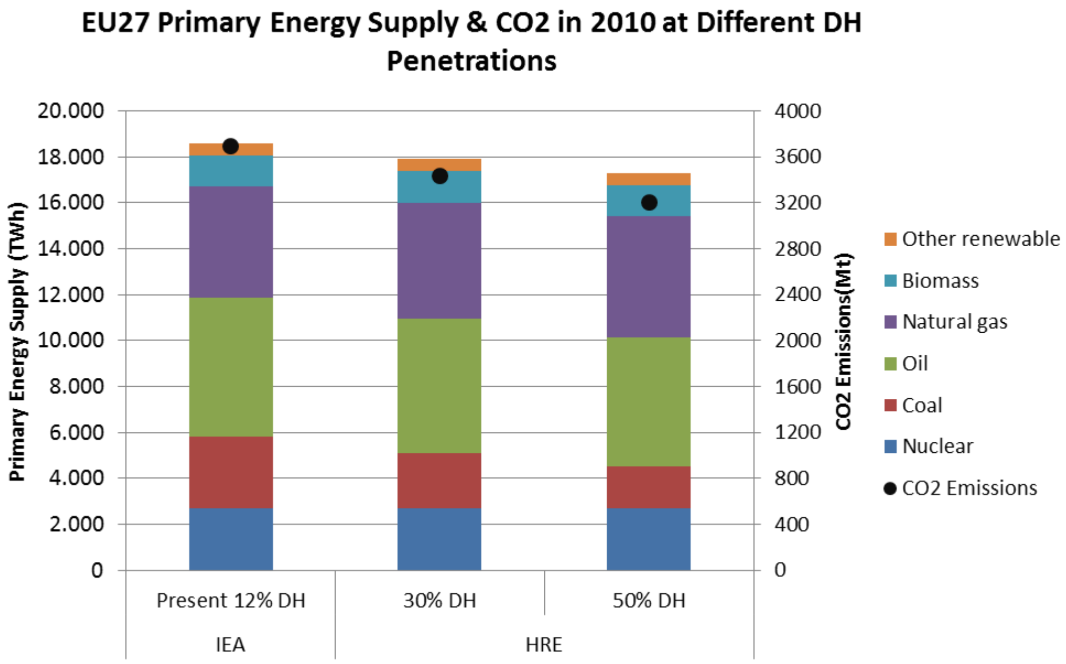

Figure 31: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010 at present and if district heating and CHP were expanded to 30% or 50%.

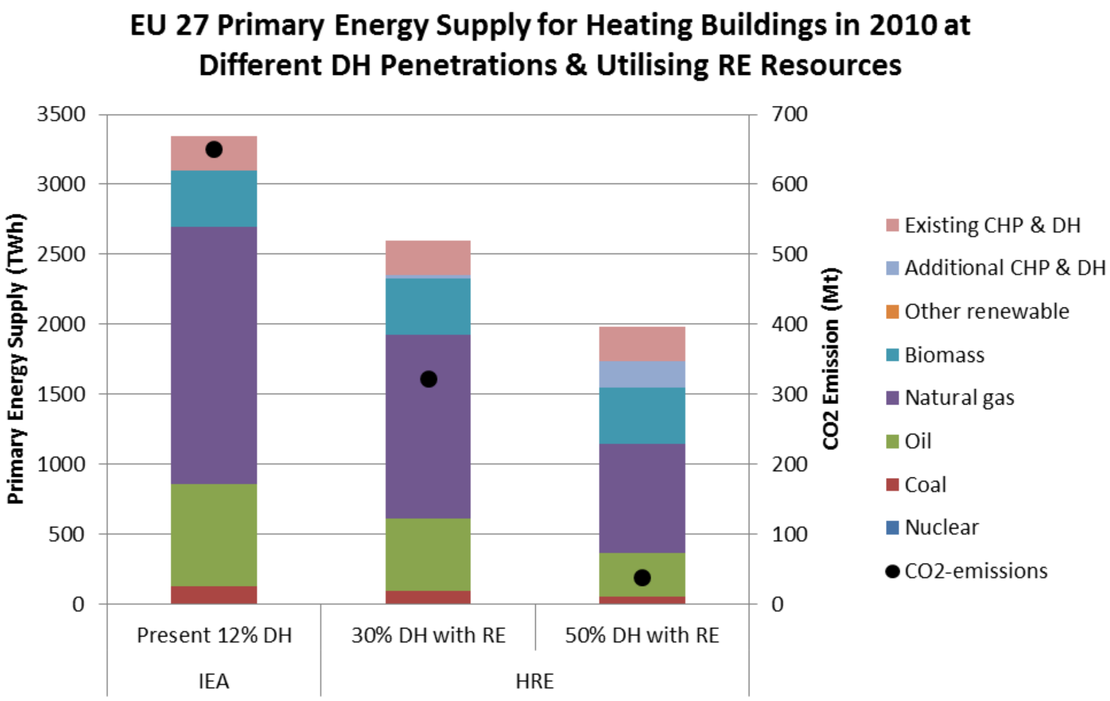

Figure 32: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010 EU27 energy system at present and if district heating and CHP were expanded to 30% or 50%, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

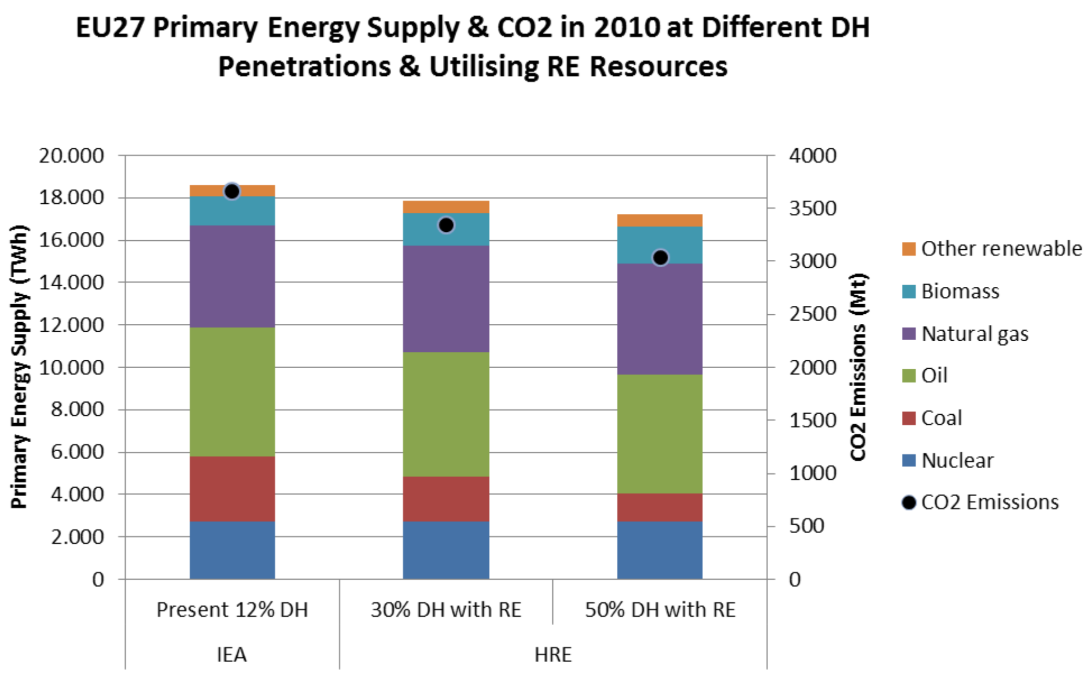

Figure 33: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010 at present and if district heating and CHP were expanded to 30% or 50%, , in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

Step 2 illustrates further benefits of district heating by implementing the following investments:

- Increase waste incineration from now 105 to 1198 TWh/year in 2050
- Increasing the use of geothermal heat from now approximately 2 to 111 TWh/year in 2050
- Increase the use of solar thermal heat from now 0.04 to 55.5 TWh/year in 2050
- Increase the use of industrial excess heat from 53 to 219 TWh/year in 2050

The results are shown in **Figure 32**.
Since these investments represent the replacement of fuels rather than efficiency improvements, such benefits will only slightly decrease the primary energy consumption further. However the share of fossil fuels as well as the carbon dioxide emissions will be reduced substantially. In total (both step 1 and 2) the total fossil fuels in Europe are reduced by 13% and the carbon dioxide emissions by 17% as illustrated in Figure 33.

4.2 DISTRICT HEATING IN 2030 AND 2050

Using the same assumptions as the 2010 analysis, district heating was also simulated in the forecasted EU CPI scenarios for 2030 and 2050. As described in section 2.4, the name of the EU CPI reference model created in the EnergyPLAN tool is the EP CPI scenario. Hence, this is the reference which the district heating alternatives are compared against in this section. The 30% DH alternative is implemented in 2030 and the 50% DH alternative in 2050.

4.2.1 PRIMARY ENERGY SUPPLY AND CARBON DIOXIDE EMISSIONS

Here, step 1 was not implemented separately since the 2010 analysis has already demonstrated the benefits of energy efficiency and renewable resources individually. Instead both steps have been implemented together.

The results of such analyses are illustrated in Figure 34 and Figure 35 with regard to primary energy supply and carbon dioxide emissions representing the heating of all buildings in Europe. In the diagrams the expansion of district heating is compared to the CPI reference. As can be seen the fuel consumption for heating is expected to decrease in the CPI reference mainly due to energy savings. If district heating is expanded at the same time then substantial fuel savings and carbon dioxide reductions will be achieved. The variety of new heat sources used to meet these new district heating demands is outlined in Figure 36, where it is clear that an expansion in district can also enable a significant expansion in renewable heat production.

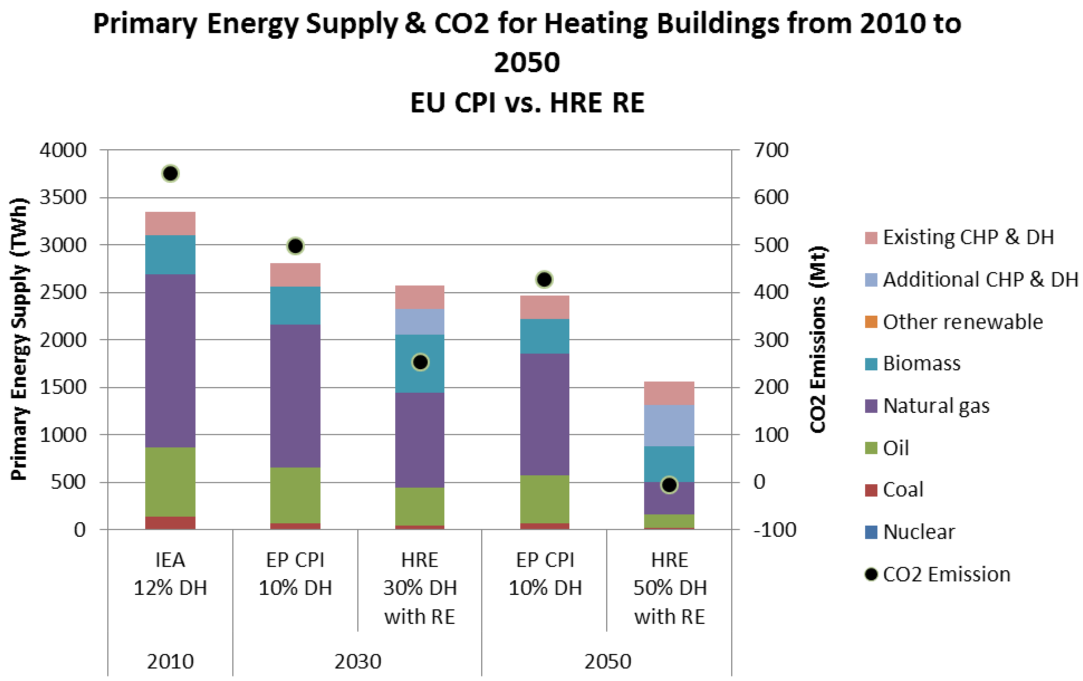

Figure 34: Primary energy supply and carbon dioxide emissions from hot water and the heating of buildings in the 2010, 2030, and 2050 EU27 energy system under a business-as-usual scenario and if district heating and CHP is expanded to 30% in 2030 and to 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

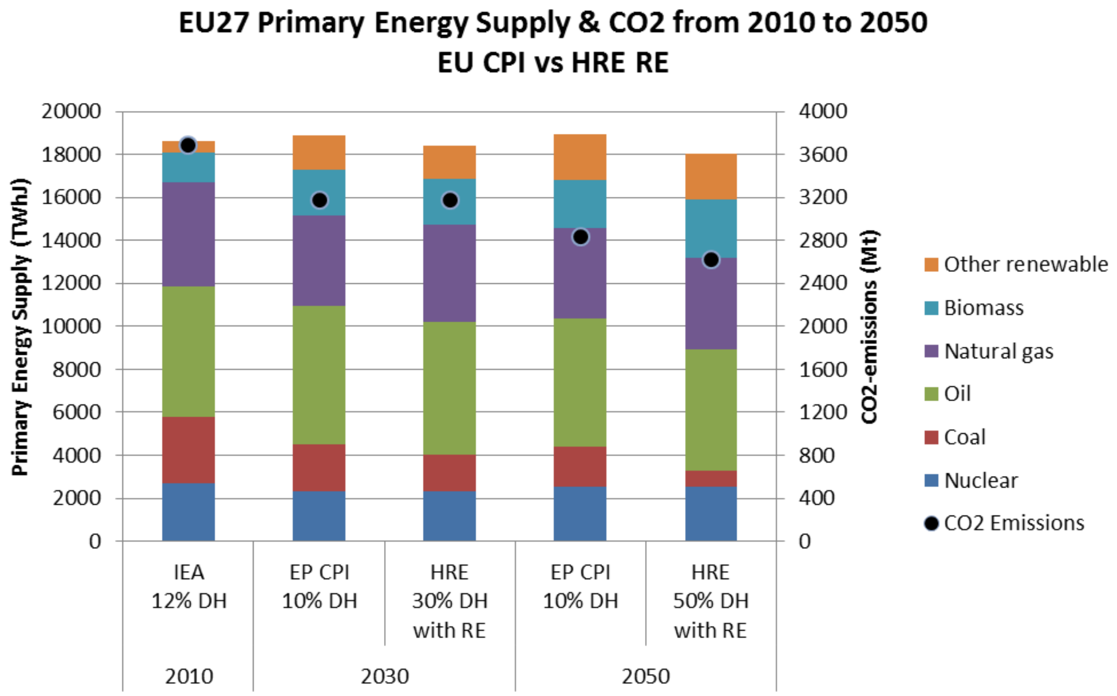

Figure 35: Primary energy supply and carbon dioxide emissions for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

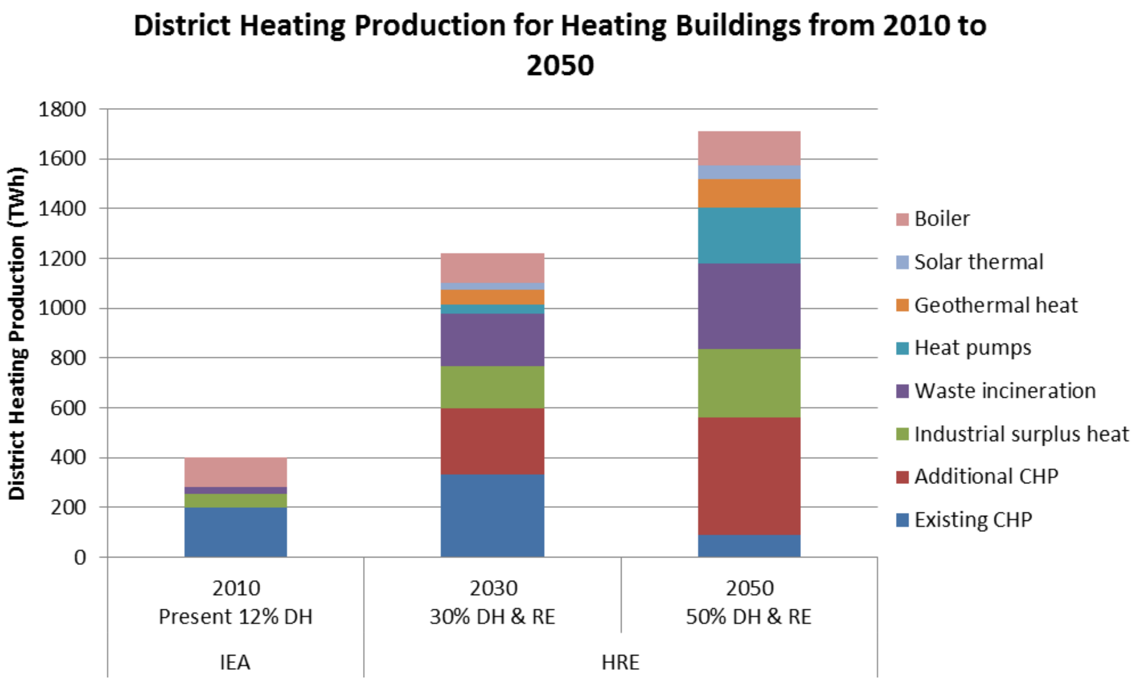

Figure 36: District heating production for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial excess heat, waste incineration, geothermal, and solar thermal heat for district heating.

