Heat Roadmap Europe

Inputs for Technical Modelling and Policy Recommendations

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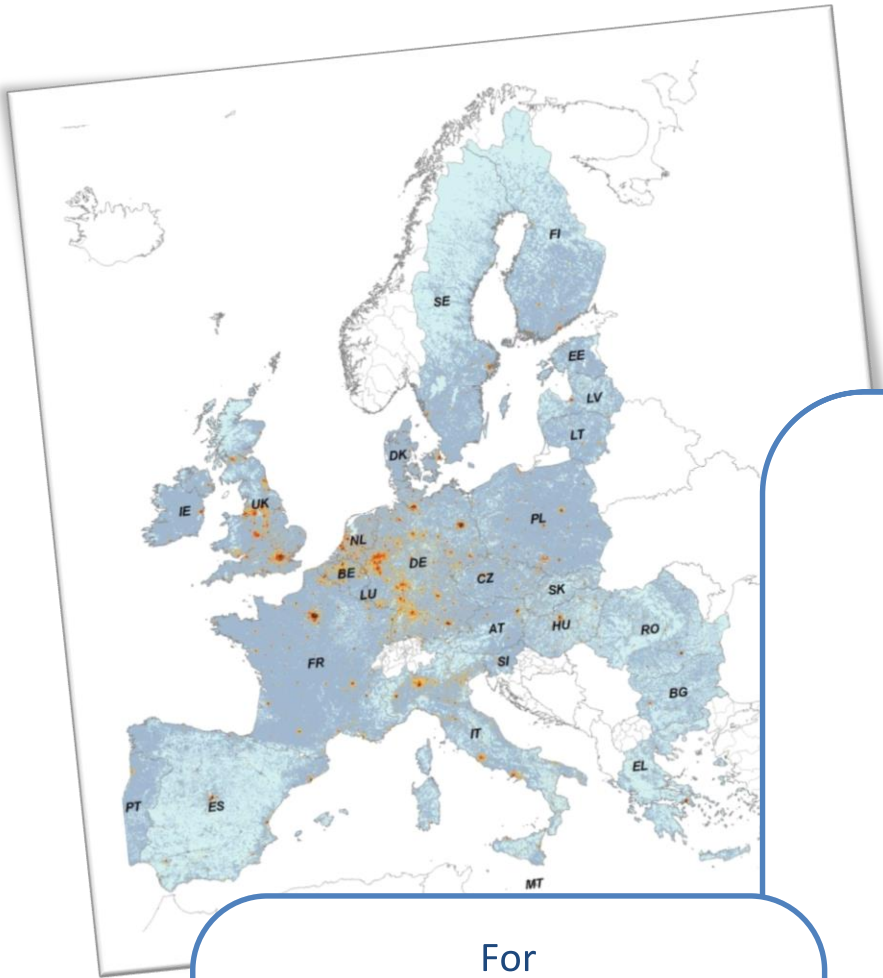
HEAT ROADMAP EUROPE

INPUTS FOR TECHNICAL MODELLING

AND

POLICY RECOMMENDATIONS



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1 INTRODUCTION

This document is a summary of the key technical inputs for the modelling of the heat strategy for Europe outlined in the latest Heat Roadmap Europe studies [1, 2]. These studies quantify the impact of alternative heating strategies for Europe in 2030 and 2050. The study is based on geographical information systems (GIS) and energy system analyses. In this report, the inputs for other modelling tools such as PRIMES are presented, in order to enable other researches to generate similar heating scenarios for Europe. Although Heat Roadmap Europe presents a complete heat strategy for Europe, which includes energy efficiency, individual heating units (such as boilers and heat pumps), and heat networks, the recommendations here are primarily relating to the potential and modelling of district heating. Although other solutions will play a significant role in decarbonising the heating and cooling sector, especially heat savings and heat pumps, these are not the focus in this document since many tools and organisations already have the ability to analyse these solutions. In contrast, there is currently a considerable shortage of basic knowledge about the modelling, implementation, and role of district heating in a low-carbon energy system context, so we have focused on this area based on our extensive experience in this area [1-10]. This report includes guidelines on the potential heat demand in European buildings that can be met by district heating as well as some general guidelines on how this district heating demand can be supplied. Typical capacities are recommended for boilers, combined heat and power (CHP) plants, centralised heat pumps, and thermal storage facilities. In addition, the potential heat available from surplus heat and renewable heat sources is outlined. These inputs can be used to model increased penetrations of district heating in the EU energy system in other energy planning tools, such as the PRIMES and JRC-EU-TIMES tools.

The key results from the Heat Roadmap Europe studies are that:

- Heat savings have a key role to play, but there is a socio-economic limit: after reducing the total heat demand by approximately 30-50%, it will be cheaper to supply heat from a sustainable resource instead of continuing with further savings, which can also enable a higher penetration of renewable energy due to cost shifted from savings and due to the availability of low cost waste heat sources.
- District heating should be implemented in the urban areas of Europe where the heat density is high enough.
- Heat pumps should be the primary individual heating solution in rural areas, but they will be supplemented by biomass boilers and solar thermal units in suitable locations. The scale and locations of these individual heating solutions has yet to be determined.

By implementing these measures, the Heat Roadmap Europe studies have indicated that it is possible to reduce the overall socio-economic costs of the EU energy system while simultaneously reducing carbon dioxide emissions and increasing the utilisation of renewable energy. To supplement these technical recommendations, this document also gives a flavour of the key policies which can be used to stimulate the growth of district heating in Europe. The key conclusion from these recommendations is that the European Union has a key role to play in the legislation of district heating, even though the implementation is required at a Member State (MS) level.

2 HOW ENERGYPLAN COMPLIMENTS THE PRIMES TOOL

The analysis carried out in Heat Roadmap Europe was completed using the EnergyPLAN tool. This is an hourly model that simulates one year at a time. One of the main objectives of the EnergyPLAN tool is to identify how the current energy system can be transformed from a linear 'segregated energy system' (Figure 1) to an integrated 'smart energy system', which is displayed in Figure 2 (www.SmartEnergySystem.eu) [11-13]. The key difference between these two systems is that:

- A segregated energy system relies on flexibility on the 'resources' side, for example using the energy stored in the form of fossil fuels
- A smart energy system relies on flexibility in the 'conversion' section of the energy system, which allows it to utilise very large amounts of intermittent renewable energy such as wind and solar.

Based on this key difference, EnergyPLAN has been designed based on hourly modelling of the complete energy system so that:

1. The hourly variations of intermittent renewable energy can be accounted for
2. The consequences of integrating the different sectors (electricity, heat and transport) of the energy system can be analysed (i.e. the new 'Conversion' part)
3. Many different alternatives can be analysed technically and economically in an interactive process by the user, which are not dependent on the current energy system design.

