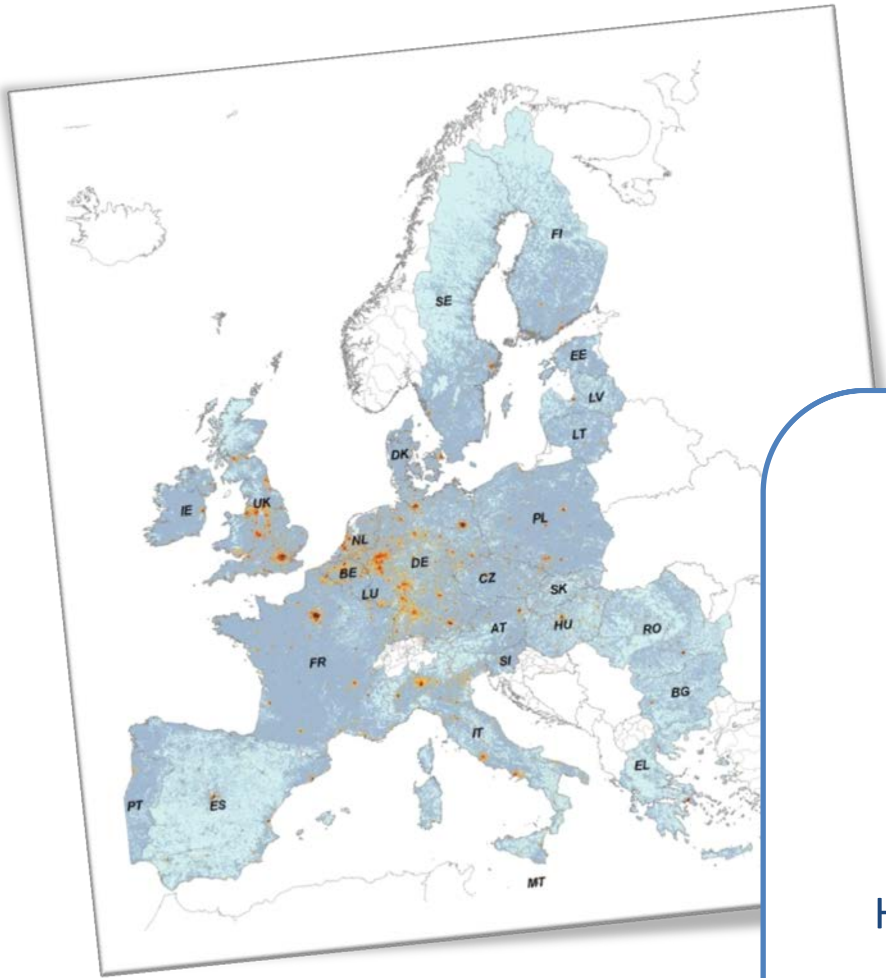
HEAT ROADMAP EUROPE 2050

SECOND PRE-STUDY FOR THE EU27



For

EUROHEAT & POWER

By

Aalborg University
David Connolly
Brian Vad Mathiesen
Poul Alberg Østergaard
Bernd Möller
Steffen Nielsen
Henrik Lund

Halmstad University
Urban Persson
Sven Werner

Ecofys Germany GmbH
Jan Grözinger
Thomas Boermans
Michelle Bosquet

PlanEnergi
Daniel Trier

Publisher:
Department of Development and Planning
Aalborg University
Vestre Havnepromenade 5
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Denmark

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Since this is a pre-study, some key assumptions were necessary due to the limited time and resources available to investigate a pan-European energy system. However, this pre-study outlines the previously unconsidered potential of district heating and cooling in the EU, while also highlighting the need for new tools, data, and methodologies to analyse the specific requirements of district heating and cooling as technologies. The authors intend to continue developing these in the future.

FOREWORD

ENHANCED ENERGY EFFICIENCY: FASTER DECARBONISATION, CHEAPER COMFORT, BETTER ENERGY - THE CHALLENGE

In 2009 the European Council committed the European Union to decarbonize its energy system to at least 80% below 1990 levels by 2050. As heat demands dominate end-use, decarbonizing the European energy system requires special attention to these sectors which given their importance for health and wellbeing also have a very strong social dimension. The challenge is for the heat market to contribute to the decarbonisation goal in a manner which allows keeping the cost of energy in general - and of comfort in particular - affordable.

A wide range of renewable and energy-efficient technologies are readily available already today to replace the two thirds of the heat market which today are covered by fossil fuels. These are outlined in various reports and studies, i.e. in the Energy Efficiency of the Energy Roadmap 2050 published by the European Commission in 2011[1].

Why another study?

Basically all existing studies exploring the road to a decarbonized energy supply in 2050 model generic solutions without investigating the possibilities and limits of their implementation in practice in an urban environment. Yet, future solutions must in the first instance be urban solutions. Forecasts indicate that 75% of the European citizens will live in urban areas in 2020 and that this share will increase to 84% by 2050.

This means that the local character of heating and cooling markets both with regard to supply and demand must be taken into account when identifying concrete pathways to a low-carbon future. For example, a compact urban environment can compromise the desired use of natural lightning, ventilation and decentralized use of solar energy. Higher densities also limit the potential of ground-source heat pumps (and hence of electrifying heating and cooling as one of the options which is currently modelled in most reports).

A compact urban environment also limits possibilities to accelerate the deep refurbishment rate of buildings due to space limitations, noise disturbances, social acceptance and relocation needs during construction work. Yet, the assumptions in the Energy Efficiency Scenario (EE-EU) of the Energy Roadmap are over-ambitious as regards the reduction of final heat demands in buildings (72% reduction of the specific heat demands), exceeding even what is considered feasible in recent reports of the European insulation manufacturing industry[2], and hence are assumed to be extremely costly.

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[1] European Commission, 2011: Energy Roadmap 2050. Available from http://eur-lex.europa.eu

[2] Boermans T., Bettgenhäuser K, Offermann M, Schimschar S. Renovation Tracks for Europe up to 2050: Building renovation in Europe – what are the choices? Ecofys, 2012

THE OPPORTUNITIES

On the positive side, the local and urban dimensions of energy provide opportunities which usually are overlooked in studies as they often are not properly reflected in statistics and models.

Heat Roadmap Europe is the first study on EU27 scale which combines geographical mapping of energy demand and supply in unprecedented detail with comprehensive energy system modelling (incl. hour-by-hour analysis). It identifies the potential for using local resources across Europe, and subsequently applies this in the EU27 energy system. The study takes the EU-EE scenario as starting point, refining and complementing it with local heat market information. As a result and beyond theoretical potentials, the new Heat Roadmap Europe Energy Efficiency scenario (HRE-EE) shows a pathway that can realistically be implemented and allows leveraging additional benefits.

THE BENEFITS

CHEAPER COMFORT

Rising energy prices and fuel poverty are a major concern for all European governments. The study shows that ambitious targets can be achieved while keeping comfort affordable and without compromising on quality of life and health. While being ambitious to the limit of what can realistically be deemed feasible in terms of future reduction of space heat demands, additional cost savings identified by refining the EU-EE amount to at least EUR 100 billion/year and up to EUR 146 billion/year due to a reduction of the costs for the total heating and cooling supply for buildings in the range of 15 to 22%. These savings benefit all European citizens from the most vulnerable customer to businesses and ultimately Europe's competitiveness on the World market.

FASTER DECARBONISATION

Redesigning the heating and cooling supply as proposed in the study provides a fast-track solution to overcoming the constraints of compact urban environments and bringing renewable energies into cities. It enables the efficient use of combined heat and power, biomass, solar thermal, large-scale heat pumps, individual heat pumps, geothermal energy, as well as heat from waste incineration and excess heat from industry. At the same time, the HRE-EE scenario introduces additional flexibility to the EU-EE scenario that facilitates the integration of more wind and photovoltaic power in the electricity sector.

BETTER ENERGY

Energy autonomy ranks evenly high on the EU's energy agenda as competitiveness and decarbonisation. The HRE-EE scenario creates a more diverse energy supply than any other EU scenario and improves the security of supply. Using local renewable sources instead of imported fossil fuels does not only serve the environment but also creates welfare and jobs within smart communities in Europe. The HRE-EE scenario uses no-regrets technologies that ensure flexibility and help avoiding lock-in effects. This reduces risks and adverse effects if heat savings in buildings do not have the expected effect due to lack of implementation (i.e. due to technical limitations or increasing costs) and creates robustness against fluctuating or increasing fuel prices, including of renewable energy sources.

THE TOOL

Based on their analysis, the authors of this study consider that while lowering energy consumption in buildings is essential, it must be combined with a robust strategy for a future heat and cooling supply in the European Union. As the results show, re-designing the heat and cooling supply in Europe will contribute to making any chosen decarbonisation path more robust and affordable.

This means that any decarbonisation strategy for the energy sector as a whole should integrate a clear strategy for addressing energy efficiency and renewable energy use in heating and cooling. A strategy embracing a district or community dimension and targeting the reduction of fossil primary energy provides substantial benefits as outlined above.

Given the urban dimension of the challenges and the resulting constraints, increasing the market penetration of heating and cooling networks to 30% by 2030 and to 50% by 2050 in combination with the use of local sustainable resources (renewable energies and recycled heat) can be considered as an essential element in achieving the ambitious goals of cheaper comfort, faster decarbonisation and better energy.

27th May 2013

Frederic Hug
President
Euroheat & Power

EXECUTIVE SUMMARY

Heat Roadmap Europe[3] is the first study on the EU27 scale which combines geographical mapping of energy demand and supply in unprecedented detail with detailed energy system modelling. Heat Roadmap Europe identifies the potential for using local resources across Europe, and subsequently applies this in the EU27 energy system. The results are recommendations for a redesign of the European heat supply.

In 2009 the European Council made the objective for the EU to decarbonise its energy system to at least 80% below the 1990 level by 2050, without affecting general economic growth. A number of measures and technologies could contribute to these goals. A scenario which achieves these goals is the Energy Efficiency scenario in the *Energy Roadmap 2050* report[4] by the European Commission.

The Heat Roadmap Europe scenario proposed here achieves these same CO_2 reduction, but at a lower cost. Lowering the energy consumption in buildings is essential. However here we combine heat savings in the buildings with higher energy efficiency by expanding district heating in the future heat supply in the EU27. Local conditions are considered using geographical information systems (GIS) and combined with hour-by-hour energy system analyses for the EU27, which enables us to find a robust strategy to increase competitiveness, integrate more renewables and reduce the risks in the energy supply. By analysing heat savings and energy efficiency, by investigating local conditions, and by making energy system analyses we are able to identify a balance between heat savings and key infrastructural changes in the energy supply. The findings in the Heat Roadmap Europe can be summarised into three key messages (see Figure 1).

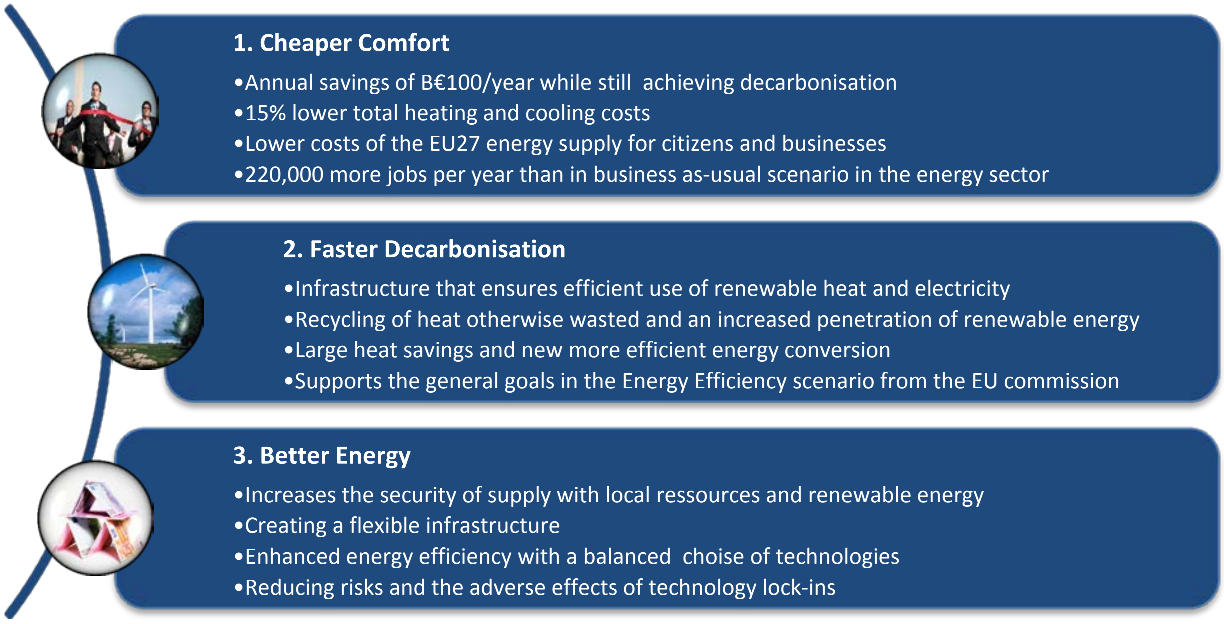

Figure 1: Three key messages from Heat Roadmap Europe.

[3] "Heat Roadmap Europe" refers to the Heat Roadmap Europe report from 2012 (First pre-study for the EU27) and this report.

[4] European Commission. Energy Roadmap 2050. European Commission, 2011. Available from: http://ec.europa.eu/.

Cheaper Comfort

First of all we are able to ***Increase the economic competitiveness of the EU27***. In Heat Roadmap Europe we have compared our results both to the current energy supply as well as to the implementation of the European Commission's Energy Efficiency scenario (EU-EE). By refining the EU-EE scenario, we are able to decarbonise to the same level while saving B€100/year, corresponding to 15% lower costs for the total heating and cooling supply for buildings. We achieve this by proposing an enhanced energy efficiency scenario (HRE-EE), which has significant heat demand reductions, combined with lower heat losses and more renewable energy in the energy supply. This ensures that the cost burden on European citizens and businesses is comparably lower with Heat Roadmap Europe, which enables stronger economic development in the EU and provides a more competitive business environment.

Faster Decarbonisation

Secondly Heat Roadmap Europe creates a ***Pathway for heat recycling and more renewable energy***, by ensuring that we can increase the penetration of renewable energy in both the heat sector and the electricity sector. In HRE-EE we re-design the heat supply in the EU27 by quantifying the benefits of using individual heat pumps and district heating, in combination with energy savings and renewable energy. Currently about half of the primary energy in the EU27 is lost in the conversion from the primary energy supply to the end use. District heating makes it possible to ***recycle heat*** that would otherwise be wasted. The new infrastructure and redesign of the heating and cooling supply presented here enables the efficient use of heat from combined heat and power, solar thermal, large-scale heat pumps, individual heat pumps and many other sources such as geothermal, waste incineration and excess heat from industry. The scenarios introduce flexibility that facilitates the integration of more wind and photovoltaic power in the electricity sector compared to the EU-EE scenario. The HRE-EE scenario includes large savings in the heat demand in buildings. Heat savings in combination with an efficient energy supply system creates a scenario that supports the goals of the European Commission.

Better Energy

Reducing risks for the EU27 is a third key message from Heat Roadmap Europe. The infrastructure proposed creates a more diverse energy supply and improves the EU's security of supply by using resources within the EU and increasing the share of renewable energy. The HRE-EE scenarios use technologies that ensure flexibility in the energy supply which reduce the risk of lock-in effects in Europe. This reduces risks and adverse effects if 1) heat savings in buildings do not have the expected effect due to a lack of implementation, which could occur due to technical limitations or increasing costs, 2) fluctuating or increasing fuel prices, or 3) the cost of some renewable energy sources increases. In Heat Roadmap Europe we suggest a more robust strategy, with a diversified supply and an enhanced energy efficiency scenario that balances heat savings and efficient energy conversion.

COMBINING HEAT SAVINGS WITH A NEW HEAT SUPPLY

The results in the HRE-EE scenario are based on thorough analyses of the heat savings feasible in the EU27 and the mapping of local conditions all over the EU27. The space heating demands in the HRE-EE scenario are reduced by as much as 47% compared to today. This is extremely ambitious and in accordance with the most ambitious deep renovation heat saving scenario in the Eurima study[5] from 2012. On the supply side, the market penetration of district heating is increased in the HRE-EE scenario based on existing and forecasted heat demands in the EU27. These have been profiled using the first ever pan-EU Heat Atlas, which was developed in this study (see Figure 2). Based on this data, the share of district heating for space heating and hot water supply in 2050 is set at 50% in the year 2050. Similar maps have been created to establish how to supply the heat for these new district heating systems from resources such as thermal power plants, solar thermal, geothermal, and industry. The resolution utilised in these maps ensures that the local conditions in the EU27 are considered in the macro modelling also carried out in this study.

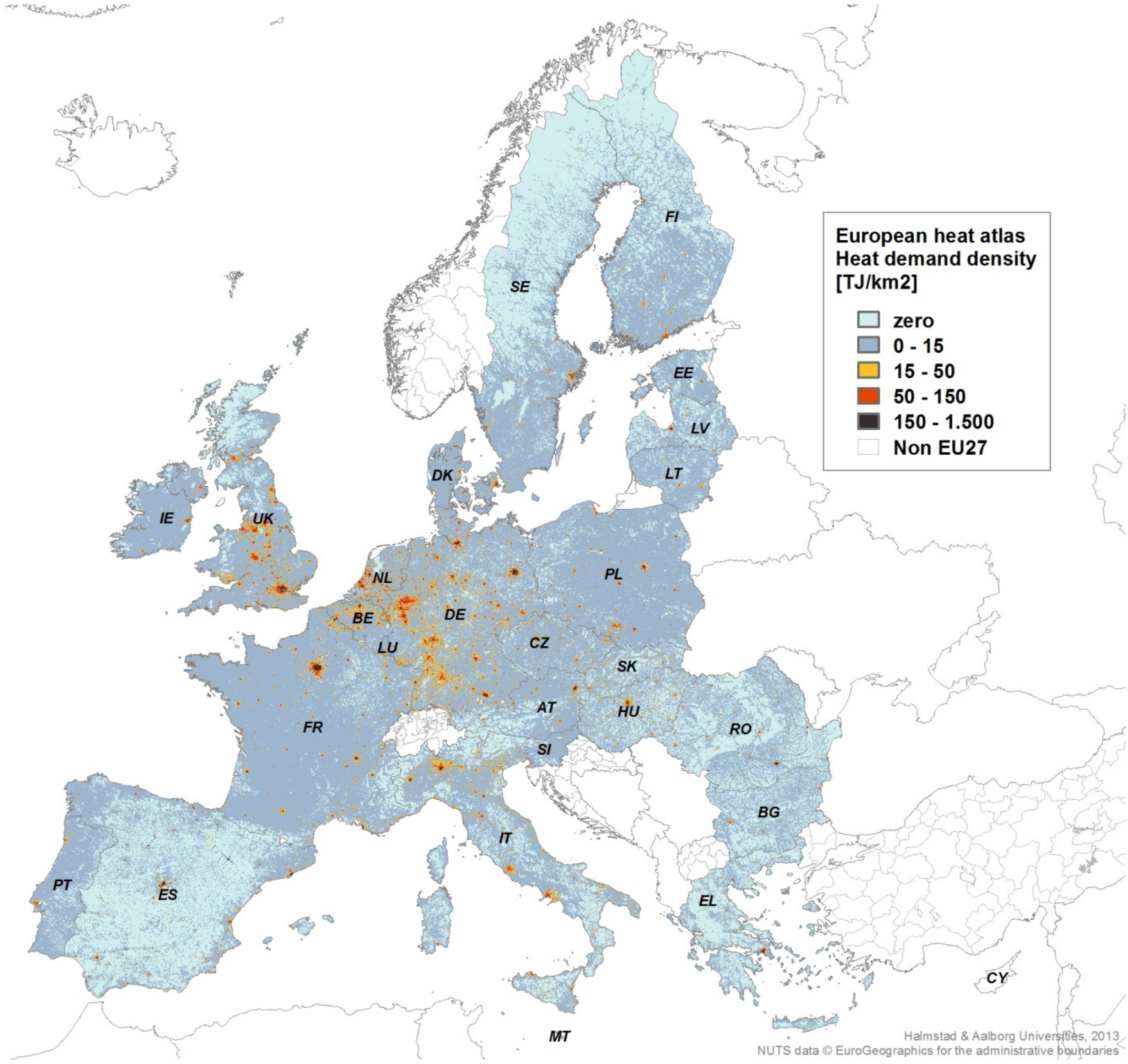

Figure 2: New European Heat Atlas developed in this study.

[5] Boermans T, Bettgenhäuser K, Offermann M, Schimschar S. Renovation Tracks for Europe up to 2050: Building renovation in Europe - what are the choices? Ecofys, 2012. Available from: http://www.eurima.org/.

QUANTIFYING THE IMPACT OF THE NEW HEAT SUPPLY

To quantify the impacts of the HRE-EE scenario, the resulting primary energy supply and the CO_2 emissions are compared to those in the original EU-EE scenario from the European Commission, using hour-by-hour modelling in the energy-systems-analysis tool EnergyPLAN. The fossil fuel and biomass consumption in both scenarios is the same for the years 2030 and 2050, though the primary energy supply is marginally larger in the HRE-EE scenario (~2%). As a result, the carbon dioxide emissions in both scenarios are also the same, but the Heat Roadmap Europe scenarios are significantly cheaper (see Figure 3). The slightly larger primary energy supply in the HRE-EE scenario is due to the additional resources utilised in the district heating network such as waste incineration, geothermal, and large-scale solar thermal. If district heating is not included in the EU energy system, these resources will be wasted. The HRE-EE scenario also utilises approximately 5% more wind power than the EU-EE scenario due to the additional flexibility introduced into the system by integrating the electricity and heat sectors.

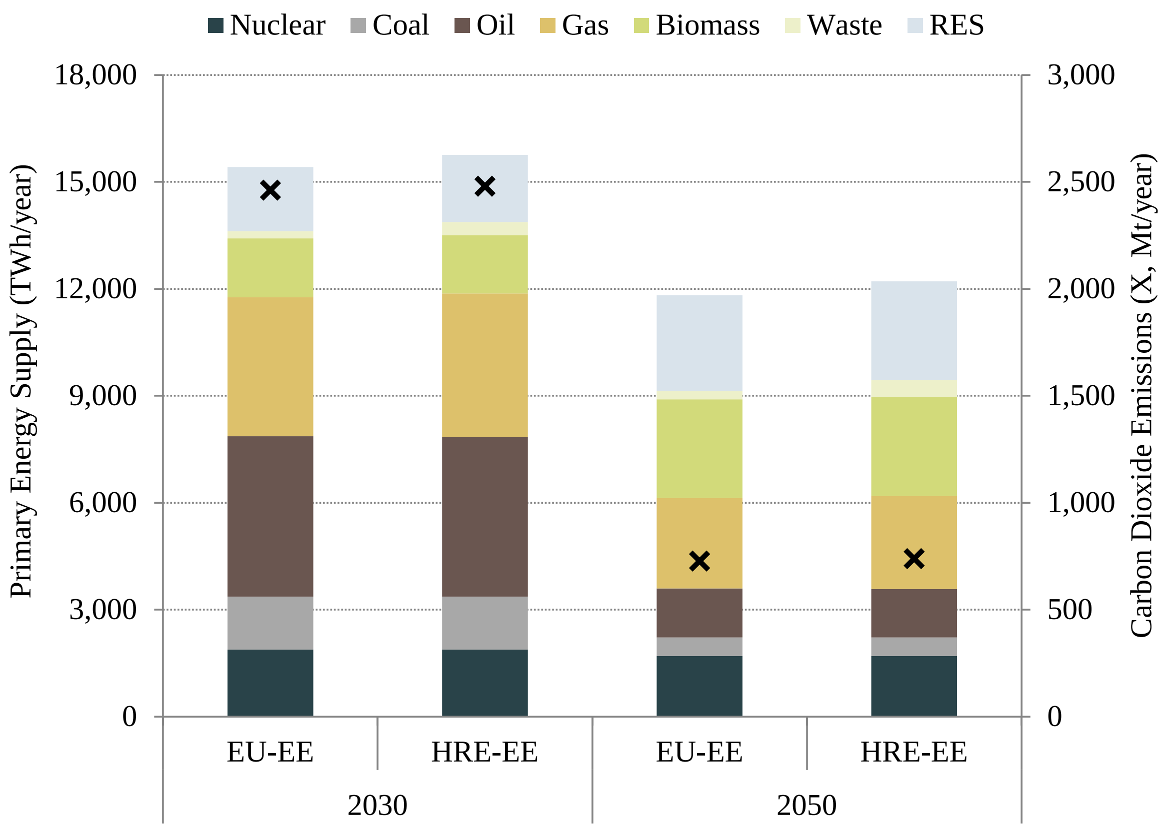

Figure 3: Primary energy supply and carbon dioxide emissions in the Energy Efficiency (EU-EE) and Heat Roadmap Europe (HRE-EE) scenarios for the years 2030 and 2050.

The HRE-EE scenario has a higher heat demand than the EU-EE scenario, due to the very high costs required to reduce the heat demand in buildings by more than the ~50%. As a result, the HRE-EE scenario proposed here also has lower investment costs in building refurbishments to reduce the heat demand than the EU-EE scenario (see “Energy Efficiency Investments” in Figure 4). Some of these savings are invested in redesigning the heating sector in the HRE-EE scenario by increasing the share of district heating and cooling and using larger individual boilers. However, these additional costs are offset by the reduced investments on building side, so the total cost of heating and cooling for buildings in the HRE-EE scenario is ~15% lower. To put this in context, the overall energy costs for the EU energy system are reduced by approximately 7-8%. Furthermore, a sensitivity analysis in this study indicates that this is a conservative estimate: the total heating and cooling costs are more likely to be approximately 22%, since the costs assumed here for heat savings in the buildings could be significantly higher while the district heating distribution costs could be lower.

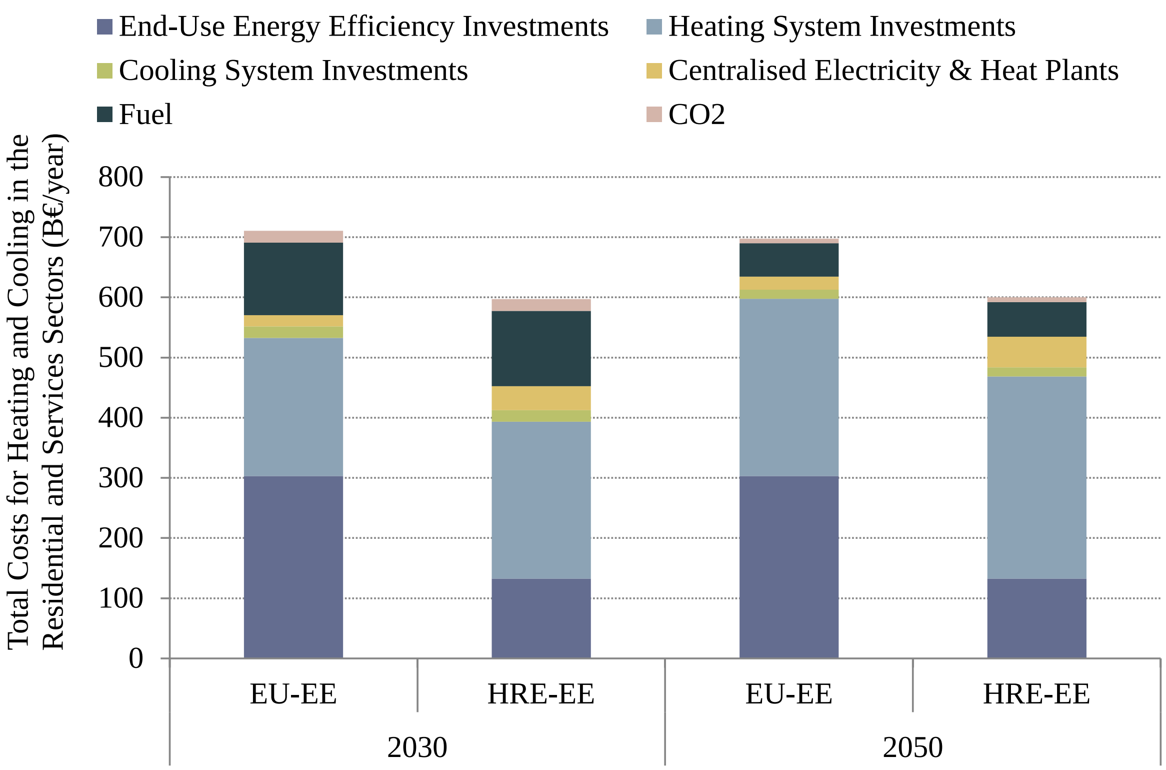

Figure 4: Total annual costs for heating and cooling in the residential and services sectors for the Energy Efficiency (EU-EE) and Heat Roadmap Europe 2 (HRE-EE) scenarios in the years 2030 and 2050.

DISTRICT HEATING IN URBAN AREAS IS ALSO CHEAPER THAN INDIVIDUAL HEAT PUMPS

The EU27 analysis in this study is also supported here by a more specific local case study, based on the city of Aarhus in Denmark. Using the case study it is possible to determine more specific costs and demands when comparing alternative heat strategies. Similar to the results already discussed on an EU27 scale, the case study reveals that heat savings and district heating together can provide an efficient and cost-effective heat supply for buildings. An additional comparison between district heating and individual heat pumps is also completed here using the case study. The results show that district heating is also a cheaper solution than individual heat pumps in urban areas (see Figure 5). This is particularly due to two reasons: firstly, it is the very large investment costs for installing an individual heat pump in each building compared to sharing thermal capacity in a centralised plant with district heating and secondly, it is the larger investment in residual power plants to supply electricity for the heat pumps. The conclusions are also valid when demands are decreased, although the individual heat pump scenarios become more competitive with very low demands, because this results in a lower need for production capacity.

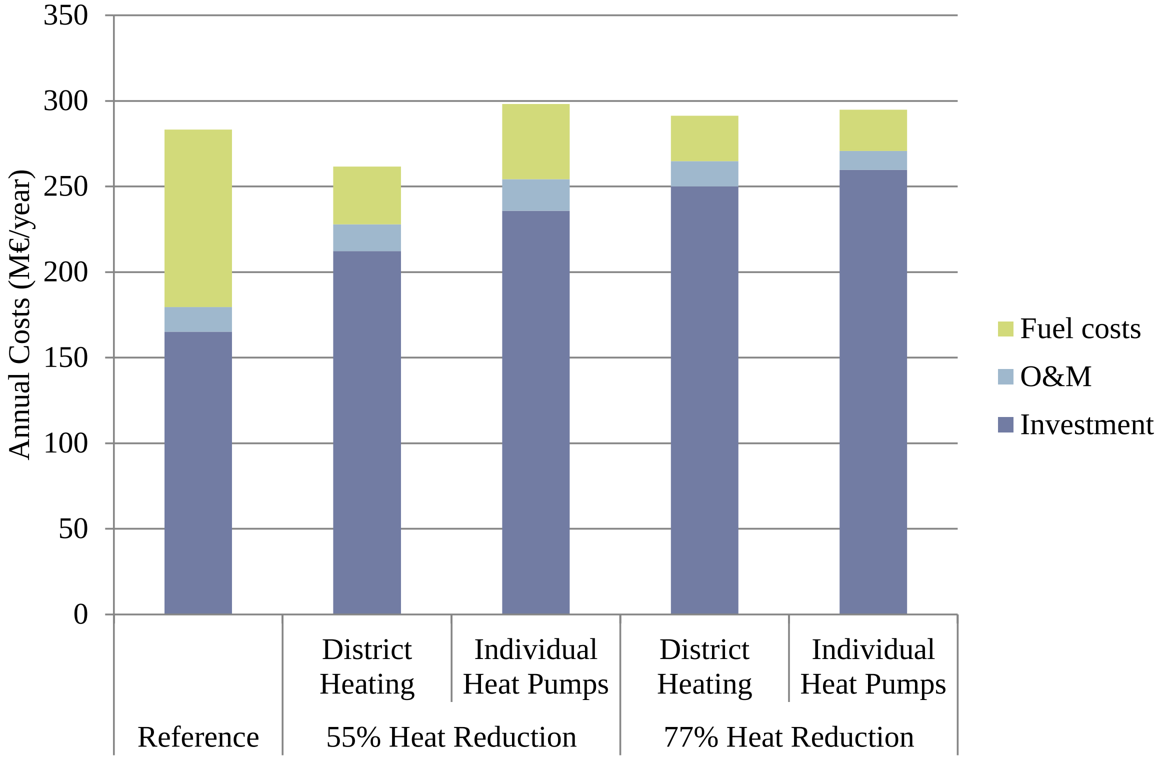

Figure 5: Annualised costs for all scenarios considered in the Aarhus case study.

FEWER HEAT SAVINGS STILL REQUIRES A NEW HEAT SUPPLY

Another scenario in the *Energy Roadmap 2050* report4 by the European Commission describes a situation where none of the current policy initiatives in the EU are changed (EU-CPI scenario). EU-CPI contains very little combined heat and power and district heating systems using excess heat.

In the first pre-study of Heat Roadmap Europe [1], we have also redesigned the heat supply in the EU-CPI scenario, to create a new HRE-CPI scenario. This highlights the benefits of a different heat supply that can recycle heat, even if fewer heat savings are achieved than expected in both the EU-EE and the HRE-EE scenarios. In HRE-CPI, the expansion of district heating could decrease the European primary energy supply, decrease fossil fuel consumption, and lower the CO_2 emissions while still supplying exactly the same energy services as in EU-CPI (see Figure 6).

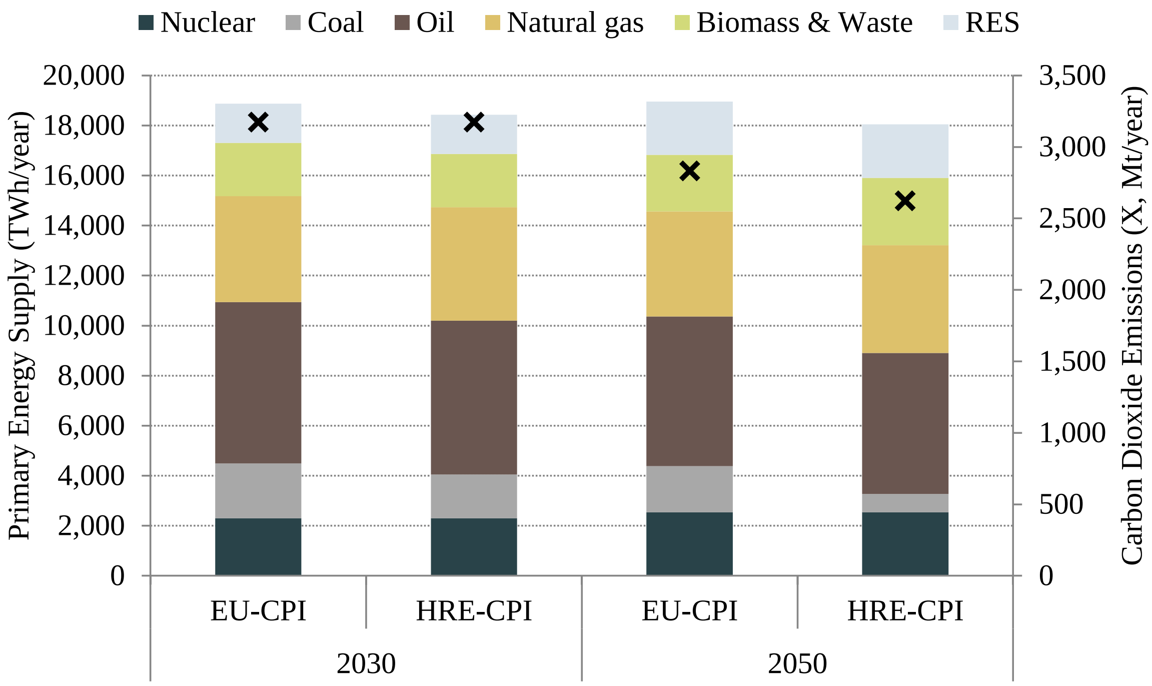

Figure 6, Primary energy supply and carbon dioxide emissions in the EU-CPI and HRE-CPI scenarios for the years 2030 and 2050.

More district heating in Europe will reduce the energy system costs considerably since local heat recycling and renewable energy will replace expensive energy imports compared to EU-CPI. The reduced energy import will increase the future security of supply and give a more positive balance of foreign exchange.

At the same time as reducing the costs of energy, more district heating will generate local labour-intensive investments. For HRE-CPI a first rough estimate of job creation indicates that around 8-9 million man-years will be created, which equals approximately 220,000 new jobs on average over the 38 year period from 2013 to 2050, due to investments in heat recycling, renewable energy supply, and extended and new district heating grids. It should be noted that these jobs are additional to the jobs in the EU-CPI 2050 scenario. In neither the EU-CPI nor the HRE-CPI scenarios are the decarbonisation goals achieved.

It should be emphasized that 220,000 jobs is a rough estimate of the minimum number of work places being created and 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 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.

When comparing the jobs in EU-EE and HRE-EE in which the goals are achieved, HRE-EE would create fewer jobs in the energy sector, as we have created a cheaper alternative. However with HRE-EE the costs for EU citizens and businesses will be lower: this reduces the cost burden with regard to the energy supply, creating better competitiveness while still achieving decarbonisation – also in a situation where heat savings are not achieved due to practical or political implementation difficulties.

Key technologies for the new heat supply in HRE-EE 2050

- *Heat savings* equal to the most ambitious deep renovation space-heating scenario in the Eurima[3] study from 2012. The total heat demand in buildings is reduced by 34% between 2010 and 2050.
- Expansion of *district heating* from the present level of 12% to 50% in 2050.
- *Combined Heat and Power*: increase from 41 GW_e in 2010 to 205 GW_e in 2050
- *Large-Scale Heat Pumps*: 0 GW_e in 2010 to 40 GW_e in 2050
- *Thermal Storage*: 160 GWh in 2010 and 750 GWh in 2050
- *Centralised Boilers*: 132 GW_{th} to 532 GW_{th} in 2050 (mostly on Biomass)
- *Heat from Waste Incineration*: 50 TWh in 2010 and 200 TWh in 2050
- *Large-Scale Solar Thermal*: 0 TWh in 2010 and 100 TWh in 2050
- *Individual Solar Thermal*: 22.5 TWh in 2010 and 130 TWh in 2050
- *Industrial Excess Heat*: 7 TWh in 2010 and 105 TWh in 2050
- *Geothermal Heat*: 2 TWh in 2010 and 100 TWh in 2050
- *Individual Heat Pumps*: 40 GW_e in 2010 and 175 GW_e in 2050
- *Wind Power*: 150 TWh in 2010 and 1490 TWh in 2050 (this includes the 65 TWh of additional wind Power in the HRE-EE scenario in 2050)

Key achievements of the HRE-EE 2050 scenario

- Same decarbonisation as in the EU-EE 2050 scenario
- Same use of fossil fuels as in the EU-EE 2050 scenario

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NOMENCLATURE

Abbreviation	Description
CC	Combined Cycle
CCS	Carbon Capture and Storage
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.
EHI	European Heating Index
EPBD	Energy Performance of Buildings Directive (EU)
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 the first pre-study.
EU-EE scenario	The future energy system scenario called the Energy Efficiency scenario from the *Energy Roadmap 2050* communication. This scenario was chosen as the reference scenario in this pre-study.
GHG	Greenhouse Gas
GIS	Geographical Information Systems
HRE	Heat Roadmap Europe, a label for a planned research project initiated by this pre-study.
HRE-CPI scenario	An alternative future energy system scenario for the EU developed in the first HRE pre-study, which includes district heating in future scenario for the EU which only includes the implementation of existing policies.
HRE-EE scenario	An alternative future energy system scenario for the EU developed in this study, which contains energy efficiency measures on both the demand and the supply side (i.e. by using district heating) of the energy system.
IEA	International Energy Agency, located in Paris.
ISWA	International Solid Waste Association, located in Vienna.
NUTS	Nomenclature of Statistical Territorial Units, defined by Eurostat; a hierarchical geographic boundary system for statistical and other purposes.
NUTS3	The third level of the European NUTS system defining the national administrative regions.
PES	Primary Energy Supply
PP	Power Plants - plants producing electricity only
PRIMES	The energy systems model used for energy modelling in the EC

	communication *Energy Roadmap 2050.*
RES	Renewable energy sources
WTE	Waste-to-energy, label for defining waste incineration plants with energy recovery

1 INTRODUCTION

1.1 OVERALL CONTEXT

In 2010, about 73% of all 502 million EU27 residents lived in urban areas, according to United Nations World Urbanization Prospects [2], indicating that a major part of the EU's buildings are in high heat density areas. This condition is in itself a strong argument for increased use of district heating in Europe. The forecast for the future indicates that the urban population fraction in the EU27 will continue to increase: it is estimated to be 75% in 2020 and 84% in 2050[6], thus highlighting one of the many reasons for this study which also include:

- The heating sector is almost always modelled and analysed in a simplified way in most future energy scenarios published concerning the European energy system. Evidence for this observation is presented in section 1.3 and Annex II of this report. Other parts of the energy system, such as electricity generation, industry, and transport, have received more attention in these scenarios.
- When heating is modelled in future energy scenarios, the heat supply is mostly based on generic options, while locally available options are omitted. Examples of omitted options are excess heat from thermal power generation, waste incineration, and industrial excess heat together with renewable sources as biomass, deep geothermal heat and solar heat.
- The future possibilities and economic benefits with more district heating have never been properly assessed within the European energy system. District heating is seldom seen as a powerful tool in most future energy scenarios. This observation is further presented in Annex I of this report.

The first Heat Roadmap Europe pre-study published in 2012 was the first study ever on the EU27 scale which estimated the future economic benefits with more district heating using local options available. However, the first pre-study was based on a scenario which only included the implementation of existing policies in the EU, so there are relatively small changes in the future heat demands for the residential and service sectors. The key focus of this second pre-study is to estimate the possibilities and benefits with considerable reductions of the heat demands in the residential and service sectors.

1.2 CURRENT SITUATION IN 2010

The current situation is described by the 2010 energy balance, the heat market context, the district heating context, and district heating within the EU energy policy context.

1.2.1 Energy balance for 2010

The current energy balance for EU27 is illustrated in Figure 7 by the 2010 energy balance. This energy balance presents the energy flows from primary energy supply to end use. The final consumption stacked bar illustrates the energy flows after the conversion losses of the central conversion plants, mostly for generating electricity. This stacked bar summarises the energy that final consumers buy. The end use stacked bar illustrates the energy flows after energy conversion at consumer facilities, such as

[6] It should be noted that such aggregated estimates for the entire EU27 are to be considered as indicative only. The reason for this being mainly that no harmonised definition of "urban area" currently is available, so Member States employ national definitions.

local boilers and vehicles. The figure reveals that about half of the primary energy supply is lost before reaching the end use. The losses are heat losses, mostly in electricity generation and vehicle engines, when fuel heat contents are converted into mechanical energy.

Fuels used for heating in buildings constitute 18% of the primary energy supply in the EU27, but some electricity is also used for heating. This electricity use constitutes about 5% of the primary energy supply. Hence, the EU27 buildings use 23% of the primary energy supply for heating. The main purpose with this report is to present a robust strategy for reducing the primary energy supply and the corresponding carbon dioxide emissions, by recycling some the heat losses encountered between primary energy supply and end use.

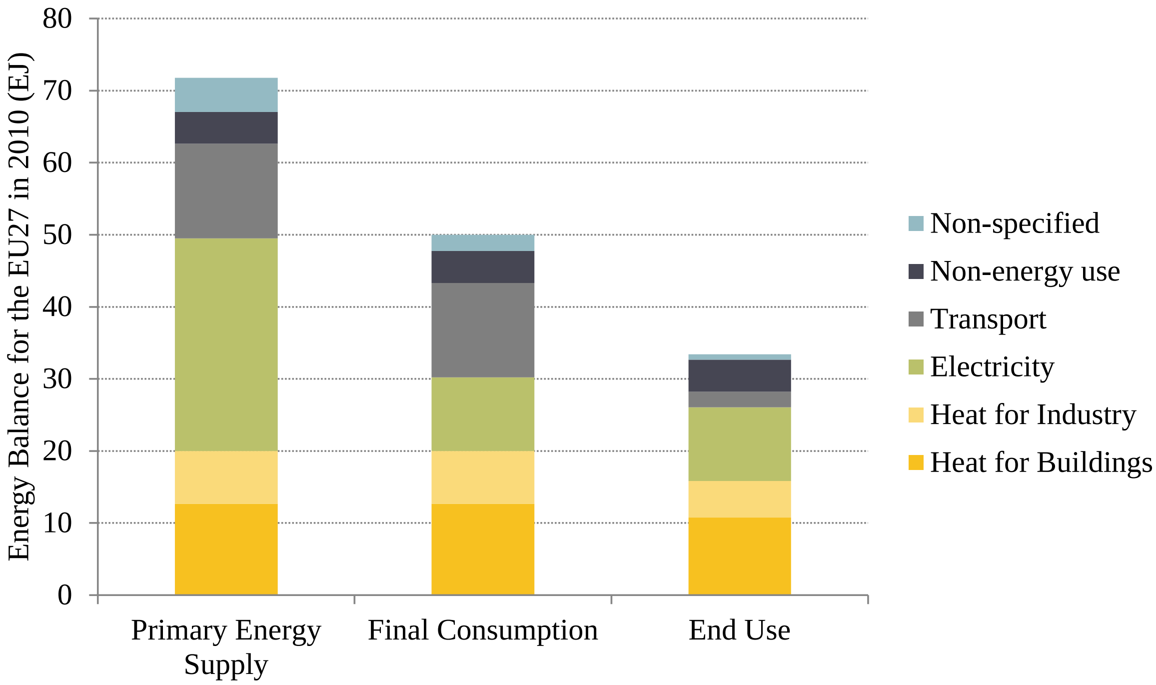

Figure 7: The energy balance in three steps during 2010 for EU27. The energy flows labelled as heat for industry and building include only fuels and district heating. Electricity used for heating is included in the electric energy flows [3].

1.2.2 Current heat market context

The current heat market for residential and service sector buildings within the EU27 is about 3300 TWh/year according to Figure 8. The market share for district heating in buildings is approximately 13%, giving heat deliveries of about 430 TWh/year. District heat is also used for low-temperature heat demands in industry. These heat deliveries are about 180 TWh/year. These two major customer groups add up to the total volume of heat sold from district heating systems of about 620 TWh/year. Furthermore, 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 840 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 the EU27, but the simple division estimated here will be used in this pre-study.

Currently, the heat market for buildings is dominated by fossil-fuels in on-site boilers, which according to Figure 8 account for two-thirds of the heat supply. This gives a future opportunity for CHP, district heating and the local use of renewables and heat pumps, by substituting fossil fuels to reduce the primary energy supply and carbon dioxide emissions. This expansion of district heating 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 national example is the two *Heat Plan Denmark* (*Varmeplan Danmark*) reports for Denmark [4, 5], while one city example is the renewable plan for the Munich district heating system and geothermal heat [6].

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

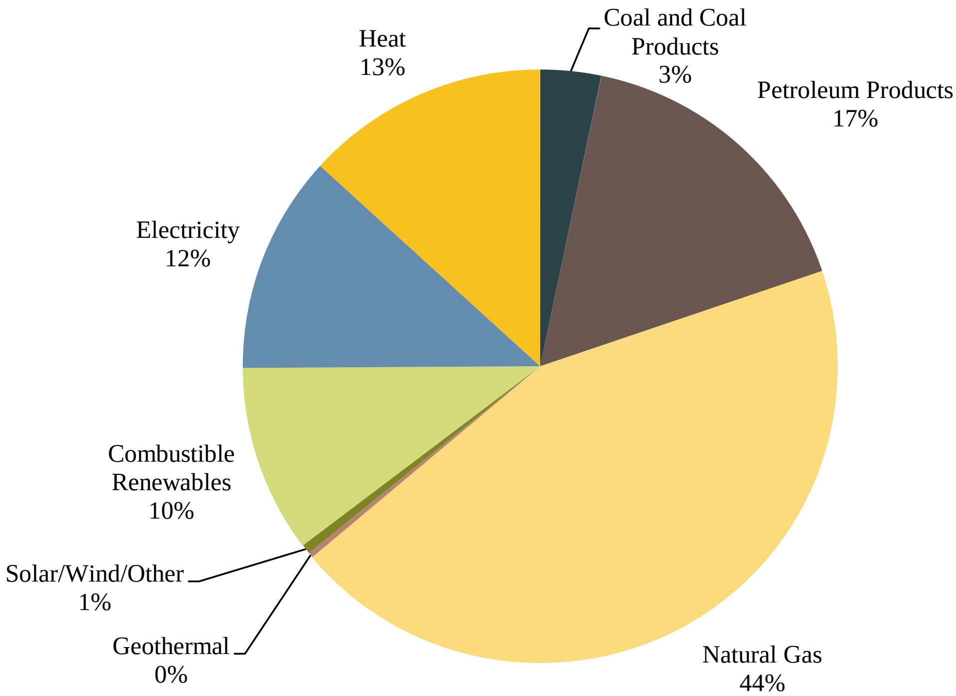

Figure 8: Composition of the origin for heat supply to residential and service sector buildings in EU27 during 2010. Total heat supply was 11.8 EJ (3300 TWh), not including indirect heat supply from all indoor electricity use. Labels refer to the standard commodity groups used in the IEA energy balances. Heat denotes mainly heat from district heating systems. Data sources: IEA energy balances for 2010 complemented with some external estimations.

1.2.3 Current district heating systems based on local conditions

District heating systems can be found all over Europe today, but levels of expansion differ significantly between the EU27 Member States. Although some national heat market shares are between 40-60% in some Scandinavian and Baltic Member States, district heating systems only cover 13% of the current European heat market for buildings in the residential and service sector. The corresponding market share for the industrial sector is about 9% [7]. European district heating systems have distribution pipes with a total trench length of almost 200,000 km, and total revenues for heat sold are about B€30/year.

Since district heating is mainly 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 16% of current urban heat markets, while these fractions can reach more than 90% in some cities with mature district heating systems.

The spread and dissemination of European district heating technology can be seen in Figure 9, where each red dot marks a city with at least one district heating system in operation. The map is based on the current contents 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 the EU27. The deficit consists mainly of small systems in Germany, France and Poland.

This overview shows that it is possible to track European 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	4209	3584	60	12%
- in cities and towns over 5000 inhabitants	2793	2445		
Number of cities concerned	3766	3268	141	28%
- in cities and towns over 5000 inhabitants	2447	2188		
Number of NUTS3 regions concerned	663	603	288	58%
Total number of NUTS 3 areas	1461	1303	500	100%

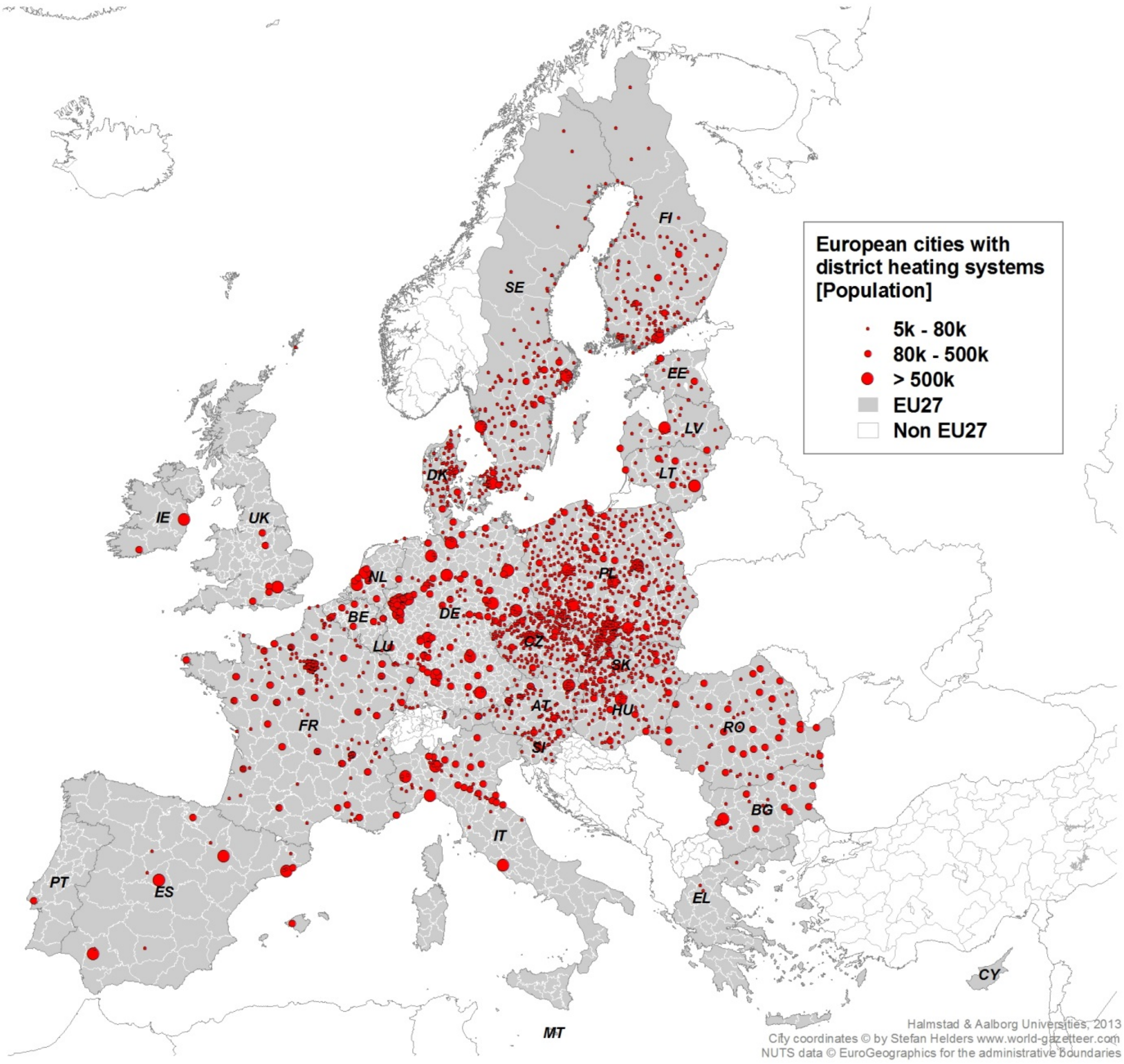

Figure 9: Cities with district heating systems in EU27 by city size and for cities having more than 5000 inhabitants. The map shows 2188 cities with 2445 systems [8].

1.2.4 District heating within the current EU energy policy context

The European Union does not have many specific energy policies or directives concerning district heating. However, the specific directives for industrial emissions, emissions trading, energy performance in buildings, renewable energy, waste management, energy taxation and energy efficiency 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 [9] 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* [10]. However, the description of the heat sector is not complete in this future projection, since some of the energy for heat is missing in the corresponding impact assessment reports [11, 12].

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 actual 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 the EU27. The average of these years amounts to about 830 TWh/year comparable to the level identified in section 1.2.2.

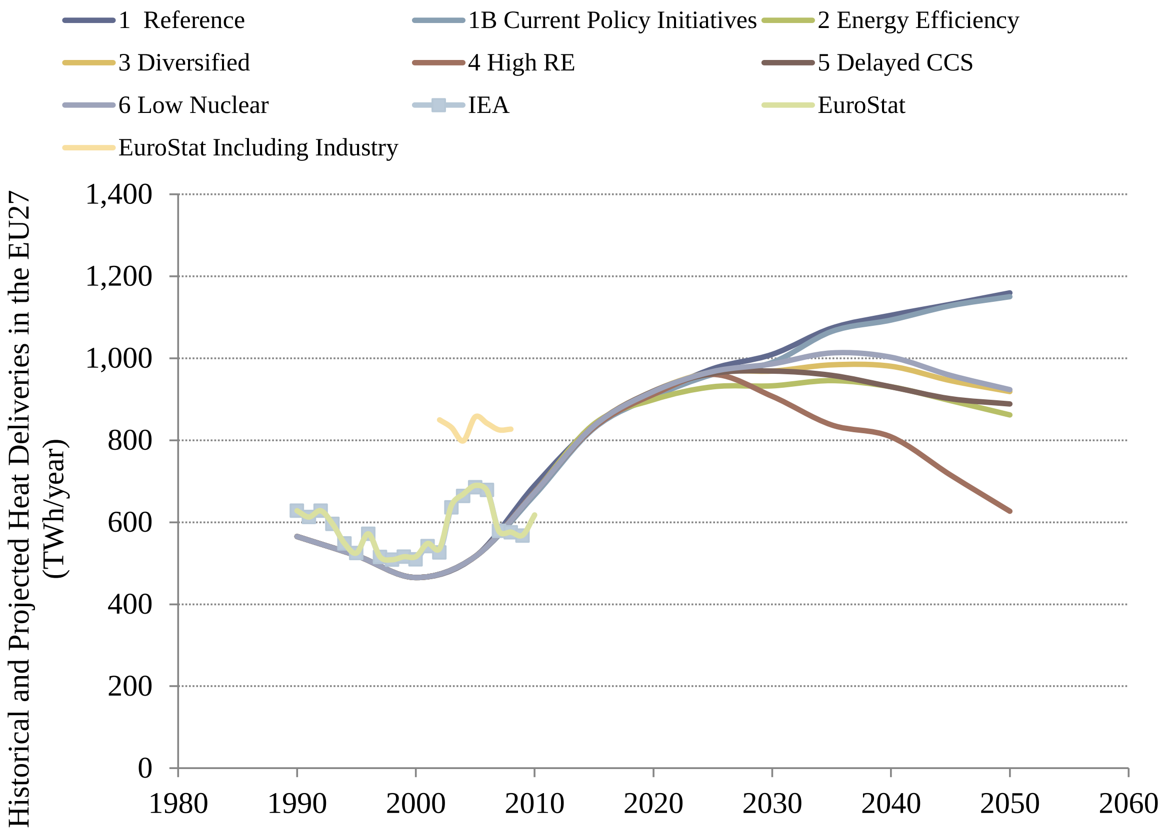

Figure 10: Expected heat deliveries for each of the seven main scenarios in the *Energy Roadmap 2050* communication [40] compared to the heat statistics available from Eurostat and IEA for recent years.

The expected development then becomes an increase of almost 20% by 2030 and almost 40% by 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 by 48% until 2030 and by 87% until 2050, while heat deliveries to residential and service sector buildings are expected to decrease by 13% until 2030 and by 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? To what extent has the substitution of electricity and gas by excess heat recovery been considered?

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. It is possible that the benefits of district heating may have been overlooked in the Energy Roadmap 2050 communication by the PRIMES tool. As we have identified from studying the background references for Annex V, the PRIMES tool does not aggregate local conditions to identify the possibilities for expanding district heating systems, thus missing many of the possibilities and advantages of district heating. This is not unique to the scenarios in the Energy Roadmap 2050 report, but as discussed in the next section, the recycling of heat is a common omission in existing energy strategies for the EU27.

1.3 FUTURE HEAT DEMANDS IN EUROPE

A number of reports regarding the decarbonisation of the energy supply and/or increase in the penetration of renewable energy have been reviewed to present how the heat sector is currently dealt with in energy scenarios for the EU27. The results are described below and a description of the different reports (in terms of heat demands) is available in Annex II. The total number of reports reviewed is 14. In Table 2, the reports and the organization behind them are presented.

The typical goal in the reports is greenhouse gas (GHG) emission reductions or to increase the share of renewable energy. The main trend in almost all the reports is that an increased electrification along with extensive energy savings are considered the main technological change to achieve reduced GHG emissions within the heating sector. Of course this implies that the electricity sector is made more efficient and reduces GHG emissions by producing electricity with low-carbon technologies. The heat demand depends highly on which scenario is followed. Typically electricity is assumed to play the largest role in the most ambitious scenarios (with a high share of renewable energy and large energy savings). In general the more ambitious the GHG goals, the larger the focus on electrification is.

Some of the reports indicate the need for further investigations in terms of heating and cooling, which underlines the relevance of the analysis in this report. One example can be found in the *Energy Technology Perspectives 2012* by IEA which states:

> *"Heating and cooling remain neglected areas of energy policy and technology, but their decarbonisation is a fundamental element of a low-carbon economy."*

The same report states that due to the projected urbanisation, district heating will be more feasible because of shorter distribution networks and more compact heat-generating infrastructure. Besides this, a compact urban development can compromise the desired use of natural lighting, ventilation and decentralised use of solar energy, and higher densities limit the potential of ground-source heat pumps.

Most of the reports do not state the heat demand separately and it is therefore unclear to what extent the different resources should supply the demand for heating/cooling in general and specially for district heating. In general the heating sector (including district heating) is not "forgotten" in the reports, but is just not a main focus area. Table 2 indicates the lack of detailed information regarding the heat demands in the reviewed reports.

The demand for space heating and domestic hot water is mainly supplied by individual ground source, air to water or air to air heat pumps in the reports. While a heat pump is in fact a heat production unit, it is in some places described as a heat savings initiative. This is due to the thought that since heat pumps are deemed to replace (mainly) inefficient oil and gas boilers (and to some extent electrical heating), the implementation will result in a lower primary energy demand for the building. However to reach any ambitious GHG targets, the extensive use of heat pumps implies that the electricity sector in the long run must be based mainly on renewables, Carbon Capture and Storage (CCS), and/or nuclear power.

In the *Energy Roadmap 2050* it is stated that some European long term energy scenarios seem to have unclear/inadequate assumptions of the necessary investment costs for the electricity distribution grid. This means that the cost of the increased electrification may actually be higher than what is expected in these scenarios.

Most reports do mention some district heating in densely populated areas using technologies such as large scale heat pumps, CHP, biomass, and to some extent solar and geothermal heat. Gas is also predicted in several reports to act as a replacement for coal and oil – at least in the short to medium term future. District heating is expected to have an important role, but this is mainly in the less ambitious scenarios in terms of GHG reductions except from the Energy Technology Perspectives 2012 report from IEA where the importance of CHP and district heating is recognised as fundamental for the "decarbonisation" of the heating and cooling sector.

One of the main ways to reduce the heat demand and energy demand in general is to include strict building requirements in all new buildings. After 2020 "nearly zero-energy buildings" are assumed to be the norm in Europe due to the energy performance of buildings directive (EPBD) [13]. Besides this, buildings which are subject to "major" renovations should at least live up to the "minimum requirements". In the EPBD it is specified that it is the sole responsibility of the Member States to set minimum requirements for the energy performance of buildings and building elements. In other words, the responsibility of these savings in the heating of buildings relies on a) the legislation in the different countries and b) the rate of refurbishment. The latter is in some reports assumed to lead to a refurbishment of the whole European building stock by 2050. While a typical renovation cycle of buildings (e.g. around 30-40 years) may make the renovations necessary within the timeframe from now till 2050, the issue is not only whether or not renovations will occur, but if the energy savings initiatives will be implemented when the renovations are carried out. In many cases there will be only one chance to improve the energy performance (i.e. one renovation within the period). Hence the uncertainty of refurbishment rates to high energy standards also lies within the assumption of the *improvement* of all renovated buildings besides the amount of buildings renovated per year. Nevertheless several reports include high refurbishment rates (to high energy standards) even without mentioning the share of the building mass which in practice cannot be improved, such as historical monuments.

Table 2: List of reports reviewed, the organization behind the report, and the relation to the heating sector.

Report title	Organisation	Is the heat demand quantified separately?	Does the report analyse the development in heat demand?	Is CHP said to be important to promote?	Is CHP a part of the analyses?	Is district heating expanded as part of the analyses?
EC Energy Roadmap 2050 / Impact Assessment	EC	Yes	Yes	Yes	Yes	For industry only, using industrial CHP
Roadmap 2050	ECF	No	No	Yes	Yes, but not quantified in the text	Yes, but not quantified
The Energy Report / Re-energising Europe	WWF	No	No	Not mentioned	No	No
ETP 2012	IEA	Yes	Yes	Yes	Yes	Yes
WEO 2012	IEA	No	No	Yes	Yes, but not quantified in the text	Not described
Deciding the future	WEC	No	No	Not mentioned	No	No
Desert Power 2050	Dii	No	No	Not mentioned	No	No
Policy Report - Contribution of EE measures…	Fraunhofer ISI	No	No	Not mentioned	Yes, but not quantified in the text	No
Rethinking 2050	EREC	Yes	Yes	Yes	Not described	Yes, but not quantified
EU Energy Policy to 2050	EWEA	No	No	Not mentioned	No	No
Renovation tracks for Europe up to 2050	Eurima	Space heating demand, yes	Space heating demand, yes	Not mentioned	No	Yes, but not included for new bldg.
Europe's buildings under the microscope	BPIE	No	No	Not mentioned	No	Not described
Power choices	Eurelectric	No	No	Not mentioned directly	Yes	Yes, but not quantified

Two of the main barriers to achieve the improvements in terms of the heat demand of buildings are the high investment cost (and long payback time) and the issue that there is often a split of incentives between tenants and landlords because the person who pays the energy bill is not the same as the one who would have to invest in building improvements. For this reason and the fact that the present annual renovation rates in most countries are well below a level which will have all buildings renovated by 2050 [14], there is an urgent need for political action to address the barriers by implementing policies and financing models to help overcome high up-front investment costs. The European Commission recognises the magnitude of this challenge when stating that the Energy Efficiency (EU-EE) scenario of the *Energy Roadmap 2050 "…pushes the limits of what the chosen measures can achieve"*. Actually none of the scenarios in the *Energy Roadmap 2050* live up to the energy efficiency 20-20-20 goals[7] [15]: the Energy Efficiency scenario only reaches 18% in 2020. This indicates that fulfilling the goals will only be that much harder if the measures to obtain them are not launched right away, but scheduled to be commissioned in the years ahead.

For most of the reports the idea is not to make a forecast of the expected future of the energy system, but to describe different ways to achieve more or less (or very) ambitious goals in terms of GHG emission reductions or share of renewables. In other words, the projections should not be seen as *the* answer on how to move towards a sustainable future, but as suggestions on how a specific target *could* be reached. The idea of HRE is to make a scenario for the European energy system towards 2050 which will argue that there is another unexplored path towards the energy objectives and that this path can contribute to address the technological challenges of implementing high shares of renewables and deep cuts in GHG emissions – even in an economically feasible way.

Concluding from the review of the analyses in the reports mentioned, it can be said that there is a need for conducting integrated energy system analysis of the electricity and heating sector – also taking into account refurbishment, energy savings and new building standards. Should the actual refurbishment rate and energy efficiency improvements not live up to the very ambitious targets for buildings, the need for other measures in the electricity sector, or transport sector could increase in order to maintain the overall GHG emission objective. Also CHP and district heating could become a good option to increase energy efficiency and include more sources for the heat sector.

[7] A 20% reduction in EU greenhouse gas emissions from 1990 levels (binding), raising the share of EU energy consumption produced from renewable resources to 20% (binding) and a 20% improvement in the EU's energy efficiency.

1.4 STRUCTURE OF THE REPORT

Overall, the key focus in this report is to create a new heat strategy for the EU27 primarily based on heat savings in buildings, the expansion of district heating, more heat recycling, more renewable energy, and individual heat pumps. The report is structured as follows:

- Chapter 2 provides a brief overview of the methodology used in this study.
- Chapter 3 describes the maps that have been created for the EU27, which are used to identify how district heating can be expanded and what resources can supply heat to district heating networks in the future.
- Chapters 4, 5, and 6 describe the modelling part of this study:
    - Chapter 4 presents the reference scenario, which is used as a starting point in the energy systems modelling. The reference scenario is based on the Energy Efficiency (EU-EE) scenario from the *EU Energy Roadmap* report.
    - Chapter 5 describes how the EU-EE scenario is redesigned to include both district heating and district cooling, along with less heat savings and the same number of individual heat pumps. This new heat strategy is called the Heat Roadmap Europe Energy Efficiency (HRE-EE) scenario.
    - Chapter 6 presents a comparison between the EU-EE and HRE-EE scenarios. The energy consumed, CO_2 emissions produced, and the costs of both scenarios are discussed.
- Chapter 6 discusses the main results from a case study, which has also been completed in this project based on the city of Aarhus in Denmark. This case study also includes a combination of mapping and modelling. Different combinations of heat savings, district heating, and individual heat pumps are compared for the city of Aarhus.
- Chapter 7 presents the main conclusions from this report.

2 METHODOLOGY

The methodology utilised in this study is based on a combination mapping and energy system modelling. The mapping of local conditions reflects the potential to expand district heating in the future, while the modelling quantifies the effect of including district heating in the EU energy system. This approach is not completely new: the same methodology was used in the *Heat Plan Denmark* (*Varmeplan Danmark*) project [4, 5] with a very high geographical resolution for the mapping of local conditions. Below is a brief discussion of both the mapping and modelling methodologies employed in this study. In addition a case study has been performed for a concrete city, using more site specific data (see chapter 0 and Annex XII).

2.1 MAPPING

Included in this study is a new methodology to map the heat demand, the potential for district heating, and the supply from excess heat and renewable energy sources at a desirable higher geographical resolution on an EU27 scale. The mapping part is then used to estimate the district heating expansion feasible in the EU in 2030 and 2050, which acts as an input for the modelling part of this study. In the future, the aim is to explore how this link between mapping and modelling can be even stronger.

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 a separate analysis of each country. A major setback in standard generic energy modelling is that national conditions constitute the basis for the 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 such as 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 such as 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 can the excess heat from various activities and sources be utilised by the recovery and distribution in district heating systems. For this reason, one fundamental idea for the planned extensive 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, according to the 2006 NUTS classification with 2008 additions, are available for 34 European countries with 1461 defined regions. The 27 Member States of the European Union consists of 1289

NUTS3 regions, see Figure 11. By using these predefined administrative regions, other statistical variables are easily available from the Eurostat and other related databases. A wide array of such publicly available data has been utilised in this study to create a heat atlas identifying the heat demands in Europe, as well as several other maps to identify resources available for future district heating systems. In the Heat Roadmap Europe context, these resources are divided into the two main strategic heat source categories of excess heat and renewable local resources, where the former includes sources such as thermal power generation plants, waste incineration facilities, and recovery of excess industrial heat, while the latter refers mainly to biomass, geothermal, and solar thermal heat.

Figure 11: The NUTS3 regions of Europe, of which 1289 are located within the EU27 European territory and 14 are located overseas.

The actual presence of sufficient heat demands in absolute terms and by geographical density is crucial for an estimate of the potentials for developing future district heating systems. The general aim of the mapping part of the project is thus to quantify the share and absolute size of heat demand by density, by population, and relative to the locations of excess heat activities, so that the total amount of district heat to be distributed by the future energy system of Europe is known. The mapping part of the project thus serves two purposes; first to create a linkage with the energy system modelling part of the project, which simulates supply and demand on an hourly basis, and, secondly, to provide input and methodological tools for regional planning of future local European heat markets. The link to the energy system modelling, where the mapping group provides regional data of probable district heat volumes, also operates in the opposite direction: the output from the energy systems modelling indicates the amount of different resources that can be utilised within the energy system.

With reference to the two main strategic sources of heat supply, such indications could – to exemplify – refer to locations where excess heat recovery from thermal power generation is a priority, or where rich availability of biomass is a major alternative. At yet other locations, Waste-to-Energy incineration in combination with significant presence of energy intensive industrial facilities, offers a quite different set of heat supply options. Mapping of European heat assets by regional resolution provides in this sense a basis for evaluations of appropriate alternative heat supply compositions, and in extension also concrete tools for planning of local and regional heat networks.

2.2 MODELLING

After profiling the potential for district heating using the new maps created in this study, the effect of district heating on the EU energy system is then analysis using an energy systems tool. In this way, the impact of district heating can be quantified.

EnergyPLAN is an energy system analysis tool specifically designed to assist the design of national or regional energy planning strategies under the "Choice Awareness" theory [16, 17]. It has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark [18]. As a result, it is now a very complex tool which considers a wide variety of technologies, costs, and regulations strategies for an energy system (see Figure 12). The algorithms used to create the tool are described in detail in the user manual [19].

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 for handling 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. As the model is based on compiled analytical procedures rather than on the interpretation of model interdependencies, 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.

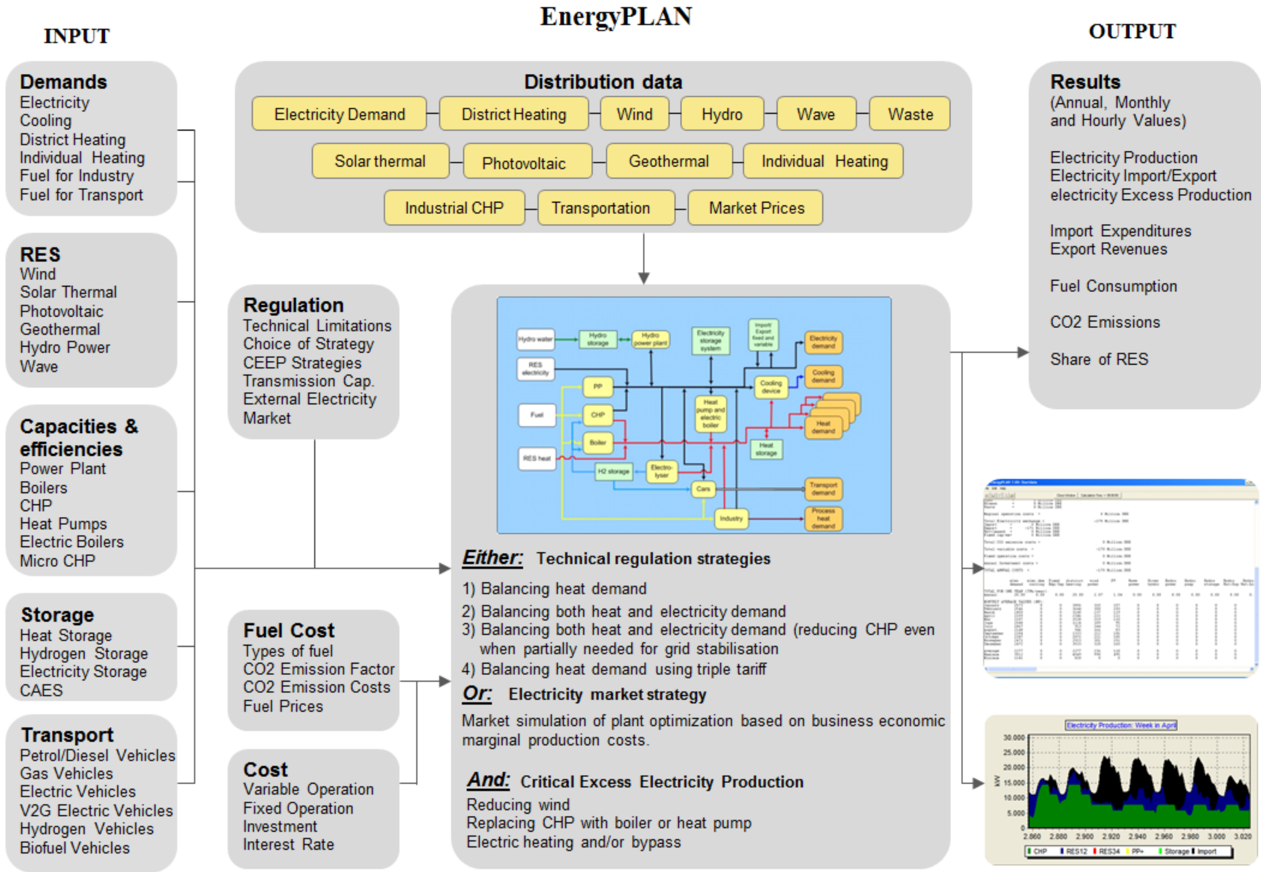

Figure 12: The structure of the EnergyPLAN tool [17].

Previously, EnergyPLAN has been used in a variety of studies at national and European level, including the *Heat Plan Denmark* (*Varmeplan Danmark*) project [4, 5] and the first HRE pre-study [1]. In this study, the EU energy system has been modelled in EnergyPLAN based on the EU-EE scenario (see chapter 4). Then, as outlined in Figure 13, the inputs from the mapping work in this study have been used to replace some of the individual heating in the EU-EE scenario with district heating. This is combined with a number of other alternations to the heat sector to produce a new HRE-EE scenario (see chapter 5). Finally, both of these scenarios are compared with one another (see chapter 6).

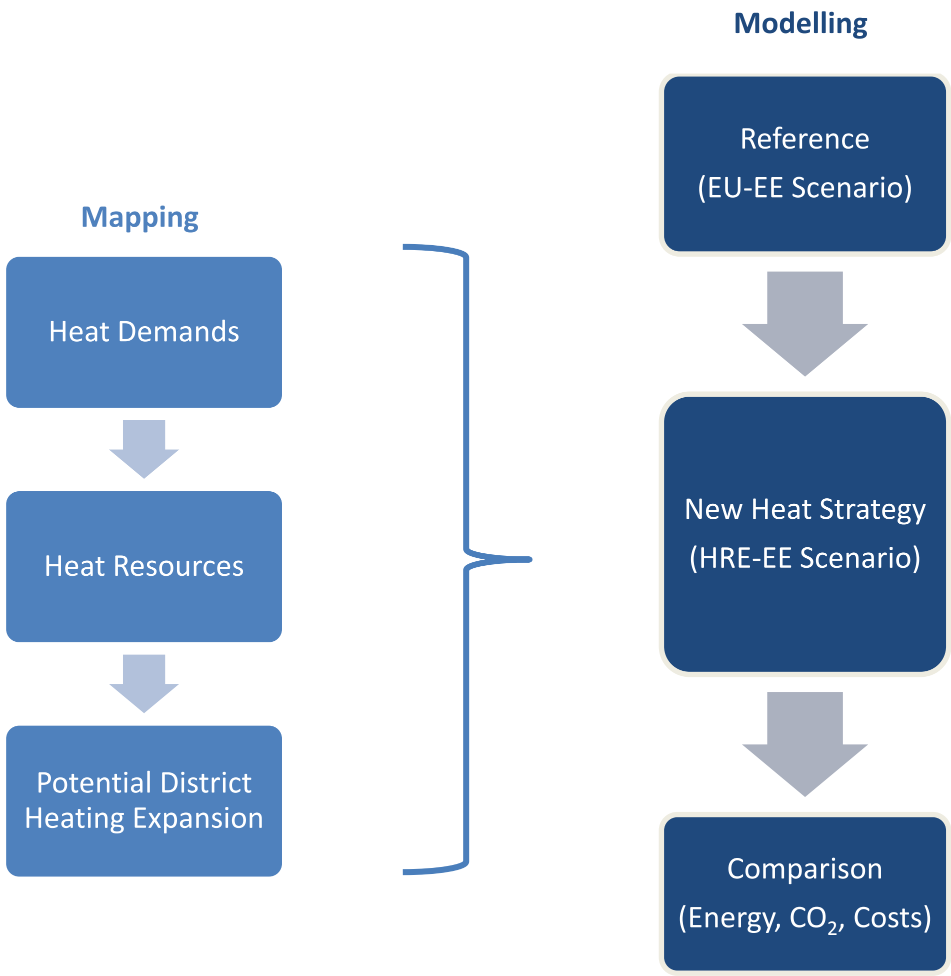

Figure 13: Linkage between the mapping and modelling in this study.