4.2.2 ENERGY SYSTEM COSTS

Using the EP CPI models simulated in EnergyPLAN, it is also possible to estimate the annual costs of the energy systems in 2010, 2030, and 2050. The fuel prices in the *Energy Roadmap 2050* report were also used here, which are illustrated in Table 2 while all of the assumed technology costs are outlined in Annex V. The socio-economic comparison in HRE does not include externalities i.e. environmental and health costs. It includes changes in the investments and in operation and maintenance costs while also taking into account the lifetime of the different technologies in the energy systems. The costs of carbon dioxide quotas are not included. In HRE a real interest rate of 3% is used excluding inflation for the evaluation of the socio-economic consequences.

Table 2: Fuel prices assumed for each year [29].

€/GJ	Oil (US$/bbl.)	Gas	Coal	Fuel Oil	Gasoline	Diesel	Jet Fuel	LPG	Biomass	Dry Biomass
2010	82	5.9	2.7	8.8	11.7	11.7	12.7	13.2	6.8	4.7
2030	106	9.0	3.0	11.7	14.8	14.8	15.9	16.8	7.3	4.6
2050	127	10.9	3.2	14.3	17.6	17.6	18.6	19.9	8.4	5.6

The annual costs for the heating sector were calculated for the IEA 2010, EP CPI 2030, and EP CPI 2050 reference scenarios along with the Heat Roadmap Europe district heating alternatives with 30% district heating in 2030 (i.e. HRE RE 2030) and with 50% district heating in 2050 (i.e. HRE RE 2050).

The results indicate that the annual cost of the EU heating sector was approximately €130 billion in 2009, which under the EP CPI business-as-usual scenario will increase to approximately €140 billion in 2030 and subsequently reduce slightly to €136 billion in 2050, primarily due to increased energy savings in buildings. At present the most significant component of this is fuel, which demonstrates the importance of energy efficiency technologies such as district heating.

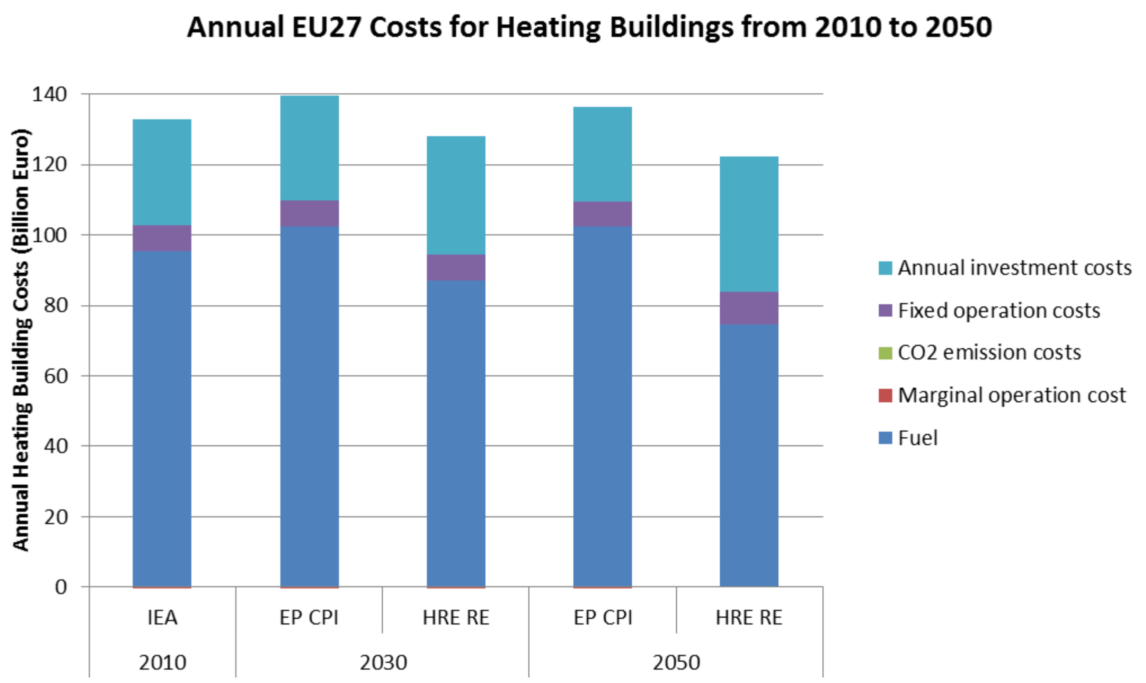

Figure 37: Socio-economic costs for the entire EU27 energy system in 2010, 2030, and 2050 under a business-as-usual scenario and if district heating and CHP were expanded to 30% in 2030 and 50% in 2050, in combination with the expansion of industrial waste heat, waste incineration, geothermal, and solar thermal heat for district heating.

In contrast, as illustrated in **Figure 37**, with the implementation of the district heating expansion scenario, the heating sector costs will decrease to €128 billion/year in 2030 and continue to decrease to €122 billion/year in 2050. Therefore, the total costs of heating buildings in Europe will be approximately €14 billion/year lower in 2050 if the district heating alternatives presented in this pre-study are implemented. Even more significant though is the fact that implementing the district heating alternative will transfer money from importing fossil fuels to investments in district heating pipelines, CHP plants, geothermal, solar thermal, industrial waste heat, and waste incineration. This will result in the creation of jobs within the EU which otherwise would not be created. A rough estimate of the number of jobs that will be created is presented in the next section.

4.2.3 JOB CREATION IN THE HRE 2050 RE SCENARIO

When fully implemented in 2050, the increase to 50% district heating decreases the annual heating sector costs in Europe by approximately €14 billion. However in order to reach this point, a number of additional investments have to be made. These investments are listed in Table 3 below.

Table 3: Additional investments required in the HRE 2050 RE scenario compared to the reference 2050 EP CPI scenario over the 38 year period between 2013 and 2050.

Investments (Billion €)	EP CPI	HRE	Difference	Lifetime	Adjusted
District heating pipes		146	146	40	146
Industrial excess heat		7	7	30	8
Waste incineration	64	157	93	20	176
Geothermal		24	24	25	37
Solar thermal		22	22	20	42
Individual boilers	254	104	-150	15	-379
CHP2		138	138	22	238
Heat pumps		62	62	20	118
Peak load boilers	17	96	79	20	150
Power plants	582	568	-14	30	-18
Total	***918***	***1324***	***406***		***518***

The additional investments in district heating, new CC-CHP, heat pumps, solar, waste and geothermal sum up to a total of €570 billion. However, some investments will also decrease, i.e. all the re-investments in individual boilers and savings in new power plants which can be replaced by the new CC-CHP plants. The saved investment in individual boilers here has been calculated as the difference between individual boilers and individual district heating units.

As a basis for the cost calculations a new natural gas boiler of €4000 is replaced with a district heating unit of €2000 representing a heat demand of 15 MWh/year. Consequently the saved costs are calculated as approximately €2000 per 15 MWh/year moved from individual boilers to district heating. Savings in power plants has been calculated on the basis of a 30% reserve capacity in all scenarios.

As can be seen in Table 3, the total net additional investments add up to €406 billion in the 38 year period from 2013 to 2050. However since the lifetime exceeds for some of the investments, reinvestments has to be partially included as listed in the next column (Adjusted).

Including re-investments the net additional investment sums up to 518 billion in the 38 year period from 2013 to 2050 equal to around 13.6 billion a year in average. A first rough estimate of job creation has been made on the following assumptions:

- 20% of all investments are import which will create no jobs in Europe
- The rest of the additional investment cost will create 20 man-years per million euros

Under these assumptions the additional jobs can be calculated as 8-9 million man-years in total during the period from 2013 to 2050 or approximately 220,000 jobs. It must however be emphasized that 220,000 jobs is a rough estimate of the minimum of work places being created. The 220,000 jobs arise from purely the additional investments. The real number will be higher due to the following:

- Multiplier effects of the jobs created are not included

- Additional jobs are not included due to that the energy costs of Europe will decrease and consequently European industry will become more competitive

Additional jobs from industrial innovation due to the investments in new energy technologies are not included

5. CONCLUSIONS

The early results in this pre-study demonstrate the potentially significant role that district heating can play in the future EU27 energy system. These results have been reached using a number of unfavourable assumptions. For example, the future energy system used for the analysis is not optimised for district heating: There is a high amount of base load nuclear and industrial CHP along with a lot of intermittent renewable energy. Hence, based on positive implications identified in this initial pre-study, the results can be considered relatively robust.

The major findings from this Heat Roadmap Europe pre-study exploring the future district heating possibilities can be summarised by the following eight conclusions:

- The first conclusion is that more district heating in Europe will reduce the energy system costs considerably since local heat recycling and renewable energy use will reduce expensive energy imports, while also increasing the efficiency of both the electricity and heat sectors. The pre-study calculations indicate that the overall annual cost reduction in the heating sector will be about €14 billion by 2050, if more district heating is implemented compared to the Energy Roadmap 2050 CPI reference. This corresponds to a relative cost decrease of 11%. At the current energy import prices, the direct socio-economic payback is estimated to be two to three years for heat distribution pipes put into the ground giving more recycled heat. In addition, there is a balance-of-payment benefit that has not been quantified in this study.

- The second conclusion follows from the first conclusion: Since fossil fuels are substituted with local resources, the reduced primary energy supply from fossil fuels will also give considerably reduced emissions of carbon dioxide for all heat demands served by district heating systems. The reduced energy import will also increase the future security of supply and give more positive balances of foreign exchange.

- The third conclusion is that more district heating will generate local labour since intensive investments will replace expensive imports of fossil fuels to Europe. An estimate indicates that approximately 8-9 million man-years will be created in Europe during the 40 year period, due to investments in heat recycling, renewable energy supply, and extended and new heat grids. This represents a rough estimate of the minimum number of jobs and should be quantified more thoroughly in the future.

- The fourth conclusion concerns the future European electricity supply system. With a high proportion of variable renewable electricity supply, a smart energy system is crucial so that all sectors can contribute to a balance between supply and demand. One of the proven flexible partners is district heating systems which can provide balancing power in both directions. For example, electric boilers and large heat pumps together with thermal storages can absorb critical excess electricity generation, while combined heat and power plants can actively support the electricity supply system during power deficits. Therefore, district heating can enable higher penetrations of intermittent electricity production on the European electricity grid.

continued on the next page

- The fifth conclusion is about the importance of communicating the local possibilities for district heating to urban and regional planners. The planned continuation of this pre-study should contain a creation of an interactive internet tool providing the local conditions for district heating for each administrative region in the EU27.

- The sixth conclusion is about the methodology applied in this pre-study, which is a combination of energy modelling and mapping of the local conditions using a high geographical resolution: The high resolution also recognises future possibilities for local activities managed by local organisations. This methodology is crucial for district heating analysis since the potential for expansion is dependent on local heat resources and demands. Therefore, this methodology should be elaborated in the planned continuation of this pre-study, while also making a tighter connection between the energy modelling part and the local mapping part.

- The seventh conclusion concerns traditional energy modelling based on national energy balances. Their low geographical resolution tends to exclude specific local possibilities. Hereby, they favour generic possibilities available everywhere such as electric and gas alternatives associated to major international energy companies. Hence, these traditional energy tools may only capture some of the alternatives available. Traditional energy tools also tend to work with a low time resolution in their analyses. However, it is important to use a high time resolution to capture the daily variations in the energy system in order to verify the true variability in energy demand and supply, especially in a future energy system with high penetrations of intermittent resources.

- The eighth and final conclusion refers to the availability of data within the current IEA and future Energy Roadmap 2050 reports. At present, there is a lack of detailed data for the heat sector in these energy balances. For example, all fuels consumed by CHP plants are recorded together and not subdivided by condensing mode, extraction mode, and back-pressure mode. In the future, it would be beneficial if the details within these energy balances could be increased for the heat sector. In line with this, we would like to thank the European Commission for providing all of the data possible during the limited timeframe of this study.

This pre-study has demonstrated the potential increase in energy efficiency and renewable energy consumption associated with district heating, so a full research study is recommended to further elaborate on the methodology applied in this pre-study.

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7. ANNEX I: REVIEW OF EXISTING ENERGY STRATEGIES

In the following pages is seen a description of a selection of the most recent energy scenarios.

Title:	**Energy Roadmap 2050**	
Year of publication: 2011	*Organization:* European Commission COM (2011) 885	
Outlook year: 2050		
Objective:		
The scenarios in *Energy Roadmap 2050* investigate the possibilities for moving towards "decarbonisation" of the energy system. The *Energy Roadmap 2050* does not replace national, regional and local improvements of the energy supply, but seeks to develop a technology-neutral framework and argues that compared to parallel national schemes, a European approach to the energy challenge will increase security and solidarity and lower costs by providing a wider and flexible market for new products and services.		
How buildings are insulated/heated:		
Short-term opportunity to reduce emissions is first and foremost through improvement of the energy performance of buildings. The analysis shows that emissions in this area could be reduced by around 90% by 2050. New buildings built from 2021 onwards should be nearly zero-energy buildings. Heat pumps and storage heaters based on electricity and renewable energy such as solar heating, biogas and biomass also provided through district heating systems, should be used.		
How district heating is mentioned:		
Energy Roadmap 2050 describes seven scenarios. Two of them assuming current trends and fixed political, economic, and technical limitations. These are called current trend scenarios. The other five are called "decarbonisation scenarios" and use different measures to reduce the greenhouse emissions of Europe. The report focuses on electricity to play a much greater role in all scenarios. However it states that future modeling improvements could consider better representation of the impacts of climate change itself, as well as energy storage and smart grid solutions for distributed generation. CHP and district heating are only mentioned briefly. In the "decarbonisation" scenarios there is seen a transition of the energy system from low capital costs and high fuel and operational costs to high capital costs and low fuel costs. The increase of capital costs is due to investments in power plants and grids, industrial energy equipment, smart meters, insulation material, more efficient low carbon vehicles, RES equipment (such as solar collectors) etc.		
Link to report: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011PC0885:EN:NOT		

Title: **Impact assessment** – accompanying document to *Energy Roadmap 2050*

Year of publication:

2011

Organization:

European Commission

SEC(2011) 1565

Outlook year:

2050

Objective:

(*Energy Roadmap 2050*)

How buildings are insulated/heated:

Coal and oil hold a share of around 25% of final energy used for heating and cooling of the built environment. In the reference scenario this decreases to around 15% in 2050 and practically disappears in the decarbonisation scenarios. Gas decreases from around 45% today to around 30% by 2050 in the decarbonisation scenarios in the context of global climate action. The share of electricity increases from currently less than 10% to more than 20% in the decarbonisation scenarios, and the share of biomass from currently over 10% to over 25%. Due to the efficiency gains the increase of biomass corresponds more or less to a stagnation of biomass used for space heating in absolute terms. Distributed heat maintains its current share of less than 10% by 2050.[2]

How district heating is mentioned:

District heating is not included in detail in the modeling. It is stated in the Impact Assessment document accompanying the report *A Roadmap for moving to a competitive low carbon economy in 2050* [51] that potential break-through technologies depending on unforeseeable structural change have not been taken into account. A particular example is the limitations in terms of modeling energy storage and smart grid solutions that would enable very wide scale deployment of distributed generation.

However district heating represents different actual quantities of energy depending on the scenario, but is in general not considered playing a major role in the long run since the report focuses on "decarbonisation".

A table from the report shows that there is not that big a difference in the share of district heating in the scenarios. However it is important to note that the energy consumption is not the same in the different scenarios. The final energy demand is in the decarbonisation scenarios 8%-14% lower in 2030 compared to the reference and 34%-40% lower in 2050.

Share of distributed heat in total heating for residential and tertiary:

Year	*2020*	*2030*	*2050*
CPI	*11.6%*	*12.0%*	*12.0%*
Energy Efficiency	*12.0%*	*12.8%*	*13.3%*
Div. Supply Technology	*11.6%*	*12.4%*	*13.4%*
High RES	*11.6%*	*11.4%*	*8.5%*
Delayed CCS	*11.6%*	*12.4%*	*12.4%*
Low Nuclear	*11.6%*	*12.5%*	*13.7%*

Link to report: http://ec.europa.eu/governance/impact/ia_carried_out/docs/ia_2011/sec_2011_1565_en.pdf

[2] This is from the Impact Assessment document (report reference no. SEC(2011) 288) accompanying the report *A Roadmap for moving to a competitive low carbon economy in 2050*, but though they are separate documents, they are referring to the same scenarios and are all published by the European Commission in 2011: http://ec.europa.eu/governance/impact/ia_carried_out/docs/ia_2011/sec_2011_0288_en.pdf.