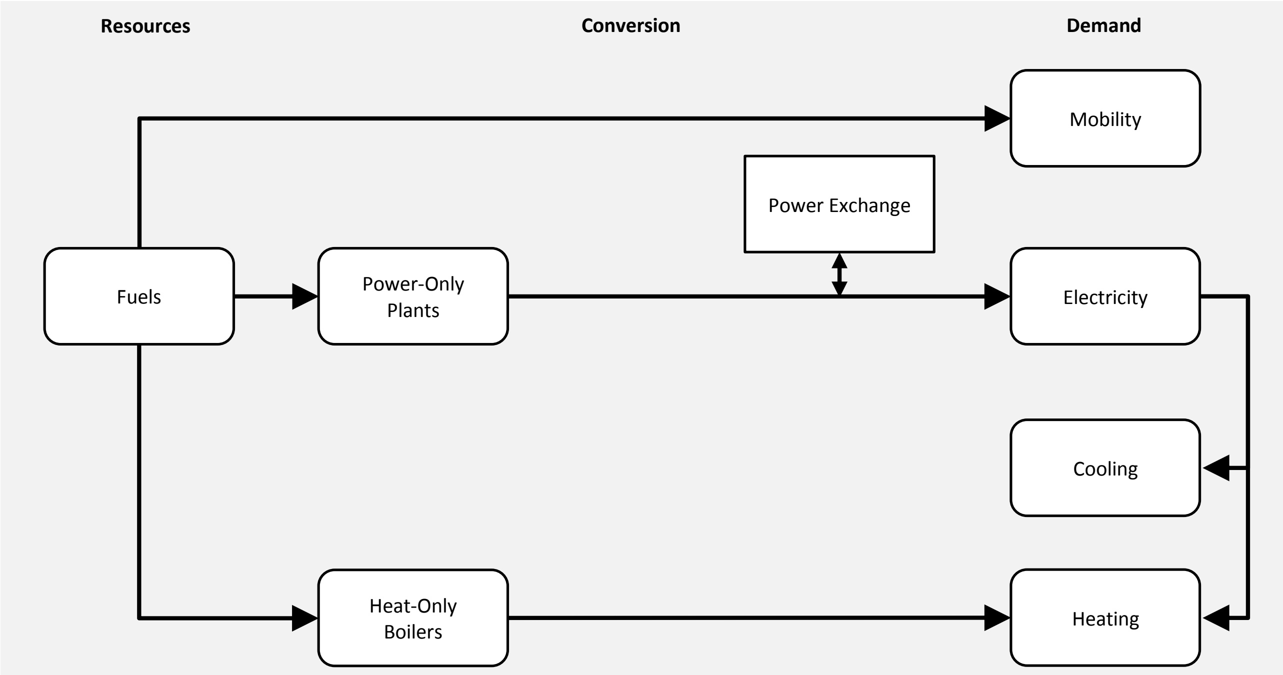

Figure 1: Interaction between sectors and technologies in today's typical energy system.

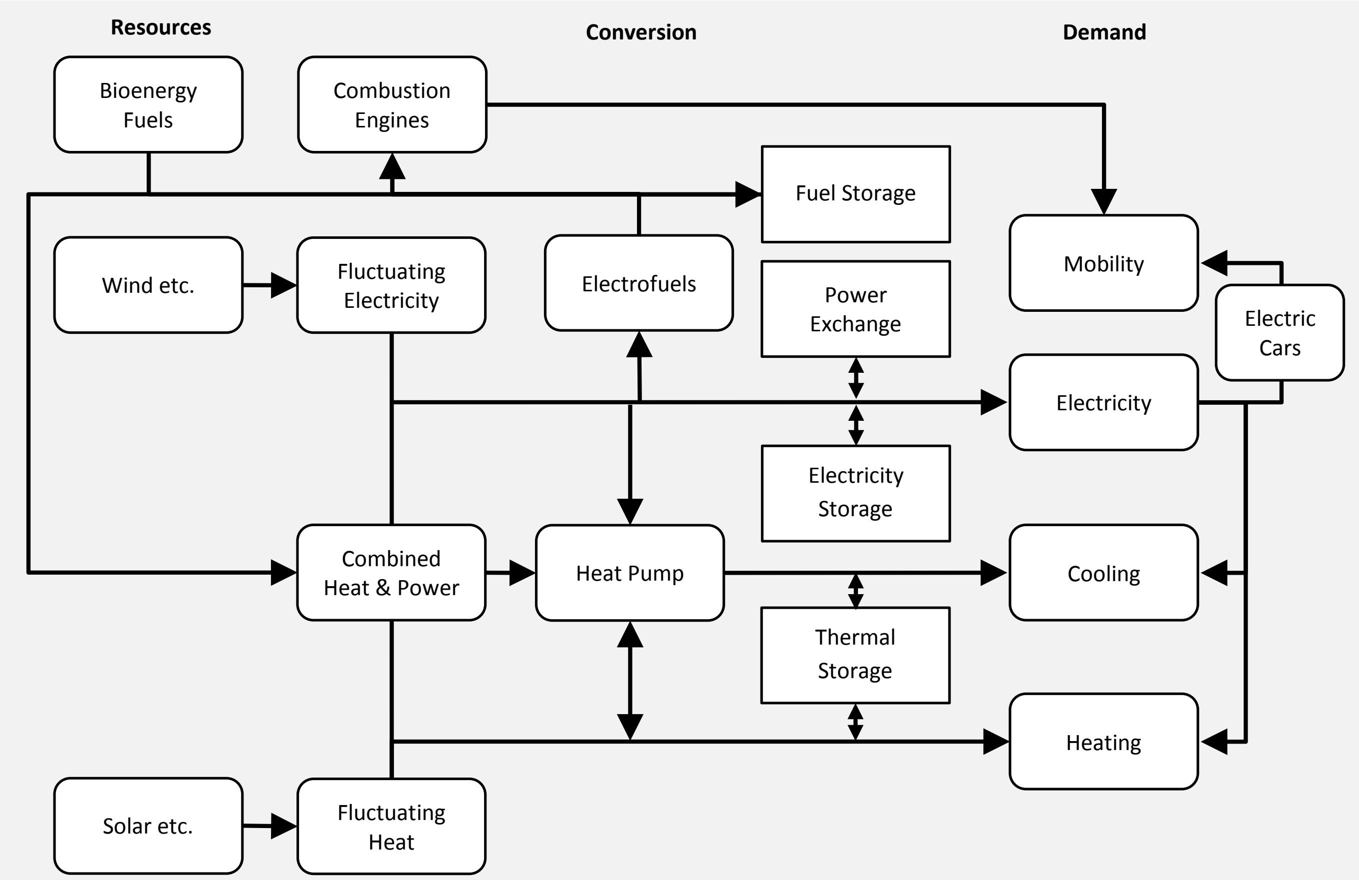

Figure 2: Interaction between sectors and technologies in a future smart energy system.