3 MAPPING FUTURE POSSIBILITIES INCLUDING LINKING

In the mapping part of the project, three fundamental categories of information relevant for district heating expansions are subject for spatial analysis; residential and service sector heat demands, excess heat activities, and local renewable heat resources. While heat demand is geographically distributed in terms of climatic location, levels of energy services required by local populations, and by human settlement patterns (such as rural areas, towns and cities), excess heat activities and local renewable heat resources are distributed spatially over the continent by influence of e.g. regional levels of economic activity, availability of raw materials, and general terrain properties.

The main objective of this chapter is thus to map the shares of total EU27 residential and service sector heat demands that are within reach of district heating; and to geographically quantify the sources of current and future district heat generation. From a strict heat supply perspective, modern district heating systems can be viewed as local heat distribution solutions that exploit two main strategic sources of heat; excess heat and renewable heat resources. Both of these main sources of heat supply consist of three activity sectors each, according to:

1. Excess heat:
    - Thermal power generation
    - Waste-to-Energy incineration
    - Energy intensive industrial sectors

2. Renewable heat:
    - Biomass
    - Geothermal
    - Solar

The first main heat source category is based on the principle of sequential energy supply, or cascade coupling, by which rejected heat flows from primary energy conversions are recovered as secondary heat. Although primary fuel sources in thermal power generation and energy intensive industrial activities consist of fossil shares, serial utilisation of excess heat improves the general energy efficiency of these processes. Waste-to-Energy incineration of municipal solid waste and industrial waste fractions, possibly also containing shares with fossil origin, serves a purpose to reduce landfill deposits, reduce landfill GHG emissions while simultaneously generating electricity and heat.

The second main heat sources category is based on the principle of utilising local renewable heat resources available in the ground, on land, or from the sky. As with the first main heat source category, these assets are heterogeneously spread over Europe depending on e.g. geology, agricultural and silvicultural management practices, and geographical location. Some European areas are rich in all three activity sectors, while others have dominant assets to exploit within only one or two of these. As a general distribution, Northern Member States are richer in biomass, while Central European areas are richer in geothermal energy. Solar irradiation is about twice as intense in Southern Europe compared to the Northern parts of the continent, but solar energy is naturally present in all Member State although at various degrees of intensity and usability.

While district heating systems today are supplied with heat originating from both fossil and renewable heat sources, a future decrease of the fossil content would further improve the sustainability of district heating. Future possibilities constitute a complex matrix of excess heat activities and renewable heat resources (including also wind energy converted to heat) heterogeneously distributed amongst city districts, urban agglomerations, rural regions, and country sides. To decide upon which future solutions to explore at different locations, a comprehensive mapping of prospective demand and supply is carried out. To be able to decide and select what options to develop at any given place, sufficient heat demand density as well as point sources for excess heat and local access to renewable energy sources has to be quantified by location. A first step to address these challenges and to generate a basic understanding of this puzzle is therefore to map European heat demands, excess heat activities, and local renewable heat resources.

In combination with spatial information and geographical data for each locality and activity, the project aims at finding regions with exceptionally 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 [20]. The Heat Plan Denmark project in 2008 used an extensive GIS-based heat atlas to identify the potentials to fully utilise existing district heating systems, and convert individual natural gas to new district heating on a national scale [5, 21]. A similar project in the UK gathered information about industrial heat loads [22]. The knowledge gained in that project is now available as interactive Internet maps for the CHP development [23] and the recently released National Heat Map [24]. A similar approach has also been used to give an overview of the European power plant infrastructure [25]. 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.

3.1 LOCATION OF CURRENT HEAT DEMANDS

A key parameter in the mapping part of the Heat Roadmap 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. Estimating total NUTS3 region heat demands for space heating and domestic hot water preparation in residential and service sectors are fairly straight forward, although at a much too coarse resolution for district heating applications. In aiming to identify and map the proportion of total NUTS3 region heat demands within reach of current and future district heating systems, i.e. heat demand in areas with sufficient density quantified by amount and location, the greatest challenge is to map heat demands with sufficiently high geographical resolution. The aim within the project is to locate heat demands within a few kilometres distance.

The methodological approach of mapping heat demands is done initially in a top-down manner, where national level energy statistics allow for the calculation of Member State average per-capita heat demands, which are subsequently associated to total population counts within each NUTS3 region in respective country. Per-capita heat demands by country include the levels of energy services available in the country, such as amount of floor space and indoor climatic comfort levels. It also indicates the technological level of heating, reflected by level of insulation, occupant behaviour, or access to thermostatic control. Finally, the general climate of each Member State is represented by use of the European Heating Index (EHI), a concept presented by Werner [26], in order to map sub-national deviations from national and European heat demand averages. The European heating index is available as an isoline with values of zero in the far South to 150 in Northern Scandinavia.

Eurostat statistics on NUTS3 region level are the smallest scale of public statistics available for all EU27 countries and contain, among other parameters, data on population and service sector activities. To achieve the highest possible resolution for mapping, the GEOSTAT European population grid by GISCO, the European Forum for Geostatistics, containing the 2006 population in one square kilometre grid cells was used [27]. Comprising of almost two million cells, this data set is assumed to be by far the best possible input to map high resolution demography in all EU27 Member States. Using the EHI-adjusted heat demands per NUTS3 region, as described above, this population grid was converted to a highly detailed heat atlas for Europe.

The one square kilometre grid that contains heat demand in Tera-joules per square kilometre (TJ/km^2) comprises a heat demand density map which could be the basis for an assessment of district heating potential by density alone. However, the grid does not allow for mapping coherent areas of similar heat demand. These are necessary to describe a distribution of heat demand over larger areas, which can be converted to areas that have a minimum threshold value for heat demand. A focal mean function in the raster-representation of a geographical information system (GIS) was used to calculate the average values of heat demand within a radius of one kilometre. The result is a smoothed heat demand density map; a European heat atlas, as presented in Figure 14. To our knowledge, this kind of heat atlas has never been published for EU27 before.

In order to present a future heat demand, which takes into account the demographic projections for the member states, and which is reduced by 34% of the current demand, another version of the heat atlas was prepared. Population growth by 2030 originates from the PRIMES model, which was multiplied by the current population count per cell. The future energy demand of 34% was normalised for all cells dividing by the overall population growth in EU27 of 104%. The resulting heat atlas and heat demand density map shows that with the same classification, the prospective district heating potential is reduced significantly.

The heat demand density map by focal mean is found to represent European urban areas and their suburban fringes very well. On the basis of a classification by Werner, four zones of heat demand density were modelled: below 15 TJ/km^2, 15-50 TJ/km^2, 50-150 TJ/km^2, and above 150 TJ/km^2, which represent levels of technological development as well as a general classification of areas by feasibility. The heat demand density class value of each square kilometre grid cell was spatially joined to the heat atlas, hereby allowing for classification of each individual 1 km^2 by heat density. Afterwards the nearly two million cells were subjected to further processing by means of a pivot table summary, which specifies the amount of heat demand by density class for all NUTS3 districts, resulting in the distribution presented in Table 3. The method is generic in a sense that statistical extracts can be made by several parameters, and for several geographical entities.

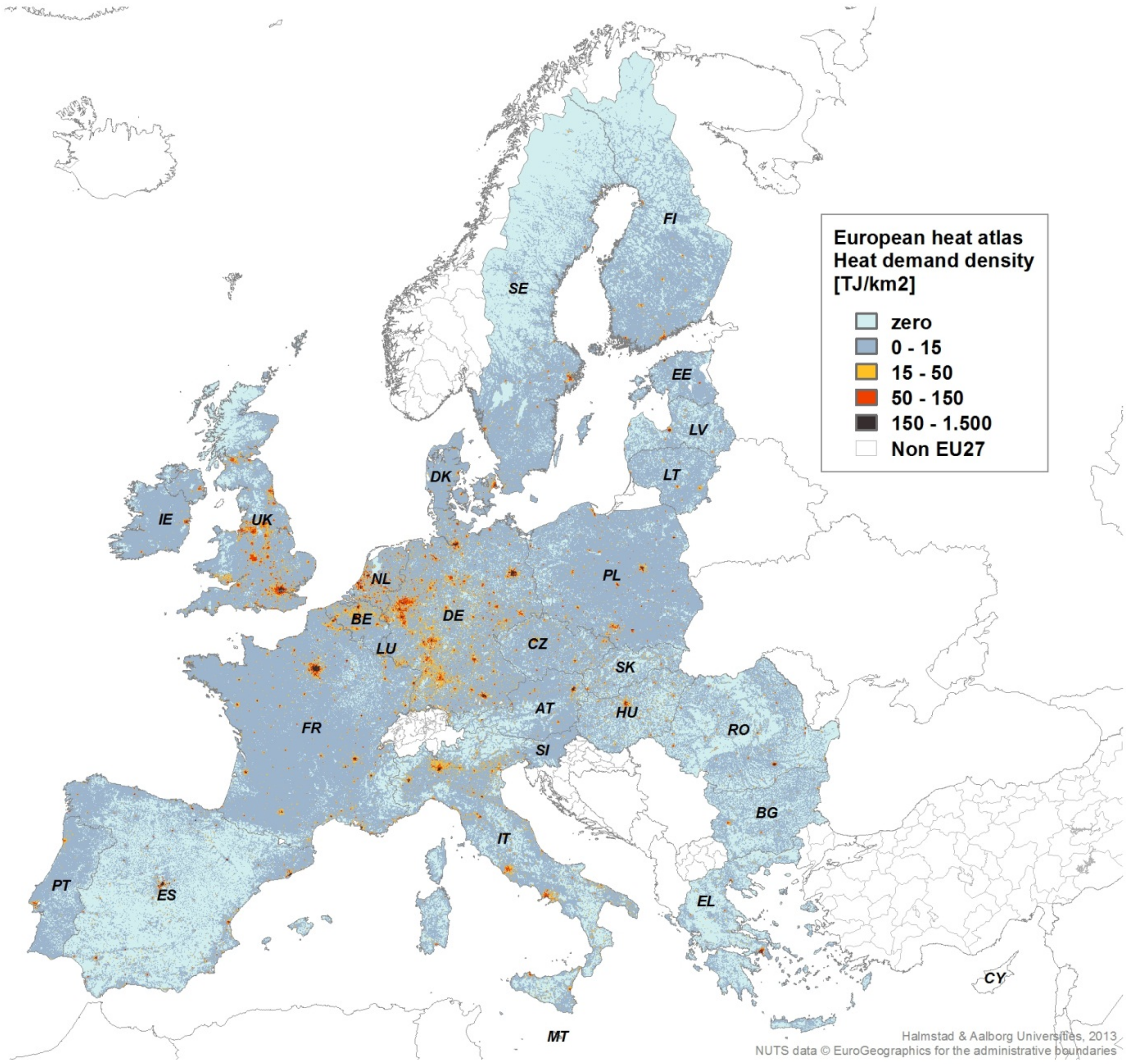

Figure 14: European Heat Atlas by heat demand density classes based on the GEOSTAT 2006 1 km^2 population grid.

Table 3: Heat demand density classes, current situation (2006) for EU27

Heat demand density class [TJ/km^2]	Population [10^6]	Share of Population [%]	Total inhabited area [km2]	Share of Total inhabited area [%]	Avg. heat demand density [TJ/km^2]	Total heat demand [PJ]	Share of heat demand [%]
zero	22.6	4	114924	5.9	1.9	221	2
0 - 15	155.7	31	1665529	85.6	2.0	3349	30
15 - 50	127.4	25	121494	6.2	25.0	3051	27
50 - 150	143.3	29	39403	2.0	87.0	3436	30
> 150	53.7	11	5111	0.3	243.0	1241	11
Total	502.6	100	1946461	100		11298	100

It was found that the focal mean density method has a levelling effect and results in lower overall density values, underestimating the district heating potentials. If using the raw density values however, the potential is overestimated. This happens because many small areas with higher densities are identified, which often are not connected to larger prospective district heating areas. The solution may be to use the focal mean and the raw density as thresholds, within which a more realistic potential may be found. Figure 15 shows the development of these density thresholds by cumulative heat demand.

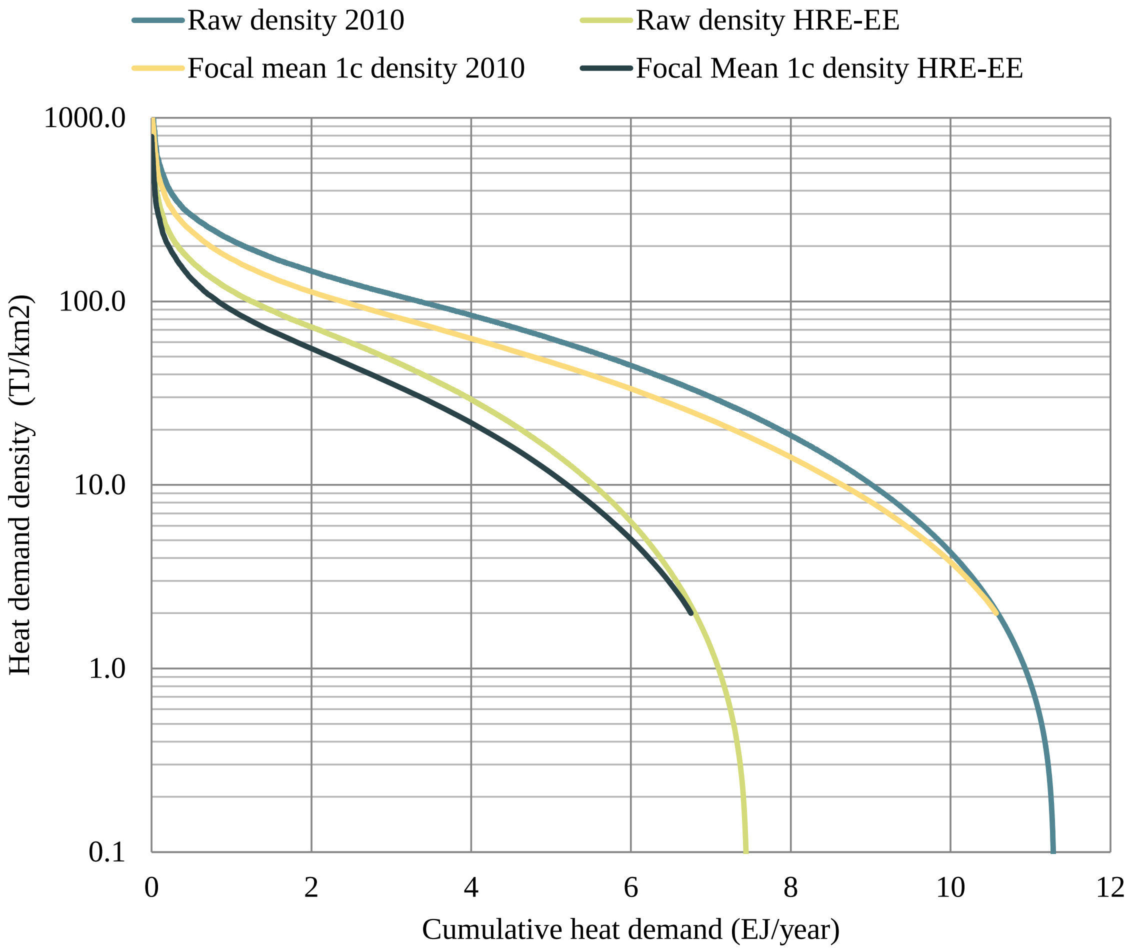

Figure 15: Cumulative heat demand according to the European Heat Atlas in 2010 and in the Heat Roadmap Europe Energy Efficiency (HRE-EE) scenario, by two different types of heat density calculations. Raw density is the density calculated in each square kilometre cell, while Focal mean density is the density if calculating the mean of a cell and its neighbourhood cells, thereby levelling out density values but resulting in more coherent prospective district heating areas.

Taking Denmark as a case, the abovementioned method was applied to reconstruct the prospective district heating areas found, and to validate the results of the heat demand calculations. Looking at the area around the city of Aarhus (which also serves as the location of the case study for a comparison between district heating and individual heat supply in this report – see chapter 0), it can be seen that the boundaries of the proposed district heating areas found by the density method correspond very well with the district heating areas charted by the municipal heat plans, see Figure 16. Of course the mapping here happens at two different scales. While the existing district heating areas are mapped at scales between 1:10,000 to 1:25,000, the European heat atlas grid resolution of 1 km^2 is equivalent to scales of 1:250,000 to 1:1,000,000 (this is an approximation; vector scale and raster resolution cannot directly be compared). The scale or resolution of one square kilometre is sufficient to identify all district heating areas of more than 1020 TJ of annual heat demand. It can further be seen that there are several smaller district heating areas existing, which however are too small to be identified by the European model[8].

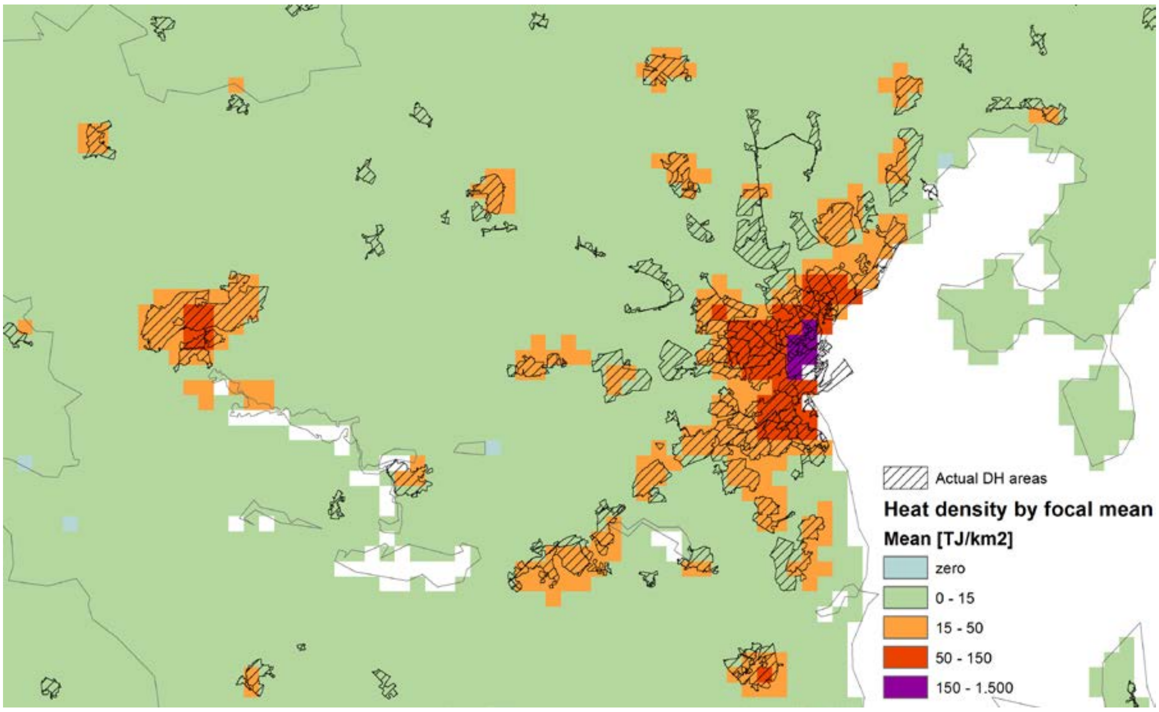

Figure 16: Comparison of prospective district heating areas found by the density method and existing district heating areas around the city of Aarhus, Denmark. The method can identify the majority of areas. The resolution of one square kilometre is just sufficient to identify all district heating areas above 10-20 TJ of annual heat demand.

3.1.1 Land use data and settlement structures

The main challenges of using uniform values of per-capita heat demands lie in the real-life heterogeneity of settlement structures, in the differing geography of a country (where particularly extensive and large countries may have different levels of heating requirements in different parts of the country), and in varying socio-economic structures – where uneven distributions of e.g. wealth may have influence on heat demand factors such as specific floor spaces, household sizes, and affordability of space and hot water heating. Different regional building practices and national building codes through times add to this complexity. Actual geographical distribution of settlement structures by type and volume within cities and urban agglomerations is not fully captured by NUTS3 level information, and rarely so even in data originating from the highest level of resolution in official European spatial data, i.e. the Local Administrative Units (LAU2, or NUTS5, i.e. municipal level).

Also from a strict district heating perspective, being a local heat distribution technology utilizing local opportunities, the ability to sub-penetrate national and NUTS3 region information levels is crucial for

[8]A comparison between the modelled heat demand and the actually measured demand in the supply area of Affald Varme Aarhus shows a very good correspondence. While the expected demand in the supply area, based on several years of recorded data and using a normalised climate profile, is 8363 TJ, the Danish Heat Atlas by Aalborg University (Möller, 2008) accounts the heat demand to 8597 TJ, while the European Heat Atlas lands at 8731 TJ, which is a difference of less than 2% to the Danish Heat atlas and of 4% if compared to the expected heat sales, which are subject to some uncertainty.

feasibility estimations and practical assessments. Altogether, heat demands, settlement structures, land use priorities, excess heat activities, local heat resources, and general geographic properties of any given location need to be analyzed at high spatial resolution to provide sufficient information for robust assessments. Since heat demands, and e.g. levels of heat demand density concentrations, are decisive for the feasibility of district heating installations, the approach of combining 1 km^2 population grids with NUTS3 regional data needs therefore – in the extension of the project – to be improved in ways that allow for the delineation of areas within which there is a certain head demand density and presence of main strategic heat supplies.

Coincidentally, a wide range of datasets are today publicly available for in-depth geographical and demographical analyses of local conditions in EU27 Member States. In Figure 17, an example of land use data from the European CORINE land cover 2000 seamless vector database is depicted with regards to some chosen land cover types in Belgium. The CORINE 2000 database [28] discretely reveals heat demand concentrations in urban areas, by label distinctions between e.g. continuous urban fabric, discontinuous urban fabric and industrial and commercial areas. In the CORINE database, the complete European land area is defined according to 44 different land cover types, and hence, it offers the possibility to identify proportions of urban areas within all NUTS3 regions.

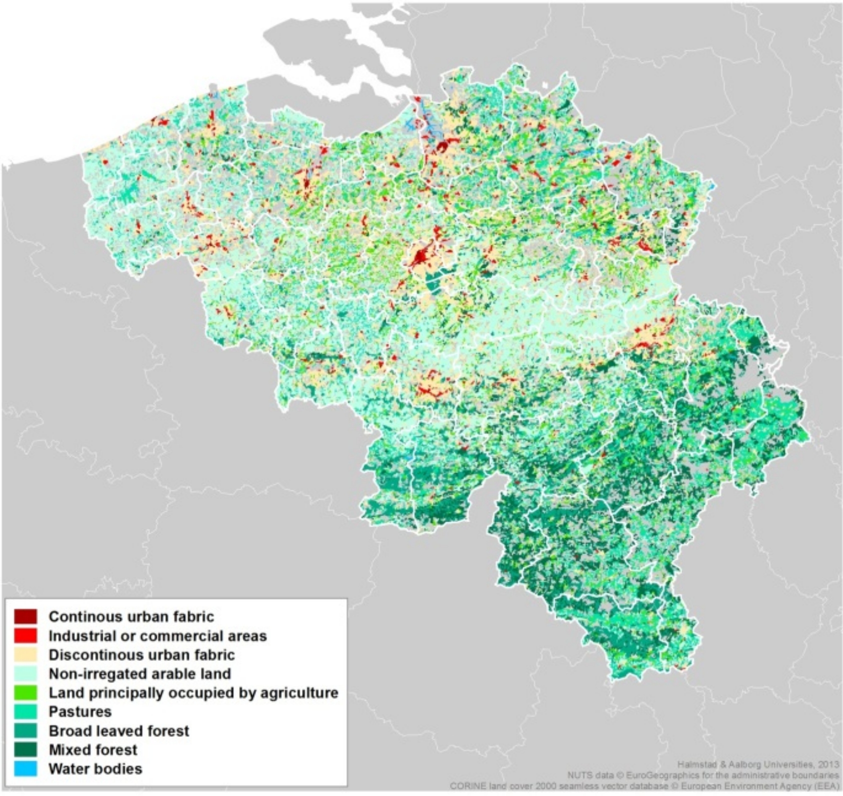

Figure 17: Example of land cover data labels for Belgium from the European CORINE land cover 2000 seamless vector database [28].

A major parameter decisive for the mapping of future district heating is also availability of high resolution data on European cities and urban agglomerations. Going beyond the CORINE 2000 dataset, in terms of geographical resolution, the Urban Audit of Eurostat has collected information on larger EU27 urban areas since late 1990s. As a cooperation between the European Commission Directorate-

General for Regional Policy and the Directorate-General for Enterprise and Industry, with support of the European Space Agency and the European Environment Agency, the European GMES Urban Atlas constitute a massive spatial dataset with high resolution data for many but not all European cities, drawing from the experiences from the Urban Audit scheme. As an example from this dataset, Figure 18 shows a wide set of land cover types for the French capitol Paris and surrounding NUTS3 regions (EEA, 2010). Using advanced spatial statistics such as cluster and outlier analysis by Morans I, or using Getis-Ord's Gi-coefficient for identification of hot spots, the urban land cover maps could be used to identify coherent areas on the basis of spatial distribution alone. Alternatively, raster-based analysis or network analysis may be used to model the cost propagation of district heating network by weighted distance using gravity-based approaches.

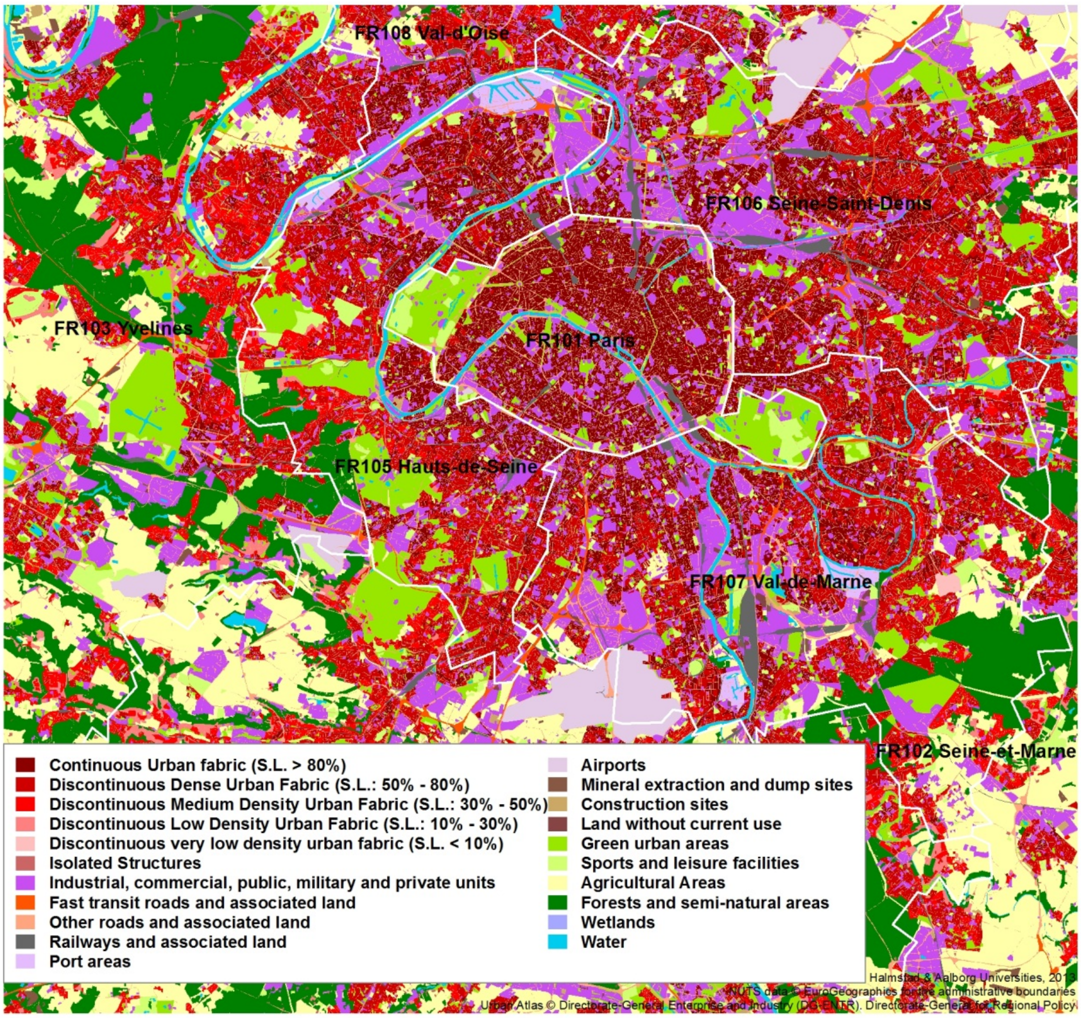

Figure 18: Example of land cover and settlement structure data for the French capitol Paris, with surrounding NUTS3 regions, from the European GMES Urban Atlas dataset [29].

In the extension of the Heat Roadmap project, as the results will be disseminated to regional energy planners and local authorities, the features of the European CORINE land cover 2000 seamless vector database, the GMES Urban Altas as well as the GEOSTAT 2006 population grid can provide the basis for a tool to identify coherent prospective district heating areas. 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. Going one step further, even a model of all urban areas, and their district heating potentials by amounts and costs can be thought of. By thus offering spatial guidance and geographical support when identifying and analysing European synergy opportunities and locations, high resolution geographical and spatial datasets constitute corner-stones in the tool-package of the project.

3.2 MAIN STRATEGIC SOURCES OF HEAT SUPPLY

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 current local excess heat streams and alternative local heat resources. Thus using a bottom-up approach to include local conditions, the project aims at establishing balances between local heat demands in residential and service sectors and available local excess heat and renewables heat resources in each NUTS3 region.

A first inspiration for the need of such a bottom-up approach, was presented in the Ecoheatcool study [30], where future possible heat resources from combined heat and power, Waste-to-Energy, industrial excess heat recovery, geothermal heat, and biomass was quantified on an aggregated level for 32 European countries. The findings from this work 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 were utilised in district heating systems

Hence, there is no shortage, in absolute terms, of available heat resources in short and medium term. To identify the relative amount of techno-economically feasible supply, 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.

3.3 FIRST MAIN HEAT SOURCE CATEGORY – EXCESS HEAT ACTIVITIES

As mentioned above, modern district heating systems are local heat distribution solutions that exploit the two main strategic sources of excess heat and renewable heat resources. The first main heat sources category, excess heat, is found mainly in thermal power generation plants, in waste-to-energy incineration facilities, and in energy intensive industrial processes. A brief overview is given below in this sub section with respect to some available information sources about excess heat locations and annual volumes. Although summoned here mainly per Member State or at EU27 level, the information itself is geo-referenced as point data with coordinates, which has been gathered and generated on NUTS3 region level and subsequently aggregated for this overview presentation.

3.3.1 Thermal power generation

The possibility of increased combined heat and power generation in the European power balance is based on an assumed continued future need for thermal power generation. Increased recovery of excess heat from thermal power generation plants will reduce heat losses to the environment and substitute the current use of fossil fuels for space heating and hot water preparation in many European buildings. Given a current ¾ approximate share of power-only operation in European thermal power generation (2008), there should be future possibilities with increased recovery of excess heat by more combined heat and power generation.

As presented in Table 5, annual EU27 Member State excess heat volumes from thermal power generation alone are substantial. If only considering major facilities with installed capacities above 50 MW, as reported in the E-PRTR for the years 2007 to 2009 (and given applied carbon emission factors and other project assumptions), total EU27 excess heat volumes from these activities sum up to some 7.1 EJ yearly. Although massive, this figure is likely to be an under-assessment, since there is also a large presence of smaller sized plants throughout the continent. The locations of major thermal power stations using fuel combustion are presented in Annex IV in Figure 81. However, many of these installations already operate as combined heat and power plants, and a large share of this generation capacity is located in more rural areas, at large distances from cities and towns that represent sufficiently sized district heat sinks.

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 EU27 Member States, since 92 million tonnes of municipal solid waste reached landfills during 2010 according to eurostat [30]. 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.

The locations of the 407 WTE plants currently operating within EU27 are presented in Annex IV in Figure 82. These plants receive about 65 million tonnes of waste per year, representing a calorific heat value of between 650 and 720 PJ. Currently, less than half of this calorific heat value is recovered as electricity as well as heat. During 2009, only 162 PJ of heat was recycled from these European WTE plants according to the Eurostat heat balance. Hence, more heat could be recycled from WTE plants, both from better utilisation of existing plants and establishment of new WTE plants.

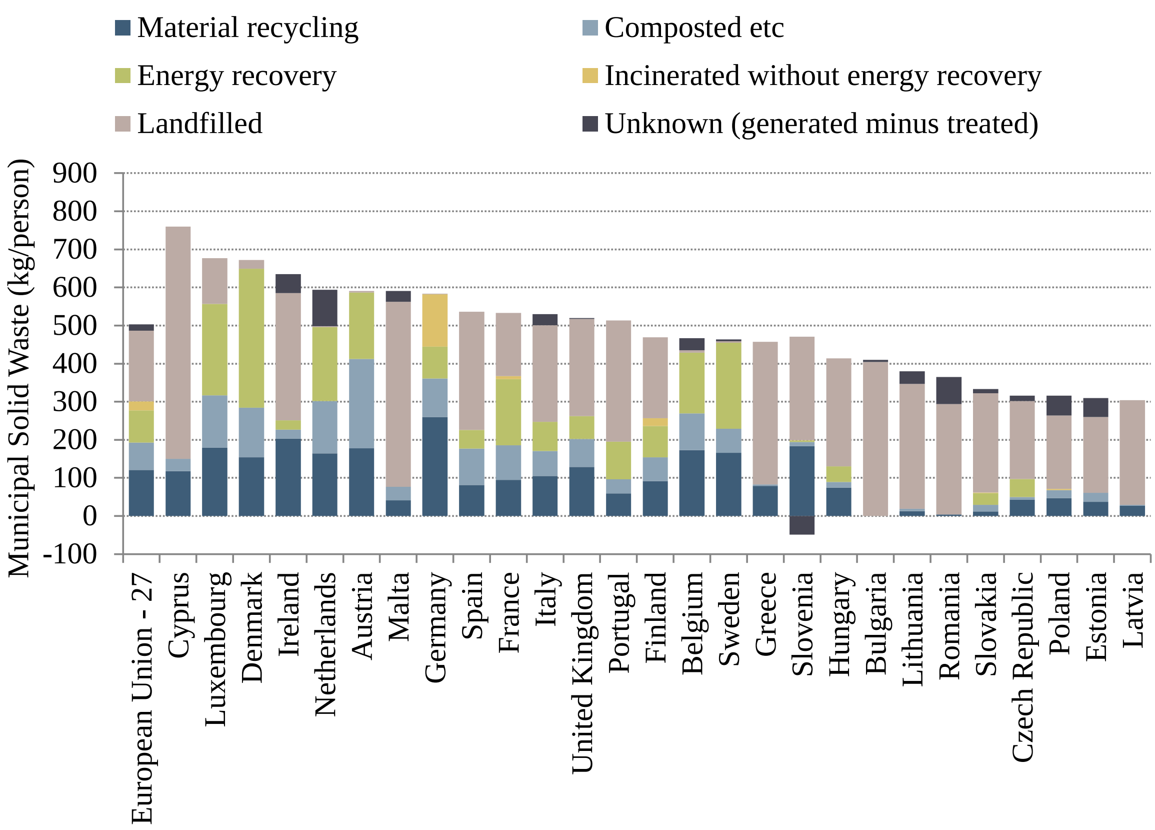

Figure 19: Distribution of municipal solid waste treatment in EU27 Member States during 2010 according to the waste hierarchy order categories [30].

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 Persson & Werner [31] for 2008: 1.1 PJ in France, 17.6 PJ in Sweden, 2.9 PJ in Denmark, 3.2 PJ in Germany, and 0.1 PJ in Italy. These volumes add up to 24.8 PJ 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 within the six sub-sectors mentioned above having excess heat are presented in Annex IV in Figure 83. Many of these plants are located near urban areas giving the possibility of transferring the excess heat to heat consumers in district heating systems. Given applied study recovery efficiencies, reflecting full capacity recovery, total annual excess heat volumes from EU27 energy intensive industrial sub-sectors are in the vicinity of 2.7 EJ, as detailed in Table 5.

3.4 SECOND MAIN HEAT SOURCES CATEGORY – RENEWABLE HEAT RESOURCES

The second main heat sources category, local renewable heat resources are found mainly in biomass availabilities, in geothermal fields, and in annual solar irradiance. An overview is given below with respect to available information sources about their locations with respect to NUTS3 regions. A brief overview is given below with respect to some available information sources about local renewable heat resources and current and potential annual volumes by location.

3.4.1 Biomass

Biomass is currently used as an 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, 241 PJ of heat with biomass origin was supplied into district heating systems. Sweden had a lead position with an input of 86 PJ, while other significant supply appeared in Austria, Denmark, and Finland.

While biomass may come from different sources, we focus here on the biomass available from established forestry as part of sustainable forest sources (mostly wastes from forestry operations of managed forests like thinning and rotation felling). Likewise, biomass from agriculture is included, but without adding to the available agricultural areas by land use change, and preferably in the form of wastes such as straw left on the fields. Potentials are limited to the extent of EU27 countries only, although an increasing proportion comes from import.

Because imported biomass is always available if transport infrastructure exists, but less desirable in a 100% renewable energy scenario [32], we shall aim here to map the EU27 domestic potentials as local potentials, which take into consideration that forest and agricultural land use, stock and productivity is preserved in each member state. Furthermore, we are aware of indirect land use change [33] as an increasing problem that adheres to the production of energy crops. Hence the potentials are mapped using current stocks, areas and management practices which are believed to have neutral consequences for carbon emissions (there may however be exemptions in some Eastern and Central European countries, but on the positive side the accumulation of carbon in Western European forests is not included either). We are furthermore aware that it is incredibly complex to identify sustainable forestry and agricultural practices without including the life cycle of forestry and agricultural products.

Finally, we have neglected the technological aspects of biomass use and we merely sketch – but do not solve – the issue of rational biomass resource allocation by location, scale, and technology of plant. As a consequence, the availability of biomass resources by geography shall only be made in a qualitative way. In order to satisfy the desire to map biomass resources by location anyway, a method has been devised that does the following:

1) Maps the current geographical extent in terms of areas used for forestry and agriculture at a high spatial resolution.
2) Maps the current management practices in terms of stock and felling in European forests, as well as cereal productivity on agricultural fields, both on a country scale.
3) Produces qualitative maps on the NUTS3 scale on the availability of biomass from forest and agriculture under current management regimes.

3.4.1.1 Forest biomass

The European forest density maps produced by the European Forestry Institute (EFI) are available as forest coverage per one square kilometre grid. No distinction is made between deciduous and coniferous species in the current version. The forest coverage comprises all forests as a percentage per one square kilometre grid, which translates to the number of hectares per square kilometre if considering full forest coverage. The percentages can therefore be summarized for each NUTS3 region using the Zonal Statistics as Table function in ArcGIS Spatial Analyst. The result is a table, which can be joined to a NUTS3 administrative map for visualization and further analysis.

Forest management practices are quantified in the Eurostat Database. Table "for_area", last updated on 08-02-2013, shows forest area by member state; forest area of managed forests only ("Forests available for wood supply") is used here. Appreciating that forests can have different yield and management practices, which are determined by geography and by country, another table with wood volumes "for_vol", last updated on 08-02-2013, has been used to calculate specific increments and specific fellings [m^3/ha] for each country, again for managed forests only. The resulting specific fellings and increments have been related to the summarized forest area (now including all forest areas, not just managed forests) from the EFI forest density map per NUTS3 region.

3.4.1.2 Biomass from agriculture

As a spatial data input for agricultural area, the 2006 Corine data set by the European Environmental Agency was used, which in its raster version allows for mapping land use in a 100m grid, i.e. each grid cell represents land use per one hectare. The land use classes for arable land (211, 212 and 213) were recoded to a grid with value "1", and summarized by NUTS3 region as the number of hectares of arable land. Because agricultural yield, like forest biomass yield, is a function of management practices as well as climate, the spatial dataset was enriched with statistical data from Eurostat. Table "tag00006" with the area of cereals grown as well as table "tag00031" with the annual cereal yield, both for 2011, were used to calculate the specific yield in tonnes/hectare by country. As cereals are the most widely used crop, and have similar characteristics to many energy crops, specific cereal yield was used as a proxy for agricultural productivity, which can be applied as a qualitative measure for straw yield or the amounts of energy crops by multiplying the total area of arable land with the cereal productivity.

Hence, the method describes the potential for energy crops if all arable land was used for this. Caveats in this method are that the current agricultural productivity may be higher or lower than in a situation where agriculture for energy may become intensified, and that we only look at cereals, where a shift in current crops of different kind to cereals or energy crops may be an option. However, we believe that the combination of arable land availability and productivity is feasible as a means to qualitatively assess the geographical distribution of agricultural wastes and dedicated energy crops.

3.4.1.3 Qualitative overlay by means of multi-criteria modelling

In order to combine agricultural and forestry biomass resources in one map, which can be used to visualize the relative biomass resource, a multi-criteria model has been applied which uses the inputs given in Table 4.

Table 4: Forestry and agriculture input data for multi-criteria modelling

Biomass origin	Criterion per NUTS3 district	Justification for biomass availability	Weight
Forestry	Forest coverage, %	High availability of forest	20%
	Forest increment, m^3	Sustainable forest management	15%
	Forest felling, m^3	Presence of forest industry	15%
Agriculture	Arable land, ha	High availability of arable land	20%
	Cereal productivity, ton/ha	Intensity of agriculture	30%

The justification of the five criteria follows rational reasoning. A high availability of forest is a precondition to actually use forest products, and to run a forest industry that accumulates sufficient volumes of wood. Forest increment is used as an indicator for sustainable forest management. Low or even negative values indicate areas which are unlikely to deliver additional forest biomass. High felling rates suggest there are established forest industries in the area, which positively influence the biomass availability. In terms of agriculture the absolute amount of arable land is a driver for biomass. Finally, an important factor is the cereal productivity, which indicates agricultural intensity. The presence of intensive agriculture is related to the availability of agricultural wastes such as straw, and a generally positive attitude to growing energy crops. A possible alternative to this approach could be the calculation of likely yield minus the actual yield in order to identify idle resources (land and management) for growing energy crops.

A multi-criteria model allows for the comparison of what otherwise is incomparable, and is a shortcut to a more elaborate account for resources and implementation of management practices. In this pre-study it was deemed feasible to qualify those NUTS3 regions, which, by the nature of their silvio- and agricultural management of natural resources, may score high in a European context. Each of the five criteria was based on Eurostat statistics, see above, and converted to a 5 grade scale (1 worst, 5 best) by means of a classification that uses a geometrical interval in order to manage the large differences in area and volumes adherent to agricultural and silviocultural statistics.

The result is a map, presented in Figure 85 of Annex IV, where each NUTS3 region has a score of 1 to 5, depending on the availability of either woody biomass or agricultural residues or energy crops, which where weighted 50/50. It can be seen that both the areas with high intensity forestry as well as high intensity agriculture achieve a moderately high score of around 3, while a few regions score highly in both disciplines, resulting in high overall scores. Low scores are the result of this model in areas with high population densities, dry climates and low agricultural and silviocultural productivity. The potentials derived from current statistics and land use mapping are subject to change if particularly the agricultural sector is subject to change, and if forestry is oriented towards energy production.

3.4.2 Geothermal heat

European Geothermal Energy Council (EGEC) reported recently [34] 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 2.5 PJ during 2009. But systems also appear in France, Poland, Romania, and United Kingdom. The French systems used 2.9 PJ 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.

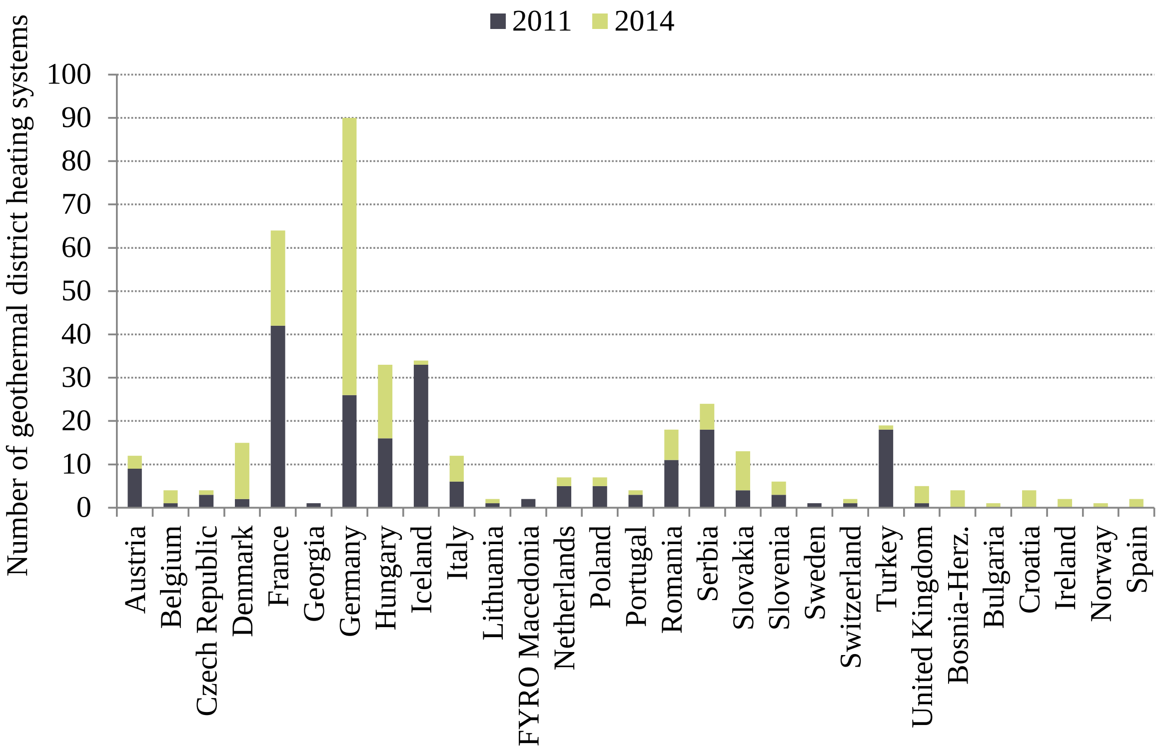

Figure 20: Number of geothermal district heating systems in Europe by country: Firstly as existing systems in 2011 and secondly as planned additions for 2014 [34].

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 84. By joining population statistics with Figure 84, we can conclude that 4 % of the EU27 population live in NUTS3 regions with geothermal temperatures above 200 ºC. The corresponding population proportions are 8 % for temperatures between 100 and 200 ºC and 20% for temperatures between 60 and 100 ºC. 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 such as Aalborg, Hamburg, Berlin, Munich, Frankfurt am Main, Hanover, Stuttgart, Groningen, Amsterdam, Rotterdam, Paris, Lyon, Strasbourg, Madrid, Barcelona, Budapest, and Bratislava.

Another way to illustrate the future possibilities with geothermal heat in European district heating systems is to consider the shares and volumes of geothermal heat at currently best practice locations. One such region is found in the French NUTS3 region FR107 Val-de-Marne, located just south of the French capitol Paris (geothermal temperatures between 60 and 100 ºC at 2000 metres depth).

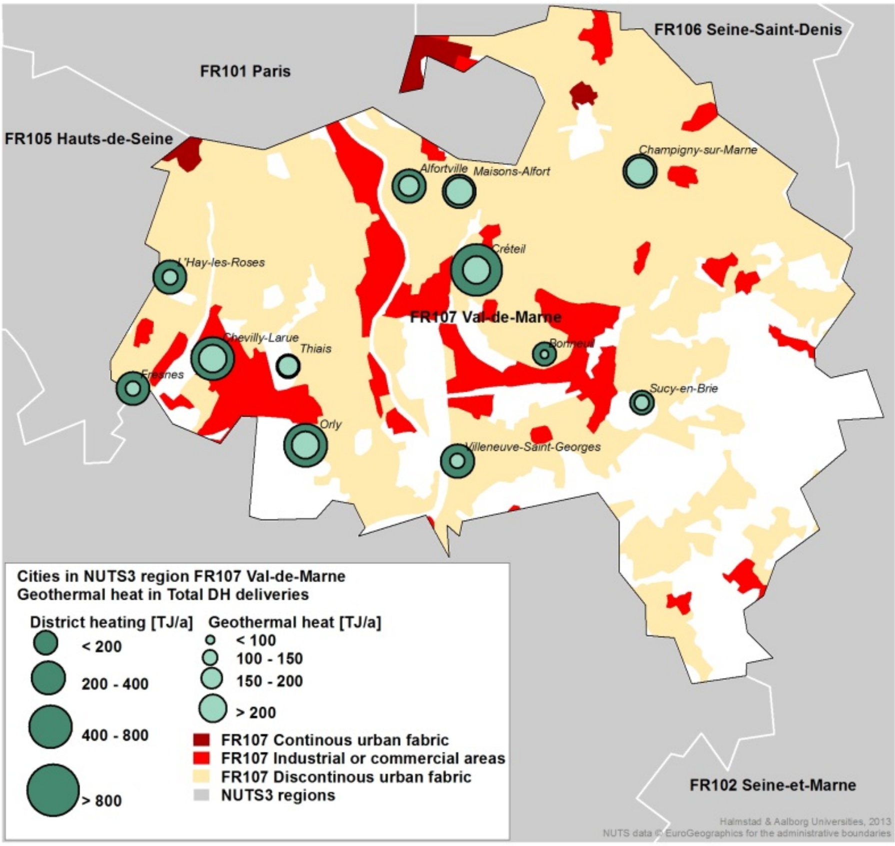

Figure 21: Cities with district heating and geothermal heat in French NUTS3 region FR107 Val-de-Marne [34].

If the level of geothermal heat utilisation in district heating systems as found in the major cities of this NUTS3 region (18% share of total city heat demands in 2011, according to [34], were to be reached by similarly large European cities in NUTS3 regions with geothermal temperatures at 2000 meters at or above 60 ºC, an estimated 430 PJ could be harnessed annually by 2050[9].

3.4.3 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 0.11 PJ during 2009 according to the Eurostat heat balance. Denmark has also seen an increasing interest in more installations according Figure 22. 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 86.

[9] This future projection for geothermal heat in EU27 is based on the assumption that all cities with more than 20000 inhabitants, within identified 461 NUTS3 regions in 17 Member States, that has geothermal heat at 2000 meters with temperature levels at or above 60 °C, will exploit these heat assets in 2050 by the same rate and extent as is currently being done in FR107.

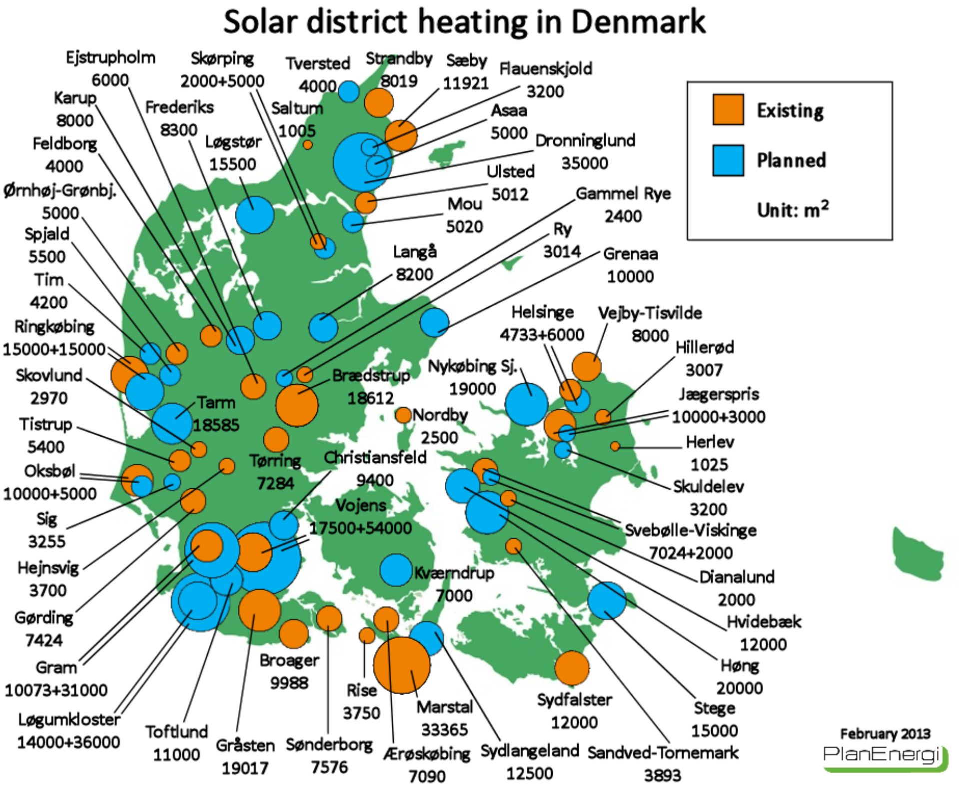

Figure 22: Overview of existing and planned solar collector fields connected to district heating systems in Denmark [35].

As can be seen in Figure 22, the Danish town of Marstal, with approximately 2200 inhabitants and a total district heat supply of 100 TJ/a (2004 [36]), hosts one of the largest solar district heating schemes in Denmark. Adding to an original 18000 m^2 solar collector field from 2003, an extension of 15000 m^2 in 2010 increased the total field area to 33000 m^2 (the extended scheme also contains a 75000 m^3 seasonal pit heat storage). Before the extension, the annual solar heat contribution to the district heat supply was 29 TJ per year. In the new system configuration, this volume has increased to approximately 47 TJ annually [37].

The local renewable heat resource of solar irradiation is unique in the sense that it is available for all, although large scale solar heat in district heating systems – as opposed to individual solar panels – is considered most suitable in smaller towns and rural areas. The main reason being that all three activity sectors within the first main strategic heat supply source are more frequent in urban regions, why large scale solar heat would constitute undesired competition in such areas, particularly during summer. Another reason being that large scale solar thermal solutions require accessibility to relatively large land areas for collector fields and storages.

As in the case of a geothermal potential for future European district heating above, a corresponding projection was made with regard to solar thermal possibilities. Based on the above reasoning, all EU27 cities with a population within the interval of 2000 ≤ n ≤ 10,000 (close to 19,000 cities and a total 84 million people) were assigned an expected solar heat per-capita value reflecting partly the solar irradiation intensity of the location (see Figure 86 in Annex IV for a map on EU27 solar irradiation

intensity levels), and partly the average solar heat generation capacity at the original Marstal field (low projection) and at the extended Marstal field (high projection).
In short, the large scale solar thermal potential for EU27 ranges by this assessment between 1250 PJ to 2060 PJ annually, although relatively lower heat demands in Southern European Member States were not considered in this assessment.

3.4.4 Conclusion with respect to available local heat resources

The main conclusions and central message from this brief overview of information sources, annual volumes, and potentials, for the two main strategic sources of heat supply is that it is possible to gather information on excess heat and renewable local heat resources by NUTS3 regions. Hereby, as a fundamental basis for calculating and assessing expansion possibilities for future European district heating systems, the balance of total main strategic heat supplies per NUTS3 region and total heat demands per NUTS3 regions can be established.

In the mapping part of the project, this data assembly constitute a matrix of 1289 rows, one for each included NUTS3 region[10]. In Table 5 this information, quantified with regards to the first main strategic heat supply source only, has been aggregated to Member State and EU27 total levels.

[10] Of 1303 EU27 NUTS3 regions, according to the 2006 classification, a total of 14 regions are excluded in the Heat Roadmap project. Four French NUTS3 regions refer to Caribbean islands, eight Spanish regions refer to Atlantic islands and North Africa coastal regions, and two Portuguese regions refer to Atlantic islands.

Table 5: Annual volumes of excess heat by activity sector and totals, Member State total heat demands in residential and service sectors, and assessed National excess heat ratios [38-40].

Member State	Sum of excess heat per EU27 Member State by activity sector and total [PJ/a]				Sum of heat demand per EU27 Member State [PJ/a]	National excess heat ratio [-]
	TPG[1]	W-t-E	IHR	Total	Total	Avg.
AT	51	13	75	139	248	0.56
BE	152	19	115	286	342	0.83
BG	122	-	22	144	65	2.23
CY	27	-	4	31	10	3.04
CZ	215	5	64	284	236	1.20
DE	1774	153	525	2451	2716	0.90
DK	105	22	13	140	183	0.77
EE	46	-	3	49	39	1.25
EL	291	-	56	347	157	2.21
ES	544	16	226	786	519	1.51
FI	48	2	82	132	196	0.67
FR	208	78	302	588	1704	0.35
HU	107	3	27	136	221	0.62
IE	88	1	13	103	119	0.86
IT	821	42	315	1178	1113	1.06
LT	10	-	21	30	57	0.54
LU	8	1	4	13	19	0.66
LV	-	-	1	1	59	0.02
MT	13	-	-	13	2	7.74
NL	358	61	160	579	501	1.16
PL	684	0	149	833	708	1.18
PT	104	8	53	166	101	1.65
RO	173	-	75	248	293	0.85
SE	12	37	97	146	254	0.57
SI	35	-	4	39	39	1.00
SK	32	1	51	84	109	0.77
UK	1049	41	252	1342	1439	0.93
EU27	**7076**	**503**	**2708**	**10287**	**11449**	**0.90**

[1] Excess heat from current combined heat and power activities recorded as "Steam and air conditioning supply" in the E-PRTR dataset was not included in this assembly focusing on future potential. By this exclusion, estimated to approximately 500 PJ/a, significant existing excess heat recovery volumes from TPG in e.g. Poland, Germany, Finland, and Sweden are omitted in this analysis.

3.5 POSSIBLE EXTENSIONS OF DISTRICT HEATING SYSTEMS

As presented in Figure 9, 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 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% [41]! 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 Persson & Werner [41] is depicted in Figure 23, 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 Persson & Werner [41] is that it utilises local conditions, e.g. population and heat densities on sub-city district 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 database (mentioned in section 3.2.1), and other relevant data sources, modelling of specific investment costs for district heating systems are made possible by this methodology.

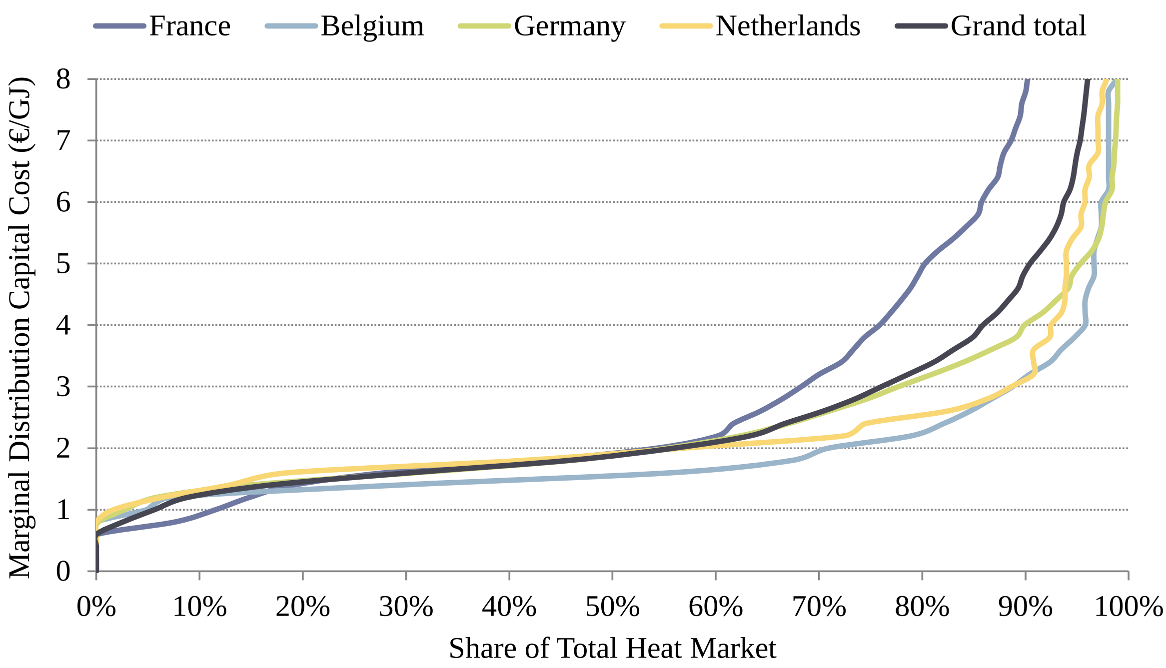

Figure 23: Current marginal distribution capital cost levels and corresponding urban district heating heat market shares in four studied European countries in 2008 [41].

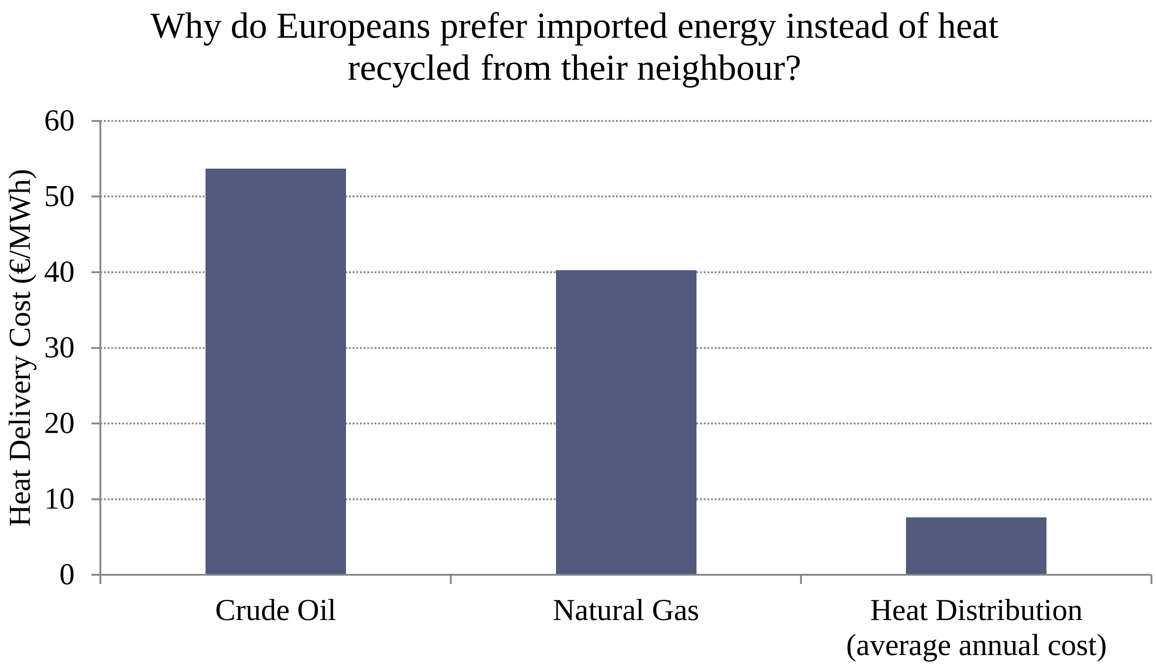

Figure 24: The simple socio-economic comparison between current import prices of fossil fuels and the heat distribution cost for connecting heat surpluses with heat demands. Current import price of crude oil has been set to US$110/barrel.

It is interesting to compare this suggested average annual cost of 2.1 €/GJ (7.6 €/MWh) for feasible and competitive urban district heat distribution to other individual heating solutions. 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 24. These import costs are substituted, when heat are recycled into district heating systems. The annual average cost for heat distribution according to Persson & Werner [41] is included as the third bar in Figure 24. 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.

3.6 LINKING TO ENERGY MODELLING

The Heat Roadmap Europe 2050 project unites the properties of both top-down modelling and bottom-up mapping (see Figure 13). By this combination of dual methodological perspectives, the project aims at identifying genuinely local heat synergy opportunities often ignored in generic energy modelling. The linkage to the energy modelling part of the project consists of volume confirmations and geographical determinations of model estimates and calculations. As detailed in above sections, current total EU27 heat demands in residential and service sectors have been spatially distributed in the European heat atlas (see Figure 14), as well as specified for each included NUTS3 region.

Regarding the main strategic sources of heat supply, a quantitative representation of current excess heat volumes recovered and rejected from thermal power generation activities, Waste-to-Energy facilities, and energy intensive industrial sub-sector activities, have been established based primarily on emission data from the E-PRTR dataset from the EEA, other complementary data sources, and according to corresponding project assumptions of carbon dioxide emission factors and excess heat recovery efficiencies. This data has been assembled and is available at NUTS3 region level, although presented here at EU27 Member State level for the sake of overview, see Table 6.

Table 6: Summary table of EU27 Member State heat demands, excess heat activities, and associated excess heat volumes (EH) and excess heat ratios (EHR) [38-40].

Member State	NUTS3 regions		Excess heat facilities		CO_2 & Excess heat		Heat demand	
	In study	With EHR	In study	Considered	CO_2 [Mt/a]	EH [PJ/a]	In study [PJ/a]	With EHR [PJ/a]
AT	35	20	63	55	29	139	248	190
BE	44	29	87	86	51	286	342	283
BG	28	17	34	25	27	144	65	38
CY	1	1	5	5	5	31	10	10
CZ	14	14	77	49	61	284	236	236
DE	429	202	476	434	464	2451	2716	1635
DK	11	11	56	56	24	140	183	183
EE	5	3	8	6	9	49	39	24
EL	51	20	39	39	63	347	157	108
ES	51	42	222	221	131	786	519	484
FI	20	15	85	51	33	132	196	176
FR	96	79	335	313	117	588	1704	1552
HU	20	10	37	31	23	136	221	141
IE	8	7	21	21	16	103	119	106
IT	107	86	305	301	186	1178	1113	996
LT	10	4	5	5	5	30	57	35
LU	1	1	7	7	2	13	19	19
LV	6	1	3	2	0	1	59	8
MT	2	1	2	2	2	13	2	2
NL	40	27	100	95	94	579	501	385
PL	66	49	149	110	167	833	708	549
PT	28	15	43	38	32	166	101	71
RO	42	25	67	57	46	248	293	194
SE	21	20	132	91	40	146	254	250
SI	12	6	7	7	8	39	39	26
SK	8	7	31	26	20	84	109	98
UK	133	77	282	194	216	1342	1439	942
Grand Total	**1289**	**789**	**2678**	**2327**	**1873**	**10287**	**11449**	**8742**
No exclusions	1303	800	2705	2678	2012	10370	11470	8763
Difference	14[1]	11	27	351[2]	139	83	21	21

[1] Excluded NUTS3 regions refer to Atlantic and Caribbean islands of French, Spanish, and Portuguese origin.

[2] Excluded or Non-considered excess heat facilities refer mainly to mining, quarrying, and extraction plants on land or in the North Sea, and to existing combined heat and power facilities sorted under the NACE main economic activity name category label "steam and air conditioning supply" in the E-PRTR dataset.

For local renewable heat resources, qualitative maps of current availabilities have been complemented with hands-on projection estimates for future potentials based on e.g. currently best practice examples. These potentials have been assessed to provide indications to the modelling group regarding model projected volumes of e.g. geothermal and large scale solar thermal heat resources.

In this sense, the link to the energy modelling group can be presented in a table format, see Table 7, where the assessed and projected annual heat supply contributions from each of the six heat source activities in the mapping part of the project, is matched to the corresponding annual volumes produced by the energy modelling group. The table specifies annual volume shares from each heat supply, given current and expected total district heating shares of total heat EU27 heat demands (in parenthesis).

As the current geographical database of the Heat Roadmap Europe 2050 project can be scaled and structured to any spatial subdivision, the link to energy systems analysis can be adjusted to future energy models, which may incorporate a division of Europe into several subsystems.

Table 7: Annually delivered district heating volumes to residential and service sectors in EU27 for current situation (2010), 2030, and 2050, by strategic heat supply sources, as modelled by the energy modelling group (EM) and resource potential assessed by the mapping group (Map).

Main strategic heat sources (PJ/year)	Potential Map	2010 (13% DH) EM	2030 (30% DH) EM	2050 (50% DH) EM
Fossil fuel power generation excess heat and heat from boilers	7075	1120	2410	1540
Waste-to-Energy incineration excess heat	500	50[1]	330	585
Industrial excess heat	2710	25	205	385
Biomass heat	n/a[2]	250	325	810
Geothermal heat	430	7	190	370
Solar thermal heat	1260	0	180	355
Large-scale heat pumps	n/a	0	1290	1875
Total district heating in modelling	**11975**	**1460**	**4930**	**5920**

[1] Total heat delivered from waste in 2010 was 170 PJ. However, only 50 PJ/year is assumed to go to the residential and services sectors due to the assumptions used to remove industry from the *Energy Roadmap 2050* projections.

[2] The biomass potential is not established in this context, but modelled levels correspond to volumes used in the reference scenario.

As outlined in Table 7, there is more surplus heat available in the EU27 than utilised in the 2050 scenario proposed here in the energy modelling. There is slightly more heat from waste incineration utilised as this was deemed a conservative estimate. The 2010 IEA energy balance for the EU27 indicates that 182 TWh of waste was consumed to produce 36 TWh of electricity and 47 TWh heat, corresponding to the efficiencies of 20 and 26% respectively. The remaining 54% became heat losses. Currently 65 million tons of waste is directed to waste incineration, while approximately 90 million tons is put into landfills. Approximately 50 million tons could be used in new waste incineration plants, so in the future 115 million tons of waste could be direct towards waste incineration, corresponding to a fuel heat value of 330 TWh. Assuming a future heat efficiency of 60%, then the total heat supply from waste would be 200 TWh (720 PJ), which is 150 TWh of additional heat compared to 2010. There are other factors which will affect the heat available from waste incineration, particularly the assumptions relating to increasing or declining waste volumes in the future. Here we assume the current volume as a compromise, making additional heat of 150 TWh/year possible.

3.7 LINKING TO REGIONAL PLANNING

A central objective in the Heat Roadmap Europe project is to outline and map synergy opportunities within European NUTS3 regions with respect to local heat resources and excess heat recovery in district heating systems. In the context of this second pre-study, this objective is pursued by combining data on available heat resources with low temperature heat demands in residential and service sectors, hereby identifying European excess 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 excess heat and local heat resources?
- Which European NUTS3 regions or agglomerations of NUTS3 regions have large volumes of low temperature heat demands in residential and service sectors?

Hence the hot spots can be used as a point of departure for local case studies, which would include more elaborate analysis of the utilisation of low temperature heat sources for the development of district heating.

In the extension of the project, follow-up questions to be asked in relation to these topics are at what acceptable investment cost levels for district heating systems identified excess heat and local heat resources in chosen NUTS3 regions will be recoverable and possible to utilise? Also, 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? Furthermore, by spatial allocation of low temperature heat resources to distributed heat demands by least cost, shortest distance or lowest CO_2 content, the potentials for low temperature heat supply can be refined to actually comprise least-cost solutions for any of the identified hot spots or for larger regions in general. But, at this stage first, a means by which to identify excess heat and district heating opportunity regions need to be developed; the excess heat ratio.

3.7.1 The excess heat ratio – identifying NUTS3 region hot spots

The definition of the excess heat ratio concept takes departure from a related identity known as heat utilisation rate (ξ_{heat}), first defined and elaborated in a recent study that analysed general conversion and recovery efficiencies in the EU27 energy balance [31]. The heat utilisation rate reveals the extent by which recovered excess heat is utilised by establishing the proportion of recovered excess heat in any given total heat demand. The heat utilisation rate is expressed as:

$$\xi_{heat} = \frac{E_{heat}}{Q_{tot}} \qquad [\%]$$

Where the term E_{heat} (J) refers to recovered (utilised) excess heat and the term Q_{tot} (J) refers to low temperature heat demands in residential and service sector buildings. In analogy with this definition of the heat utilisation rate, the excess heat ratio ($\xi_{heat,o}$) can be defined in a principally similar way:

$$\xi_{heat,o} = \frac{E_{heat,o}}{Q_{tot}} \qquad [\%]$$

Where $E_{heat,o}$ (J) refers to theoretically recoverable (potentially utilisable) excess heat from any given excess heat activity. A corresponding concept referring to local renewable heat resources, i.e. a renewable heat ratio could principally be established in a similar way.

In this context, the recoverable volume of excess heat from any given excess heat activity has been established by use of the following condition:

$$E_{heat,o} = E_{prim,act} \cdot \eta_{heat} \qquad \text{[J]}$$

Where the annual primary energy input ($E_{prim,act}$) to any given excess heat activity was calculated by applying carbon dioxide emission factors[11] to reported total annual carbon dioxide emission volumes from each considered excess heat activity [38], and recovery efficiencies were chosen to reflect complete realisation of conceivable excess heat recovery from the considered activities. For each NUTS3 region, the total sum of available excess heat were then related to total low temperature heat demands in residential and service sectors, to produce the distribution of EU27 NUTS3 region excess heat ratios as shown in Figure 25.

[11] Carbon dioxide emission factors used in this context were based on IPCC standard values for stationary combustion of fuels in corresponding activity sectors, and further adjusted to constitute unique Member State values by reflecting fuel supply compositions within national excess heat activities, as reported in the IEA Energy Balances for the year 2010 (IEA, 2012).

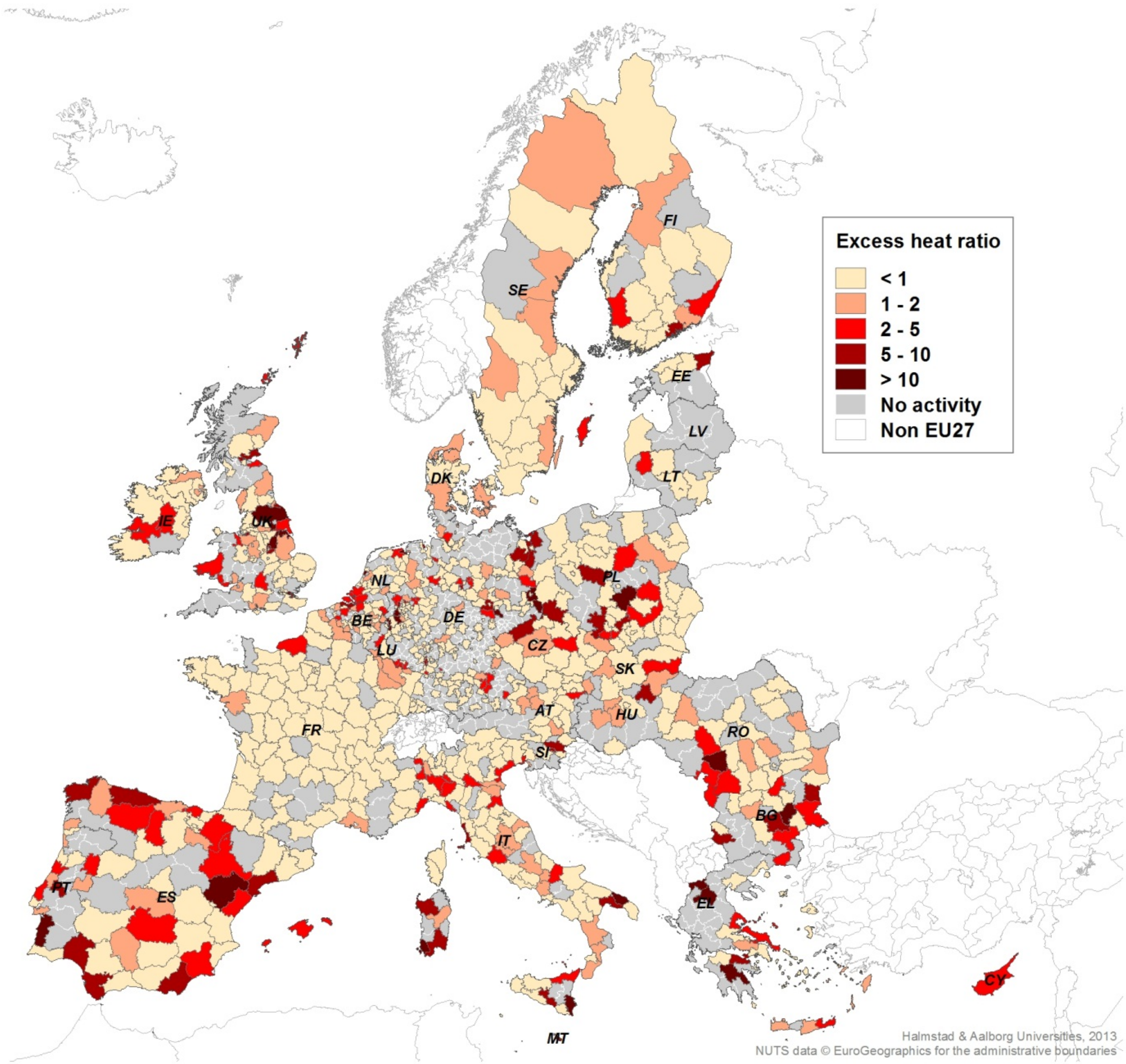

Figure 25: EU27 NUTS3 regions by their excess heat ratio, i.e. their share of excess heat relative their share of low temperature heat demands in residential and service sectors.

In Figure 25, the 789 EU27 NUTS3 regions with an excess heat ratio value above zero are distinguished from the grey colour label of “no activity” and assigned a colour according to the level of excess heat by heat demands in the region at hand. It is noticeable that excess heat volumes in many instances are larger than current heat demands, i.e. excess heat ratios being above one. Yet, in some occasions, EU27 NUTS3 region excess heat volumes are found at above ten times the magnitudes of corresponding heat demands! This confirms that many excess heat activities are located remotely to urban areas. On the other hand, five hundred NUTS3 regions have no recorded excess heat activities within the activity sectors considered in his project at all, and hence, have excess heat ratios equal to null. A conclusion must be that while the NUTS3 regions form a good spatial reference for access to statistical data, as administrative units they are rather arbitrary when it comes to the spatial structure of cities, industry and the power sector, where major activities not necessarily follow administrative boundaries. Also, the map of Europe reveals that the NUTS system has led to an uneven division into areas (compare e.g. France and Germany), which means that they are less suitable as containers for the distributed heat demand and the point locations of excess heat, which may require an even higher spatial resolution.

However, since the main objective by using the excess heat ratio is to provide a tool to identify NUTS3 regions where recovery and utilisation of existing excess heat is reasonable – and not just any NUTS3 region with larger volumes of excess heat than prevailing heat demands – the excess heat ratio needs to be complemented with manual evaluations regarding the possibilities in each case. As an example, a high excess heat ratio is in itself not sufficient enough an indicator of heat synergy opportunities, since the total volumes at hand might be of insignificant magnitudes. Hence, the excess heat ratio is suitable as a preliminary indicator of likely synergy regions selectable for deeper analysis and evaluation.

3.7.2 Most promising NUTS3 region hot spots

Based on data analyses and thorough evaluation of found excess heat ratio values, all NUTS3 regions that were found to have excess heat available were sorted by ratio magnitude and by Member State belonging. By hereafter performing complementary manual analyses of total volumes of excess heat and heat demands in found NUTS3 regions, combined with experience based considerations of e.g. district heating developments, technology preferences, and future prospects, an exclusive list of most promising NUTS3 region hot spots were extracted from the mapping work results (see Table 8 for a summary and Annex IV a full list).