Title:	**Roadmap 2050** – A practical guide to prosperous low-carbon Europe – Technical analysis	
Year of publication: 2010 *Outlook year:* 2050	*Organization:* The European Climate Foundation (ECF), McKinsey & Company, KEMA, The Energy Futures Lab at Imperial College London, Oxford Economics	
Objective: The mission of the "Roadmap 2050" project is to provide a practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union. The focus is on the description of a plausible way to realize an economy-wide GHG reduction of 80%, and the development and assessment of pathways to decarbonize the power sector.		
How buildings are insulated/heated: The report mentions that an urgent implementation challenge is to make a large scale fuel shift possible. In terms of the building sector it suggest more heat pumps both for individual and in district heating applications, and district heating based on industry waste heat, biomass or alternatively geothermal heat.		
How district heating is mentioned: The report addresses the implications of electrification in buildings and transport on the final energy demand. However it does not provide a detailed analysis on the issues. The report does mention district heating as part of the system and discuss the entire emission scope in general, but focuses particularly at the power sector. Out of scope is i.e. detailed trade-offs in the decarbonisation of building heat via electrification, biomass/biogas, zero carbon district heating schemes or other options. District heating with large scale heat pumps is assumed where building density is high. Alternatives are biomass or biogas fired CHP or district heating plants, or biogas fired boilers in homes.		
Link to report: http://www.roadmap2050.eu/attachments/files/Volume1_ExecutiveSummary.pdf		

Title:	**Governing the transition to low-carbon futures: A critical survey of energy scenarios for 2050**	
Year of publication: 2011 *Outlook year:* 2050	*Organization:* Luleå University of Technology – Economics Unit Lund University – Dept. of Political Science and Environmental, Energy System Studies and AgriFood Economics Center	
Objective: The article addresses the role of energy future studies in providing insights on the societal transitions that are implied by contemporary visions of low-carbon futures. The analysis is based on a critical review of 20 scenario exercises of relevance for meeting long-term (i.e., 2050) climate policy objectives.		
How buildings are insulated/heated: Not described.		
How district heating is mentioned: District heating, cogeneration and CHP are not mentioned directly.		
Link to report: -		

Title: **Providing all global energy with wind, water, and solar power** (part I and II)

Year of publication:	*Organization:*	
2010	Stanford University – Dept. of Civil and Environmental Engineering University of California at Davis – Institute of Transportation Studies	
Outlook year:		
2050		

Objective:

In the article the feasibility of providing worldwide energy for all purposes (electric power, transportation, heating/cooling, etc.) from wind, water, and sunlight (WWS) is analysed.

How buildings are insulated/heated:

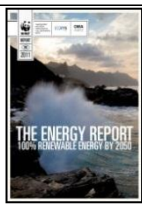
The article proposes air- and ground-source heat-pump water and air heaters and electric resistance water and air heaters. For high-temperature industrial processes, we propose that energy be obtained by combustion of electrolytic hydrogen. It is assumed that 5% of fuel use for space heating and 20% of fuel use for ''appliances'' (mainly cooking) are not electrified.

How district heating is mentioned:

The article focuses distinctly on electricity and does not cover district heating.

Link to report: -

Title: **The energy report** – 100% renewable energy by 2050

Year of publication:	*Organization:*	
2011	WWF International ECOFYS OMA (Office for Metropolitan Architecture)	
Outlook year:		
2050		

Objective:

WWF has a vision of a world powered by 100% of renewable energy sources by the middle of this century. The Energy Scenario in the report includes an energy system (global) with 95% of renewable energy in 2050.

How buildings are insulated/heated:

Existing buildings should be insulated and new buildings should be constructed to use as little energy as possible. Heating needs can be reduced by 60% in all existing buildings by 2050 if 2-3% of the total floor area is retrofitted with extra insulation each year. Solar and geothermal sources, as well as heat pumps should provide a large share of heat for buildings and industry. Almost no energy will be needed for heat and cooling in all new buildings by 2030.

How district heating is mentioned:

The report only mentions district heating briefly when referring to the potential of geothermal heating. In does not mention large scale CHP and focuses mainly on electricity.
In the scenario geothermal and solar are mentioned in a general way without going into details if it implies large or small scale units.
The report describes a scenario where the world as far as possible use electrical energy rather than solid and liquid fuels. Wind, solar, biomass and hydropower are the main sources of electricity, with solar and geothermal sources, as well as heat pumps providing a large share of heat for buildings and industry.

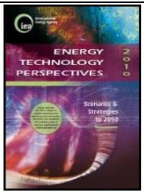
Link to report: http://assets.panda.org/downloads/101223_energy_report_final_print_2.pdf

Title: **Energy Technology Perspectives 2010** – Scenario and strategies to 2050 (part 1 and 2)

Year of publication:
2010

Outlook year:
2050

Organization:
IEA (International Energy Agency)



Objective:

The goal of the book is to contribute to the reduction in carbon dioxide emissions by acting as a reference point for (among others) policy makers who need to be able to identify the role of new technologies, potential technical and political barriers, and to provide the measures to overcome them.

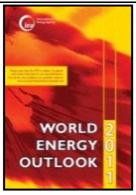
How buildings are insulated/heated:

In the short run low-cost energy efficiency options will reduce carbon dioxide emissions caused by the building sector. In the longer term highly efficient heat pumps for heating and cooling, solar thermal space and water heating, and small scale CHP systems with hydrogen fuel cells are some of the main technologies to decarbonize the energy consumption of buildings. The book states that CHP can be an attractive abatement option in buildings, but that the use of it depends on the application and location.

How district heating is mentioned:

The book examines the fuels and technologies that are likely to be important in a) a “Baseline scenario” and b) in a range of scenarios, in which global carbon dioxide emissions are reduced by 50% from 2005 levels by 2050, called “the BLUE Map scenario” and a series of variants of it.
However district heating is only occasionally mentioned and CHP/DH is described as playing an important, but small role.
The use of CHP approximately triples in the BLUE Map scenario in absolute terms between 2007 and 2050. The share of CHP in power generation increases to 13% over this period, up from 10% in the Baseline scenario.
It is mentioned that Denmark, Finland and the Netherlands already have high share of CHP and that many other countries have significant potential to expand their use of CHP, if they take steps to address barriers such as unfavorable regulatory frameworks in the form of buy-back tariffs, exit fees, and backup fees, challenges in locating suitable heat users, and the relative cost-ineffectiveness of CHP units of less than 1 MW capacity.
The book describes that thermal storage is likely to become increasingly important in the long term as thermal loads begin increasingly to use electricity generated through heat pump technologies and as CHP plays a stronger role. Besides this, it explains that for CHP plants the desired energy output can be difficult to control since the ratio of electricity and heat most often is not perfectly matching the demand. However CHP units can store excess heat energy for use at a later time in response to heat demand by responding to electricity system signals.

Link to report: iea.org/Textbase/nppdf/free/2010/etp2010_part1.pdf and iea.org/Textbase/nppdf/free/2010/etp2010_part2.pdf

Title:	**World energy outlook** – 2011	
Year of publication: 2011	*Organization:* IEA (International Energy Agency)	
Outlook year: 2035		
Objective:		
IEA *World Energy Outlook* is based on the *Energy Technology Perspectives*. See description of this report above.		
How buildings are insulated/heated:		
(See *Energy Technologies Perspectives*.)		
How district heating is mentioned:		
(See *Energy Technologies Perspectives*.)		
Link to report: -		

Title:	**Deciding the Future** – Energy Policy Scenarios to 2050	
Year of publication: 2007	*Organization:* World Energy Council (WEC)	
Outlook year: 2050		
Objective:		
The study seeks to - better understand possible energy futures - assess the challenges presented in these energy futures - identify the role that policy may play to help or hinder the achievement of WEC's Millennium Goals of Accessibility, Availability, and Acceptability. It is not a theoretical study, but a product of several workshops held to discuss energy policies for different regions of the world.		
How buildings are insulated/heated:		
Advanced building technologies produce major energy savings and buildings might even become net energy producers rather that consumers. However these technologies have not been implemented in old buildings and in the developing world, either because the technology has not been made available or it is too expensive.		
How district heating is mentioned:		
District heating, cogeneration and CHP are not mentioned directly.		
Link to report: http://www.worldenergy.org/documents/scenarios_study_online_1.pdf		

8. ANNEX II: THE PRIMES MODELLING TOOL

Description of the PRIMES model from the [26, 30] references.

<table>
<tr><td>Title:</td><td colspan="2">PRIMES model</td></tr>
<tr><td>Year of publication:
2010
Outlook year:
n/a</td><td>Organization:
National Technical University of Athens, Department of Electrical and Computer Engineering (E3MLab)</td><td>
</td></tr>
<tr><td colspan="3">Objective:
Used for the 2010 scenarios for the European Commission.</td></tr>
<tr><td colspan="3">Overview:
PRIMES simulates a market equilibrium solution for energy supply and demand [31]. It has been developed by the National Technical University of Athens (NTUA) since 1994, but it is not sold to third parties. Instead, the tool is used within consultancy projects undertaken by NTUA and partners.
The equilibrium used in PRIMES is static (within each time period) but repeated in a time-forward path, under dynamic relationships. In the Energy Roadmap 2050 project, PRIMES was used to model the period 1990-2050, in time steps of 5 years. For the years 1990, 1995, 2000 and 2005 the model results are calibrated to Eurostat statistics. For the year 2010, the model results are semi-calibrated by taking into account the latest statistics and short-term expectations. All thermal, renewable, storage/conversion, and transport technologies can be simulated except battery energy storage, compressed-air energy storage, intelligent battery-electric-vehicles, and hybrid vehicles. PRIMES is organized in sub-tools, each one representing the behavior of a specific ‘demander’ and/or a ‘supplier’ of energy. PRIMES simulates time-of-use varying load for network-supplied energy carriers to synchronize electricity, gas and steam/heat in all sectors of demand, supply and trading. To do this, load curves are computed by the model in a bottom up manner depending on the load profiles of individual uses of energy. The tool can support policy analysis in the following fields: (1) standard energy policy issues: security of supply, strategy, costs (includes all costs), etc., (2) environmental issues, (3) pricing policy and taxation, standards on technologies, (4) new technologies and renewable sources, (5) energy efficiency in the demand-side, (6) alternative fuels, (7) conversion to decentralisation and electricity-market liberalisation, (8) policy issues regarding electricity generation, gas distribution, and new energy forms. PRIMES is organised by an energy production sub-system for supply consisting of oil products, natural gas, coal, electricity and heat production, biomass supply, and others, and by end-use sectors for demand consisting of residential, commercial, transport, and nine industrial sectors. Some demanders may also be suppliers, as for example industrial co-generators of electricity and steam. PRIMES has previously been used to create energy outlooks for the EU [32], develop a climate change action and renewable energy policy package for the EU [33] and also, to analyse a number of different policies to reduce GHG in the EU25 by 2030 [34, 35]. Finally, PRIMES has been used for several EU governments as well as private companies.</td></tr>
<tr><td colspan="3">How district heating is mentioned:
The optimisation is simultaneous for power, CHP, distributed steam, distributed heat, district heating and industrial boilers. The optimisation is intertemporal (perfect foresight) and solves simultaneously a unit commitment-dispatching problem; a capacity expansion problem; and a DC-linearized optimum power flow problem (over interconnectors).
Promotion of CHP and micro-generation: priority grid access for CHP, CHP values representing marginal benefits for CHP can be introduced. Micro-generation is included only in the low voltage grid, reducing the transmission costs.
The use of biomass is optimally allocated endogenously and might therefore not be used for CHP.</td></tr>
<tr><td>Link to report:</td><td colspan="2">http://www.sciencedirect.com/science/article/pii/S0306261909004188
http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1569_2_prime_model.pdf</td></tr>
</table>

9. ANNEX III: DATA USED TO MODEL THE REFERENCE ENERGY SCENARIOS FOR 2010, 2030, AND 2050

9.1 2010

Unit	Year:	2010		
TWh	Data	IEA[a]	Reference[a]	EnergyPLAN[a]
Demands	Electricity	2,720	3,178	3,179
	Plus Additional Losses	*458*		
	Including Electric Heating	-	381[b]	381
	Including Electric Cooling	-	40[c]	40
	District Heating for Residential & Services	338	338	402
	Plus Additional Losses	-	64	
	District Heating for Industry	230	230	See Note[d]
	Plus Additional Losses	-	43	
	Total District Heating Consumption	567	567	567
	Total District Heating Production	675	675	675
Fuel for Production	Power Plants (excl. Waste & Nuclear)	2,639	-	3,572
	Power Plants Operating in Condensing Mode	-	3,583[e]	
	CHP Extraction Plants (excl. Waste & Nuclear)	1,333	-	385
	Fuel Consumed in Back Pressure CHP Mode	-	389[e]	
	Centralised Peak Boilers (excl. Waste)	151	43[f]	45
	Centralised Heat-Only Boilers (excl. Waste)		108[f]	107
	Nuclear Power Plants	2,711	2,711	2,712
	Fuel Refinery Losses & Energy Industry Own Use	950	1,080[g]	1,081
	Hydroelectricity	328	328	328
	Intermittent RE: Wind, Solar PV, Wave, Tidal	147	147	149
Final Energy Consumption (excluding electricity & district heating)	Industry	1,864	2,590	2,590
	Industry CHP & Boilers	651		
	Agriculture / Fishing (excluding oil)	76		
	Residential	2,340	3,099	3,099
	Services	759		
	Transport	4,414	4,414	4,414
	Jet Fuel	583	583	583
	Petrol	1,127	1,127	1,127
	Diesel	2,234	2,403	2,403
	Agricultural Oil Consumption	169		
	Gas	25	25	26
	LPG	60	60	60
	Electricity	71	71	71
	Biofuels	143	143	143
Total Fuel	Coal	3,100	3,100	3,091
	Oil	See Note[h]	6,059	6,059
	Gas	4,842	4,842	4,838
	Biomass/Waste	1,340	1,340	1,340
	Renewables	557	544	545
	Nuclear	2,711	2,711	2,712
	Total	18,609		18,583
CO2 (Mt)	Energy System	See Note[i]	-	3,690
	Heating Sector	-	-	651

9.2 2030

Unit	Year:	2030		
TWh	Data	EU CPI[a]	Reference[a]	EnergyPLAN[a]
Demands	Electricity	3,239	3,780	3,775
	Plus Additional Losses	*541*		
	Including Electric Heating	-	446[b]	446
	Including Electric Cooling	-	46[c]	46
	District Heating for Residential & Services	312	312	376
	Plus Additional Losses	-	65	
	District Heating for Industry	678	678	Note[d]
	Plus Additional Losses	-	141	
	Total District Heating Consumption	990	990	990
	Total District Heating Production	1,195	1,195	1,195
Fuel for Production	Power Plants (excl. Waste & Nuclear)	1,859	-	2,837
	Power Plants Operating in Condensing Mode	-	2,833[e]	
	CHP Extraction Plants (excl. Waste & Nuclear)	1,248	-	274
	Fuel Consumed in Back Pressure CHP Mode	-	275[e]	
	Centralised Peak Boilers (excl. Waste)	94	35[f]	35
	Centralised Heat-Only Boilers (excl. Waste)		59[f]	59
	Nuclear Power Plants	2,301	2,301	2,301
	Fuel Refinery Losses & Energy Industry Own Use	See Note[j]	1,938	1,938
	Hydroelectricity	364	364	365
	Intermittent RE: Wind, Solar PV, Wave, Tidal	945	945	945
Final Energy Consumption (excluding electricity & district heating)	Industry	1,779	2,758	2,758
	Industry CHP & Boilers	915		
	Agriculture / Fishing (excluding oil)	64		
	Residential	1,927	2,558	2,558
	Services	631		
	Transport	4,496	4,496	4,498
	Jet Fuel	777	777	777
	Petrol	1,094	1,094	1,094
	Diesel	1,917	2,049	2,049
	Agricultural Oil Consumption	132		
	Gas	8	8	8
	LPG	54	54	54
	Electricity	116	116	116
	Biofuels	399	399	399
Total Fuel	Coal	2,267	2,267	2,272
	Oil	6,454	6,454	6,452
	Gas	4,297	4,297	4,301
	Biomass/Waste	3,649	2,075	2,075
	Renewables		1,575	1,567
	Nuclear	2,301	2,301	2,301
	Total	18,969		18,967
CO_2 (Mt)	Energy System	See Note[i]	-	3,410
	Heating Sector	-	-	497