These are key features which distinguish EnergyPLAN from PRIMES and many other tools: a detailed comparison between EnergyPLAN and 36 other tools is available in Connolly *et al.* [14]. The PRIMES tool simulates the energy system on a yearly basis over long time horizons: for example, in 5-year time steps from 2010 to 2050. Therefore, while PRIMES can model long-term scenarios on a yearly basis, EnergyPLAN is designed to model a single year on an hourly basis. In this way, both tools can complement each other very well. PRIMES is very useful for creating a long-term pathway, while EnergyPLAN is very useful for analysing the technical robustness of specific years in that pathway. For example, in the Energy Roadmap 2050 reports, PRIMES was used to create different scenarios for the EU for the year 2050. The outputs from the PRIMES tool were energy balances for the EU every 5 years between 2010 and 2050. In the Heat Roadmap Europe project, three of these energy balances were used to analyse the energy system on an hourly basis, which were the energy balances from 2010, 2030, and 2050. In these hourly models, it is possible to identify some issues that are overlooked in the yearly modelling by the PRIMES tool. For example, during the Heat Roadmap Europe project, EnergyPLAN identified some intermittent renewable energy in the Energy Efficiency scenario that could not be integrated in the EU energy system, than originally reported in PRIMES. This was possible since the hourly balance between supply and demand of electricity is considered in the EnergyPLAN tool.

Another example of this key methodological is evident in the heat sector. In EnergyPLAN it is possible to optimise the combination of district heating supply technologies between boilers, CHP plants, thermal storage and others, since the hourly demand and supply of heat is accounted for, while at the same time the electricity supply is being balanced. By including these technologies it is possible to integrate the electricity and heat sectors of the energy system, which is not visible in yearly modelling. In this way, EnergyPLAN should be seen as a tool which looks at the hourly operation of the energy system, while PRIMES focuses on the annual development.

In the remainder of this document, some of the key trends that have been identified during the hourly modelling with the EnergyPLAN tool in Heat Roadmap Europe will be highlighted, particularly in relation to district heating.

3 TECHNICAL RECOMMENDATIONS

These technical recommendations relate to the potential demand for district heating in Europe, along with recommendations on how this demand can be met. These guidelines can be utilised in other energy planning tools, such as PRIMES, when analysing the role of district heating in the future.

3.1 DISTRICT HEATING DEMAND

A key output from the Heat Roadmap Europe project was the first every pan-European heat atlas, which is displayed in Figure 3. This heat atlas illustrates the heat density for buildings in the residential and services sectors across Europe on a 1 km^2 resolution. In other words, it is the amount of heat used in each kilometre cell of the EU27. This is a very important tool since heat density is the key metric which defines the potential for district heating. For example, a building with a high heat demand which is located in an isolated location may not be suitable for district heating, while a building with a low heat demand located close to many other buildings can be suitable for district heating. This is due to the economic breakdown of developing district heating.

The first key conclusion from Figure 3 is that the heat densities in European cities are very similar to one another. In other words, Copenhagen has almost 100% district heating, while London has very little. However, even from a visual inspection it is clear that London has more heat within a heat density of more than 150 TJ/km2 than Copenhagen. This is similar to the conclusions discussed in the ecoheatcool study [5], where a heating index was created for the EU. This heating index is displayed in Figure 4 and it estimates the variation in heat demand across the EU. The centre of Europe is designated as 100%, so all of the other figures are relative to that. The results suggest that the majority of the heat demand in Europe varies by only +/-20% around Europe. This is due to a combination of climate and building differences in Europe. For example, the climate in the North of Europe is cold but the buildings in the North are insulated more, while in the South of Europe the climate is hotter but the buildings are insulated less. This means that the heat demand in a building doesn't vary as much as the climate does, since the building stock has evolved with the local conditions. This results in the high heat densities in cities all over Europe that are displayed in the pan-EU heat atlas (see Figure 3).

The second key conclusion from the heat atlas is that there is a very large potential to expand the level of district heating in Europe. When district heating is compared to an individual solution, one of the key economic benefits is the elimination of the individual boiler unit. It is comparably more expensive to install an individual boiler in every home or commercial building. It is also expensive to build a pipeline to connect buildings to a district heating network. However, if buildings are located sufficiently close to one another, it is often cheaper to construct a district heating pipe and share a district heating production unit, such as a boiler, than it is to install a separate boiler in each building. This is why the heat density can be used to identify the potential heat demand which can be economically converted from an individual solution to district heating.