Table 8: Selection of most promising EU27 NUTS3 region excess heat hot spots by population, total heat demand, and excess heat volumes, per Member State

Member States	Count of NUTS3 regions	Total population [Mn]	Heat demand [PJ]	Excess heat [PJ]
FR	6	9.2	254	345
AT	2	0.8	24	42
BE	9	3.9	126	231
CZ	2	2.1	47	180
DE	29	11.1	359	973
IT	9	11.5	245	142
PL	4	2.7	51	188
UK	7	2.6	60	288
Grand Total	**68**	**43.9**	**1166**	**2389**

This selection resulted in the identification of 68 promising NUTS3 regions, depicted in Figure 26, where initiative and efforts for increased heat synergy projects are considered most optimal.

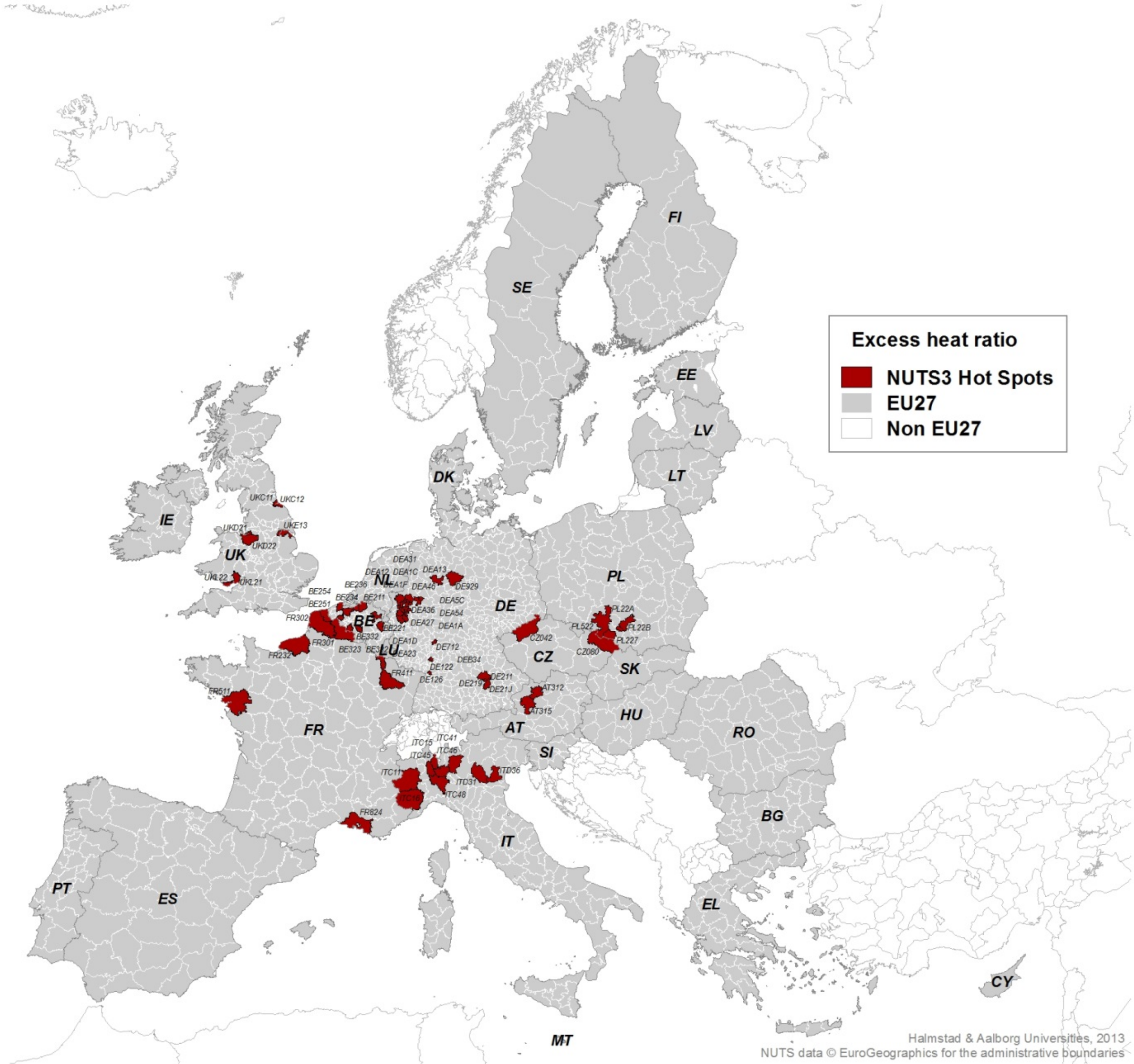

Figure 26: Selection of most promising EU27 NUTS3 region excess heat hot spots.

As a general reference of classification for this selection, all identified NUTS3 region hot spots were sorted in three descriptive regional labels indicating current levels of district heating technology use. These three labels, i.e. “Expansion”, “Refurbishment”, and “New developments”, are also used as sub-headings in the following section where some NUTS3 region hot spots characteristic for these labels are presented in more detail.

3.7.3 Expansion

Four EU27 Member States with favourable expansion possibilities for district heating are France, Austria, Italy, and Germany. Already today district heating is well established in many towns and city districts in these countries, but considering current moderate average heat market shares for district heating in general, there is opportunity for expansions within these nations. As an example, the single French NUTS3 region of FR232 Seine-Maritime, one of six identified French NUTS3 region excess heat hot spots in the pre-study, shows a strong geographical resemblance with regard to excess heat activities and larger urban agglomerations, see Figure 27, which constitute ideal basic conditions for excess heat recovery and utilisation by means of district heating systems.

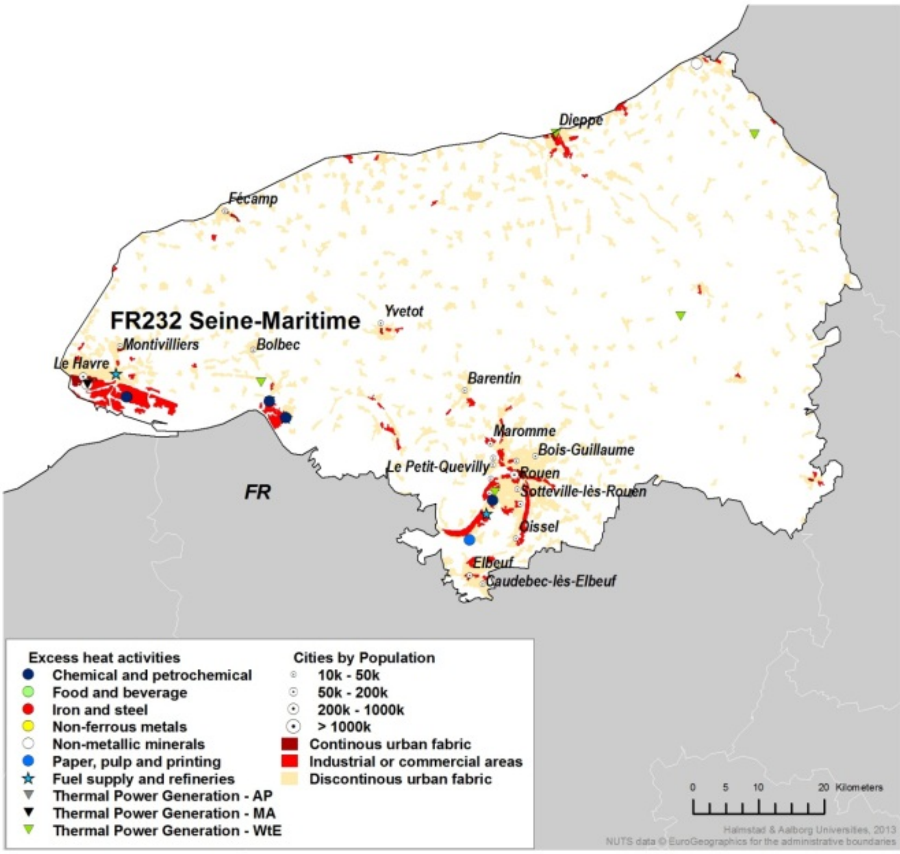

Figure 27: Example of Expansion NUTS3 region hot spots: French NUTS3 region of FR232 Seine-Maritime at the Atlantic coast.

Annual excess heat volumes from excess heat activities in Seine-Maritime are found at 95.6 PJ, according to the pre-study investigation. At an annual heat demand in residential and service sectors of only 35.0 PJ, the corresponding excess heat ratio in the French coastal region is as high as 2.7. The strong coherence of industrial activity locations and urban settlements is noticeable in this case.

Another example where excess heat activities and vicinities to larger urban agglomerations are possible to identify is found in the twin Austrian NUTS3 regions of AT315 Traunviertel and AT312 Linz-Wels, as illustrated in Figure 28. These regions show similar properties as the French example, although at slightly lower excess heat ratios of 1.8 in both instances, and constitute most beneficial expansion regions in Austria. Another common feature for both of these country examples are also relatively low NUTS3 region population densities (< 350 n/km2), although population and heat density concentrations within urban areas are significantly higher.

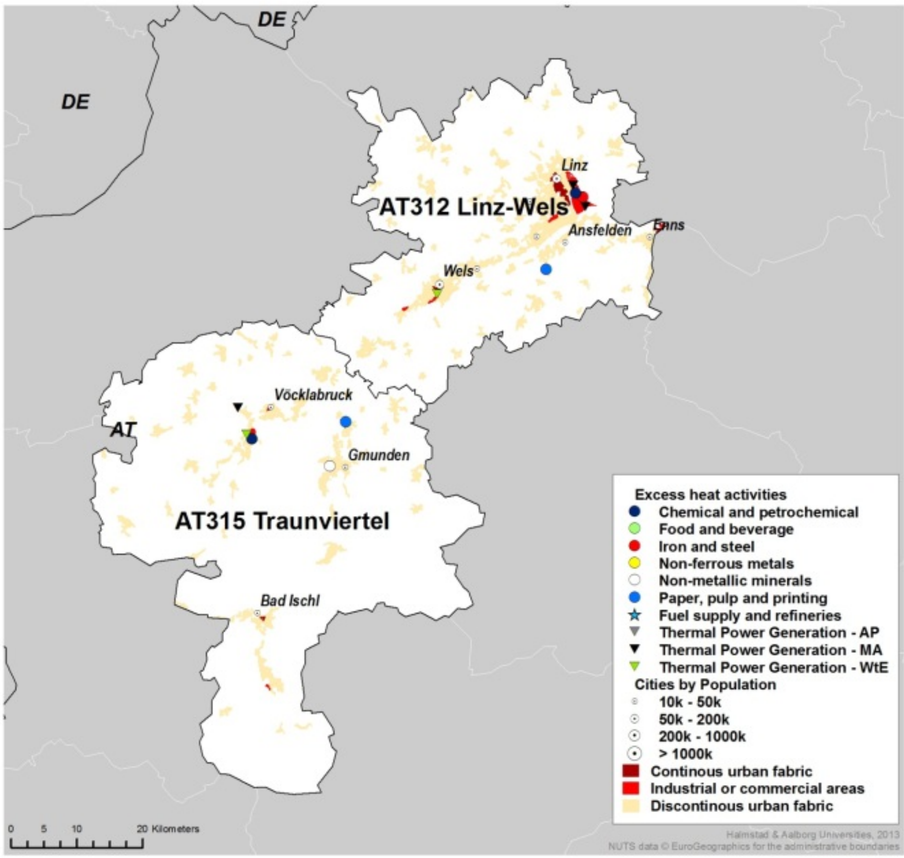

Figure 28: Example of Expansion NUTS3 region hot spots: twin Austrian NUTS3 regions of AT315 Traunviertel and AT312 Linz-Wels.

The two other EU27 Member States that were considered to suit well into the Expansion group for future district heating are Italy and Germany. Within both of these, larger clusters of NUTS3 region excess heat hot spots were identified in the analysis, see Figure 29 and Figure 30. As can be seen, these kinds of highly populated, as well as highly developed, regions, offer extended expansion possibilities for excess heat recovery and utilisation of renewable heat resources by district heat distribution – here there are possibilities for regional heating networks exploiting a rich variety of present heat sources!

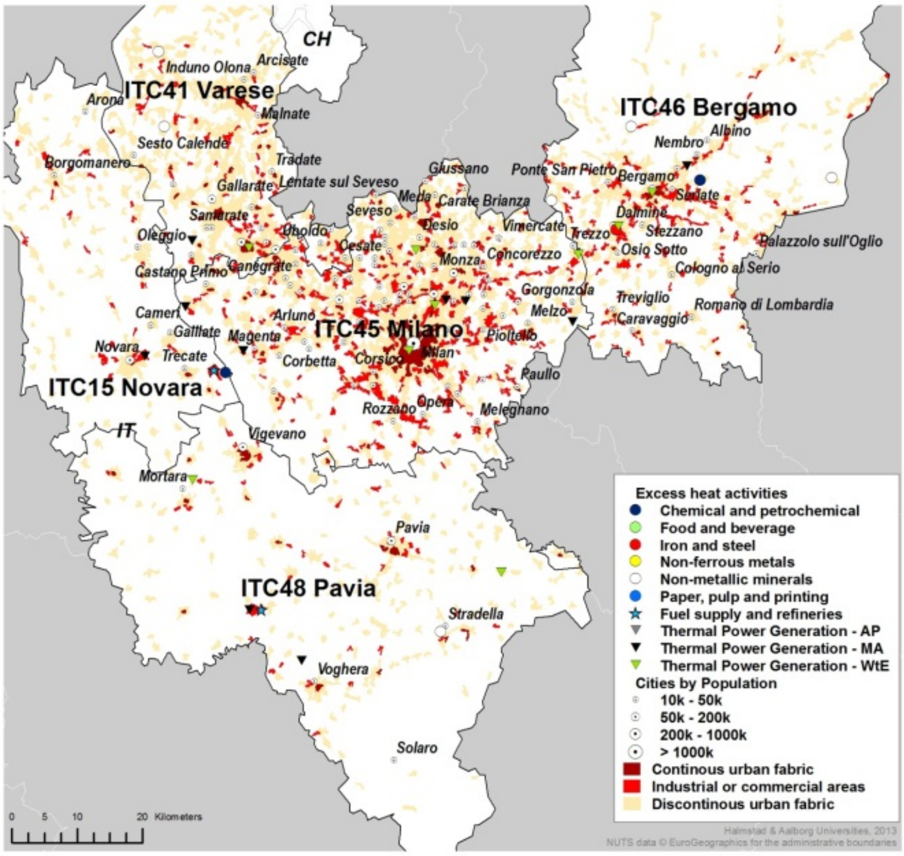

Figure 29: Example of Expansion NUTS3 region hot spots: large clusters of NUTS3 region excess heat hot spots in the Milan region in Italy.

None of the Italian NUTS3 hot spot regions have very high excess heat ratios (typically between 0.2 and 0.9), but both excess heat and heat demand volumes are often large. As an example, the NUTS3 region of Milan itself, holds a total population of 3.9 million people, generating a total low temperature heat demand of roughly 83 PJ per year, to which a total annual excess heat volume of 28 PJ could be utilised.

In the German example, the Ruhr region stands out as perhaps the most significant excess heat and heat synergy opportunity region in all of EU27 today. There are already plenty of district heating networks distributing heat in this region, but to recover more of all available excess heat in the region, future expansions are a likely option. Basic hot spot data for all NUTS3 regions within the Ruhr cluster are presented in Table 9.

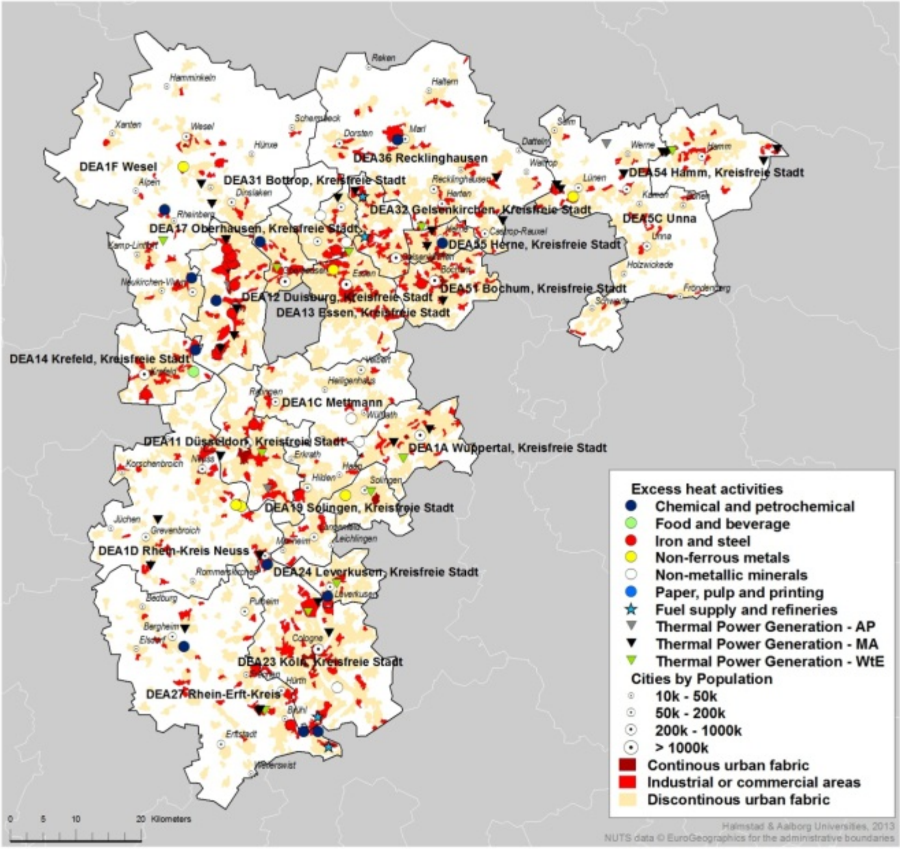

Figure 30: Example of Expansion NUTS3 region hot spots: large clusters of NUTS3 region excess heat hot spots in the Ruhr region of Germany.

Table 9: 20 NUTS3 region hot spots in the Ruhr region of Germany, per NUTS3 region

NUTS3 region	NUTS3 region Name	Population [Mn]	Land area [km^2]	Population density [n/km^2]	Heat demand [PJ]	Excess heat [PJ]	Excess heat ratio [-]
DEA11	Düsseldorf, Kreisfreie Stadt	0.58	217	2697	18.8	10.3	0.5
DEA12	Duisburg, Kreisfreie Stadt	0.49	233	2118	15.9	107.3	6.8
DEA13	Essen, Kreisfreie Stadt	0.58	210	2748	18.7	5.6	0.3
DEA14	Krefeld, Kreisfreie Stadt	0.24	138	1712	7.6	1.2	0.2
DEA17	Oberhausen, Kreisfreie Stadt	0.22	77	2789	6.9	5.9	0.8
DEA19	Solingen, Kreisfreie Stadt	0.16	90	1803	5.2	1.7	0.3
DEA1A	Wuppertal, Kreisfreie Stadt	0.35	168	2091	11.4	7.4	0.7
DEA1C	Mettmann	0.50	407	1223	16.1	5.4	0.3
DEA1D	Rhein-Kreis Neuss	0.44	576	769	14.2	203.9	14.3
DEA1F	Wesel	0.47	1042	452	15.1	37.1	2.4
DEA23	Köln, Kreisfreie Stadt	1.00	405	2460	32.1	37.9	1.2
DEA24	Leverkusen, Kreisfreie Stadt	0.16	79	2041	5.2	3.8	0.7
DEA27	Rhein-Erft-Kreis	0.46	705	659	14.9	191.1	12.8
DEA31	Bottrop, Kreisfreie Stadt	0.12	101	1168	3.8	0.9	0.3
DEA32	Gelsenkirchen, Kreisfreie Stadt	0.26	105	2488	8.5	63.5	7.5
DEA36	Recklinghausen	0.64	760	834	20.5	31.0	1.5
DEA51	Bochum, Kreisfreie Stadt	0.38	145	2595	12.2	1.3	0.1
DEA54	Hamm, Kreisfreie Stadt	0.18	226	805	5.9	24.7	4.2
DEA55	Herne, Kreisfreie Stadt	0.17	51	3234	5.4	16.5	3.1
DEA5C	Unna	0.42	543	765	13.5	55.7	4.1
Total		**7.82**	**6279**		**252.2**	**812.2**	

3.7.4 Refurbishment

The second label, Refurbishment, indicates district heating opportunities in the form of decarbonisation efforts of heating markets by extended use of excess heat and local renewable heat resources. To exemplify this kind of future opportunity conditions, two examples are drawn, one from Poland and one from the Czech Republic, see Figure 31 and Figure 32.

In the Polish case, the NUTS3 region of Sosnowiecki in the southern part of the country has a high excess heat ratio well above 5 (5.6) due to large shares of thermal power generation activities and a relatively small population (0.71 million). Not far away, close to the Czech border, the neighbouring region of Katowicki, has less excess heat but considerably higher population concentrations than Sosnowiecki, indicating generally better conditions for large scale heat recovery and distribution.

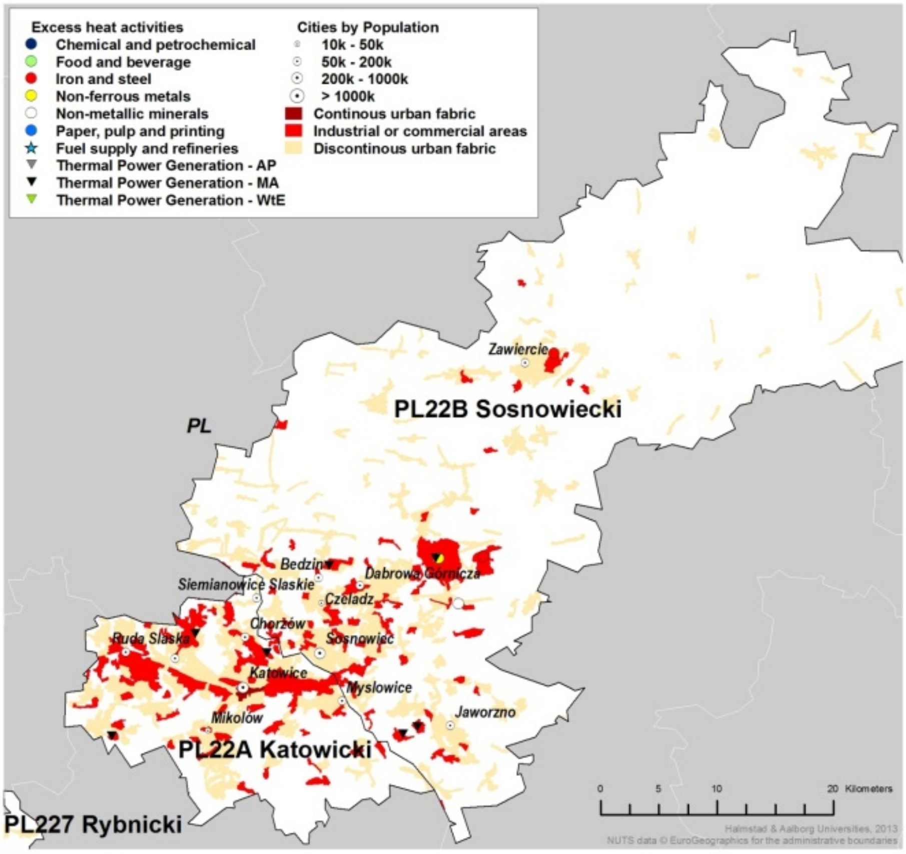

Figure 31: Example of Refurbishment NUTS3 region excess heat hot spots: PL22A Katowicki and PL22B Sosnowiecki in Southern Poland.

Similar to the Polish example, the Czech Republic NUTS3 region of CZ042 Ústecký kraj harbours a total of astonishing 135 PJ per annum of excess heat mainly from thermal power generation and energy intensive industrial activities. At very sparsely populated land areas (population density of only 160 n/km^2), this serves as a good example that not even very high excess heat ratios (in this case at 7.1) automatically signals absolute recovery possibilities. Once again, within urban agglomerations, the conditions for network heat distribution can be expected to be most beneficial – but how far are they from the plentiful excess heat sources in this case?

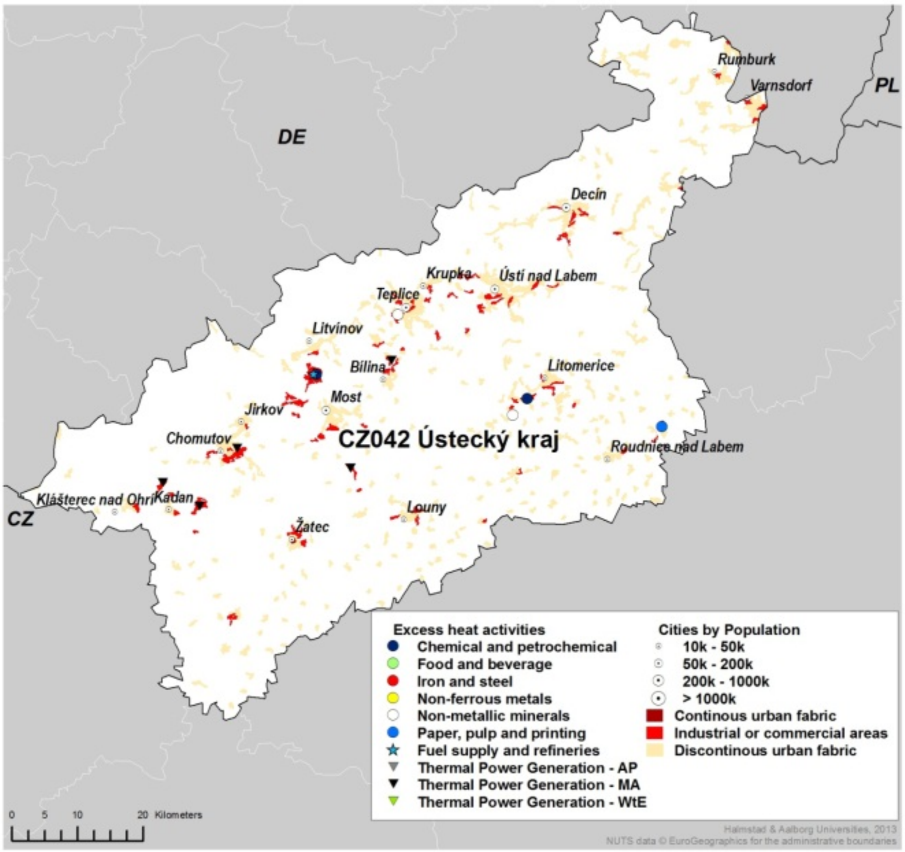

Figure 32: Example of Refurbishment NUTS3 region excess heat hot spots: Czech Republic NUTS3 region of CZ042 Ústecký kraj.

3.7.5 New developments

If not considering the fourth label category sometimes mentioned in this context (the fourth label being; "Further developments", mainly considering mature district heating markets and current developments to 4th generation heat distribution technology), the third and final category to exemplify in this section is the New Development cases. Quite naturally, these new development examples come from EU27 Member States currently in the midst of integrating concepts such as district heating and cooling solutions in a broader sense than previously.

Due to many reasons, e.g. different preferences regarding low temperature heating options in different regions of Europe, district heating have not been broadly recognised in these New Development regions before. But now, many new initiatives are being made all around Europe, to harvest the benefits of low carbon and energy efficient district heating in communities and regions acting for a more sustainable way of providing space and hot water heating.

To exemplify, the twin NUTS3 regions of UKC12 South Teesside and UKC11 Hartlepool and Stockton-on-Tees, up on the east United Kingdom coast, together with Belgian cluster of NUTS3 regions surrounding the big city of Antwerp, constitute such new development regions see Figure 33 and Figure 34. Both of these examples share common features such as high presence of excess heat activities, large populations, and high heat densities.

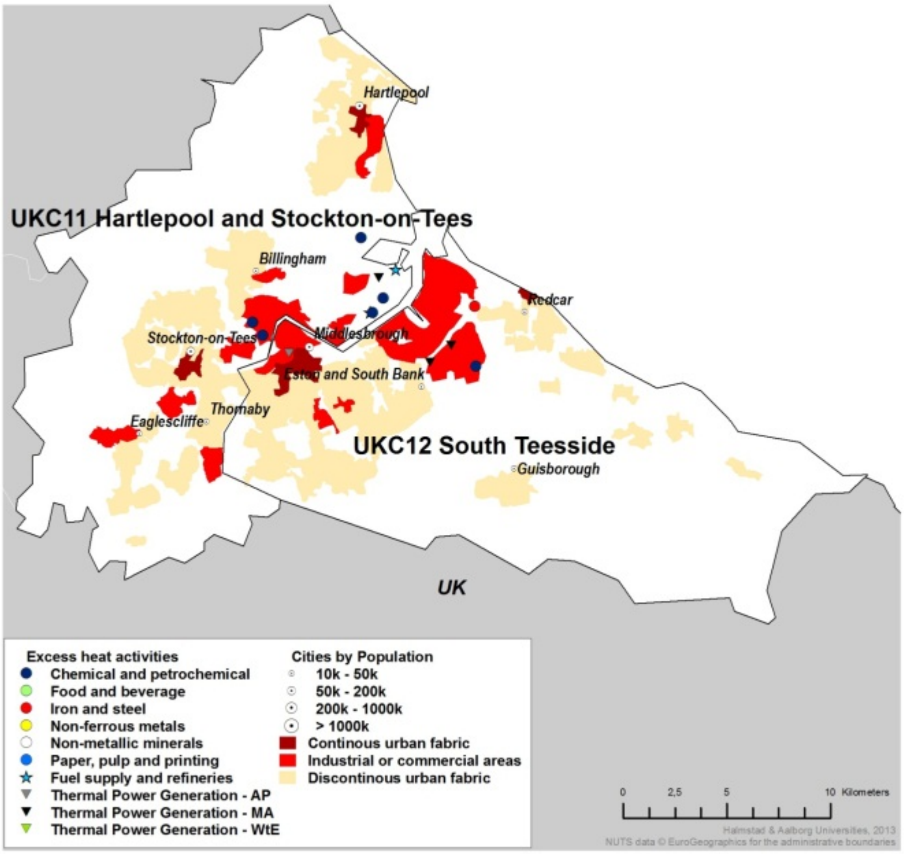

Figure 33: Examples of New Development NUTS3 region excess heat hot spots: twin United Kingdom NUTS3 regions of UKC12 South Teesside and UKC11 Hartlepool and Stockton-on-Tees.

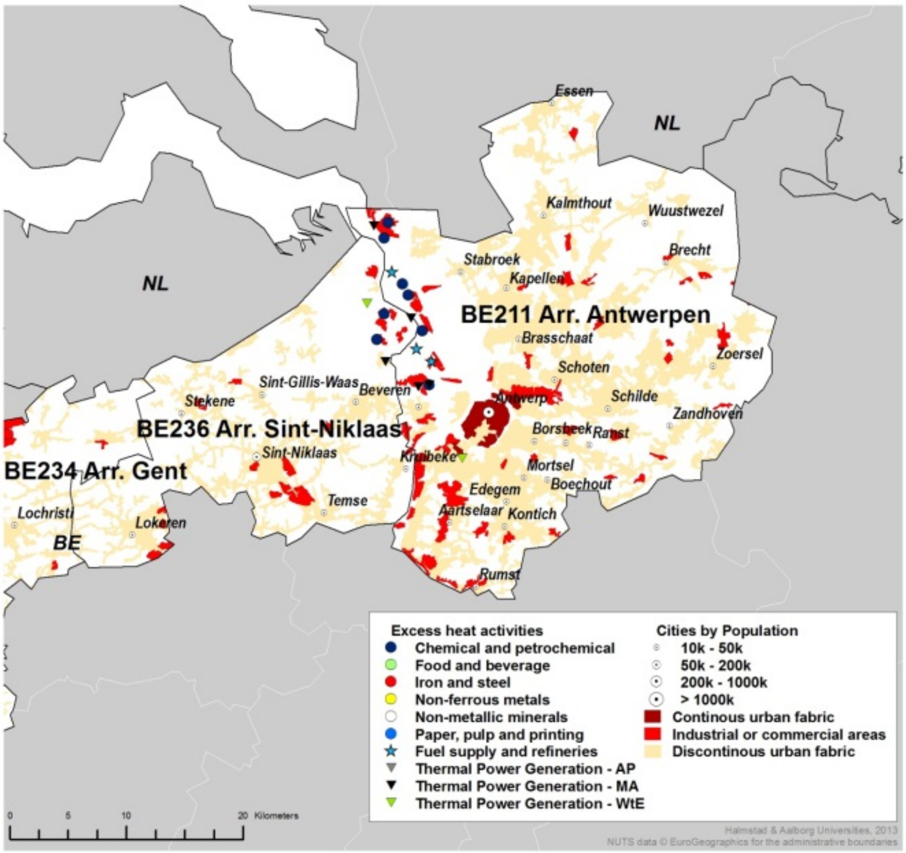

Figure 34: Examples of New Development NUTS3 region excess heat hot spots: Belgian twin NUTS3 regions of BE236 Arr. Sint-Niklaas and BE211 Arr. Antwerpen.

3.7.6 Conclusion

To conclude, the mapping part of the second pre-study of the Heat Roadmap Europe 2050 project, has performed a bottom-up analysis and a spatial mapping of EU27 heat demands in residential and service sectors, of excess heat activities within thermal power generation, Waste-to-Energy incineration, and energy intensive industrial sub-sectors, together with projections and potential estimates of local renewable heat resources, to provide a linkage to the modelling team of the project. By this linkage, proposed future levels of heat demands and district heating deliveries from the modellers have been balanced against the anticipated corresponding levels found by spatially mapping the distributions of these local opportunities.

By development of theoretical concepts to describe excess heat availabilities in relation to local and regional heat demands, the mapping group has performed a selection of EU27 NUTS3 regions according to their excess heat ratios and complementary conditions, by which three distinguished categories of European district heating progression has been exemplified. For the next phase of the project, a renewable heat ratio should be established as well, which in combination with the excess heat ratio, would allow for a single “heat ratio” to be calculated for all NUTS3 regions of EU27. Unlike the excess heat ratio, which of course has a zero value for regions without excess heat activities, a renewable heat ratio would have a positive value for all EU27 NUTS3 regions. Hence, there is a “heat ratio” waiting to be established for all regions in Europe!

4 REFERENCE SCENARIO FOR 2030 AND 2050

In this chapter the reference energy system that serves as the basis for creating new scenarios for Europe are constructed. First the energy systems scenarios in *Energy Roadmap 2050* [9] are described in general and specifically with regards to the heat demands. Finally based on this, the reference energy systems used in this study is described.

4.1 EUROPEAN ENERGY SYSTEM SCENARIOS IN ENERGY ROADMAP 2050

The EC published in 2011 *Energy Roadmap 2050* [9], which analysed cost-effective ways of reducing greenhouse gas emissions in the European Union. It contains six different scenarios for the future of the EU energy system. In the first pre-study for Heat Roadmap Europe (HRE1) [1], the Current Policy Initiatives (CPI) scenario from the *Energy Roadmap 2050* report was used as a reference. The CPI scenario is based on the assumption that there will be no changes in European energy policies beyond the publication of the *Energy Roadmap 2050* report. It is described not as a forecast, but as 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. The PRIMES model – which is described in Annex V – was used to develop the projections in *Energy Roadmap 2050*. The CPI scenario was utilised in HRE1 since the aim was to investigate if the addition of district heating can improve the EU energy system, compared to a scenario which only includes the implementation of existing policies. In this study, the aim is

To improve the methodologies developed in the first pre-study [1] for mapping and modelling district heating in the EU energy system and subsequently, to investigate if the addition of district heating can improve the EU energy system in combination with significant heat reductions in the residential and services sectors. Furthermore, in this study electric heating and district cooling are also considered.

In line with this, the EU Energy Efficiency (EU-EE) scenario from the *Energy Roadmap 2050* report is used as a reference in this report. “This scenario is driven by a political commitment of very high primary energy savings by 2050 and includes a very stringent implementation of the Energy Efficiency plan” [11]. In addition to a number of common proposal for all of the decarbonisation scenarios in the *Energy Roadmap 2050* report, the EU-EE scenario includes the following policies also [12]:

- Additional strong minimum requirements for appliances
- High renovation rates for existing buildings due to better/more financing and planned obligations for public buildings (more than 2% refurbishment per year)
- Passive houses standards after 2020
- Marked penetration of ESCOs and higher financing availability
- Obligation of utilities to achieve energy savings in their customers' energy use over 1.5% per year (up to 2020)
- Strong minimum requirements for energy generation, transmission and distribution including obligation that existing energy generation installations are upgraded to the best available technology every time their permit needs to be updated
- Full roll-out of smart grids, smart metering
- Significant renewable energy sources (RES) with highly decentralised generation

As a result, the gross inland consumption is approximately 10% and 30% lower in the EU-EE scenario than in the CPI scenario in the years 2030 and 2050 respectively (see Figure 35). Furthermore, there is more renewable energy utilised in the EU-EE scenario in 2050 than in the CPI scenario.

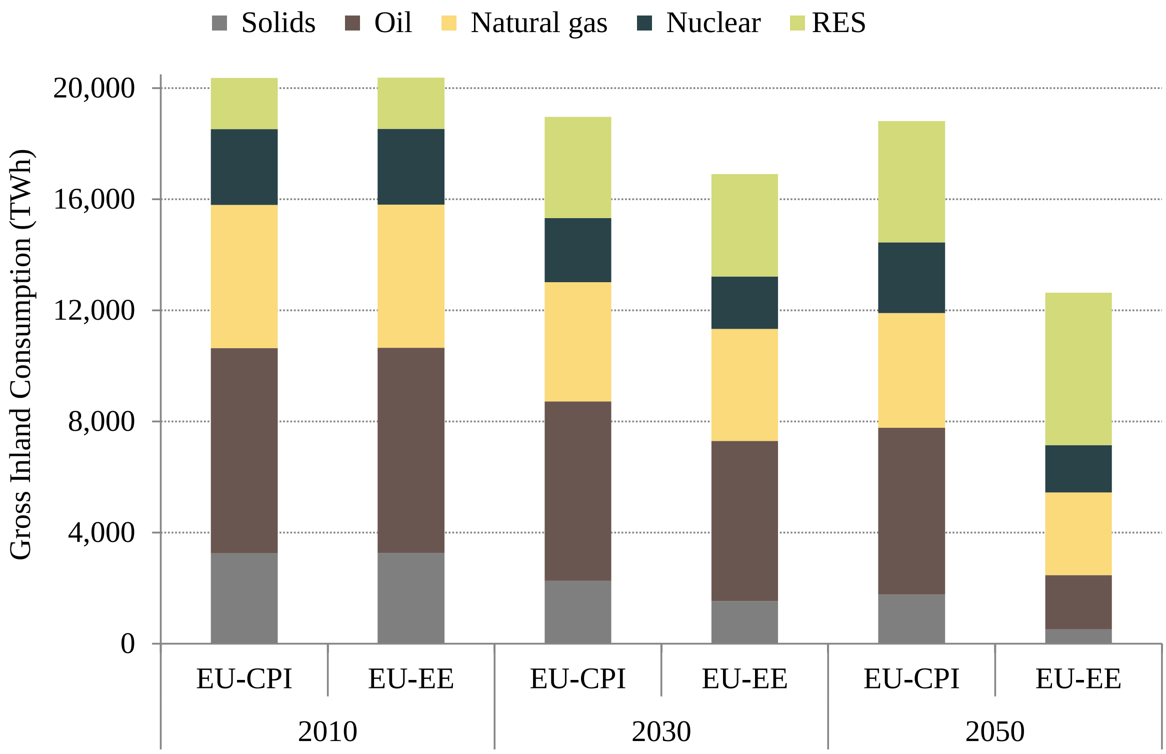

Figure 35: Gross inland consumption in the EU-CPI scenario from the first pre-study [1] and the EU-EE scenario used in this study. Note: electricity is excluded from this diagram since it only represents the net annual exchange which is less than 0.25% of the total in all years.

This is also reflected in the installed electricity capacities for both scenarios. As outlined in Figure 36, there is more solar and wind power in the EU-EE scenario than the CPI scenario, primarily at the expense of gas-fired power plants and some nuclear power.

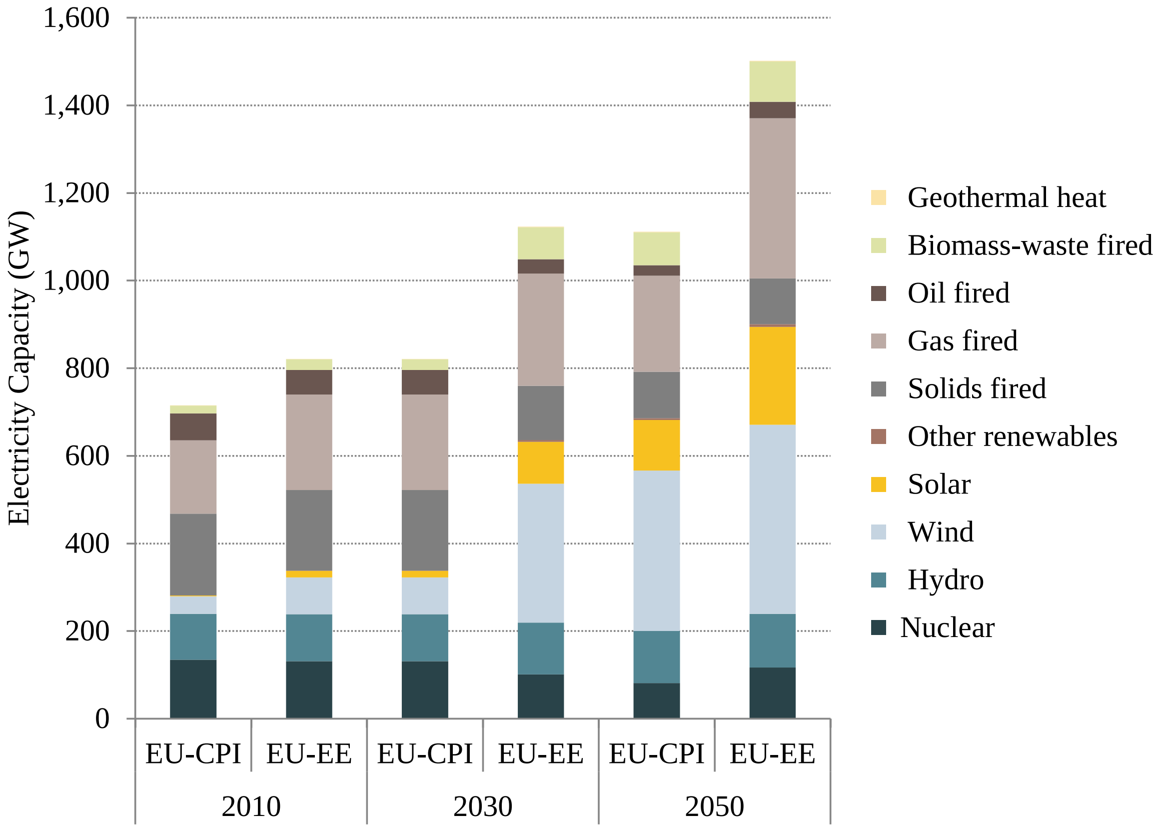

Figure 36: Electricity capacity by fuel in the EU-CPI scenario from the first pre-study [1] and the EU-EE scenario used in this study.

A more detailed breakdown of electricity production is available in Figure 37, which also indicates that in 2050 there is three times more electricity from CCS plants in the EU-EE scenario than in the CPI scenario, while electricity production from CHP plants is approximately 33% less. In summary, the EU-EE scenario has a lower energy consumption, more intermittent renewable energy, more electricity from CCS, less electricity from nuclear, and less electricity from CHP than the CPI scenario. This means that the EU-EE scenario will require more flexibility than the CPI scenario since there is more baseload power in the form of CCS and more intermittent electricity in the form of wind and solar.

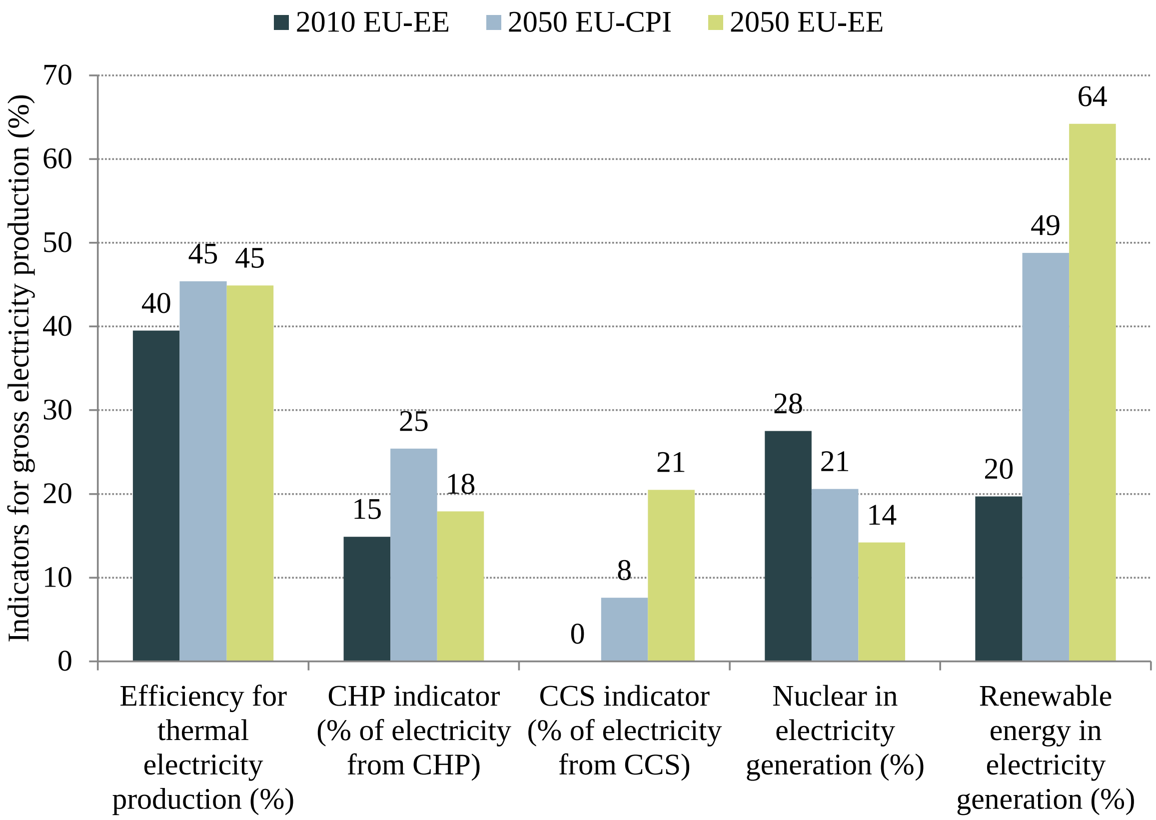

Figure 37: Indicators for gross electricity production in the EU-CPI scenario from the first pre-study [1] and the EU-EE scenario used in this study.

Looking at the EU-EE scenario in more detail, it is clear from Figure 38 that the transport and industry sectors will continue to be the largest energy consumers between now and 2050. Due to the large-scale implementation of energy efficiency measures, the residential and services sector only represent 32% of the total consumption in 2050 compared to 39% in 2010. This is important to consider here since this study will focus on the heat demands for the residential and services sectors.

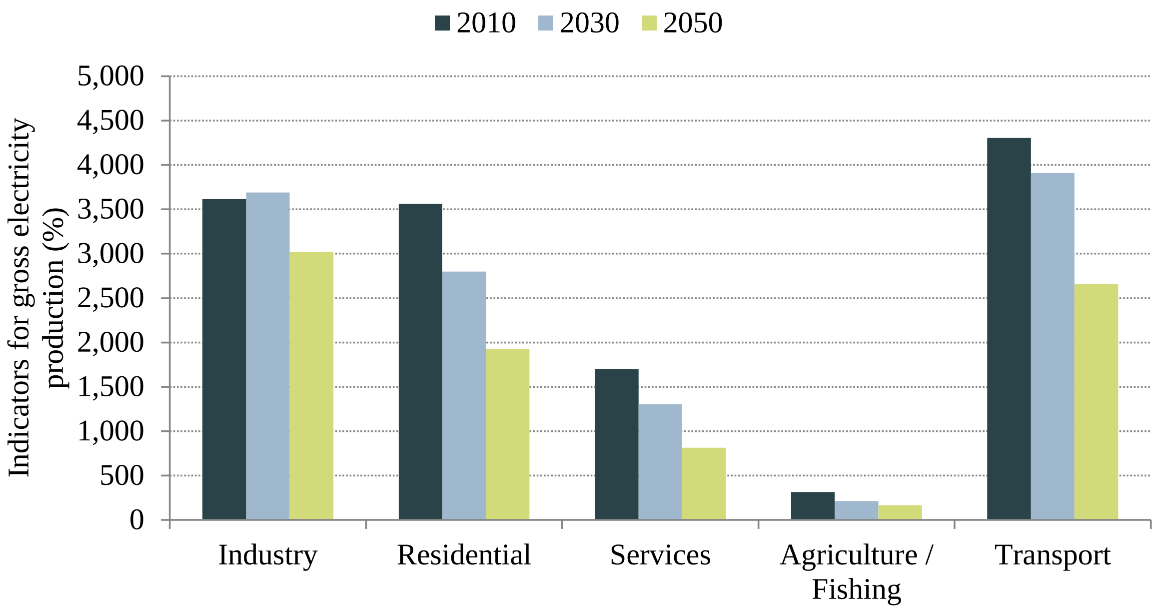

Figure 38: Final energy consumption by sector in the EU-EE scenario for the years 2010, 2030, and 2050.

4.2 ENERGY EFFICIENCY SCENARIO HEAT DEMAND

Since this study will focus on the heat sector for the residential and services sector, the assumptions used for the future heat demand in the EU-EE scenario are of critical importance. In Heat Roadmap Europe 1, the results indicated that under existing policies (i.e. the CPI scenario), the heat demand will be sufficient for district heating to be implemented at a cheaper cost than using the technologies being pursued by existing policies. Hence, a key motivation for choosing the EU-EE scenario in this study was to investigate the feasibility of district heating if the heat demands are reduced significantly compared to the heat demand expected under existing policies only. To begin, the first step is to analyse exactly how much the heat demand for the residential and services sectors is being reduced in the EU-EE scenario.

As outlined in Figure 39, the total heat demand in the EU-EE scenario is expected to drop by approximately 60% between 2015 and 2050. This is a much larger reduction than in the CPI scenario: by 2050, the total heat demand in the EU-EE scenario is approximately 50% of the heat demand in the CPI scenario.

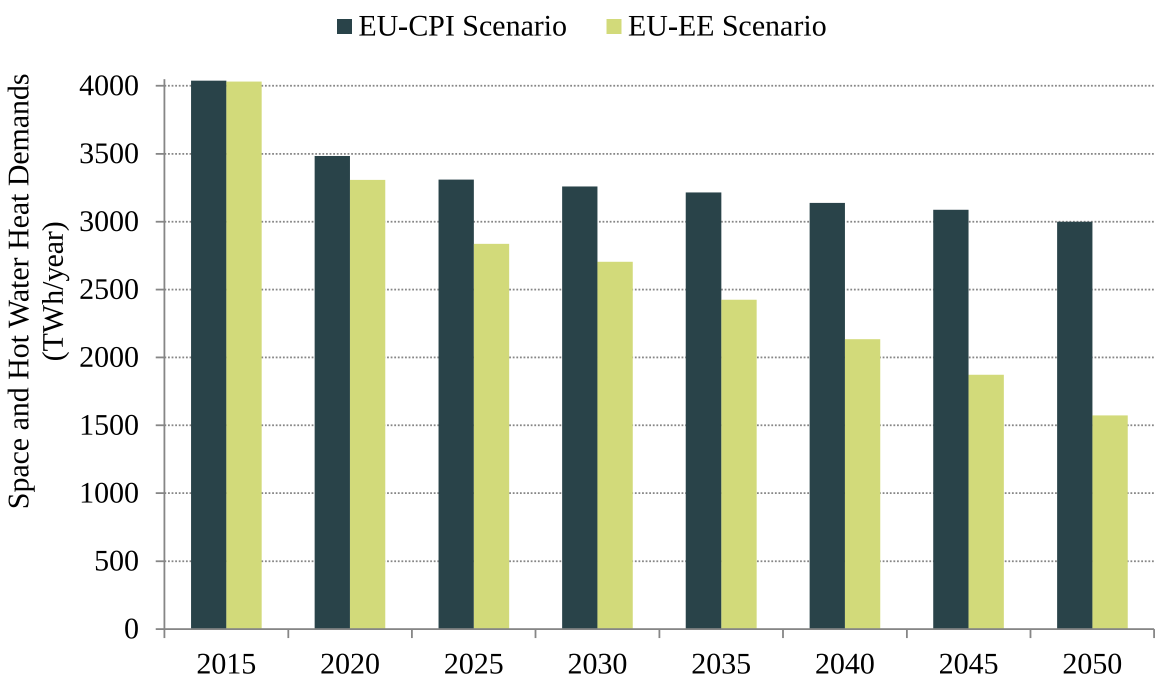

Figure 39: Total heat demand for the residential and services sectors in the EU-CPI scenario from the first pre-study [1] and EU-EE scenario used in this study for 2015-2050.

This total heat demand can be broken down into a number of key sectors: firstly the heat demand provides two distinct services, hot water and space heating. Figure 40 outlines how the total heat demand in the EU-EE scenario is divided between these two services, which indicates that the space heating demand is expected to drop by approximately 60% and the hot water demand by 55% between 2015 and 2050.

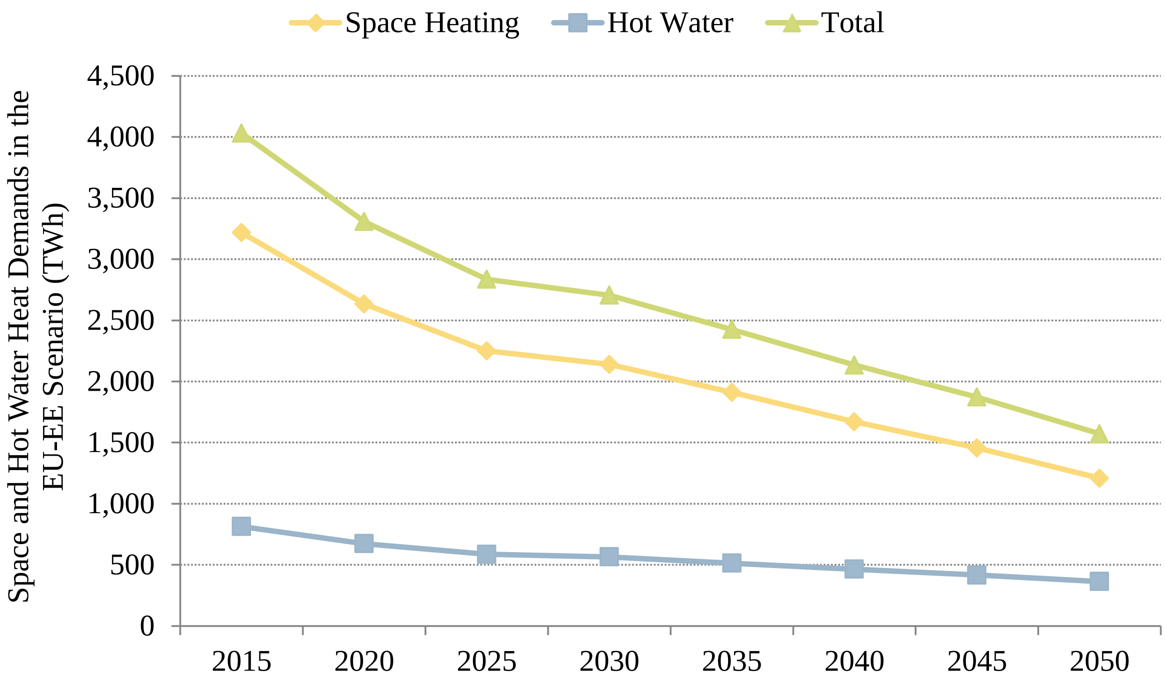

Figure 40: Space heating and hot water demand for the residential and services sectors in the EU-EE scenario between 2015 and 2050.

Secondly, the heat demand can be divided in terms of two distinct sectors, residential and non-residential/services. Figure 41 indicates that the heat demand will reduce by approximately 60-62% in both of these sectors between 2015 and 2050, similar to the overall trend in the total heat demand. However, it is important to recognise that there are other dynamics involved in these changes also such as the population and the building stock.

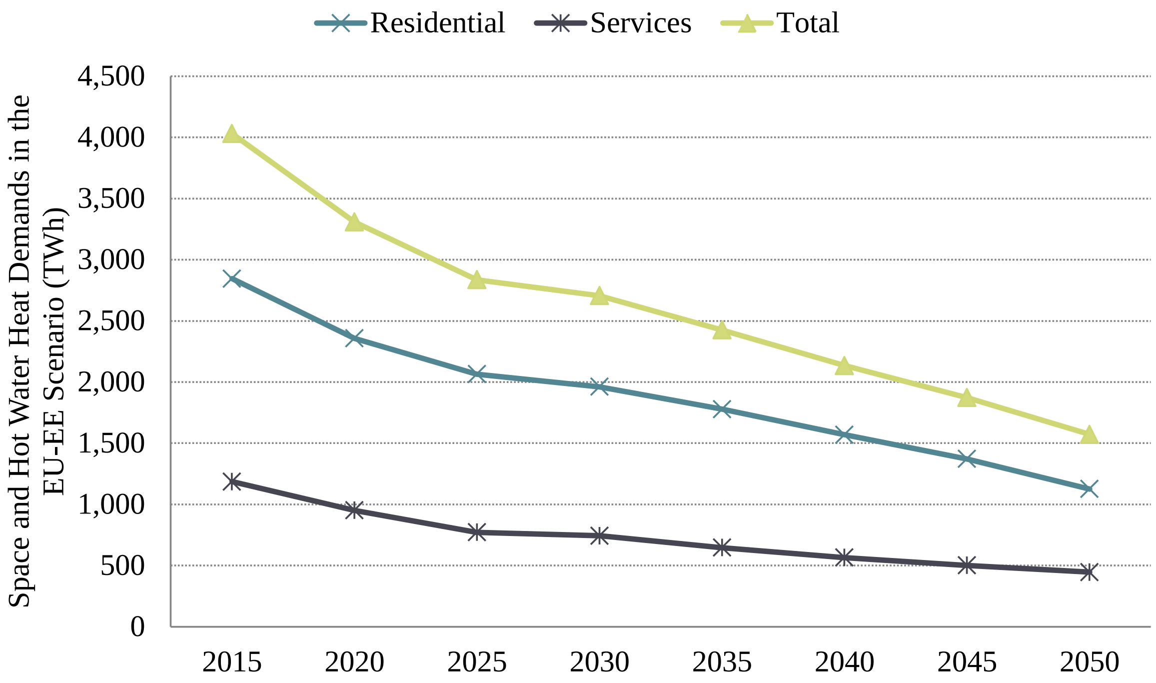

Figure 41: Heat demand for the residential and services sectors separately in the EU-EE scenario between 2015 and 2050.

Table 10: Population assumptions in the Energy Efficiency scenario between 1990 and 2050 [9].

Year	Population (Million)	Population 1-Year Change (%)	Population 5-Year Change (%)	Population 20-Year Change (%)	Population 40-Year Change (%)
1990	470.4	Start	Start		
1995	477.0	0.28%	1.4%		
2000	481.1	0.17%	0.9%		
2005	489.2	0.34%	1.7%		
2010	499.4	0.41%	2.1%	Start	Start
2015	507.7	0.33%	1.7%		
2020	513.8	0.24%	1.2%		
2025	517.8	0.15%	0.8%		
2030	519.9	0.08%	0.4%	4.1%	
2035	520.7	0.03%	0.1%		
2040	520.1	-0.02%	-0.1%		
2045	518.4	-0.07%	-0.3%		
2050	515.3	-0.12%	-0.6%	-0.9%	3.2%

While the heat demand is reducing in the EU-EE scenario, both the population and the building stock experience an increase. Table 10 summarises the changes assumed in population in the EU-EE scenario, suggesting a 3.2% overall growth in population between 2010 and 2050. Table 11 presents similar statistics for the building stock in Europe: the total building stock is expected to grow by 35% between 2015 and 2050, which includes a growth of 42% for the residential sector and 32% for the services sector.

Table 11: Estimated building floor area for the residential and non-residential/service sectors in the EU27 between 2015 and 2050.

Residential Floor Area										
		Period	2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
PRIMES Estimate [9]*	Residential floor area	*(mio. m²)*	21724	23579	25066	26387	27343	28053	28515	28730
	Residential floor area	%/year	Start	1.7%	1.2%	1.0%	0.7%	0.5%	0.3%	0.2%
Ecofys Estimate [42]	Non-Residential floor area	*(mio. m²)*	8642	9398	9870	10343	10815	11288	11760	12233
	Non-Residential floor area	%/year	Start	1.7%	1.0%	0.9%	0.9%	0.9%	0.8%	0.8%

*In 2050, Ecofys estimated a residential floor area 15% lower than PRIMES.

This data is significant since it means that the specific heat demand reductions (i.e. kWh/m^2) are even larger than the absolute heat demand reductions portrayed in Figure 40 and Figure 41. Overall, Figure 42 shows that the specific heat demand reduction is very similar for both services and both sectors considered here, with a 70% reduction (+/-3%) for each between 2015 and 2050.

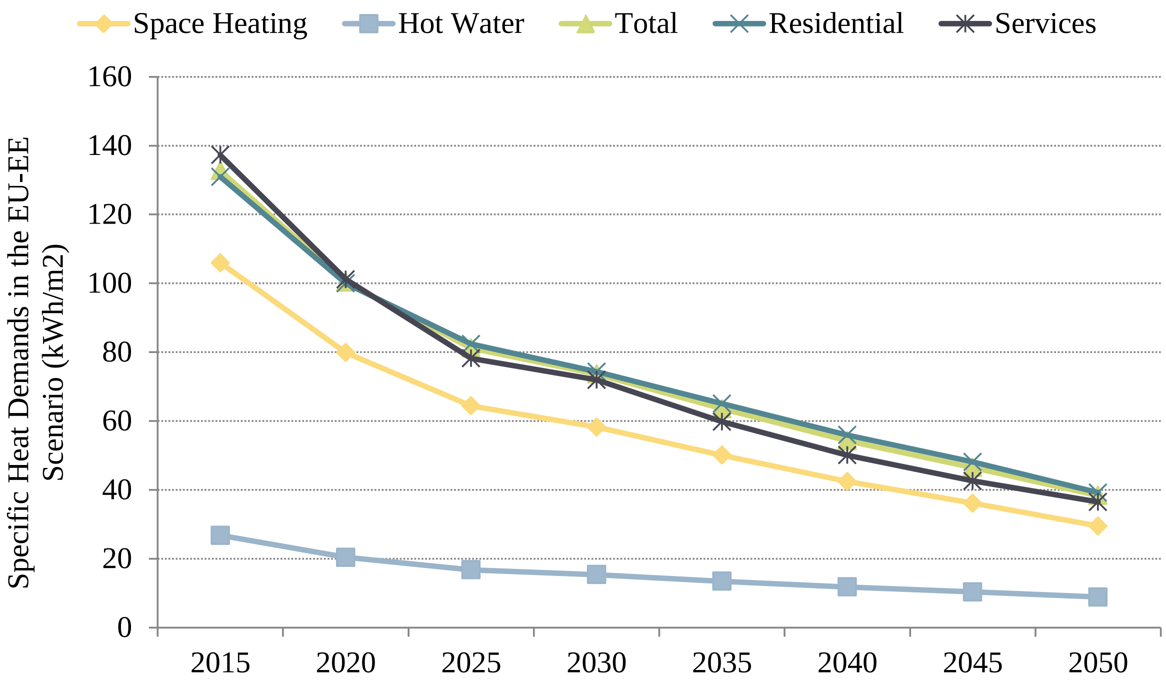

Figure 42: Specific heat demand in the EU-EE scenario for the residential and services sectors, as well as for the space heating, hot water, and total heat demand.

4.3 MODELLING THE EU-EE SCENARIO IN ENERGYPLAN

The PRIMES tool is an annual energy balance tool which forecasts the development of the EU energy system over 5-year periods (see Annex V). In contrast, the EnergyPLAN tool is an hourly energy-system-analysis tool which focuses on the integration of intermittent renewable energy (see section 2.2 and Annex VI). Therefore, a number of issues are naturally encountered when data from the PRIMES tool is interpreted for the EnergyPLAN tool. During this process, a number of issues have been identified which are discussed in detail in Annex VII, along with an explanation of the assumptions made to overcome them.

By modelling the EU-EE scenario in EnergyPLAN using these assumptions, it is possible to replicate the original projections created by the PRIMES model. As outlined in Figure 43, the PES is almost exactly the same in 2010, 2030, and 2050 in both the reference EU-EE scenario and the EnergyPLAN EU-EE scenario. The minor differences in 2030 (<0.5%) occur since the CHP plants cannot operate as much as the initial projections suggest. Due to a combination of a small heat demand, a high share of intermittent renewable energy, and a lack of flexibility in the system, the boiler needs to provide heat instead of the CHP plants more than the projections suggest. Since the boilers primarily use gas, there is a slightly higher gas consumption in the EnergyPLAN model. Similarly, since the CHP plants use considerable amounts of coal and biomass, due to a lower number of operating hours, there is a slightly lower coal and biomass consumption in the EnergyPLAN model.

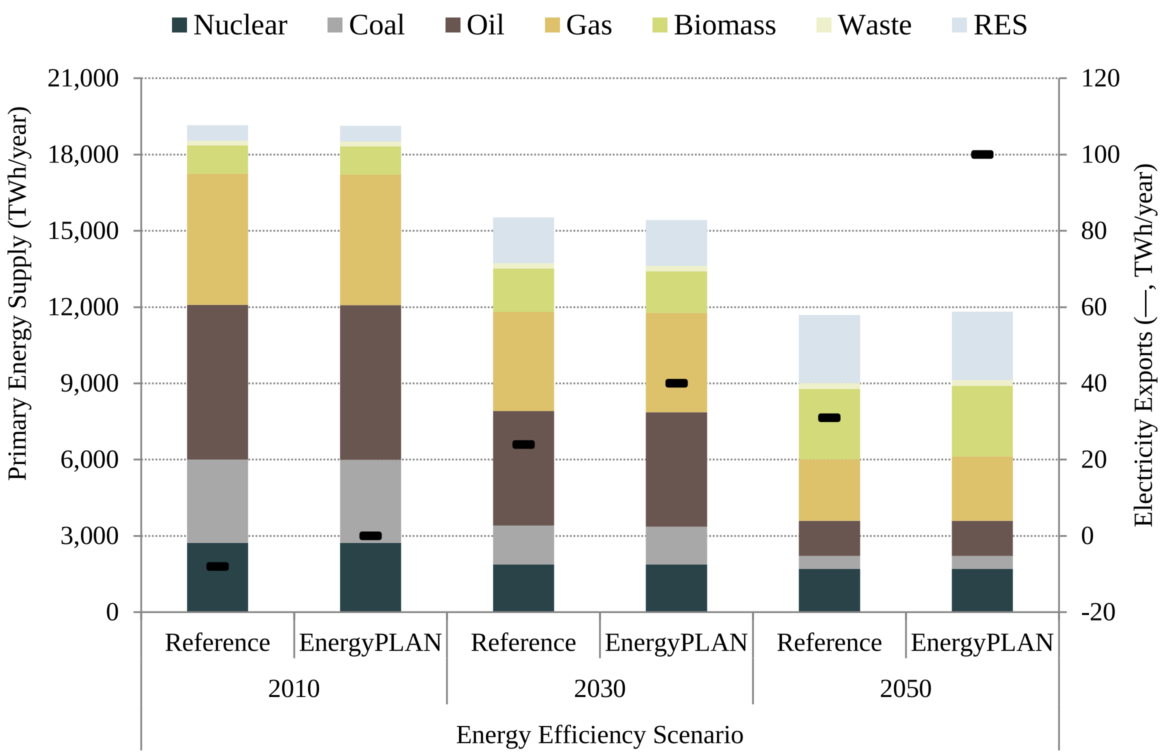

Figure 43: Primary energy supply by fuel and the net electricity exports for the EU-EE scenario from the original 'reference' projections and the EnergyPLAN model.

For 2050, the minor differences (<2.5%) seem to be caused for two reasons. Firstly, due to the same reason outlined for the year 2030 i.e. the CHP units do not operate as much as the projections suggest. Secondly, there is a larger electricity export in the EnergyPLAN model than in the original EU-EE projections. The original EU-EE projections had a net electricity export of 31 TWh in 2050 whereas the EnergyPLAN model produces a net electricity export of 100 TWh (see Figure 43). This additional 70 TWh is evident in the EnergyPLAN tool since it considers the hourly balance between demand and supply for electricity, heat, and gas, which may be overlooked by the PRIMES tool, which primarily focuses on the annual energy balance.

The overall difference for both 2030 and 2050 is so small that it can be concluded that the EU-EE scenario has been successfully replicated in the EnergyPLAN tool based on the key assumptions discussed in Annex VII. A full breakdown of the original EU-EE projections, how they have been interpreted to create a reference, and the results from the EnergyPLAN model is provided in Annex VIII.

5 NEW HEAT SCENARIO FOR 2030 AND 2050

After creating a model of the EU-EE scenario in EnergyPLAN, the Heat Roadmap Europe (HRE-EE) scenario could be created. The HRE-EE scenario contains a number of specific alterations for the space and hot water demands to residential and services buildings in the EU27 for the years 2030 and 2050. In summary, the key changes made to the EU-EE scenario when creating the HRE-EE scenario are as follows:

1. The heat demand is increased as the reductions identified in the EU-EE scenario seem very difficult to implement and they are very expensive. The hot water demand is increased by 16% compared to 2010 in the HRE-EE scenario, which is in line with a growth in population and building stock. The space heating demand is reduced by 47% in comparison to 2010 in the HRE-EE scenario. In comparison, the EU-EE scenario has a reduction of 55% in hot water demand and 62% in space heating demand between 2010 and 2050. Since there are less energy efficiency measures implemented in the HRE-EE scenario, the costs for energy efficiency are also reduced.
2. Individual boilers are replaced by district heating. In 2030, district heating meets 30% of the heat demand and in 2050 it meets 50% of the heat demand in residential and services buildings. Individual coal, oil, gas, biomass, and direct electric heating systems are replaced, but individual heat pumps are not since these are also considered a key technology to decarbonise the EU energy system. It is assumed here that these individual heat pumps are installed outside the urban areas that contain district heating.
3. Individual cooling units are replaced with district cooling. 10% of the cooling demand for residential and services buildings is provided using district cooling in 2030 and 20% in the year 2050. District cooling is supplied from both natural cooling and from absorption heat pumps, which require heat from the district heating network.
4. To supply the heat for these new district heating demands, new production units are added to the HRE-EE scenario. Some existing condensing power-plants are converted to CHP plants and new decentralised natural gas plants are constructed. Centralised boilers, heat pumps, and thermal storage facilities are also constructed.
5. With district heating now installed, additional resources can be utilised in the HRE-EE scenario that could not be utilised in the EU-EE scenario. These include more wind power of the large-scale heat pumps, large-scale solar thermal plants, geothermal heat, surplus industrial heat, and heat from waste incineration. Therefore, heat from each of these resources is also added to the HRE-EE scenario.
6. After these measures are implemented, the HRE-EE scenario consumed slightly less biomass than the EU-EE scenario. Therefore, the biomass consumption was increased in the HRE-EE scenario until it was at the same level as the EU-EE, by replacing some natural gas in the centralised district heating boilers.
7. Finally, the HRE-EE scenario is more flexible than the EU-EE scenario since it integrates the electricity and heating sectors. To exploit the benefits of this, wind power is increased in the HRE-EE scenario until there is the same level of critical excess electricity production (CEEP) in the HRE-EE scenario as the EU-EE scenario.

The assumptions used and results obtained during each of these steps is described in more detail in the rest of this chapter.

5.1 INCREASING THE HEAT DEMAND

The heat demand in the EU-EE scenario has already been presented and discussed in section 4.2. In summary, the reductions identified in the EU-EE scenario seem very ambitious and they are likely to be extremely difficult to implement. For example, the most ambitious scenario for heat savings in buildings presented in a recent report by EURIMA (European insulation Manufacturers Association) [42], outlines that with deep renovations in the EU27, a space heating reduction of 47% or specific space heating demand (i.e. kWh/m^2) reduction of 62% will be feasible between 2015 and 2050[12]. In comparison, the EU-EE scenario achieves corresponding reductions of 62% and 72% respectively. Since energy efficiency measures in buildings typically become more expensive as larger savings are achieved, the additional measures in the EU-EE scenario are likely to be extremely expensive. Comparing the cost of the energy efficiency measures in EU-EE scenario with those in the EURIMA report also suggest this. The cost of the energy efficiency measures in buildings in the EU-EE scenario are estimated at an annual average cost of B€295/year [9]. In contrast, the annual average investment costs for the energy efficiency measures in the Deep Renovation scenario completed by Ecofys for EURIMA are approximately B€160/year, although as outlined in Figure 44 these vary over the 45-year period including a steep drop in the last few years (which occurs because the whole building stock is then retrofitted). It is difficult to make a definite conclusion from this comparison since there are a lot of unknown assumptions behind the cost data in the EU-EE scenario. For example, the EU-EE scenario includes the following energy efficiency measures, with some of them occurring in other sectors such as electricity and transport:

a. More stringent minimum requirements for appliances and new buildings;
b. Energy generation, transmission and distribution;
c. High renovation rates for existing buildings;
d. The establishment of energy savings obligations on energy utilities;
e. The full roll-out of smart grids, smart metering and significant and highly decentralised RES generation

The costs for the EU-EE scenario are then divided into three types:

- Capital
- Energy purchases
- Direct efficiency investments

It is assumed here that a lot of the energy efficiency costs are accounted for under capital costs rather than direct efficiency investments. For example, better appliances, new electric grids, the smart grid, and more renewable energy generation are assumed to be under capital costs. Hence, it is assumed that direct efficiency investments relates to the implementation of space and hot water savings in the buildings sector, which amounts to B€295/year. This may not be the case so the cost of energy efficiency measures may be over-estimated based on this. In any case, other reports based on the Danish building stock also report a significant increase in energy efficiency costs when you reach this scale of energy savings [43] (which is presented in more detail later). Therefore, the costs assumed here may not be correct, but the scale of the costs for energy efficiency measures seems to be correct.

[12] The specific heat reduction (i.e. kWh/m^2) is greater than the absolute reduction (i.e. kWh) in space heating since the building area increases in combination with a decrease in the absolute heat demand.

The aim in designing a new "enhanced energy efficiency" scenario in this report is to identify if the same objectives in the EU-EE scenario, in terms of energy and emission reductions, can be achieved in a way that is both cheaper and easier to implement. To achieve such an objective, the strategy is to replace some of the energy efficiency measures in buildings, which are either very expensive and/or difficult to implement, with a heat supply from units such as district heating or individual boilers. In line with this, the following two subjects have been investigated further in the EU-EE scenario:

- The high reductions in the hot water end use seem very difficult to implement.
- The reduction per unit of space heating demand, below a total average reduction of 40-50% of the existing level, seems to be very ambitious in terms of implementation and also very expensive.

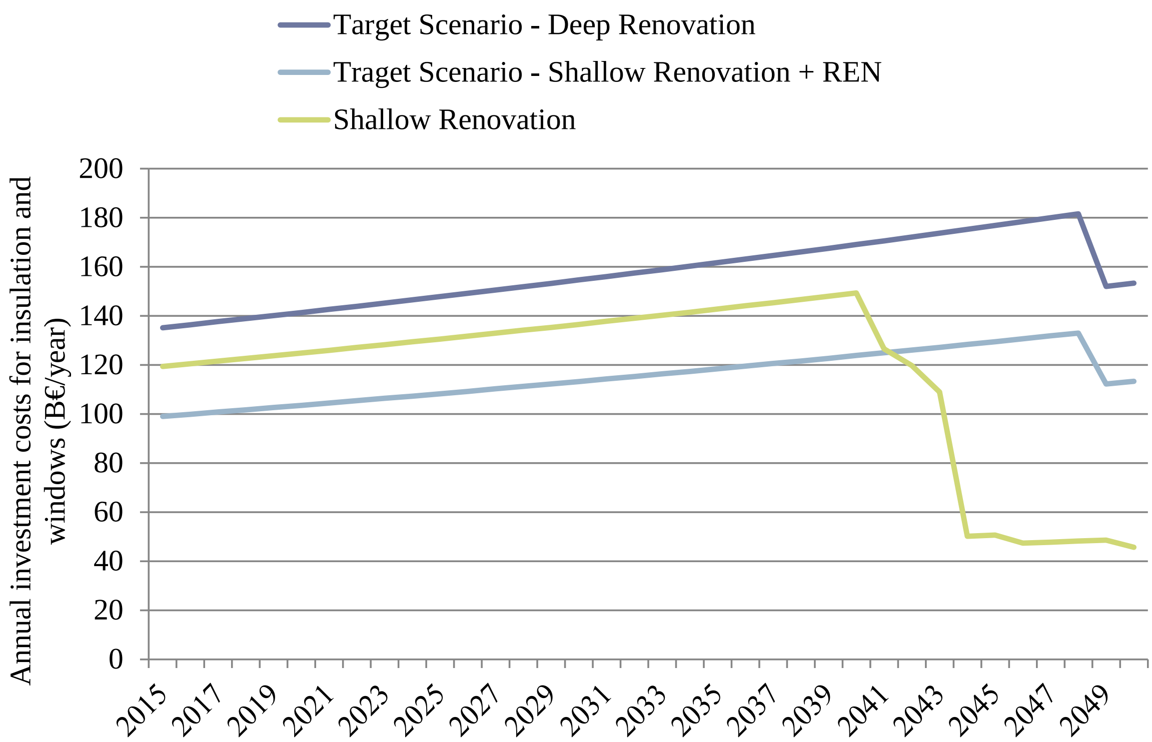

Figure 44: Annual investment costs for insulation and windows in the three scenarios created by Ecofys for energy efficiency in the EU27 [42].

Firstly to account for this, the hot water demand is not reduced in the HRE-EE scenario for the following reasons:

1. Table 10 and Figure 45 indicate that population will grow by 3.2% between 2010 and 2050.
2. According to a number of interviews with industry experts, people tend to wash more today than they did in the past, which is likely to continue into the future. In other words, individuals are likely to take more showers and baths in the future than they do today.
3. People are not expected to live with one another as much in the future. Hence, there will be a larger number of people living in their own houses rather than living together. This is also expected to increase the demand for hot water for an individual.
4. At present, there are regions in Europe where the use of hot water is limited due to technical and financial limitations. As these regions become wealthier, the demand for hot water is expected to rise in these regions.
5. The building area for residential and non-residential buildings is expected to grow by 32% and 42% respectively between 2015 and 2050 (see Table 11).

For these reasons, the hot water demand is not expected to decrease in this study, even with appliances that use less water, pipes with more insulation, and better hot water management in buildings. Therefore, it is assumed here that the hot water will increase rather than decrease. It is unlikely that the hot water demand will increase as fast as the building area, since people will live in larger houses and use the hot water more efficiently. However, it is unlikely that the hot water demand will increase at a lower rate than the population, for the reasons outlined in 1-4 above. Therefore, it is assumed here that the hot water demand will grow at a rate between the residential floor area and the population.