9.3 2050

Unit	Year:	2050		
TWh	Data	EU CPI[a]	Reference[a]	EnergyPLAN[a]
Demands	Electricity	3,952	4,620	4,616
	Plus Additional Losses	*668*		
	Including Electric Heating	-	528[b]	528
	Including Electric Cooling	-	55[c]	55
	District Heating for Residential & Services	282	282	334
	Plus Additional Losses	-	52	
	District Heating for Industry	869	869	Note[d]
	Plus Additional Losses	-	160	
	Total District Heating Consumption	1,150	1,150	1,150
	Total District Heating Production	1,363	1,363	1,363
Fuel for Production	Power Plants (excl. Waste & Nuclear)	1,068	-	2,873[m]
	Power Plants Operating in Condensing Mode	-	2,364[e]	
	CHP Extraction Plants (excl. Waste & Nuclear)	1,488	-	192
	Fuel Consumed in Back Pressure CHP Mode	-	192[e]	
	Centralised Peak Boilers (excl. Waste)	76	376[f]	37
	Centralised Heat-Only Boilers (excl. Waste)		39[f]	39
	Nuclear Power Plants	2,545	2,545	2,545
	Fuel Refinery Losses & Energy Industry Own Use	See Note[j]	1,916	1,915
	Hydroelectricity	384	384	384
	Intermittent RE: Wind, Solar PV, Wave, Tidal	1,465	1,465	1,465
Electricity Imbalance	Forced Export of Electricity (CEEP)	-	-	222[k]
	Pumped Hydroelectric Energy Storage (PHES) Losses	-	-	13[l]
	Additional Fuel for Power Plants due to CEEP & PHES Losses	-	-	484[m]
	Extra Fuel for Power Plants in EnergyPLAN compared the Reference			509
Final Energy Consumption (excluding electricity & district heating)	Industry	1,780	3,034	3,034
	Industry CHP & Boilers	1,196		
	Agriculture / Fishing (excluding oil)	58		
	Residential	1,671	2,220	2,220
	Services	549		
	Transport	4,322	4,322	4,322
	Jet Fuel	776	776	776
	Petrol	935	935	935
	Diesel	1,746	1,872	1,872
	Agricultural Oil Consumption	126		
	Gas	3	3	3
	LPG	28	28	28
	Electricity	255	255	255
	Biofuels	453	453	453
Total Fuel	Coal	1,769	1,769	2,007[m]
	Oil	6,010	6,010	6,011
	Gas	4,120	4,120	4,389[m]
	Biomass/Waste	4,367	2,227	2,227
	Renewables		2,140	2,131
	Nuclear	2,545	2,545	2,545
	Total	18,810		19,310
CO2 (Mt)	Energy System	See Note[i]	-	3,219
	Heating Sector	-	-	427

9.4 NOTES FOR DATA IN TABLES

a. IEA represents the data recorded in the 2009 EU27 energy balance completed by the International Energy Agency. EU CPI refers to the data obtained from the Current Policy Initiatives scenario contained in *Energy Roadmap 2050* energy report, which documents a business-as-usual scenario for the EU energy system. The Reference column illustrates how the data was interpreted in this study while the EnergyPLAN column presents the results from the EnergyPLAN tool after the reference data was modelled in it.
b. The percentage of electricity used for electric heating is based on a survey completed by the Joint Research Centre, which analysed the various demands for electricity within the residential and service sectors [52]: 27.3% of electricity in the residential sector and 19.7% in the service sector are used for heating.
c. The percentage of electricity used for electric cooling is based on a survey completed by the Joint Research Centre, which analysed the various demands for electricity within the residential and service sectors [52]: 2.8% of electricity in the residential sector and 2.1% in the service sector are used for cooling.
d. In the IEA energy balance, there is heat consumption for industry of 230 TWh. However, this is used for both space heating and process heat. Since it was not possible to establish what the breakdown is between these, industrial heat consumption was not modelled as district heating in this study, but instead it was modelled as fuel consumption in industry. Hence, the focus in this study is district heating for space heating in the residential and services sectors. However, the demand for district heating in industry is still accounted for in the fuels consumed by industry.
e. The fuel consumed by power plants which can operate as both condensing and back-pressure mode (i.e. extraction CHP plants) is all recorded as CHP fuel consumption in the IEA energy balance. For example, in the Danish energy balance constructed by the IEA, all electricity production for coal and gas power plants is recorded as CHP. However, although these plants are capable of operating in CHP mode, they often operate in condensing only mode. Therefore, it would be inaccurate to model CHP exactly as it is reported in the IEA energy balance. Instead, the fuel required for the power plants was estimated separately for condensing mode and CHP mode. This was done by calculating the total district heating demand which CHP plants must provide after boilers, waste incineration, and excess industrial heat are taken into account. Then, assuming a thermal efficiency of 52%, the total fuel consumed for the power plant while operating in CHP mode is estimated. The remaining fuel recorded in the IEA energy balance as CHP is then reassigned to the power plants operating in condensing mode.
f. Boilers are recorded as either main-activity or industrial boilers in the IEA energy balance. However, for modelling purposes it is also important to know what the primary function of a boiler is on a district heating network: to provide all of the heat (i.e. heat-only) or to simply act as backup during peak heat demands. Since this distinction is not available in the IEA data, it is estimated in this study by assuming that all coal, biomass, and half of the natural gas boilers are used as heat-only boilers, while the other half of natural gas along with all of the oil boilers are used as peaking boilers.
g. When the primary energy supply in the reference data was compared to the IEA primary energy supply statistics, there were some minor differences in the range of approximately 0.5%. For completeness and to ensure all fuel is accounted for, this difference was

included as losses in the reference statistics and hence it increases from 950 TWh in the IEA statistics to 1080 TWh in the reference.

h. The primary energy supply recorded for oil in the IEA EU27 energy balance contains a number of negative numbers due to the large amounts of exported oil products. As a result, a signal figure was not identified in the statistics which indicated the total oil consumed. To overcome this, the total oil was calculated by adding the total oil under the final energy consumption (including international aviation from the *Energy Roadmap 2050* report), power plants, CHP plants, boilers, and the oil losses relating to oil refineries and the energy industry's own use.
i. The IEA energy balance does not provide carbon dioxide emissions. Also, the EU CPI carbon dioxide emissions for the total energy system are not included here since they are not directly comparable to the EnergyPLAN results for many reasons. Firstly, the emission factors in EnergyPLAN are based on Danish emission factors and hence they do not account for the country specific variations in the EU energy system. Also, carbon dioxide reductions due to carbon capture and storage (CCS) is not accounted for in the EnergyPLAN results and they have not been corrected to account for the import/export of electricity. Finally, it was not possible to establish which fuels were used in the EU CPI scenario to estimate the carbon dioxide emissions for the total energy system i.e. were the carbon dioxide calculations based on the gross inland consumption only or was this adjusted based on net imports? For these reasons, the carbon dioxide emission calculations are different in this study compared to the EU CPI study and it was not possible due to the timeframe of the project, to find the data necessary to align the two datasets.
j. In the EU CPI, it was not possible to calculate from the statistics presented how much of each fuel (solids, oil, gas, and biomass/waste) was lost due to the energy industry's own use, refinery losses, and other fuel transformation processes. Therefore, this number was estimated based on the difference between the gross inland consumption in the EU CPI report and the reference statistics after all other statistics were compared and verified. It is important to note that this does not affect the electricity and district heating dynamics in the modelling and hence, it is primarily included to ensure that no fuels are left unaccounted for in the energy system.
k. When the 2050 reference data is modelled in the EnergyPLAN tool, the electricity system is forced to export during some hours of the calculation in order to maintain grid stability. After investigating the hourly calculations in EnergyPLAN, this occurs for a combination of reasons including an increase in inflexible baseload production (in particular nuclear power) along with an increase in intermittent renewable energy production (in particular wind and PV). Therefore, it is likely that the EU CPI scenario will need to be redesigned to ensure that this does not occur. For example, more flexible demands could be introduced along with electricity, heat, and fuel storages: many of these alternatives are presented in detail in [25, 28, 36].
l. The 'PHES losses' is the net difference between consumption and production at the PHES plants.
m. Since there is approximately 220 TWh of CEEP and 13 TWh of PHES losses, the power plants produce more electricity than calculated in the reference statistics. Assuming the average condensing power plant efficiency, which was calculated form the statistics as

48.5%, the additional fuel required by the power plants to produce this fuel is approximately 485 TWh. It was concluded that this, along with minor modelling differences accounts for the difference between the reference statistics and the EnergyPLAN simulations, since these are approximately the same at 485 TWh and 510 TWh respectively. It is assumed here that this additional electricity demand from the power plants will be met by coal and natural gas power plants only, which explains the additional coal and natural gas demands in the EnergyPLAN simulations compared to the reference statistics.

10. ANNEX IV: LOCAL CONDITIONS ILLUSTRATED BY MAPS

10.1 URBAN AREAS

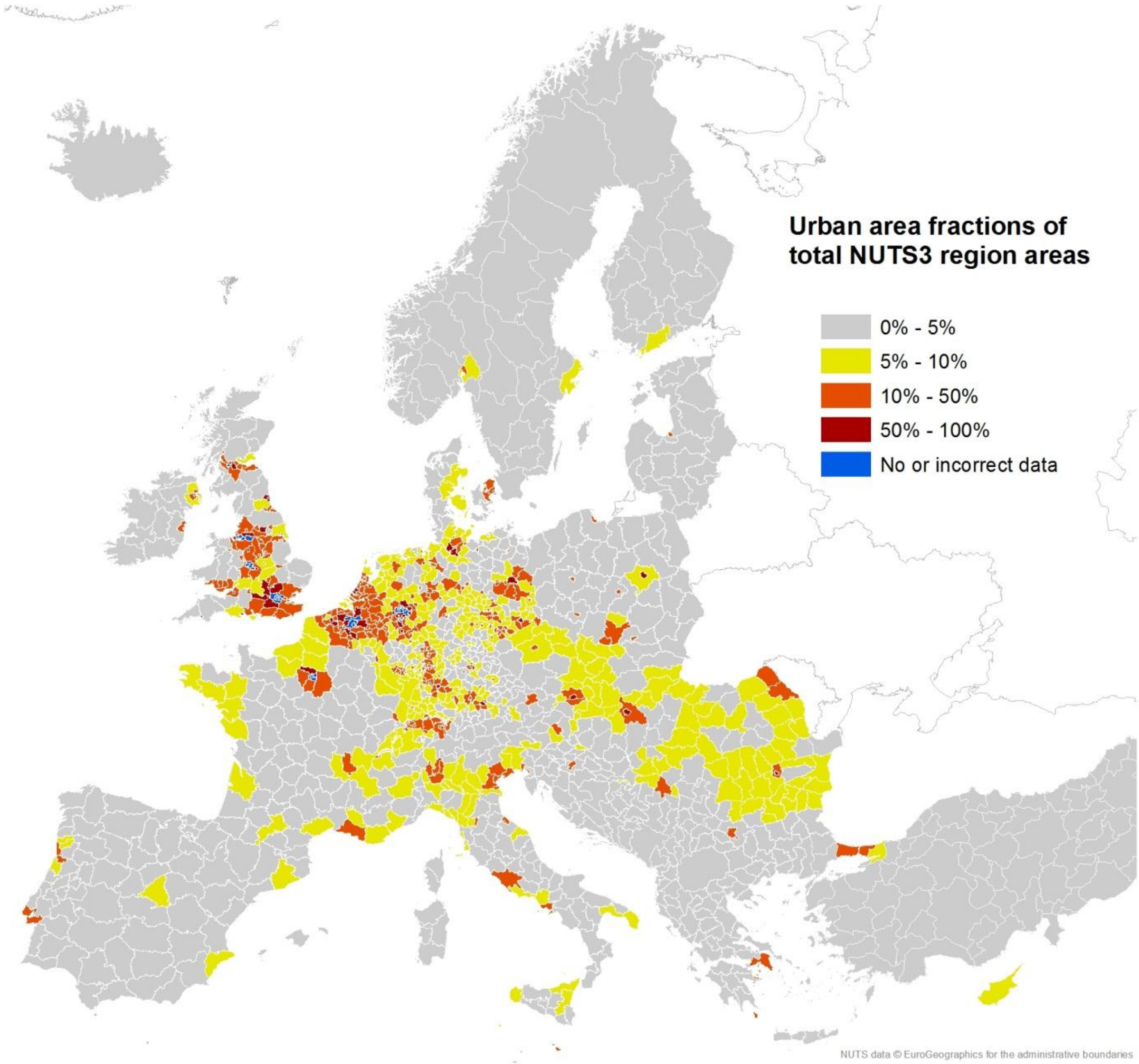


Figure 38: Proportion of urban areas within the NUTS3 regions.

10.2 CARBON DIOXIDE EMISSIONS

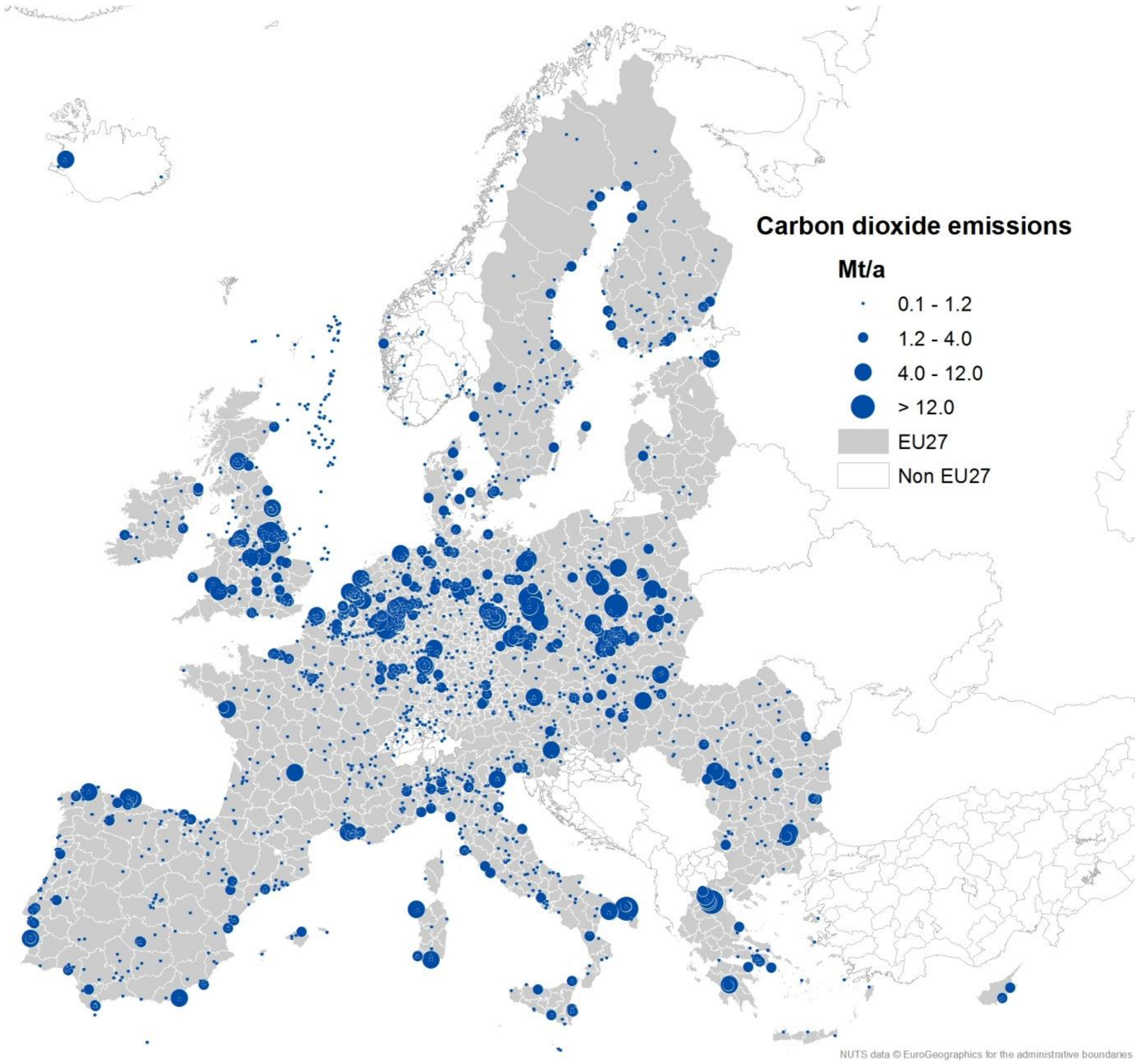


Figure 39: Major carbon dioxide emitters in Europe. Source: The E-PRTR database at EEA in Copenhagen. However, some of this information is wrong giving to high emissions compared to national aggregated emissions and the ETS. These errors must be corrected before estimating the corresponding excess heat quantities.