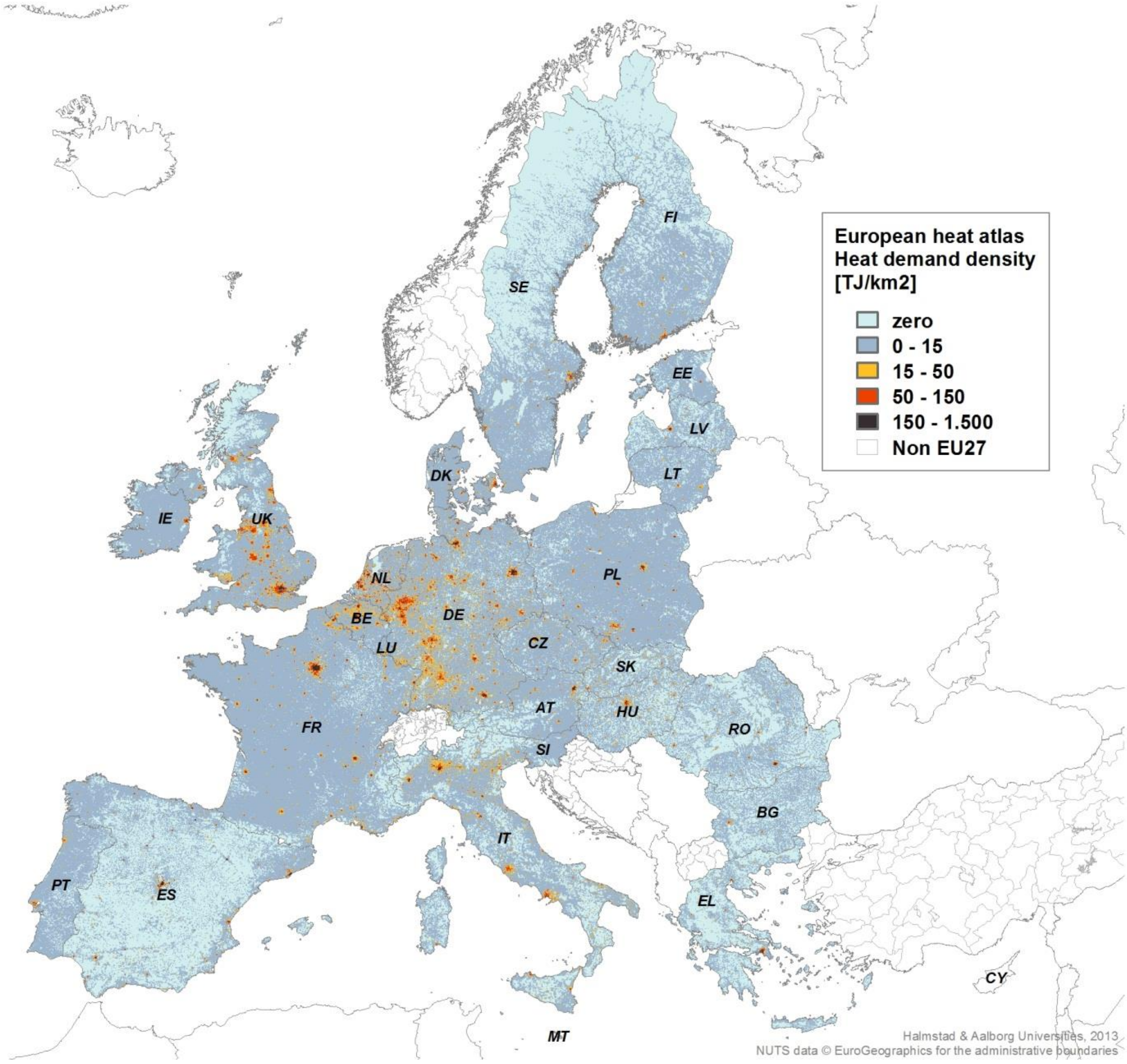

Figure 3: European Heat Atlas developed in the Heat Roadmap Europe study.

Currently there is approximately 10% of the EU heat demand in the residential and services sector which is supplied by district heating. Based on the pan-European heat atlas, this can be increased to a penetration of approximately 50%, so in the Heat Roadmap Europe it is recommended that district heating is used for

- 30% of the heat demand in 2030
- 50% of the heat demand in 2050

Further analyses could increase this district heating potential, could include district cooling potentials and could divide these potentials into more specific MS potentials. For example, the results from the STRATEGO project have already demonstrated how the Heat Roadmap Europe methodology can be transferred to five Member States: Czech Republic, Croatia, Italy, Romania, and the United Kingdom [15].

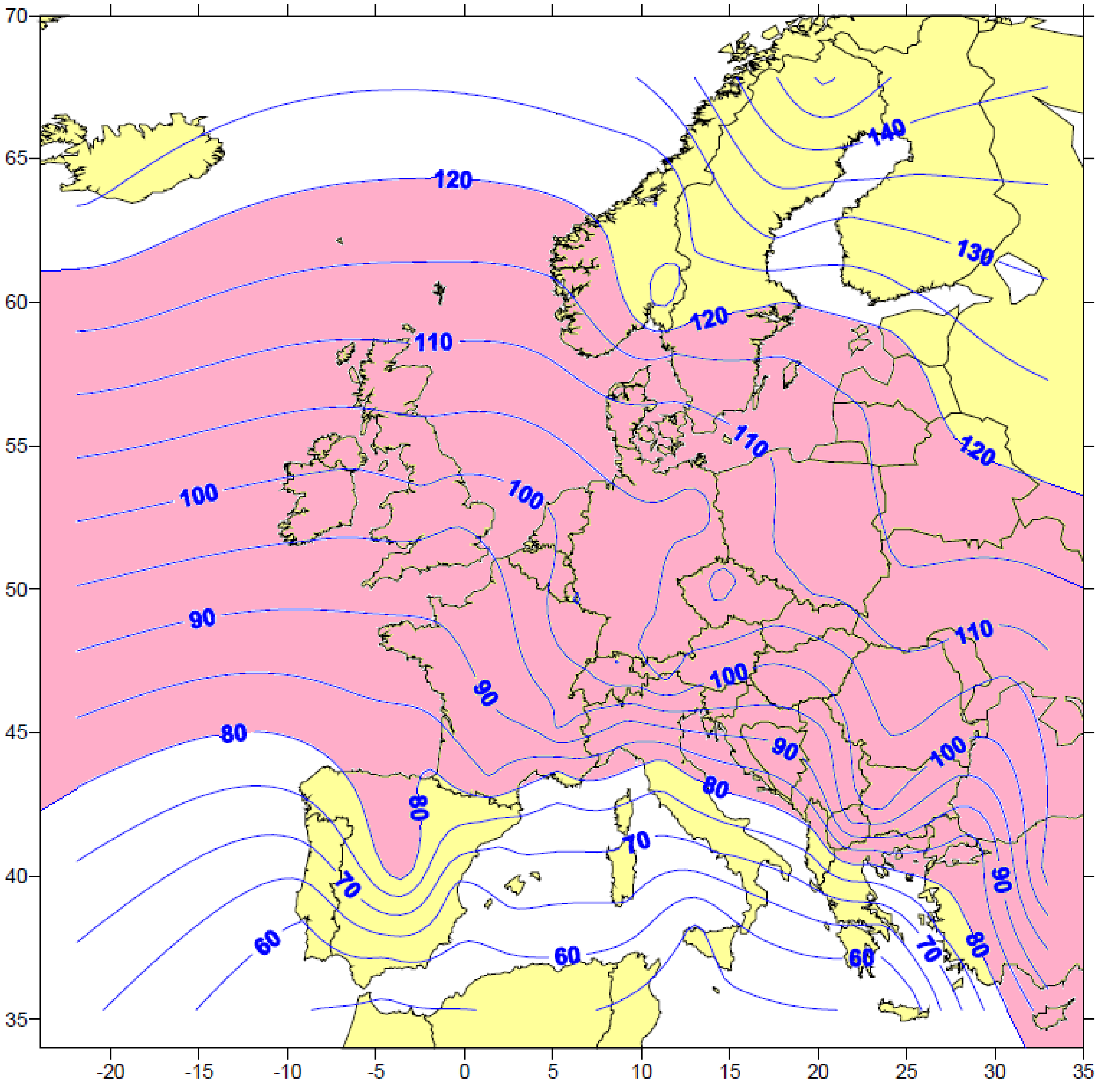

Figure 4: The European heating index (EHI) in a contour map computed from information for 80 urban locations in Europe. The space heating demand should be proportional to this index. Note that the map is not representative for all locations in each country, since the existing data grid consists of only 80 locations [5].