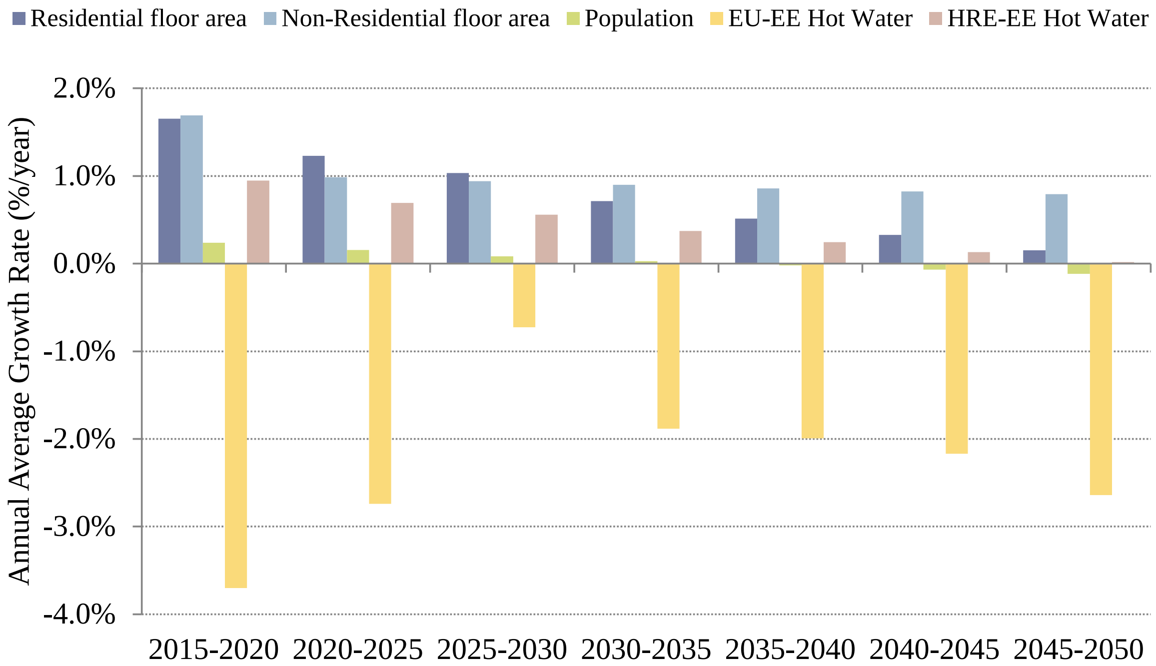

Figure 45: Average annual growth rates for the residential floor area, non-residential floor area, population, the original EU-EE scenario hot-water demand, and the new hot water demand assumed for the HRE-EE scenario (which is based on the average annual growth rate for the residential floor area and the population).

The new hot water demand grows by 16% between 2015 and 2050 instead of reducing by 55% as in the original hot water demand projection for the EU-EE scenario, as outlined in Figure 46. The specific hot water demand now drops from approximately 27 kWh/m^2 in 2015 to 23 kWh/m^2 in 2050, instead of from 27 kWh/m^2 to 9 kWh/m^2 as in the EU-EE scenario.

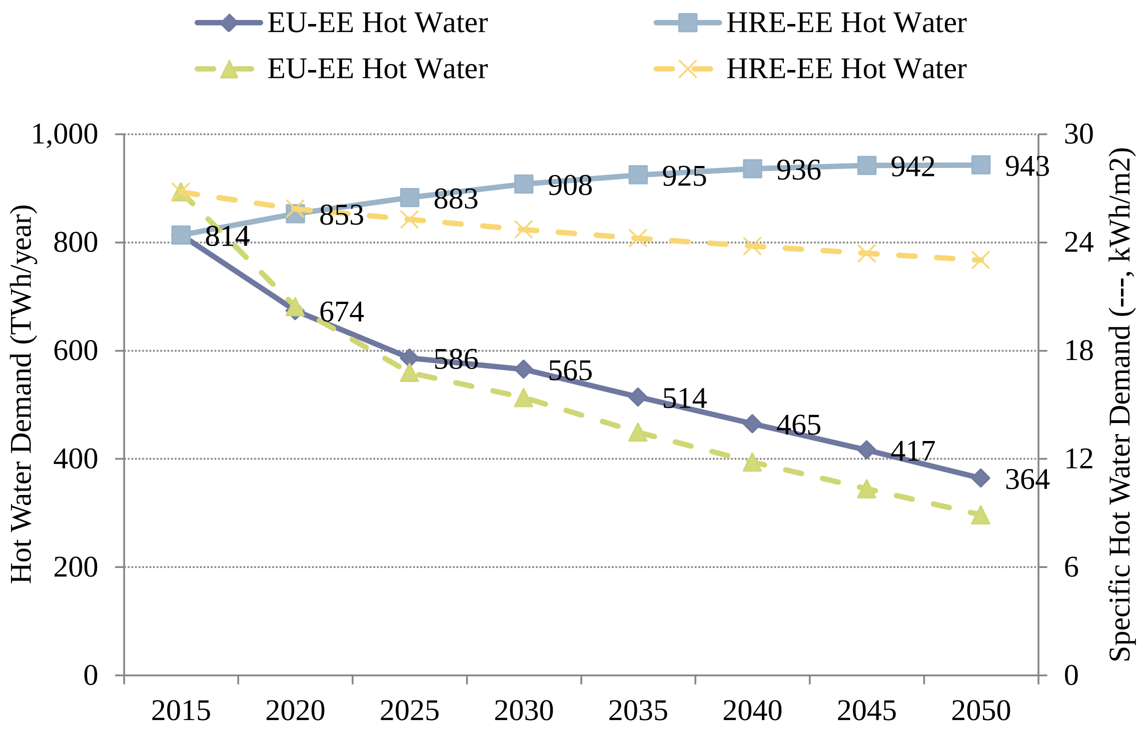

Figure 46: Original hot water demand in the EU-EE scenario and the new hot water demand for the HRE-EE scenario, along with the corresponding specific hot water demands (dotted lines).

For the space heating demand, the reductions achieved in the Deep Renovation scenario of the EURIMA report [42] are likely to cost significantly less than those proposed in the EU-EE scenario. Hence, a reduction of 47% in the total space heating demand is assumed here, instead of 62%. It is important to note that one significant difference between the Deep Renovation scenario and the EU-EE scenario is the space heating demand in 2015. As outlined in Figure 47, this is approximately 2,600 TWh in the Deep Renovation scenario, but it is approximately 3,200 TWh in the EU-EE scenario. Looking at actual historical data from the International Energy Agency (IEA) indicates that the total heat demand for both space heating and hot water in 2010 was approximately 3,300 TWh (as displayed in Figure 8). Data from the EU-EE scenario indicates that the hot water demand is approximately 800 TWh in 2015 (see Figure 46). Assuming the same hot water demand is the same in the IEA 2010 data, then the space heating demand for the EU27 was approximately 2,700 TWh in 2010. Although this means that the heat demand in the Deep Renovation scenario is more likely closer to the current situation in Europe than the EU-EE scenario, the HRE-EE heat demand created for this study uses the same starting point as the EU-EE scenario. This is to make the results of this study comparable to the analysis in the EU-EE scenario since the principal objective here is to compare a scenario with energy efficiency only to a scenario with both energy efficiency and district heating. The final space heating demand assumed in the new HRE-EE scenario is outlined in Figure 47.

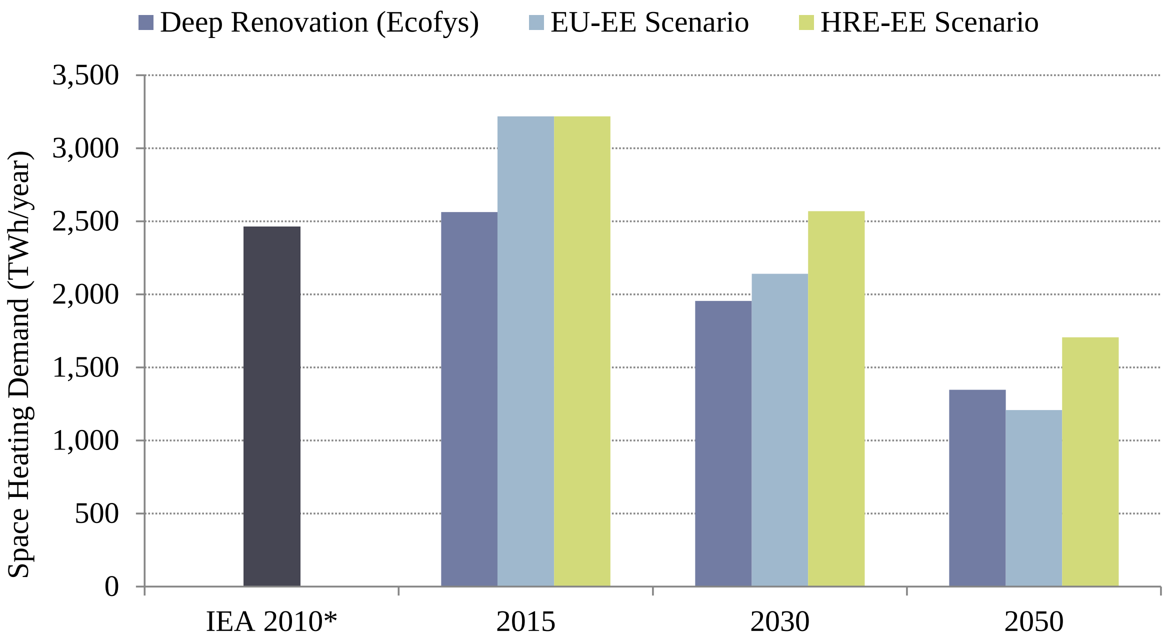

Figure 47: Space heating in the EU-EE scenario from the *Energy Roadmap 2050* report [9], the Deep Renovation scenario form Ecofys [42], and the new space heating demand assumed in the HRE-EE scenario. *This space heating demand is estimated based on the total heat demand from the 2010 EU27 IEA Energy Balance minus the hot water demand identified from the PRIMES data for 2015.

The final total heat demand for the new HRE-EE scenario assumed in this study is outlined in Figure 48: there is a total reduction of 34% between 2015 and 2050 in the HRE-EE scenario instead of 61% as originally proposed in the EU-EE scenario.

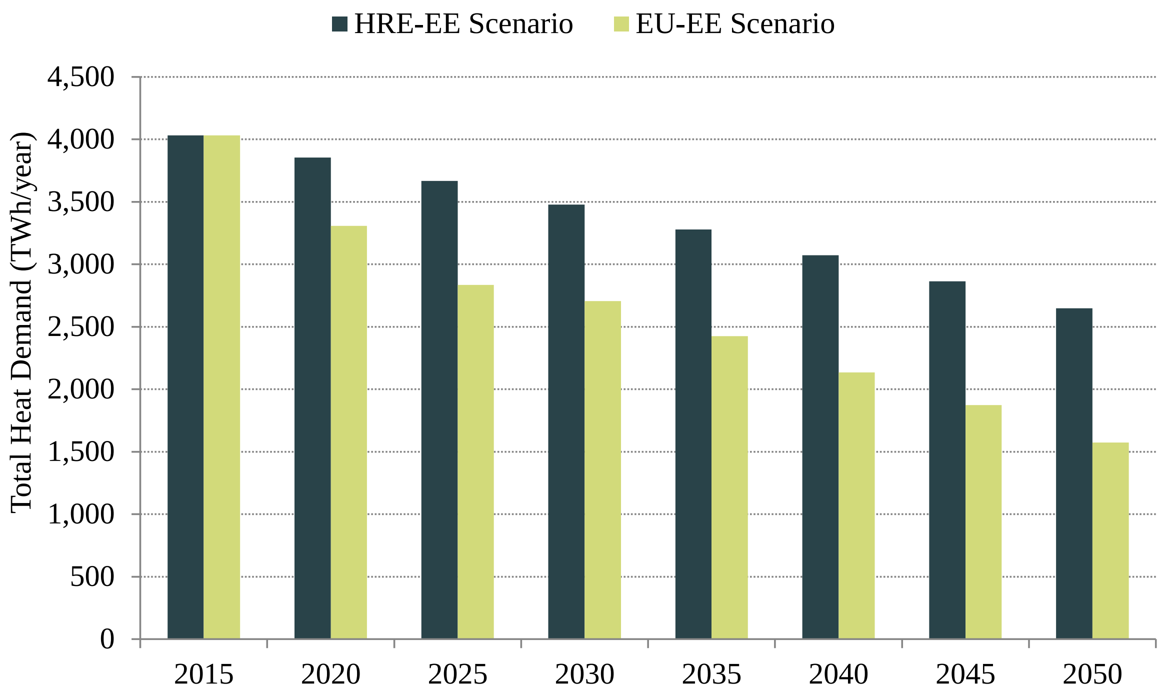

Figure 48: Total heat demand for the EU-EE and HRE-EE scenarios for 2015-2050.

The cost for the energy efficiency measures also need to be adjusted downwards from the B€295/year in the EU-EE scenario, since there are now less energy efficiency measures in the HRE-EE heat demand forecast. To do so, an energy efficiency cost curve, which is displayed in Figure 49, has been utilised. This cost curve was developed based on data from the Danish Research Building Institute [43] and a Danish Heat Atlas [44, 45]. The costs reflect the 'additional' cost of energy efficiency measures, which means that they are implemented at the same time as other renovations which are taking place in the building. Assuming a 3% interest rate and an average lifetime of 30 years for these energy efficiency measures, indicative annual costs of implementing energy efficiency measures in the EU27 have been estimated in Figure 50. These are indicative only since they reflect total energy savings and not the reduction in specific heat demand. However, these results demonstrate how the unit cost of energy savings increases as more savings are implemented. For example, the first B€200/year on energy savings in Europe will achieve savings of approximately 53%, while investments of B€400/year will only achieve 22% more at 75%.

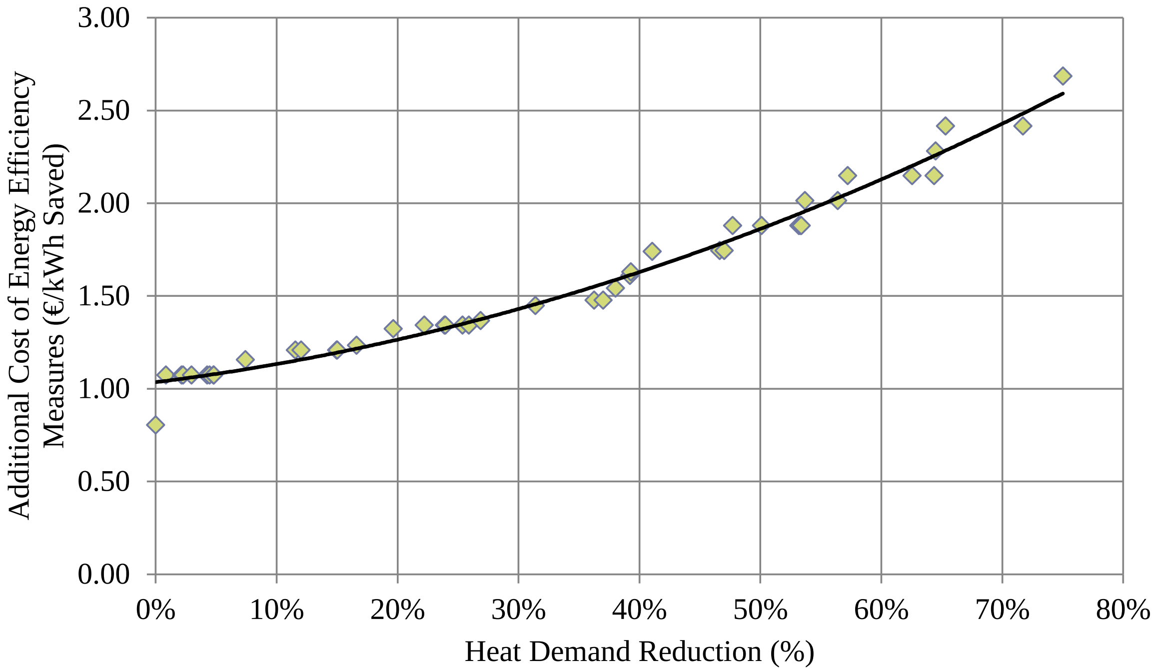

Figure 49: Additional costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings (scenario C) [43]. 'Additional' means it is assumed that these are the extra costs of completing the energy efficiency measures at the same time as implementing other building refurbishments.

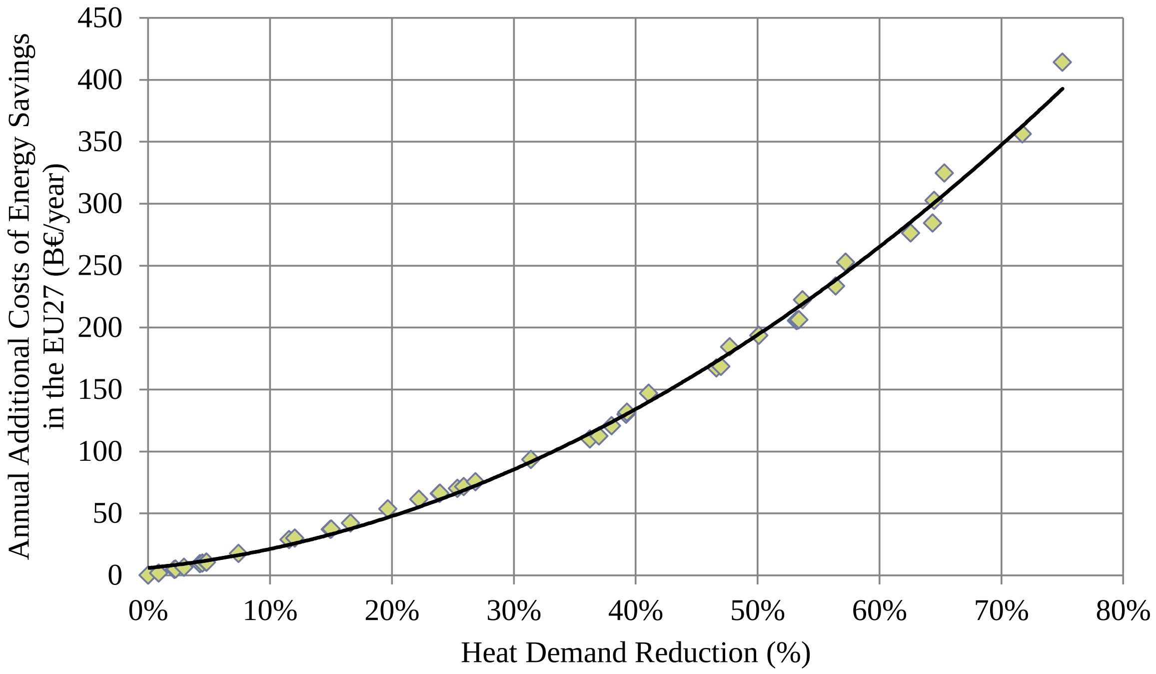

Figure 50: Annual 'additional' costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings (scenario C) [43], an interest rate of 3%, and assuming an average lifetime of 30 years. These are indicative only as they not consider the change in specific heat demand, but instead it considers the change in total heat demand.

As displayed in Figure 40, there is a total reduction of approximately 70% in the specific heat demand in the EU-EE scenario, equating to total savings of 2,460 TWh. Assuming a cost of €2.4/kWh (18 DKK/kWh) based on the data in Figure 49, a 3% interest rate, and an average lifetime of 30 years for the energy efficiency measures, the annual costs of implementing the energy efficiency measures in the EU-EE scenario are calculated as approximately B€303/year. This is very similar to the costs suggested in the EU Energy Roadmap report of B€295/year, although as mentioned previously the B€295/year may include savings in other sectors such as electricity and transport.

Using the same assumptions, the costs for the energy efficiency measures in the new heat demand scenario can also be estimated. In the HRE-EE scenario, there is a 51% reduction in the specific heat demand between 2015 and 2050, equating to a total energy saving of 1,215 TWh. Assuming a cost of €1.9/kWh (14 DKK/kWh), this means that the total annual costs for energy efficiency measures in this scenario are approximately B€133/year. Comparing this to the annual investment costs estimate by Ecofys in the EURIMA report [42] suggests that this is a 17% underestimation of the total energy efficiency costs required. As displayed earlier in Figure 44, the average annual investments required in the Deep Renovation scenario (for a 47% reduction in space heating) are approximately B€160/year. This difference warrants further investigation in the future, but based on these comparisons, the indicative costs provided by the unit costs in Figure 49 are deemed an adequate representation of the variation in costs as more energy efficiency measures are implemented.

Overall, the EU-EE scenario is extremely ambitious in terms of energy efficiency, since it will be extremely difficult and expensive to achieve. Hence, a new heat demand has been created for this study, which is also very ambitious in terms of energy efficiency since it follows the space heating recommendations of the Deep Renovation scenario created for EURIMA [42]. This new HRE-EE heat demand will be used to investigate the feasibility of district heating in an EU energy system with very low heat demands for residential and services buildings.

5.2 REPLACING INDIVIDUAL BOILERS WITH DISTRICT HEATING

After creating a new heat demand for the HRE-EE scenario, individual boilers could then be replaced with district heating. In the EU-EE scenario, district heating provides 12.8% of the heat demand for residential and services buildings in 2030 and 13.3% in 2050 [12]. In the HRE-EE scenario, the share of district heating is increased to 30% in 2030 and 50% in 2050, as outlined in Table 12.

Table 12: Individual and district heating demands in the EU-EE and HRE-EE (before and with the district heating expansion) scenarios for the years 2030 and 2050.

Scenario	Individual Heat Demand (TWh)	District Heating Heat Demand (TWh)	District Heating Production (TWh)	Total Heat Demand (TWh)
		2030		
EU-EE	2,445	270	337	2,715
HRE-EE Before the DH Expansion	3,131	346	431	3,477
HRE-EE	2,434	1,043	1,268*	3,477
		2050		
EU-EE	1,426	159	180	1,584
HRE-EE Before the DH Expansion	2,383	265	301	2,648
HRE-EE	1,324	1,324	1,571*	2,648

*Includes an additional 17% in network losses for all new district heating systems.

It is assumed here that individual heat pumps are not replaced by district heating since these are also considered a key decarbonisation technology for the EU27 energy system. Therefore, there is the same amount of individual heat pumps in the EU-EE scenario as in the HRE-EE scenario. There is an underlying assumption here that individual heat pumps are also placed outside the urban areas where district heating is implemented. Inside the urban areas, it is assumed that coal, oil, gas, biomass, and electric boilers are replaced by district heating. As a result, Figure 51 indicates that there is a lower fossil fuel and biomass consumption for individual boilers in the HRE-EE scenario than in the EU-EE scenario, even though the heat demand is larger in the HRE-EE scenario. The volume of each type of boiler that is replaced by district heating is currently unclear, so in the HRE-EE scenario the different boilers have been replaced by district heating proportional to the heat demand they satisfy.

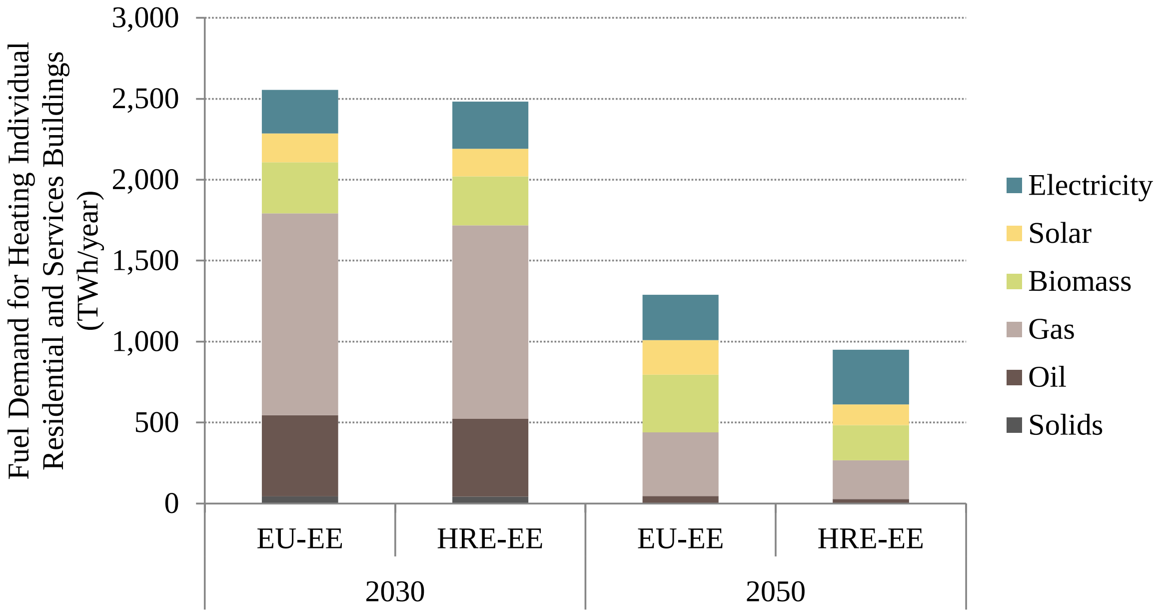

Figure 51: Fuel consumption by individual boilers in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

The cost of transforming individual boilers into district heating is estimated here based on the number of boilers replaced, the size of these boilers, and the heat demand replaced. The number of boilers has been estimated using the BEAM tool developed by Ecofys (see Annex III). Table 13 displays the number of residential boilers in the EU-EE and HRE-EE scenarios for the years 2030 and 2050, while Table 14 displays the number of services boilers for the same. Both Table 13 and Table 14 illustrate the decrease in the total number of individual boilers in the HRE-EE scenario, the same number of heat pumps in both the EU-EE and HRE-EE scenario, and the increase in the number of district heating substations in the HRE-EE scenario.

Table 13: Number of residential boilers (million units) for the EU-EE and HRE-EE scenarios for the years 2030 and 2050

(Million)	Oil	Gas	Pellet/ Coal	Direct Electricity	Air Heat Pump	Brine Heat Pump	District Heating Substation	Total
2030								
EU-EE	13.618	62.719	28.475	9.630	10.610	26.582	16.848	168.483
HRE-EE	9.608	44.252	20.091	6.795	10.610	26.582	50.545	168.483
2050								
EU-EE	5.977	52.253	39.946	18.561	15.803	47.408	19.994	199.942
HRE-EE	1.882	16.454	12.579	5.845	15.803	47.408	99.971	199.942

Table 14: Number of services boilers (million units) for the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

(Million)	Oil	Gas	Pellet/ Coal	Direct Electricity	Air Heat Pump	Brine Heat Pump	District Heating Substation	Total
2030								
EU-EE	1.375	4.559	1.893	0.626	0.659	1.855	1.219	12.185
HRE-EE	0.978	3.244	1.347	0.446	0.659	1.855	3.656	12.185
2050								
EU-EE	0.432	3.779	2.889	1.342	1.143	3.429	1.446	14.461
HRE-EE	0.136	1.190	0.910	0.423	1.143	3.429	7.230	14.461

Since the HRE-EE scenario has a higher heat demand than the EU-EE scenario, the individual heating systems are assumed to have larger heat capacities in the HRE-EE scenario. As the specific heat demand is also reducing over time in both the EU-EE and HRE-EE scenarios, the individual boiler capacities are reduced between 2010 and 2050. Similarly, the investment costs for individual boiler units are lower in the EU-EE scenario than the HRE-EE scenario. The final average boiler capacities and investment costs assumed are outlined in Table 15 for residential boilers and Table 16 for services boilers. These have been estimated based on previous Danish experiences [4, 5] and inputs from Ecofys (see section 1.2 in Annex III).

Table 15: Average thermal capacities and corresponding investment costs assumed for residential boilers in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

	Oil	Gas	Pellet/ Coal	Air Heat Pump	Brine Heat Pump	Direct Electricity	District Heating Substations
Average Size of Residential Boilers (kWth)							
2012	12.9	12.9	12.9	10.8	10.8	12.9	12.9
EU-EE 2030	10.5	10.5	10.5	9.4	9.4	10.5	10.5
HRE-EE 2030	11.5	11.5	11.5	10.3	10.3	11.5	11.5
EU-EE 2050	8.0	8.0	8.0	8.0	8.0	8.0	8.0
HRE-EE 2050	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Specific Investment for Residential Boilers (k€/unit)							
2012	3.8	5.6	7.0	13.0	17.3	10.3	6.2*
EU-EE 2030	3.1	4.5	5.6	11.3	14.1	8.4	5.6*
HRE-EE 2030	3.4	5.0	6.2	12.4	15.5	9.2	5.9*
EU-EE 2050	2.3	3.5	4.3	9.6	11.2	6.4	5.0*
HRE-EE 2050	2.6	3.8	4.8	10.6	12.3	7.0	5.2*

*Includes the cost of a meter and a branch pipe from the district heating network to the building.

Table 16: Average thermal capacities and corresponding investment costs assumed for services boilers in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

	Oil	Gas	Pellet/ Coal	Air Heat Pump	Brine Heat Pump	Direct Electricity	District Heating Substations
				Average Size of Services Boilers (kW_{th})			
2012	263	263	263	240	240	263	250
EU-EE 2030	263	263	263	240	240	263	250
HRE-EE 2030	289	289	289	264	264	289	275
EU-EE 2050	263	263	263	240	240	263	250
HRE-EE 2050	289	289	289	264	264	289	275
				Specific Investment for Services Boilers (k€/unit)			
2012	26.3	13.6	45	240	264	175	21.5*
EU-EE 2030	26.3	13.6	45	240	264	175	21.5*
HRE-EE 2030	28.9	15.0	49	264	290	192	23.3*
EU-EE 2050	26.3	13.6	45	240	264	175	21.5*
HRE-EE 2050	28.9	15.0	49	264	290	192	23.3*

*Includes the cost of a meter and a branch pipe from the district heating network to the building.

To annualise the boiler costs, technical lifetimes were also assumed for each type of boiler as outlined in Table 17. In addition, Table 17 indicates the fixed and marginal O&M costs assumed for each type of boiler.

Table 17: Other financial assumptions for residential and services boilers for both the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

	Oil	Gas	Pellet/ Coal	Air Heat Pump	Brine Heat Pump	Direct Electricity	District Heating Substations
				Residential Boilers			
Technical lifetime (years)	20	22	20	20	20	30	20
Fixed O&M (€/unit/year)	270	46	25	135	135	50	150
Variable O&M (€/MWh)	0	7.2	0	0	0	0	0
				Services Boilers			
Technical lifetime (years)	20	25	20	20	20	30	20
Fixed O&M (€/unit/year)	1,000	1,540	3,465	400	400	4,000	150
Variable O&M (€/MWh)	0	7.2	0	0	0	0	0

Direct electric heating is also replaced by district heating in this study. These systems do not have central heating systems in the buildings already, so the additional cost of the central heating system also needs to be considered in the economic calculations. The costs assumed for central heating systems are outlined in Table 18.

Table 18: Costs assumed for central heating systems in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Cost	Residential	Services
Specific investment (1000€/unit)	5.4	15
Technical lifetime (years)	40	40
Fixed O&M (€/unit/year)	70	70
Variable O&M (€/MWh)	0	0

The costs assumed for the district heating network are outlined in Table 19. It is assumed that all district heating proposed in the EU-EE scenario is conventional district heating, since there is no increase in the market share for district heating in the EU-EE scenario. However, from a cost point of view, all additional district heating constructed in the HRE-EE scenario is assumed to be low-temperature district heating [44] (see Table 20). As presented in Table 19, this means that the additional district heating in the HRE-EE scenario has investment costs over 7 times more per unit of heat demand met than the conventional district heating used today. Hereby, the highest marginal cost for the expansion is used as an estimate for the average cost of the whole expansion. This very conservative assumption is made, since we have not yet completed a thorough assessment of the actual investment cost for the future heat distribution from the European heat atlas in Figure 14. In reality, if the HRE-EE scenario is implemented, then there will be an expansion of both conventional and low-temperature district heating in the future, so this can be seen as a worst case scenario in terms of the district heating pipeline costs. Although low-temperature district heating is not in use today, it is expected to grow in the future since the heat demands in the buildings will reduce and also, so that low-temperature heat sources can be utilised by district heating networks.

Table 19: Financial assumptions for conventional and low-temperature district heating assumed in the EU-EE and HRE-EE scenarios [45].

	Conventional District Heating Network for a heat demand of >120 TJ/km^2	Low-temperature district heating for a heat demand of 20-48 TJ/km^2
Specific Investment costs* (1000 €/TWh of heat demand)	72,000	522,000#
Technical lifetime (years)	40	40
Average Fixed O&M (€/TWh/year)	900,000	3,960,000
Variable O&M (€/MWh)	0	0

*Branch pipes to the buildings are not included here, but instead are included in the district heating substation costs.
#This cost represents the price per unit of heat delivered. It is important to recognise that the difference between conventional and low-temperature district heating is very large since low-temperature district heating is assumed to supply buildings with lower heat demands. Therefore, the cost per metre of district heating pipelines is not reflected here, but the cost per unit of heat supplied.

Table 20: Type of district heating assumed in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Heat Demand (TWh)	Conventional District Heating Network for a heat demand of >120 TJ/km2	Low-temperature district heating for a heat demand of 20-48 TJ/km2	Total
EU-EE 2030	270	0	270
HRE-EE 2030	346*	697	1,043
EU-EE 2050	159	0	159
HRE-EE 2050	265*	1,059	1,324

*Conventional district heating supplies the same market share in the HRE-EE scenarios as in the EU-EE scenario, but the heat demand is higher since there are less energy efficiency measures.

Based on these assumptions, the annual investments and operation costs for heating networks and consumer installations for the EU-EE and HRE-EE scenarios are displayed in Figure 52. The investment costs for the individual boiler units are the dominant cost in all scenarios considered, representing approximately 70% of the total costs on average. This is followed by the central heating system costs, which represent approximately 25% of the total costs in all scenarios. Although the costs assumed for the district heating network in the HRE-EE scenario are very high (see Table 19), these only represent approximately 10% of the total costs in 2050 when there is a 50% district heating market share. However, the total annual costs are still higher in both HRE-EE scenarios and the costs of the production units still need to be added to these scenarios.

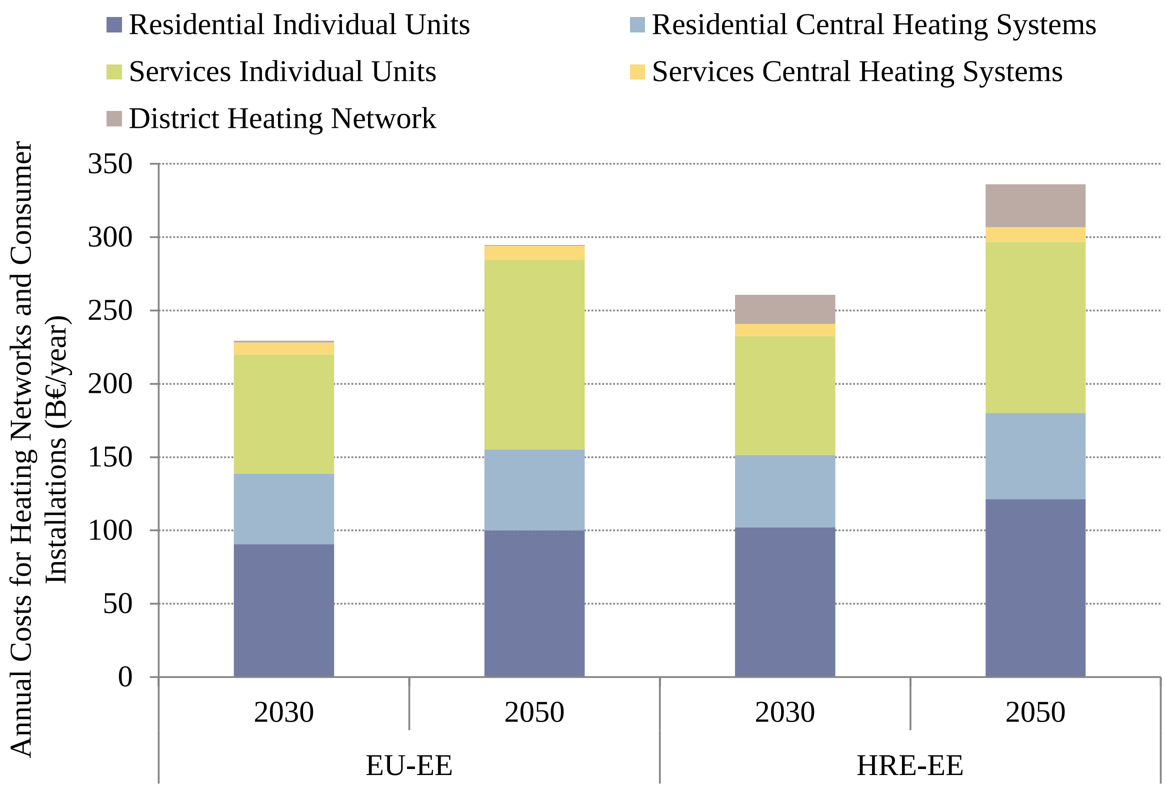

Figure 52: Annual investment and operation costs for heating networks and consumer installations for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

5.3 REPLACING INDIVIDUAL COOLING WITH DISTRICT COOLING

The cooling demand in the EU-EE scenario is approximately 15% of the heat demand between 2010 and 2050, so less emphasis is placed on cooling in this report. However, based on a forecast from the EU project RESCUE [46], it is assumed here that district cooling can supply 10% of the cooling demand in 2030 and 20% in 2050 in the HRE-EE scenario (see Figure 53). No information was identified or developed in this study to specify exactly how this district cooling would be provided. Therefore, it is simply assumed that 50% of the district cooling is from natural cooling and 50% is from absorption heat pumps.

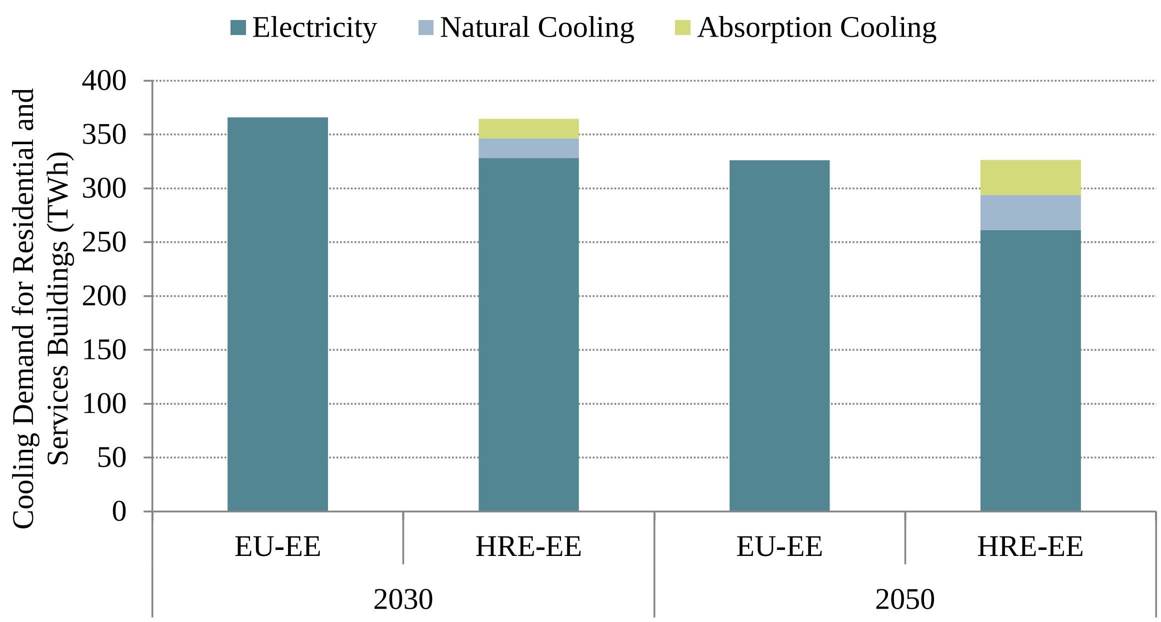

Figure 53: Cooling demand by fuel source for residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

It is assumed that the compression heat pumps have a COP of 2 [45], and so the electricity demand for cooling is half the cooling demand (see Figure 54). However, the absorption heat pumps only have a COP of 0.6 [47] and so there is an additional heat demand of 30.5 TWh in 2030 and 54 TWh in 2050 from the district heating network.

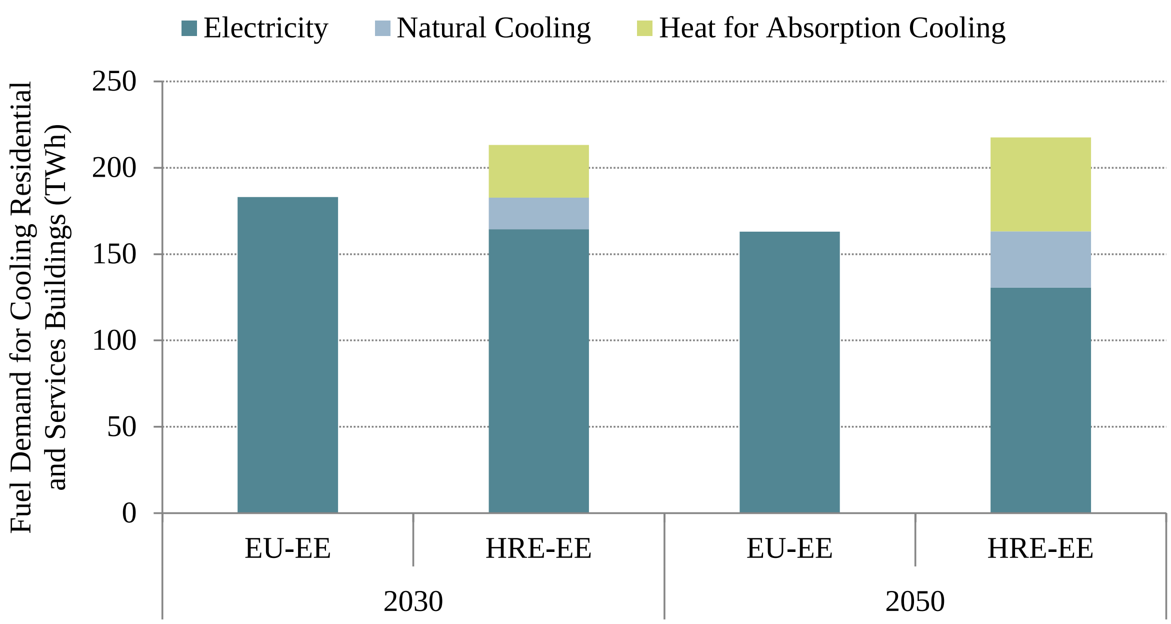

Figure 54: Fuel demand for cooling residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

The costs for district cooling are difficult to estimate since there is currently very little data available for cooling demands. However, since the cooling demand is very small compared to the heating demand, the costs are also less significant. For cooling that is provided by electricity, it is assumed that an air-to-water heat pump is utilised with the investment costs outlined in Table 21.

Table 21: Financial assumptions for air-to-water heat pumps which use electricity to provide cooling in the EU-EE and HRE-EE scenarios.

	Individual heat pump air-to-air
Average Size ($kW_{cooling}$)	267
Specific investment (1000€/unit)	240
Technical lifetime (years)	20
Fixed O&M (€/unit/year)	400
Variable O&M (€/MWh)	0

The number of cooling units has been estimated for 2010 based on an assumed average cooling capacity of 267 $kW_{cooling}$/unit and a total estimated cooling capacity in the EU of 275 GW [48]. Then, the total cooling capacity is increased proportionately to the cooling demand for the years 2030 and 2050, as displayed in Table 22. Similarly, it is then assumed that the number of individual heat pump units replaced in the HRE-EE scenario is proportionate to the cooling demand replaced with district cooling.

Table 22: Assumptions used to estimate the number of individual cooling units and the capacity of individual heat pumps in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Total Cooling Demand (TWh)	323	365	326
Estimated Cooling Capacity Installed in 2010 ($MW_{Cooling}$)	275,000	311,024	245,692
Cooling Capacity of a Heat Pump ($kW_{Cooling}$)	267	267	267
Number of Heat Pumps Required in the EU-EE scenario	1,031,250	1,166,339	921,346
District Cooling in the HRE-EE scenario (%)	0%	10%	20%
District Cooling in the HRE-EE scenario (TWh)	0	37	65
Number of Heat Pumps Replaced with District Cooling in the HRE-EE scenario	0	116,634	184,269
Individual Heat Pump Capacity Replaced with District Cooling ($kW_{Cooling}$)	0	31,102	49,138
Centralised Absorption Heat Pump Capacity Required in the HRE-EE scenario ($kW_{Cooling}$)	0	23,327	36,854

The cost of natural cooling is assumed to be 150% of the cost for conventional district heating networks, while the additional district heating demand for absorption cooling is provided by low-temperature district heating (see Table 19). It is not possible to be specific about the breakdown of cooling units used for district cooling since it is often composed of backup chillers and absorption heat pumps. Therefore, here it is assumed that 75% of the individual heat pump capacity replaced by district cooling is rebuilt as centralised absorption heat pumps (see Table 22) using the costs outlined in Table 23.

Table 23: Financial assumptions for the centralised absorption heat pumps used to provide district cooling in the EU-EE and HRE-EE scenarios: based on the costs for thermal absorption heat pumps in [45].

Specific investment (M€/$MW_{Cooling}$)	0.97
Lifetime (years)	20
Fixed O&M (% of Investment)	5.00%

The costs assumed here will need to be investigated in more detail in the future, but it is a sufficient proxy for this study since the cooling systems costs (Figure 55) are less than 10% of the heating system costs (Figure 52).

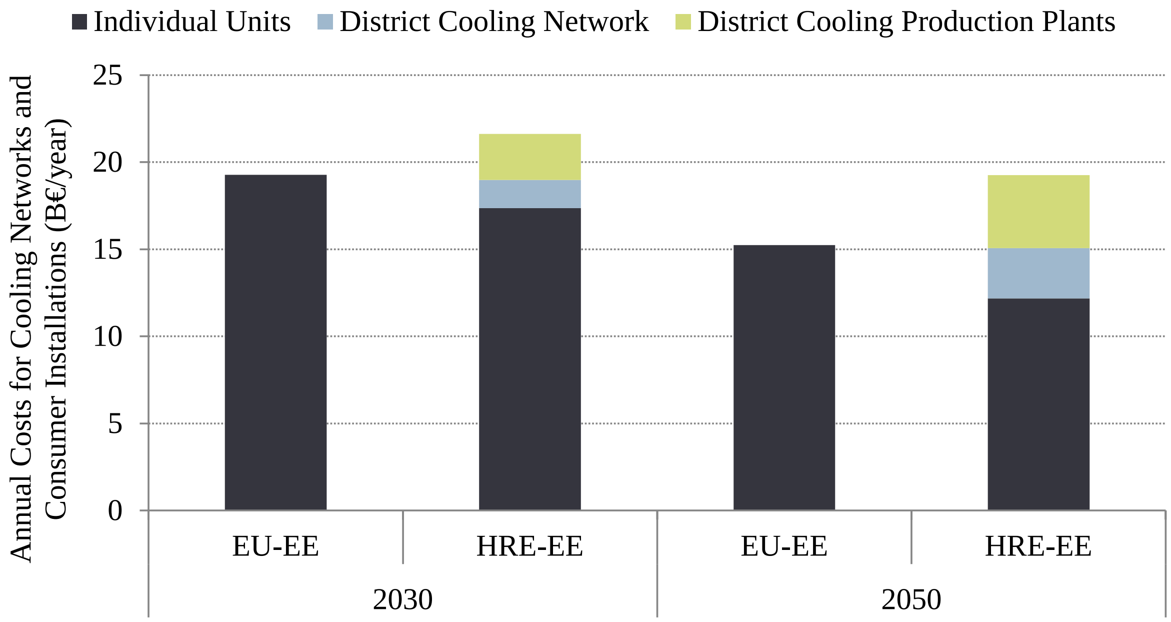

Figure 55: Annual cooling system costs for the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

5.4 ADDING DISTRICT HEATING PRODUCTION UNITS

Now the total district heating demand has been defined for the HRE-EE scenarios, which includes district heating for hot water and space heating (section 5.1) as well as district heating for absorption heat pumps for district cooling (section 5.2). The next step is to define the capacities for the production units in the HRE-EE scenarios, which are displayed in Table 24.

It is assumed that half of the district heating expansion in the HRE-EE scenarios will be decentralised and so, this will require the construction of new relatively small CHP plants. These are assumed to be 10-100 MW gas power plants with an average electrical efficiency of 50% and an average thermal efficiency of 40% [47]. The remaining district heating is provided by centralised CHP plants that either already exists or are created by converting existing electricity-only power plants. It is assumed that the fuel mix for these power plants in the HRE-EE scenarios are the same as the fuel mix already defined for CHP plants in the EU-EE scenarios for 2030 and 2050.

Table 24: District heating production unit capacities assumed in the EU-EE and HRE-EE scenarios for the residential and services sectors for the years 2030 and 2050.

	Assumed Efficiencies [47]	2030		2050	
		EU-EE	HRE-EE	EU-EE	HRE-EE
District Heating Production for Boiler Only Systems (TWh)	n/a	55	70	11	19
Boilers for Boiler Only Systems (MW_{th})	2030: $\eta_{thermal}$ = 80% 2050: $\eta_{thermal}$ = 81.5%	17,089	21,750	3,190	5,364
Other District Heating Production (TWh)	n/a	282	1268	169	1,571
CHP (MW_e)	Centralised: 2030 η_{elec}=40% & $\eta_{thermal}$=45% 2050 η_{elec}=45% and $\eta_{thermal}$=45% Decentralised: η_{elec}=50% and $\eta_{thermal}$=45%	33,570	103,570	25,916	205,916
Backup Boilers* (MW_{th})	$\eta_{thermal}$=90%	105,150	472,850	57,250	532,230
Heat Pumps (MW_e)	COP = 3	0	26,000	0	40,000
Thermal Storage# (GWh)	n/a	130	600	80	750

*Assuming a boiler capacity that is 20% greater than the maximum heat demand.
#Assuming a thermal storage capacity that is 17% of the average daily heat supply into the network [49].

5.5 ADDING ADDITIONAL RESOURCES TO SUPPLY HEAT TO THE DISTRICT HEATING NETWORK

By adding district heating networks to the energy system, it is possible to utilise a number of additional resources that could otherwise not be utilised. As displayed in Figure 56, the following additional heat production is provided by unconventional resources in the HRE-EE scenario:

- Industrial surplus heat: 100 TWh/year
- Direct geothermal heat: 100 TWh/year
- Waste incineration: 150 TWh/year
- Large-scale solar thermal: 100 TWh/year

These values have been determined based on the mapping discussed in chapter 3. This is a conservative estimate of the additional heat that could be utilised for district heating in the future. It does not consider the surplus heat that is likely to be available from a number of new technologies such as bioethanol plants, biomass gasification facilities, and large-scale electrolysers. The costs assumed for the unconventional resources utilised in the HRE-EE scenarios are outlined in Table 25.

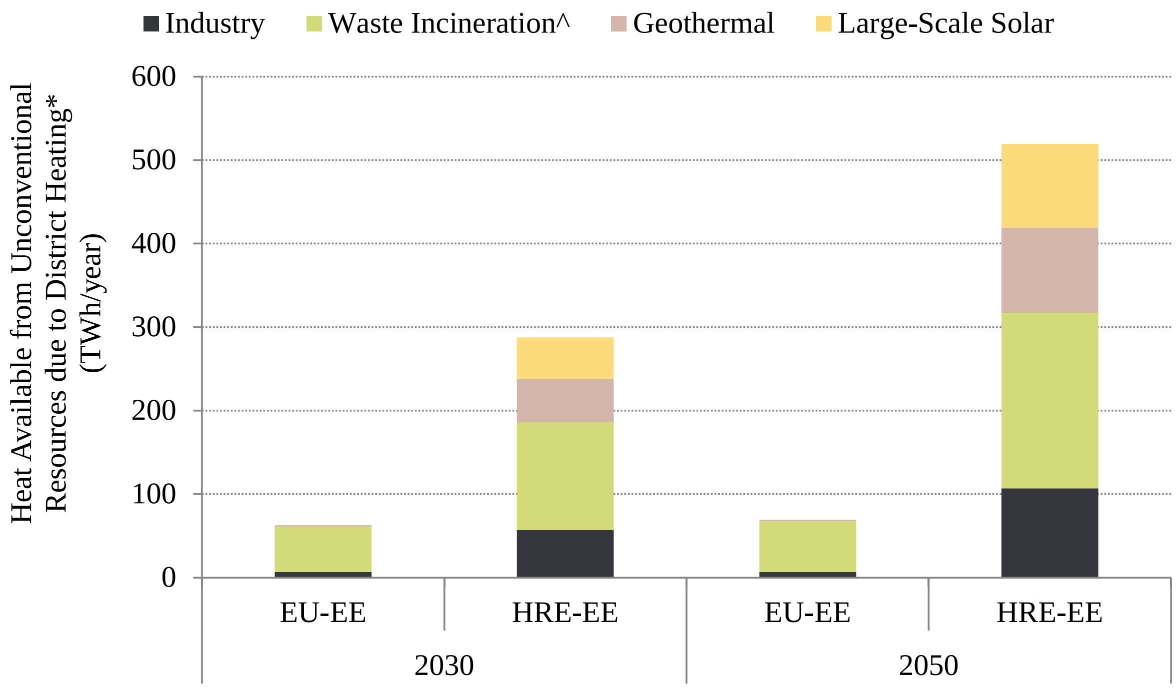

Figure 56: Heat from unconventional resources in the EU-EE and HRE-EE scenarios for the years 2030 and 2050. *In the Energy Efficiency scenario it is assumed that these resources will remain the same as 2010 levels, since there is no growth in district heating. ^Includes waste incineration heat for industry.

Table 25: Unit cost for the unconventional resources added to the HRE-EE scenario.

	Investment Costs (M€/TWh)	Annual Fixed O&M Costs (% of investment)	Lifetime (years)
Industrial Surplus Heat	40*	1	30
Direct Geothermal Heat	216*	2.4	25
Waste Incineration	250#	1.8	20
Solar Thermal	440*	0.001	20

*These investment costs are expressed in terms of the heat delivered.
#These investment costs are expressed in terms of the input resource.

5.6 UTILISING THE SAME AMOUNT OF BIOMASS AS THE EU-EE SCENARIO

Biomass will be a very valuable resource in future sustainable energy systems [50] since it is a limited resource and also, the only renewable energy than can directly substitute all forms of fossil fuels: biomass for coal, biogas for natural gas, and biofuels for oil. The HRE-EE scenario uses less biomass in individual boilers than the EU-EE scenario, which was already displayed in Figure 51. However, the same amount of biomass is utilised in the HRE-EE scenario as in the EU-EE scenario by converting centralised boilers for district heating from natural gas to biomass.

5.7 UTILISING THE ADDITIONAL FLEXIBILITY OF THE HRE-EE SCENARIO

The EU-EE scenario has a small share of district heating (10-15% of the heat demand), but otherwise the electricity and heat sectors are not significantly interconnected. As a result, the energy system in the EU-EE scenario is more segregated like the energy system displayed in Figure 57.

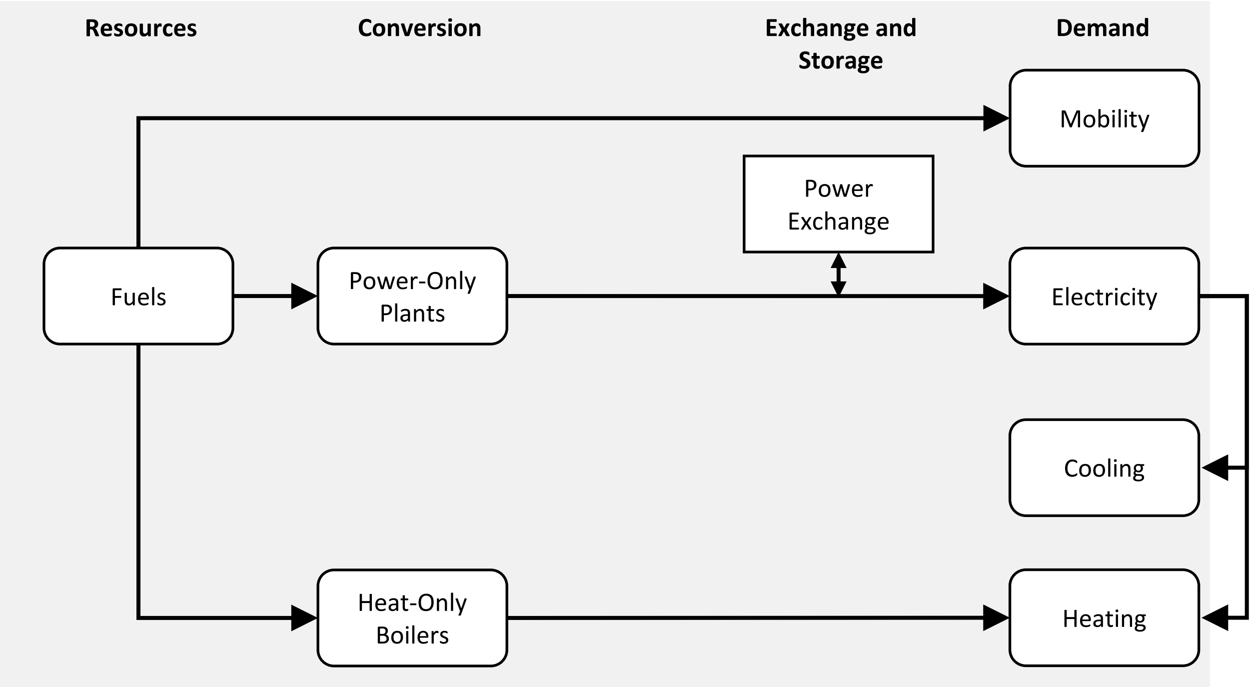

Figure 57: Interaction between sectors and technologies in segregated energy systems [51].

In contrast, the energy system in the HRE-EE scenarios contains a lot of district heating with thermal storage facilities and large-scale heat pumps. As a result, the electricity and heat sectors are more interconnected like the energy system displayed in Figure 58. This means that the overall system is more flexible and it can accommodate larger amounts of intermittent renewable energy such as wind power.

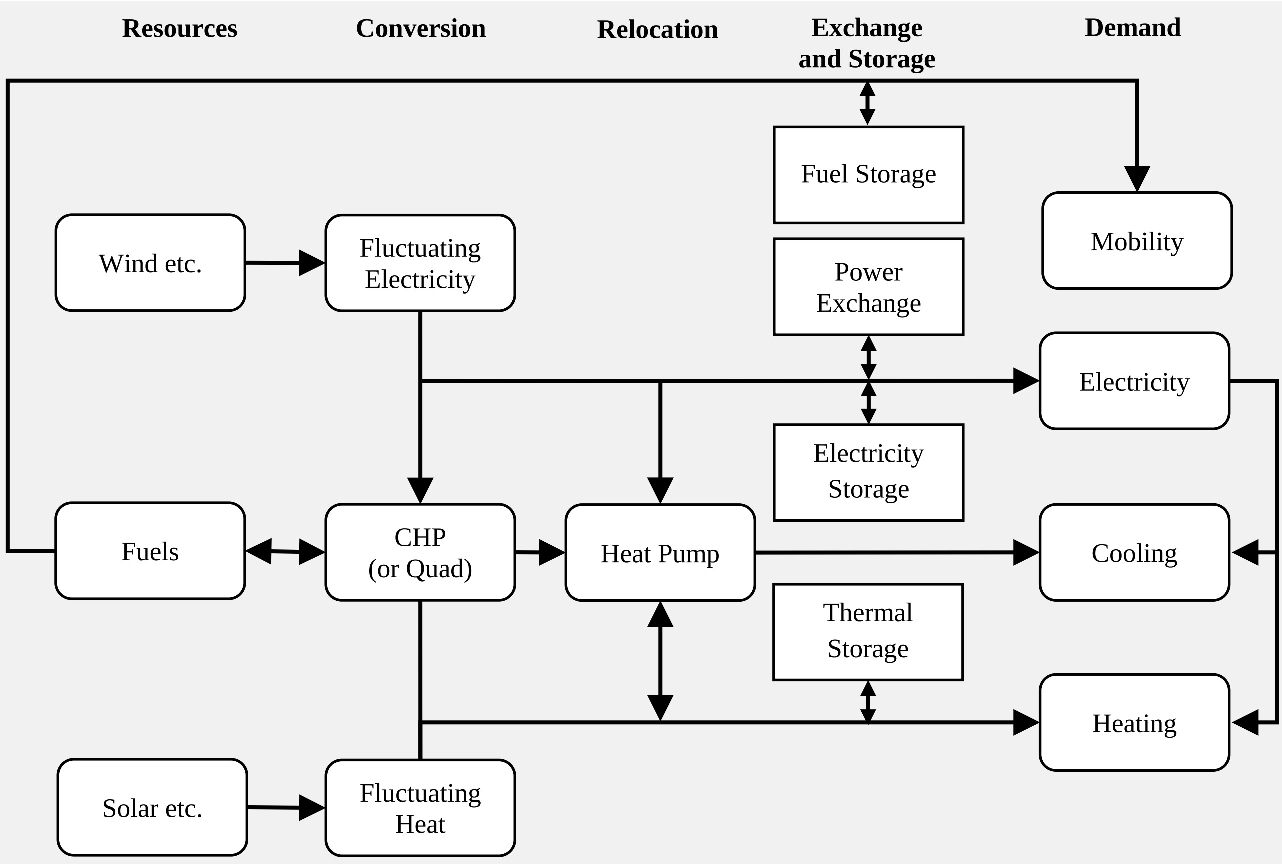

Figure 58: Interaction between sectors and technologies in a future sustainable energy system [52].

Critical excess electricity production (CEEP) measures the amount of intermittent renewable energy that cannot be utilised on an annual basis in an energy system. It occurs when there is an over production of electricity from intermittent electricity resources such as wind power and photovoltaic units during different hours of the year. In the HRE-EE scenarios, these hours can be accommodated more often than in the EU-EE scenario, since the HRE-EE scenario contains large-scale thermal storage and heat pumps in the district heating system. To reflect this, the wind power capacity is increased in the HRE-EE scenario until the level of CEEP is the same as in the EU-EE scenario.

5.8 SUMMARY

The HRE-EE scenario has a higher heat demand than the EU-EE scenario and it utilises more district heating and cooling instead of individual units in 2030 and 2050 (see Figure 59 and Figure 53 respectively). As a result, Figure 51 indicates that the HRE-EE scenario uses less fuel for heating residential and services buildings, but Figure 60 shows that there is more much more fuel consumed for district heating production in the HRE-EE scenario. Furthermore, Figure 52 and Figure 55 show that the cost of the heating and cooling systems is now higher in the HRE-EE scenario than the EU-EE scenario, and these costs do not include for the production units for district heating discussed in section 5.3. Therefore, the energy system analysis, which is discussed in chapter 6, will indicate if this reduction in fuel costs in the HRE-EE scenario along with a reduction in energy efficiency costs will offset the increase in the investment costs for the heating and cooling system as well as for the district heating production units. In this way, the final HRE-EE scenario is a mix of energy efficiency and district heating, which aims to produce a similar level of CO_2 emissions as the EU-EE scenario.

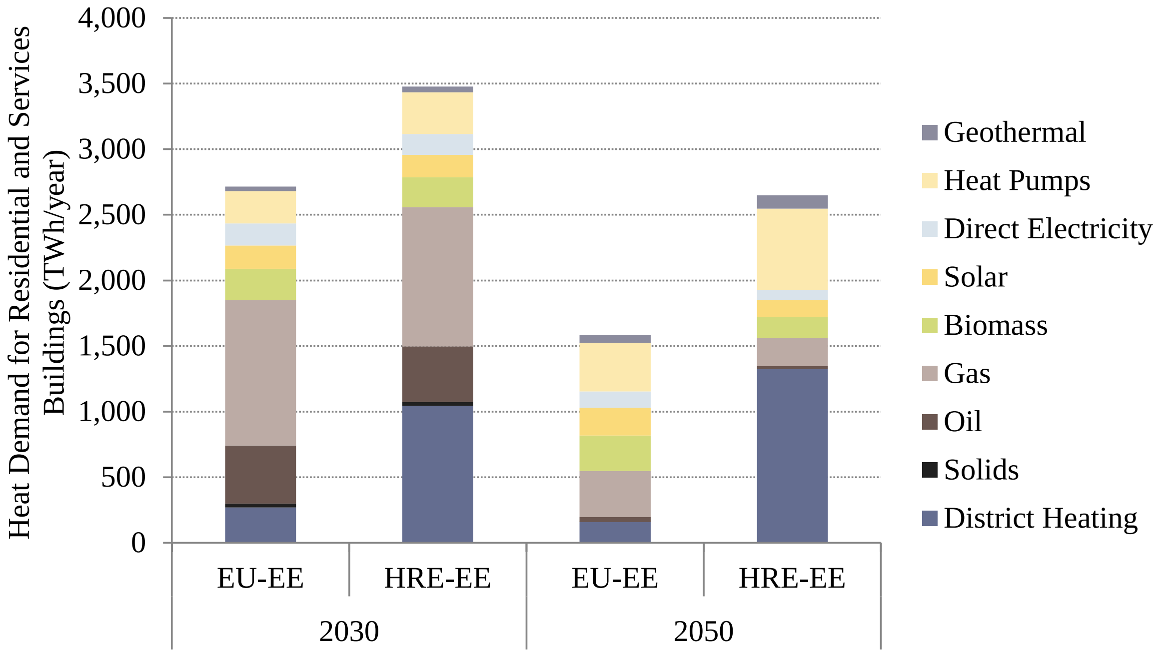

Figure 59: Heat demand by fuel for residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

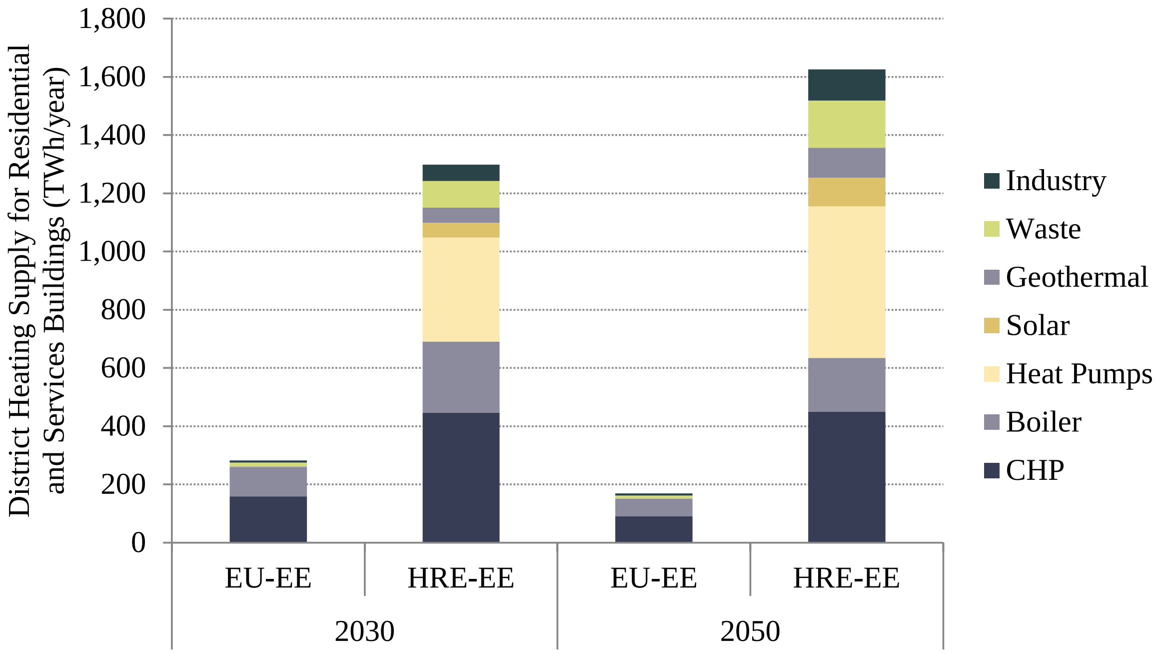

Figure 60: District heating production by plant type in the EU-EE and HRE-EE scenarios for the years 2030 and 2050. Note: some of the district heating is used by absorption heat pumps to provide cooling as discussed in section 5.2.

The energy systems analysis considers the design of the heating system in the context of the whole energy system. In future sustainable energy systems this is an essential consideration as integrating the different sectors (i.e. electricity, heat, and transport) can provide excellent opportunities for integrating intermittent renewable energy such as wind and solar (see Annex VI).

Using the EnergyPLAN tool discussed in section 2.2, the primary energy supply (PES) and the CO_2 emissions have been estimated for both the EU-EE and HRE-EE scenarios in the years 2030 and 2050. As displayed in Figure 61, the PES is slightly larger in the HRE-EE scenario (~2%), but the fossil fuel and biomass consumption in both scenarios is the same (<1% difference). As a result, the carbon dioxide emissions in both scenarios are also the same. The slightly larger PES in the HRE-EE scenario is due to the additional resources utilised in the district heating network such as waste incineration, geothermal, and large-scale solar thermal (see Figure 56). The HRE-EE scenario can also utilise approximately 5% more wind power than the EU-EE scenario due to the additional flexibility introduced into the system by integrating the electricity and heat sectors (see section 5.6).

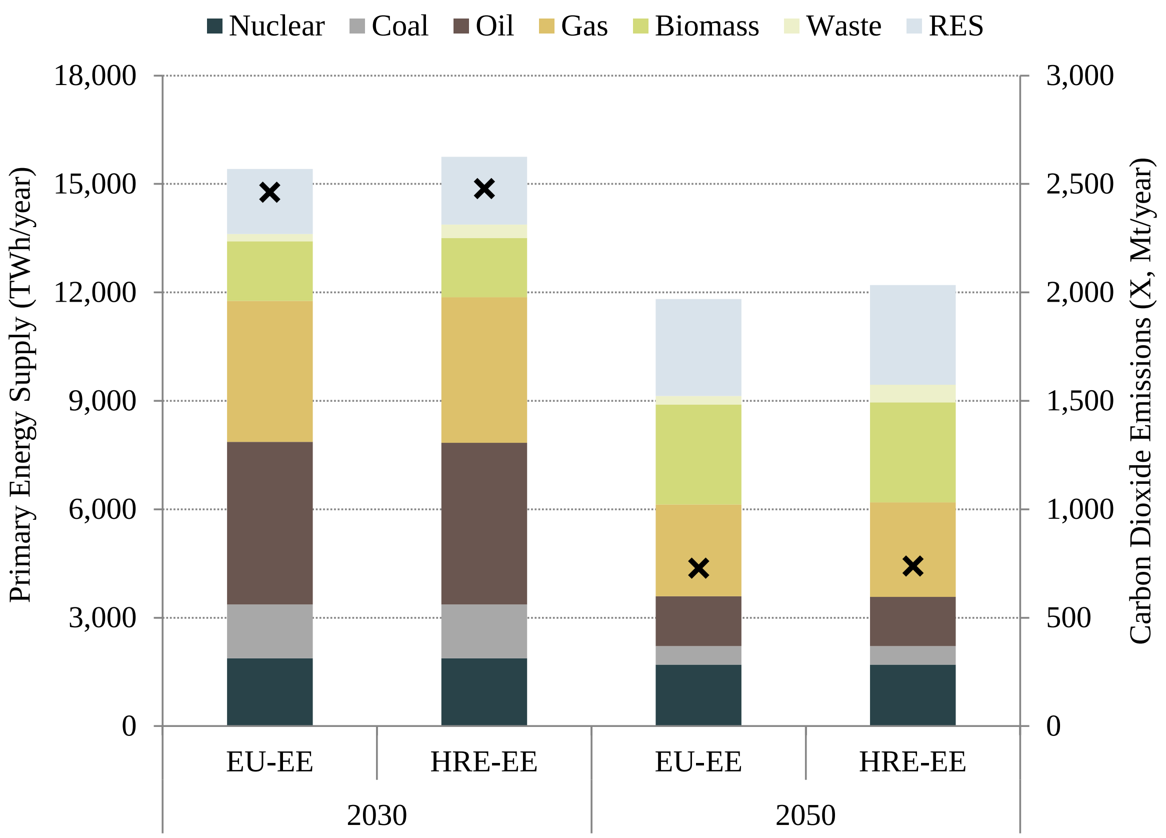

Figure 61: Primary energy supply and carbon dioxide emissions for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

Figure 62 presents the PES for heating and cooling in buildings separate to the rest of the energy system. Once again, these results indicate that both the EU-EE and HRE-EE scenarios have the same level of biomass and fossil fuel consumption in 2030 and 2050, so the additional heat demands in the HRE-EE scenario are met using CO_2 neutral resources.

The HRE-EE scenario utilises a lot of large-scale heat pumps in the district heating system since there is a very large amount of surplus electricity production in the original EU-EE scenario. It is likely that there would be fewer large-scale heat pumps in a system optimised for the integration of intermittent renewable energy.

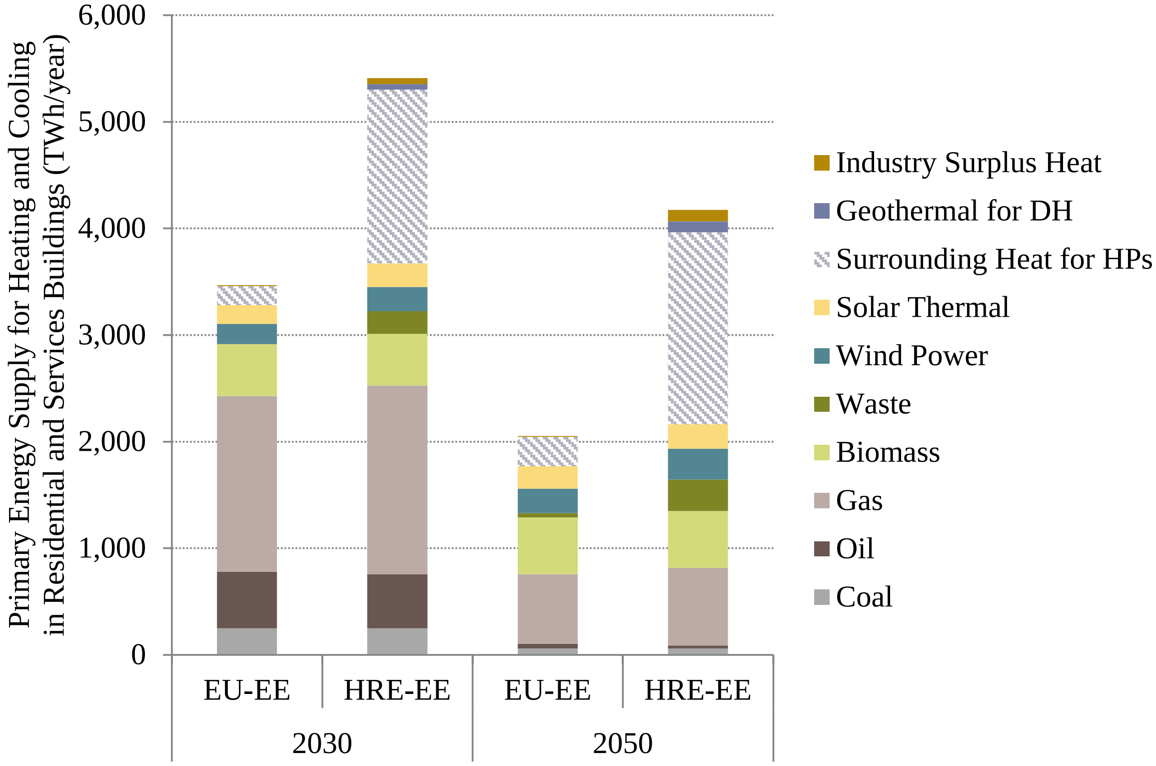

Figure 62: Primary energy supply for heating and cooling in residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Figure 63 indicates that the HRE-EE scenario has lower annual costs than the EU-EE scenario, while achieving the same level of PES and CO_2 emissions. Both scenarios have very similar fuel, O&M, and CO_2 emission costs, but the HRE-EE scenario reduces the investment costs by approximately 10%.

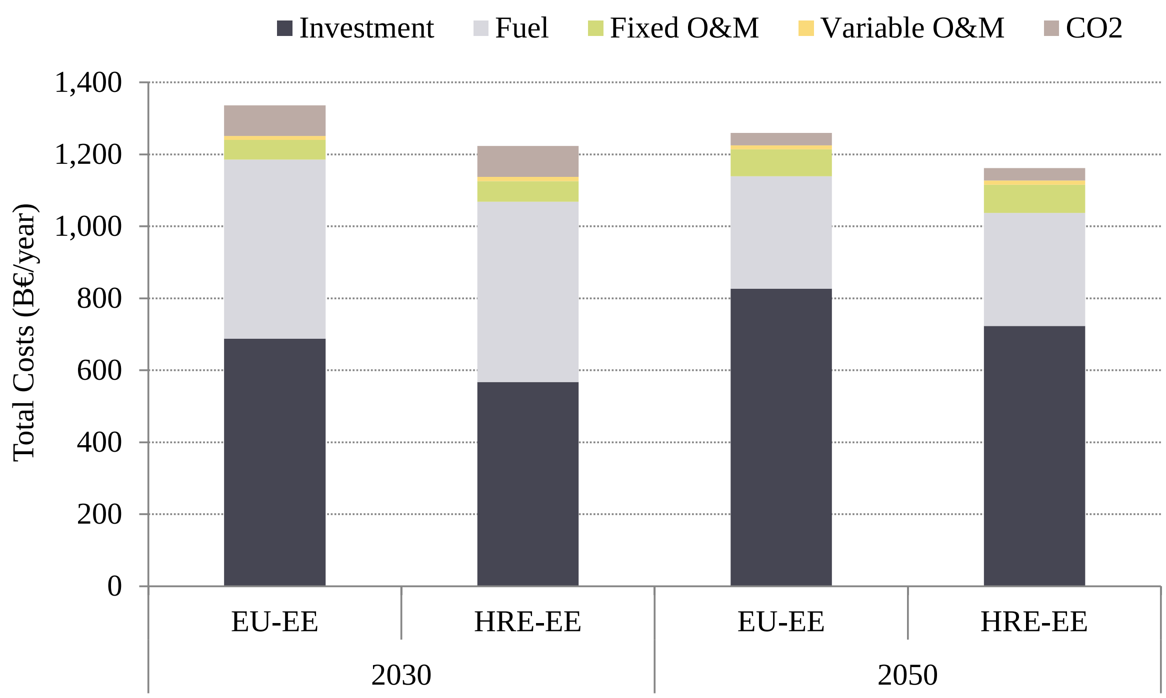

Figure 63: Total annual energy system costs for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

The source of these investment savings is more evident when the costs for heating and cooling buildings are separated from the whole energy system costs (see Figure 64). The HRE-EE scenario saves a lot of money on energy efficiency investments, which result in higher heat demands. However, to overcome these savings the HRE-EE scenario has higher shares of district heating and cooling, larger individual boilers, and it produces more heat. Therefore, the heating system, cooling system, and fuels are more expensive in the HRE-EE scenario than the EU-EE scenario. However, Figure 64 indicates that these additional costs are offset by the reduced energy efficiency investments, so the total cost of heating and cooling for buildings in the HRE-EE is ~15% cheaper than in EU-EE scenario.