10.3 MAJOR COMBUSTION INSTALLATIONS FOR POWER AND HEAT GENERATION

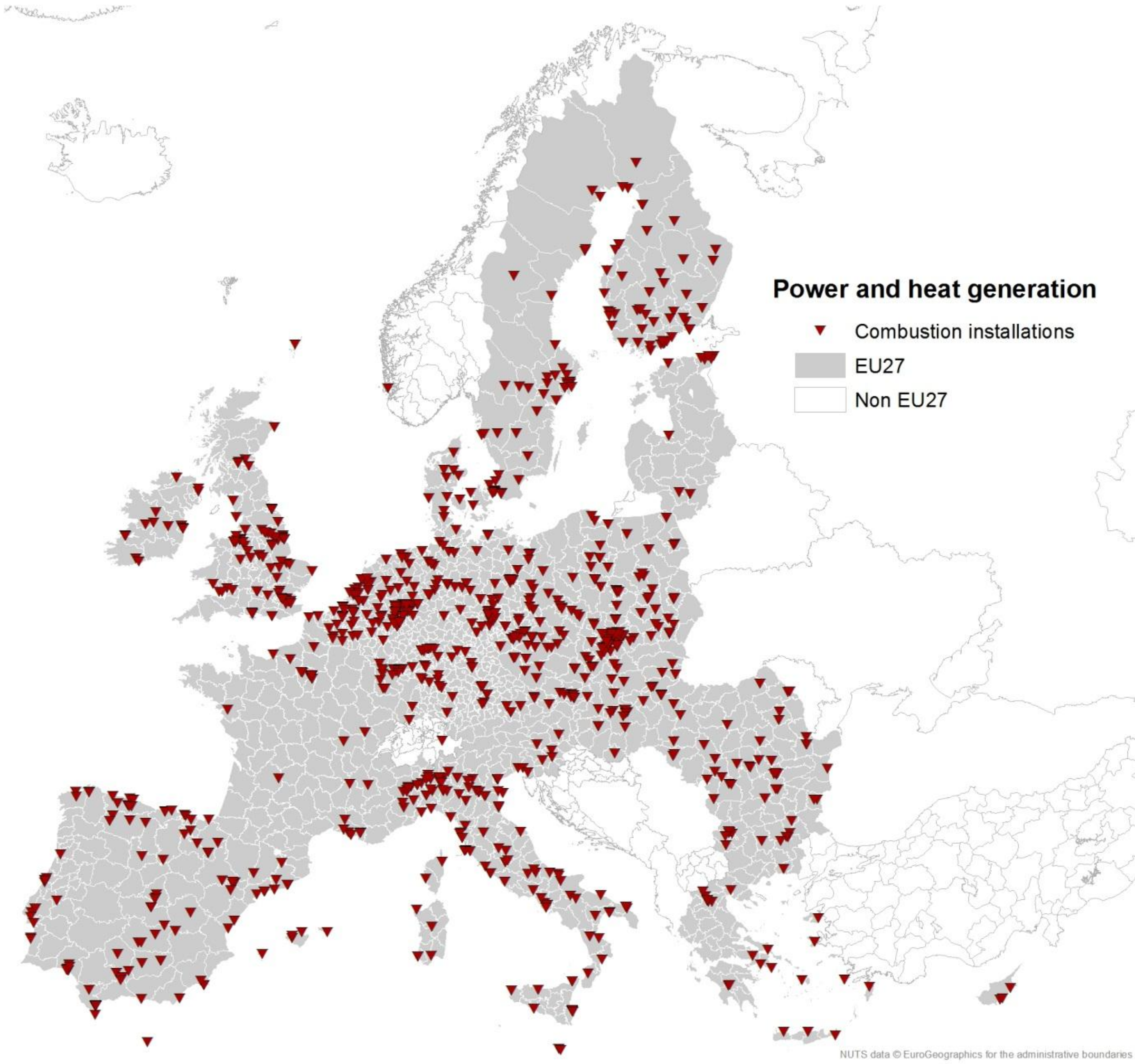


Figure 40: Major combustion installations above 50 MW for power and heat generation in Europe. Source: The E-PRTR database at EEA in Copenhagen.

10.4 WASTE-TO-ENERGY

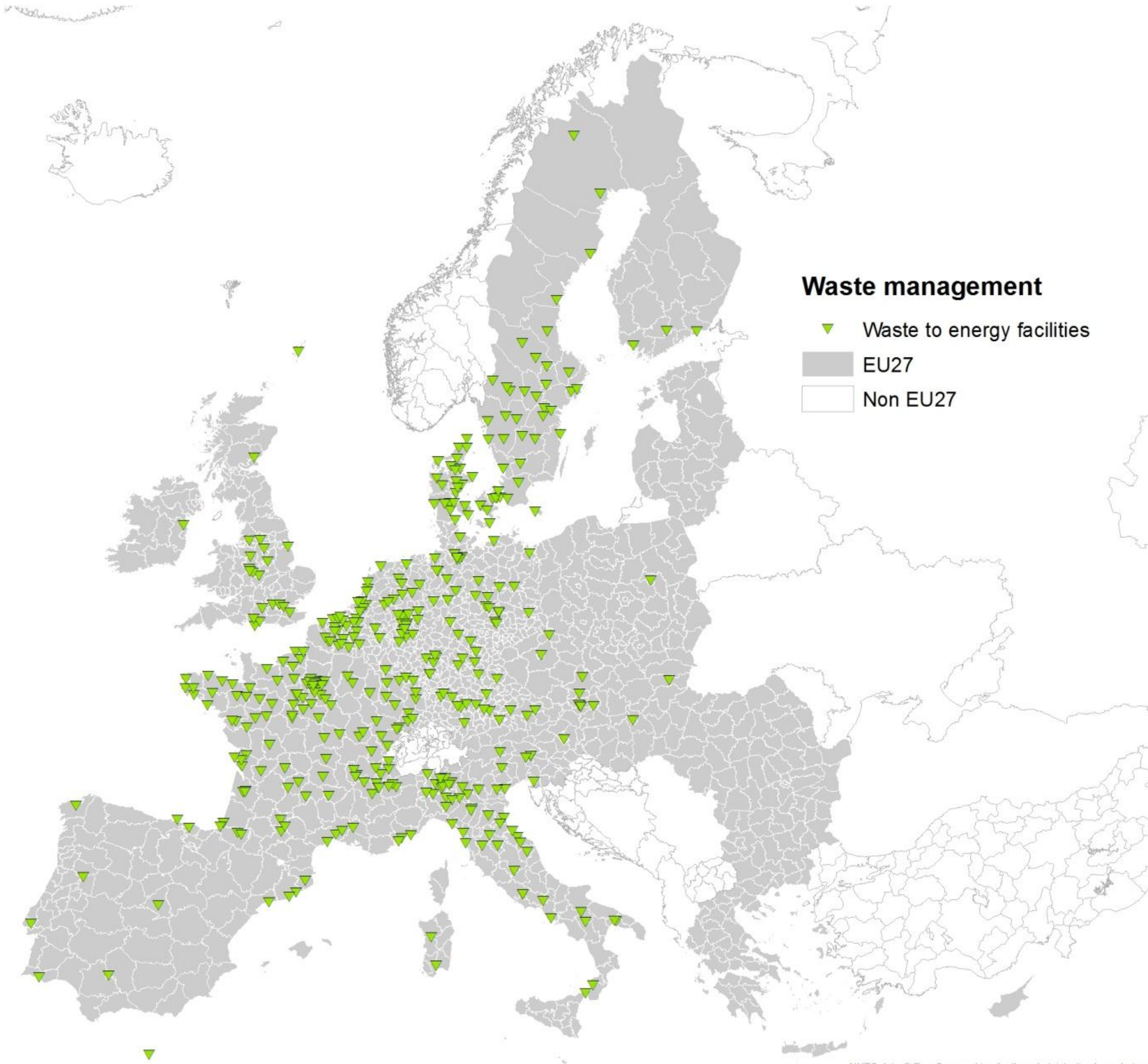


Figure 41: Locations of 414 waste incineration plants in Europe. Sources: CEWEP, E-PRTR, ISWA, and some national sources for Sweden, Denmark, and France.

10.5 INDUSTRIAL EXCESS HEAT

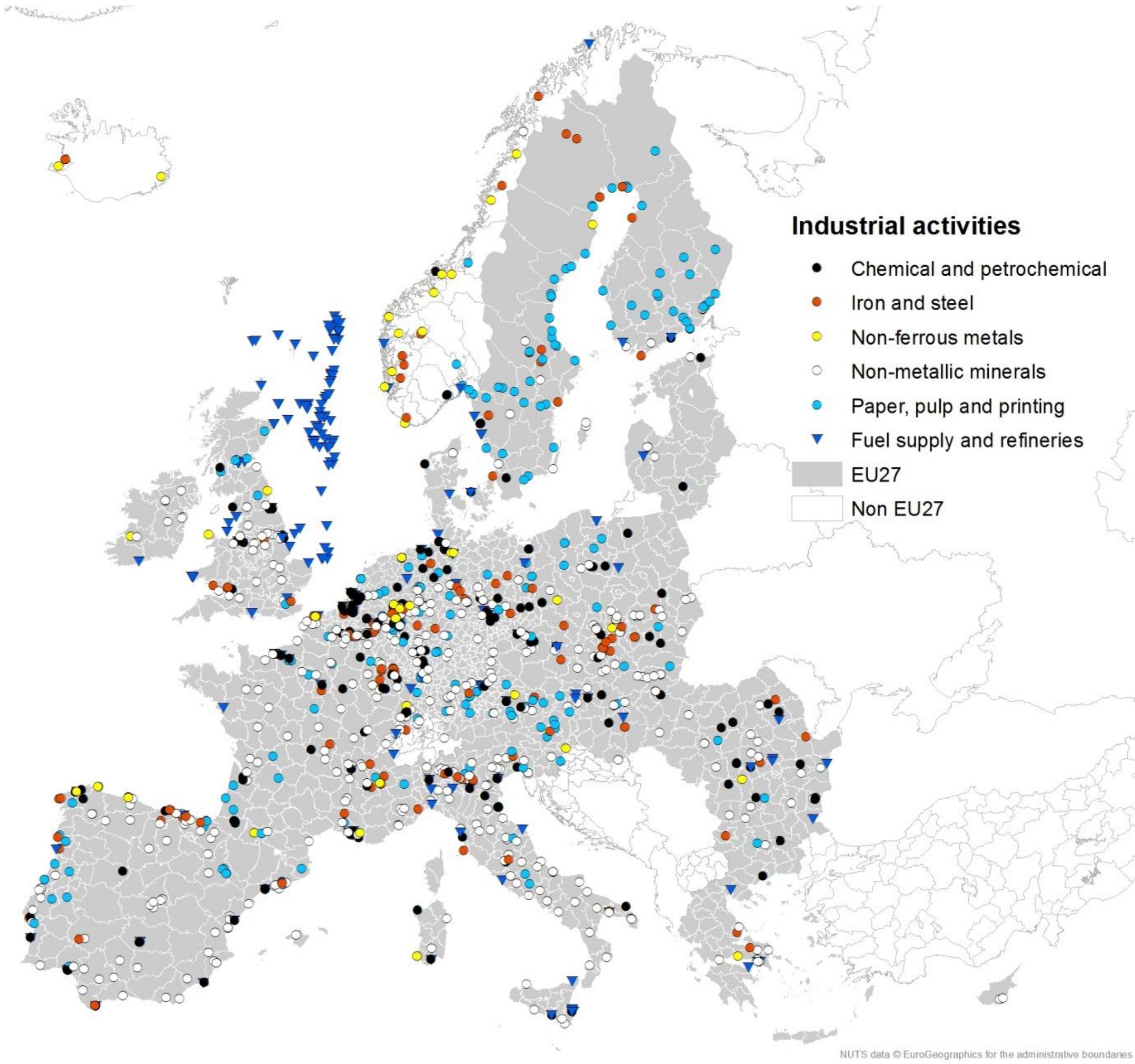


Figure 42: Locations of major energy intensive industries with considerable volumes of excess heat. Source: The E-PRTR database at EEA in Copenhagen.

10.6 GEOTHERMAL HEAT

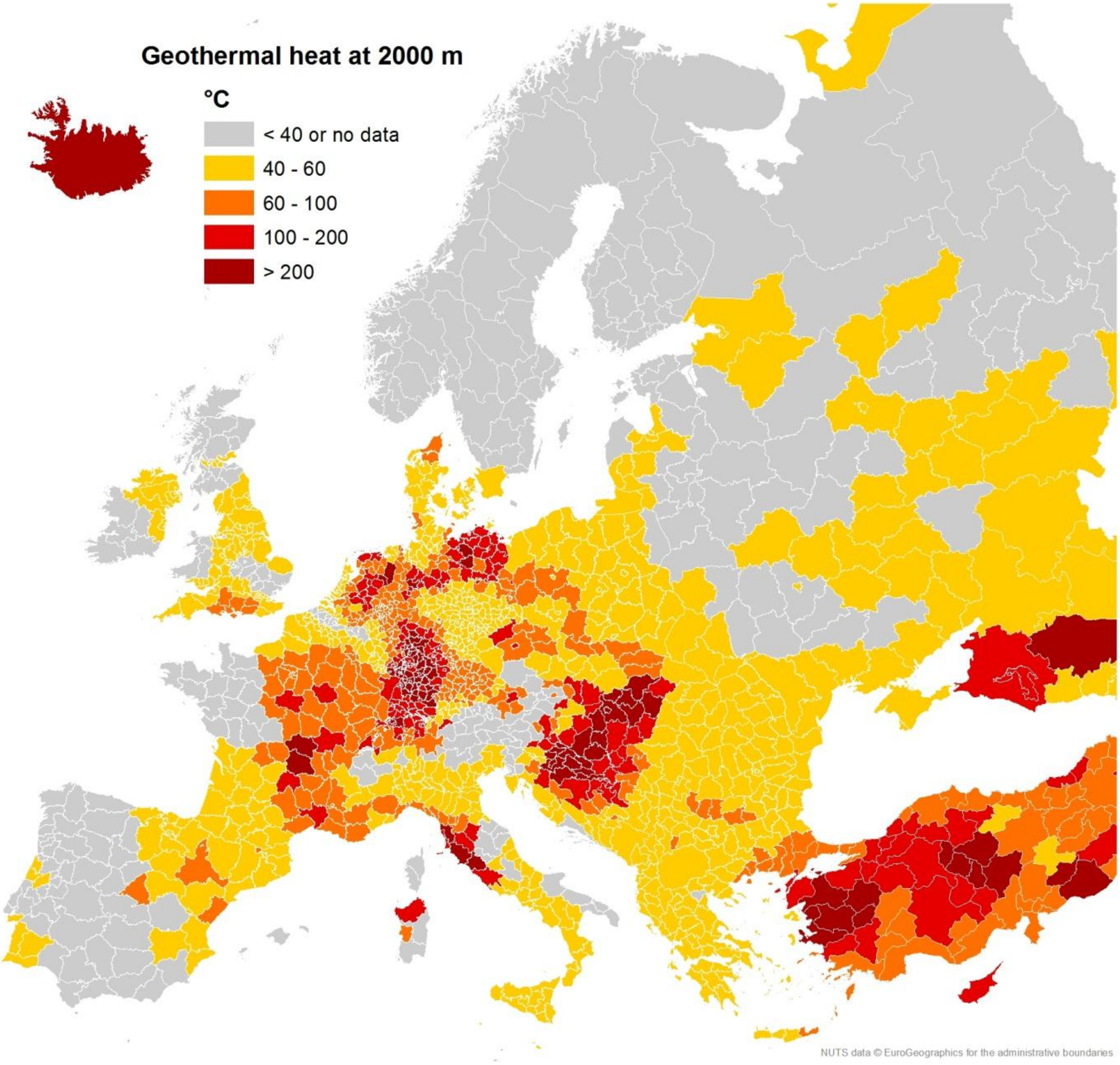


Figure 43: Identified geothermal heat resources by temperature at 2000 m depth by NUTS3 region. Source: European Commission, Atlas of Geothermal Resources in Europe. Publication EUR 17811, Luxembourg 2002.

10.7 BIOMASS

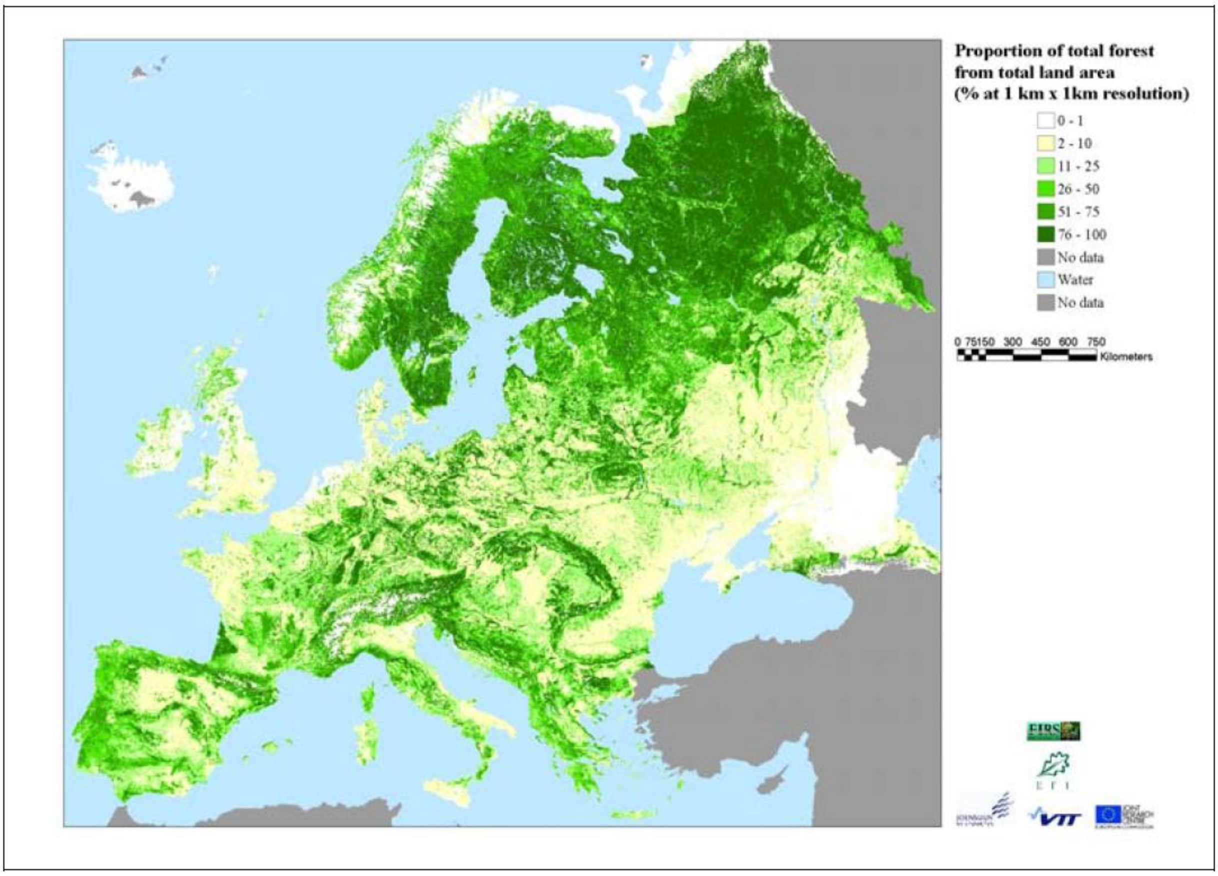


Figure 44: Proportion of forest area in various parts of Europe. Source: European Forest Institute.