Heat Roadmap Europe Pre-Study 1 [1] analysed the EU energy system under a business-as-usual situation, which was based on the Current Policy Initiatives (EU-CPI) scenario from the Energy Roadmap 2050 report [16, 17]. Heat Roadmap Europe Pre-Study 2 [2] analysed the EU energy system under a low-heat demand situation, which was based on the Energy Efficiency (EU-EE) scenario from the Energy Roadmap 2050 report.

In both studies, a district heating demand of 30% in 2030 and 50% in 2050 was deemed feasible. The key difference between these two scenarios is that the total heat demand in buildings is much lower in the EU-EE scenario. This did not significantly reduce the potential share of district heating, but it did increase the price of district heating. When the heat demand is lower, there is a higher share of district heating which will be utilised in lower heat density areas. The cost of district heating at different heat densities is presented in section 3.4.2.

The technical potential of district heating can be kept at 30% of the total heat demand in 2030 and 50% of the total heat demand in 2050, but the costs for the district heating network will need to reflect the heat density.

There are still many improvements that can be made to this pan-European heat atlas. For example, some of the current developments include a better distribution of the heat demand within each MS and a more detailed calculation of the district heating network costs. The heat atlas also includes potentials for waste heat and renewable energy sources, which can be developed in more detail in the future.

3.2 DISTRICT HEATING HEAT SOURCES

One of the key advantages of district heating is that it connects a low-quality energy source to a low-quality end user demand. Heat is the lowest quality energy demand that the end user requires. Its sole purpose is usually to heat water or empty space. Since heat is a low-quality energy source, it is already wasted in many parts of the energy system today. For example, a typical condensing power plant will produce 40% electricity and 60% heat, but the heat is not utilised. Instead it is released into a cooling source such as a river, lake, sea, or the atmosphere. This means that district heating connects this surplus heat in the energy system to a demand which the end user requires. In Heat Roadmap Europe, the scale of this surplus heat was estimated for the following three sources:

- Large power plants (>50 MW_e), which are outlined in Figure 11 in the Appendix, currently produce ~2000 TWh of surplus heat which could potentially be utilised in district heating networks.
- Existing waste Incinerators, which are outlined in Figure 12 in the Appendix, currently produce ~50 TWh of heat each year, but they could potentially produce ~160 TWh of heat for district heating.
- Large-scale industry, as outlined in Figure 13 in the Appendix, currently supplies ~7 TWh of heat to district heating each year, but it could potentially produce ~750 TWh of heat.

In addition to these surplus heat resources, geothermal and solar thermal plants can be developed to produce heat for district heating systems. A first estimate of the potential from these resources in Heat Roadmap Europe indicated that there is:

- Approximately 120 TWh of deep geothermal heat that be utilised for district heating based on the resource displayed in Figure 14 in the Appendix.
- Approximately 350 TWh of large-scale solar thermal that can be utilised for district heating based on the resource displayed in Figure 15 in the Appendix.

Heat pumps can also be defined as renewable if the electricity source is based on renewable resources such as wind or solar. This is particularly relevant when the smart energy system from Figure 2 is in place.

In summary, there is a very large potential to connect surplus and renewable heat to the end-user heat demand with district heating.

As outlined in Figure 5, there is potentially more heat available for district heating from surplus and renewable resources than the total heat demand for all residential and services buildings in Europe even with no heat savings in the buildings.

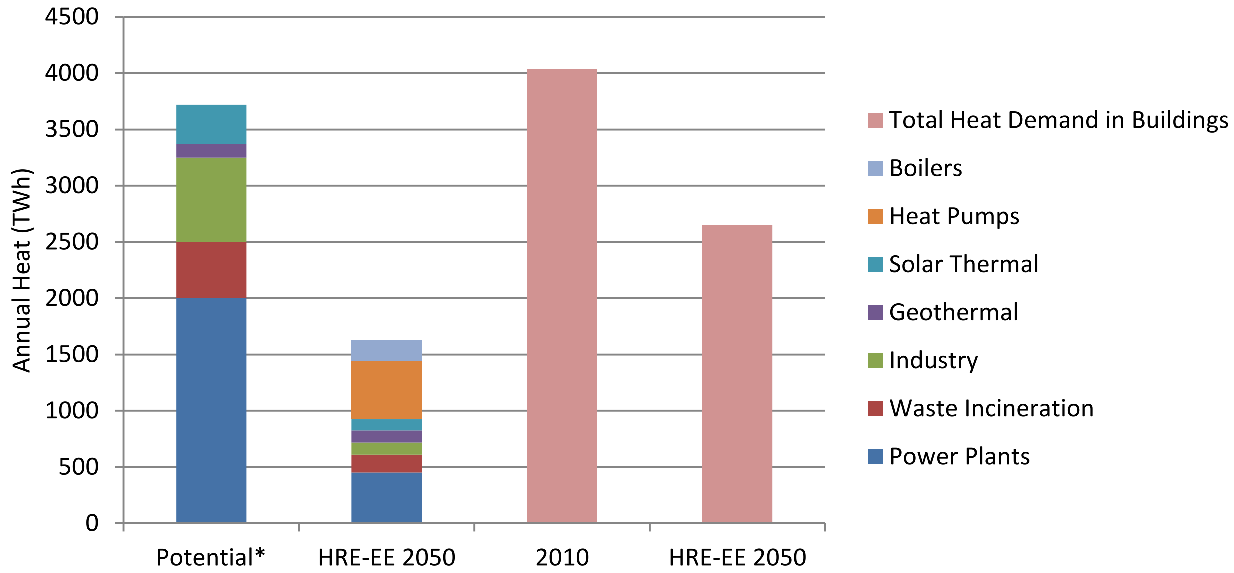

Figure 5: Potential surplus and renewable heat for district heating systems, along with the actual district heating production in the HRE-EE 2050 scenario. The red bars on the right illustrate the total heat demand in buildings in 2010 and the HRE-EE 2050 scenario. *This potential excludes heat pumps supplied by renewable electricity and boilers supplied by bioenergy.

3.3 DISTRICT HEATING PLANT CAPACITIES

A variety of different plants can be used to supply heat to a district heating system. Here, some guidelines are provided for the typical capacity of plants required when the district heating supply is increased in the EU energy system, based on the results from the Heat Roadmap Europe studies. During this explanation, it is important to distinguish between heat production and heat demand: as outlined in Figure 6, heat production is the amount of heat produced by the district heating plants, while heat demand is the amount of heat reaching the end user. The heat demand is less than the heat production due to losses in the district heating pipes. Typically these losses correspond to 10-15% of the heat production in new district heating networks and 20-25% in older/established district heating systems.