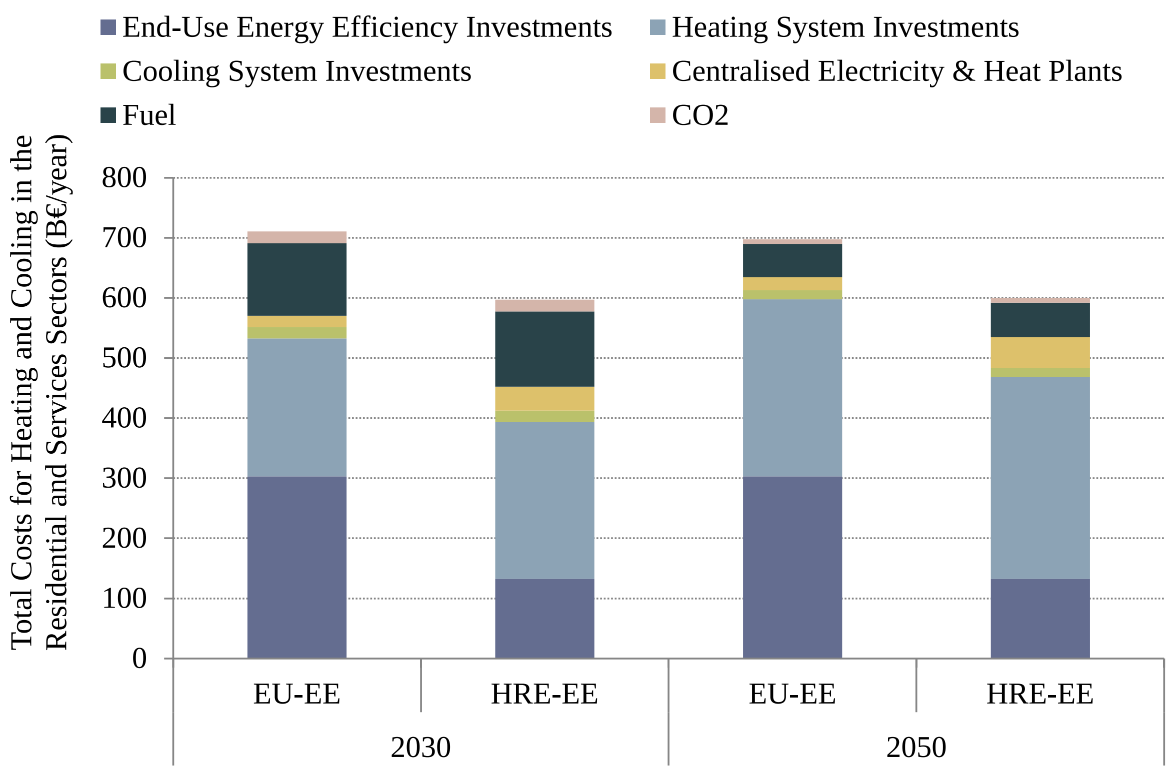

Figure 64: Total annual costs for heating and cooling in the residential and services sectors for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

As discussed in section 5.1, the investment costs for energy efficiency measures are very difficult to estimate, particularly for the entire EU27. In this study, a cost curve has been used based on Danish experiences to estimate the cost of the energy efficiency measures in the EU-EE and HRE-EE scenarios created (see Figure 49). Afterwards, these estimates have been validated based on data in the *Energy Roadmap 2050* report [9] and based on inputs from Ecofys [42]. Since the energy efficiency measures are the primary source of savings in the HRE-EE scenario, it is important to recognise that the energy efficiency costs assumed in this study are 'additional' costs. In other words, it is assumed that all of these energy efficiency measures are carried out at the same time as other renovations are taking place in the building. If these energy efficiency measures cannot be carried out at the same time as other renovations, then they are referred to as direct costs. As outlined in Figure 65, the cost per unit of heat saved is approximately double for direct energy efficiency measures as for additional energy efficiency measures. If these costs were assumed in this study, then the investment costs for energy efficiency measures in the EU-EE scenario would be approximately B€600/year instead of B€300/year. In reality, it is likely that the actual costs for energy efficiency measures will be somewhere between these two cost curves. In the beginning there will be a lot of opportunities to implement energy efficiency measures so these can be done at the same time as the buildings are renovated for other purposes. Fewer opportunities will be available as more buildings are renovated and eventually, it is likely that buildings will have to be renovated specifically for the purpose of energy efficiency measures. Hence, the costs will move from additional costs to direct costs. This is also highlighted in the EU Energy Roadmap report, which concludes that "A clear result concerning the strategic energy efficiency direction is that a substantial speeding up of energy efficiency improvements from historical trends is crucial for achieving the decarbonisation objective" [12]. Therefore, the key point here is that the costs assumed for energy efficiency measures in this study can be considered conservative, especially for the EU-EE scenario.

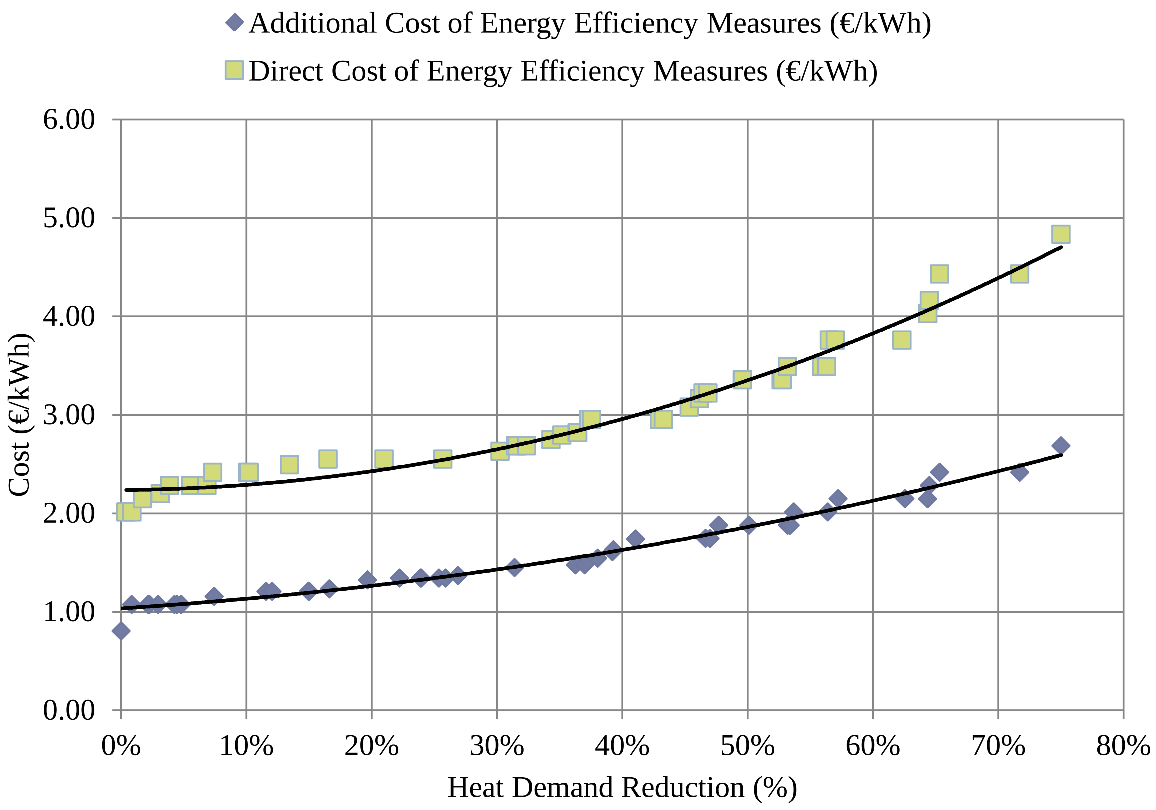

Figure 65: Additional and direct costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings (scenario C) [43].

Similarly, low-temperature district heating in low heat density areas is assumed when estimating the distribution cost of all additional district heating added to the HRE-EE scenario (see Table 20). The highest marginal distribution cost for low-temperature district heating is approximately seven times more expensive per unit of heat delivered than conventional district heating (see Table 19). Even with substantial energy savings, many high-density urban areas will have heat demands which are similar to those in conventional district heating networks today (see Figure 15). Therefore, the costs of these district heating networks are likely to be much lower than assumed in this study, so this can also be considered as a very conservative estimate from a HRE-EE perspective.

To illustrate these sensitivities, the heating and cooling costs have been recalculated assuming an equal share of additional and direct energy efficiency measures in 2050, along with a higher share of conventional district heating: it has been increased from a share of 20% in the original HRE-EE scenario to a share of 40% based on the heat densities forecasted for the EU27 using the European Heat Atlas (see Figure 14). This reduces the cost of district heating pipes in the HRE-EE scenario by 20%, but since the district heating pipes account for a relatively small proportion of the total heating costs (see Figure 52), the overall heating system costs are only reduced by 2%. Based on this sensitivity analysis, the results presented in Figure 66 indicate that:

1. The total heating and cooling costs savings reported here for the HRE-EE scenario are conservative: in 2050 the HRE-EE scenario is ~15% but with a more pessimistic outlook for energy efficiency costs and optimistic outlook for district heating costs, the cost savings in the HRE-EE scenario would be ~22%.
2. The total heating and cooling costs are very sensitive to variations in the costs for energy efficiency, but very robust against costs for district heating pipelines. Therefore, utilising a combination of energy efficiency and district heating reduces the economic risks for the EU27.

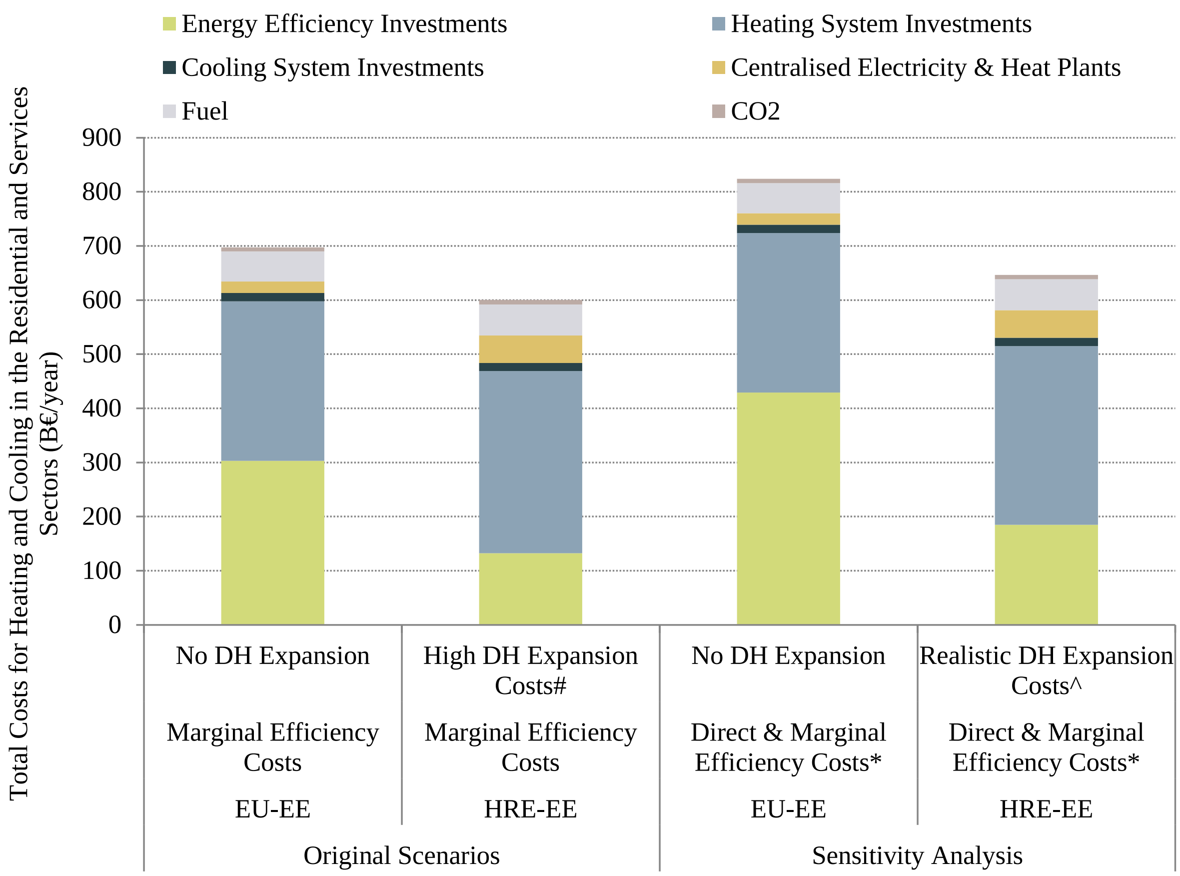

Figure 66: Total annual costs for heating and cooling in the residential and services sectors for the EU-EE and HRE-EE scenarios in 2050 for different energy efficiency and district heating cost assumptions. *Represents a scenario with 50% additional energy efficiency costs and 50% direct energy efficiency costs (see Figure 65). #Assumes that all additional district heating in the EU27 is in areas with a heat density less than 50 TJ/km^2. ^Based on forecasted heat densities in the European Heat Atlas (Figure 14).

Finally, from a technical point of view, the HRE-EE scenario also provides a more robust alternative. In the EU-EE scenario, the CO_2 emission target for 2050 is highly dependent on the implementation of significant energy savings. As outlined in the EU Energy Roadmap report, "Energy efficiency tends to show better results in a model than in reality. Energy efficiency improvements are often hampered by split incentives, cash problems of some group of customers; imperfect knowledge and foresight leading to lock-in of some outdated technologies" [11]. This indicates that the EU-EE scenario will be extremely difficult to implement in reality. In contrast, the HRE-EE scenario will rely on putting district heating in the houses as well as energy efficiency measures. Therefore, if the district heating targets cannot be achieved, then more energy efficiency measures can still be implemented. Similarly, if the energy efficiency measures cannot be achieved, then more district heating can be added. As discussed in sections 3.4 and 5.4, there is potentially more heat available from unconventional heat resources such as large-scale solar thermal and geothermal than is utilised in the HRE-EE scenario here. If more district heating is required, there are thus a number of opportunities still available to supply this heat with carbon neutral resources. In this way, the HRE-EE scenario is a technically a more reliable and easier solution to implement than the EU-EE scenario.

Aarhus case study

The case study quantifies the energy flows and costs related to establishing an individual or collective heating supply system in the Danish city of Aarhus. This was done by using GIS data on the existing supply system, demands and buildings in combination with related cost data. The analyses were carried out in four scenarios; two district heating and two individual heating scenarios. Another difference between the scenarios was the extent to which heat savings were implemented, with either 55% or 77% reductions in the annual building heat demands. They were labelled as:

- Scenario 1: District heating with 55% reduction
- Scenario 2: Individual heating with 55% reduction
- Scenario 3: District heating with 77% reduction
- Scenario 4: Individual heating with 77% reduction

The results show that, with a reduced heat demand, the extent to which CHPs can be used in district heating areas is reduced, minimizing the benefits of district heating. On the other hand, the electricity demand is not reduced to the same extent, giving an additional demand of electricity production capacity in all scenarios. This is especially seen in the individual scenarios in which compression heat pumps are added to cover the heat demand. The overall fuel consumption is therefore lower in the two district heating scenarios, with the lowest consumption in Scenario 3 due to the larger heat reductions. These demand reductions are, however, associated with a higher investment cost than the reductions in Scenario 1.

Therefore, the main result shows that implementing heat savings is feasible to some degree in combination with district heating, but the benefits achieved by applying Scenario 3 are more costly than Scenario 1. The individual scenarios are both more costly than the district heating scenarios, due to the large investments in individual heat pumps and additional electricity production capacity. There is, however, a tendency that, with large reductions in heat demand, heat pumps become a more attractive solution, but this is still more costly than the district heating scenarios.

The Aarhus case study underlines some of the points made in the main Heat Roadmap Europe study:

1. District heating is an attractive solution in areas with a high heat density.
2. District heating can be seen as an efficiency measure similar to reductions in heat demand, because it enables the use of fuels in a more efficient way.
3. Heat reductions in buildings can be combined with district heating in a way which makes it competitive with individual solutions both in regard to resource use and costs.

7 CONCLUSIONS

Based on the urban heat densities identified in the new EU Heat Atlas developed in this study (see Figure 14), a district heating share of 50% is feasible for buildings in the EU by 2050. This is even feasible if significant heat savings are implemented in the buildings. Overall, in the EU-EE scenario considered in this study, there is a 60% reduction in space heating and a 55% reduction in hot water demand between 2015 and 2050 (see Figure 40). These heat demand reductions will be very difficult to implement in reality, which is also acknowledged in the *Energy Roadmap 2050* report:

> *"Energy efficiency tends to show better results in a model than in reality. Energy efficiency improvements are often hampered by split incentives, cash problems of some group of customers; imperfect knowledge and foresight leading to lock-in of some outdated technologies" [11].*

This level of energy efficiency measures will also be very expensive to implement. In this study, an indicate cost curve is created to estimate these costs based on previous work by the Danish Building Research Institute (Statens Byggeforskningsinstitut) for Danish buildings [43]. Using this curve, the estimated cost of the 60% reduction in the heat demands implemented in the EU-EE scenario is ~B€300/year (which is approximately €600/person in Europe each year). Since these energy efficiency measures will be difficult to implement and they are relatively expensive, the idea of this study HRE-EE is to illustrate and quantify how the same goals for CO_2-emssion reductions can be reached by replacing some of the most expensive and most difficult energy conservation measures by district heating efficiency measures, which is both cheaper and easier to implement. Two expensive conservation measures have been identified in the EU-EE scenario:

One is the assumed reduction in the hot water demand of Europe for the following reasons:

- The EU population will grow by 3.2% between 2010 and 2050.
- According to a number of interviews with industry experts, people tend to wash more today than they did in the past, which is likely to continue into the future. In other words, individuals are likely to take more showers and baths in the future than they do today.
- People are not expected to live with one another as much in the future. Hence, there will a larger number of people living in their own houses rather than living together. This is also expected to increase the demand for hot water for an individual.
- At present, there are regions in Europe where the use of hot water is limited due to technical and financial limitations. As these regions become wealthier, the demand for hot water is expected to rise in these regions.

The building area for residential and non-residential buildings is expected to grow by 32% and 42% respectively between 2015 and 2050.Therefore, in the new heat demand for the HRE-EE scenario, the hot water demand is not reduced, but instead it is increased by ~15% between 2015 and 2050.

The second change is that the space heating demand is not reduced as much in the HRE-EE scenario as in the EU-EE scenario. The most ambitious energy efficiency scenario from a recent report carried out by Ecofys for EURIMA, which is called the 'Deep Renovation' scenario, concluded that a 47% reduction in EU space heating demands is feasible between 2010 and 2050 [42]. Therefore, a 47% reduction in space heating is assumed here instead of the 62% reduction assumed in the EU-EE scenario. The energy efficiency measures in the HRE-EE scenario are still extremely ambitious, but less than in the EU-EE scenario. Based on these new assumptions, the total heat demand in the HRE-EE scenario is ~70% more in 2050 than in the EU-EE scenario (see Figure 48). However, since the heat demand is higher, the cost of the energy efficiency measures in the HRE-EE scenario is only B€130/year, instead of the B€300/year for the EU-EE scenario.

The HRE-EE scenario has higher heat demands than the EU-EE scenario, but in doing so, the HRE-EE scenario has saved ~B€170/year. The key challenge now is to establish if these savings can be spent on new production technologies elsewhere in the energy system to enable the same reductions in CO_2 emissions as the original EU-EE scenario. The supply side of the heating system for residential and services buildings have therefore been redesigned in the HRE-EE scenario by carrying out the following steps:

1. Individual boilers are replaced by district heating. In 2030, district heating meets 30% of the heat demand and in 2050 it meets 50% of the heat demand in residential and services buildings. Individual coal, oil, gas, biomass, and direct electric heating systems are replaced, but individual heat pumps are not since these are also considered a key technology to decarbonise the EU energy system. It is assumed here that these individual heat pumps are installed outside the urban areas that contain district heating.
2. Individual cooling units are replaced with district cooling. 10% of the cooling demand for residential and services buildings is provided using district cooling in 2030 and 20% in the year 2050. District cooling is supplied from both natural cooling and from absorption heat pumps, which require heat from the district heating network.
3. To supply the heat for these new district heating demands, new production units are added to the HRE-EE scenario. Some existing condensing power-plants are converted to CHP plants and new decentralised natural gas plants are constructed. Centralised boilers, heat pumps, and thermal storage facilities are also added.
4. With district heating now installed, additional resources can be utilised in the HRE-EE scenario that could not be utilised in the EU-EE scenario. These include more wind power of the large-scale heat pumps, large-scale solar thermal plants, geothermal heat, surplus industrial heat, and heat from waste incineration. Therefore, heat from each of these resources is also added to the HRE-EE scenario.
5. After these measures are implemented, the HRE-EE scenario consumed slightly less biomass than the EU-EE scenario. Therefore, the biomass consumption was increased in the HRE-EE scenario until it was at the same level as the EU-EE by replacing some natural gas in the centralised district heating boilers.
6. Finally, the HRE-EE scenario is more flexible than the EU-EE scenario since it integrates the electricity and heating sectors. To exploit the benefits of this, wind power is increased in the HRE-EE scenario until there is the same level of critical excess electricity production (CEEP) in the HRE-EE scenario as the EU-EE scenario.

After implementing these changes, the primary energy supply (PES) and the CO_2 emissions can be compared between the HRE-EE scenario in the years 2030 and 2050. As displayed in Figure 61, the PES is slightly larger in the HRE-EE scenario (~2%), but the fossil fuel and biomass consumption in both scenarios is the same (<1% difference). As a result, the carbon dioxide emissions in both scenarios are also the same. The slightly larger PES in the HRE-EE scenario is due to the additional resources utilised in the district heating network such as waste incineration, geothermal, and large-scale solar thermal. If district heating is not included in the EU energy system, these resources will be wasted. The HRE-EE scenario can also utilise approximately 5% more wind power than the EU-EE scenario due to the additional flexibility introduced into the system by integrating the electricity and heat sectors.

Even though the heat demands in buildings are much higher in the HRE-EE scenario (see Figure 48), these additional heat demands can be met using CO_2 neutral resources, as outlined in Figure 62. Once again, these results indicate that both the EU-EE and HRE-EE scenarios have the same level of biomass and fossil fuel consumption in 2030 and 2050, so the additional heat demands in the HRE-EE scenario are met using heat from waste incineration, industry, geothermal, large-scale solar thermal, and heat pumps.

As already discussed, the HRE-EE scenario has lower investment costs in energy efficiency measures than the EU-EE scenario. However, these savings then need to be reinvestment in redesigning the heating sector in the HRE-EE scenario, so the same CO_2 reductions can be obtained as the EU-EE scenario. However, these reinvestments in the HRE-EE scenario are less than the initial savings realised due to less energy efficiency measures, which means that the overall energy costs for the EU energy system are reduced by approximately 7-8% (see Figure 63). For the heating and cooling of buildings, the total costs are reduced in the HRE-EE scenario by ~15% compared to the EU-EE scenario (see Figure 64).

The cost savings realised in the HRE-EE scenario are very dependent on the costs assumed for the energy efficiency measures, which will need to be investigated in more detail in the future. However, the conclusion in this study is relatively robust since the energy efficiency costs assumed here are relatively low and the district heating costs assumed are relatively high. In contrast, the costs assumed for district heating are relatively high in the HRE-EE scenario. To illustrate this, a sensitivity analysis is completed assuming more probably costs for both energy efficiency and district heating. The results in Figure 66 indicate that the savings for the heating and cooling sector would be ~22% if these costs assumptions are used instead. Therefore, the cost savings for the original HRE-EE scenario can be considered as conservative.

Although the EU27 is a very large area, the results presented here have also been supported using on a specific case study based on the city of Aarhus in Denmark. This results from this case study, which allows for more specific demand, supply and cost data to be considered, also indicate that a combination of district heating and energy efficiency is a very efficiency and cost-effective heating strategy. The case study also compared district heating to individual heat pumps in urban areas, which included detached houses, concluding that district heating is a more efficiency and cheaper solution.

To conclude, the key points from this study can be summarised as follows:

1. This first pre-study indicates that by adding district heating to a 'business-as-usual' EU energy system (i.e. the CPI scenario which only includes the implementation of existing policies), it is possible to reduce the primary energy supply, reduce CO_2 emissions, and reduce energy system costs.

2. This second pre-study indicates that by adding district heating to an EU energy system with very low heat demands, it is possible to use the same amount of fossil fuels and biomass as the EU Energy Efficiency (EU-EE) scenario in the *Energy Roadmap 2050* report, but the total energy system costs will be approximately 7-8% lower.
3. Energy efficiency measures will provide essential heat demand reductions in buildings in the future EU energy system, but at a certain point, these will become very difficult to implement and very costly. Ambitious energy efficiency targets should be pursued in the EU, but not to the extent that the EU-EE scenario suggests.
4. The HRE-EE scenario uses energy efficiency on both the demand and supply side of the energy system. By adding district heating for buildings, it is possible to utilise surplus heat from power plants, industry, and waste incineration, while also using more renewable energy such as wind power, large-scale solar thermal, and geothermal.
5. The EU-EE scenario relies heavily on heat savings in buildings to reach its CO_2 reduction targets. By introducing more district heating as an alternative energy efficiency measure, the HRE-EE scenario is a safer and more realistic alternative: there are more technologies to choose from, more renewable energy resources to utilise, and the heat demand does not need to be reduced as much.

In future research, more information will need to be obtained about the specific energy efficiency measures that are necessary in the EU, the energy efficiency costs, profiling the cooling system, and cooling system costs. Also, a district heating scenario will need to be compared to an all-electric heating scenario and there are many opportunities that could be explored for increasing intermittent renewable energy (such as reducing baseload CCS and nuclear).

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9 ANNEX I: REVIEW OF EXISTING ENERGY STRATEGIES

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

Title: **Energy Roadmap 2050**

Year of publication:	*Organization:*
2011	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 modelling 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=COM:2011:0885:FIN:EN:PDF

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.[13]

How district heating is mentioned:

District heating is not included in detail (e.g. described by fuel type) in the modelling. 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 modelling 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 residential and service sector in the long run.

A table from the report shows that there is not that big a difference in the share of district heating for this sector 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

[13] 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:	*Organization:*
2010	The European Climate Foundation (ECF), McKinsey & Company, KEMA, The Energy Futures Lab at Imperial College London, Oxford Economics
Outlook year:	
2050	

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 excess 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.a. 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:	*Organization:*	
2011	Luleå University of Technology – Economics Unit Lund University – Dept. of Political Science and Environmental, Energy System Studies and AgriFood Economics Center	
Outlook year:		
2050		

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 analyzed.

How buildings are insulated/heated:

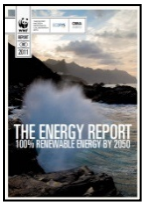
The article proposes air- and ground-source heat-pump water and air heaters and electric resistance water and air heaters. For high-temperature industrial processes, we propose that energy be obtained by combustion of electrolytic hydrogen. It is assumed that 5% of fuel use for space heating and 20% 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:

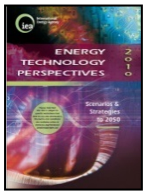
2010

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 decarbonise 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/district heating 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 unfavourable 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: http://www.iea.org/media/etp2010.pdf

Title: **World energy outlook** – 2011

Year of publication:

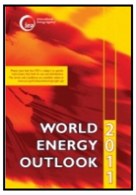
2011

Outlook year:

2035

Organization:

IEA (International Energy Agency)



Objective:

The IEA *World Energy Outlook* scenarios are in general in accordance with the *Energy Technology Perspectives* (ETP). However compared to ETP 2010, the scenarios in this version of the WEO are updated, i.a. to include the most recent policies (and in one scenario to assume that announced political commitments will be enforced though not finally decided yet). The most ambitious scenario is called the 450 Scenario, which sets out an energy pathway consistent with the goal to limit the concentration of greenhouse gases in the atmosphere to 450 parts per million of CO_2-equivalent and the increase in global temperature to 2 °C.

How buildings are insulated/heated:

Not described in detail.

How district heating is mentioned:

Not mentioned in detail.

Link to report: -

Title: **Deciding the Future** – Energy Policy Scenarios to 2050

Year of publication:

2007

Outlook year:

2050

Organization:

World Energy Council (WEC)

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

10 ANNEX II: REVIEW OF FUTURE HEAT DEMANDS WITHIN VARIOUS ENERGY STRATEGIES

10.1 ENERGY ROADMAP 2050 (EU COMMISSION)

Heat sector in general

The main focus is on electrification, the use of heat pumps and extensive savings in the demand. There will be a need for significant increase in capital costs for the energy system due to investments in power plants and grids, in industrial energy equipment, heating and cooling systems (including district heating and cooling), smart meters, insulation material, more efficient and low carbon vehicles, devices for exploiting local renewable energy sources (solar heat and photovoltaic), durable energy consuming goods etc.

In the table below is seen the development in heat demand for the residential and service sector compared to 2015 for the different scenarios. It is seen that there is a decrease of 53-60% from 2015-2050 in “decarbonisation scenarios” (all but the reference and CPI scenario).

Heat demand development	**2020**	**2030**	**2040**	**2050**
Reference	-3%	-14%	-19%	-24%
CPI	-13%	-19%	-22%	-26%
Energy Efficiency	-17%	-31%	-45%	-60%
Diversified Supply Technology	-12%	-24%	-37%	-55%
High RES	-12%	-21%	-34%	-53%
Delayed CCS	-12%	-24%	-41%	-55%
Low Nuclear	-12%	-25%	-37%	-55%

Heat savings

The prime focus is on energy efficiency. Higher energy efficiency in new and existing buildings is essential in the “decarbonisation” scenarios. Nearly zero energy buildings are assumed to become the norm after 2020. Besides this, products and appliances will have to fulfil highest energy efficiency standards (which reduces the total energy demand of the residential sector, but does not decrease the need for heating).

The energy efficiency scenario includes more stringent minimum requirements for appliances and new buildings, high renovation rates of existing buildings and establishment of energy savings obligations on energy utilities. This is expected to lead to a decrease in energy demand of 41% by 2050 as compared to the peaks in 2005-2006.

Incentives to change behaviour (e.g. taxes, grants or on-site advice by experts) are required in order to make households and companies invest in the energy system transformation. Greater access to capital for consumers and innovative business models are needed. With “smart meters” and “smart technologies” the energy consumption will be a continuously “hands-on-experience” for the consumers.

Sufficient interconnection capacity and a smarter grid to manage the variations of wind and solar power could diminish the need for storage, backup capacity and baseload supply.

How is the heat produced?	In all scenarios electricity plays a much greater role than now (almost doubling its share in final energy demand to 36-39% in 2050) and contributes to the decarbonisation of transport and heating/cooling. Renewables is assumed to move from small-scale, subsidised technology developments to competitive, large-scale mass production in the entire energy system. This requires changes in policies parallel to their further development. In terms of heating and cooling, a shift in energy consumption towards low carbon, locally produced energy sources (incl. the use of heat pumps and storage heaters) and renewable energy such as solar heating, geothermal, biogas and biomass are needed (i.a. included through district heating systems). In the short to medium term gas is assumed to help reduce emissions and the consumption stays high in the power sector over longer period – until at least 2030-2035. Though the gas consumption in the residential sector is believed to decrease in some member states, it is said to have a possible growth potential in others due to the higher energy efficiency compared to electric heating (based on fossil fuels) or other types of fossil fuel heating.

10.2 IMPACT ASSESSMENT ACCOMPANYING THE ENERGY ROADMAP 2050

Heat sector in general	As mentioned for the Energy Roadmap 2050, electricity becomes in general the most important final energy source. The goal of decarbonisation in 2050 requires an almost carbon free electricity sector in the EU, and around 60% CO_2 reductions by 2030.
Heat savings	Since the space demand is assumed to increase (from 2.4 inhabitants per household in 2005 to 2.0 in 2050 and from 87 m^2 per household to 113 m^2 in the same period) the savings have to be made through changes in a) the energy efficiency of the building itself (particularly in the thermal insulation) and b) the efficiency and fuel mix of the heating and cooling equipment for buildings. The Efficient Energy scenario is driven by a political commitment of very high primary energy savings by 2050. It includes further and more stringent minimum requirements for • appliances and new buildings (all new houses after 2020 comply with passive house standards – around 20-50 kWh/m^2 depending on the country). • energy generation (e.g. obligation of utilities to achieve energy savings in their customers' energy use – over 1.5% per year up to 2020). • transmission and distribution (all scenarios will reflect significant development of electrical storage and interconnections). • high renovation rates for existing buildings (due to better/more financing tools and planned obligations for public buildings). • the establishment of energy savings obligations on energy utilities. • the full roll-out of smart grids, smart metering and highly decentralised RES generation to build on synergies with energy efficiency. In the report's own words the high renovation rates for existing buildings which in the Energy Efficiency scenario is (more than 2% refurbishment per year) "pushes the limits of what the chosen measures can achieve". This indicates that this assumption is foreseen to be quite a challenge to achieve.
How is the	In the reference and CPI scenarios there is seen an increase in demand for distributed heat based

heat produced?	on biomass and gas based CHP between 2005 and 2020. In the longer run this development slows down in the tertiary and residential sectors due to the trend towards electrification (i.e. the use of heat pumps) and higher energy efficiency which limits the overall demand for heating. In the industry sector the increase in demand for distributed steam is projected to continue in the future especially for chemicals, food, tobacco, and engineering. However in the "decarbonisation scenarios" the demand for distributed heat is lower due to the shift towards electricity use for heating reducing especially district heating from fossil fuels. It is stated that though CHP leads to emission reductions compared to conventional systems, it is only "decarbonized" when fired with biomass which in the Primes model is used elsewhere in the energy system. In other words CHP plants and district heating boilers is not allowed to use biomass in the model and district heating is on this basis assumed to decrease throughout the projection period. For the "decarbonisation scenarios", locally produced heating from solar, geothermal, biogas and biomass installations is needed in the short-to-medium term and in the long run especially heat pumps for the low amount needed for the nearly zero-energy buildings are assumed. In the table below is seen the share of renewables in the final heating and cooling demand. There is not provided a breakdown into fuels of the demand.

Share of RES in gross final consumption of heating and cooling	**2020**	**2030**	**2050**
CPI	20.9%	22.7%	23.8%
Energy Efficiency	21.0%	23.3%	44.9%
Diversified Supply Technology	20.9%	23.8%	44.0%
High RES	20.9%	26.8%	53.5%
Delayed CCS	20.9%	24.2%	44.9%
Low Nuclear	20.8%	24.3%	44.6%

10.3 ROADMAP 2050 (EUROPEAN CLIMATE FOUNDATION)

Heat sector in general	It is stated that the report addresses the implications of electrification in buildings and transport on final power demand, but it does not attempt to provide a detailed analysis of the decarbonisation pathways for either sector. An extensive expansion of the interregional transmission grid across Europe is assumed in order to electrify most of the energy sector to reach 80% emission levels compared to 1990 by 2050. This however means that there is a large amount of backup power needed and the assumed investments in the grid has in other reviews been deemed suspiciously low to maintain an acceptable security of supply. It is stated that a detailed assessment of distribution system investments is outside the scope of the report and that grid investments required are around 10% of generation investments. Though this still is a substantial cost, it should be considered that if the necessary grid investments are not made, the result can in practice be an increase in backup and operational costs amounting to far more than the grid investments saved. The electrification of buildings (vs. biogas heating or zero-carbon district heating) can be viewed as a conservative case for the electricity demand. The report states that if other (non-electric) decarbonisation solutions should emerge for some portion of either sector, these will only make the power challenge more manageable. In other words the report focuses on electrifying the energy sector and though some CHP/district heating is included, it does not seem to be aimed at its maximum potential.
Heat savings	The scenario does not rely on technology breakthroughs, but improvements in existing technologies. The savings are not described in detail separately, but it is deemed necessary to take political action to include a complex mix of different incentives and top-down regulations. Coordinating support for development and deployment of energy efficiency technologies, CCS (also for gas), PV, offshore wind, biomass, electric vehicles, integrated heat pump and thermal storage systems, smart grids that allow demand response, and networked HVDC technologies (incl. using adoption of common standards) are requested.
How is the heat produced?	The target of 80% reduction in GHG emissions is shown to be reachable by different variations of the use of RES, CCS (e.g. in combination with gas power plants) and nuclear. A fuel shift in the building sector is required. In the short term a ramp-up in the application of heat pumps (both in individual premises and in district heating applications), along with biomass district heating or CHP from the industry is needed. In dense areas there are assumed to be district heating based on large heat pumps and (to a small extent) biomass/biogas fired CHP/district heating plants or biogas fired boilers in homes. In 2050 almost 90% of the heat demand in buildings is covered by electricity.

10.4 THE ENERGY REPORT – 100% RENEWABLE ENERGY BY 2050 (WWF)

Heat sector in general	Compared to today's level the "heat demand" in the building sector decreases below 10% per floor area and the floor area is assumed to increase around 70% compared to today. The electricity consumption for heat pumps are however not included in this demand and since new buildings are thought to be "all-electric" i.e. without any fuel consumption, the increase of around 50% in residential electricity demand per unit floor area indicates that the actual development in the heat demand depends on the assumed COP of the heat pumps.
Heat savings	The overall result of the "Energy Scenario" is that energy demand can be reduced over the next four decades while providing more energy services to more people. This is primarily achieved through the aggressive roll-out of the most efficient technologies. It is assumed that all existing buildings will be retrofitted by 2050 to ambitious energy efficiency standards based on retrofit rates of up to 2.5% of floor area per year, which is explained as "high compared to current practice, yet feasible." For a given retrofit, it is assumed that, on average, 60% of the heating needs could be abated. The buildings will have an energy use at levels comparable to the passive house standard developed in Germany and this will apply to 100% of new buildings by 2030.
How is the heat produced?	As far as possible, electricity is used. Wind solar biomass and hydro are the main producers of electricity. Solar and geothermal sources as well as heat pumps provide a large share of heat for buildings (and industry). Solar thermal is projected to have a potential share of around 10% of current heat demand in buildings, i.e. a large share of the solar potential is to be covered by solar electricity. Energy efficiency is the key requisite to meeting our future energy needs from sustainable sources. A quarter of the remaining heating and hot water in existing buildings (after the retrofitting) need would be met by local solar thermal systems, the rest by heat pumps. For the (residual) heat demand of the "near zero energy use" buildings passive solar, internal gains, solar thermal and/or heat pumps are used. No fuel supply of any kind, i.e. it is all-electric buildings in terms of energy supply from outside the building itself. Cooling is mentioned to be provided by local, renewable solutions where possible. The current use of traditional biomass will be phased out and only a small share deemed sustainable (up to 30% of the current amount) will be used in latter decades. In the last part of the projection period towards 2050 this demand for biomass is phased out completely. Concentrating solar heating (CSH) is included in very small scale as a conservative assumption because the technology is said no to be on the market yet. It is stated that "further study on the distribution of the industrial heat demand and the availability of nearby CSH sources is recommended."

10.5 RE-ENERGISING EUROPE – PUTTING THE EU ON TRACK FOR 100% RENEWABLE ENERGY (WWF)

<table>
<tr>
<td>Heat sector in general</td>
<td>
The report follows up on “The Energy Report – 100% renewable energy by 2050” from 2011 (see above). It is produced to describe what should be achieved in the EU by 2030 to secure a 100% renewable European energy system by 2050, which in brief is stated to require the following:

38% primary energy savings (compared to a business as usual projection).
41% share of renewable energy in total consumption.
50% cut in energy-related GHG emissions (compared to 1990).

As seen in the table below indicating the development in the fuel and heat supply for buildings (i.e. mainly space and water heating), the energy savings are dominating the path towards reducing GHG emissions.
<table>
<tr><th>[EJ/a]</th><th>2000</th><th>2005</th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th></tr>
<tr><td>Building fuels and heat in total</td><td>12.2</td><td>13.6</td><td>13.1</td><td>12.7</td><td>11.1</td><td>9.4</td><td>7.7</td></tr>
<tr><td>Total renewable energy</td><td>1.7</td><td>1.5</td><td>2.3</td><td>1.8</td><td>2.1</td><td>2.4</td><td>2.9</td></tr>
<tr><td>Fossil fuels</td><td>10.5</td><td>12.0</td><td>10.8</td><td>10.8</td><td>9.0</td><td>6.9</td><td>4.8</td></tr>
</table>
</td>
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<tr>
<td>Heat savings</td>
<td>
The largest energy savings are seen in the building sector (26% from 2005-2030) and in industry (31% from 2005-2030). In buildings the heat demand in 2030 is said to be 40% (commercial) to 50% (residential) of 2005 levels. Electricity is 90% (commercial) to 120% (residential) of 2005 levels. This is to be obtained by retrofitting the existing building stock (75% of European buildings in 2030) at rates of up to 2.5% a year. By 2030 approximately 45% of the Europe’s existing buildings are assumed to be retrofitted. The term “retrofitting” is defined as:

60% of heating needs abated by insulation and ventilation systems with heat recovery mechanisms.
25% of remaining heating and hot water need met by local solar thermal systems, the rest by heat pumps.
Cooling provided by local, renewable solutions where possible.
Electricity needs increase per floor area due to increased cooling demand.

(In line with “The Energy Report” from WWF.)

Besides this, new building stock (25% of European buildings in 2030) is assumed to be much more energy efficient and are defined as follows:

By 2030 all new buildings will use energy at levels comparable to the German passive house standard and will be powered only by electricity.
Residual heat demand will be met by passive solar, internal gains, solar thermal installations and heat pumps.
There will be some increase in electricity use in buildings because of greater use of appliances and in order to power heat pumps. The increase is only partially offset by more efficiency in these technologies.

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</tr>
<tr>
<td>How is the heat produced?</td>
<td>
In 2030 35% of the final heat demand is met by means of renewables. For electricity the share is 65%. For the building sector the share of renewables increases from 19% in 2010, to 29% in 2020 and 49% in 2030.
Biomass is assumed to continue to be the main RES used in industry and buildings. For electricity production, wind power (mainly onshore) takes over from hydro as the main RES by 2020.
</td>
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</table>

10.6 ENERGY TECHNOLOGY PERSPECTIVES 2012 (IEA)

Heat sector in general	It is stated that heating and cooling remain neglected areas of energy policy and technology, but their decarbonisation is a fundamental element of a low-carbon economy. In EU the energy consumption of buildings is assumed to be almost constant between 2015 and 2050. The decrease seen in the residential sector is approximately compensated by the increase seen in the service sector. The heat demand in the industry sector decreases towards 2050. Some of the main trends determining future demand for heating and cooling, and the technologies that can deliver these services are described to be: • *The future need for thermal comfort in residential and commercial buildings* Radiators do not need to use high grade energy and high temperatures when the same comfort can be reached with lower temperatures. This statement underlines the need for the development of low temperature district heating. • *Rate and pattern of urbanisation in emerging economies* Due to the projected urbanisation (globally 6.3 billion people living in cities in 2050 from 3.5 billion today) district heating becomes feasible because distribution networks are shorter and heat-generating infrastructure is more compact. Compact urban development can compromise the desired use of natural lighting, ventilation and decentralised use of solar energy, and higher densities limit the potential of ground-source heat pumps (because there are limits to the rate at which heat can be extracted). This statement underlines the need for district heating in order to decarbonise the heating sector. • *Heat demand from industry* Due to a future decrease in construction activity plus further improvements in energy efficiency, the scenarios project a decline in heat demand beyond 2020, particularly from higher-temperature industries.
Heat savings	In the most ambitious scenario (2DS), investments in the buildings sector dominates in all countries compared to the 6DS scenario (current trends), highlighting importance of energy efficiency. Higher investments will be needed for more efficient HVAC systems and building shell improvements. It is stated that around 60% of today's residential dwellings in the OECD will still be standing in 2050 and must be refurbished to low-energy standards (output energy needs of approximately 50 kWh/m^2 per year for heating and cooling). In the short term the level of investment is higher in OECD countries, because existing building stock requires significant retrofitting. In the residential subsector of EU more than twice the additional investment needs of the commercial subsector is required. The energy demand for space heating in these countries is expected to remain flat and begin a declining trend in 2020, as a result of the new energy efficient buildings in combination with an ambitious annual retrofit of 2.5% for existing buildings. Barriers such as split incentives between tenants and landlords, lack of awareness of efficient technologies and high initial investment costs is needed to be addressed by governments. At national and sub-national level governments are urged to • require all new buildings, as well as buildings undergoing renovation, to meet energy codes and minimum energy performance standards.

	• support and encourage construction of buildings with net-zero energy consumption. • implement policies to improve the energy efficiency of existing buildings especially during renovations. • develop building energy performance labels or certificates that provide information to owners, buyers and renters. • establish policies to improve the energy efficiency performance of critical building components in order to improve the overall energy performance of new and existing buildings.
How is the heat produced?	Heat pumps for space and water heating is assumed. In some places the space heating demand is deemed to be fully met with solar photovoltaic (PV) and some form of storage, or with a low-capacity heat pump. However also industrial excess heat and heat from thermal power generation are included in high-density areas where demands are concentrated and diverse. In the report it is recognised that these networks offer larger potential for other, low-grade heat resources including renewable heating and cooling technologies and large-scale heat pumps. Besides this a widespread deployment of solar thermal systems is deemed needed to achieve the 2DS targets. For the 2DS scenario the CO_2 intensity of the district energy networks is reduced to one sixth of today in 2050 by use of mainly biomass and excess heat (and due to improvements in the efficiency of the building stock). Besides this gas represents around 30%. The share of district energy networks in useful energy demand in buildings is doubled in the period from 2010 to 2050.

10.7 WORLD ENERGY OUTLOOK, 2012 (IEA)

Heat sector in general	As in most other reports, the energy consumption is defined for the sectors industry, transport and buildings and the heat demand is not a specific focus area. Looking at the building sector, the energy consumption covers energy for heating, cooling, lighting, refrigeration and for powering electrical appliances. However the change in demand for space and water heating from 2010 to 2035 is provided separately for the residential sector and shows a reduction of more than 60% for the most ambitious scenario ("Efficient World Scenario"). For the "New Policies Scenario" which takes broad policy commitments and plans that have already been implemented as well as those that only have been announced into account, the development in space and water heating demand shows an increase close to 50%. Looking at Europe separately, the space heating demand accounts for 43% of the savings in the residential sector in 2020 in the "Efficient World Scenario" compared to the "New Policies Scenario" (and 42% in 2035).
Heat savings	In the "New Policies Scenario" several political initiatives are assumed. For Europe some of these are: • The Energy Efficiency Directive. • Building energy performance requirements for new buildings (zero-energy buildings by 2021) and for existing buildings when extensively renovated. (A 3% renovation rate of central government buildings is assumed.) • Mandatory energy labelling for sale or rental of all buildings and some appliances, lighting and equipment. In the "450 scenario", which sets out an energy pathway that is consistent with a 50% chance of

	meeting the goal of limiting the increase in average global temperature to 2 °C (compared with pre-industrial levels), the zero-carbon footprint for all new buildings is assumed already from 2015. Besides energy efficiency measures, an important way to achieve GHG emission reductions is by introducing more renewables. However in 2020, almost three-quarters of the emissions saved originate from energy efficiency, including electricity savings, end-use efficiency and power plant efficiency. In other words, energy savings are seen as the main way to achieve the GHG reductions.
How is the heat produced?	Since the report covers the entire world, there is a large variation on the way to supply the heat demand. Electricity's dominance of energy use in buildings grows, mainly at the expense of traditional biomass, which becomes a less important energy source for households in developing countries. The share of electricity in building energy use continues to grow strongly in both the "New Policies Scenario" and the "Efficient World Scenario". In the latter case it increases from 29% in 2010 to 36% in 2035. The use of oil in buildings worldwide is expected to decline, due to the use of more efficient appliances and increasing substitution with electricity and gas. In the "New Policies Scenario", worldwide use of gas for power (and delivered heat) increases by half between 2010 and 2035 (an average rate of 1.6% per year). The gas consumption in buildings for space and water heating grows at 1.3% per year on average over the projection period. The building sector remains the largest end-use sector for gas (43% in 2035), even though, in many OECD countries, most of the scope for switching from heating oil and other fuels to gas is said to be exhausted. The use of modern renewables to produce heat almost doubles, from 337 Mtoe (14.11 EJ) in 2010 to 604 Mtoe (25.29 EJ) in 2035. This heat is used mainly by industry (where biomass is used to produce steam, in co-generation and in steel production) but also by households (where biomass, solar and geothermal energy are used primarily for space and water heating). It is stated that lack of data makes analysis of CHP on a global level difficult. In the IEA's statistics, the heat produced by CHP installations is measured only if the heat is sold by the producer to another entity. Heat produced in an industrial CHP facility and used by the same firm is not reported and only the corresponding fuel consumption is accounted for. This makes it difficult to analyse the current extent of CHP use globally, and to model its future development.

10.8 DESERT POWER 2050: PERSPECTIVES ON A SUSTAINABLE POWER SYSTEM FOR EUMENA (DII)

Heat sector in general	The heating sector is not considered separately. The demand which the report addresses is the electricity demand. In this, the electricity used for heating is included, but it does not explain to what extent the heating and cooling demand is expected to be based on electricity. The report refers to EU energy trends 2030 - Update 2009 (renewable energy sources – electricity scenario) regarding the electricity demand of EU27 (+2) assuming that the total electricity demand in the year 2010 stagnates until 2050. It is stated that "the idea that renewable electricity should be produced in areas with optimal resources and exported to regions with high demand has become known as the Desertec vision." The primary purpose of the study is to analyse whether an EUMENA-wide power system integration is able to deliver advantages in terms of system cost and security of supply and it concludes that a power system based on more than 90% renewable energy is technically possible and economically viable.
Heat savings	In the "Low Demand Connected Scenario" it is assumed that there will be an implementation of energy efficiency measures, energy-efficient/generating buildings (especially with regard to the electricity need for heating/air-conditioning) and the expansion of distributed PV, possibly in combination with decentralized storage. All of these enable consumers to consume their "own" electricity and thus reduce demand for power from the transmission grid. This scenario does not assume a given self-supply rate.
How is the heat produced?	Disregarded.

10.9 POLICY REPORT – CONTRIBUTION OF ENERGY EFFICIENCY MEASURES TO CLIMATE PROTECTION WITHIN THE EUROPEAN UNION UNTIL 2050 (FRAUNHOFER)

And the Scientific Support in the Preparation of Proposals for an EU Energy Roadmap (March 2012) accompanying the report mentioned above

Heat sector in general	The energy system is described in sectors, where the heat demand is not indicated separately. In a comparison of different reports a conclusion underlines the need for further investigations: "On the basis of this analysis of different energy scenarios, a strong need for a more in-depth analysis of single energy efficiency technologies is identified. In order to exploit the energy saving potential that is advocated as an important option in the whole set of all decarbonisation scenarios, concrete technologies need to be evaluated regarding their potential and their cost-effectiveness."
Heat savings	In terms of the household sector demand, the baseline final energy demand is said to decline after 2015 reaching today's level by 2040 and that it is possible to reduce it by 71% by 2050 compared to the baseline. Half of the savings relate to the building shell refurbishment of existing buildings and efficiency options such as refurbishment, replaced heating systems, implementing highly efficient new buildings are said to be able to trigger 80% of the cumulative energy cost reduction. 100% conversion efficiency is assumed for all renewable energy carriers (apart from biogenic sources) and this way renewables have a significant impact not only on the reduction of primary energy demand, but also on lowering GHG emissions. By 2050, 25% of the projected primary energy demand is deemed possible to reduce via the shift towards a highly efficient power sector, and an additional 42% from final energy related efficiency measures.
How is the heat produced?	Be electrifying the heating sector and including a lot more heat pumps, the GHG emission reductions rely on the "decarbonisation" of the power generation sector.

10.10 RETHINKING 2050 – A 100% RENEWABLE ENERGY VISION FOR THE EU (EREC)

Heat sector in general	The report states under the headline "Heating and Cooling – Measures to Awaken the Sleeping Giant" that "Most people, including some decision makers, underestimate the share of energy used for heating purposes." Additional policy support for district heating infrastructure and CHP systems based on renewable energy sources is deemed needed to unfold the full potential of the heating and cooling sector. New policy initiatives in this field need to address the key barriers to growth, including often high upfront investment costs particularly for households. The aim is to reach 100% renewable energy in 2050 stating that the precise mix of renewable energy technologies is not forecasted but rather seen as a prognosis, within which a wide range of options exist. Hence, the aim of the report is not to discriminate between the various RES technologies, but rather to keep a focus on remaining on the overall 100% RES pathway, showing that both in technical and economic terms, it is feasible to get to a fully sustainable energy system based on renewable energy in the EU by 2050. As a sector, heating and cooling remains the largest contributor to final energy demand. The heating and cooling demand accounts for 49% of the overall final energy demand in the EU and is assumed most likely to remain a high share of the final energy demand in the future to come.
Heat savings	In the report net- or nearly-zero-energy buildings are mentioned as the norm from 2020. Besides this, the European Union is said to have to develop a strategy that ensures that all existing buildings after 2030 and all buildings (existing and new constructions) become net-zero/positive energy buildings as of 2040.
How is the heat produced?	To meet the overall target of at least 20% by 2020, the share of renewable heating and cooling could almost triple compared to the current share of about 10%. Most of the growth is suggested to be based on biomass. In 2030, solar thermal comes second with a contribution of 48 Mtoe (2.0 EJ) and geothermal third with 24 Mtoe (1.0 EJ). In the long run solar thermal will make up a share of about 20% of total RES heat contribution, while geothermal will increase to about 10%. By 2050, biomass is projected to contribute with 214.5 Mtoe (8.98 EJ), while geothermal could account for 136.1 Mtoe (5.70 EJ) and solar thermal for 122 Mtoe (5.11 EJ) supplying about 26% of the EU´s total heat consumption. Between 2020 and 2050, RES-heating and cooling will see an increase of about 30% amounting to around 470 Mtoe (19.68 EJ) in 2050. It will reach a share of almost 30% of total heat consumption by 2020 and cover more than half of the EU´s heat demand by 2030. By 2050 renewable heating and cooling will provide 100% of the consumption assumed in the "2050 scenario". Thermally-driven cooling technologies are assumed to play a major role in the future, thereby helping to reduce electricity peaks in summer.

10.11 EU ENERGY POLICY TO 2050 – ACHIEVING 80-95% EMISSIONS REDUCTIONS (EWEA)

Heat sector in general	The study focuses on the policies which in EWEA's opinion are to be promoted/implemented in order to achieve emission reductions of 80-95% – with main focus on the electricity grid. The heating sector is not dealt with separately.
Heat savings	Not described.
How is the heat produced?	Not described

10.12 RENOVATION TRACKS FOR EUROPE UP TO 2050 (EURIMA/ECOFYS)

Heat sector in general	The aim of the study is to evaluate different building renovation strategies at the EU level with respect to the speed of renovation and the future ambition level. Besides this it relates the results to existing and newly discussed targets with a view to create and support a common understanding of the mechanisms and implications (achieving or missing long-term targets and their financial consequences).
Heat savings	Heat savings are included by renovating building stock with retrofit rates of 2.3-3.0% per year.
How is the heat produced?	Since the target of the report is the renovation possibilities and not the energy sector (outside the buildings) the focus is not on the produced heat. For the shallow renovation the future heating systems for retrofits are based on • 75% Gas condensing boiler • 15% Oil condensing boiler • 3% Air-water heat pump • 3% Ground-water heat pump • 4% Biomass boilers (And no solar thermal systems for domestic hot water.) For the scenario Shallow renovation + REN the future heating systems for retrofits is based on: • 40% Air-water heat pump • 40% Ground-water heat pump • 15% Biomass boilers • 5% District heat (with growing share of renewable energy) 80% of all retrofits have solar thermal systems for domestic hot water with maximum domestic hot water coverage of 60%. For the deep renovation scenario the future heating systems for retrofits is based on • 35% Air-water heat pump • 35% Ground-water heat pump • 15% Biomass boilers • 15% District heat (with growing share of renewable energy) 80% of all retrofits have solar thermal systems for domestic hot water with maximum domestic hot water coverage of 60%.

10.13 EUROPE'S BUILDINGS UNDER THE MICROSCOPE – A COUNTRY-BY-COUNTRY REVIEW OF THE ENERGY PERFORMANCE OF BUILDINGS (BPIE)

Heat sector in general	The report only focuses on buildings. A renovation model has been specifically developed to illustrate the impact on energy use and CO_2 emissions at different rates (percentage of buildings renovated each year) and depths of renovation (extent of measures applied and size of resulting energy and emissions reduction) from now up to 2050. Two decarbonisation pathways are considered: A slow pathway based on what has been witnessed since 1990 and a fast pathway based on what is needed to achieve the levels of carbon reduction assumed in the EU 2050 Roadmap. All but one scenario assume that a building will be renovated once between 2010 and 2050. The so-called two-stage scenario even allows for a second renovation during the 2010-2050 period. Individual scenarios combine different speeds and depths, and are compared to a business-as-usual scenario, which assesses what would happen if there were no changes from the approach taken today.
Heat savings	A key driver for implementing energy efficiency measures are the building energy codes, through which energy-related requirements are incorporated during the design or retrofit phase of a building. However the current EU legislation is said only to partially cover the field of buildings renovation. The EPBD stipulates the implementation of energy saving measures only in case of deep renovation of the building without specifying the depth of renovation measures. More targeted measures are deemed required for fostering the deep renovation of the existing building stock. However the recast EPBD which should also gradually converge to nearly zero energy standards is predicted to implement major changes through the application of a cost-optimality concept in energy performance requirements for new buildings from 2020 onwards. The ambition is to see all EU buildings renovated between now and 2050. It can be seen that, in order to achieve 100% renovation within 40 years, an average renovation rate of 2.5% p.a. needs to be attained. However, with current rates as low as 1%, levels of activity need to more than double to achieve the required annual rate. In the deep and two-stage scenarios there is a 71-73% CO_2 emission reduction even under the slow decarbonisation assumption, a figure which is close to the CO_2 emission reduction for the slow and shallow scenario under the fast decarbonisation assumption. This highlights the role of renovation measures in the decarbonisation strategy.
How is the heat produced?	Not described. Referring to Eurostat and Primes forecasts and targets of "A Roadmap for moving to a competitive low carbon economy in 2050".

10.14 POWER CHOICES – PATHWAYS TO CARBON-NEUTRAL ELECTRICITY IN EUROPE BY 2050 (EURELECTRIC)

Heat sector in general	The heating sector is not a focus area. The main focus is on electrifying the final energy usage (and then use either heat pumps or direct electricity for heating).
Heat savings	Heat savings are not mentioned in detail besides the fact that it will require improved building insulation. A major reason for the decrease in primary energy consumption is the considerably lower demand in the residential sector due to substitution of (inefficient) oil and gas to electricity and improvement in building insulation. Besides this, more efficient electric appliances are mentioned as a contributor to the decrease in demand for the residential sector. However a point not mentioned in the report is that this will in fact not help to decrease the heat demand, but just the opposite.
How is the heat produced?	The heating is supplied mainly by means of heat pumps or direct electric heating and to some extent direct use of solar thermal and biomass. Some DH/CHP is assumed – co-generation is assumed to double from 2010 to 2020 and represent almost 20% of power generation by 2030 (both for industrial and district heating uses, mainly through gas and biomass plants). However the development slows down thereafter because CHP is said not to be unable to deliver a fully decarbonised output. This indicates implicitly that the report deem it undesirable (or at least unfeasible) to combine CHP with CCS. Due to already made decisions on investments in gas power plants and carbon prices, the use of gas is assumed to increase in the short-term future, but after CCS is believed to be commercial in 2020, gas plants with CCS is said to be less competitive than coal fired power plants with CCS. Since around 60% of the power generation is assumed to come from gas, nuclear, solids and oil in 2050 the report strongly depends on the predicted competitiveness of CCS (by 2020-2025).

11 ANNEX III: PROFILING BOILERS IN THE EU27 AND EVALUATING THE FUTURE HEAT DEMANDS

Report by Ecofys

By:
Jan Grözinger
Thomas Boermans
Michelle Bosquet
(Ecofys Germany GmbH)

David Connolly
(Aalborg University)

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11.1 OVERVIEW OF INVESTMENT COSTS

11.1.1 Overview of investment costs per heating system

11.1.1.1 Data assessment

Information on investment costs for replacement of heating systems in buildings are mainly based on the BMVBS-online publication Nr. 07/2012. The project was executed by the *Institute of Wohnen und Umwelt* (IWU) [BMVBS (Hrsg.), 2012]. The study investigated the investment costs of building and equipment components. Additional cost data was gathered from producers such as Windhager, Viessmann, Brötje, Weishaupt, Buderus.

It is important that costs for boilers in case of small boilers (up to 40 kW) are not significantly dependent from the system size. The IWU in its study calculates cost curves that are floor area dependent. The reason is that in case of small systems, the share of installation costs in the total costs is relatively high.

In large buildings with boilers larger than 40kW, the dependency on floor area is not so strong anymore; the costs are more dependent on system size. The costs from IWU have been adapted to consider this phenomenon, taking into account costs from the producers for different size of boilers.
The developed investment costs per system represent the purchase price for consumers (excluding taxes) and comprise the costs of the system (including fuel and thermal storage), the installation and other costs (average costs of necessary grid connections, storage, chimneys and disposal costs). The costs do not include maintenance and operation costs.

Based on country factors [Baukosteninformationszentrum Deutscher Architektenkammern (BKI), 2011] the cost data for Germany were extrapolated to the other Member States.

11.1.1.2 Costs for replacement of heating systems in all EU27 countries

Table 26: Costs (in Euro) for replacement of gas heating systems in EU27, by ranges

	8 - 20 kW	20 - 40 kW	120 - 170 kW	250 - 350 kW
AUSTRIA	6,025	8,996	17,310	21,554
BELGIUM	4,903	7,322	14,088	17,542
BULGARIA	2,243	3,349	6,444	8,024
CYPRUS	3,698	5,523	10,626	13,231
CZECH REPUBLIC	3,269	4,881	9,392	11,695
DENMARK	7,373	11,009	21,184	26,377
ESTONIA	3,531	5,273	10,146	12,634
FINLAND	5,405	8,070	15,528	19,335
FRANCE	5,906	8,818	16,967	21,127
GERMANY	5,965	8,907	17,139	21,341
GREECE	3,603	5,380	10,352	12,890
HUNGARY	3,072	4,587	8,827	10,990
IRELAND	5,100	7,616	14,654	18,246
ITALY	3,925	5,861	11,277	14,042
LATVIA	4,122	6,155	11,843	14,746
LITHUANIA	3,669	5,478	10,540	13,124
LUXEMBOURG	5,082	7,589	14,602	18,182
MALTA	3,197	4,774	9,186	11,439
NETHERLANDS	6,389	9,540	18,356	22,856
POLAND	3,537	5,282	10,163	12,655
PORTUGAL	2,941	4,391	8,449	10,521
ROMANIA	2,273	3,394	6,530	8,131
SLOVAKIA	3,454	5,157	9,923	12,356
SLOVENIA	3,770	5,629	10,832	13,487
SPAIN	4,068	6,075	11,689	14,554
SWEDEN	7,188	10,733	20,652	25,715
UNITED KINGDOM	5,774	8,622	16,590	20,658

Table 27: Costs (in Euro) for replacement of oil heating systems in EU27, by ranges

	8 - 20 kW	20 - 40 kW	120 - 170 kW	250 - 350 kW
AUSTRIA	7,112	10,739	21,575	25,819
BELGIUM	5,788	8,740	17,559	21,013
BULGARIA	2,648	3,998	8,032	9,612
CYPRUS	4,366	6,592	13,244	15,849
CZECH REPUBLIC	3,859	5,827	11,706	14,009
DENMARK	8,704	13,142	26,403	31,596
ESTONIA	4,169	6,294	12,646	15,133
FINLAND	6,380	9,633	19,354	23,160
FRANCE	6,971	10,526	21,148	25,308
GERMANY	7,042	10,632	21,361	25,563
GREECE	4,253	6,422	12,902	15,440
HUNGARY	3,626	5,476	11,001	13,165
IRELAND	6,021	9,091	18,264	21,857
ITALY	4,633	6,996	14,056	16,821
LATVIA	4,866	7,347	14,761	17,664
LITHUANIA	4,331	6,539	13,137	15,721
LUXEMBOURG	6,000	9,059	18,200	21,780
MALTA	3,774	5,699	11,450	13,702
NETHERLANDS	7,542	11,387	22,878	27,378
POLAND	4,176	6,305	12,667	15,159
PORTUGAL	3,472	5,242	10,531	12,603
ROMANIA	2,683	4,051	8,139	9,740
SLOVAKIA	4,077	6,156	12,368	14,801
SLOVENIA	4,450	6,720	13,500	16,156
SPAIN	4,802	7,251	14,569	17,434
SWEDEN	8,485	12,812	25,741	30,804
UNITED KINGDOM	6,816	10,292	20,678	24,745

Table 28: Costs (in Euro) for replacement of pellet heating systems in EU27, by ranges

	8 - 20 kW	20 - 40 kW	120 - 170 kW	250 - 350 kW
AUSTRIA	15,160	20,939	30,451	47,425
BELGIUM	12,338	17,041	24,783	38,598
BULGARIA	5,644	7,795	11,336	17,655
CYPRUS	9,306	12,854	18,692	29,113
CZECH REPUBLIC	8,225	11,361	16,522	25,732
DENMARK	18,552	25,624	37,264	58,038
ESTONIA	8,886	12,273	17,848	27,798
FINLAND	13,599	18,783	27,315	42,542
FRANCE	14,860	20,524	29,848	46,486
GERMANY	15,010	20,732	30,149	46,956
GREECE	9,066	12,522	18,210	28,361
HUNGARY	7,730	10,677	15,527	24,182
IRELAND	12,833	17,725	25,778	40,147
ITALY	9,876	13,641	19,838	30,897
LATVIA	10,372	14,326	20,833	32,447
LITHUANIA	9,231	12,750	18,542	28,878
LUXEMBOURG	12,788	17,663	25,687	40,006
MALTA	8,045	11,112	16,160	25,168
NETHERLANDS	16,075	22,204	32,290	50,290
POLAND	8,901	12,294	17,878	27,845
PORTUGAL	7,400	10,221	14,864	23,149
ROMANIA	5,719	7,899	11,487	17,890
SLOVAKIA	8,691	12,004	17,456	27,187
SLOVENIA	9,486	13,102	19,054	29,676
SPAIN	10,237	14,139	20,562	32,024
SWEDEN	18,087	24,982	36,330	56,582
UNITED KINGDOM	14,529	20,068	29,184	45,453

Table 29: Costs (in Euro) for replacement of air heat pumps in EU27, by ranges

	8 kW	15 kW	20 kW	30 kW	150 kW	300 kW
AUSTRIA	14,456	18,193	20,862	26,201	90,263	170,342
BELGIUM	11,765	14,806	16,979	21,324	73,462	138,635
BULGARIA	5,382	6,773	7,766	9,754	33,603	63,414
CYPRUS	8,874	11,168	12,806	16,084	55,409	104,566
CZECH REPUBLIC	7,843	9,871	11,319	14,216	48,975	92,423
DENMARK	17,690	22,264	25,530	32,063	110,461	208,458
ESTONIA	8,473	10,663	12,228	15,357	52,907	99,844
FINLAND	12,967	16,319	18,714	23,503	80,969	152,802
FRANCE	14,169	17,832	20,449	25,682	88,476	166,969
GERMANY	14,313	18,013	20,655	25,941	89,370	168,655
GREECE	8,645	10,880	12,476	15,668	53,979	101,868
HUNGARY	7,371	9,276	10,638	13,360	46,025	86,858
IRELAND	12,237	15,401	17,660	22,180	76,411	144,200
ITALY	9,418	11,852	13,591	17,069	58,805	110,975
LATVIA	9,890	12,447	14,273	17,925	61,754	116,541
LITHUANIA	8,802	11,078	12,703	15,954	54,962	103,723
LUXEMBOURG	12,194	15,347	17,598	22,102	76,143	143,694
MALTA	7,672	9,655	11,071	13,904	47,902	90,399
NETHERLANDS	15,329	19,292	22,122	27,783	95,715	180,630
POLAND	8,487	10,681	12,249	15,383	52,996	100,013
PORTUGAL	7,056	8,880	10,183	12,789	44,059	83,147
ROMANIA	5,453	6,863	7,870	9,884	34,050	64,258
SLOVAKIA	8,287	10,429	11,960	15,020	51,745	97,652
SLOVENIA	9,046	11,384	13,054	16,395	56,482	106,590
SPAIN	9,761	12,285	14,087	17,692	60,950	115,023
SWEDEN	17,247	21,705	24,890	31,259	107,691	203,230
UNITED KINGDOM	13,855	17,436	19,994	25,111	86,510	163,258

Table 30: Costs (in Euro) for replacement of brine heat pump systems in EU27, by ranges

	8 kW	15 kW	20 kW	30 kW	150 kW	300 kW
AUSTRIA	23,108	31,467	37,438	49,380	192,681	371,807
BELGIUM	18,807	25,610	30,469	40,188	156,815	302,600
BULGARIA	8,603	11,714	13,937	18,383	71,731	138,415
CYPRUS	14,185	19,316	22,982	30,312	118,279	228,238
CZECH REPUBLIC	12,538	17,073	20,313	26,792	104,544	201,733
DENMARK	28,278	38,508	45,815	60,429	235,796	455,004
ESTONIA	13,544	18,444	21,944	28,943	112,938	217,931
FINLAND	20,728	28,227	33,583	44,295	172,840	333,522
FRANCE	22,650	30,844	36,697	48,402	188,865	364,445
GERMANY	22,879	31,155	37,067	48,891	190,773	368,126
GREECE	13,819	18,818	22,389	29,530	115,227	222,348
HUNGARY	11,783	16,045	19,090	25,179	98,248	189,585
IRELAND	19,562	26,638	31,692	41,802	163,111	314,748
ITALY	15,054	20,500	24,390	32,170	125,529	242,227
LATVIA	15,809	21,528	25,613	33,784	131,824	254,375
LITHUANIA	14,071	19,161	22,796	30,068	117,325	226,398
LUXEMBOURG	19,493	26,544	31,581	41,655	162,539	313,643
MALTA	12,263	16,699	19,868	26,205	102,254	197,316
NETHERLANDS	24,503	33,368	39,699	52,362	204,318	394,263
POLAND	13,567	18,475	21,981	28,992	113,128	218,299
PORTUGAL	11,279	15,360	18,274	24,103	94,051	181,486
ROMANIA	8,717	11,870	14,123	18,627	72,685	140,256
SLOVAKIA	13,247	18,039	21,462	28,308	110,458	213,145
SLOVENIA	14,460	19,690	23,426	30,899	120,569	232,656
SPAIN	15,603	21,248	25,280	33,343	130,107	251,062
SWEDEN	27,569	37,542	44,666	58,913	229,882	443,592
UNITED KINGDOM	22,147	30,158	35,881	47,326	184,668	356,346

11.1.1.3 Investments in heating system replacements in Europe in 2012 and 2050

Merging the assessed costs data with information on replacement activities (replacement rates and technology mix based on information from the Ecofys BEAM² model), the average investments in heating system replacements in Europe per year were calculated, see Table 31 and Table 32.

Table 31: Investment costs (in Mio Euro) per heating system in EU27 in 2012

	Gas	Oil	Pellet	Air heat pump	Brine heat pump	others	Total
Residential	19,990	7,333	6,689	4,091	7,689	473	46,265
Non-residential	4,251	1,497	1,103	1,576	3,714	30	12,169
Total	24,241	8,830	7,792	5,667	11,402	503	**58,434**

Table 32: Investment costs (in Mio Euro) per heating system in EU27 in 2050

	Gas	Oil	Pellet	Air heat pump	Brine heat pump	others	Total
Residential	2,835	392	5,300	5,603	15,971	259	30,359
Non-residential	7,686	1,064	9,034	16,543	64,932	237	99,496
Total	10,521	1,455	14,334	22,146	80,903	495	**129,855**

11.1.2 Impact of reduced heat load

In case of renovation, heat load is reduced. This might result in different impacts on costs for heating systems different, depending on system size and system:

- in case of heat pumps the costs are directly dependent on system size, e.g. in case of the brine heat pump every additional kW needed results in higher costs (additional drilling, additional tube).
- in case of boilers, the impact depends on the size of the system:
    - if the system is up to 20 kW (normally installed in single family houses), the costs are the same (e.g. for a 8 kW or for a 15 kW boiler)
    - if the system size ranges from 20-40 kW, the costs of boiler are the same as for the boilers of up to 20 kW. However; the study from IWU found out that boilers in the range 20-40 kW (that are normally installed in small multifamily houses) the companies charge higher installation costs, which increases the total costs
    - if the size is larger than 40 kW, the costs for boilers increase with increasing power (kW), the share of the installation costs becomes marginal.

Table 33 examples for the impact of reduced heat demand on the heating systems costs in Germany for a gas heating system and an air heat pump for a single family, a small multifamily and a large multifamily building:

Table 33: Example of effect of reduced heat demand on costs of heating systems in Germany (Euro)

	Partly renovated			**Not renovated**		
	Single family building	Small multifamily building	Large multifamily building	Single family building	Small multifamily building	Large multifamily building
Capacity in kW	<10	20	150	<20	30	300
Costs of gas heating system	5,965	8,907	17,139	5,965	8,907	21,341
Costs of air heat pump	14,313 (8 kW)	20,655	89,370	18,013 (15 kW)	25,941	168,655

11.1.3 Building stock floor area in 2012 and 2050

The following figure illustrates the development of the heated floor areas in the EU27 countries. As for most statistics 1979 is a crucial date (i.e. introduction of the Thermal Insulation Ordinance in Germany) and from then on mandatory requirements for the building shell have been introduced, we distinguish buildings before and after 1979. In the deep renovation scenario, the stock is completely renovated by 2045, with a very small share of buildings assumed to have not been renovated. About one quarter of the building stock in 2050 will be new buildings.

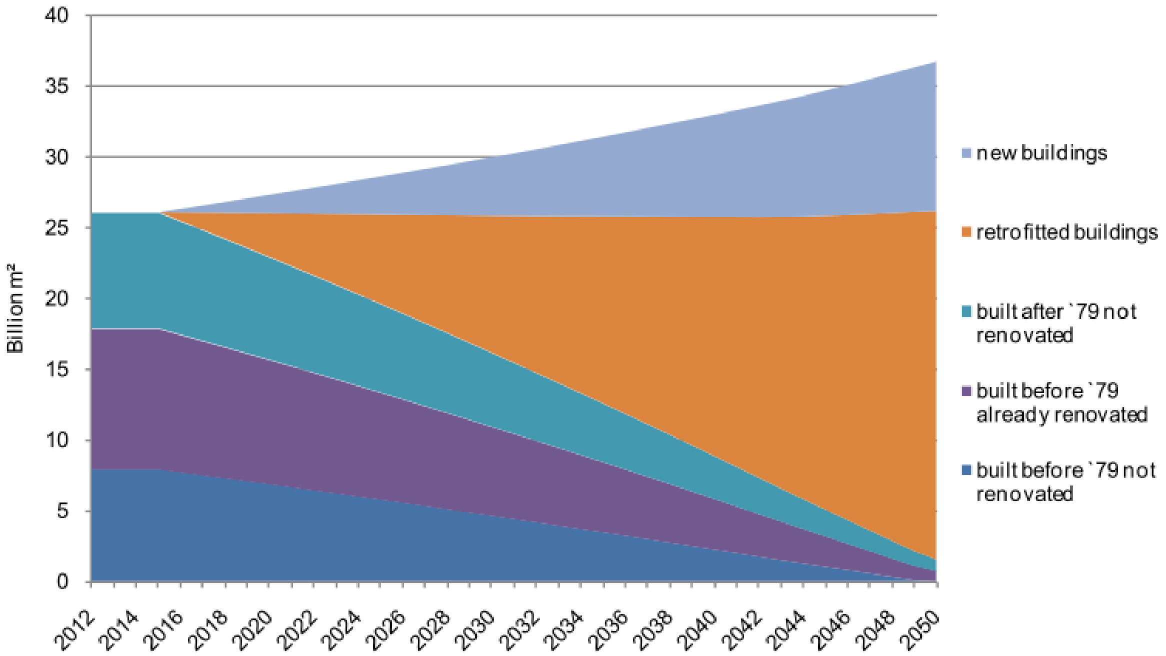

Figure 67: Heated floor area EU27 – track "Target Scenario, Deep Renovation" [billion m²]

11.1.4 Number of boilers in 2012 and 2050

The number of boilers is based on the number of buildings. To calculate the number of buildings we made assumptions[14] on reference buildings and on the share of central and decentred heating systems. In 2050 the boiler stock grows by about 46%.

Table 34: Number of boilers in the EU in 2012 and in 2050 in Mio units

		Gas	Oil	Pellet	Heat pump	el-direct and coal*	Total
2012	Residential	73.2	21.3	10.6	11.2	7.1	123
	Non-residential	5.3	2.3	0.5	0.5	0.3	9
	Total	79	24	11	12	7	132
2050	Residential	52.3	6.0	39.9	63.2	18.6	180
	Non-residential	3.8	0.4	2.9	4.6	1.3	13
	Total	56	6	43	68	20	193

* it was assumed that in 2050 the number of coal heating system will be insignificant

[14] We made assumptions regarding the share of central and decentred boilers and on geometries of the reference residential and non-residential buildings. For single family buildings that is safer than for non-residential buildings. In comparison, the uncertainty for non-residential buildings grows.

11.1.5 Recommended boiler efficiencies

Illustrated the recommends boiler efficiencies for EnergyPLAN in Energy Efficiency Scenario.

Table 35: Recommended boiler Efficiencies for EnergyPLAN in Energy Efficiency Scenario

	2010	2030	2050
Solids	70%	70%	70%
Oil cond.	95%	95%	95%
Oil non-cond.	80%	80%	80%
Gas cond.	98%	98%	98%
Gas non-cond.	80%	80%	80%
Biomass	75%	75%	75%
Solar	100%	100%	100%
Electricity	100%	100%	100%
Geothermal	100%	100%	100%
Heat Pumps ground water	300%	300%	300%
Heat Pumps air	250%	250%	250%

11.2 WP 3B: EVALUATION OF THE USED SCENARIOS

The scenarios from the *Energy Roadmap 2050* report have been used during the first pre-study to describe the demand side of the EUs building sector. However; uncertainties remain about the suitability of the scenarios (are they ambitious enough/overambitious?) and related estimated investment costs. This chapter first summarizes the basic assumptions of the high energy efficient scenario of the *Energy Roadmap 2050* and then looks into previous work by Ecofys with the BEAM² model for a study for Eurima: "Renovation tracks for Europe, up to 2050" [EURIMA, 2012]. The scenarios will be compared with focus on underlying assumptions and on the calculated outcome (heating demand) in order to afterwards evaluate the suitability of the *high energy efficiency scenario* (scenario 2). On that basis, recommendations on possible adaptations of the scenarios for the second pre-study will be made.

11.2.1 Energy roadmap 2050 – the high efficient scenario [European Commission, 2011a; European Commission, 2011b]

11.2.1.1 Assumptions

The objective of the study is to shape a vision and strategy of how the EU energy system can be decarbonised by 2050 while taking into account the security of supply and competitiveness objectives [European Commission, 2011a].