10.8 SOLAR THERMAL HEAT

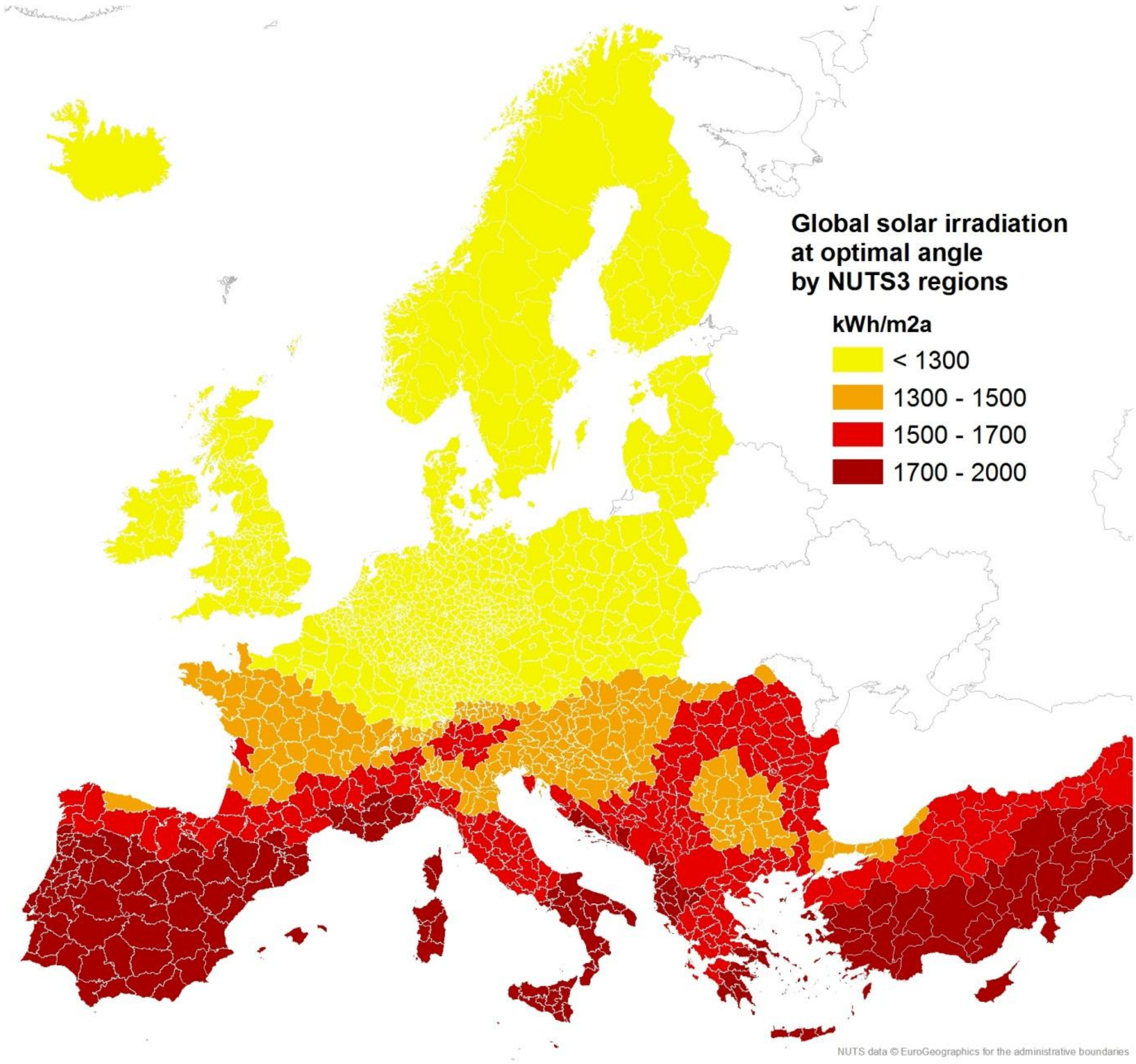


Figure 45: Annual solar irradiation on a south-oriented tilted surface at optimal angle by NUTS3 region.

11. ANNEX V: TECHNOLOGY COSTS FOR THE ENERGY SYSTEMS ANALYSIS

Table 4: Technology costs for the energy system analysis.

Production Type	Unit	Investment (M€/unit)	Lifetime (Years)	Fixed O&M (% of Investment)
Solar Thermal	TWh/year	440	20	0.001%
District Heating Piping	TWh/year	112	40	1.00%
Excess Industrial Process Heat	TWh/year	40	30	1.00%
Geothermal Heat	TWh/year	216	25	2.42%
Heat Storage	GWh	2.7	20	0.70%
Large CHP	MWe	1.35	30	2.00%
Waste CHP	TWh/year	250.45	20	1.82%
Absorption Heat Pump	MWth	1.9	25	2.42%
Centralized Boilers	MWth	0.15	20	3.00%
Large-Scale Heat Pump	MWe	2.7	20	0.20%
Wind Onshore	MWe	1.4	20	3.00%
Wind Offshore	MWe	2.7	20	2.90%
Photovoltaic	MWe	3.45	30	0.77%
Wave Power	MWe	4.285	20	3.50%
Tidal Power	MWe	3.5	20	3.00%
River Hydro	MWe	1.9	50	2.70%
Hydro Power	MWe	1.9	50	2.70%
Hydro Storage	GWh	7.5	50	1.50%
Hydro Pump	MWe	0.6	50	1.50%
Large Power Plants	MWe	0.890	26.0	1.822%
Nuclear	MWe	3	25	3.74%
Geothermal Power Plant	MWe	2.63	20	3.42%
Electrolyzer	MWe	0.57	20	2.46%
Hydrogen Storage	GWh	10	30	0.50%
Pump	MWe	0.6	50	1.50%
Turbine	MWe	0.6	50	1.50%
Pump Storage	GWh	7.5	50	1.50%
Individual Boilers	MWth	0.588	15	2.10%
Individual CHP	MWe	0.671	10	2.80%
Individual Heat Pump	MWe	1.879	15	0.60%
Individual Electric Heat	MWe	0.3	20	0.90%
Individual Solar Thermal	TWh/year	671	20	0.93%
Biogas Plant	TWh/year	376.5	20	11.25%
Gasification Plant	MWe	2.6	20	2.08%
Biodiesel Plant	MWe	0.535	20	5.19%
Bioethanol Plant	MWe	1.42	20	5.00%

Table 5: Power plant investment costs by fuel type.

Type	Investment Costs (M€/MW)	Fixed O&M Costs (€/MW/year)	Variable O&M Costs (€/MWh)	Lifetime (Years)
Solids	2.04	57200	2	40
Gas	0.87	30000	2.5	25
Oil	1.455	43600	2.25	32.5
Biomass	2.04	57200	2	40

Table 6: Renewable energy costs which were altered over the model timeframe.

Cost (M€/MW)	2010	2030	2050
Onshore Wind	1.4	1.22	1.16
Offshore Wind	2.7	2.2	2.0
PV	3.45	1.75	0.95

A 3% interest rate is used when investment costs are converted into annual costs.

12. ANNEX VI: ENERGYPLAN OUTPUT SHEETS

12.1 IEA 2010

Input EU27_2009XE_EP_IEA_New.txt — **The EnergyPLAN model 9.0**

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	2687,82	Fixed imp/exp.	0,00
Electric heating	380,54	Transportation	71,30
Electric cooling	39,64	Total	3179,30

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	84,60	0,00	317,00	401,60
Solar Thermal	0,00	0,00	0,04	0,04
Industrial CHP (CSHP)	0,00	0,00	53,00	53,00
Demand after solar and CSHP	84,60	0,00	263,97	348,56

Wind	64604 MW	134,01	TWh/year	0,00 Grid
Photo Voltaic	15307 MW	14,1	TWh/year	0,00 stabili-
Wave Power	249 MW	0,49	TWh/year	0,00 sation
River Hydro	41307 MW	163,5	TWh/year	0,00 share
Hydro Power	66008 MW	164	TWh/year	
Geothermal/Nuclear	132120 MW	899,51	TWh/year	

	Capacities MW-e	MJ/s	Efficiencies elec.	Ther	COP
Group 2:					
CHP	0	0	0,47	0,44	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	18000	29714	0,32	0,52	
Heat Pump	0	0			3,00
Boiler		121700		0,82	
Condensing	483337		0,39		

Heatstorage: gr.2: 0 GWh gr.3: 289 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	259,00	32,70

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	0,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	0	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	36000	216	0,85	
Hydro Turbine:	36000		0,85	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	4113,20	85,90	0,00
Household	130,80	747,15	1833,00	405,40
Industry	385,00	509,00	1292,00	404,00
Various	248,50	501,00	297,00	34,00

Output

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	73569	0	14619	15498	29645	0	0	13807	0	0
February	75270	2	14957	15856	29714	0	0	14738	0	3
March	64129	2	12743	13509	29714	0	0	8146	0	143
April	51388	6	10212	10825	28456	0	0	1965	0	-76
May	40318	7	8012	8493	23626	0	0	0	0	180
June	18270	9	3631	3849	10832	0	0	0	0	-49
July	18270	7	3631	3849	10784	0	0	0	0	0
August	18270	7	3631	3849	10784	0	0	0	0	0
September	28048	4	5574	5909	16562	0	0	0	0	0
October	41775	2	8301	8800	24622	0	0	0	0	49
November	54810	1	10892	11546	29515	0	0	2933	0	-77
December	65444	0	13005	13786	29714	0	0	8800	0	138
Average	45719	4	9085	9631	22809	0	0	4174	0	16
Maximum	128483	50	25532	27066	29714	0	0	48161	0	20546
Minimum	16003	0	3180	3371	3419	0	0	0	0	-11080
Total for the whole year TWh/year	401,60	0,04	79,80	84,60	200,36	0,00	0,00	36,66	0,00	0,14

Electricity

	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW
January	334537	8145	528	0	76309	0	0	57028	42005	102403	53436	17958	146689
February	331639	8121	542	0	78323	0	0	49967	30666	102403	54671	18000	162917
March	311740	8080	451	0	65127	0	0	46841	32561	102403	46579	18000	139014
April	275238	8137	346	0	50035	0	0	24681	5790	102403	37325	17238	147758
May	280789	8122	256	0	36924	0	0	24982	5068	102403	29284	14312	151589
June	290560	8086	75	0	10810	0	0	23135	6379	102403	13270	6561	168950
July	289061	8145	75	0	10810	0	0	33088	18796	102403	13270	6532	148146
August	280243	8108	75	0	10810	0	0	31240	18390	102403	13270	6533	142610
September	292297	8088	155	0	22391	0	0	26471	9130	102403	20373	10033	163160
October	300575	8154	267	0	38650	0	0	23611	7375	102403	30343	14915	170537
November	334104	8102	374	0	54089	0	0	30922	9456	102403	39811	17880	196487
December	351737	8113	461	0	66684	0	0	54140	37782	102403	47534	18000	167137
Average	305991	8117	300	0	43322	0	0	35530	18670	102403	33208	13817	158614
Maximum	475011	15813	978	0	141351	0	0	106163	54745	102403	93322	18000	319399
Minimum	171118	0	56	0	8125	0	0	0	0	102403	11624	2071	0
Total for the whole year TWh/year	2687,82	71,30	2,63	0,00	380,54	0,00	0,00	312,10	164,00	899,51	291,70	121,37	1393,26

Electricity Balance and Exchange

	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million EUR)	Exp (Million EUR)
January	244	0	0	0	0	0	0
February	249	0	0	0	0	0	0
March	252	0	0	0	0	0	0
April	271	0	0	0	0	0	0
May	277	0	0	0	0	0	0
June	296	0	0	0	0	0	0
July	286	0	0	0	0	0	0
August	287	0	0	0	0	0	0
September	286	0	0	0	0	0	0
October	282	0	0	0	0	0	0
November	273	0	0	0	0	0	0
December	253	0	0	0	0	0	0
Average	271	0	0	0	0	Average price (EUR/MWh)	
Maximum	321	0	0	0	0		
Minimum	168	0	0	0	0	0	0
Total for the whole year TWh/year		0,00	0,00	0,00	0,00	Million EUR 0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Elc./gas	Waste	CAES	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	44,84	-	205,90	-	0,00	2075,70	-	-	-	-	-	-	-	-	-	-	-	130,80	385,00	248,50	3090,74	0,00	3090,74	1095,98	1095,98
Oil	-	-	13,80	-	11,30	180,30	-	-	-	-	-	-	-	-	-	-	4113,20	730,19	509,00	501,00	6058,79	0,00	6058,79	1590,07	1590,07
N.Gas	31,45	-	140,80	-	33,41	1124,67	-	-	-	-	-	-	-	-	-	-	85,90	1833,00	1292,00	297,00	4838,23	0,00	4838,23	991,65	1004,02
Biomass	30,80	-	24,80	-	0,00	191,80	-	-	166,63	105,24	-	-	-	-	-	-	-	405,40	404,00	34,00	1362,67	0,00	1362,67	12,31	0,00
Renewable	-	-	-	-	-	-	54,98	164,00	-	-	-	134,01	14,10	0,49	163,50	13,64	-	-	-	-	544,71	0,00	544,71	0,00	0,00
H2 etc.	-	-	0,00	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear	-	-	-	-	-	-	2711,58	-	-	-	-	-	-	-	-	-	-	-	-	-	2711,58	0,00	2711,58	0,00	0,00
Total	107,09	-	385,30	-	44,71	3572,47	2766,57	164,00	166,63	105,24	-	134,01	14,10	0,49	163,50	13,64	4199,10	3099,39	2590,00	1080,50	18606,73	0,00	18606,73	3690,01	3690,07

23-april-2012 [11:42]

12.2 EP CPI 2030

Input EU27_2030XE_New.txt — **The EnergyPLAN model 9.0**

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	3166,93	Fixed imp/exp.	0,00
Electric heating	445,60	Transportation	116,00
Electric cooling	46,40	Total	3774,93

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	47,10	0,00	329,10	376,20
Solar Thermal	0,00	0,00	0,04	0,04
Industrial CHP (CSHP)	0,00	0,00	87,00	87,00
Demand after solar and CSHP	47,10	0,00	242,07	289,17

Wind	317537 MW	807,20	TWh/year	0,00	Grid
Photo Voltaic	95654 MW	129	TWh/year	0,00	stabili-
Wave Power	4130 MW	8,6	TWh/year	0,00	sation
River Hydro	45253 MW	179,12	TWh/year	0,00	share
Hydro Power	72314 MW	185,4	TWh/year		
Geothermal/Nuclear	102507 MW	790,4	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,47	0,44	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	13800	21421	0,34	0,52	
Heat Pump	0	0			3,00
Boiler		126346		0,83	
Condensing	486617		0,42		

Heatstorage: gr.2: 0 GWh gr.3: 300 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	401,00	80,18

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	1,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	0,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	0	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	36000	216	0,85	
Hydro Turbine:	36000		0,85	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	3920,80	62,00	0,00
Household	61,60	592,10	1678,25	429,21
Industry	569,00	346,00	1240,00	603,00
Various	201,00	1489,00	248,00	0,00

Output WARNING!!: (1) Critical Excess;