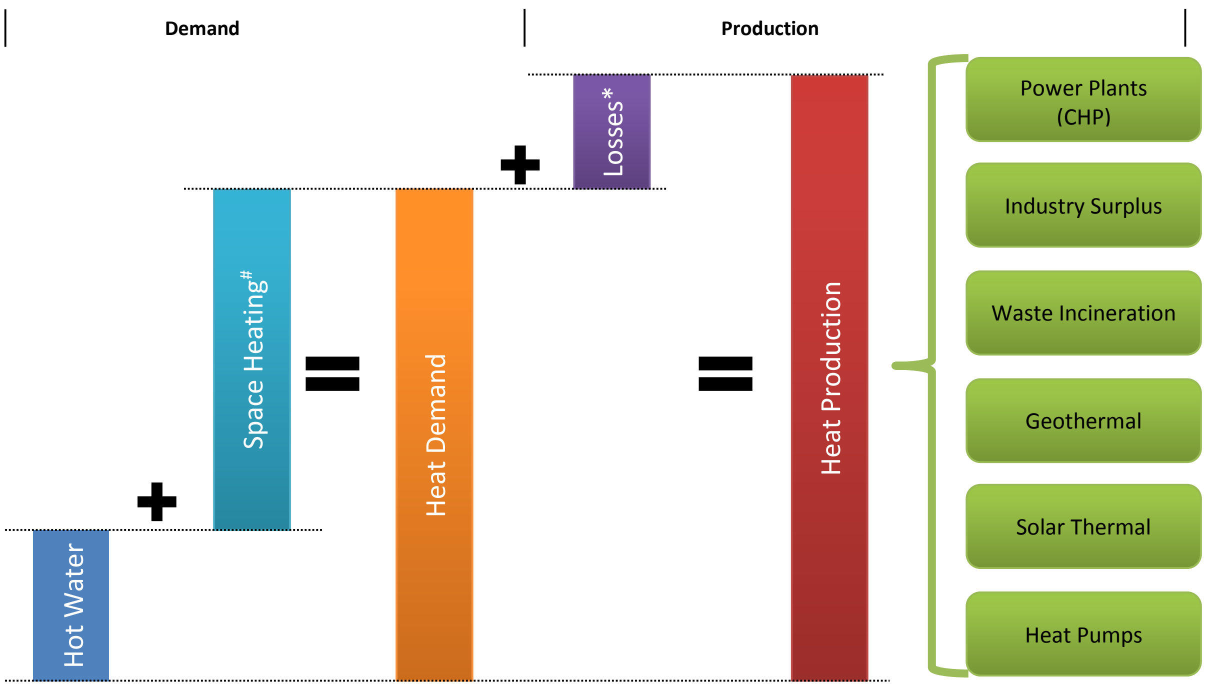

Figure 6: Energy demand and production for a district heating system. *These losses occur in the district heating network: older district heating networks have losses of approximately 20-25% of the heat production while new networks have losses of 10-15%. Please note that very small losses occur in the transmission system, with the main source of losses occurring closer to the buildings where the pipelines get smaller and flow rates get lower. #Space heating is usually the largest demand and typically represents 65-75% of the total today, but in the future it will have a lower share due to improved building envelopes. The space heating demand varies significantly over the year, while the hot water demand as well as district heating network losses usually remains constant.

The size of the district heating production units are closely linked to the type of demand (i.e. the relationship between hot water and space heating). The *hourly district heat demand distribution at the building level* during the year is dependent on the level of insulation and the including or excluding of the hot water demands. The *hourly district heat production distribution at the plant level* is additionally dependent on the losses in the district heating grids.

Ideally, an hourly energy systems analysis should be carried out to ensure that the district heating production plants are optimised for the district heating demand. However, since this is not always possible, some general guidelines are provided here to define the capacity of district heating production plants based on the results in Heat Roadmap Europe.

- The installed boiler capacity should be equal to 120% of the peak heat production over the year.
- The peak heat production occurring in one hour is approximately 275% of the average heat production. However, this is very sensitive to assumptions relating to the level of heat savings for the buildings and the breakdown of the total heat demand, which is the ratio between hot water demand and space heating. An hourly energy systems analysis of a scenario is required to define this exactly.
- The boiler usually produces approximately 10% of the (total heat) demand annually, since its primary function is to service peak load production and to act as a backup in case of a breakdown or extreme cold period. It should be noted that the concrete operation of the boiler for district heating is

dependent on the amount of intermittent resources in the system, the opportunities for the CHP plant to operate, the presence of a thermal storage, and the presence of a large-scale heat pump.

- The installed CHP thermal capacity should be approximately 120% of the average hourly heat production. Usually the CHP plant is not dimensioned to cover the peak heat demand due to the economic performance of such plants. Normally boilers or thermal storage plants are used to cover the peak heat demands in cold periods, thus optimising the economic operation of CHP plants.
- The heat pump thermal capacity (assuming a COP of 3) should be approximately 50% of the average heat production if the share of intermittent renewable energy in the system is high, such as the levels experienced in the EU-EE scenario. For a lower intermittent renewable share, such as the one in the EU-CPI scenario, the heat pump capacity is approximately 15% of the average heat production. In general large-scale heat pumps can increase the feasible potential for intermittent renewable electricity production.
- The thermal storage capacity should be approximately 6 hours of the average heat production [18].

To put this into practice, here are some guidelines for the recommended capacities if 100 TWh of heat is produced for district heating in the EU:

- Average heat production = (100/8760)*1000 = 11.4 GWth
- Peak heat production = 11.4 GWth*275% = 31.35 GWth
- Boiler Capacity = 31.35*120% = 37.6 GWth
- Boiler Production = 100 TWh*10% = 10 TWh
- CHP Thermal Capacity = 11.4 GWth*120% = 13.7 GWth
- Heat Pump Capacity:
    - Low intermittent renewable share = 11.4 GWth*15% = 1.7 GWth
    - High intermittent renewable share = 11.4 GWth*50% = 5.7 GWth
- Thermal Storage Capacity = 11.4 GWth*4 hours = 45.6 GWh

The boilers are expected to use biomass or gas in the future. The CHP plants are expected to use gas, which could be natural gas in the short-term and some form of biogas or synthetic gas in the long-term.

These are only guidelines since optimising the capacities for the various heat production units requires an hourly energy systems analysis of that particular scenario.

3.4 DISTRICT HEATING INVESTMENT COSTS

This section presents the costs associated with district heating systems, which in Heat Roadmap Europe included the cost of:

- Reducing the heat demand in Europe, using various energy efficiency costs
- Building new district heat networks
- Utilising the surplus and renewable heat sources in the district heating systems

Each of these costs are presented separately here.