The study modelled different scenarios:

- Business as usual (BAU, Reference scenario)
- Current Policy Initiatives – CPI scenario (updated Reference scenario)
- Decarbonisation Scenarios
- High Energy Efficiency
- Diversified supply technologies
- High RES
- Delayed CCS
- Low nuclear

The BAU and CPI scenarios are built on a modelling framework including PRIMES, PROMETHEUS, GAINS, and GEM-E3 models (see [European Commission, 2011a] for more information).

Since the objective of this task is the evaluation of the energy efficient scenario, the focus is on this scenario. Main assumptions of the reference and the high efficient scenario are summarized in Table 36.

Table 36: Short description of the business as usual and the high energy efficiency scenario

Business as usual (Reference scenario)	This scenario is based on the scenarios up to 2030 published in the report *Energy Trends to 2030: update 2009*, but extends the projection period to 2050 The Reference scenario includes current trends and long-term projections on economic development (GDP growth 1.7% pa). It takes into account rising fossil fuel prices and includes policies implemented by March 2010. The 2020 targets for GHG reductions and RES shares will be achieved but no further policies and targets after 2020 (besides the ETS directive) are modelled. Sensitivities for higher/ lower GDP growth rates and energy import prices are modelled. The scenario focuses on direct impacts on final energy demand.
High Energy Efficiency (Scenario 2)	This scenario is driven by a political commitment of very high primary energy savings by 2050 and includes a very stringent implementation of the Energy Efficiency plan. It includes further and more stringent minimum requirements for appliances and new buildings; energy generation, transmission and distribution; **high renovation rates for existing buildings (more than 2% refurbishment rate)**; the establishment of energy savings obligations on energy utilities; the full roll-out of smart grids, smart metering and significant and highly decentralised RES generation to build on synergies with energy efficiency and passive house standards after 2020 (**all new buildings comply with the passive house standard – 20-50 kWh/m²** (depending on the country). The EU-EE scenario includes the following energy efficiency measures, with some of them occurring in other sectors than buildings, such as electricity and transport.

Details of macroeconomic and demographic assumptions, assumptions on energy import prices, policy assumptions, assumptions on energy infrastructure development, technology assumptions and any other assumptions are found in [European Commission, 2011a; European Commission, 2011b].

11.2.1.2 Heat demands

The assumptions relating to the future heat demand in the EU27 are of critical importance when analysing the future role of district heating. In Heat Roadmap Europe 1, the results indicated that under existing policies (i.e. the CPI scenario), the heat demand will be sufficient for district heating to be implemented at a cheaper cost than a business-as-usual scenario. Hence, a key motivation for choosing the Energy Efficiency (EE) scenario in this study was to investigate the feasibility of district heating if the heat demands are reduced significantly compared to the business-as-usual scenario. To begin, the first step is to analyse the scale of energy efficiency measures being implemented in the EU-EE scenario.

As outlined in Figure 68, the total heat demand in the EU-EE scenario is expected to drop by approximately 60% between 2015 and 2050. This is a much larger reduction than in the CPI scenario: by 2050, the total heat demand in the EU-EE scenario is approximately 50% of the heat demand in the CPI scenario.

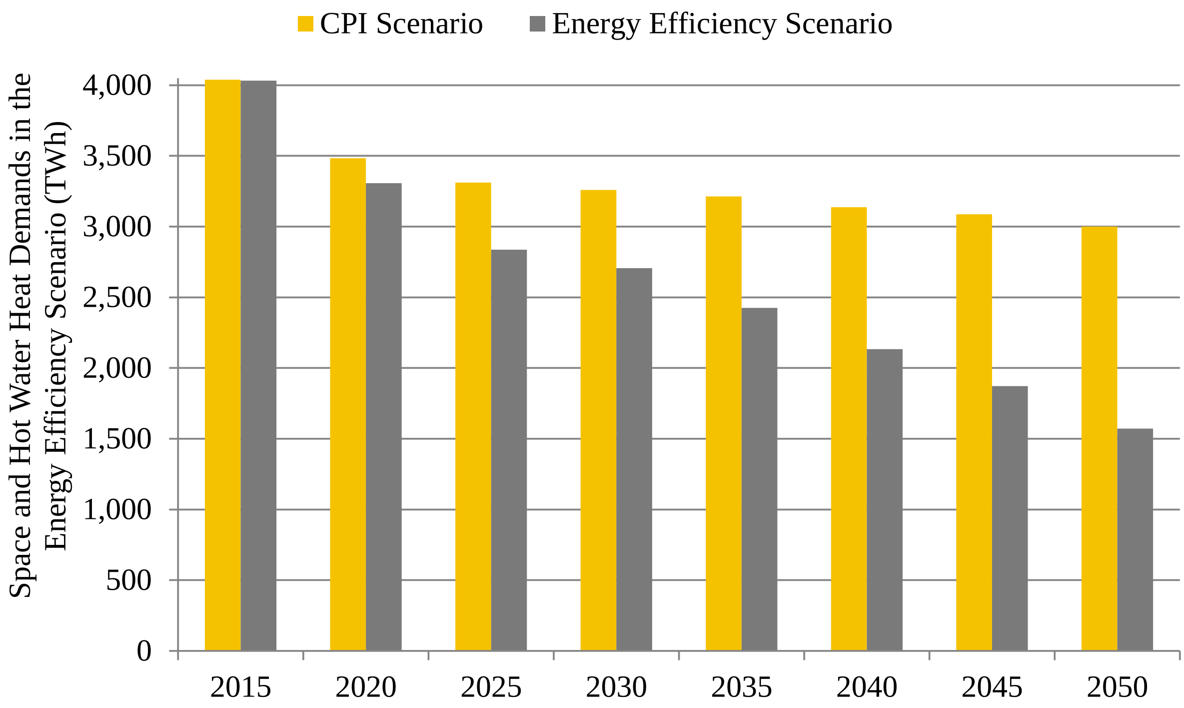

Figure 68: Total heat demand in the EU-CPI and EU-EE scenarios for 2015-2050.

This total heat demand can be broken down into a number of key sectors: firstly the heat demand provides two distinct services, hot water and space heating. Figure 69 outlines how the total heat demand in the EU-EE scenario is divided between these two services, which indicates that the space heating demand is expected to drop by approximately 60% and the hot water demand by 55% between 2015 and 2050.

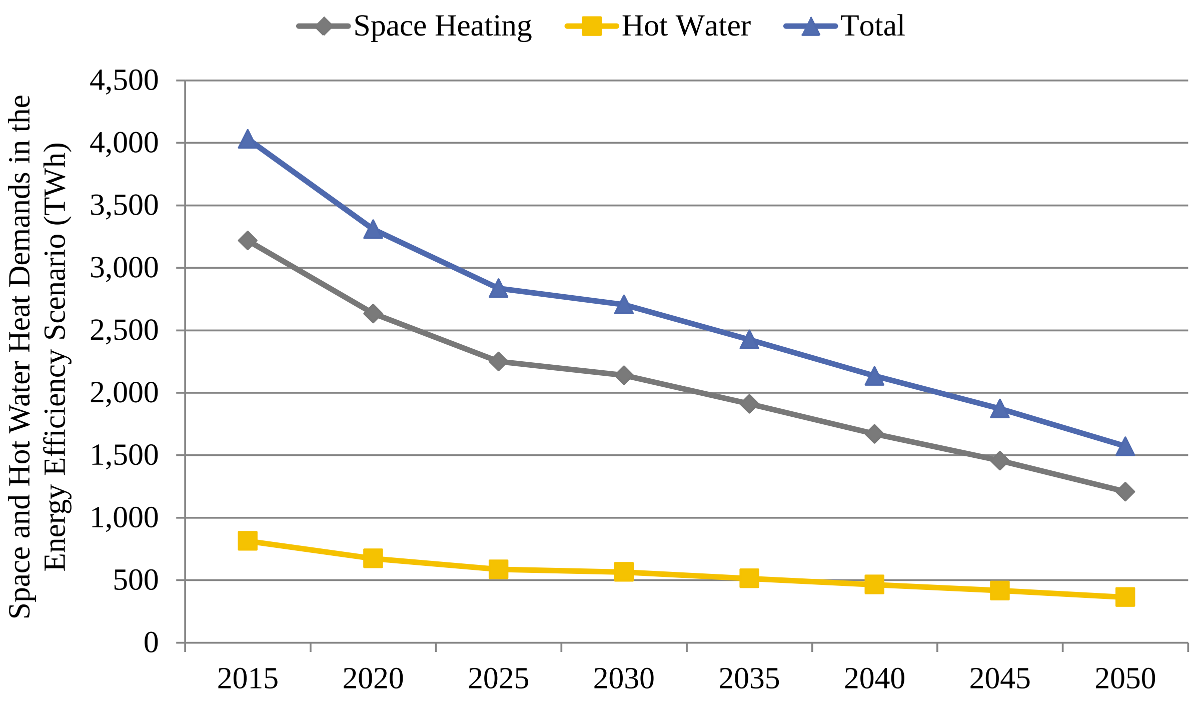

Figure 69: Space heating and hot water demand in the Energy Efficiency scenario between 2015 and 2050.

Secondly, the heat demand can be divided in terms of two distinct sectors, residential and non-residential/services. Figure 70 indicates that the heat demand will reduce by approximately 60-62% in both of these sectors between 2015 and 2050, similar to the overall trend in the total heat demand. However, it is important to recognise that there are other dynamics involved in these changes also such as the population and the building stock.

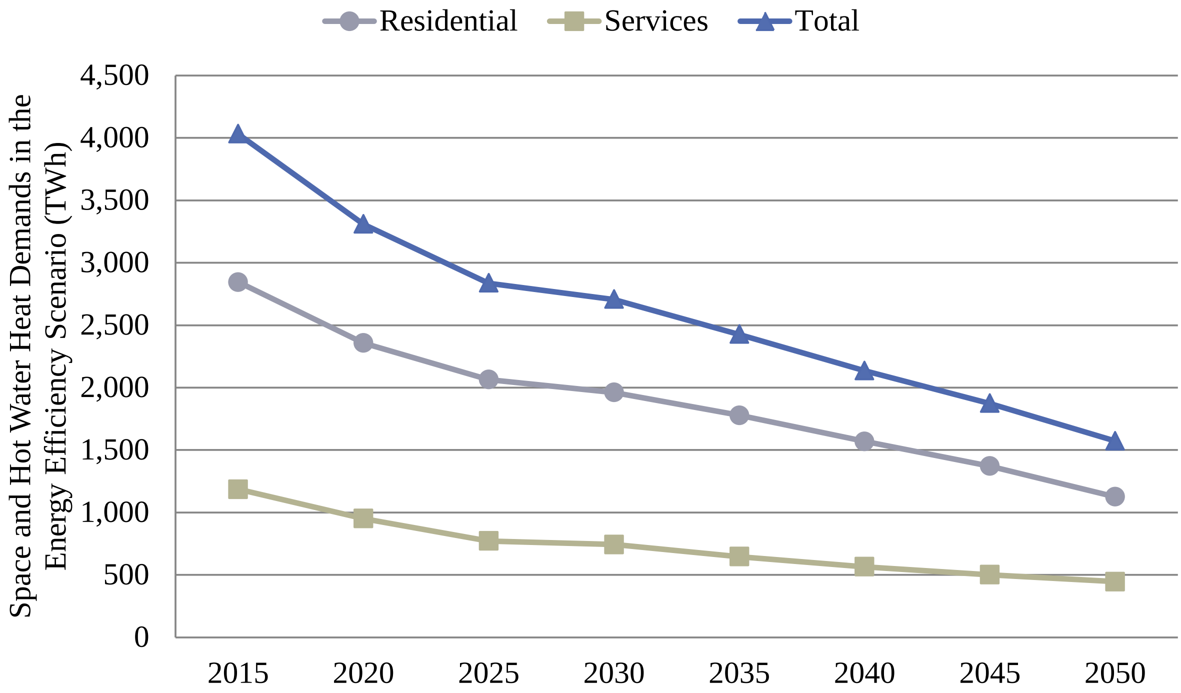

Figure 70: Residential and services heat demand in the Energy Efficiency scenario between 2015 and 2050.

While the heat demand is reducing in the EU-EE scenario, both the population and the building stock experience an increase.

Table 37 summarises the changes assumed in population in the EU-EE scenario, suggesting a 3.2% overall growth in population between 2010 and 2050. Table 38 presents similar statistics for the building stock in Europe: the total building stock is expected to grow by 35% between 2015 and 2050, which includes a growth of 42% for the residential sector and 32% for the services sector.

Table 37: Population assumptions in the Energy Efficiency scenario between 1990 and 2050 [European Commission, 2011].

Year	Population (Million)	Population 1-Year Change (%)	Population 5-Year Change (%)	Population 20-Year Change (%)	Population 40-Year Change (%)
1990	470.4	Start	Start		
1995	477.0	0.28%	1.4%		
2000	481.1	0.17%	0.9%		
2005	489.2	0.34%	1.7%		
2010	499.4	0.41%	2.1%	Start	Start
2015	507.7	0.33%	1.7%		
2020	513.8	0.24%	1.2%		
2025	517.8	0.15%	0.8%		
2030	519.9	0.08%	0.4%	4.1%	
2035	520.7	0.03%	0.1%		
2040	520.1	-0.02%	-0.1%		
2045	518.4	-0.07%	-0.3%		
2050	515.3	-0.12%	-0.6%	-0.9%	3.2%

Table 38: Estimated building floor are for the residential and non-residential/service sectors in the EU27 between 2015 and 2050.

	Floor area in Mio m²	2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
PRIMES Estimate* [9]	Residential	21,724	23,579	25,066	26,387	27,343	28,053	28,515	28,730
	Change per year in%		1.7%	1.2%	1.0%	0.7%	0.5%	0.3%	0.2%
Ecofys Estimate [42]	Residential	17,498 (in 2012)							24,198
	Non-Residential	8,642 (in 2012)							12,233

*In 2050, Ecofys estimated the residential floor area to be 15% lower than PRIMES.

This data is significant since it means that the specific heat demand reductions (i.e. kWh/m^2) are even larger than the absolute heat demand reductions portrayed in Figure 69 and Figure 70. Overall, Figure 71 shows that the specific heat demand reduction is very similar for both services and both sectors considered here, with a 70% reduction (+/-3%) for each between 2015 (2012) and 2050.

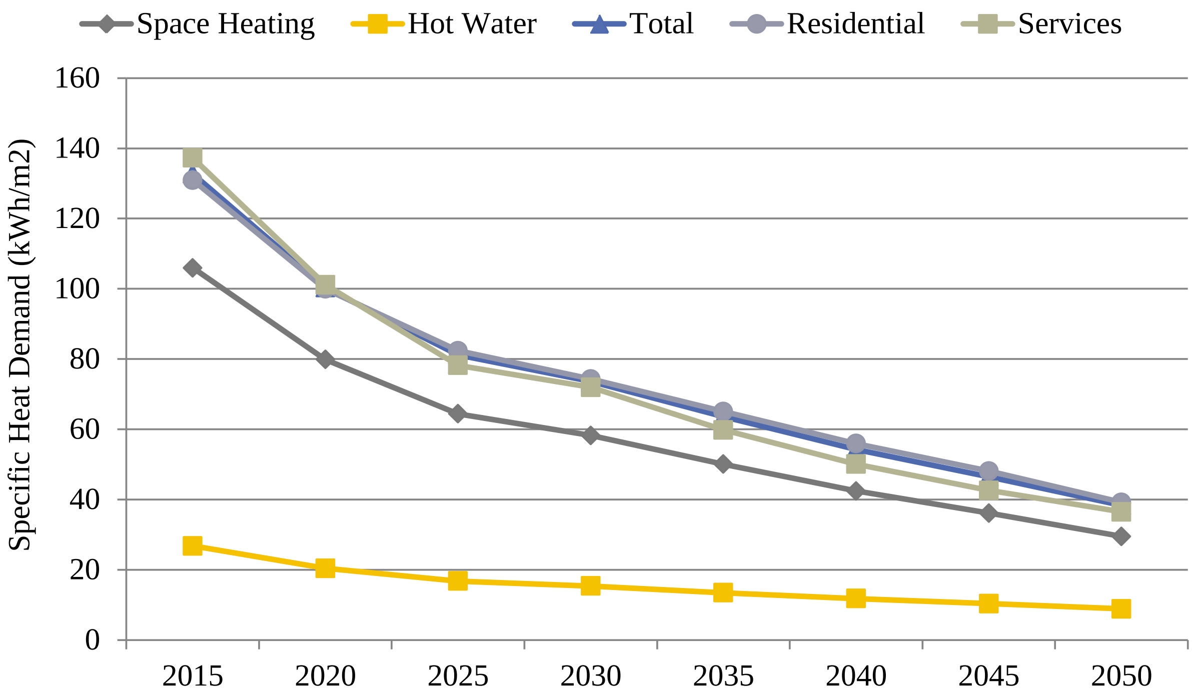

Figure 71: Specific heat demand in the Energy Efficiency scenario for the residential and non-residential/services sectors, as well as for the space heating, hot water, and total heat demand.

11.2.1.3 Investment costs

The costs for the EE scenario are then divided into three types:

- Capital
- Energy purchases
- Direct efficiency investments

The costs related to the scenario are summarized in Table 39.

Table 39: Results for 2050 for residential and tertiary sector

	Capital cost * [BN EUR'08]	Fuel and electricity costs	Average annual direct efficiency investment costs** [BN EUR'08]
Reference scenario	955	1,622	28
High energy efficiency scenario	1115	1,220	295
Additional costs [BN EUR'08]	160	-402	267
Additional costs [%]	17%	-24%	954%

- * Costs for energy installations such as power plants and energy infrastructure, energy using equipment, appliances and vehicles [European Commission, 2011a].
- ** direct efficiency investment costs include costs for house insulation, double/triple glazing, control systems, energy management and for efficiency enhancing changes in production processes not accounted for under energy capital and fuel/ electricity purchase costs.

It is assumed here that a lot of the energy efficiency costs are accounted for under capital costs rather than direct efficiency investments. For example, better appliances, new electric grids, the smart grid, and more renewable energy generation are assumed to be under capital costs. Hence, it is assumed that direct efficiency investments relates to the implementation of space and hot water savings in the buildings sector, which amounts to B€295/year. This may not be the case so the cost of energy efficiency measures may be over-estimated based on this. In any case, other reports based on the Danish building stock also report a significant increase in energy efficiency costs when you reach this scale of energy savings [Kragh,Wittchen, 2010]. Therefore, the costs assumed here may not be correct, but the scale of the costs for energy efficiency measures seems to be correct.

The aim in designing a new "enhanced energy efficiency" scenario in HRE-EE is to identify if the same objectives in the EU-EE scenario, in terms of energy and emission reductions, can be achieved in a way that is both cheaper and easier to implement. To achieve such an objective, the strategy is to replace some of the energy efficiency measures which are either very expensive and/or difficult to implement. In line with this, the following two subjects have been investigated further in the EU-EE scenario:

- The high reductions in the hot water end use seem very difficult to implement.
- The reduction per unit of space heating demand, below a total average reduction of 40-50% of the existing level, seems to be very ambitious in terms of implementation and also very expensive.

11.2.2 Renovation tracks for Europe, up to 2050. Building renovation in Europe – what are the choices? [EURIMA, 2012]

11.2.2.1 Assumptions

This study analyses and compares the possible tracks for the renovation of the EU building stock, quantifying and illustrating graphically energy savings and avoided CO_2 emissions, financial impacts and employment effects. The study examines three renovation scenarios from 2012 to 2050, which are characterized by parameters: *speed of renovation* (= renovation rate) and *ambition level* regarding *energy efficiency* improvement and *use of renewable energy*. The different scenarios are designed to indicate the likely implications of using different approaches to meet the 2050 targets.

Track 1: Shallow renovation:

- Retrofit rate: 3% per year
- Retrofit standard (demand side): Average standard, accompanied by market failures where certain measures are not carried out due to perceived barriers (Market failures described effects, where e.g. measures that are in principle financially feasible from a lifecycle perspective are not carried out, due to various barriers (e.g. high upfront investment/ financing needs, lack of information, aesthetics/tradition, investor user conflict, technical limitations etc.).
- Renewable energy: Low contribution, no ventilation systems with heat recovery
- Solar thermal systems for domestic hot water: none

Track 2: Shallow renovation + RES:

- Doubling of renovation rate & average ambition level + market failures; no focus on energy efficiency; use of renewable energy
- Retrofit rate: 2.3% per year (which is approximately a doubling of the current renovation rate).
- Retrofit standard (demand side): accompanied by market failures where certain measures are not carried out due to perceived barriers. The demand side level (related to the building envelope) of the shallow renovation is the same level as applied in Track 1 (shallow renovation)
- Renewable energy: high contribution, all retrofits with ventilation systems and heat recovery
- Solar thermal systems for domestic hot water (max. DHW coverage 60%): 80% of all retrofits have solar thermal systems installed.

Track 3: Deep renovation:

- "Doubling" of renovation rate & high ambition level; focus on energy efficiency; use of renewable energy
- Retrofit rate: 2.3% per year (which is approx. a doubling of the current renovation rate).
- Retrofit standard (demand side): Very ambitious standard (reflects the level of Passive House standard for the building envelope
- Renewable energy: high contribution , all retrofits with ventilation systems and heat recovery
- Solar thermal systems for domestic hot water (max. domestic hot water coverage of 60%): 33% of all retrofits have Solar Thermal systems installed.
-

It is important to note that all three scenarios assume renovation rates of no more than 3% taking into account normal renovation cycles (30 to 40 years), which enables to connect the measures with already anticipated and (also non-energy related) renovation activities. The renovation rate in Tracks 2 and 3, namely 2.3% per year (which is approx. a doubling of the current renovation rate) still ensures that the building stock is renovated before 2050.

New building standards:

High ambition level for new buildings:

- New building rate: 1.0% per year
- New building standard (demand side): Ambitious standard (typically with final energy demand for heating and cooling below 15 kWh/m^{2}a.)
- Renewable energy: High contribution
- All new buildings with ventilation systems and heat recovery
- Solar thermal systems for domestic hot water (maximum DHW coverage 60%): 66% of all new buildings have solar thermal systems installed.

The calculations are based on the five climate zones within the EU27.

Important other assumptions:

- Retrofitting activities (according to the three defined scenarios) are implemented in the market from 2015
- All 3 scenarios assume a small fraction of buildings will not be improved in the time period (e.g. monument type of buildings or due to compliance issues)
- Energy uses of space heating and domestic hot water are included
- Not included: cooling energy, lighting (for non-residential buildings) and auxiliary energy
- New construction rate: 1.0%, demolition rate: 0.1%

11.2.2.2 Heat demands

Cooling, lighting and auxiliary energy are not included in this assessment. Energy consumption for hot water has been assessed. Following Table 40 gives an overview of the useful space heating demand.

Table 40: Overview of the useful space heating demands in 2012 and 2050 for the three scenarios

Scenario	Retrofit rate	Useful space heating demand 2012 [TWh]	Useful space heating demand 2050 [TWh]	Reduction in 2050 compared to 2012 [%]
Shallow renovation	3%	2,562	2,870	12%
Shallow renovation +RES	2.3%	3,364	2,397	- 6%
Deep renovation	2.3%	3,364	1,208	- 47%

11.2.2.3 Investment costs

Based on investment costs for windows, insulation and building equipment (heating systems, etc.), the following Figure 72 and Figure 73 show the total investment costs per year required for the different scenarios.

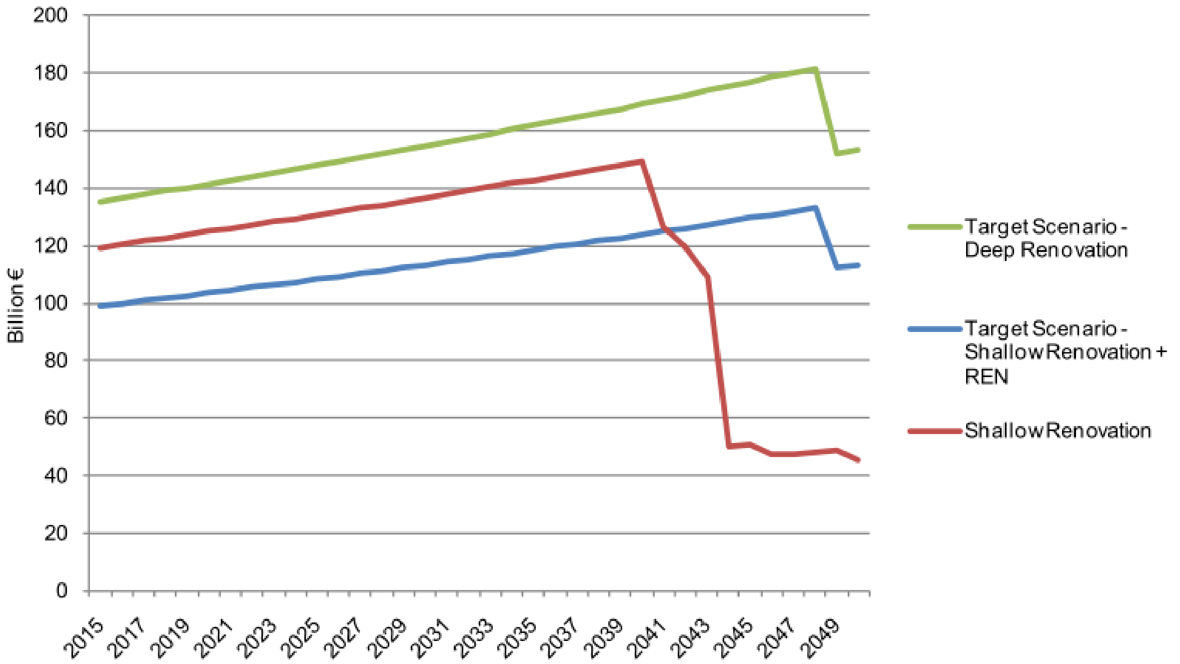

Figure 72: Annual investment costs for insulation and windows in the three scenarios created by Ecofys for energy efficiency in the EU27 [Boermans, Bettgenhäuser et al., 2012].

In the “shallow renovation” scenario (Track 1), higher investments are necessary (lower investments per building but more renovations per year assumed) until approximately 2044. After that time, the whole building stock is retrofitted in the shallow renovation scenario and investment costs are dropping. Just the part for new buildings is remaining.

For the “Target” scenarios (Tracks 2 and 3) retrofit activities continue to 2050. The “deep renovation” scenario shows higher investments in the building envelope.

Figure 73 shows the investments for heating and ventilation systems.

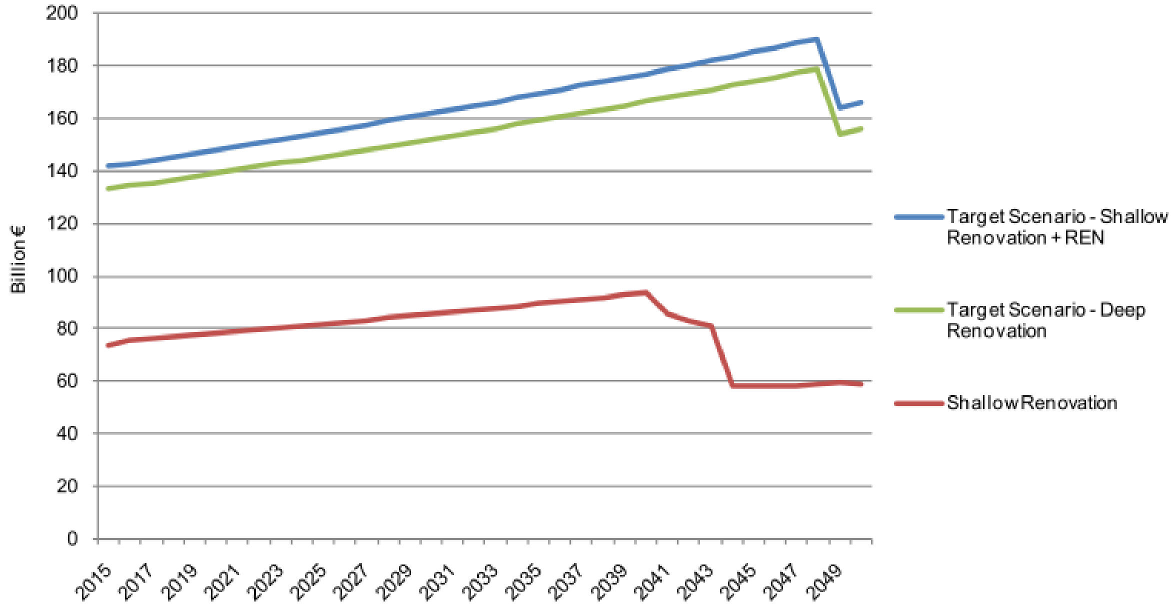

Figure 73: Investments for heating and ventilation systems per year EU27 [billion €/a]

Related to heating and ventilation system, the “shallow renovation” scenario (Track 1) shows lower necessary investments. This is a result of staying with standard fossil systems and not implementing ventilation systems in a large scale.

The following graph shows the total investment necessary for the different scenarios.

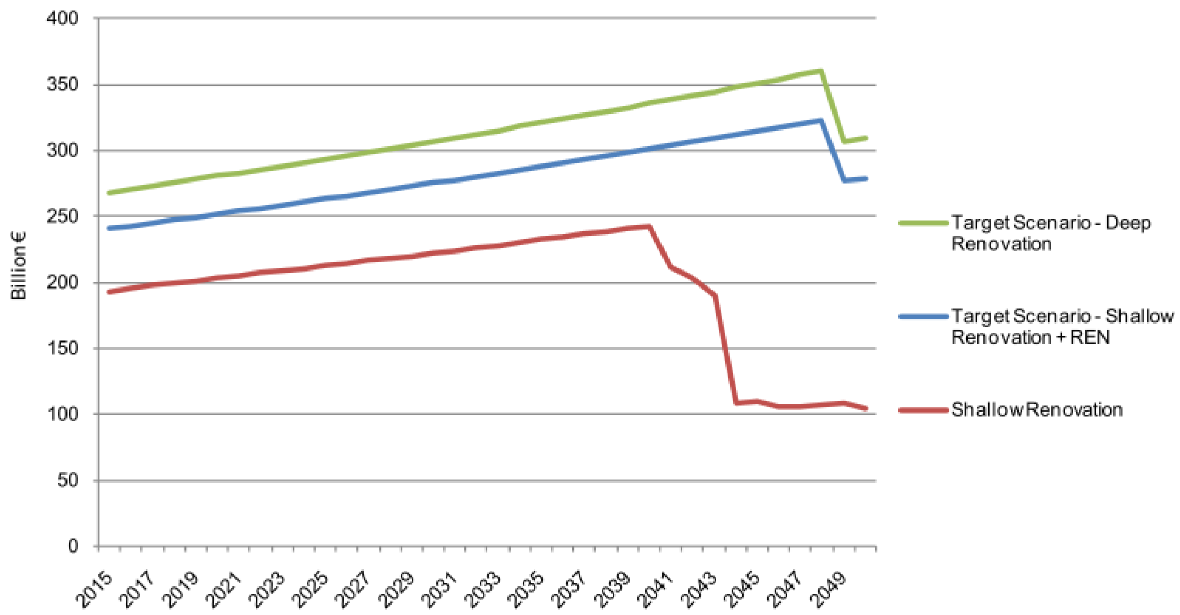

Figure 74: Investments for building envelope (insulation + windows) and heating + ventilation systems per year EU27 [billion €/a].

The "shallow renovation" scenario shows lower investments due to less extensive measures that are not overcompensated in terms of investments by the higher speed of implementation. Around 2044, the "shallow renovation" scenario drops in investments, because most retrofit activities will have finished, except at a low (shallow) ambition level.

The "shallow renovation + renewables" track shows approximately 50 billion EURO of additional investments per year compared to the "shallow renovation" track, while the "deep renovation" track triggers additional investments of approximately 80 billion EURO per year compared to the "shallow renovation" track.

Based on the assumption of approximately 17 jobs created per million invested[15] that would lead to 0.9 Million additional jobs (compared to the "shallow renovation" scenario) created and maintained in the "shallow renovation + high use of renewable energy scenario" and 1.4 million additional jobs in the "deep renovation scenario". After 2044, the difference will get even more significant, when investments drop in the "shallow renovation" scenario while renovations continue for the other tracks.

[15] Source: Urge-Vorsatz, D. (2011) et al. Employment Impacts of a Large-Scale Deep Building Energy Retrofit Programme in Hungary. Centre for Climate Change and Sustainable Energy Policy - Central European University & European Climate Foundation.

11.2.3 Recommendations for possible adaptations of the energy efficiency scenario

Hot water demand

The hot water demand should not be reduced in this study for the following reasons:

1. Table 37 indicates that population will grow by 3.2% between 2010 and 2050.
2. According to a number of interviews with industry experts, people tend to wash more today than they did in the past, which is likely to continue into the future. In other words, individuals are likely to take more showers and baths in the future than they do today.
3. Families are not expected to live with one another as much in the future. Hence, there will a larger number of people living in their own houses rather than living with their family. This is also expected to increase the demand for hot water for an individual.
4. At present, there are regions in Europe where the use of hot water is limited due to technical and financial limitations. As these regions become wealthier, the demand for hot water is expected to rise in these regions.
5. The building area for residential and non-residential buildings is expected to grow by 32% and 42% respectively between 2015 and 2050 (see Table 38).

For these reasons, the hot water demand is not expected to decrease in this study, even with appliances that use less water, pipes with more insulation, and better hot water management in buildings. Therefore, it is assumed here that the hot water will increase rather than decrease. It is unlikely that the hot water demand will increase as fast as the building area, since people will live in larger houses and use the hot water more efficiently. However, it is unlikely that the hot water demand will increase at a lower rate than the population, for the reasons outlined in 1-4 above. Therefore, it is assumed here that the hot water demand will grow at a rate between the residential floor area and the population, see Figure 75.

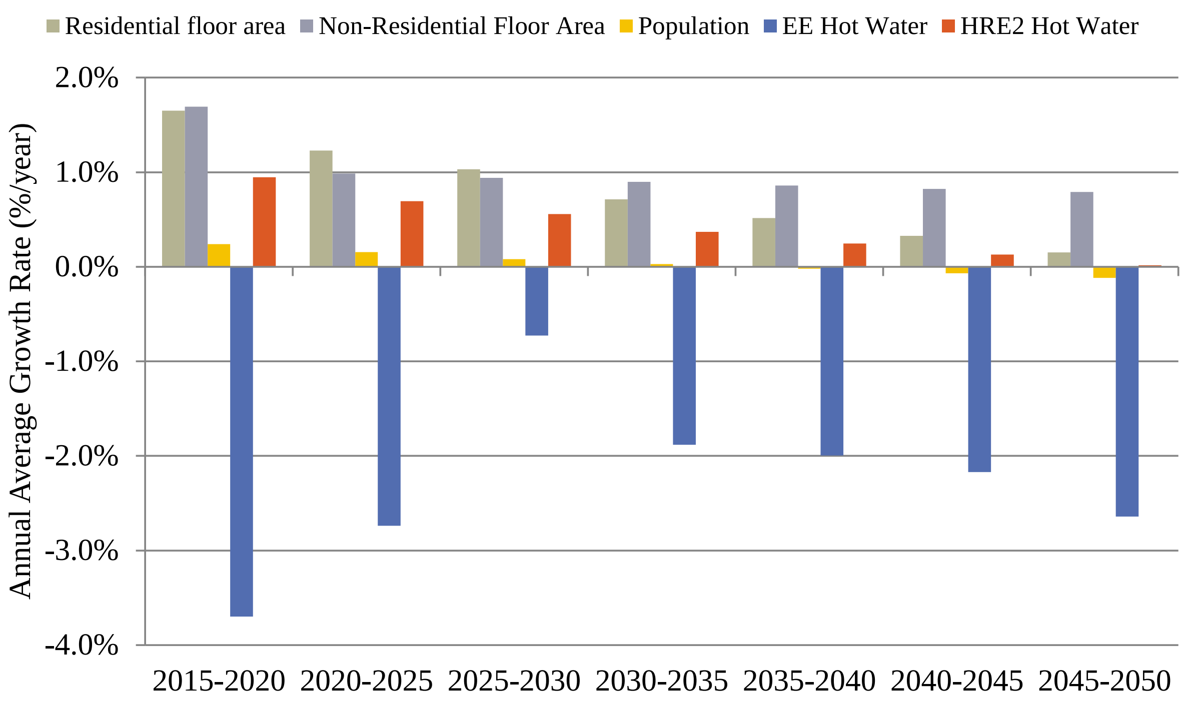

Figure 75: Average annual growth rates for the residential floor area, non-residential floor area, population, the original EE scenario hot-water demand, and the new hot water demand assumed in this study (which is based on the average annual growth rate for the residential floor area and the population).

The hot water demand in the new scenario is assumed to grow by 16% between 2015 and 2050 instead of reducing by 55% as in the original hot water demand projection for the EE scenario, as outlined in Figure 76. The specific hot water demand is assumed to drop from approximately 27 kWh/m^2 in 2015 to 23 kWh/m^2 in 2050, instead of from 27 kWh/m^2 to 9 kWh/m^2 as in the EE scenario (Figure 76).

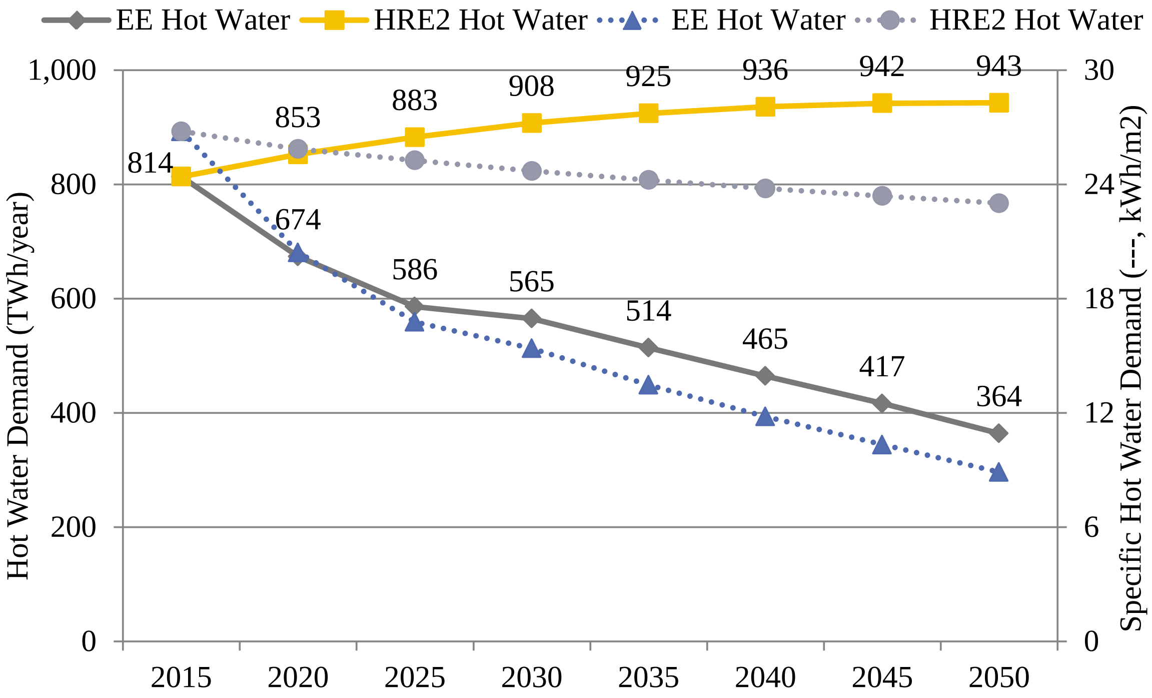

Figure 76: Original hot water demand in the EE scenario and the new hot water demand which is used in this study, along with the corresponding specific hot water demands (dotted lines).

Space heating demand

The space heating demand reductions calculated in the EE scenario seem very ambitious. For example, a quite ambitious scenario for energy efficiency measures presented in a recent report by EURIMA (European insulation Manufacturers Association) [Boermans, Bettgenhäuser et al., 2012], outlines that with deep renovations in the EU27, a space heating reduction of 47% or specific space heating demand (i.e. kWh/m^2) reduction of 62% will be possible between 2015 and 2050[16]. In the assessed deep renovation scenario bad performing buildings achieve savings of around 75% while the energy demand for the total stock is reduced by the mentioned 47%. Reasons for this are that the deep renovation scenario also takes into account new buildings. By 2050 the building stock will increase by about one third. Additionally, the scenario considers that buildings have been partly renovated which limits the saving potential. Finally, the scenario takes also into account the limitations in renovation for some

[16] The specific heat reduction (i.e. kWh/m^2) is greater than the absolute reduction (i.e. kWh) in space heating since the building area increases in combination with a decrease in the absolute heat demand.

buildings (e.g. some buildings will not be renovated due to cultural heritage, etc.). All these effects have an impact on the overall saving potential.

It is important to note that one significant difference between the Deep Renovation scenario and the EE scenario is the heat demand in 2015. As outlined in Figure 77, this is approximately 2,560 TWh in the Deep Renovation scenario, but it is approximately 3,220 TWh in the EE scenario. Looking at actual historical data from the International Energy Agency (IEA) indicates that the total heat demand for both space heating and hot water in 2010 was approximately 3,500 TWh. Data from the EE scenario estimates that this includes approximately 800 TWh of hot water demand (see Figure 76), which suggests that the space heating demand is approximately 2,700 TWh. Although this means that the heat demand in the Deep Renovation scenario is more likely closer to the current situation in Europe than the EE scenario, the HRE2 heat demand created for this study uses the same starting point as the EE scenario. This is to make the results of this study comparable to the analysis in the EE scenario since the principal objective here is to compare a scenario with energy efficiency only to a scenario with both energy efficiency and district heating. The final space heating demand assumed in the new HRE2 scenario is outlined in Figure 77.

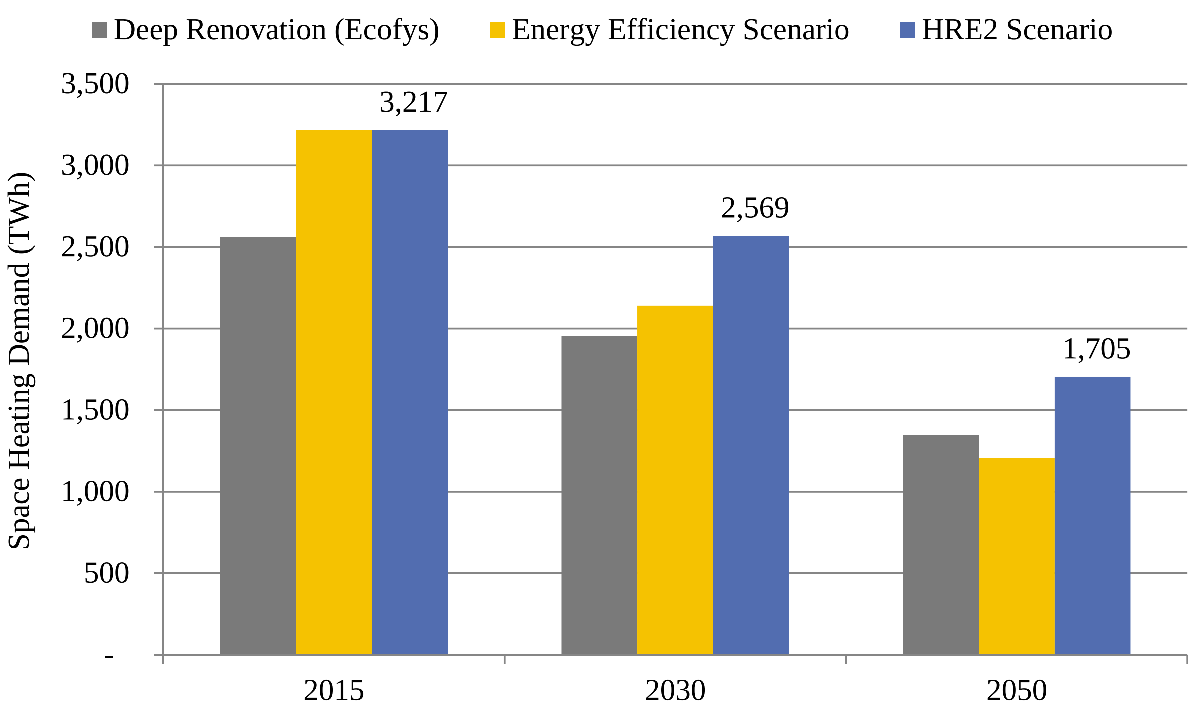

Figure 77: Space heating in the EE scenario from the *Energy Roadmap 2050* [9], the Deep Renovation scenario form Ecofys [Boermans, Bettgenhäuser et al., 2012], and the new space heating demand assumed in this study.

The final total heat demand for the new scenario assumed in this study is outlined in Figure 78: there is a total reduction of 34% between 2015 and 2050 in the HRE2 scenario instead of 61% as originally proposed in the EE scenario.

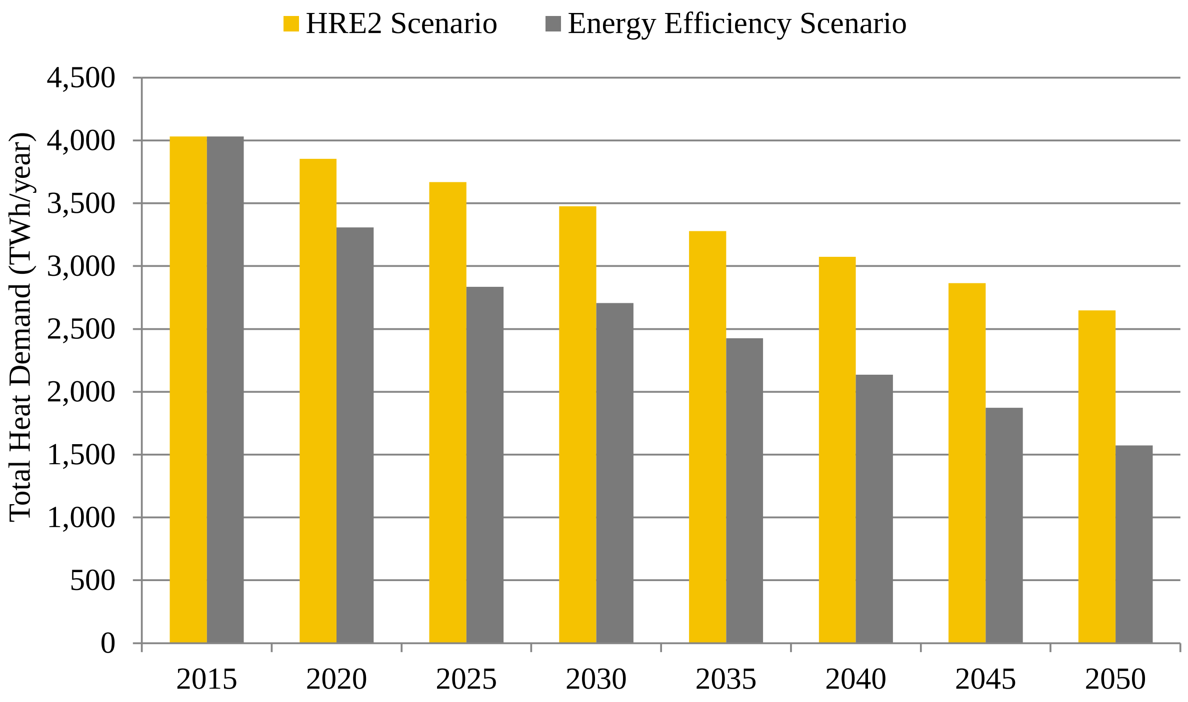

Figure 78: Total heat demand for the new scenario assumed in this study and the EE scenario for 2015-2050.

Costs of the measures

The cost of the energy efficiency measures in the EE scenario are estimated for three categories (costs for capital, energy purchases and for direct efficiency investments). We assume that a lot of the costs that refer to the measures of the EE scenario such as for example better appliances, new electric grids, the smart grid, and more renewable energy generation are counted for under capital costs. In consequence, the direct efficiency investments (B€295/year) would account for measures such as e.g. better insulation etc. The remaining question would then be where more efficient heating systems are accounted for.

The deep renovation track scenario includes investment costs for windows, insulation and building equipment (heating systems, etc.). The annual average investment costs for the energy efficiency measures in the Deep Renovation scenario completed by Ecofys for EURIMA are approximately B€160/year, although as outlined in Figure 72 these vary over the 45-year period including a steep drop in the last few years.

It is difficult to make a definite conclusion from the comparison of the two calculations since there are a lot of unknown assumptions behind the cost data in each report.

We recommend to adjust the cost for the energy efficiency measures downwards from the B€295/year in the EE scenario, since there are now less energy efficiency measures in the HRE2 heat demand forecast. To do so, an energy efficiency cost curve, which is displayed in Figure 79, has been utilised. This cost curve was developed based on data from the Danish Research Building Institute [Kragh,Wittchen, 2010] and a Danish Heat Atlas [Möller, 2008; Sperling,Möller, 2012]. The costs reflect the additional cost of energy efficiency measures, which means that they are implemented at the same time as other renovations are taking place in the building. Assuming a 3% interest rate and an average lifetime of 30 years for the energy efficiency measures, indicative annual costs of implementing energy efficiency measures in the EU27 have been estimated in Figure 80. These are indicative only since they reflect total energy savings and not the reduction in specific heat demand. However, these results demonstrate how the unit cost of energy savings increases as more savings are implemented. For example, the first B€200/year on energy savings in Europe will achieve savings of approximately 53%, while investments of B€400/year will only 22% more at 75%.

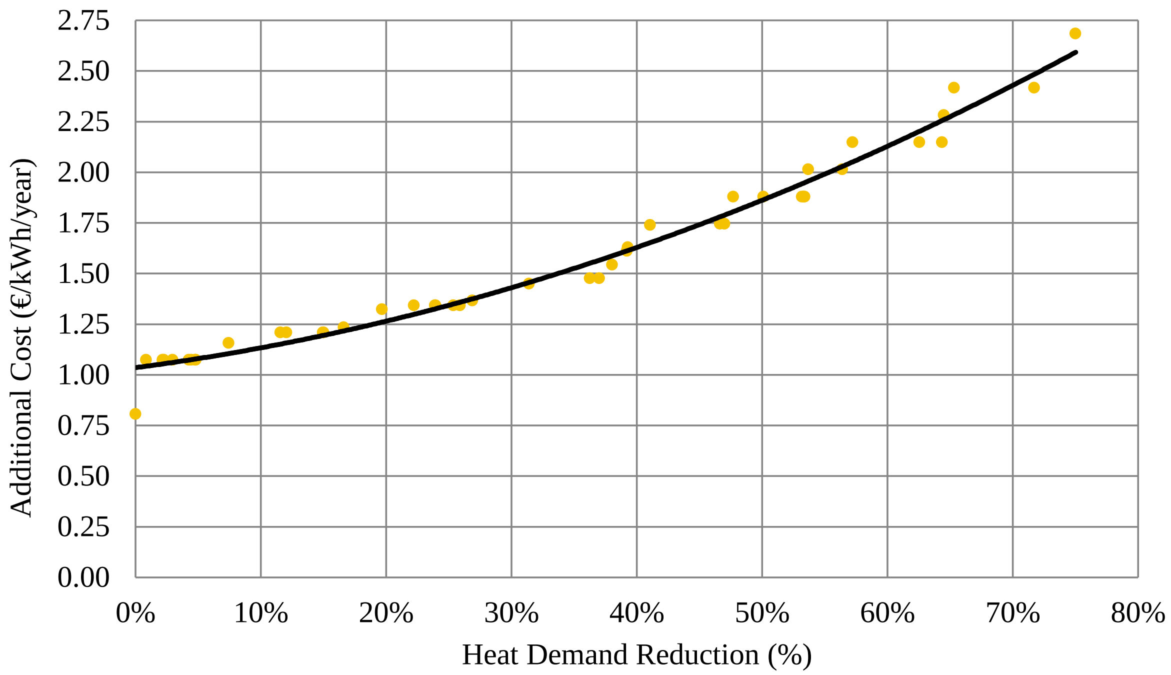

Figure 79: Additional costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings [Kragh,Wittchen, 2010].

As displayed in Figure 69, there is a total reduction of approximately 70% in the specific heat demand in the EE scenario, equating to total savings of 2,460 TWh. Assuming a cost of €2.4/kWh (18 DKK/kWh) based on the data in Figure 79, a 3% interest rate, and an average lifetime of 30 years for the energy efficiency measures, the annual costs of implementing the energy efficiency measures in the EE scenario are calculated as approximately B€303/year. This is very similar to the costs suggested in the EU Energy Roadmap report of B€295/year, although as mentioned previously the B€295/year may include savings in other sectors such as electricity and transport.

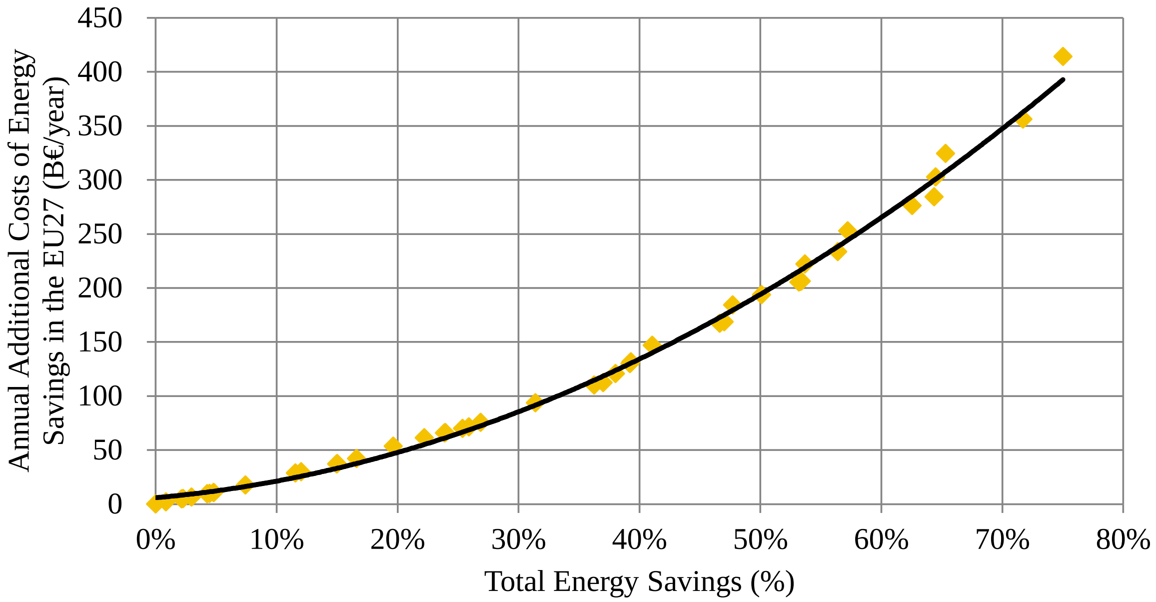

Figure 80: Annual 'additional' costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings [Kragh,Wittchen, 2010], an interest rate of 3%, and assuming an average lifetime of 30 years. These are indicative only as they not consider the change in specific heat demand, but instead it considers the change in total heat demand.

Using the same assumptions, the costs for the energy efficiency measures in the new HRE2 heat demand scenario can also be estimated. In the HRE2 scenario, there is a 51% reduction in the specific heat demand between 2015 and 2050, equating to a total energy saving of 1,215 TWh. Assuming a cost of €1.9/kWh (14 DKK/kWh), this means that the total annual costs for energy efficiency measures in this scenario are approximately B€133/year. Comparing this to the annual investment costs estimated by Ecofys in the EURIMA report [Boermans, Bettgenhäuser et al., 2012] suggests that this is a 17% underestimation of the total energy efficiency costs required. As displayed earlier in Figure 72, the average annual investments required in the Deep Renovation scenario (for a 47% reduction in space heating) are approximately B€160/year. This difference warrants further investigation in the future, but based on these comparisons, the indicate costs provided by the unit costs in Figure 79 are deemed an adequate representation of the variation in costs as more energy efficiency measures are implemented.

Overall, the EE scenario is extremely ambitious in terms of energy efficiency. Hence, a new HRE2 heat demand has been created for this study, which is also very ambitious in terms of energy efficiency since it follows the space heating recommendations of the Deep Renovation scenario created for EURIMA [Boermans, Bettgenhäuser et al., 2012]. This new HRE2 heat demand will be used to investigate the feasibility of district heating in a scenario with very low heat demands.

11.3 REFERENCES

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12 ANNEX IV: LOCAL CONDITIONS ILLUSTRATED BY MAPS

12.1 MAJOR COMBUSTION INSTALLATIONS FOR POWER AND HEAT GENERATION

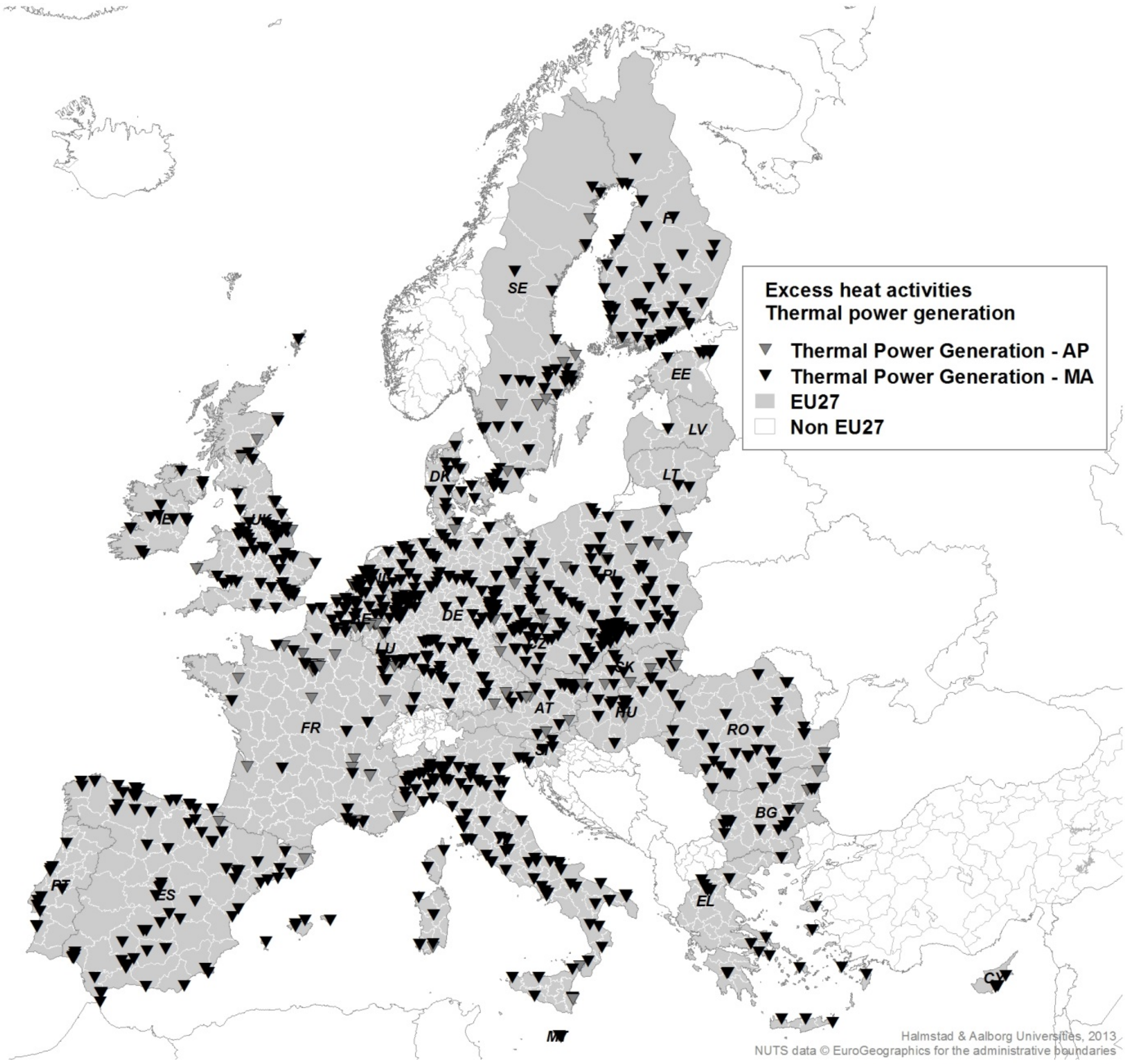


Figure 81: Major combustion installations above 50 MW for power and heat generation in Europe. Source: The E-PRTR database at EEA in Copenhagen.

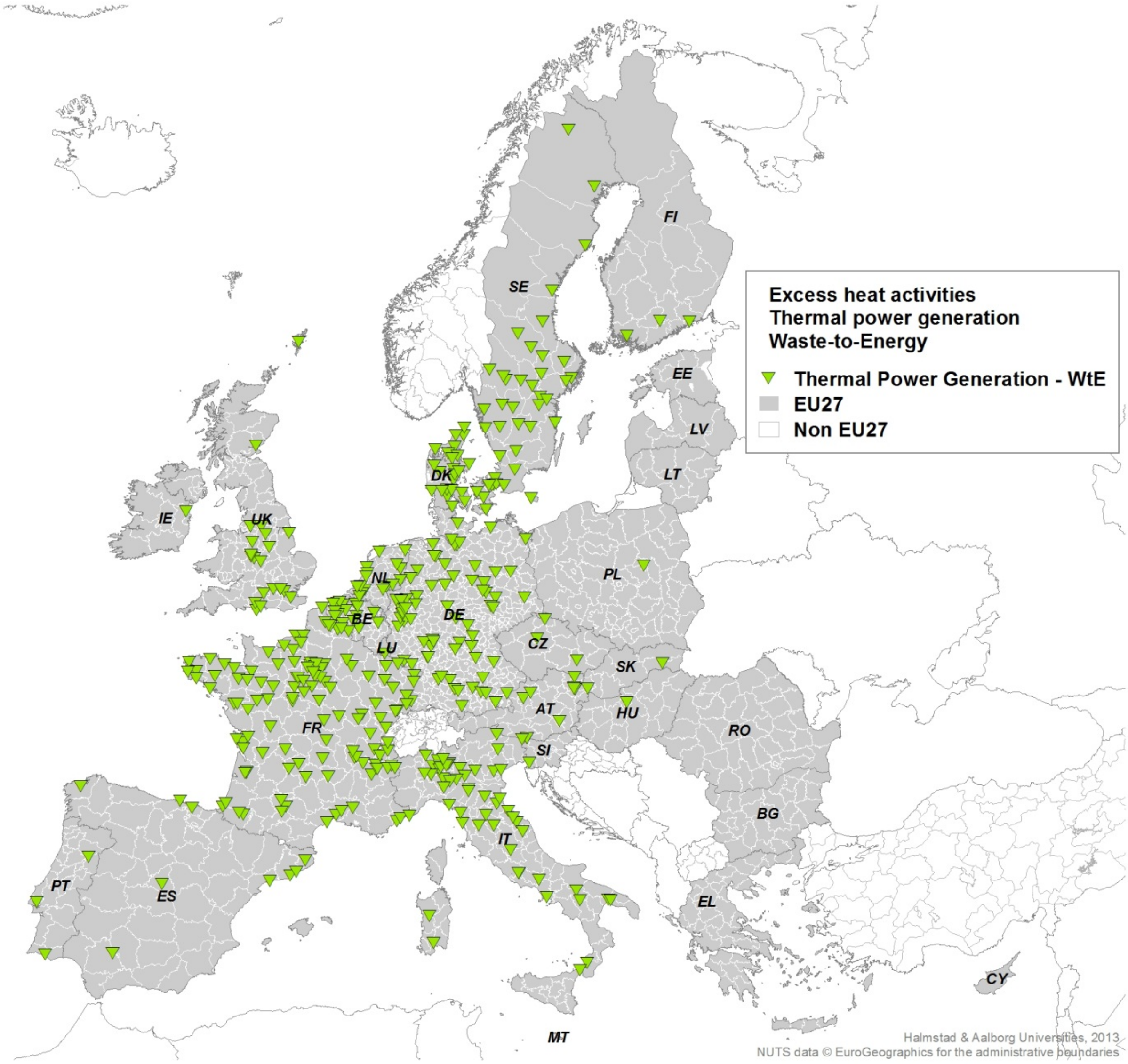


Figure 82: Locations of 410 waste incineration plants in Europe. Sources: CEWEP, E-PRTR, ISWA, and some national sources for Sweden, Denmark, and France.

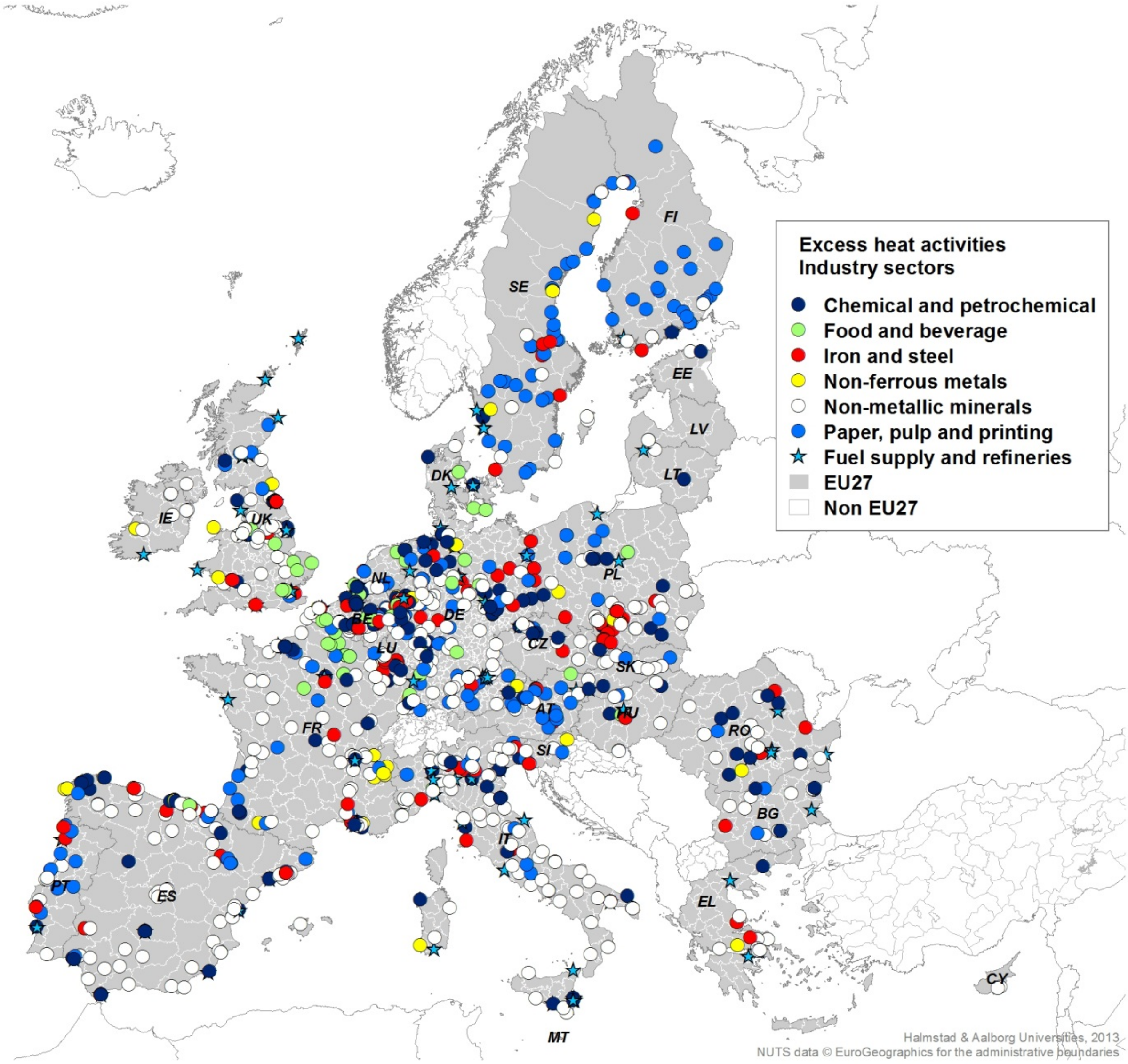


Figure 83: Locations of major energy intensive industries with considerable volumes of excess heat. Source: The E-PRTR database at EEA in Copenhagen.

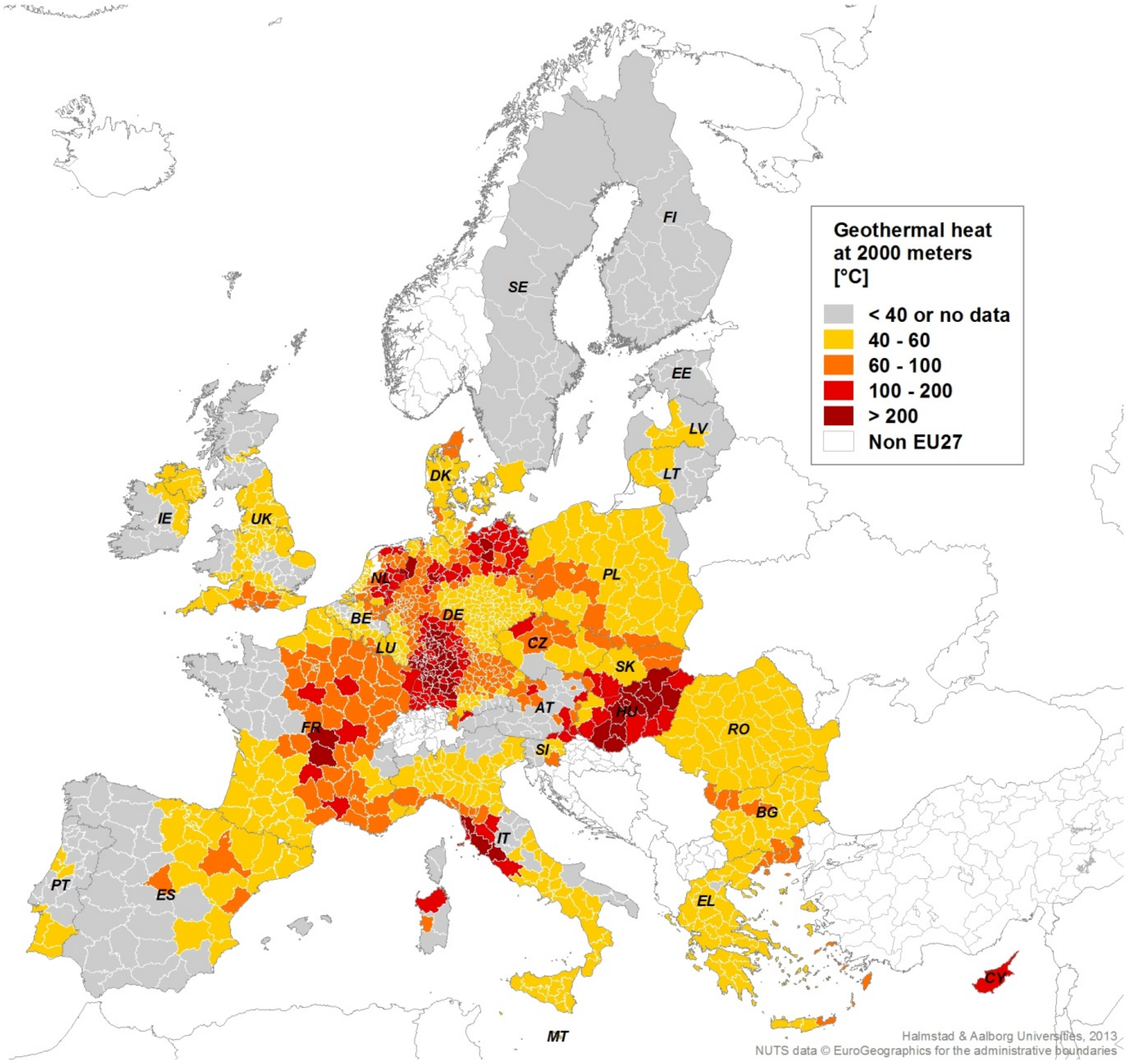


Figure 84: Identified geothermal heat resources by temperature at 2000 m depth by NUTS3 region. Source: European Commission, Atlas of Geothermal Resources in Europe. Publication EUR 17811, Luxembourg 2002.

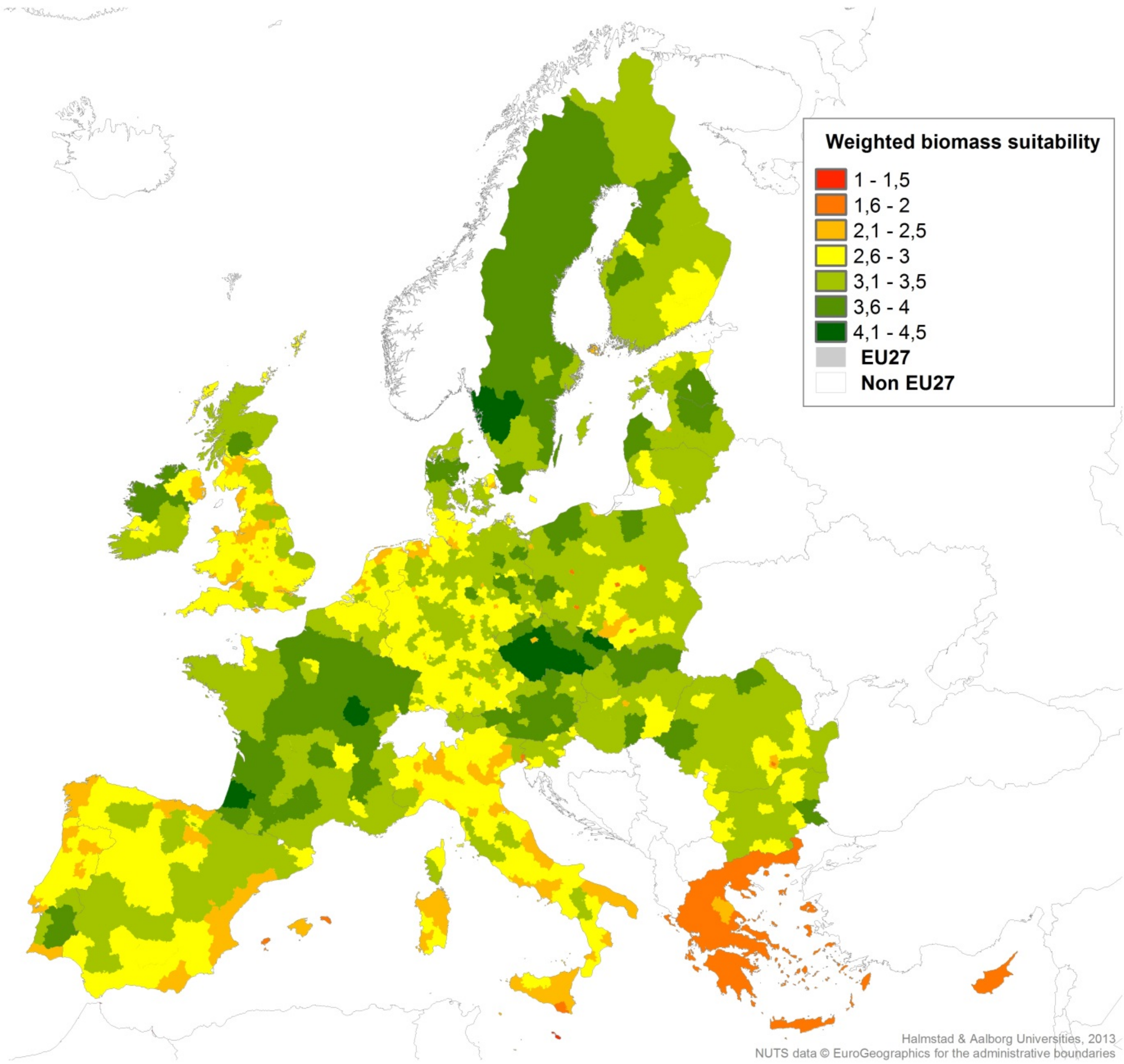


Figure 85: A qualitative map of local biomass availability based on a weighted overlay using forestry and agricultural statistics, forest density and land use for agriculture. Source: European Forest Institute.

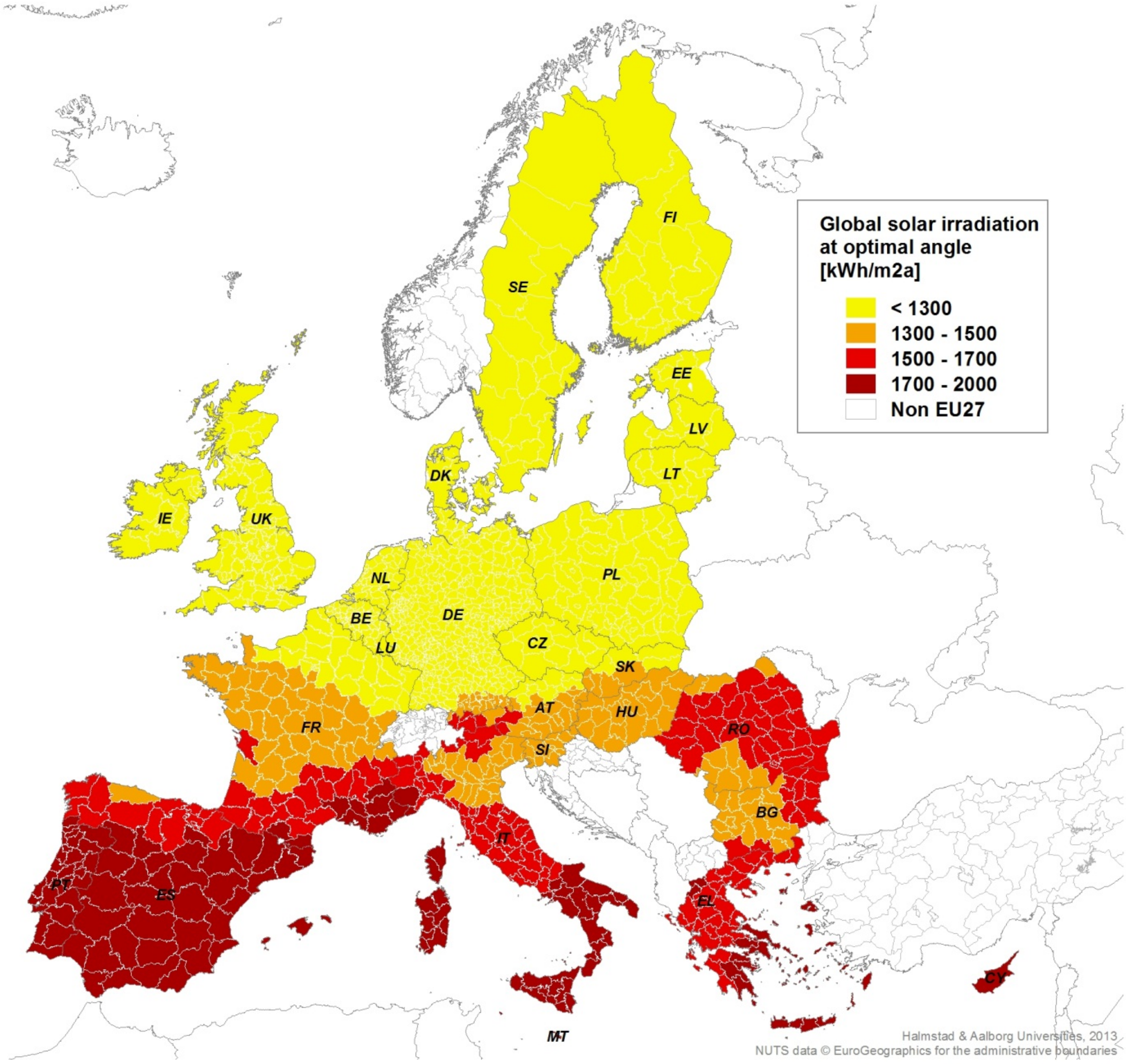


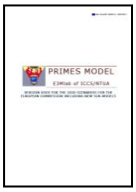
Figure 86: Annual solar irradiation on a south-oriented tilted surface at optimal angle by NUTS3 region.