	District Heating Demand	District Heating Production									Electricity Consumption						Electricity Production							Electricity Balance					Exchange Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp
January	68916	0	28853	8628	20482	0	0	10952	0	0	393692	13252	1711	0	89355	4654	3560	161689	47486	89982	88147	13195	116010	175	0	17406	17406	0	0	0
February	70509	2	29520	8828	20815	0	0	11343	0	1	390246	13212	1756	0	91713	3108	2246	161032	34668	89982	90184	13410	118862	169	0	10347	10347	0	0	0
March	60073	2	25150	7521	20579	0	0	6811	0	9	366966	13145	1460	0	76261	3117	2252	141409	36810	89982	76835	13258	107629	180	0	7224	7224	0	0	0
April	48137	6	20154	6027	20541	0	0	1566	0	-156	324146	13239	1122	0	58590	3818	2758	119225	6546	89982	61570	13233	120239	191	0	10957	10957	0	0	0
May	37768	7	15812	4729	17027	0	0	0	0	193	330878	13214	828	0	43237	2809	2029	125205	5729	89982	48307	10969	129394	198	0	18839	18839	0	0	0
June	17115	9	7165	2143	7831	0	0	0	0	-33	342854	13155	242	0	12658	1463	1057	112080	7211	89982	21891	5045	147226	219	0	1047	1047	0	0	0
July	17115	7	7165	2143	7684	0	0	0	0	116	341111	13252	242	0	12658	2543	1837	110441	21249	89982	21891	4950	140340	224	0	4326	4326	0	0	0
August	17115	7	7165	2143	7924	0	0	0	0	-124	330722	13191	242	0	12658	1394	1007	102496	20790	89982	21891	5105	135883	227	0	1141	1141	0	0	0
September	26274	4	11000	3290	12011	0	0	0	0	-31	344717	13158	502	0	26219	2682	1938	110980	10322	89982	33606	7738	149125	217	0	6301	6301	0	0	0
October	39133	2	16384	4899	17642	0	0	0	0	205	354187	13266	867	0	45258	2396	1621	102204	8338	89982	50053	11366	160568	215	0	6357	6357	0	0	0
November	51343	1	21496	6428	21287	0	0	2354	0	-222	393498	13182	1213	0	63336	3483	2630	131534	10690	89982	65670	13714	167818	195	0	6989	6989	0	0	0
December	61305	0	25666	7675	20849	0	0	7018	0	96	414112	13200	1495	0	78085	4591	3119	158015	42713	89982	78411	13432	134876	183	0	9065	9065	0	0	0
Average	42828	4	17931	5362	16206	0	0	3319	0	6	360534	13206	971	0	50729	3006	2172	127950	21107	89982	54779	10441	135642	200	0	8344	8344	0	Average price	
Maximum	120357	50	50390	15069	21421	0	0	42761	0	27529	559739	25726	3170	0	165518	36000	36000	422593	61890	89982	153942	13800	377401	316	0	345004	345004	0	(EUR/MWh)	
Minimum	14991	0	6276	1877	0	0	0	0	0	-7940	201290	0	182	0	9514	0	0	0	0	89982	19174	0	0	100	0	0	0	0	0	0
Total for the whole year TWh/year	376,20	0,04	157,50	47,10	142,36	0,00	0,00	29,15	0,00	0,0[illegible]	3166,93	116,00	8,53	0,00	445,60	26,40	19,0[illegible]	1123,91	185,40	790,40	481,18	91,71	1191,48		0,00	73,30	73,30	0,00	Million EUR 0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Elc./gas	Waste	CAES	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	17,59	-	71,98	-	-	1350,44	-	-	-	-	-	-	-	-	-	-	-	61,60	569,00	201,00	2271,61	-83,04	2188,57	805,51	776,07
Oil	0,00	-	16,90	-	3,10	83,60	-	-	-	-	-	-	-	-	-	-	3920,80	592,10	346,00	1489,00	6451,50	-5,16	6446,34	1693,1[illegible]	1691,78
N.Gas	31,48	-	94,88	-	32,03	1082,52	-	-	-	-	-	-	-	-	-	-	62,00	1509,71	1240,00	248,00	4300,62	-66,56	4234,05	881,46	878,89
Biomass	9,80	-	90,00	-	-	320,30	-	-	474,85	258,63	-	-	-	-	-	-	-	394,60	603,00	-	2151,18	-19,76	2131,42	30,26	0,00
Renewable	-	-	-	-	-	-	83,03	185,40	-	-	-	807,20	129,00	8,60	179,12	174,26	-	-	-	-	1566,61	0,00	1566,61	0,00	0,00
H2 etc.	-	-	0,00	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear	-	-	-	-	-	-	2301,31	-	-	-	-	-	-	-	-	-	-	-	-	-	2301,31	0,00	2301,31	0,00	0,00
Total	58,87	-	273,76	-	35,13	2836,86	2384,34	185,40	474,85	258,63	-	807,20	129,00	8,60	179,12	174,26	3982,80	2558,01	2758,00	1938,00	19042,83	-174,51	18868,32	3410,37	3346,74

23-april-2012 [11:36]

Input EU27_2050XE_New.txt

The EnergyPLAN model 9.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	3777,59	Fixed imp/exp.	0,00
Electric heating	528,30	Transportation	255,00
Electric cooling	55,00	Total	4615,89

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	32,10	0,00	301,60	333,70
Solar Thermal	0,00	0,00	0,04	0,04
Industrial CHP (CSHP)	0,00	0,00	105,00	105,00
Demand after solar and CSHP	32,10	0,00	196,57	228,67

Wind	431501 MW	1139,82	TWh/year	0,00	Grid
Photo Voltaic	223547 MW	312	TWh/year	0,00	stabili-
Wave Power	6523 MW	12,8	TWh/year	0,00	sation
River Hydro	49927 MW	194,39	TWh/year	0,00	share
Hydro Power	72314 MW	189,2	TWh/year		
Geothermal/Nuclear	117971 MW	961,26	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,47	0,44	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	9600	14062	0,35	0,52	
Heat Pump	0	0			3,00
Boiler		115788		0,83	
Condensing	600885		0,48		

Heatstorage: gr.2: 0 GWh gr.3: 275 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	509,00	79,69

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	1,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	0,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	0	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	36000	216	0,85	
Hydro Turbine:	36000		0,85	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	3583,10	31,00	0,00
Household	61,90	510,00	1456,33	417,94
Industry	571,00	433,00	1369,00	661,00
Various	208,00	1328,00	305,00	73,50

Output WARNING!!: (1) Critical Excess;

	District Heating									Electricity																			Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	61131	0	31337	5880	13831	0	0	10082	0	0	469844	29131	1811	0	105939	6033	4583	218027	48459	109434	107842	9442	151577	170	0	36605	36605	0	0	0
February	62544	2	32061	6016	14026	0	0	10438	0	0	465759	29044	1859	0	108735	5954	4302	227258	35378	109434	110334	9576	143793	159	0	28724	28724	0	0	0
March	53286	2	27316	5126	13848	0	0	6995	0	0	437896	28897	1546	0	90414	5100	3685	203898	37564	109434	94003	9454	131316	169	0	25497	25497	0	0	0
April	42699	6	21889	4107	14015	0	0	2708	0	-26	386748	29102	1188	0	69464	6979	5043	187566	6680	109434	75326	9568	139931	176	0	38073	38073	0	0	0
May	33501	7	17173	3223	12761	0	0	222	0	116	394641	29049	877	0	51261	5636	4072	205617	5846	109434	59100	8712	137688	175	0	46857	46857	0	0	0
June	15181	9	7782	1460	6014	0	0	0	0	-84	408723	28919	257	0	15007	4675	3377	181588	7359	109434	26782	4106	153906	196	0	13476	13476	0	0	0
July	15181	7	7782	1460	5912	0	0	0	0	20	406668	29131	257	0	15007	4993	3607	177528	21684	109434	26782	4036	156147	205	0	23534	23534	0	0	0
August	15181	7	7782	1460	5945	0	0	0	0	-13	394299	28998	257	0	15007	3187	2303	152527	21216	109434	26782	4058	154929	212	0	8396	8396	0	0	0
September	23306	4	11947	2242	9119	0	0	0	0	-7	411037	28925	532	0	31086	4213	2997	167068	10533	109434	41114	6226	169941	202	0	19536	19536	0	0	0
October	34712	2	17794	3339	13216	0	0	411	0	-51	422426	29163	917	0	53657	3327	2329	150256	8508	109434	61236	9023	189054	204	0	18213	18213	0	0	0
November	45543	1	23346	4381	14062	0	0	3704	0	49	469399	28978	1284	0	75091	5334	3978	184769	10909	109434	80343	9600	202591	187	0	21138	21138	0	0	0
December	54379	0	27876	5231	14020	0	0	7245	0	7	494078	29017	1583	0	92577	6472	4452	211663	43588	109434	95931	9571	172542	177	0	23454	23454	0	0	0
Average	37990	4	19474	3654	11390	0	0	3466	0	1	430054	29030	1028	0	60143	5153	3723	188867	21539	109434	67018	7776	158612	186	0	25298	25298	0	Average price	
Maximum	106760	50	54728	10270	14062	0	0	30170	0	11420	667392	56552	3355	0	196237	36000	36000	657570	63158	109434	188337	9600	464151	316	0	626623	626623	0	(EUR/MWh)	
Minimum	13298	0	6817	1279	0	0	0	0	0	-4402	240417	0	193	0	11279	0	0	0	0	109434	23458	0	0	100	0	0	0	0	0	0
Total for the whole year TWh/year	333,70	0,04	171,06	32,10	100,05	0,00	0,00	30,45	0,00	0,01	3777,59	255,00	9,03	0,00	528,30	45,26	32,70	1659,00	189,20	961,26	588,69	68,30	1393,25		0,00	222,21	222,21	0,00	Million EUR 0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Elc./gas	Waste	CAES	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt): Total	CO2 emission (Mt): Netto
Coal	3,00	-	46,83	-	-	1116,75	-	-	-	-	-	-	-	-	-	-	-	61,90	571,00	208,00	2007,48	-170,17	1837,31	711,85	651,51
Oil	-	-	17,50	-	5,30	133,70	-	-	-	-	-	-	-	-	-	-	3583,10	510,00	433,00	1328,00	6010,60	-25,91	5984,69	1577,42	1570,62
N.Gas	31,74	-	74,97	-	31,38	1262,62	-	-	-	-	-	-	-	-	-	-	31,00	1283,00	1369,00	305,00	4388,72	-192,40	4196,32	899,26	865,58
Biomass	4,40	-	53,10	-	-	359,60	-	-	556,21	257,05	-	-	-	-	-	-	-	365,40	661,00	73,50	2330,26	-69,69	2260,57	30,07	0,00
Renewable	-	-	-	-	-	-	91,96	189,20	-	-	-	1139,82	312,00	12,80	194,39	191,08	-	-	-	-	2131,24	0,00	2131,24	0,00	0,00
H2 etc.	-	-	0,00	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear	-	-	-	-	-	-	2544,69	-	-	-	-	-	-	-	-	-	-	-	-	-	2544,69	0,00	2544,69	0,00	0,00
Total	39,15	-	192,40	-	36,68	2872,67	2636,65	189,20	556,21	257,05	-	1139,82	312,00	12,80	194,39	191,08	3614,10	2220,30	3034,00	1914,50	19412,99	-458,17	18954,82	3218,61	3087,71

23-april-2012 [11:34]

12.4 HRE 2030 RE

Input EU27_2030XE_30%DH_RE_New.txt — **The EnergyPLAN model 9.0**

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	3166,93	Fixed imp/exp.	0,00
Electric heating	445,60	Transportation	116,00
Electric cooling	46,40	Total	3774,93

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	47,10	358,50	713,70	1119,30
Solar Thermal	0,00	9,30	18,60	27,90
Industrial CHP (CSHP)	0,00	0,00	170,00	170,00
Demand after solar and CSHP	47,10	349,20	525,10	921,40

Wind	317537 MW	807,20	TWh/year	0,00	Grid
Photo Voltaic	95654 MW	129	TWh/year	0,00	stabili-
Wave Power	4130 MW	8,6	TWh/year	0,00	sation
River Hydro	45253 MW	179,12	TWh/year	0,00	share
Hydro Power	72314 MW	185,4	TWh/year		
Geothermal/Nuclear	102507 MW	790,4	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	70000	65487	0,47	0,44	
Heat Pump	6000	18000			3,00
Boiler		137633		0,90	
Group 3:					
CHP	70000	108657	0,34	0,52	
Heat Pump	0	0			3,00
Boiler		274000		0,83	
Condensing	410000		0,42		

Heatstorage: gr.2: 327 GWh gr.3: 650 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	401,00	124,80

Regulation Strategy:	Technical regulation no. 2
KEOL regulation	00000000
Minimum Stabilisation share	0,29
Stabilisation share of CHP	1,00
Minimum CHP gr 3 load	0 MW
Minimum PP	0 MW
Heat Pump maximum share	0,50
Maximum import/export	0 MW
Distr. Name :	Hour_nordpool.txt
Addition factor	0,00 EUR/MWh
Multiplication factor	0,00
Dependency factor	0,00 EUR/MWh pr. MW
Average Market Price	0 EUR/MWh
Gas Storage	0 GWh
Syngas capacity	0 MW
Biogas max to grid	0 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	36000	216	0,85	
Hydro Turbine:	36000		0,85	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,0(	3920,80	62,00	0,00
Household	41,20	395,9(	1175,00	429,21
Industry	569,00	346,0(	1240,00	603,00
Various	228,0(	1395,00	401,00	7,30

Output WARNING!!: (1) Critical Excess;

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	205045	253	79679	8628	80475	8943	0	27465	0	-397
February	209784	1377	81520	8828	83042	8969	0	24719	0	1328
March	178733	1916	69454	7521	82157	6989	0	11682	0	-986
April	143222	4795	55655	6027	64838	4669	0	7544	0	-306
May	112370	5357	43666	4729	52935	3543	0	1773	0	368
June	50921	7053	19788	2143	22106	696	0	0	0	-864
July	50921	5713	19788	2143	21930	1621	0	0	0	-273
August	50921	5473	19788	2143	23314	897	0	0	0	-693
September	78173	3468	30377	3290	38821	2221	0	0	0	-3
October	116431	1820	45244	4899	58022	2850	0	2462	0	1133
November	152761	560	59361	6428	76025	4579	0	7163	0	-1356
December	182398	315	70878	7675	78526	7479	0	16449	0	1075
Average	127425	3176	49516	5362	56776	4445	0	8232	0	-83
Maximum	358096	40084	139152	15069	174144	18000	0	183470	0	103923
Minimum	44603	0	17332	1877	0	0	0	0	0	-89982
Total for the whole year TWh/year	1119,30	27,90	434,95	47,10	498,72	39,05	0,00	72,31	0,00	-0,73

Electricity / Exchange

	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp (Million EUR)	Exp
January	393692	13252	4692	0	89355	3557	2817	161689	47486	89982	96321	69809	54676	177	0	18233	18233	0	0	0
February	390246	13212	4746	0	91713	2865	1806	161032	34668	89982	98547	71986	55233	170	0	10472	10472	0	0	0
March	366966	13145	3790	0	76261	2117	1776	141409	36810	89982	83961	71388	44882	182	0	7927	7927	0	0	0
April	324146	13239	2678	0	58590	3413	2466	119225	6546	89982	67279	56602	72445	193	0	10797	10797	0	0	0
May	330878	13214	2009	0	43237	2732	1974	125205	5729	89982	52786	46390	89676	201	0	17861	17861	0	0	0
June	342854	13155	475	0	12658	1373	992	112080	7211	89982	23921	19863	130368	225	0	830	830	0	0	0
July	341111	13252	783	0	12658	2414	1744	110441	21249	89982	23921	19553	123776	230	0	3890	3890	0	0	0
August	330722	13191	541	0	12658	1281	925	102496	20790	89982	23921	20805	118222	233	0	943	943	0	0	0
September	344717	13158	1242	0	26219	2544	1838	110980	10322	89982	36722	34204	119549	221	0	5606	5606	0	0	0
October	354187	13266	1817	0	45258	2132	1296	102204	8338	89982	54694	50781	117208	219	0	6044	6044	0	0	0
November	393498	13182	2739	0	63336	2969	2398	131534	10690	89982	71760	66102	110566	198	0	6970	6970	0	0	0
December	414112	13200	3988	0	78085	3810	2506	158015	42713	89982	85682	67683	76012	185	0	9399	9399	0	0	0
Average	360534	13206	2453	0	50729	2599	1878	127950	21107	89982	59858	49534	92753	203	0	8259	8259	0	Average price (EUR/MWh)	
Maximum	559739	25726	9170	0	165518	36000	36000	422593	61890	89982	168217	140000	316542	325	0	336736	336736	0		
Minimum	201290	0	182	0	9514	0	0	0	0	89982	20952	0	0	100	0	0	0	0	0	0
Total for the whole year TWh/year	3166,93	116,00	21,55	0,00	445,60	22,83	16,50	1123,91	185,40	790,40	525,80	435,11	814,74		0,00	72,55	72,55	0,00	Million EUR 0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Elc./gas	Waste	CAES	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	17,59	-	88,45	-	-	625,43	-	-	-	-	-	-	-	-	-	-	-	41,20	569,00	228,00	1569,67	-62,68	1506,99	556,61	534,38
Oil	0,00	-	16,90	-	3,10	83,60	-	-	-	-	-	-	-	-	-	-	3920,80	395,90	346,00	1395,00	6161,30	-3,89	6157,41	1616,97	1615,95
N.Gas	31,48	609,51	248,34	46,61	33,48	910,53	-	-	-	-	-	-	-	-	-	-	62,00	1009,55	1240,00	401,00	4592,51	-91,25	4501,25	941,25	933,62
Biomass	9,80	-	90,00	-	-	320,30	-	-	474,85	443,80	-	-	-	-	-	-	-	394,60	603,00	7,30	2343,65	-14,91	2328,74	51,92	0,00
Renewable	-	-	-	-	-	-	83,03	185,40	-	-	-	807,20	129,00	8,60	179,12	199,38	-	-	-	-	1591,72	0,00	1591,72	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear	-	-	-	-	-	-	2301,31	-	-	-	-	-	-	-	-	-	-	-	-	-	2301,31	0,00	2301,31	0,00	0,00
Total	58,87	609,51	443,69	46,61	36,58	1939,86	2384,34	185,40	474,85	443,80	-	807,20	129,00	8,60	179,12	199,38	3982,80	1841,25	2758,00	2031,30	18560,17	-172,74	18387,43	3166,76	3083,95