3.4.1 Energy Efficiency Costs

The most economical solution for a more sustainable energy supply is often reducing the demand instead of creating a new supply. In regards to establishing district heating it is important to locate and implement these feasible heat savings while simultaneously establishing or expanding district heating systems. This is also the case for other individual heating solutions, as the costs of energy efficiency measures usually increase after a new heating system is installed. For the heating sector, there is a large potential across Europe to reduce the demand, since the building stock in many MSs is relatively old. It is currently very difficult to quantify the exact level of heat savings that should be implemented due to the differences in building stock, climate, and heat production units. In Heat Roadmap Europe, detailed costs from the Danish building stock were applied to the EU heat sector to estimate the general level of heat savings that could be implemented.

The principal in Heat Roadmap Europe is that the heat demand in the EU should be reduced until we reach the point where it is cheaper to have a sustainably supply heat instead of implementing more heat savings.

To estimate this, the unit cost of saving heat was estimated. Figure 7 displays the cost of reducing the heat demand in Europe based on the marginal additional costs of energy efficiency for a building while it is undergoing other renovations at the same time (i.e. additional Costs), and the direct costs of energy efficiency for a building when the sole purpose of the renovations are to reduce the heat demand (i.e. direct costs). Figure 7 also displays the unit cost of supplying heat from:

- A natural gas boiler based on 2011 prices, which was one of the cheapest forms of heat in 2011
- An oil boiler based on 2050 prices, which is forecast to be the most expensive form of heat in 2050

These two boiler solutions represent two extremes. Any energy efficiency measures that are cheaper than a natural gas boiler in 2011 should definitely be implemented, since they are cheaper than cheapest form of existing heat supply. Any energy efficiency measures above the price of an oil boiler in 2050 should not be implemented, since they are more expensive than the most costly form of heat supply. This creates an initial lower and upper limit for energy efficiency measures in Europe.

There are of course numerous considerations that need to then be considered within these limits, such as

- What other type of heat production units could be used (for example, heat pumps)?
- How sensitive are these cost estimates to the assumptions applied?

- What percentage of the energy efficiency costs will require 'additional' costs and what percentage will require 'direct' costs?

Each of these issues requires a substantial amount of further analysis to fully conclude upon. However, based on existing knowledge, Figure 7 confirms that energy efficiency is often the most economical solution, but eventually there is a point where heat supply is more affordable than further heat savings. In Heat Roadmap Europe it was concluded that the heat demand in Europe is likely to be reduced by approximately 30-50% between 2010 and 2050, which will cost approximately €135 billion/year. It is important to note that this reduction of 30-50% includes the same level of savings for the space heating demand as the most ambitious Deep Renovation scenario of the EURIMA report [19], which is the European Insulation Manufacturers Association. Therefore, a very high level of heat savings will be necessary in the future, and even with this very high level, some form of sustainable heat supply is still necessary.

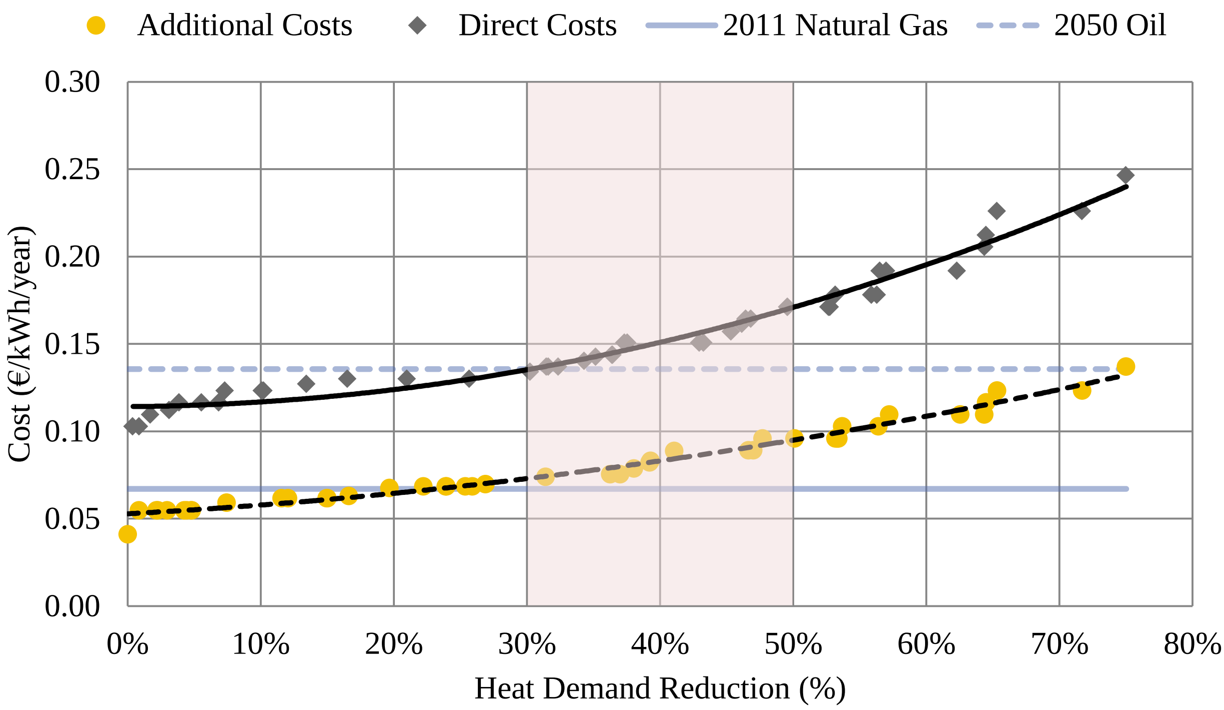

Figure 7: Additional costs for energy efficiency measures that reduce the heat demand by different percentages based on Danish buildings (scenario C) [20], along with the unit cost of supplying heat from a natural gas boiler in 2011 and an oil boiler in 2050. 'Additional' means it is assumed that these are the extra costs of completing the energy efficiency measures at the same time as implementing other building refurbishments.

3.4.2 District Heating Network Costs

To construct a district heating network requires two types of investments:

1. The district heating pipes connecting the buildings to one another.
2. The district heating substation, which is the heat exchanger unit which transfers heat from the network into the individual building.

The average cost of the district heating pipes is outlined in Table 1. Two costs are presented, one for conventional district heating which is the average price of constructing district heating today. The heat density in these areas is >120 TJ/km^2 since it is usually in urban areas with relatively high heat demands. The other cost displayed in Table 1 is the price of district heating in low heat density areas. This type of district heating could be used today in low heat-density areas like the suburbs, or it will be required in more central locations in the future when the heat demand in buildings is significantly reduced.