12.7 NUTS3 REGION HOT SPOTS – FULL LIST

NUTS3 region	NUTS3 region Name	Country Code	Population [Mn]	Land area [km²]	Population density [n/km²]	Heat demand [PJ]	Excess heat [PJ]	Excess heat ratio [-]
AT312	Linz-Wels	AT	0.55	1744	322	16.7	29.7	1.8
AT315	Traunviertel	AT	0.23	2517	96	6.9	12.5	1.8
BE211	Arr. Antwerpen	BE	0.98	1000	1029	31.1	74.2	2.4
BE221	Arr. Hasselt	BE	0.41	906	456	13.0	18.1	1.4
BE234	Arr. Gent	BE	0.52	944	562	16.4	46.5	2.8
BE236	Arr. Sint-Niklaas	BE	0.26	475	516	7.4	7.6	1.0
BE251	Arr. Brugge	BE	0.28	661	422	8.6	10.7	1.2
BE254	Arr. Kortrijk	BE	0.28	403	696	8.8	19.6	2.2
BE322	Arr. Charleroi	BE	0.42	555	765	13.5	20.0	1.5
BE323	Arr. Mons	BE	0.25	584	433	7.9	10.9	1.4
BE332	Arr. Liège	BE	0.60	797	764	19.4	23.2	1.2
CZ042	Ústecký kraj	CZ	0.84	5335	160	19.0	134.9	7.1
CZ080	Moravskoslezský kraj	CZ	1.25	5426	235	28.1	45.0	1.6
DE122	Karlsruhe, Stadtkreis	DE	0.29	174	1680	9.5	30.8	3.2
DE126	Mannheim, Stadtkreis	DE	0.31	145	2150	10.3	6.8	0.7
DE211	Ingolstadt, Kreisfreie Stadt	DE	0.12	133	931	4.2	10.3	2.5
DE219	Eichstätt	DE	0.12	1215	103	4.2	5.4	1.3
DE21J	Pfaffenhofen an der Ilm	DE	0.12	761	154	3.9	8.3	2.1
DE712	Frankfurt am Main, Kreisfreie	DE	0.66	248	2692	22.0	10.6	0.5
DE929	Region Hannover	DE	1.13	2291	493	37.5	20.3	0.5
DEA11	Düsseldorf, Kreisfreie Stadt	DE	0.58	217	2697	18.8	10.3	0.5
DEA12	Duisburg, Kreisfreie Stadt	DE	0.49	233	2118	15.9	107.3	6.8
DEA13	Essen, Kreisfreie Stadt	DE	0.58	210	2748	18.7	5.6	0.3
DEA14	Krefeld, Kreisfreie Stadt	DE	0.24	138	1712	7.6	1.2	0.2
DEA17	Oberhausen, Kreisfreie Stadt	DE	0.22	77	2789	6.9	5.9	0.8
DEA19	Solingen, Kreisfreie Stadt	DE	0.16	90	1803	5.2	1.7	0.3
DEA1A	Wuppertal, Kreisfreie Stadt	DE	0.35	168	2091	11.4	7.4	0.7
DEA1C	Mettmann	DE	0.50	407	1223	16.1	5.4	0.3
DEA1D	Rhein-Kreis Neuss	DE	0.44	576	769	14.2	203.9	14.3
DEA1F	Wesel	DE	0.47	1042	452	15.1	37.1	2.4
DEA23	Köln, Kreisfreie Stadt	DE	1.00	405	2460	32.1	37.9	1.2
DEA24	Leverkusen, Kreisfreie Stadt	DE	0.16	79	2041	5.2	3.8	0.7
DEA27	Rhein-Erft-Kreis	DE	0.46	705	659	14.9	191.1	12.8
DEA31	Bottrop, Kreisfreie Stadt	DE	0.12	101	1168	3.8	0.9	0.3
DEA32	Gelsenkirchen, Kreisfreie Stadt	DE	0.26	105	2488	8.5	63.5	7.5
DEA36	Recklinghausen	DE	0.64	760	834	20.5	31.0	1.5
DEA46	Minden-Lübbecke	DE	0.32	1152	275	10.4	33.0	3.2
DEA51	Bochum, Kreisfreie Stadt	DE	0.38	145	2595	12.2	1.3	0.1
DEA54	Hamm, Kreisfreie Stadt	DE	0.18	226	805	5.9	24.7	4.2
DEA55	Herne, Kreisfreie Stadt	DE	0.17	51	3234	5.4	16.5	3.1
DEA5C	Unna	DE	0.42	543	765	13.5	55.7	4.1
DEB34	Ludwigshafen am Rhein,	DE	0.16	78	2104	5.4	35.0	6.5
FR232	Seine-Maritime	FR	1.25	6278	199	35.0	95.6	2.7
FR301	Nord (FR)	FR	2.57	5743	448	74.9	80.5	1.1
FR302	Pas-de-Calais	FR	1.46	6671	219	42.0	8.3	0.2
FR411	Meurthe-et-Moselle	FR	0.73	5246	140	22.1	25.2	1.1
FR511	Loire-Atlantique	FR	1.27	6815	187	33.1	44.8	1.4
FR824	Bouches-du-Rhône	FR	1.97	5088	388	46.6	90.6	1.9

Italy, Poland, and United Kingdom continue on next page.

NUTS3 region	NUTS3 region Name	Country Code	Population [Mn]	Land area [km²]	Population density [n/km²]	Heat demand [PJ]	Excess heat [PJ]	Excess heat ratio [-]
ITC11	Torino	IT	2.29	6830	341	49.1	25.5	0.5
ITC15	Novara	IT	0.37	1338	286	7.9	10.0	1.3
ITC16	Cuneo	IT	0.59	6903	86	11.9	10.5	0.9
ITC41	Varese	IT	0.87	1199	785	19.2	6.0	0.3
ITC45	Milano	IT	3.93	1984	2034	83.1	28.2	0.3
ITC46	Bergamo	IT	1.08	2723	408	23.5	11.1	0.5
ITC48	Pavia	IT	0.54	2965	190	11.1	41.5	3.7
ITD31	Verona	IT	0.91	3121	315	19.5	4.0	0.2
ITD36	Padova	IT	0.92	2142	440	19.9	5.5	0.3
PL227	Rybnicki	PL	0.64	1353	471	11.7	43.5	3.7
PL22A	Katowicki	PL	0.77	380	2016	14.1	11.7	0.8
PL22B	Sosnowiecki	PL	0.72	1800	399	13.3	73.8	5.6
PL522	Opolski	PL	0.62	5140	122	11.5	59.1	5.1
UKC11	Hartlepool and Stockton-on-	UK	0.28	298	947	6.8	12.8	1.9
UKC12	South Teesside	UK	0.28	299	932	6.7	49.3	7.4
UKD21	Halton and Warrington	UK	0.32	260	1218	7.5	51.0	6.8
UKD22	Cheshire CC	UK	0.69	2083	331	16.3	29.7	1.8
UKE13	North and North East	UK	0.32	1038	307	7.5	104.6	13.9
UKL21	Monmouthshire and Newport	UK	0.23	1041	220	5.2	5.9	1.1
UKL22	Cardiff and Vale of Glamorgan	UK	0.46	471	977	10.4	34.8	3.3
Total			**43.95**	**113029**		**1166.5**	**2389.0**	

Title:	**PRIMES model**	
Description from:	*Organization:*	
[53, 54]	National Technical University of Athens, Department of Electrical and Computer Engineering (E3MLab)	
Outlook year:		
n/a		

Objective:

Used for the 2010 scenarios for the European Commission.

Overview:

PRIMES simulates a market equilibrium solution for energy supply and demand [55]. 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 behaviour 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 [56], develop a climate change action and renewable energy policy package for the EU [57] and also, to analyse a number of different policies to reduce GHG in the EU25 by 2030 [58, 59]. Finally, PRIMES has been used for several EU governments as well as private companies.

How district heating is mentioned:

The optimisation is simultaneous for power, CHP, distributed steam, distributed heat, district heating and industrial boilers. The optimisation is inter-temporal (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.
Link to reports:	http://www.sciencedirect.com/science/article/pii/S0306261909004188 http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1569_2_prime_model.pdf

14 ANNEX VI: CHARACTERISTICS OF A SUITABLE ENERGY SYSTEMS ANALYSIS

In 2009 the European Council made the objective for the EU to decarbonisation its energy system to at least 80% below the 1990 level by 2050, without affecting general economic growth. One can imagine that there are a number of measures and technologies that could contribute to such a goal. The question is with which scenarios one could achieve these goals? We believe that any scenario developed for this objective should include the following two key elements:

A. An energy system in 2050 with 80% lower CO_2-emissions than 1990 will require radical technological changes, for both energy consumption and production compared to the energy system in the EU today.
B. This CO_2 reduction should be achieved with the lowest socio-economic costs.

Initially one should ask, which analysis and scenarios one wants to conduct? In Heat Road Map Europe 2, the aim is to analyse feasible and sustainable pathways to make energy efficient buildings and supply them with heat in the future as part of the overall target of the European Council. Also the scenarios conducted represent radical technological change compared to today, as the system changes from a predominately centralised system to a system with much more distributed and fluctuating energy sources. To conduct such analyses a number of key principles for choosing the tool used in the analyses have been considered, which EnergyPLAN is able to meet [60]. The tool should:

1. Include integrated analyses of the electricity and heat sector, in order to be able to identify synergies between these sectors – and preferably also include other sectors such as transport.
2. Use hour-by-hour simulations in order to take into account that the increasing amounts of fluctuating renewable energy in the European energy system changing from the current centralised energy system.
3. Be able to include changes in the energy demand hour-by-hour when implementing heat demand savings, since savings will reduce peak demands significantly.
4. Be able to identify energy systems with low socio-economic costs by implementing different technological alternatives.

Key principles 1-3 relate to the radical technological change principal in point A above. Key principle 4 relates to point B, which is to complete the analysis from a socio-economic perspective: this ensures that the cost burden on European citizens and businesses is comparably lower, which enables stronger economic development in the EU.

In Connolly *et al.* [54], a review of the different computer tools that can be used to analyse the integration of renewable energy was conducted. The paper provides the information necessary to direct the decision-maker towards a suitable energy tool for an analysis that must be completed. 68 tools were initially considered, but 37 were included in the final analysis which was carried out in collaboration with the tool developers or recommended points of contact. The typical applications for the tools reviewed ranges from analysing single-building systems to analysing national or international energy systems. Table 41 lists the tools that are included in the review along with a brief overview of how the models are defined. The different categories of tools are described in the paper as follows:

- A simulation tool simulates the operation of a given energy-system to supply a given set of energy demands. Typically a simulation tool is operated in hourly time-steps over a one-year time-period.
- A scenario tool usually combines a series of years into a long-term scenario. Typically scenario tools function in time-steps of 1 year and combine such annual results into a scenario of typically 20–50 years.
- An equilibrium tool seeks to explain the behaviour of supply, demand, and prices in a whole economy or part of an economy (general or partial) with several or many markets. It is often assumed that agents are price takers and that equilibrium can be identified.
- A top-down tool is a macroeconomic tool using general macroeconomic data to determine growth in energy prices and demands. Typically top-down tools are also equilibrium tools (see 3).
- A bottom-up tool identifies and analyses the specific energy technologies and thereby identifies investment options and alternatives.
- Operation optimisation tools optimise the operation of a given energy-system. Typically operation optimisation tools are also simulation tools (see 1) optimising the operation of a given system.
- Investment optimisation tools optimise the investments in an energy-system. Typically optimisation tools are also scenario tools (see 2) optimising investments in new energy stations and technologies.

Table 41: List and type of each tool reviewed in [54].

Tool	Type						
	Simulation	Scenario	Equilibrium	Top-Down	Bottom-Up	Operation Optimisation	Investment Optimisation
AEOLIUS	Yes	-	-	-	Yes	-	-
BALMOREL	Yes	Yes	Partial	-	Yes	Yes	Yes
BCHP Screening Tool	Yes	-	-	-	Yes	Yes	-
COMPOSE	-	-	-	-	Yes	Yes	Yes
E4cast	-	Yes	Yes	-	Yes	-	Yes
EMCAS	Yes	Yes	-	-	Yes	-	Yes
EMINENT	-	Yes	-	-	Yes	-	-
EMPS	-	-	-	-	-	Yes	-
EnergyPLAN	Yes	Yes	-	-	Yes	Yes	Yes
energyPRO	Yes	Yes	-	-	-	Yes	Yes
ENPEP-BALANCE	-	Yes	Yes	Yes	-	-	-
GTMax	Yes	-	-	-	-	Yes	-
H2RES	Yes	Yes	-	-	Yes	Yes	-
HOMER	Yes	-	-	-	Yes	Yes	Yes
HYDROGEMS	-	Yes	-	-	-	-	-
IKARUS	-	Yes	-	-	Yes	-	Yes
INFORSE	-	Yes	-	-	-	-	-
Inv*ert*	Yes	Yes	-	-	Yes	-	Yes
LEAP	Yes	Yes	-	Yes	Yes	-	-
MARKAL/TIMES	-	Yes	Yes	Partly	Yes	-	Yes
Mesap PlaNet	-	Yes	-	-	Yes	-	-
MESSAGE	-	Yes	Partial	-	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	-	-
NEMS	-	Yes	Yes	-	-	-	-
ORCED	Yes	Yes	Yes	-	Yes	Yes	Yes
PERSEUS	-	Yes	Yes	-	Yes	-	Yes
PRIMES	-	-	Yes	-	-	-	-
ProdRisk	Yes	-	-	-	-	Yes	Yes
RAMSES	Yes	-	-	-	Yes	Yes	-
RETScreen	-	Yes	-	-	Yes	-	Yes
SimREN	-	-	-	-	-	-	-
SIVAEL	-	-	-	-	-	-	-
STREAM	Yes	-	-	-	-	-	-
TRNSYS16	Yes	Yes	-	-	Yes	Yes	Yes
UniSyD3.0	-	Yes	Yes	-	Yes	-	-
WASP	Yes	-	-	-	-	-	Yes
WILMAR Planning Tool	Yes	-	-	-	-	Yes	-

From the methodology in the review paper a number of advantages can be identified using the EnergyPLAN tool compared to the other tools reviewed:

- It is a simulation and scenario tool that simulates the operation of a given energy system to supply a given set of energy demands.
- Conducts analyses in hourly time-steps over a one-year time-period.
- Uses bottom-up inputs for specific energy technologies and can identify investment options and alternatives.
- Can use different regulation strategies in order to optimise the operation of a given energy system.
- Can optimise investments in new energy technologies on the consumption and production side.
- Includes all sectors (electricity, heat, transport and gas).

- Has been used to conduct many energy system analysis of large-scale integration of renewable energy sources as well as energy savings, including case-studies of 100% renewable energy systems.
- The tool conducts either technical energy system analyses that seeks to make efficiency improvements in the energy conversion to reduce the primary energy supply.
- The tool conducts market economic system optimisation showing the socio-economic results regarding cost for the society analysed.
- The tool is open source, transparent, free of costs and all analyses and documentation is available online for previous analyses.

When analysing energy systems such as in this reports, EnergyPLAN, and other tools that have these properties, can avoid a lock-in to the existing technologies and markets. General equilibrium tools typically include current market conditions and current technologies that can make it difficult to identify new technological regimes and energy system designs. Such tools seek to explain the behaviour of supply, demand, and prices in the entire economy or part of an economy (general or partial) with several or many markets. It is often assumed that agents are price takers and that equilibrium can be identified. Having such agents included in the tool means that different current market designs are included and hence part of the analyses when looking at new scenarios. Such a methodology however can make it difficult to get the tool to identify and analyse new combinations of technologies or new uses of known technologies. In addition, general equilibrium tools as well as top-down tools (which use general macroeconomic data to determine growth in energy prices and demands) can make it hard to identify the lowest socio-economic costs of energy systems due to the fact that such approaches assume current market conditions and profit of agents (sometimes also assuming perfect market structures).

15 ANNEX VII: KEY ASSUMPTIONS WHEN MODELLING THE ENERGY EFFICIENCY SCENARIO

While transferring the original EU Energy Efficiency (EU-EE) scenario statistics from the *Energy Roadmap 2050* report [9] into the EnergyPLAN tool, a number of issues were identified. Below is an overview of these issues along with the assumptions made to overcome them. In the majority of cases, these issues simply reflect a misunderstanding in relation to, or a lack of information about, the original EU-EE scenario.

15.1 HOT WATER DEMAND IS REDUCED BY 50% BETWEEN 2015 AND 2050

This is discussed in section 5.1 of the main report.

15.2 MISMATCH IN THE TOTAL CO_2 EMISSIONS

The gross inland consumption from the Energy Efficiency scenario for 2010, 2030, and 2050 is outlined in the table below:

Table 42: Gross inland consumption for the Energy Efficiency scenario from the original statistics [9].

Unit	Energy Efficiency Scenario		
TWh	**2010**	**2030**	**2050**
PES / Gross Inland Consumption	20,391	16,883	12,610
Solids	3,269	1,531	516
Oil	7,385	5,764	1,948
Gas	5,150	4,041	2,986
Nuclear	2,733	1,878	1,700
Electricity	8	-24	-31
Renewable Energy	1,844	3,692	5,491

Some of this energy is not burned, but instead it is used for non-energy use purposes such as fertiliser production, plastics and road cover material. The total amount of energy utilised for non-energy purposes is available from the EU Energy Roadmap [12]: this is 1300 TWh (112 Mtoe) in 2010, 1400 TWh (121 Mtoe) in 2030, and 1140 TWh (98 Mtoe) in 2050. However, it is not possible to determine from the data available what type of fuel this is. Therefore, it is assumed that all of this is oil in 2010, 10% of this is gas and 90% is oil in 2030, while 50% is gas and 50% is oil in 2050. Originally, it was assumed to be all oil in all years, but with this assumption the total oil in the gross inland consumption would then be exceeded in 2050. Hence, a 50% split with gas is assumed in 2050 and 10% in 2030. This non-energy use consumption is then subtracted from the gross inland consumption to estimate the CO_2 emissions for the EU Energy Efficiency (EU-EE) scenario.

The following CO_2 emission factors are assumed in line with those reported by the European Topic Centre on Air and Climate Change [61]: coal 95 kg/GJ; oil 73 kg/GJ; and gas 56 kg/GJ. Nuclear, biomass, waste, and renewable energy are assumed to have no carbon dioxide emissions. Using these emission factors, the total CO_2 emissions are 3755 Mt in 2010, 2492 Mt in 2030, and 1026 Mt in 2050 (see Table

43). Using this methodology, the CO_2 emissions have been estimated accurately for 2030 and 2050, but there is a 7% error for the year 2050. This has been compensated for in this study by assuming that CCS captures less CO_2 than in the original Energy Efficiency scenario. Since it is assumed that CCS captures the same amount of CO_2 in all scenarios for each of the years, this will have very little impact on the results when comparing the EU-EE scenario with the HRE-EE scenario.

Table 43: Carbon dioxide emissions for the Energy Efficiency scenario [9].

Unit	Energy Efficiency Scenario		
Mt	**2010**	**2030**	**2050**
Final CO_2 Emissions from the Energy Efficiency (Ref Approach)	3,757	2,485	728
CO_2 Captured by CCS in the Energy Efficiency Scenario	0	17	377
Total CO_2 in the Energy Efficiency Scenario	3,757	2,502	1,105
Total CO_2 Estimated Here for the EU-EE scenario	3,755	2,492	1,026
Difference	-2	-10	-79
Difference (%)	0%	0%	7%

15.3 ASSUMPTIONS FOR THE HOURLY BALANCING ARE AMBITIOUS

As outlined in Figure 87, the EU-EE scenario has more electricity from intermittent renewable energy (+15%) and CCS (+13%) than the CPI scenario, while at the same time there is less electricity from nuclear (-7%) and CHP (-7%). Nuclear and CCS are typically operated as baseload technologies which means there is a net difference of ~6% in baseload electricity production between the EU-EE and the EU-CPI scenarios. Overall, this means that more intermittency has been added to the EU-EE scenario, more baseload has been added, and a flexible technology in the form of CHP has been reduced. However, the statistics also report that the annual trade of electricity is the same in both the CPI and EU-EE scenarios at a net export of 30-31 TWh. According to [12], “Electricity balancing and reliability is ensured endogenously by various means such as import and export flows (in case of high RES it is facilitated by expanding interconnections), investment in flexible thermal units, pumped storage and if required hydrogen based storage”. Therefore, it may be possible to have the same net export of electricity in the EU-EE and EU-CPI scenarios, but it likely to be extremely expensive considering the additional technologies in the EU-EE scenario.

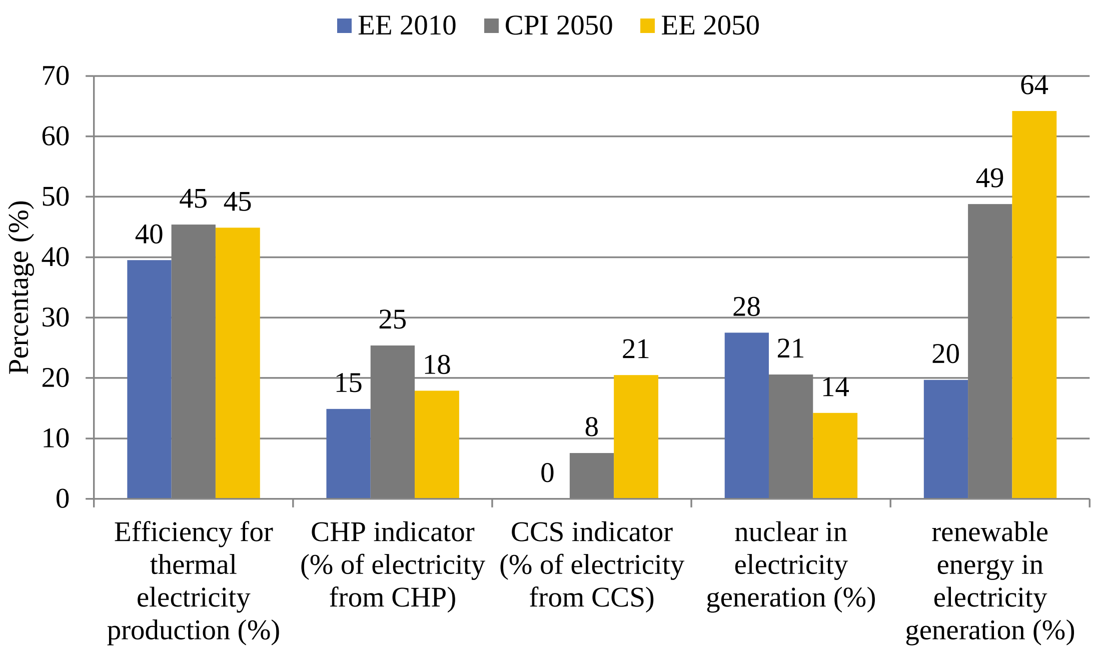


Figure 87: Indicators for gross electricity production in the EU-CPI scenario from the first pre-study [1] and the EU-EE scenario used in this study.

This problem is also evident in the results from the EnergyPLAN tool when modelling the EU-EE scenario. As outlined in the results for 2050 in Annex VIII, there is 100 TWh of net exports in the EU-EE scenario instead of the 31 TWh reported in the original statistics. This is due to imbalances between the hourly demand and supply of electricity. This indicates that the original statistics may not consider some of the issues that occur on an hourly level in the energy system, which can be essential for outlining the importance of district heating especially in relation to renewable energy. In this study, the annual export of electricity has been reduced by assuming that the CCS plants can operate in a flexible manner.

15.4 MISMATCH IN THE BIOMASS/WASTE STATISTICS

It is not possible to match the biomass statistics in the gross inland consumption figures with the breakdown of biomass from the *Energy Roadmap 2050* report. For example, Table 44 outlines the breakdown of biomass/waste based on bottom-up statistics, while Table 45 represents an estimate of the biomass/waste consumption based on a top-down approach using the gross inland consumption. According to Table 44, there is a biomass/waste consumption of 2,995 TWh in 2050, but according to Table 45 it is 2,809 TWh. It is assumed here that the bottom-up approach in Table 44 is correct, but by doing so it is not possible to match the gross inland consumption statistics for biomass/waste, which can be seen Annex VIII. This error is either a reporting error or a misinterpretation of some statistics from the *Energy Roadmap 2050* report. Therefore, it is not due to the EnergyPLAN model, but due to an error in the inputs. Overall, the difference is only approximately 5% of the biomass/waste consumed so it will not have a significant impact on the results.

Table 44: Breakdown of fuel consumption in 2050 for the EU-EE scenario

Fuel (TWh)	Total Final Consumption incl. Industry CHP	Elec & Heat Production	Boilers	Total Consumption
Solids	32	440	0	472
Oil	1,339	4	0	1343
Natural Gas	1,070	1229	29	2328
Biomass/Waste	1,633	1355	7	2995

Table 45: Gross inland consumption for renewable energy in the Energy Efficiency scenario

Year	2010	2030	2050
Total for Renewable Energy	1,844	3,692	5,491
Hydro	349	373	394
Wind	149	936	1,423
PV, tidal, etc.	17	164	452
Geothermal for PP	63	116	141
Geothermal for Buildings	12	33	60
Solar for Buildings	23	177	212
Total IRES	612	1,799	2,682
Total Remaining for Biomass/Waste	1,232	1,893	2,809

15.5 BIOMASS AND WASTE ARE RECORDED TOGETHER IN THE STATISTICS

Biomass and waste are recorded as one entity in the Energy Efficiency scenario statistics. This is not a major concern for the current energy system, but in the 2050 EU-EE scenario biomass/waste accounts for almost 25% of all energy (see Table 44 and Table 42). Therefore, it becomes important to know how much is waste and how much is biomass separately. According to the latest EU27 energy balance from the International Energy Agency, 182 TWh of waste was used in 2010. In this study, it is assumed that waste does not increase significantly between now and 2050 since district heating does not increase significantly in the EU-EE scenario. Therefore, it is assumed that there is approximately 200 TWh of waste in 200 TWh of waste in 2030 and 230 TWh of waste in 2050 in the EU-EE scenario.

15.6 ELECTRICITY LOSSES ARE VERY HIGH IN 2050

It is assumed that any difference between total electricity production and total electricity consumption in the statistics is caused by electricity losses. As outlined in Table 46, this means that 25% of all electricity produced is lost. This seems too high, but it is assumed here that in addition to transmission and distribution losses, the additional electricity required to CCS is also included here which explains the relatively high figure.

Table 46: Electricity consumption and production in the Energy Efficiency scenario.

Unit	Energy Efficiency Scenario		
TWh	**2010**	**2030**	**2050**
Electricity Consumption (TWh)	2,818	3,003	3,204
Electricity Losses (TWh)	502	442	1,077
Electricity Losses (% of consumption)	18%	15%	34%
Electricity Losses (% of production)	15%	13%	25%
Total Electricity Production	3,319	3,444	4,281

15.7 FUEL CONSUMPTION IN POWER PLANTS IS REPORTED BY TYPE RATHER THAN BY MODE

The Energy Efficiency scenario statistics report the total fuel consumed for power plants and CHP plants separately. However, the fuel consumed by a CHP plant could occur while the CHP plant is in condensing mode i.e. producing electricity only. As a result, it is not possible to determine from the statistics how much fuel is required while plants operate in back-pressure mode separately to the fuel required while plants operate in condensing mode. This is important to determine the amount of fuel consumed by CHP plants for district heating. To verify that the statistics make sense, the average heat efficiency of CHP plants is estimated based on the total fuel consumed and the total heat produced by CHP plants. For 2030 the average heat efficiency for CHP is 46% and in 2050 it is 44%. These are realistic values and so no changes were necessary.

15.8 DISTRICT HEATING HAD TO DIVIDED BETWEEN INDUSTRY AND BUILDINGS (I.E. RESIDENTIAL AND SERVICES)

The focus in this study is on the role of district heating for buildings for the residential and services sectors. However, statistics relating to district heating, CHP capacities, and boilers in the Energy Efficiency scenario statistics do not distinguish between these two forms. Therefore, to extract the statistics for the residential and services sectors separately, all of these statistics were divided based on the percentage of the total district heating demand required for the residential and services sectors. As outlined in Table 47, 25% of the district heating demand is for the residential and services sectors in 2030, while it is 17% in 2050. This means that the majority of district heating in the Energy Efficiency scenario is for the industrial sector in 2030 and 2050.

Table 47: Heat consumption by sector in the Energy Efficiency scenario.

Unit	Energy Efficiency Scenario		
TWh	**2010**	**2030**	**2050**
Industry	317	660	701
Households	240	187	108
Tertiary	116	86	52.4
Energy branch	105	132	72
Residential and Services (% of industry and energy branch)	45%	25%	17%

15.9 ELECTRICITY FOR HEATING IS NOT DIVIDED FOR DIRECT ELECTRIC HEATING AND HEAT PUMPS

To estimate the heat demand for individual units, the total fuel consumed is identified and then the heat demand is estimated based on average boiler efficiencies. In this study, the average boiler efficiencies in Table 48 have been used based on recommendations by Ecofys in Annex III.

Table 48: Average boiler efficiencies assumed in the Energy Efficiency scenario.

Boiler	2010	2030	2050
Solids	70%	70%	70%
Oil.	88%	88%	88%
Gas	89%	89%	89%
Biomass	75%	75%	75%
Solar	100%	100%	100%
Direct Electricity	100%	100%	100%
Geothermal	100%	100%	100%
Heat Pumps	275%	275%	275%

For electricity this methodology could not be used directly as electricity consumption for heating purposes is not divided between direct electricity and heat pumps. To divide these, the total heat demand in the years 2030 and 2050 was aligned with the statistics by adjusting the proportion of electricity used in direct electric heating and in heat pumps. For 2030, 40% of heat demand from electricity is provided by direct electric heating and 60% is provided by heat pumps. In 2050, this is 25% by direct electric heating and 75% from heat pumps. With these assumptions the total heat demand assumed here is the same as that reported in the statistics.

16 ANNEX VIII: DATA INPUT FOR MODELLING THE ENERGY EFFICIENCY SCENARIO

The tables in this annex summarises some of the key used when transferring the original Energy Efficiency scenario into the EnergyPLAN tool. For each piece of data, a value is provided from the original statistics, a value outlining how this was interpreted to create the reference, and finally the resulting value from the final EnergyPLAN model created.

<table>
<tr><td>Unit</td><td>Year</td><td colspan="3">2010 Energy Efficiency Scenario</td></tr>
<tr><td>TWh</td><td>Data</td><td>Statistics</td><td>Reference</td><td>EnergyPLAN</td></tr>
<tr><td rowspan="10">Demands</td><td>Electricity</td><td>2,818</td><td rowspan="2">3,319</td><td rowspan="2">3,319</td></tr>
<tr><td>Plus Additional Losses</td><td>502</td></tr>
<tr><td>Including Electric Heating</td><td>256</td><td>256</td><td>256</td></tr>
<tr><td>Including Electric Cooling</td><td>162</td><td>162</td><td>162</td></tr>
<tr><td>District Heating for Residential & Services</td><td>352</td><td>352</td><td rowspan="2">422</td></tr>
<tr><td>Plus Additional Losses</td><td></td><td>71</td></tr>
<tr><td>District Heating for Industry</td><td>321</td><td>321</td><td rowspan="2">419</td></tr>
<tr><td>Plus Additional Losses</td><td></td><td>98</td></tr>
<tr><td>Total District Heating Consumption</td><td>673</td><td>673</td><td>673</td></tr>
<tr><td>Total District Heating Production</td><td>842</td><td>842</td><td>841</td></tr>
<tr><td rowspan="9">Fuel for Electricity & District Heating for Residential & Services</td><td>Power Plants (excl. Waste & Nuclear)</td><td>3,137</td><td rowspan="2">3,447</td><td rowspan="2">3,433</td></tr>
<tr><td>Power Plants Operating in Condensing Mode</td><td>-</td></tr>
<tr><td>CHP Extraction Plants (excl. Waste & Nuclear)</td><td>762</td><td rowspan="2">621</td><td rowspan="2">623</td></tr>
<tr><td>Fuel Consumed in Back Pressure CHP Mode</td><td>-</td></tr>
<tr><td>Centralised Peak Boilers (excl. Waste)</td><td rowspan="2">134</td><td>40</td><td>26</td></tr>
<tr><td>Centralised Heat-Only Boilers (excl. Waste)</td><td>94</td><td>94</td></tr>
<tr><td>Nuclear Power Plants</td><td>2,733</td><td>2,733</td><td>2,733</td></tr>
<tr><td>Hydroelectricity</td><td>349</td><td>349</td><td>349</td></tr>
<tr><td>Intermittent RE: Wind, Solar PV, Wave, Tidal</td><td>166</td><td>166</td><td>167</td></tr>
<tr><td rowspan="15">Final Energy Consumption (excluding electricity & district heating)</td><td>Fuel Refinery Losses & Energy Industry Own Use*</td><td>*</td><td>657</td><td rowspan="4">3,782</td></tr>
<tr><td>Industry</td><td>2,158</td><td rowspan="3">3,126</td></tr>
<tr><td>Industry CHP & Boilers</td><td>889</td></tr>
<tr><td>Agriculture / Fishing (excluding oil)</td><td>80</td></tr>
<tr><td>Residential</td><td>2,503</td><td rowspan="2">3,365</td><td rowspan="2">3,365</td></tr>
<tr><td>Services</td><td>861</td></tr>
<tr><td>Transport</td><td>4,487</td><td>4,487</td><td></td></tr>
<tr><td>Jet Fuel</td><td>601</td><td>601</td><td>601</td></tr>
<tr><td>Petrol</td><td>1,215</td><td>1,215</td><td>1,215</td></tr>
<tr><td>Diesel</td><td>2,193</td><td rowspan="2">2,377</td><td rowspan="2">2,377</td></tr>
<tr><td>Agricultural Oil Consumption</td><td>184</td></tr>
<tr><td>Gas</td><td>9</td><td>9</td><td>9</td></tr>
<tr><td>LPG</td><td>63</td><td>63</td><td>63</td></tr>
<tr><td>Electricity</td><td>79</td><td>79</td><td>79</td></tr>
<tr><td>Biofuels</td><td>142</td><td>142</td><td>142</td></tr>
<tr><td rowspan="7">Total Fuel (excluding fuel for non-energy use)</td><td>Coal</td><td>3,269</td><td>3,269</td><td>3,262</td></tr>
<tr><td>Oil</td><td>6,083</td><td>6,083</td><td>6,078</td></tr>
<tr><td>Gas</td><td>5,150</td><td>5,150</td><td>5,135</td></tr>
<tr><td>Biomass/Waste</td><td rowspan="2">1,844</td><td>1,306#</td><td>1,305</td></tr>
<tr><td>Renewables</td><td>612</td><td>613</td></tr>
<tr><td>Nuclear</td><td>2,733</td><td>2,733</td><td>2,733</td></tr>
<tr><td>Total</td><td>19,080</td><td>19,153</td><td>19,126</td></tr>
<tr><td rowspan="2">CCO_2 (Mt)</td><td>Energy System</td><td>3,757</td><td>3,755</td><td>3,749</td></tr>
<tr><td>Assuming CO_2 Captured by CCS</td><td>0</td><td>0</td><td>0</td></tr>
</table>

*Based on the difference between final energy consumption and gross inland consumption minus fuel for non-energy use in the EU-EE statistics.

#Assuming that biofuels are counted in the primary energy supply and not the biomass required when creating those biofuels. See Annex VII for an explanation of the difference between the statistics and the reference.

Unit TWh	Year / Data	2030 Energy Efficiency Scenario: Statistics	Reference	EnergyPLAN
Demands	Electricity	3,003	3,444	3,444
	Plus Additional Losses	*442*		
	Including Electric Heating	*270*	270	270
	Including Electric Cooling	*183*	183	183
	District Heating for Residential & Services	270	270	337
	Plus Additional Losses		67	
	District Heating for Industry	663	663	781
	Plus Additional Losses		119	
	Total District Heating Consumption	933	933	1,203
	Total District Heating Production	1,118	1,118	1,118
Fuel for Electricity & District Heating for Residential & Services	Power Plants (excl. Waste & Nuclear)	1,238	1,238	1,201
	Power Plants Operating in Condensing Mode	-		
	CHP Extraction Plants (excl. Waste & Nuclear)	501	501	352
	Fuel Consumed in Back Pressure CHP Mode	-		
	Centralised Peak Boilers (excl. Waste)	103	35	112
	Centralised Heat-Only Boilers (excl. Waste)		69	69
	Nuclear Power Plants	1,878	1,878	1,879
	Hydroelectricity	373	373	373
	Intermittent RE: Wind, Solar PV, Wave, Tidal	1,100	1,100	1,100
Fuel for Electricity Imbalance	Annual Balance of Electricity (CEEP)	24	0	40
	Pumped Hydroelectric Energy Storage (PHES) Losses	-	-	4.1
	Additional Fuel for Power Plants due to CEEP & PHES Losses	-	-	39
	Extra Fuel for Power Plants in EnergyPLAN compared the Reference			-108
Final Energy Consumption (excluding electricity & district heating)	Fuel Refinery Losses & Energy Industry Own Use*	*	519	4,137
	Industry	1,904	3,621	
	Industry CHP & Boilers	1,663		
	Agriculture / Fishing (excluding oil)	54		
	Residential	1,743	2,318	2,318
	Services	575		
	Transport	4,026	4,026	
	Jet Fuel	743	743	743
	Petrol	814	814	814
	Diesel	1,701	1,816	1,816
	Agricultural Oil Consumption	115		
	Gas	5	5	5
	LPG	41	41	41
	Electricity	316	316	316
	Biofuels	291	291	290
Total Fuel (excluding fuel for non-energy use)	Coal	1,531	1,531	1,487
	Oil	4,498	4,498	4,498
	Gas	3,901	3,901	3,905
	Biomass/Waste	3,692	*1,919*#	1,851
	Renewables		1,799	1,799
	Nuclear	1,878	1,878	1,879
	Total	15,500	15,527	15,419
CO_2 (Mt)	Energy System	2,485	2,485	2,462
	Assuming CO_2 Captured by CCS	17	17	17

*Based on the difference between final energy consumption and gross inland consumption minus fuel for non-energy use in the EU-EE statistics.

#Assuming that biofuels are counted in the primary energy supply and not the biomass required when creating those biofuels. See Annex VII for an explanation of the difference between the statistics and the reference.

Unit	Year	2050 Energy Efficiency Scenario		
TWh	Data	Statistics	Reference	EnergyPLAN
Demands	Electricity	3,204	4,281	4,281
	Plus Additional Losses	*1,077*		
	Including Electric Heating	*281*	281	281
	Including Electric Cooling	*163*	163	163
	District Heating for Residential & Services	159	159	180
	Plus Additional Losses		21	
	District Heating for Industry	703	703	793
	Plus Additional Losses		90	
	Total District Heating Consumption	862	862	862
	Total District Heating Production	973	973	973
Fuel for Electricity & District Heating for Residential & Services	Power Plants (excl. Waste, Geothermal & Nuclear)	878	-	1,076
	Fuel Assumed for Power Plants Operating in Condensing Mode	-	878	
	CHP Extraction Plants (excl. Waste, Geothermal, & Nuclear)	327	-	202
	Fuel Assumed for CHP Operating in Back Pressure Mode	-	327	
	Centralised Peak Boilers (excl. Waste)	24	10	65
	Centralised Heat-Only Boilers (excl. Waste)		14	14
	Nuclear Power Plants	1,700	1,700	1,700
	Hydroelectricity	394	394	394
	Intermittent RE: Wind, Solar PV, Wave, Tidal	1,875	1,875	1,875
Fuel for Electricity Imbalance	Annual Balance of Electricity (CEEP)	31	0	101
	Pumped Hydroelectric Energy Storage (PHES) Losses	-	-	2.0
	Additional Fuel for Power Plants due to CEEP & PHES Losses	-	-	132
	Extra Fuel for Power Plants in EnergyPLAN compared the Reference			129
Final Energy Consumption (excluding electricity & district heating)	Fuel Refinery Losses & Energy Industry Own Use*	*	166	3,226
	Industry	1,208	3,068	
	Onsite and Offsite CHP & Boilers for Industrial Heat	1,796		
	Agriculture / Fishing (excluding oil)	64		
	Residential	790	1,069	1,069
	Services	278		
	Transport	2,679	2,679	2,678
	Jet Fuel	404	404	404
	Petrol	249	249	249
	Diesel	545	562	562
	Agricultural Oil Consumption	17		
	Gas	0	0	
	LPG	4	4	4
	Electricity	664	664	664
	Biofuels	795	795	795
Total Fuel (excluding fuel for non-energy use)	Coal	516	516	519
	Oil	1,378	1,378	1,378
	Gas	2,416	2,425	2,535
	Biomass/Waste	5,491	*2,995*#	*3,001*
	Renewables		2,682	2,682
	Nuclear	1,700	1,700	1,700
	Total	11,501	11,696	11,816
CO_2 (Mt)	Energy System	728	728	728
	Assuming CO_2 Captured by CCS	377	298	323^

*Based on the difference between final energy consumption and gross inland consumption minus fuel for non-energy use in the EU-EE statistics.; #Assuming that biofuels are counted in the primary energy supply and not the biomass required when creating those biofuels. See Annex VII for an explanation of the difference between the statistics and the reference.; ^The differences in the total CO_2 emissions have een compensated for by assuming less CO_2 is captured by CCS plants (see Annex VII). This does not affect the results since the same amount of CO_2 is captured by CCS in all scenarios.

17 ANNEX IX: KEY COSTS ASSUMED FOR THE ENERGY SYSTEM ANALYSES

Table 49: Key financial inputs assumed for electricity and heat production plants [45, 47, 62-67].

Production Type	Unit	Investment (M€/unit)	Lifetime (Years)	Fixed O&M (% of Investment)
Solar Thermal	TWh/year	440	20	0.001%
Small CHP	MWe	0.84	25	2.30%
Heat Pump Group 2	MWe	2.7	20	0.20%
Heat Storage CHP	GWh	3	20	0.70%
Large CHP	MWe	0.84	25	2.30%
Heat Pump Group 3	MWe	2.7	20	0.20%
Heat Storage Solar	GWh	3	20	0.70%
Boilers Group 2 & 3	MWth	0.15	20	3.00%
Coal Power Plants	MWe	2.04	40	2.80%
Gas Power Plants	MWe	0.87	25	3.45%
Oil Power Plants	MWe	1.455	32.5	3.00%
Biomass Power Plants	MWe	2.04	40	2.80%
Wind Onshore	MWe	(see Table 50)	20	2.45%
Wind Offshore	MWe	(see Table 50)	20	2.90%
Photovoltaic	MWe	(see Table 50)	30	2.04%
Wave Power	MWe	4.285	20	3.50%
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%
Nuclear	MWe	3	25	3.74%
Geothermal	MWe	2.63	20	3.42%
Alkaline Electrolyser	MWe	0.23	15	3.04%
SOEC Electrolyser	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 Solar Thermal	TWh/year	671	25	0.80%
Waste CHP	TWh/year	250.45	20	1.82%
Absorption Heat Pump	MWth	1.9	25	2.42%
Biogas Plant	TWh/year	376.5	20	11.25%
Gasification Plant	MWgas	0.649	20	9.77%
Biodiesel Plant	MW-Bio	0.272	20	1.00%
Bioethanol Plant	MW-Bio	1.920	20	3.32%
Bio-jetfuel Plant	MW	1.920	20	3.32%
Tidal	MWe	3.5	20	3.00%

Table 50: Investment costs assumed for wind and photovoltaic plants in 2010, 2030, and 2050 [47].

Investment Costs (M€/MW)	2010	2030	2050
Onshore Wind	1.4	1.22	1.16
Offshore Wind	2.7	2.2	2
Photovoltaic	2	1.1	0.9

Table 51: Fuel prices assumed [68].

€/GJ	Crude Oil (US$/bbl)	Natural Gas	Coal	Fuel Oil	Diesel	Petrol/JP1	LPG	Biomass	Nuclear
2011	82	5.9	2.7	8.8	11.7	12.7	13.2	6.8	1.5
2030	106	9.0	3.0	11.7	14.8	15.9	16.8	7.3	1.5
2050	127	10.9	3.2	14.3	17.6	18.6	19.9	8.4	1.5

Table 52: Fuel handling prices assumed [68].

€/GJ Fuel	Centralised Power Plants	Decentralised Power Plants & Industry	Consumer
Natural Gas	0.412	2.050	3.146
Coal	-	-	-
Fuel Oil	0.262	-	-
Diesel/Petrol	0.262	1.905	2.084
Jet Fuel	-	-	0.482
Straw	1.754	1.216	2.713
Wood Chips	1.493	1.493	
Wood Pellets	-	0.543	3.256
Energy Crops	1.493	1.493	

Table 53: Carbon prices assumed [68].

Year	CO2 Price (€/t)
2011	15.2
2020	28.6
2030	34.6
Projected assuming the same trends as in 2020-2030	
2040	40.6
2050	46.6

Table 54: Carbon dioxide emission factors assumed [61].

Fuel	Coal/Peat	Oil	Natural Gas
Emission Factor (kg/GJ)	95	73	56

18 ANNEX X: ENERGYPLAN OUTPUT SHEETS

18.1 EU-EE 2030

Input 0_EU27_PRIMES_ EE_2030.txt **The EnergyPLAN model 10.1**

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	2675.32	Fixed imp/exp.	0.00
Electric heating	168.00	Transportation	316.00
Electric cooling	183.00	Total	3342.32

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	55.00	0.00	282.00	337.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	8.90	8.90
Demand after solar and CSHP	55.00	0.00	273.10	328.10

Wind	366453	MW	936.00	TWh/year	0.00	Grid
Photo Voltaic	155047	MW	155.6	TWh/year	0.00	stabili-
Wave Power	4265	MW	8.5	TWh/year	0.00	sation
River Hydro	46301	MW	187.6	TWh/year	0.00	share
Hydro Power	72314	MW	185.31	TWh/year		
Geothermal/Nuclear	83003	MW	650.9	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.50	0.40	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	33571	37767	0.40	0.45	
Heat Pump	0	0			3.00
Boiler		105150		0.90	
Condensing	425271		0.40		

Heatstorage: gr.2: 10 GWh gr.3: 130 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:	733.00	10.60

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0.15	
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

DiGB_2020_market_price_400high.txt		
Addition factor	0.00	EUR/MWh
Multiplication factor	2.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	129	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	41900	252	0.85	
Hydro Turbine:	41900		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	3373.00	5.00	0.00
Household	49.40	550.20	1363.30	351.70
Industry	610.00	381.00	1606.00	1021.00
Various	257.00	207.00	55.00	0.00

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 GW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES GW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP GW	Stab- Load %	Imp MW	Exp GW	CEEP GW	EEP MW	Imp Million EUR	Exp Million EUR
January	60638	0	2698	9896	23097	0	0	24947	0	0	352	33726	19539	0	32124	2098	1516	175	21487	74101	84743	20531	65	267	0	4	4	0	0	379
February	62004	0	2698	10119	22154	0	0	27032	0	0	350	35979	20021	0	32917	2141	1547	185	23719	74101	84743	19693	57	253	0	5	5	0	0	468
March	53085	0	2698	8664	21021	0	0	20708	0	-5	330	37040	16859	0	27718	2039	1473	173	19480	74101	84743	18685	42	239	0	0	0	0	0	42
April	42887	0	2698	6999	24981	0	0	8366	0	-157	296	34875	13242	0	21771	737	533	101	23946	74101	84743	22205	60	304	0	0	0	0	0	0
May	34050	0	2698	5557	13940	0	0	11783	0	73	298	37949	10099	0	16605	3073	2220	164	15714	74101	84743	12391	18	226	0	6	6	0	0	530
June	16429	0	2238	2681	8776	0	0	2704	0	30	313	33933	3841	0	6315	1421	1027	130	21608	74101	84389	7801	49	268	0	10	10	0	0	992
July	16429	0	2238	2681	7651	0	0	3889	0	-31	318	36035	3841	0	6315	2268	1639	167	15641	74101	84389	6801	29	223	0	12	12	0	0	1232
August	16429	0	2238	2681	8961	0	0	2540	0	8	306	35950	3841	0	6315	1627	1176	127	19170	74101	84389	7965	41	258	0	2	2	0	0	207
September	24210	0	2696	3951	15209	0	0	2330	0	24	315	36755	6616	0	10878	867	598	115	21783	74101	84741	13519	60	284	0	0	0	0	0	0
October	35193	0	2698	5744	20388	0	0	6309	0	54	319	39456	10513	0	17285	1389	791	121	23122	74101	84743	18123	67	291	0	0	0	0	0	30
November	45630	0	2698	7447	20208	0	0	15293	0	-16	346	31555	14213	0	23368	780	812	171	20214	74101	84743	17963	63	256	0	16	16	0	0	1513
December	54140	0	2698	8836	30159	0	0	12433	0	15	364	38223	17232	0	28331	1229	888	129	27548	74101	84743	26808	106	328	0	0	0	0	0	27
Average	38365	0	2582	6261	18031	0	0	11491	0	0	325	35974	11633	0	19126	1644	1188	147	21097	74101	84654	16028	55	266	0	5	5	0	Average price	
Maximum	104710	0	2698	17089	37767	0	0	79785	0	29036	484	329324	35127	0	57753	41900	41900	484	44536	74101	84743	33571	262	539	0	293	293	0	(EUR/MWh)	
Minimum	14575	0	2238	2379	0	0	0	0	0	-27809	193	0	3197	0	5256	0	0	0	0	74101	84389	0	0	100	0	0	0	0	125	134
TWh/year	337.00	0.00	22.68	55.00	158.39	0.00	0.00	100.93	0.00	0.00	2858	316.00	102.18	0.00	168.00	14.44	10.43	1288	185.31	650.90	743.60	140.79	481		0.00	40	40	0.00	0	5420

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Synthetic Fuel	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	26.62	-	70.96	-	-	478.38	-	-	-	-	-	-	-	-	-	-	-	-	44.11	867.00	1487.07	-40.12	1446.95	508.58	494.86
Oil	-	-	14.75	-	9.02	10.67	-	-	-	-	-	-	-	-	-	-	-	3373.00	502.25	588.00	4497.70	-0.90	4496.80	1181.96	1181.76
N.Gas	32.02	-	107.49	-	103.13	710.29	-	-	-	-	-	-	-	-	-	-	-	46.00	1245.55	1661.00	3905.48	-59.57	3845.90	787.93	784.19
Biomass	10.11	-	158.77	-	-	1.94	-	-	53.00	-	341.88	-	-	-	-	-	-	-	316.23	1021.00	1902.94	-0.16	1902.77	0.00	0.00
Renewable	-	-	-	-	-	-	116.04	185.31	-	-	-	-	936.00	155.60	8.50	187.60	177.30	-	-	-	1766.35	0.00	1766.35	0.00	0.00
H2 etc.	-	-	0.00	-	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	0.00	-	-	-	-	-	-	-	-290.00	-	-	-	-	-	-	290.00	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	1878.64	-	-	-	-	-	-	-	-	-	-	-	-	-	1878.64	0.00	1878.64	-17.00	-17.00
Total	68.75	-	351.97	-	112.15	1201.29	1994.67	185.31	53.00	-	51.88	-	936.00	155.60	8.50	187.60	177.30	3709.00	2108.14	4137.00	15438.16	-100.76	15337.41	2461.51	2443.81

12-March-2013 [16:36]

Output specifications 0_EU27_PRIMES_ EE_2030.txt The EnergyPLAN model 10.1

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW
January	9896	0	0	9896	0	0	0	0	0	0	0	0	0	0
February	10119	0	0	10119	0	0	0	0	0	0	0	0	0	0
March	8664	0	0	8664	0	0	0	0	0	0	0	0	0	0
April	6999	0	0	6999	0	0	0	0	0	0	0	0	0	0
May	5557	0	0	5557	0	0	0	0	0	0	0	0	0	0
June	2681	0	0	2681	0	0	0	0	0	0	0	0	0	0
July	2681	0	0	2681	0	0	0	0	0	0	0	0	0	0
August	2681	0	0	2681	0	0	0	0	0	0	0	0	0	0
September	3951	0	0	3951	0	0	0	0	0	0	0	0	0	0
October	5744	0	0	5744	0	0	0	0	0	0	0	0	0	0
November	7447	0	0	7447	0	0	0	0	0	0	0	0	0	0
December	8836	0	0	8836	0	0	0	0	0	0	0	0	0	0
Average	6261	0	0	6261	0	0	0	0	0	0	0	0	0	0
Maximum	17089	0	0	17089	0	0	0	0	0	0	0	0	0	0
Minimum	2379	0	0	2379	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	55.00	0.00	0.00	55.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES specification RES1 Wind GW	RES2 Photo \ GW	RES3 Wave ! GW	RES4 River H GW	Total o GW
January	50742	0	2698	23097	0	0	24947	0	1	0	130	2	2	41	175
February	51884	0	2698	22154	0	0	27032	0	26	0	142	8	2	34	185
March	44421	0	2698	21021	0	0	20708	0	38	-5	123	15	1	34	173
April	35887	0	2698	24981	0	0	8366	0	71	-157	70	22	0	9	101
May	28493	0	2698	13940	0	0	11783	0	53	73	116	39	1	8	164
June	13748	0	2238	8776	0	0	2704	0	77	30	89	31	0	10	130
July	13748	0	2238	7651	0	0	3889	0	57	-31	105	38	0	24	167
August	13748	0	2238	8961	0	0	2540	0	67	8	80	25	0	22	127
September	20259	0	2696	15209	0	0	2330	0	75	24	86	14	1	13	115
October	29449	0	2698	20388	0	0	6309	0	74	54	101	8	1	11	121
November	38183	0	2698	20208	0	0	15293	0	47	-16	151	7	1	13	171
December	45304	0	2698	30159	0	0	12433	0	61	15	87	2	2	38	129
Average	32104	0	2582	18031	0	0	11491	0	54	0	107	18	1	21	147
Maximum	87621	0	2698	37767	0	0	79785	0	130	29036	366	155	4	46	484
Minimum	12196	0	2238	0	0	0	0	0	0	-27809	0	0	0	0	0
Total for the whole year TWh/year	282.00	0.00	22.68	158.39	0.00	0.00	100.93	0.00		0.00	936	156	9	188	1288

ANNUAL COSTS (Million EUR)

Total Fuel =		372271
Uranium =	10145	
Coal =	16060	
FuelOil =	40909	
Gasoil/Diesel=	135182	
Petrol/JP =	91940	
Ngas =	27561	
Biomass =	55473	
Food income =	-5000	
Waste =	0	
Marginal operation costs =		11509
Total Electricity exchange =		0
Import =	0	
Export =	-5420	
Bottleneck =	5420	
Fixed imp/ex=	0	
Total CO2 emission costs =		85168
Total Ngas Exchange costs =		125209
Total variable costs =		594157
Fixed operation costs =		54547
Annual Investment costs =		688013
TOTAL ANNUAL COSTS =		1336717

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	31251	15675	95650	259615	569	189094	591854	0	0	0	0	0	0	591854	591854	0
February	33511	15035	84952	261307	569	189094	584469	0	0	0	0	0	0	584469	584469	0
March	26202	14265	62331	216840	569	189094	509301	0	0	0	0	0	0	509301	509301	0
April	12623	16953	88318	156432	569	189094	463989	0	0	0	0	0	0	463989	463989	0
May	15274	9460	27080	112133	569	189094	353611	0	0	0	0	0	0	353611	353611	0
June	4323	5955	72845	21807	569	189094	294594	0	0	0	0	0	0	294594	294594	0
July	5534	5193	42237	26808	569	189094	269435	0	0	0	0	0	0	269435	269435	0
August	4156	6081	61054	28143	569	189094	289097	0	0	0	0	0	0	289097	289097	0
September	4682	10321	89386	73640	569	189094	367691	0	0	0	0	0	0	367691	367691	0
October	9790	13836	98321	132580	569	189094	444191	0	0	0	0	0	0	444191	444191	0
November	19961	13714	92800	187266	569	189094	503404	0	0	0	0	0	0	503404	503404	0
December	17847	20467	156280	228576	569	189094	612833	0	0	0	0	0	0	612833	612833	0
Average	15386	12237	80862	141797	569	189094	439945	0	0	0	0	0	0	439945	439945	0
Maximum	90884	25631	387163	468661	569	189094	921836	0	0	0	0	0	0	921836	921836	0
Minimum	1385	0	0	10664	569	189094	201712	0	0	0	0	0	0	201712	201712	0
Total for the whole year TWh/year	135.15	107.49	710.29	1245.55	5.00	1661.00	3864.48	0.00	0.00	0.00	0.00	0.00	0.00	3864.48	3864.48	0.00

RES Share: 23.8 Percent of Primary Energy 49.2 Percent of Electricity 1559.5 TWh electricity from RES 12-March-2013 [16:36]

18.2 HRE-EE 2030

Input 5_EU27_HRE_ EE&DH&RE_Cooling_2030_BiomassSameAsEE.txt The EnergyPLAN model 10.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	2675.32	Fixed imp/exp.	0.00
Electric heating	161.00	Transportation	316.00
Electric cooling	164.40	Total	3316.72

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	70.00	418.00	850.00	1338.00
Solar Thermal	0.00	19.30	30.86	50.16
Industrial CHP (CSHP)	0.00	20.00	38.90	58.90
Demand after solar and CSHP	70.00	378.70	780.24	1228.94

Wind	381000	MW	973.16	TWh/year	0.0(Grid
Photo Voltaic	155047	MW	155.6	TWh/year	0.0(stabili-
Wave Power	4265	MW	8.5	TWh/year	0.0(sation
River Hydro	46301	MW	187.6	TWh/year	0.0(share
Hydro Power	72314	MW	184.7	TWh/year	
Geothermal/Nuclear	83003	MW	650.9	TWh/year	

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	50000	40000	0.50	0.40	
Heat Pump	16000	48000			3.00
Boiler		155850		0.90	
Group 3:					
CHP	93571	105267	0.40	0.45	
Heat Pump	10000	30000			3.00
Boiler		317000		0.90	
Condensing	425271		0.40		

Heatstorage: gr.2: 200 GWh gr.3: 400 GWh
Fixed Boiler: gr.2: 1.0 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	11.15
Gr.3:	733.00	52.88

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0.15	
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

DiGB_2020_market_price_400high.txt

Addition factor	0.00	EUR/MWh
Multiplication factor	2.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	129	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	41900	252	0.85	
Hydro Turbine:	41900		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(	3373.00	5.00	0.00
Household	47.30	527.3(	1306.80	337.10
Industry	610.00	381.0(	1606.0(	1021.00
Various	257.00	207.00	55.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating: Demand	Production									Electricity: Consumption					
	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 GW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW
January	244227	543	23992	12596	74534	64242	0	68231	0	88	349	34162	46445	0	30785	2054
February	249648	2962	23992	12879	66635	65797	0	77401	0	-19	348	35975	47582	0	31546	2017
March	214237	4099	23992	11027	53922	60877	0	60507	0	-188	328	36580	41890	0	26563	2029
April	173746	9646	23992	8908	67677	44418	0	19628	0	-524	294	35349	31771	0	20864	708
May	138662	10875	23992	7073	30120	45751	0	20359	0	491	296	37537	28189	0	15913	2498
June	68700	9836	19278	3413	20896	15556	0	61	0	-339	311	34364	10106	0	6051	1582
July	68700	8872	19278	3413	15057	21840	0	97	0	144	315	36009	12201	0	6051	2165
August	68700	8621	19278	3413	19902	17629	0	85	0	-227	303	35981	10797	0	6051	1819
September	99594	7187	23973	5029	40669	20834	0	1434	0	470	313	36843	15421	0	10425	1041
October	143200	3826	23992	7310	59650	35181	0	13104	0	137	317	38801	25195	0	16565	1310
November	184638	1205	23992	9478	60689	49245	0	40477	0	-449	344	32137	34624	0	22395	633
December	218426	678	23992	11246	100760	48512	0	33215	0	24	361	37787	38247	0	27151	1211
Average	155795	5697	22806	7969	50827	40778	0	27749	0	-31	323	35974	28496	0	18329	1593
Maximum	419204	69037	23992	21750	145267	78000	0	253440	0	48822	482	342384	71003	0	55347	41900
Minimum	61340	0	19278	3027	0	476	0	0	0	-52618	190	0	4255	0	5037	0
TWh/year	1368.50	50.04	200.32	70.00	446.46	358.19	0.00	243.75	0.00	-0.27	2840	316.00	250.31	0.00	161.00	13.99

	Electricity: Production							Balance					Exchange: Payment	
	Tur- bine MW	RES GW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP GW	PP GW	Stab- Load %	Imp MW	Exp GW	CEEP GW	EEP MW	Imp Million EUR	Exp Million EUR
January	1752	181	21856	74101	91275	73	22	269	0	2	2	0	0	241
February	1458	190	23426	74101	91275	65	23	256	0	4	4	0	0	363
March	1284	178	17034	74101	91275	53	21	241	0	0	0	0	0	39
April	699	104	19107	74101	91275	66	27	302	0	0	0	0	0	3
May	1518	169	14717	74101	91275	29	7	224	0	6	6	0	0	587
June	1439	134	25838	74101	89140	21	29	260	0	11	11	0	0	1053
July	1564	172	18521	74101	89140	15	16	217	0	14	14	0	0	1341
August	1314	131	21888	74101	89140	20	24	251	0	2	2	0	0	239
September	485	118	21517	74101	91266	40	31	275	0	0	0	0	0	0
October	926	125	20186	74101	91275	59	29	287	0	0	0	0	0	45
November	746	177	20020	74101	91275	60	25	253	0	14	14	0	0	1381
December	607	132	28440	74101	91275	99	40	327	0	0	0	0	0	29
Average	1151	151	21026	74101	90737	50	24	263	0	5	5	0	Average price	
Maximum	41900	497	59036	74101	91275	144	159	536	0	288	288	0	(EUR/MWh)	
Minimum	0	0	0	74101	89140	0	0	100	0	0	0	0	125	134
TWh/year	10.11	1325	184.70	650.90	797.04	438	215		0.00	40	40	0.00	0	5320

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Synthetic Fuel	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	26.62	-	70.96	-	-	478.38	-	-	-	-	-	-	-	-	-	-	-	-	42.16	867.00	1485.12	-38.87	1446.24	507.91	494.61
Oil	-	-	14.75	-	9.02	10.67	-	-	-	-	-	-	-	-	-	-	-	3373.00	481.28	588.00	4476.72	-0.87	4475.85	1176.4[illegible]	1176.25
N.Gas	50.77	287.53	492.08	23.53	225.28	45.99	-	-	-	-	-	-	-	-	-	-	-	46.00	1193.99	1661.00	4026.17	-59.48	3966.68	812.27	808.54
Biomass	10.11	-	158.77	13.00	-	1.94	-	-	212.40	-	341.88	-	-	-	-	-	-	-	303.10	1021.00	2062.20	-0.16	2062.05	0.00	0.00
Renewable	-	-	-	-	-	-	116.04	184.70	-	-	-	-	973.16	155.60	8.50	187.60	220.04	-	-	-	1845.63	0.00	1845.63	0.00	0.00
H2 etc.	-	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	0.00	-	-	-	-	-	-	-	-290.00	-	-	-	-	-	-	290.00	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	1878.64	-	-	-	-	-	-	-	-	-	-	-	-	-	1878.64	0.00	1878.64	-17.00	-17.00
Total	87.50	287.53	736.56	36.53	234.30	536.98	1994.67	184.70	212.40	-	51.88	-	973.16	155.60	8.50	187.60	220.04	3709.00	2020.53	4137.00	15774.47	-99.38	15675.08	2479.6[illegible]	2462.41

12-March-2013 [16:37]

Output specifications 5_EU27_HRE_ EE&DH&RE_Cooling_2030_BiomassS The EnergyPLAN model 10.1

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage GW	Gr.2 Balance MW
January	12596	0	0	12596	75213	226	8396	19298	36200	0	11004	0	67	88
February	12879	0	0	12879	76907	1234	8396	16994	37722	0	12565	0	65	-6
March	11027	0	0	11027	65844	1696	8396	12803	33649	0	9498	0	99	-198
April	8908	0	0	8908	53195	3781	8396	16764	22934	0	1374	0	100	-55
May	7073	0	0	7073	42234	4244	8396	7475	21470	0	493	0	104	157
June	3413	0	0	3413	20378	3494	6727	5405	4722	0	61	0	97	-31
July	3413	0	0	3413	20378	3215	6727	3956	6370	0	97	0	99	13
August	3413	0	0	3413	20378	3108	6727	5183	5315	0	79	0	94	-34
September	5029	0	0	5029	30029	2871	8389	10860	7839	0	97	0	98	-27
October	7310	0	0	7310	43652	1549	8396	16121	17083	0	366	0	89	137
November	9478	0	0	9478	56597	502	8396	15984	27027	0	4735	0	72	-48
December	11246	0	0	11246	67153	282	8396	26421	27243	0	4836	0	114	-25
Average	7969	0	0	7969	47587	2183	7976	13093	20592	0	3743	0	92	-2
Maximum	21750	0	0	21750	129877	28765	8396	40000	48000	0	58216	0	200	25143
Minimum	3027	0	0	3027	18078	0	6727	0	476	0	0	0	0	-25220
Total for the whole year TWh/year	70.00	0.00	0.00	70.00	418.00	19.18	70.06	115.01	180.88	0.00	32.88	0.00		-0.02

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW
January	156418	317	15596	55236	28041	0	57227	0	0	0
February	159862	1728	15596	49641	28075	0	64836	0	16	-13
March	137366	2403	15596	41119	27228	0	51009	0	10	11
April	111643	5865	15596	50913	21484	0	18254	0	135	-469
May	89355	6631	15596	22646	24281	0	19866	0	206	335
June	44910	6342	12550	15491	10835	0	0	0	360	-308
July	44910	5657	12550	11101	15471	0	0	0	251	131
August	44910	5513	12550	14719	12313	0	6	0	191	-192
September	64536	4317	15583	29809	12995	0	1337	0	268	497
October	92238	2276	15596	43530	18098	0	12738	0	185	0
November	118563	703	15596	44705	22218	0	35742	0	175	-401
December	140028	395	15596	74339	21270	0	28379	0	237	49
Average	100239	3513	14829	37733	20185	0	24006	0	170	-29
Maximum	267577	43957	15596	105267	30000	0	195225	0	400	40458
Minimum	40234	0	12550	0	0	0	0	0	0	-51607
Total for the whole year TWh/year	880.50	30.86	130.26	331.45	177.31	0.00	210.87	0.00		-0.25

RES specification

	RES1 Wind GW	RES2 Photo V GW	RES3 Wave P GW	RES4 River H GW	Total o GW
January	135	2	2	41	181
February	148	8	2	34	190
March	128	15	1	34	178
April	72	22	0	9	104
May	120	39	1	8	169
June	93	31	0	10	134
July	110	38	0	24	172
August	83	25	0	22	131
September	90	14	1	13	118
October	105	8	1	11	125
November	157	7	1	13	177
December	91	2	2	38	132
Average	111	18	1	21	151
Maximum	381	155	4	46	497
Minimum	0	0	0	0	0
Total for the whole year TWh/year	973	156	9	188	1325

ANNUAL COSTS (Million EUR)

Total Fuel =		372454
Uranium =	10145	
Coal =	16039	
FuelOil =	40909	
Gasoil/Diesel=	133860	
Petrol/JP =	91940	
Ngas =	29177	
Biomass =	55384	
Food income =	-5000	
Waste =	0	
Marginal operation costs =		11763
Total Electricity exchange =		0
Import =	0	
Export =	-5320	
Bottleneck =	5320	
Fixed imp/ex=	0	
Total CO2 emission costs =		85796
Total Ngas Exchange costs =		129119
Total variable costs =		599133
Fixed operation costs =		57452
Annual Investment costs =		567095
TOTAL ANNUAL COSTS =		1223680

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	78149	130250	4785	248856	569	189094	651703	0	0	0	0	0	0	651703	651703	0
February	87601	116183	4908	250481	569	189094	648835	0	0	0	0	0	0	648835	648835	0
March	69290	93054	4452	207857	569	189094	564316	0	0	0	0	0	0	564316	564316	0
April	26945	117496	5802	149960	569	189094	489867	0	0	0	0	0	0	489867	489867	0
May	26706	52307	1429	107498	569	189094	377604	0	0	0	0	0	0	377604	377604	0
June	2518	36511	6147	20919	569	189094	255758	0	0	0	0	0	0	255758	255758	0
July	2544	26371	3384	25711	569	189094	247673	0	0	0	0	0	0	247673	247673	0
August	2538	34810	5137	26989	569	189094	259136	0	0	0	0	0	0	259136	259136	0
September	5145	71404	6602	70596	569	189094	343410	0	0	0	0	0	0	343410	343410	0
October	19172	104926	6281	127090	569	189094	447132	0	0	0	0	0	0	447132	447132	0
November	48448	106330	5390	179506	569	189094	529337	0	0	0	0	0	0	529337	529337	0
December	41936	176417	8584	219103	569	189094	635703	0	0	0	0	0	0	635703	635703	0
Average	34105	88753	5235	135928	569	189094	453685	0	0	0	0	0	0	453685	453685	0
Maximum	265081	256282	34052	449238	569	189094	994457	0	0	0	0	0	0	994457	994457	0
Minimum	2196	0	0	10222	569	189094	202251	0	0	0	0	0	0	202251	202251	0
Total for the whole year TWh/year	299.58	779.61	45.99	1193.99	5.00	1661.00	3985.17	0.00	0.00	0.00	0.00	0.00	0.00	3985.17	3985.17	0.00

RES Share: 24.8 Percent of Primary Energy 50.2 Percent of Electricity 1649.5 TWh electricity from RES 12-March-2013 [16:37]

18.3 EU-EE 2050

Input 0_EU27_PRIMES_ EE_2050.txt **The EnergyPLAN model 10.1**

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	3176.06	Fixed imp/exp.	0.00
Electric heating	124.00	Transportation	664.00
Electric cooling	163.00	Total	4127.06

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	11.30	0.00	169.00	180.30
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	8.90	8.90
Demand after solar and CSHP	11.30	0.00	160.10	171.40

Wind	547588 MW	1422.90	TWh/year	0.00	Grid
Photo Voltaic	329948 MW	434.7	TWh/year	0.00	stabili-
Wave Power	8804 MW	17.5	TWh/year	0.00	sation
River Hydro	53102 MW	204.52	TWh/year	0.00	share
Hydro Power	72314 MW	189.2	TWh/year		
Geothermal/Nuclear	80518 MW	622.2	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.50	0.40	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	25916	25916	0.45	0.45	
Heat Pump	0	0			3.00
Boiler		57250		0.90	
Condensing	425271		0.55		

Heatstorage: gr.2: 0 GWh gr.3: 80 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:	804.00	7.90

Regulation Strategy:	Technical regulation no. 2
KEOL regulation	00000000
Minimum Stabilisation share	0.00
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

DiGB_2020_market_price_400high.txt

Addition factor	0.00 EUR/MWh
Multiplication factor	1.00
Dependency factor	0.00 EUR/MWh pr. MW
Average Market Price	65 EUR/MWh
Gas Storage	0 GWh
Syngas capacity	0 MW
Biogas max to grid	0 MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	47900	287	0.85	
Hydro Turbine:	47900		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	1215.00	0.00	0.00
Household	0.60	59.30	511.10	483.60
Industry	333.00	82.00	1040.00	1605.00
Various	44.00	35.00	87.00	0.00

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 GW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP GW	Stab-Load %	Imp MW	Exp GW	CEEP GW	EEP MW	Imp Million EUR	Exp Million EUR
January	30721	0	2269	1925	14236	0	0	12354	0	-63	415	71778	28711	0	22716	454	328	255	23652	70834	92496	14236	85	100	0	3	3	0	0	160
February	31342	0	2269	1964	12993	0	0	14049	0	67	414	75602	29375	0	23241	485	351	279	21644	70834	92496	12993	78	100	0	12	12	0	0	621
March	27261	0	2269	1709	11310	0	0	12079	0	-105	388	78898	25027	0	19801	980	708	271	19016	70834	92496	11310	51	100	0	3	3	0	0	142
April	22598	0	2269	1416	13566	0	0	5329	0	18	347	74216	20054	0	15867	0	0	179	25447	70834	92496	13566	76	100	0	0	0	0	0	0
May	18553	0	2269	1163	6654	0	0	8443	0	25	348	80243	15734	0	12449	3413	2466	287	13384	70834	92496	6654	15	100	0	28	28	0	0	1294
June	10477	0	1926	657	5638	0	0	2191	0	65	361	70527	7130	0	5641	1379	996	233	19471	70834	92232	5638	43	100	0	20	20	0	0	1015
July	10477	0	1926	657	4764	0	0	3218	0	-88	366	75488	7130	0	5641	1531	1106	287	14314	70834	92232	4764	21	100	0	35	35	0	0	1746
August	10477	0	1926	657	5956	0	0	1890	0	47	352	75695	7130	0	5641	454	328	217	19614	70834	92232	5956	41	100	0	6	6	0	0	282
September	14057	0	2267	881	9141	0	0	1753	0	14	365	76104	10946	0	8660	0	0	190	24506	70834	92495	9141	74	100	0	0	0	0	0	0
October	19083	0	2269	1196	11346	0	0	4246	0	27	372	82658	16303	0	12899	0	0	193	25012	70834	92496	11346	92	100	0	0	0	0	0	0
November	23860	0	2269	1495	10641	0	0	9522	0	-68	406	65989	21390	0	16923	764	552	265	20124	70834	92496	10641	81	100	0	29	29	0	0	1432
December	27745	0	2269	1739	18215	0	0	5467	0	56	427	79406	25540	0	20207	0	0	186	32398	70834	92496	18215	153	100	0	0	0	0	0	0
Average	20526	0	2182	1286	10364	0	0	6694	0	-1	380	75592	17842	0	14117	793	573	237	21539	70834	92429	10364	67	100	0	11	11	0	Average price	
Maximum	50903	0	2269	3190	25916	0	0	45444	0	23319	565	573861	50141	0	39671	47900	47900	816	42754	70834	92496	25916	399	100	0	507	507	0	(EUR/MWh)	
Minimum	9647	0	1926	605	0	0	0	0	0	-18800	228	0	6245	0	4941	0	0	0	0	70834	92232	0	0	100	0	0	0	0	64	67
TWh/year	180.30	0.00	19.17	11.30	91.04	0.00	0.00	58.80	0.00	-0.01	3339	664.00	156.73	0.00	124.00	6.96	5.03	2080	189.20	622.20	811.90	91.04	592		0.00	100	100	0.00	0	6692

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	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	-	-	38.36	-	-	103.40	-	-	-	-	-	-	-	-	-	-	-	-	0.46	377.00	519.22	-17.51	501.72	177.57	171.59
Oil	-	-	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1215.00	45.55	117.00	1378.17	0.00	1378.17	362.18	362.18
N.Gas	9.97	-	45.16	-	18.07	937.67	-	-	-	-	-	-	-	-	-	-	-	4.00	393.46	1127.00	2535.34	-158.74	2376.60	511.18	479.99
Biomass	3.89	-	118.17	-	47.27	35.25	-	-	39.50	-	1017.65	-	-	-	-	-	-	-	356.94	1605.00	3223.67	-5.97	3217.70	0.00	0.00
Renewable	-	-	-	-	-	-	141.00	189.20	-	-	-	-	1422.90	434.70	17.50	204.52	211.89	-	-	-	2621.70	0.00	2621.70	0.00	0.00
H2 etc.	-	-	0.00	-	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	0.00	-	-	-	-	-	-	-	-795.00	-	-	-	-	-	-	795.00	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	1700.03	-	-	-	-	-	-	-	-	-	-	-	-	-	1700.03	0.00	1700.03	-323.00	-323.00
Total	13.87	-	202.31	-	65.33	1076.33	1841.03	189.20	39.50	-	222.65	-	1422.90	434.70	17.50	204.52	211.89	2014.00	796.42	3226.00	11978.14	-182.22	11795.92	727.94	690.76

12-March-2013 [16:37]

Output specifications 0_EU27_PRIMES_ EE_2050.txt The EnergyPLAN model 10.1

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age MW	Gr.2 Ba-lance MW
January	1925	0	0	1925	0	0	0	0	0	0	0	0	0	0
February	1964	0	0	1964	0	0	0	0	0	0	0	0	0	0
March	1709	0	0	1709	0	0	0	0	0	0	0	0	0	0
April	1416	0	0	1416	0	0	0	0	0	0	0	0	0	0
May	1163	0	0	1163	0	0	0	0	0	0	0	0	0	0
June	657	0	0	657	0	0	0	0	0	0	0	0	0	0
July	657	0	0	657	0	0	0	0	0	0	0	0	0	0
August	657	0	0	657	0	0	0	0	0	0	0	0	0	0
September	881	0	0	881	0	0	0	0	0	0	0	0	0	0
October	1196	0	0	1196	0	0	0	0	0	0	0	0	0	0
November	1495	0	0	1495	0	0	0	0	0	0	0	0	0	0
December	1739	0	0	1739	0	0	0	0	0	0	0	0	0	0
Average	1286	0	0	1286	0	0	0	0	0	0	0	0	0	0
Maximum	3190	0	0	3190	0	0	0	0	0	0	0	0	0	0
Minimum	605	0	0	605	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	11.30	0.00	0.00	11.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age MW	Gr.3 Ba-lance MW
January	28796	0	2269	14236	0	0	12354	0	29815	-63
February	29378	0	2269	12993	0	0	14049	0	24613	67
March	25553	0	2269	11310	0	0	12079	0	39828	-105
April	21181	0	2269	13566	0	0	5329	0	47692	18
May	17390	0	2269	6654	0	0	8443	0	29977	25
June	9820	0	1926	5638	0	0	2191	0	39437	65
July	9820	0	1926	4764	0	0	3218	0	32980	-88
August	9820	0	1926	5956	0	0	1890	0	38360	47
September	13176	0	2267	9141	0	0	1753	0	42267	14
October	17887	0	2269	11346	0	0	4246	0	44251	27
November	22365	0	2269	10641	0	0	9522	0	31276	-68
December	26006	0	2269	18215	0	0	5467	0	43577	56
Average	19240	0	2182	10364	0	0	6694	0	37039	-1
Maximum	47713	0	2269	25916	0	0	45444	0	80000	23319
Minimum	9042	0	1926	0	0	0	0	0	0	-18800
Total for the whole year TWh/year	169.00	0.00	19.17	91.04	0.00	0.00	58.80	0.00		-0.01