23-april-2012 [11:38]

Input EU27_2050XE_50%DH_RE_New.txt — The EnergyPLAN model 9.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	3777,59	Fixed imp/exp.	0,00
Electric heating	528,30	Transportation	255,00
Electric cooling	55,00	Total	4615,89

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	32,10	673,90	996,10	1702,10
Solar Thermal	0,00	18,50	37,00	55,50
Industrial CHP (CSHP)	0,00	0,00	272,00	272,00
Demand after solar and CSHP	32,10	655,40	687,10	1374,60

Wind	431501	MW	1139,82	TWh/year	0,00 Grid
Photo Voltaic	223547	MW	312	TWh/year	0,00 stabili-
Wave Power	6523	MW	12,8	TWh/year	0,00 sation
River Hydro	49927	MW	194,39	TWh/year	0,00 share
Hydro Power	72314	MW	189,2	TWh/year	
Geothermal/Nuclear	117971	MW	961,26	TWh/year	

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	160000	149685	0,47	0,44	
Heat Pump	15000	45000			3,00
Boiler		258720		0,90	
Group 3:					
CHP	9600	14062	0,35	0,52	
Heat Pump	8000	24000			3,00
Boiler		382417		0,83	
Condensing	450000		0,48		

Heatstorage: gr.2: 614 GWh gr.3: 907 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,00
Gr.3:	509,00	168,77

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0,30	
Stabilisation share of CHP	1,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	0,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	0	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	36000	216	0,85	
Hydro Turbine:	36000		0,85	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	3583,10	31,00	0,00
Household	16,90	139,40	474,30	417,94
Industry	571,00	433,00	1445,00	661,00
Various	132,00	1328,00	305,00	73,50

Output WARNING!!: (1) Critical Excess;

	DH Demand: Distr. heating MW	DH Prod.: Solar MW	Waste+CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	El. Cons.: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	El. Prod.: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million EUR)	Exp (Million EUR)
January	311809	503	133247	5880	89932	43705	0	38904	0	-361	469844	29131	16380	0	105939	4893	3734	218027	48459	109434	124161	92155	68462	166	0	38245	38245	0	0	0
February	319016	2740	136327	6016	89493	44771	0	38787	0	882	465759	29044	16783	0	108735	5535	3735	227258	35378	109434	127031	91618	61332	155	0	29931	29931	0	0	0
March	271796	3811	116148	5126	86147	43153	0	17364	0	49	437896	28897	15930	0	90414	3629	2637	203898	37564	109434	108228	87798	53822	165	0	26613	26613	0	0	0
April	217796	9539	93072	4107	70118	33050	0	8957	0	-1048	386748	29102	12205	0	69464	6218	4605	187566	6680	109434	86726	70868	77852	172	0	38000	38000	0	0	0
May	170879	10657	73023	3223	58816	23984	0	2287	0	-1111	394641	29049	8871	0	51261	5470	4075	205617	5846	109434	68043	58911	85101	171	0	45587	45587	0	0	0
June	77435	14030	33091	1460	28848	4322	0	0	0	-4317	408723	28919	1697	0	15007	4426	3198	181588	7359	109434	30834	28203	127113	194	0	13461	13461	0	0	0
July	77435	11365	33091	1460	29107	5502	0	0	0	-3090	406668	29131	2091	0	15007	4921	3550	177528	21684	109434	30834	28362	129048	202	0	22994	22994	0	0	0
August	77435	10887	33091	1460	30528	4431	0	0	0	-2962	394299	28998	1734	0	15007	3014	2182	152527	21216	109434	30834	29806	126296	209	0	8139	8139	0	0	0
September	118877	6898	50800	2242	48221	11368	0	0	0	-653	411037	28925	4321	0	31086	3926	2620	167068	10533	109434	47336	47424	125726	199	0	18861	18861	0	0	0
October	177055	3621	75662	3339	68978	21658	0	3123	0	673	422426	29163	8137	0	53657	3000	2130	150256	8508	109434	70503	69057	126182	200	0	17553	17553	0	0	0
November	232300	1115	99270	4381	83193	34513	0	10707	0	-878	469399	28978	12788	0	75091	4387	3424	184769	10909	109434	92501	84038	127105	183	0	21137	21137	0	0	0
December	277370	627	118530	5231	85144	41109	0	26025	0	705	494078	29017	15286	0	92577	5304	3634	211663	43588	109434	110448	86705	95156	173	0	24365	24365	0	0	0
Average	193773	6318	82806	3654	63975	25917	0	12113	0	-1012	430054	29030	9668	0	60143	4553	3289	188867	21539	109434	77160	64507	100324	183	0	25410	25410	0	Average price	
Maximum	544550	79737	232705	10270	163747	69000	0	232575	0	101547	667392	56552	26355	0	196237	36000	36000	657570	63158	109434	216838	169600	366552	314	0	627499	627499	0	(EUR/MWh)	
Minimum	67826	0	28985	1279	0	0	0	0	0	-67588	240417	0	193	0	11279	0	0	0	0	109434	27008	0	0	100	0	0	0	0	0	0
Total for the whole year TWh/year	1702,10	55,50	727,37	32,10	561,96	227,66	0,00	106,40	0,00	-8,85	3777,59	255,00	84,92	0,00	528,30	39,99	28,85	1659,00	189,20	961,26	677,77	566,63	881,25		0,00	223,20	223,20	0,00	Million EUR 0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Elc./gas	Waste	CAES	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry	Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	3,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16,90	571,00	132,00	722,90	0,00	722,90	256,34	256,34
Oil	-	-	17,50	-	5,30	133,70	-	-	-	-	-	-	-	-	-	-	3583,10	139,40	433,00	1328,00	5640,00	-1,73	5638,27	1480,1[illegible]	1479,71
N.Gas	31,74	1077,52	98,96	80,08	36,07	1323,70	-	-	-	-	-	-	-	-	-	-	31,00	350,80	1445,00	305,00	4779,87	-453,82	4326,06	979,38	892,16
Biomass	4,40	-	53,10	-	-	359,60	-	-	556,21	627,40	-	-	-	-	-	-	-	365,40	661,00	73,50	2700,61	-4,66	2695,95	73,41	0,00
Renewable	-	-	-	-	-	-	91,96	189,20	-	-	-	1139,82	312,00	12,80	194,39	202,19	-	-	-	-	2142,36	0,00	2142,36	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear	-	-	-	-	-	-	2544,69	-	-	-	-	-	-	-	-	-	-	-	-	-	2544,69	0,00	2544,69	0,00	0,00
Total	39,15	1077,52	169,56	80,08	41,37	1817,00	2636,65	189,20	556,21	627,40	-	1139,82	312,00	12,80	194,39	202,19	3614,10	872,50	3110,00	1838,50	18530,43	-460,21	18070,22	2789,25	2628,21

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13. ANNEX VII: DATA USED TO CREATE FIGURES WITH RESULTS

13.1 STEP 1: INCREASING DISTRICT HEATING IN 2010

Primary Energy Supply EU27						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH	50% DH	Present 12% DH	30% DH	50% DH
Nuclear	2,712	2,712	2,712	9,762	9,762	9,762
Coal	3,091	2,401	1,810	11,127	8,644	6,515
Oil	6,059	5,850	5,639	21,812	21,058	20,299
Natural gas	4,838	5,045	5,238	17,418	18,161	18,857
Biomass	1,363	1,363	1,363	4,906	4,906	4,906
Other renewable	545	545	545	1,961	1,960	1,961
Total	18,607	17,914	17,305	66,984	64,491	62,299

Individually Heated Buildings						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH	50% DH	Present 12% DH	30% DH	50% DH
Nuclear	0	0	0	0	0	0
Coal	131	93	56	471	336	200
Oil	730	521	310	2,629	1,875	1,116
Natural gas	1,833	1,308	778	6,599	4,707	2,800
Biomass	405	405	405	1,459	1,459	1,459
Other renewable	0	0	0	0	0	0
Total	3,099	2,327	1,549	11,158	8,378	5,575

Fuel for Heating Houses that are Converted to District Heating						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH	50% DH	Present 12% DH	30% DH	50% DH
Nuclear	0	0	0	0	0	0
Coal	75	38	0	271	135	0
Oil	420	209	0	1,513	753	0
Natural gas	1,055	526	0	3,799	1,892	0
Biomass	0	0	0	0	0	0
Other renewable	0	0	0	0	0	0
Additional CHP & DH	0	86	249	0	309	898
Total	1,551	858	249	5,583	3,089	898

Primary Energy Supply for Heating All Buildings in 2010						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH	50% DH	Present 12% DH	30% DH	50% DH
Nuclear	0	0	0	0	0	0
Coal	131	93	56	471	336	200
Oil	730	521	310	2,629	1,875	1,116
Natural gas	1,833	1,308	778	6,599	4,707	2,800
Biomass	405	405	405	1,459	1,459	1,459
Other renewable	0	0	0	0	0	0
Additional CHP & DH	0	86	249	0	309	898
Existing CHP & DH	246	246	246	884	884	884
Total	3,345	2,659	2,044	12,042	9,571	7,357

Carbon Dioxide Emissions for the Total Energy System in 2010			
UNIT	Mt		
Scenario	IEA	HRE	
Fuel	Present 12% DH	30% DH	50% DH
Nuclear	0	0	0
Coal	1,096	851	642
Oil	1,590	1,535	1,480
Natural gas	1,004	1,046	1,086
Biomass	0	0	0
Other renewable	0	0	0
Total	3,690	3,433	3,207

13.2 STEP 2: INCREASING DISTRICT HEATING IN 2010 WHILE UTILISING RENEWABLE RESOURCES

Primary Energy Supply EU27: High RE						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH with RE	50% DH with RE	Present 12% DH	30% DH with RE	50% DH with RE
Nuclear	2,712	2,712	2,712	9,762	9,762	9,762
Coal	3,091	2,129	1,319	11,127	7,666	4,749
Oil	6,059	5,850	5,639	21,812	21,058	20,299
Natural gas	4,838	5,045	5,240	17,418	18,162	18,864
Biomass	1,363	1,548	1,733	4,906	5,572	6,239
Other renewable	545	573	600	1,961	2,062	2,161
Total	18,607	17,856	17,243	66,984	64,282	62,073

Individually Heated Buildings: High RE						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH with RE	50% DH with RE	Present 12% DH	30% DH with RE	50% DH with RE
Nuclear	0	0	0	0	0	0
Coal	131	93	56	471	336	200
Oil	730	521	310	2,629	1,875	1,116
Natural gas	1,833	1,308	778	6,599	4,707	2,800
Biomass	405	405	405	1,459	1,459	1,459
Other renewable	0	0	0	0	0	0
Total	3,099	2,327	1,549	11,158	8,378	5,575

Fuel for Heating Houses that are Converted to District Heating: High RE						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH with RE	50% DH with RE	Present 12% DH	30% DH with RE	50% DH with RE
Nuclear	0	0	0	0	0	0
Coal	75	38	0	271	135	0
Oil	420	209	0	1,513	753	0
Natural gas	1,055	526	0	3,799	1,892	0
Biomass	0	0	0	0	0	0
Other renewable	0	0	0	0	0	0
Additional CHP & DH	0	28	187	0	100	672
Total	1,551	800	187	5,583	2,880	672

Primary Energy Supply for Heating All Buildings in 2010: High RE						
UNIT	TWh			PJ		
Scenario	IEA	HRE		IEA	HRE	
Fuel	Present 12% DH	30% DH with RE	50% DH with RE	Present 12% DH	30% DH with RE	50% DH with RE
Nuclear	0	0	0	0	0	0
Coal	131	93	56	471	336	200
Oil	730	521	310	2,629	1,875	1,116
Natural gas	1,833	1,308	778	6,599	4,707	2,800
Biomass	405	405	405	1,459	1,459	1,459
Other renewable	0	0	0	0	0	0
Add. CHP & DH	0	28	187	0	100	672
Additional CHP & DH	246	246	246	884	884	884
Total	3,345	2,601	1,981	12,042	9,362	7,131

Carbon Dioxide Emissions for the Total Energy System in 2010: High RE			
UNIT	TWh		
Scenario	IEA	HRE	
Fuel	Present 12% DH	30% DH with RE	50% DH with RE
Nuclear	0	0	0
Coal	1,097	759	468
Oil	1,595	1,535	1,480
Natural gas	970	1,046	1,086
Biomass	0	0	0
Other renewable	0	0	0
Total	3,663	3,340	3,034

13.3 STEP 3: INCREASING DISTRICT HEATING IN 2030 AND 2050 WHILE UTILISTING RENEWABLE RESOURCES

Primary Energy Supply for the EU27										
UNIT	TWh					PJ				
Scenario	2010	2030		2050		2010	2030		2050	
Fuel	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE
Nuclear	2,712	2,301	2,301	2,545	2,545	9,762	8,285	8,285	9,161	9,161
Coal	3,091	2,189	1,744	1,837	723	11,127	7,879	6,278	6,614	2,602
Oil	6,059	6,446	6,156	5,985	5,638	21,812	23,207	22,163	21,545	20,298
Natural gas	4,838	4,234	4,527	4,196	4,303	17,418	15,243	16,296	15,107	15,492
Biomass	1,363	2,131	2,140	2,261	2,696	4,906	7,673	7,703	8,138	9,705
Other renewable	545	1,567	1,564	2,131	2,142	1,961	5,640	5,630	7,672	7,712
Total	18,607	18,868	18,432	18,955	18,047	66,984	67,926	66,354	68,237	64,971

Primary Energy Supply for Heating All Buildings in 2010: High RE										
UNIT	TWh					PJ				
Scenario	2010	2030		2050		2010	2030		2050	
Fuel	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE
Nuclear	0	0	0	0	0	0	0	0	0	0
Coal	131	62	41	62	17	471	222	148	223	61
Oil	730	592	396	510	139	2,629	2,132	1,425	1,836	502
Natural gas	1,833	1,510	1,010	1,283	351	6,599	5,435	3,634	4,619	1,263
Biomass	405	395	603	365	365	1,459	1,421	2,171	1,315	1,315
Other renewable	0	0	0	0	0	0	0	0	0	0
Additional CHP & DH	0	0	280	0	441	0	0	1,008	0	1,588
Existing CHP & DH	246	246	246	246	246	884	884	884	884	884
Total	3,345	2,804	2,575	2,466	1,559	12,042	10,093	9,271	8,877	5,613

Individually Heated Buildings: High RE										
UNIT	TWh					PJ				
Scenario	2010	2030		2050		2010	2030		2050	
Fuel	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE	IEA 12% DH	EP CPI 10% DH	HRE 30% DH with RE	EP CPI 10% DH	HRE 50% DH with RE
Nuclear	0		0	0	0	0	0	0	0	0
Coal	131	62	41	62	17	471	222	148	223	61
Oil	730	592	396	510	139	2,629	2,132	1,425	1,836	502
Natural gas	1,833	1,510	1,010	1,283	351	6,599	5,435	3,634	4,619	1,263
Biomass	405	395	395	365	365	1,459	1,421	1,421	1,315	1,315
Other renewable	0	0	0	0	0	0	0	0	0	0
Total	3,099	2,558	1,841	2,220	873	11,158	9,209	6,629	7,993	3,141

EU27 Carbon Dioxide Emissions (Mt)			
Scenario	IEA / EP CPI	HRE	HRE with RE
2010	3,690	3,690	3,690
2030	3,347	3,173	3,084
2050	3,088	2,832	2,624

District Heating Production from 2010 to 2030			
UNIT	TWh		
Scenario	IEA	HRE	
Fuel	2010 Present 12% DH	2030 30% DH & RE	2050 50% DH & RE
Existing CHP	200	331	88
Additional CHP	0	268	474
Industrial surplus heat	53	170	272
Waste incineration	27	209	344
Heat pumps	0	39	228
Geothermal heat	0	56	111
Solar thermal	0	28	56
Boiler	121	119	139
Total	401	1,220	1,711