	RES specification RES1 Wind GW	RES2 Photo \ GW	RES3 Wave F GW	RES4 River H GW	Total o GW
January	197	8	4	46	255
February	215	23	3	37	279
March	187	44	3	38	271
April	106	62	1	10	179
May	176	101	1	8	287
June	136	87	1	10	233
July	161	100	1	25	287
August	122	70	1	24	217
September	132	43	1	14	190
October	153	26	2	11	193
November	228	21	2	14	265
December	133	7	4	42	186
Average	162	49	2	23	237
Maximum	548	330	9	53	816
Minimum	0	0	0	0	0
Total for the whole year TWh/year	1423	435	18	205	2080

ANNUAL COSTS (Million EUR)

Total Fuel =		213296
Uranium =	9180	
Coal =	5981	
FuelOil =	34778	
Gasoil/Diesel=	19401	
Petrol/JP =	36116	
Ngas =	13690	
Biomass =	103650	
Food income =	-9500	
Waste =	0	
Marginal operation costs =		11164
Total Electricity exchange =		0
Import =	0	
Export =	-6692	
Bottleneck =	6692	
Fixed imp/ex=	0	
Total CO2 emission costs =		33922
Total Ngas Exchange costs =		99330
Total variable costs =		357712
Fixed operation costs =		74704
Annual Investment costs =		826958
TOTAL ANNUAL COSTS =		1259374

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	5495	7062	134633	92507	0	128301	367999	0	0	0	0	0	0	367999	367999	0
February	6050	6446	123310	89673	0	128301	353781	0	0	0	0	0	0	353781	353781	0
March	5219	5611	80470	73103	0	128301	292705	0	0	0	0	0	0	292705	292705	0
April	2888	6730	120795	44095	0	128301	302809	0	0	0	0	0	0	302809	302809	0
May	3620	3301	23600	27509	0	128301	186332	0	0	0	0	0	0	186332	186332	0
June	1253	2797	68490	180	0	128301	201021	0	0	0	0	0	0	201021	201021	0
July	1568	2363	33619	0	0	128301	165852	0	0	0	0	0	0	165852	165852	0
August	1160	2955	65133	64	0	128301	197614	0	0	0	0	0	0	197614	197614	0
September	1316	4535	116909	17436	0	128301	268498	0	0	0	0	0	0	268498	268498	0
October	2360	5629	145243	45077	0	128301	326611	0	0	0	0	0	0	326611	326611	0
November	4246	5279	128223	67265	0	128301	333314	0	0	0	0	0	0	333314	333314	0
December	3215	9036	241855	81887	0	128301	464295	0	0	0	0	0	0	464295	464295	0
Average	3192	5142	106748	44793	0	128301	288176	0	0	0	0	0	0	288176	288176	0
Maximum	16778	12857	632442	163515	0	128301	866617	0	0	0	0	0	0	866617	866617	0
Minimum	534	0	0	0	0	128301	128835	0	0	0	0	0	0	128835	128835	0
Total for the whole year TWh/year	28.04	45.16	937.67	393.46	0.00	1127.00	2531.34	0.00	0.00	0.00	0.00	0.00	0.00	2531.34	2531.34	0.00

RES Share: 48.8 Percent of Primary Energy 67.5 Percent of Electricity 2363.4 TWh electricity from RES 12-March-2013 [16:37]

Input 5_EU27_HRE_ EE&DH&RE_Cooling_2050_BiomassSameAsEE.txt The EnergyPLAN model 10.1

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	3176.06	Fixed imp/exp.	0.00
Electric heating	76.00	Transportation	664.00
Electric cooling	130.60	Total	4046.66

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	19.00	635.00	936.00	1590.00
Solar Thermal	0.00	40.00	59.37	99.37
Industrial CHP (CSHP)	0.00	40.00	68.90	108.90
Demand after solar and CSHP	19.00	555.00	807.73	1381.73

Wind	572000 MW	1486.33	TWh/year	0.0(Grid
Photo Voltaic	329948 MW	434.7	TWh/year	0.0(stabili-
Wave Power	8804 MW	17.5	TWh/year	0.0(sation
River Hydro	53102 MW	204.52	TWh/year	0.0(share
Hydro Power	72314 MW	189.2	TWh/year	
Geothermal/Nuclear	80518 MW	622.2	TWh/year	

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	80000	64000	0.50	0.40	
Heat Pump	24000	72000			3.00
Boiler		215130		0.90	
Group 3:					
CHP	125916	125916	0.45	0.45	
Heat Pump	16000	48000			3.00
Boiler		317100		0.90	
Condensing	425271		0.55		

Heatstorage: gr.2: 300 GWh gr.3: 450 GWh
Fixed Boiler: gr.2: 1.0 Per cent gr.3: 1.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	22.28
Gr.3:	804.00	60.62

Regulation Strategy:	Technical regulation no. 2	
KEOL regulation	00000000	
Minimum Stabilisation share	0.00	
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
DiGB_2020_market_price_400high.txt		
Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	65	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	47900	287	0.85	
Hydro Turbine:	47900		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(1215.00		0.00	0.00
Household	0.34	36.00	310.30	293.60
Industry	333.00	82.0(1040.0(1605.00		
Various	44.00	35.00	87.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating									
	Demand	Production								
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	277107	996	44466	3237	82602	88793	0	56898	0	114
February	282580	5431	44466	3303	72410	94673	0	62228	0	68
March	246594	7553	44466	2873	51306	91960	0	48587	0	-151
April	205466	18370	44466	2381	65087	63366	0	12642	0	-846
May	169797	20763	44466	1955	25440	68788	0	7612	0	774
June	98574	21116	35720	1104	19183	21706	0	352	0	-607
July	98574	18580	35720	1104	14801	27781	0	508	0	81
August	98574	18144	35720	1104	20164	23011	0	383	0	47
September	130147	13600	44430	1481	36994	33317	0	529	0	-203
October	174476	7159	44466	2011	56260	55154	0	9015	0	410
November	216598	2209	44466	2514	58648	77808	0	30780	0	172
December	250861	1242	44466	2924	112473	65254	0	24399	0	101
Average	187196	11267	42265	2163	51234	59220	0	21047	0	0
Maximum	455082	132724	44466	5364	189916	120000	0	241175	0	71493
Minimum	91259	0	35720	1017	0	1850	0	0	0	-64829
TWh/year	1644.33	98.97	371.26	19.00	450.04	520.19	0.00	184.88	0.00	0.00

	Electricity																		Exchange	
	Consumption						Production							Balance					Payment	
	Elec. demand GW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP GW	PP GW	Stab-Load %	Imp MW	Exp GW	CEEP GW	EEP MW	Imp Million EUR	Exp Million EUR
January	411	72526	77561	0	13923	454	328	264	21448	70834	101663	89	29	100	0	1	1	0	0	62
February	410	75595	80629	0	14244	485	351	288	19706	70834	101663	78	30	100	0	7	7	0	0	378
March	385	77701	72461	0	12136	0	0	279	15385	70834	101663	56	25	100	0	0	0	0	0	0
April	343	75150	54623	0	9725	0	0	183	19182	70834	101663	71	37	100	0	0	0	0	0	0
May	344	80459	49214	0	7630	650	167	295	13834	70834	101663	28	1	100	0	28	28	0	0	1279
June	357	71976	19146	0	3458	949	998	239	25817	70834	98900	21	19	100	0	24	24	0	0	1165
July	363	75408	21171	0	3458	1023	739	294	19527	70834	98900	16	5	100	0	42	42	0	0	2064
August	349	75125	19582	0	3458	455	329	222	24393	70834	98900	22	16	100	0	8	8	0	0	387
September	361	75892	29391	0	5308	0	0	196	25494	70834	101652	41	38	100	0	0	0	0	0	0
October	369	80980	45619	0	7906	0	0	200	23890	70834	101663	61	46	100	0	0	0	0	0	0
November	402	67244	61669	0	10372	472	341	275	19987	70834	101663	64	36	100	0	26	26	0	0	1264
December	424	78658	64417	0	12385	0	0	192	29826	70834	101663	122	63	100	0	0	0	0	0	0
Average	376	75592	49546	0	8652	374	270	244	21539	70834	100968	56	29	100	0	11	11	0	Average price (EUR/MWh)	
Maximum	561	601725	123763	0	24315	47900	47900	839	72314	70834	101663	206	238	100	0	543	543	0		
Minimum	225	0	11050	0	3029	0	0	0	4314	70834	98900	0	0	100	0	0	0	0	63	66
TWh/year	3307	664.00	435.21	0.00	76.00	3.28	2.37	2143	189.20	622.20	886.90	489	252		0.00	100	100	0.00	0	6599

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	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	-	-	38.36	-	-	103.40	-	-	-	-	-	-	-	-	-	-	-	-	0.24	377.00	519.00	-14.17	504.82	177.50	172.65
Oil	-	-	0.62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1215.00	27.59	117.00	1360.21	0.00	1360.21	357.46	357.46
N.Gas	19.42	393.65	493.03	-	17.43	318.90	-	-	-	-	-	-	-	-	-	-	-	4.00	238.96	1127.00	2612.38	-162.14	2450.24	526.71	494.83
Biomass	3.89	-	118.17	34.99	153.00	35.25	-	-	293.30	-	1017.65	-	-	-	-	-	-	-	216.81	1605.00	3478.06	-4.83	3473.23	0.00	0.00
Renewable	-	-	-	-	-	-	141.00	189.20	-	-	-	-	1486.33	434.70	17.50	204.52	227.54	-	-	-	2700.79	0.00	2700.79	0.00	0.00
H2 etc.	-	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-795.00	-	-	-	-	-	-	795.00	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	1700.03	-	-	-	-	-	-	-	-	-	-	-	-	-	1700.03	0.00	1700.03	-323.00	-323.00
Total	23.31	393.65	650.18	34.99	170.43	457.55	1841.03	189.20	293.30	-	222.65	-	1486.33	434.70	17.50	204.52	227.54	2014.00	483.59	3226.00	12370.47	-181.14	12189.33	738.67	701.95

12-March-2013 [16:38]

Output specifications 5_EU27_HRE_ EE&DH&RE_Cooling_2050_BiomassS:The EnergyPLAN model 10.1

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age GW	Gr.2 Ba-lance MW
January	3237	0	0	3237	108198	407	16779	27041	51714	0	12112	0	114	145
February	3303	0	0	3303	110384	2222	16779	23464	54820	0	13064	0	101	36
March	2873	0	0	2873	96012	3090	16779	17140	50938	0	8172	0	138	-105
April	2381	0	0	2381	79587	7470	16779	23474	31217	0	954	0	162	-308
May	1955	0	0	1955	65342	8438	16779	9536	29555	0	711	0	102	324
June	1104	0	0	1104	36897	8303	13445	7095	8135	0	134	0	208	-213
July	1104	0	0	1104	36897	7380	13445	5465	10428	0	190	0	215	-10
August	1104	0	0	1104	36897	7200	13445	7425	8680	0	143	0	190	6
September	1481	0	0	1481	49507	5544	16765	14147	12942	0	162	0	177	-53
October	2011	0	0	2011	67210	2921	16779	20863	26041	0	266	0	174	340
November	2514	0	0	2514	84033	904	16779	21028	42814	0	2506	0	123	3
December	2924	0	0	2924	97716	508	16779	38597	37129	0	4878	0	205	-175
Average	2163	0	0	2163	72291	4534	15939	17926	30306	0	3585	0	160	0
Maximum	5364	0	0	5364	179276	52409	16779	64000	72000	0	60754	0	300	31688
Minimum	1017	0	0	1017	33976	0	13445	0	723	0	0	0	0	-49743
Total for the whole year TWh/year	19.00	0.00	0.00	19.00	635.00	39.82	140.01	157.46	266.21	0.00	31.49	0.00		0.00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age GW	Gr.3 Ba-lance MW	RES specification RES1 Wind GW	RES2 Photo \ GW	RES3 Wave f GW	RES4 River H GW	Total o GW
January	165671	589	27688	55561	37079	0	44786	0	22	-31	206	8	4	46	264
February	168893	3209	27688	48947	39853	0	49164	0	40	33	225	23	3	37	288
March	147709	4463	27688	34166	41022	0	40415	0	22	-46	195	44	3	38	279
April	123498	10900	27688	41613	32149	0	11687	0	115	-538	111	62	1	10	183
May	102500	12325	27688	15904	39233	0	6901	0	153	450	184	101	1	8	295
June	60573	12814	22276	12088	13571	0	218	0	389	-394	142	87	1	10	239
July	60573	11200	22276	9336	17352	0	318	0	299	91	168	100	1	25	294
August	60573	10945	22276	12739	14331	0	240	0	232	42	128	70	1	24	222
September	79159	8056	27665	22847	20375	0	367	0	237	-149	138	43	1	14	196
October	105254	4237	27688	35397	29113	0	8750	0	284	70	160	26	2	11	200
November	130051	1306	27688	37620	34995	0	28274	0	223	169	238	21	2	14	275
December	150221	734	27688	73876	28125	0	19521	0	249	276	139	7	4	42	192
Average	112743	6734	26326	33308	28913	0	17462	0	189	0	169	49	2	23	244
Maximum	270442	80314	27688	125916	48000	0	180421	0	450	53332	572	330	9	53	839
Minimum	56266	0	22276	0	1127	0	0	0	0	-57974	0	0	0	0	0
Total for the whole year TWh/year	990.33	59.15	231.24	292.58	253.98	0.00	153.38	0.00		0.00	1486	435	18	205	2143

ANNUAL COSTS (Million EUR)

Total Fuel =		212214
Uranium =	9180	
Coal =	5979	
FuelOil =	34778	
Gasoil/Diesel=	18088	
Petrol/JP =	36116	
Ngas =	14660	
Biomass =	102913	
Food income =	-9500	
Waste =	0	
Marginal operation costs =		11531
Total Electricity exchange =		0
Import =	0	
Export =	-6599	
Bottleneck =	6599	
Fixed imp/ex=	0	
Total CO2 emission costs =		34422
Total Ngas Exchange costs =		102353
Total variable costs =		360520
Fixed operation costs =		78427
Annual Investment costs =		723079
TOTAL ANNUAL COSTS =		1162026

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	8398	161228	37203	56164	0	128301	391294	0	0	0	0	0	0	391294	391294	0
February	8962	141139	37506	54449	0	128301	370357	0	0	0	0	0	0	370357	370357	0
March	7528	100423	31079	44391	0	128301	311723	0	0	0	0	0	0	311723	311723	0
April	3762	128807	46766	26794	0	128301	334431	0	0	0	0	0	0	334431	334431	0
May	2783	50639	1047	16727	0	128301	199496	0	0	0	0	0	0	199496	199496	0
June	1153	38106	24487	109	0	128301	192158	0	0	0	0	0	0	192158	192158	0
July	1165	29394	6739	0	0	128301	165599	0	0	0	0	0	0	165599	165599	0
August	1156	40030	20471	43	0	128301	190001	0	0	0	0	0	0	190001	190001	0
September	1556	73866	47633	10606	0	128301	261963	0	0	0	0	0	0	261963	261963	0
October	3050	111805	57833	27376	0	128301	328365	0	0	0	0	0	0	328365	328365	0
November	5783	115963	45912	40840	0	128301	336800	0	0	0	0	0	0	336800	336800	0
December	5207	220982	79688	49717	0	128301	483895	0	0	0	0	0	0	483895	483895	0
Average	4195	100942	36305	27203	0	128301	296947	0	0	0	0	0	0	296947	296947	0
Maximum	25694	372182	301878	99274	0	128301	810137	0	0	0	0	0	0	810137	810137	0
Minimum	1039	0	0	0	0	128301	129385	0	0	0	0	0	0	129385	129385	0
Total for the whole year TWh/year	36.85	886.68	318.90	238.96	0.00	1127.00	2608.38	0.00	0.00	0.00	0.00	0.00	0.00	2608.38	2608.38	0.00

RES Share: 49.9 Percent of Primary Energy 61.1 Percent of Electricity 2501.8 TWh electricity from RES 12-March-2013 [16:38]

19 ANNEX XI: DATA USED TO CREATE ENERGY-SYSTEMS-ANALYSIS FIGURES

Figure 3: Primary energy supply and carbon dioxide emissions in the Energy Efficiency (EU-EE) and Heat Roadmap Europe (HRE-EE) scenarios for the years 2030 and 2050.

Figure 61: Primary energy supply and carbon dioxide emissions for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

Primary Energy Supply (TWh/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
Nuclear	1,879	1,879	1,700	1,700
Coal	1,487	1,485	519	519
Oil	4,498	4,477	1,378	1,360
Gas	3,905	4,026	2,535	2,612
Biomass	1,643	1,643	2,769	2,769
Waste	208	367	233	486
RES	1,799	1,879	2,682	2,761
Total	15,419	15,756	11,816	12,208
Nuclear, Fossil Fuels & Biomass (TWh/year)	13,412	13,510	8,901	8,961
Carbon Dioxide Emissions (X, Mt/year)	2,462	2,480	728	739
Electricity Exports (•, TWh/year)	40	40	100	100

Figure 4: Total annual costs for heating and cooling in the residential and services sectors for the Energy Efficiency (EU-EE) and Heat Roadmap Europe 2 (HRE-EE) scenarios in the years 2030 and 2050.

Figure 64: Total annual costs for heating and cooling in the residential and services sectors for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

Total Costs for Heating and Cooling in the Residential and Services Sectors (B€/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
Energy Efficiency Investments	303	133	303	133
Heating System Investments	229	261	295	336
Cooling System Investments	19	19	15	15
Centralised Electricity & Heat Plants	18	40	21	51
Fuel	121	125	56	57
CO2	19	20	8	8
Total	710	597	697	600
Difference		-113		-97
Difference (%)		-15.9%		-14.0%

Figure 43: Primary energy supply by fuel and the net electricity exports for the EU-EE scenario from the original 'reference' projections and the EnergyPLAN model.

Primary Energy Supply (TWh/year)	Energy Efficiency Scenario					
	2010		2030		2050	
	Reference	EnergyPLAN	Reference	EnergyPLAN	Reference	EnergyPLAN
Nuclear	2,733	2,733	1,878	1,879	1,700	1,700
Coal	3,269	3,262	1,531	1,487	516	519
Oil	6,083	6,078	4,498	4,498	1,378	1,378
Gas	5,150	5,135	3,901	3,905	2,425	2,535
Biomass	1,119	1,118	1,711	1,643	2,762	2,769
Waste	187	187	208	208	233	233
RES	612	613	1,799	1,799	2,682	2,682
Total	19,153	19,126	15,527	15,419	11,696	11,816
Electricity Exports (-, TWh/year)	-8	0	24	40	31	100

Figure 51: Fuel consumption by individual boilers in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Fuel Demand for Heating Individual Residential and Services Buildings (TWh/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
Solids	44	42	0	0
Oil	502	481	46	28
Gas	1,246	1,194	394	239
Biomass	316	303	357	217
Solar	177	170	212	129
Electricity	270	292	281	337
Total	2,555	2,482	1,289	950

Figure 52: Annual investment and operation costs for heating networks and consumer installations for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

Annual Costs for Heating Networks and Consumer Installations (B€/year)	Scenario / Year	EU-EE		HRE-EE	
		2030	2050	2030	2050
Residential	Individual Units	90	100	102	121
Residential	Central Heating Systems	48	55	49	59
Services	Individual Units	81	129	81	117
Services	Central Heating Systems	8	9	8	10
District Heating Network		1	1	20	29
Total		**229**	**295**	**261**	**336**

Figure 59: Heat demand by fuel for residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Heat Demand for Residential and Services Buildings (TWh/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
District Heating	270	1,043	159	1,324
Solids	31	30	0	0
Oil	442	424	40	24
Gas	1,109	1,063	350	213
Biomass	237	227	268	163
Solar	177	170	212	129
Direct Electricity	168	161	124	76
Heat Pumps	248	318	371	619
Geothermal	33	42	60	101
Total	**2,715**	**3,477**	**1,584**	**2,648**

Figure 60: District heating production by plant type in the EU-EE and HRE-EE scenarios for the years 2030 and 2050. Note: some of the district heating is used by absorption heat pumps to provide cooling as discussed in section 5.2.

District Heating Supply for Residential and Services Buildings (TWh/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
CHP	158	446	91	450
Boiler	156	314	70	204
Heat Pumps	0	358	0	520
Solar	0	50	0	99
Geothermal	2	52	2	102
Waste	14	91	10	162
Industry	7	57	7	107
Total	**337**	**1,369**	**180**	**1,644**

Figure 62: Primary energy supply for heating and cooling in residential and services buildings in the EU-EE and HRE-EE scenarios for the years 2030 and 2050.

Primary Energy Supply for Heating and Cooling in Residential and Services Buildings (TWh/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
Coal	250	248	59	59
Oil	528	507	46	28
Gas	1,649	1,770	652	729
Biomass	486	485	533	534
Waste	0	212	40	293
Wind Power	190	227	228	291
Solar Thermal	177	220	212	228
Surrounding Heat for HPs	179	1,631	274	1,802
Geothermal for DH	0	52	0	102
Industry Surplus Heat	7	57	7	107
Total	**3,467**	**5,411**	**2,051**	**4,173**

Figure 63: Total annual energy system costs for the EU-EE and HRE-EE scenarios in the years 2030 and 2050.

Total Costs (B€/year)	2030		2050	
	EU-EE	HRE-EE	EU-EE	HRE-EE
Investment	688.0	567.1	827.0	723.1
Fuel	497.5	501.6	312.6	314.6
Fixed O&M	54.5	57.5	74.7	78.4
Variable O&M	11.5	11.8	11.2	11.5
CO2	85.2	85.8	33.9	34.4
Total	**1,336.7**	**1,223.7**	**1,259.4**	**1,162.0**

Figure 66: Total annual costs for heating and cooling in the residential and services sectors for the EU-EE and HRE-EE scenarios in 2050 for different energy efficiency and district heating cost assumptions. *Represents a scenario with 50% additional energy efficiency costs and 50% direct energy efficiency costs (see Figure 65). #Assumes that all additional district heating in the EU27 is in areas with a heat density less than 50 TJ/km2. ^Based on forecasted heat densities in the European Heat Atlas (Figure 14).

Total Costs for Heating and Cooling in the Residential and Services Sectors (B€/year)	Original Scenarios		Sensitivity Analysis	
	EU-EE	HRE-EE	EU-EE	HRE-EE
	Marginal Efficiency Costs	Additional Efficiency Costs	Direct & Additional Efficiency Costs*	Direct & Additional Efficiency Costs*
	No DH Expansion	High DH Expansion Costs#	No DH Expansion	Realistic DH Expansion Costs^
Energy Efficiency Investments	303	133	429	185
Heating System Investments	295	336	295	330
Cooling System Investments	15	15	15	15
Centralised Electricity & Heat Plants	21	51	21	51
Fuel	56	57	56	57
CO_2	8	8	8	8
Total	697	600	824	647
Difference		-97		-177
Difference (%)		-14.0%		-21.5%

20 ANNEX XII: AARHUS CASE STUDY

20.1 PURPOSE WITH THE CASE STUDY

This case study has several purposes. The first is to examine the technical and economic consequences of supplying a larger urban area with district heating, based on information on the heat demands, the size of the grid and the supply units in an actual area. The second is to examine the consequences of reducing the heat consumption of buildings in the area, and the third is to compare the district heating solution to an individual heat pump solution.

Aarhus was chosen as a good case, because it currently has a large share of district heating, a large variation in building types, and access to excess heat from waste incineration and industry.

20.2 STRUCTURE OF THE CASE STUDY

The case study is structured as illustrated in Figure 88.

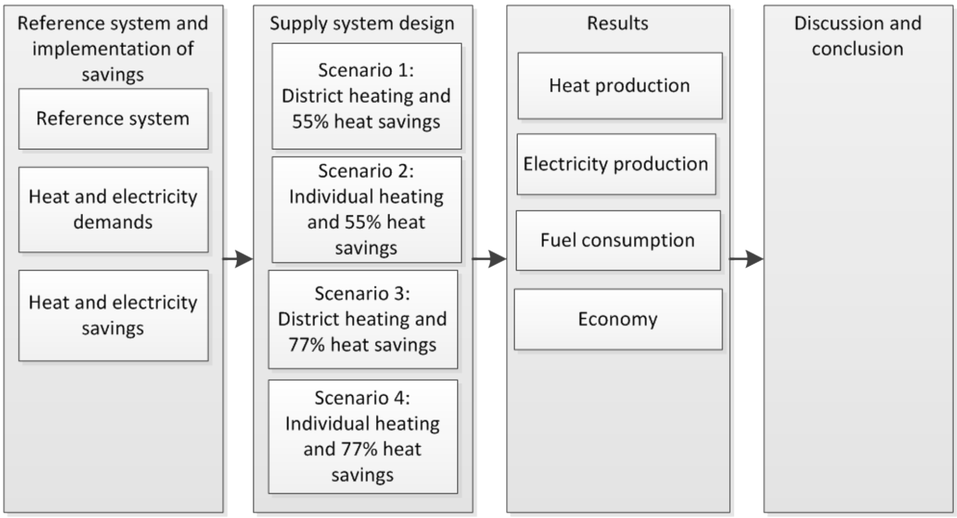


Figure 88: Case study structure.

First, the reference system is described with an emphasis on the boundaries of the study and the production units in the area. The reference system is used as the basis for the analyses in the case study. This is followed by a section about the demands in the reference system for both heat and electricity. The demand section is followed by a section about the implemented savings, which will have an effect on the design of the supply systems in each scenario. In the following sections, supply systems are designed for both scenarios. From this, the results in the form of heat and electricity production, fuel use, and economy will be presented. Finally, the discussion and conclusions are presented.

20.3 GEOGRAPHIC BOUNDARIES AND ENERGY DEMANDS

The geographic boundaries of the case study are defined in Figure 1. The reason for working with these specific boundaries is that the properties of the district heating network within this area were available, since the grid within this area is operated by one company, the municipality owned district heating company in Aarhus. There are other areas connected to the Aarhus district heating grid, but these are excluded from this analysis, since network data is not available for these. The areas used in the case study represent approximately 82.4% of the heat demand in Aarhus municipality and the area is around 110 km^2.

Figure 89: Geographic boundaries used in the case study.

In the reference, the total heat demand of buildings is 2,323 GWh/year and, by including a 20% grid heat loss, the final energy consumption is assumed to be 2,904 GWh/year. The heat demand density in Aarhus is high compared to a large share of the European cities. Figure 90 illustrates the population density and heat demand density for European cities that are included in the urban morphological zone dataset [1], which includes cities with more than 17,300 inhabitants. The information on population and heat demands are from the heat atlas described in chapter 3 of the main report.

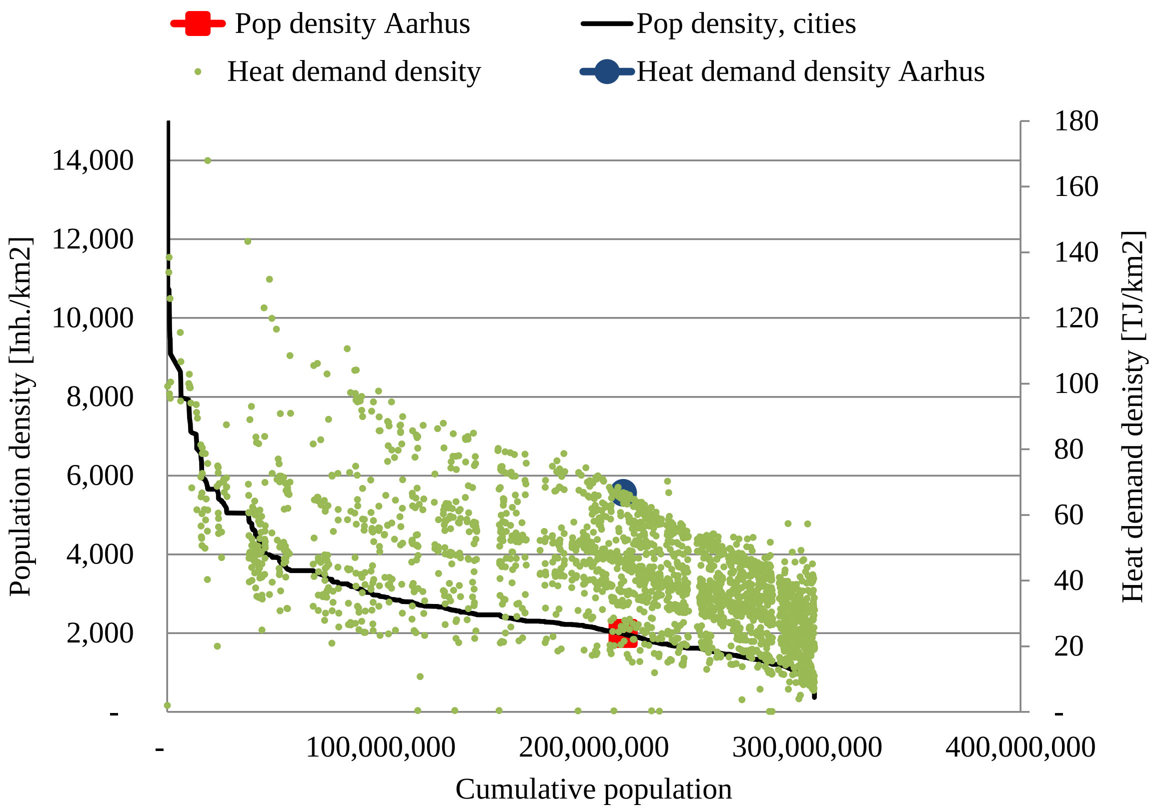


Figure 90: Population and heat demand density in European Cities based on [1].

The population density of Aarhus is in the lower end with around 2,000 inhabitants per km^2, but the heat demand density is high with around 70 TJ/km^2. Therefore, Aarhus could be seen as a good case of district heating and the results of the case study should reflect this.

Since the benefits of district heating are mainly related to the use of combined heat and power (CHP) plants, the electricity demand is included in the case study as well. The electricity consumption of the area is assumed to be 82.4% of the total electricity demand in Aarhus municipality. The current demand in the municipality is estimated at 1,700 GWh/year and 82.4% of this is 1,401 GWh/year.

20.4 METHODS

The methods used in the case study consists of two categories; the first is an energy system analysis made in EnergyPRO [2] and the second is a geographic analysis that applies geographic information systems with information about heat demands and district heating networks. In short EnergyPRO is a deterministic model that in this case is used to simulate the case area on an hourly basis, where the heat and electricity demands are fulfilled according to a fixed operation strategy of the energy production units within the area. The reason for including an hourly modelling of the case system is to find the impact from savings on 1) the demand for production capacity 2) the resource use related to the production. These are further on used to find the annual costs of the different Scenarios.

20.5 REFERENCE SYSTEM

The reference system used in this case study is based on the supply system which is expected to be in place in the year 2016, according to the district heating company in Aarhus [3], see Figure 91.

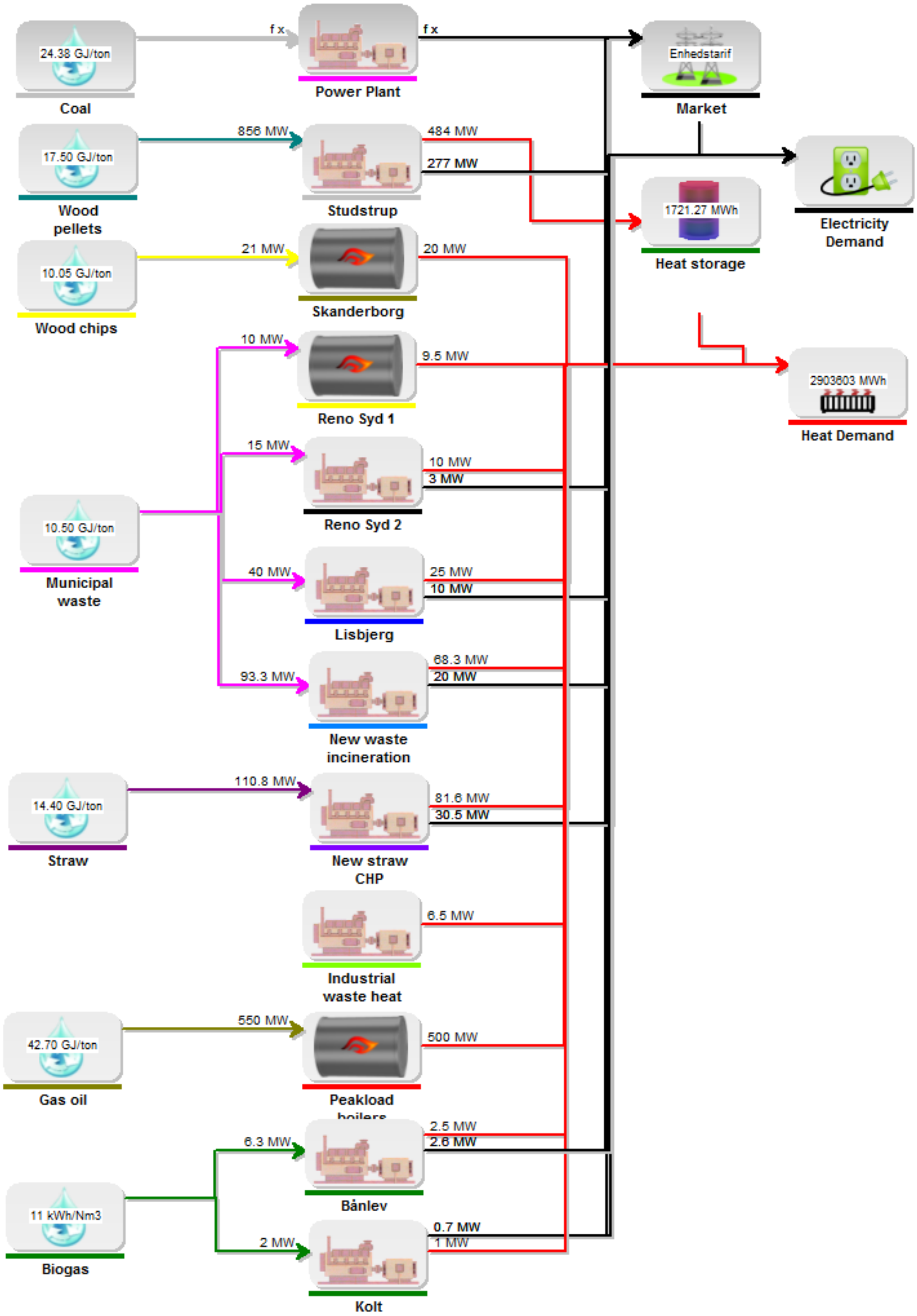


Figure 91: Reference system design for the Aarhus case study.

The system utilizes a variety of different fuels and production units. As in the major part of larger district heating systems in Denmark, waste incineration plants are used as base-load plants, in this case with a heat production capacity of 112 MW in total. Another large producer that operates as base load is a new straw-fired CHP plant with a heat production capacity of 81.6 MW. In the present system, the largest producer in Aarhus is the Studstrup CHP plant with a heat capacity of 484 MW. The Studstrup CHP plant currently utilizes coal, but will be rebuilt to run on wood pellets in 2016. To be able to cover the electricity demand in the summer, a coal-fired power plant unit with an electrical efficiency of 45% is added. This could be any marginal power plant within the Nordic power market, but could also be the Studstrup plant operating in condensing mode, when heat production is not needed. In Figure 92, the monthly fuel consumption of the reference is shown.

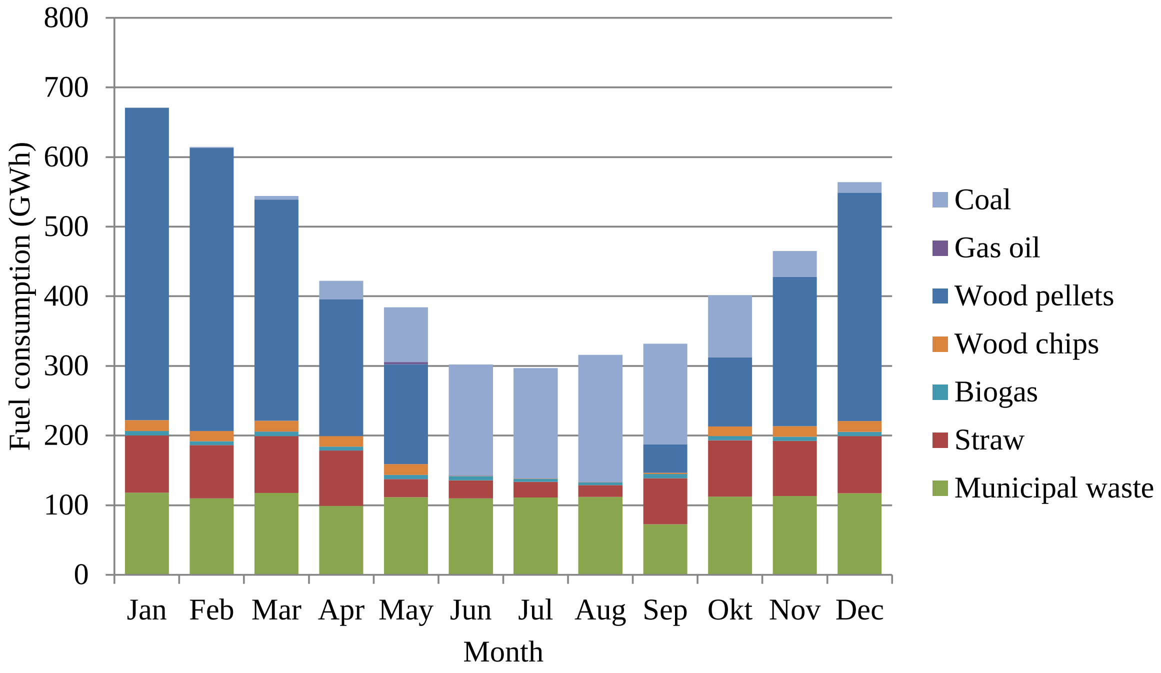


Figure 92: Monthly fuel consumption of the reference system for Aarhus.

The fuel consumption is used to supply both the heat and electricity demands within the area. The demands are described in detail in section 20.7. The monthly fuel consumption in Figure 92 shows that the municipal waste, straw, biogas and wood chips are utilized as base production. From September to June, the wood pellet-fired CHP plant is used, while the coal-fired power plant is used in the summer period when the heat demand is low.

As mentioned in the methods part, the software EnergyPRO is used for all the energy system analyses in the case study. EnergyPRO is normally used to optimize the operation of decentralised CHPs according to the electricity markets and demands. However, in this case study, a more simple operation strategy is chosen in which each production unit has the same priority all year around, not taking into account, e.g., variations in electricity prices. The priority list is as follows:

1. Industrial excess heat
2. Kolt
3. Bånlev
4. Lisbjerg
5. New waste incineration
6. Reno syd 1

7. Reno syd 2
8. New straw CHP
9. Skanderborg
10. Studstrup
11. Peak load

In the reference system, the main priority of these units is to supply the heat demand. The CHP plants produce electricity and cover parts of the electricity demand, while the remaining electricity demand is covered by a residual coal power plant with an average electric efficiency of 45%. Additionally, all the production units have periods in which they are scheduled for maintenance. Most importantly, the Studstrup CHP plant does not produce heat from the beginning of June to the end of August.

20.6 THE SCENARIOS IN THE CASE STUDY

In this case study, four different scenarios are used to examine the impacts of implementing large heat savings and using either district heating or individual heating.

- Scenario 1: 55% heat savings and district heating
- Scenario 2: 55% heat savings and individual heating
- Scenario 3: 77% heat savings and district heating
- Scenario 4: 77% heat savings and individual heating

The savings in these scenarios are not identical to the savings in the main Heat Road Map Europe scenarios and cannot be directly compared to these. This is mainly because the scenarios used are based on the buildings in Aarhus and include reductions in domestic hot water consumption as well.

The district heating scenarios are based on the current production units in Aarhus; however, when introducing large heat savings, some of the production units are not needed anymore. The supply systems for each scenario will be described in more detail in section 20.8. In the scenarios with individual heating, individual heat pumps are added to supply the whole heat demand. Also, all the current production units in Aarhus are changed in such a way that they only produce electricity and not all boilers and excess heat are utilized in these cases.
Before going into depth with each scenario, the hourly heat and electricity demands will be described in the following section.

20.7 HOURLY HEAT AND ELECTRICITY LOADS

The annual heat demand is based on buildings within the geographic boundaries that are currently connected to district heating, as shown in Figure 89. The total annual heat demand is estimated at 2,322,882 MWh, based on historical measurements from 51,382 heat installations [4]. To find the heat saving potential of the area, a heat atlas including all buildings in Denmark is applied [5, 6]. In the heat atlas, 24 building categories with different saving potentials are included. The heat atlas also includes three scenarios with different levels of heat savings based on a method by the Danish

Building Research Institute (SBi) [7]. In this analysis, Scenario A and Scenario C are used. Scenario A includes average savings of around 55%, while Scenario C includes savings of around 77%. By applying the saving potential of each building category to the measured data from Aarhus, the annual demands used in this study are found, see Table 55.

Table 55: Annual heat consumption of the reference and heat saving scenarios

Building type	Reference	Scenarios 1 & 3	Scenarios 2 & 4
Farmhouse	1,479	746	382
Detached house	783,841	410,154	246,503
Terrace house	10,765	5,502	3,374
Block of flats	822,494	320,436	133,145
Hostel	15,090	5,798	2,887
Residential institution	14,976	6,360	3,209
Other dwelling	1,185	637	386
Agricultural building	41,368	17,003	6,563
Industrial building	48,367	20,199	10,106
Utilities	3,107	1,289	668
Other production	29	12	5
Transport	4,098	1,696	791
Trade and commerce	267,514	115,688	62,081
Hotel and service	12,399	5,094	2,188
Other trade	2,184	919	494
Cultural building	23,851	10,645	5,747
School	144,066	60,517	29,158
Hospital	69,751	30,872	16,310
Kindergarten	29,670	12,310	6,217
Other public institutions	6,528	2,680	1,184
Summer house	68	36	22
Tourism	466	187	65
Sports	16,815	7,996	4,959
Other leisure buildings	2,772	1,128	518
Grand Total	**2,322,882**	**1,037,904**	**536,961**

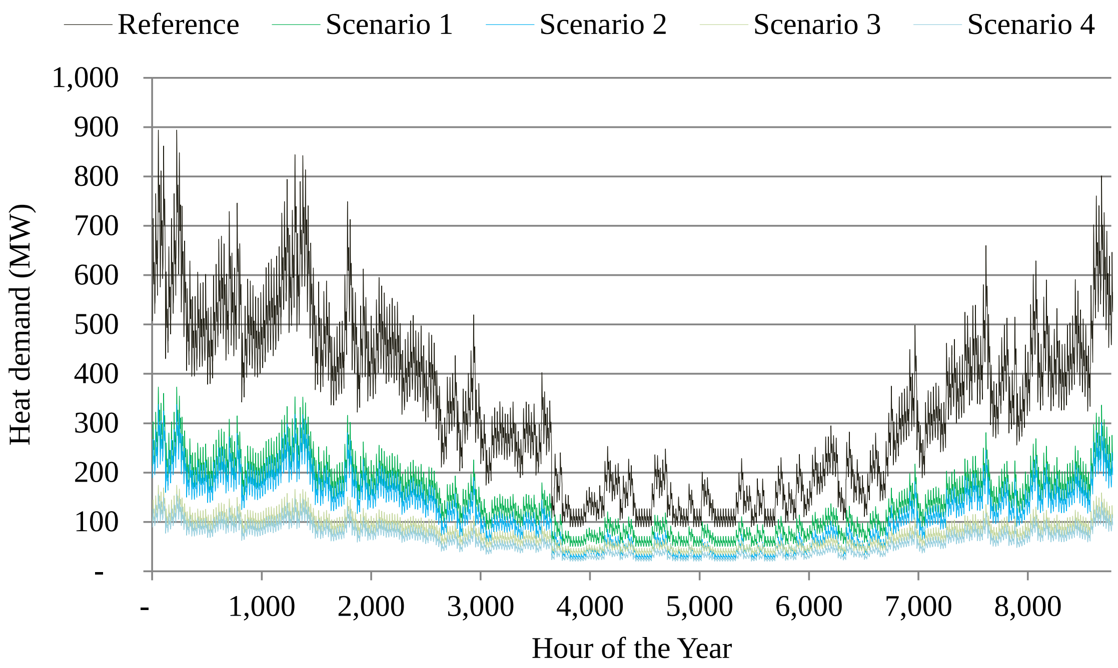
Single-family and multi-storey buildings account for the major part of the heat demand in Aarhus. Other significant building categories are office, trade and public administration and education and research. The reason for going into detail with the type of buildings when assessing the heat demand is that the reduction potential and related costs depend on this information. In general, by implementing heat savings, the total heat demand in Aarhus can be reduced to 1,038 GWh/year. Assuming a heat distribution loss of 20% of the final energy consumption, the total heat demand is 1,297 GWh/year for Scenario 1 and 671 GWh/year for Scenario 3.

Implementing heat savings influences the hourly heat load during the year. Since a major part of the savings is carried out as reductions in space heat demands, the reductions will be implemented during the hours with the highest space heat demand.

- In the Reference, the hourly heat load distribution is based on the existing demands. In annual shares of the total demand, 68% is space heat, 12% is domestic hot water and 20% is grid losses.

- In Scenario 1, the hourly heat load distribution is changed as the demand is reduced. In terms of annual shares, 60% is space heat, 20% is domestic hot water and 20% is grid losses.
- Scenario 2 is similar to Scenario 1 without grid losses; this gives annual shares of 75% of space heat and 25% of domestic hot water.
- In Scenario 3, the hourly heat load distribution is changed as the demand is reduced. In terms of annual shares, 49% is space heat, 31% is domestic hot water and 20% is grid losses.
- Scenario 4 is similar to Scenario 3 without grid losses; this gives annual shares of 61% of space heat and 39% of domestic hot water.

Assuming that the space heat demand is temperature dependent, while domestic hot water and grid losses are constant during the year, heat load profiles can be identified as shown in Figure 93. In EnergyPRO, the hourly heat load is created by using a daily variation profile and an outdoor temperature based on the Danish reference year. The fixed shares do not follow the temperature, while the shares for space heat do. The fact that the grid loss share is 20% in the Reference, Scenario 1 and Scenario 3 implies that improvements are made in the system when introducing heat savings; otherwise, the loss would be relatively higher in the two scenarios.



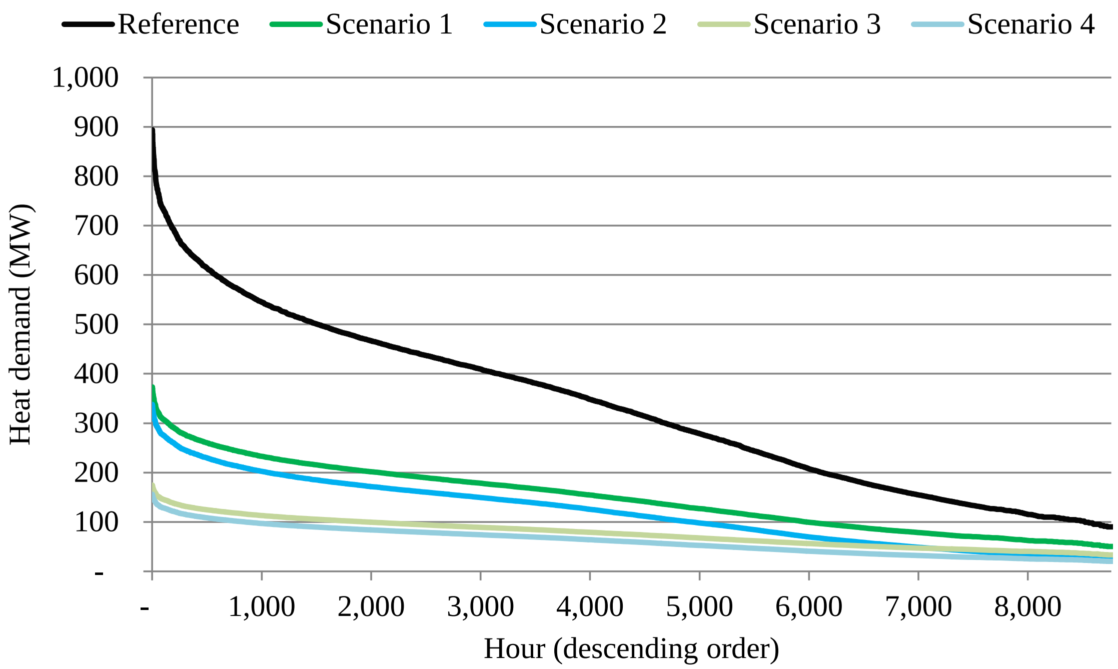


Figure 93: Hourly heat loads for the reference and both scenarios.

Figure 93 shows that the hourly heat load profiles in the two scenarios are very different from the reference scenario in which the peak loads are reduced significantly. In the Reference, the peak load is 894 MW, while it is 373 MW and 337 MW in Scenario 1 and 2, respectively. The implementation of larger heat savings lowers the peak further to 175 MW in Scenario 3 and 156 MW in Scenario 4.

The electricity consumption is reduced by 10% in accordance with the main Heat Road Map Europe (HRME) scenarios, which gives an annual electricity consumption of 1,260,749 MWh/year in the area.

For the hourly electricity load, the distribution of the electricity consumption in Western Denmark in 2011 is used [8]. The demand is found by combining the annual demand with the hourly distribution, see Figure 94.

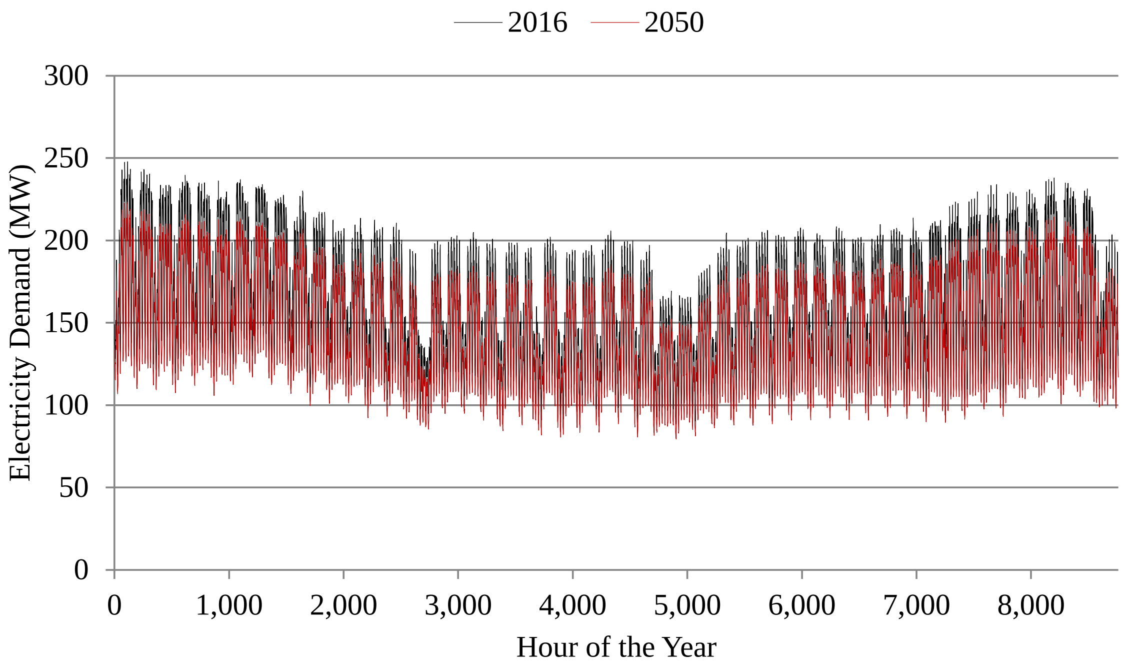


Figure 94: Hourly electricity load in the years 2016 and 2050.

The electricity demand does not change as much over the year as the heat demand. The electricity demand is slightly lower in summer with peaks around 200 MW, while the winter peaks are around 250 MW in the 2016 Reference. With a 10% decrease in the annual demand, the 2050 demand load is lower with peaks around 180 MW in the summer and 230 MW in the winter. Additional to this, and not included in the figure, is the electricity demand of heat pumps in the scenarios with individual heating.

20.8 SUPPLY SYSTEMS IN THE FOUR SCENARIOS

With the demands in place, the supply systems for all four scenarios can be designed. In the scenarios with district heating, the heat savings mainly influence the need for production capacity, which is generally lower compared to the reference. For the scenarios with individual solutions, the existing production units only produce electricity, and heat pumps will be added for the heat production.

As shown in Figure 91, the marginal heat producer in the reference is Studstrup CHP plant. If heat savings are implemented to the degree proposed in Scenario 1, the needed capacity from the marginal producer will be much lower than today. With an annual heat demand of 1,297 GWh, the peak heat demand will be 373 MW. All the existing base-load units combined have a capacity of 334 MW, giving a 39 MW difference between the base-load and the peak-load heat demand. Therefore, in Scenario 2, the Studstrup CHP is removed and the peak-load boilers will cover the difference. Apart from this, the supply system in Scenario 1 is the same as in the Reference.

In Scenario 2, the heat demand is covered by individual heat pumps. A 50/50 share of ground source heat pumps and air to water heat pumps is chosen, assuming an average coefficient of performance (COP) of 2.75 and a lifetime of 20 years based on [9], similar to the figures used for individual heat pumps in the HRME scenarios. The heat demand does not include distribution heat losses; all the boiler units have been removed and the heat production from the remaining units is not utilized.

Scenario 3 introduces larger heat savings than in the previous two scenarios. Compared to Scenario 1, the only difference in the supply system is that the new straw CHP is removed.
The supply system in Scenario 4 is almost identical to Scenario 2, the main difference being that the heat pump capacity is lower. The straw plant is included in this study, since it is only used to supply electricity and is not influenced by the savings in heat demand to the same extent as in Scenario 3.

20.9 RESULTS OF THE ENERGYPRO SIMULATION

The results of the energy system analysis are presented with a focus on heat and electricity production and fuel consumption as annual amounts for all scenarios.

20.9.1 Energy production and consumption

The first result is the annual heat production in all scenarios, see Figure 95.

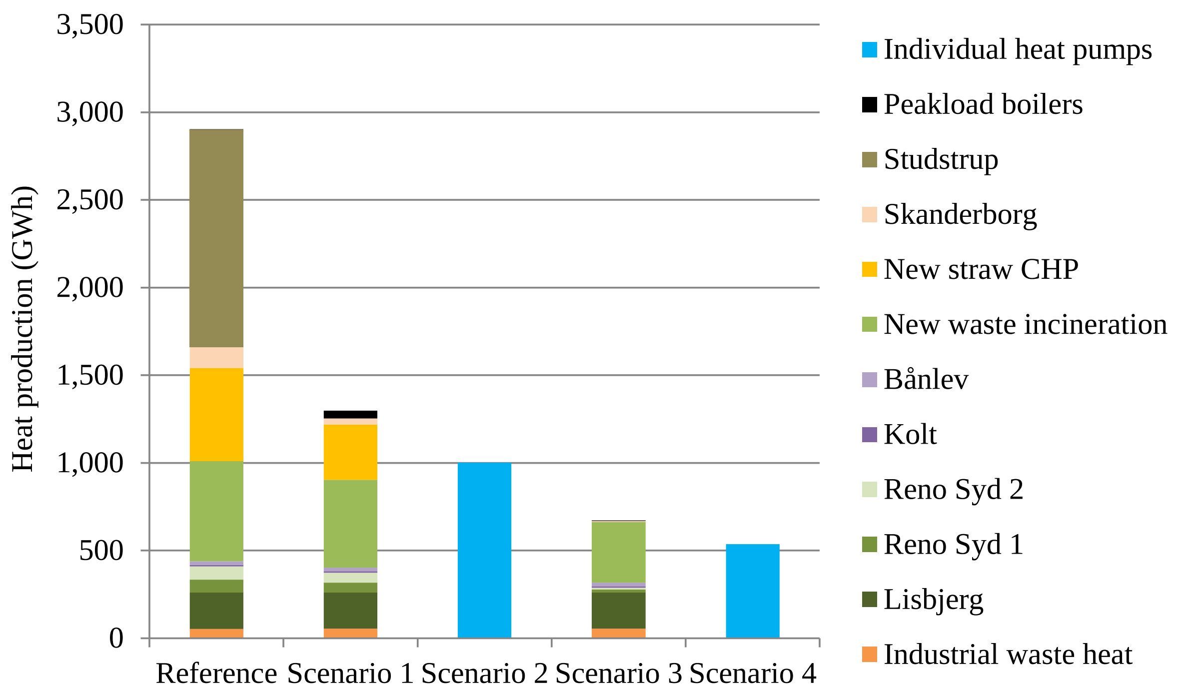


Figure 95: Annual heat production.

The overall tendency is that the heat demand is reduced for each scenario. Therefore, Scenario 4 ends up with a heat demand around 500 GWh/year, while the reference is 2,900 GWh/year including grid loss. In Scenario 1, the peak-load boilers cover more than in the Reference, since the Studstrup CHP is removed. The heat production from the straw CHP is reduced to about half of the figure of the

Reference and the new waste incineration is also reduced, but only to a minor extent. In Scenario 3, this goes even further, as the new straw CHP is removed and the production from the new waste incineration plant corresponds to half of the production used in the Reference. For Scenario 2 and 4, the total heat demand is covered by heat pumps; the plants producing electricity for these are included in Figure 96.

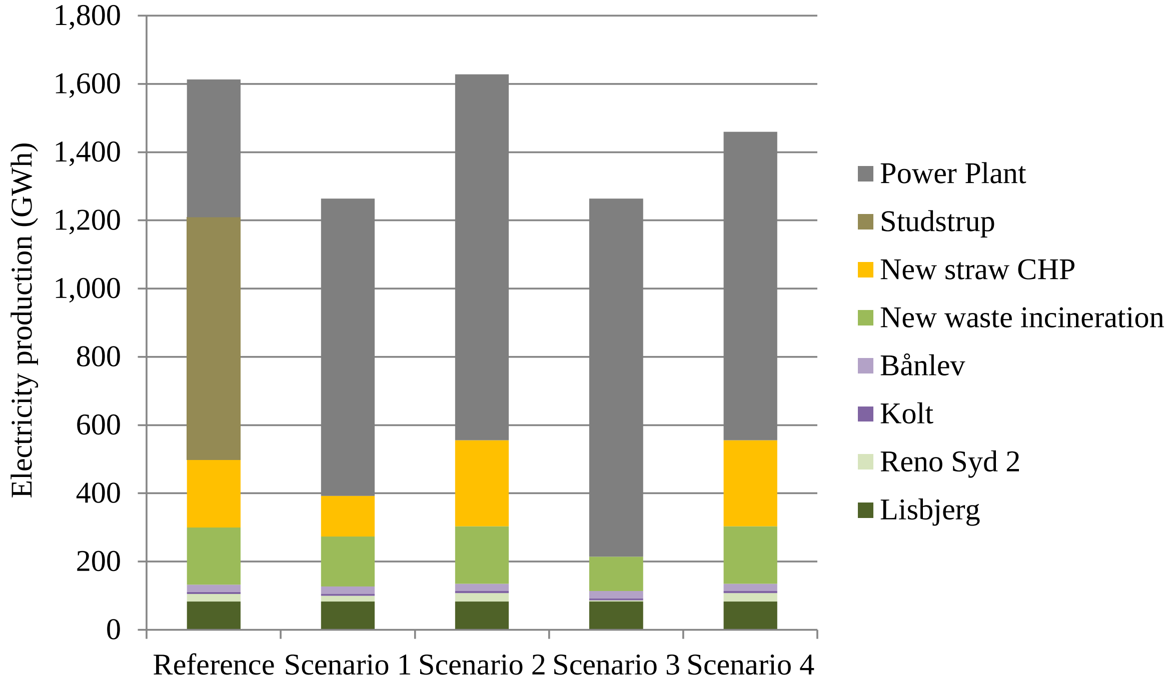


Figure 96: Annual electricity production.

Figure 96 shows the annual electricity production in all scenarios. The electricity production decreases from the Reference to the other scenarios. However, in the individual scenarios, the electricity production is higher due to the added electricity demand from the heat pumps. A general development from the Reference to all other scenarios is that more power plant capacity is needed to cover the electricity demand. This is due to the reduced utilization of CHP plants with low heat demands in the area. In the district heating scenarios, this could to some extent be improved by using heat storages. However, this has not been analysed in this study. Due to the way in which the system is modelled, it is possible to use all the straw and waste incineration plants for electricity production in the individual scenarios. In Figure 97, the fuel consumption for all scenarios is presented.

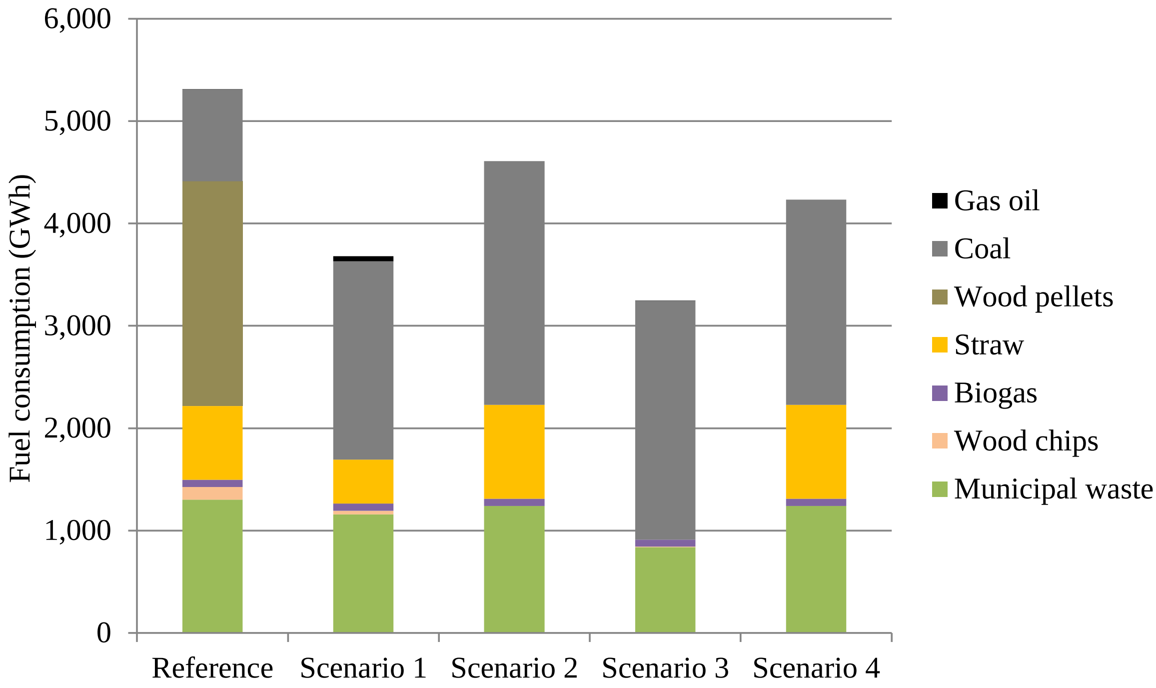


Figure 97: Annual fuel consumption.

The Reference has the highest fuel consumption, mainly due to the much higher heat demand. Apart from this, both of the district heating scenarios have a lower resource use than the individual scenarios. Actually, due to the smaller heat demand in Scenario 4, this is the scenario with the lowest overall fuel consumption. The downside is that a large share of this fuel is coal used by the coal-fired power plant.

20.10 ECONOMY

In the case study, all costs are annualised to make the data comparable. The economic analysis includes investments in district heating grids, production units and heat savings, as well as operation and maintenance costs (O&M) and fuel costs. First, all costs are presented individually and, in section 20.10.4, the annualised costs of all scenarios are compared.

20.10.1 Building renovation

The cost for renovations is presented in Table 56, which shows the long-term marginal costs and the full short-term costs of renovation for all 24 building categories. The total costs of Scenarios 1 and 3 are identical, and the total costs of Scenarios 2 and 4 are identical. As in the case of the reduction in heat demand, the costs for renovation are based on the heat atlas. Therefore, the age of buildings in Aarhus is taken into account, and the marginal costs are not directly comparable to the ones used in the main HRME scenarios, which use a different model.

Table 56: Renovation costs used in the case study [5].

Building type	Marginal cost	Scenarios 1&3	Scenarios 2&4
	EUR/kWh	EUR	EUR
Farmhouse	1.90	1,389,211	2,080,471
Detached house	2.21	826,761,187	1,188,790,571
Terrace house	1.35	7,083,808	9,955,550
Block of flats	1.41	706,052,215	973,750,285
Hostel	1.31	12,163,249	15,998,008
Residential institution	1.37	11,767,431	16,142,588
Other dwellings	2.17	1,185,859	1,730,921
Agricultural building	1.46	35,667,428	51,178,085
Industrial building	1.31	36,847,489	50,228,445
Utilities	1.21	2,204,474	2,967,357
Other production	1.35	23,647	32,696
Transport	1.35	3,236,980	4,484,797
Trade and commerce	1.31	198,474,622	270,334,376
Hotel and service	1.40	10,257,700	14,443,872
Other trade	1.22	1,545,131	2,068,895
Cultural building	1.31	17,356,233	23,993,584
School	1.35	112,749,681	155,663,794
Hospital	1.30	50,426,014	69,727,515
Kindergarten	1.27	22,087,407	29,994,344
Other public institutions	1.38	5,301,571	7,429,841
Summer house	2.04	65,782	94,645
Tourism	1.67	465,518	670,467
Sports	1.28	11,282,021	15,252,535
Other leisure buildings	1.36	2,235,218	3,095,418
Total		**2,076,629,875**	**2,910,109,058**

The costs for heat savings are quite high; 2 billion EUR in Scenarios 1 and 2, and 2.9 billion EUR in Scenarios 3 and 4. These investment costs are annualised with a lifetime of 30 years and a discount rate of 3%, giving an annual cost of 106 million EUR/year and 148 million EUR/year, respectively.

20.10.2 Investments in district heating networks

To determine the investment cost in distribution grids, data on the dimensions and the length of the pipes in the network are needed.

The length of the transmission grid is in total 98,548 meters. Unfortunately it has not been possible to acquire detailed data on the dimensions of the transmission grid. The dimension of the pipes are known to be between 200 mm and 1,200 mm, therefore an average DN700 with a cost of 1,383 EUR/m [10] is used for all of the transmission grid. This gives a total investment cost of 136 million EUR.

In Table 57, the total length and size of the Aarhus distribution grid is shown.

Table 57: Investment cost in distribution network based on [10].

		Existing system		Reduced demand	
DN	EUR/m	m	EUR	m	EUR
25	206	108,287	22,323,695	165,933	34,207,694
32	243	57,646	14,012,477	223,394	54,302,029
40	281	223,394	62,841,248	187,469	52,735,384
50	334	187,469	62,563,644	130,331	43,494,982
65	376	130,331	48,985,838	77,613	29,171,478
80	422	77,613	32,762,803	115,652	48,820,227
100	508	115,652	58,756,724	68,458	34,779,903
125	600	68,458	41,066,697	84,169	50,491,422
150	718	84,169	60,392,482	102,233	73,353,744
200	848	102,233	86,734,784	37,706	31,989,895
250	907	37,706	34,212,097	48,718	44,203,810
300	1,011	48,718	49,271,653	8,769	8,868,812
400	1,145	8,769	10,042,533	2,112	2,418,600
500	1,317	2,112	2,780,752	1,015	1,336,238
600	1,522	1,015	1,544,372	-	-
	sum	1,253,572	588,291,797	1,253,572	510,174,217

When implementing heat savings, less heat needs to be transferred. Therefore, the distribution grid requires less capacity and is downscaled one pipe size. This gives a reduction in total investment cost from 588 million EUR to 524 million EUR. Again these investment costs are annualised with a lifetime of 30 years and a discount rate of 3%, giving an annual cost of 30 million EUR/year and 26 million EUR/year, respectively. The costs of service pipes are based on those displayed in Table 58.

Table 58: Total investment costs (EUR/m) for service pipes; sizes 18-32 are twin flex; sizes 40-200 are polyurethane (PUR) twin and 250 is PUR single [10].

DN	Materials	Pipe work	Coupler Work	Field work	Sum
18	22.6	3.6	1.2	142.4	169.7
20	24.1	3.6	1.2	142.4	171.2
22	25.6	3.6	1.2	160.4	190.7
25	30.8	3.6	1.2	167.0	202.5
32	37.3	4.7	2.4	200.7	245.1
40	22.6	21.1	5.9	231.7	281.3
50	29.5	24.7	5.9	273.6	333.7
65	34.9	30.3	8.9	301.8	375.9
80	37.3	33.8	8.9	342.1	422.1
100	58.0	46.2	21.3	382.6	508.0
125	75.7	58.7	25.4	440.0	599.9
150	93.5	73.8	27.2	523.0	717.5
200	142.0	115.0	27.2	564.1	848.4
250	176.3	84.7	16.0	630.3	907.3

These costs are combined with the length of each type of pipe within the Aarhus area giving the total costs in Table 59.

Table 59: Total investment costs for service pipes in the Aarhus area [10].

	Existing system		Reduced Demand	
DN	m	EUR	m	EUR
18	212,964	36,140,910	268,627	45,587,152
20	288,929	49,244,232	332,686	56,458,126
22	107,137	20,425,780	65,568	11,127,098
25	57,850	11,713,768	1,766	299,710
32	6,079	1,414,559	4,455	756,007
40	40,689	11,440,820	40,691	6,905,479
50	32,420	10,811,965	32,497	5,514,828
65	24,626	9,246,633	35,317	5,993,404
80	10,911	4,606,040	25	4,269
100	14,656	7,387,051	15,084	2,559,816
125	4,971	2,940,294	4,592	779,282
150	4,597	3,289,567	5,579	946,698
200	1,056	896,084	5	905
250	5	4,837	-	-
Total	**806,891**	**169,562,540**	**806,891**	**136,932,774**

This gives a total cost of the existing system of 170 million EUR and in a system with a reduced pipe diameter 137 million EUR. Again these investment costs are annualised with a lifetime of 30 years and a discount rate of 3%, giving an annual cost of 8.6 million EUR/year and 7 million EUR/year, respectively.

Additional to the investment in pipes, investments in pumping stations and heat exchanger stations are needed, see Table 60. These costs are based on assumed average costs of 1.34 million EUR per heat exchanger station and 0.67 million EUR per pumping station.

Table 60: Costs of pump and heat exchanger stations

	Count	Investment (EUR)	Annual investment (EUR)
Pumping stations	31	20,833,333	1,062,901
Heat exchanger stations	36	48,387,097	2,468,674
Total		**69,220,430**	**3,531,575**

The costs of pumps and heat exchangers correspond to a minor part of the annual investment.

20.10.3 Investments in heat pumps

Since the reference system does not include heat pumps, the number of heat pumps will be based on all the buildings in the area. The cost of investing in heat pumps is based on the information in Table 61.

Table 61: Investment cost of heat pumps [9].

	Ground source heat pumps		
Capacity	0-5 kW	5-10 kW	Above 10 kW
Investment	20,000 EUR	23,000 EUR	1,770 EUR/kW
O&M (EUR/year)	135	135	400
	Air to water		
Capacity	0-5 kW	5-10 kW	Above 10 kW
Investment	10,500 EUR	13,000 EUR	1,000 EUR/kW
O&M (EUR/year)	133	135	400

Each building is assumed to be supplied by one heat pump: Buildings with a peak capacity below 5 kW use a 5 kW heat pump; buildings with a capacity between 5 kW and 10 kW use a 10kW heat pump, and buildings above 10 kW use the cost per kW needed. The reason for modelling heat pumps in this way is that the kW cost decreases as the size of the heat pumps increases. This gives an investment cost of 858 million EUR for Scenario 2 and 654 million EUR for Scenario 4. Annualising these costs, with a lifetime of 20 years and a discount rate of 3%, gives annual costs of 58 million EUR in Scenario 2 and 44 million EUR in scenario 4.

20.10.4 Annualised costs for all scenarios

To compare all of the scenarios, the annualised costs for all scenarios are shown in Figure 98.

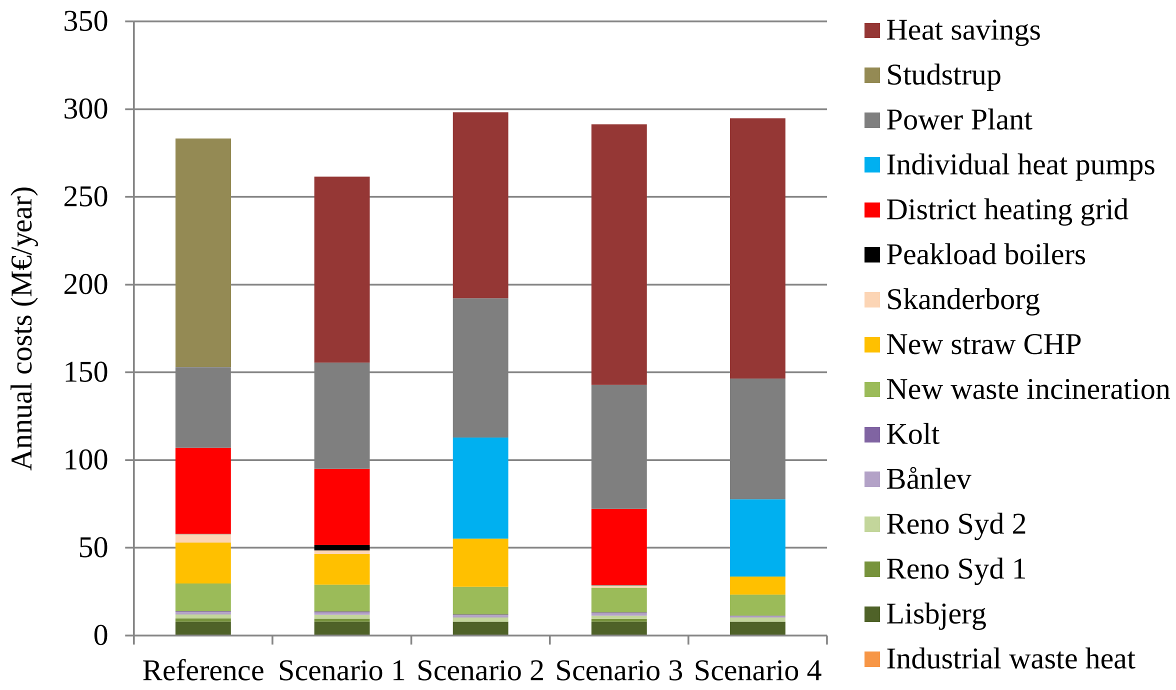


Figure 98: Annualised costs for all scenarios categorised by type of cost

Scenario 1 has the lowest annualised costs, which is due to the fact that the investment costs of district heating networks are low in this scenario compared to Scenario 2, which has higher costs for individual heat pumps and power plant capacity. Scenario 3 has low costs for district heating grids, but has much higher costs related to the implementation of heat savings. In general, the district heating scenarios have the lowest annualised costs compared to the individual scenarios. However when implementing large heat savings the individual scenario is close to the district heating scenario with the same heat savings. In Figure 99, the same results are categorised by fuel, operation and maintenance and investment costs.

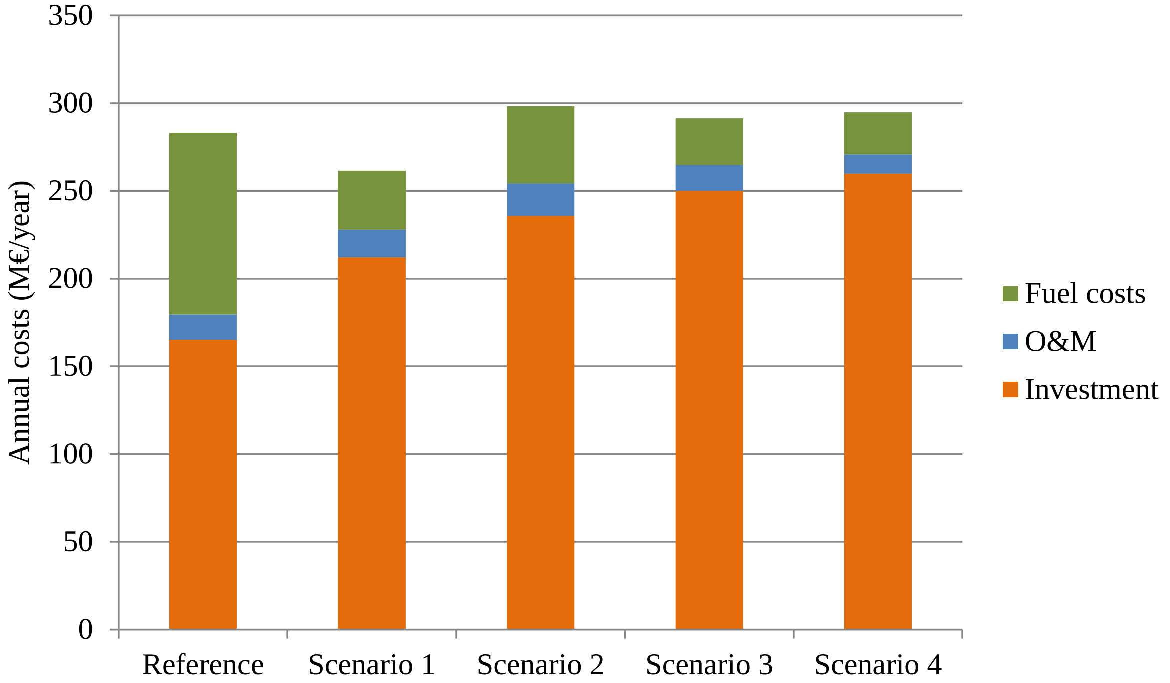


Figure 99: Annualised costs for all scenarios, categorised by fuel, O&M and investment costs

The costs change from high running costs in the Reference to high investments and low running costs in the Scenarios. Therefore, implementing large heat savings reduces the running costs.

20.11 CONCLUSION

The case study quantifies the energy flows and costs related to establishing an individual or collective heating supply system in the Danish city of Aarhus. This was done by using GIS data on the existing supply system, demands and buildings in combination with related cost data. The analyses were carried out in four scenarios; two district heating and two individual heating scenarios. Another difference between the scenarios was the extent to which heat savings were implemented, with either 55% or 77% reductions in the annual building heat demands.

The results show that, with a reduced heat demand, the extent to which CHPs can be used in district heating areas is reduced, minimizing the benefits of district heating. On the other hand, the electricity demand is not reduced to the same extent, giving an additional demand of electricity production capacity in all scenarios. This is especially seen in the individual scenarios in which compression heat pumps are added to cover the heat demand. The overall fuel consumption is therefore lower in the two district heating scenarios, with the lowest consumption in Scenario 3 due to the larger heat reductions. These demand reductions are, however, associated with a higher investment cost than the reductions in Scenario 1. Therefore, the main result shows that implementing heat savings is feasible to some degree in combination with district heating, but the benefits achieved by applying Scenario 3 are more costly than Scenario 1. The individual scenarios are both more costly than the district heating scenarios, due to the large investments in individual heat pumps and additional electricity production capacity. There is, however, a tendency that, with large reductions in heat demand, heat pumps become a more attractive solution, but this is still more costly than the district heating scenarios.

The case study underlines some of the points made in the main Heat Road Map Europe study: 1) District heating is an attractive solution in areas with a high heat density; 2) District heating can be seen as an efficiency measure similar to reductions in heat demand, because it enables the use of fuels in a more efficient way; and 3) Heat reductions in buildings can be combined with district heating in a way which makes it competitive with individual solutions both in regard to resource use and costs.

20.12 REFERENCES

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