Table 1: Financial assumptions for conventional and low-temperature district heating assumed in the EU-EE and HRE-EE scenarios [21].

	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* (M€/TWh of heat demand)	72	522#
Technical lifetime (years)	40	40
Average Fixed O&M (M€/TWh/year)	0.9	3.96
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.

Based on the pan-European heat atlas from Heat Roadmap Europe, some guidelines can be followed in relation to the amount of conventional and low-temperature district heating that is required in the future, which are:

- If we continue with a business-as-usual heat demand, similar to today, then for a 50% district heating share we will have:
    - Approximately 50% of the district heating demand from conventional district heating
    - Approximately 50% of the district heating demand from low-temperature district heating
- If we reduce the heat demands in the EU by approximately 30-50%, similar to the level proposed in Heat Roadmap Europe Pre-Study 2, then for a 50% district heating share we will have:
    - Approximately 25% of the district heating demand from conventional district heating
    - Approximately 75% of the district heating demand from low-temperature district heating

The district heating substation costs assumed in Heat Roadmap Europe are outlined in Table 2. The costs of other individual heat units is also provided so a relative cost can also be used if it is more relevant for other energy planning models/tools. The district heating substation cost presented here includes the cost of the 'distribution' pipeline connecting the building to the main district heating network.

Table 2: Financial assumptions (including the installation) for residential and services boilers in Heat Roadmap Europe Pre-Study 2.

	Oil	Gas	Pellet/ Coal	Air Heat Pump	Brine Heat Pump	Direct Electricity	District Heating Substations
Residential Heating Units							
Specific Investment (k€/unit)[#]	3.8	5.6	7.0	13.0	17.3	10.3	6.2*
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 Heating Units							
Specific Investment (k€/unit)[#]	26.3	13.6	45	240	264	175	21.5*
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

***Includes the cost of a meter and a branch pipe from the district heating network to the building.**
[#]These are the costs used for 2012 in Heat Roadmap Europe. The specific investment of an individual boiler is very sensitive to the peak heat demand that needs to be satisfied in the building. Any reduction in the heat demand due to energy efficiency measures will reduce the size of the individual boiler and thus the investment cost also.

3.4.3 District Heating Plant Costs

The final cost presented here is the cost of producing the heat to the district heating network. The cost of boilers, CHP plants, heat pumps, thermal storage, waste incineration, and large-scale solar thermal facilities is presented in Table 3. These costs can be used with the potential heat sources presented in section 3.2 and the typical capacities presented in section 3.3.

Table 3: Key financial inputs assumed for district heating production plants [5, 21-23].

Production Type	Unit	Investment (M€/unit)	Lifetime (Years)	Fixed O&M (% of Investment)
Gas Boilers	MWth	0.1	35	3.70%
Biomass Boilers	MWth	0.8	20	1.35%
Gas CHP	MWe	0.85	25	2.30%
Heat Pump	MWe	2.7	20	0.20%
Thermal Storage	GWh	3	20	0.70%
Waste Incineration	TWh*	355#	20	1.82%
Large-Scale Solar Thermal	TWh*	440#	20	0.00%

***Expressed in terms of the heat delivered to the district heating network.**
#Assuming a heat efficiency of 70% for a typical waste incineration plant. This would increase if the temperature in the district heating system is reduced.

The remaining heat sources and their average heat supply costs are:

- Geothermal heat, which has an estimated average heat supply cost of €200/MWh of heat delivered [22].
- Industrial surplus heat, which has an estimated average heat supply cost of €40/MWh of heat delivered

4 POLICY RECOMMENDATIONS REGARDING THE IMPLEMENTATION OF HEAT ROADMAP EUROPE

Member States (MS) in the EU have very different levels of district heating in their energy mix. Some countries such as Denmark and Sweden, use district heating to provide heat to over half of their homes, while other countries with similar climates such as Ireland and the UK, have almost no district heating. Hence there is a role for the EU to transfer this knowledge and best practise of regulations from the MSs with experience in district heating to those that have very little. In this section we outline a non-complete list of recommended policy measures that could support the actual implementation of the results in the Heat Roadmap Europe studies [1, 2]. As mentioned these studies outline coherent scenarios regarding:

1. Savings in heat demands
2. Potentials for district heating supply
3. Potential individual heating technologies

4. The production of district heating, including the potentials to use surplus heat or renewable energy heat sources

The list of policy recommendations outlined here is focused on the implementation of district heating, and to some extent also the combined policies necessary to implement district heating in combination with heat savings. The list is NOT complete and should be seen as an inspiration. Also these are only selected recommendations which primarily relate to the implementation of district heating. In general the EU could focus on these 5 key areas of support for developing this technology:

- **Long-Term Strategy (see section 4.1):** district heating networks are large infrastructure with natural monopolies and long lifetimes, just like the natural gas grid and electricity grid. Therefore, establishing district heating networks requires a long-term strategy and commitment, so that investments today fit with the future energy system. The EU can play a key role in defining a strategy for district heating for all the MSs.
- **Knowledge (see section 4.2):** The EU can promote and can gather experiences from different trials and compare them to one another to identify the successes regarding policies and why there are a success. This will help to identify local barriers for district heating in the different MSs [24]. Similarly, the EU can connect expertise and knowledge from MSs with skills and experience in district heating to those that do not have experience with district heating. For example, this could include training in construction techniques for building contractors and planning skills for consultancies performing feasibility studies.
- **Financing (see section 4.3):** obtaining sufficient funds for feasibility studies and developing district heating networks is usually very difficult. This could be overcome by creating a fund for feasibility studies as a part of the fees for existing heating systems, such as the natural gas grid, similar to those obtained from PSO levies for feasibility studies in the electricity sector in many MS. For the capital funds, the EU could identify how low-rate loans have been used in some MS to stimulate the development of district heating, and encourage these in member states that do not have district heating.
- **Regulation, particularly for ownership and operation (see section 4.4):** there are overall institutional problems that can be addressed at the level of the EU. For example natural gas companies and electricity companies are well-established in many MS and promote individual natural gas boilers and direct electric heating. Similar institutions do not exist to promote district heating as a solution in most MSs. Therefore new institutions and actors will need to be created to promote, construct, own, and operate district heating networks.
- **Communication (see section 4.5):** There is a need to rebrand district heating. In the past some district heating networks, especially those in Eastern Europe, were not developed for efficiency or comfort. This brand still exists for district heating in many MSs, even though the technology has proven that it can improve the efficiency of the energy system as well as the end-user's comfort levels.

Each of these regulations is elaborated on in more detail in the following sections. However, before consulting the details of these policies, it is important to understand why district heating does not fit with the demands in the current market economy.

District heating is a long-term infrastructure, with a lifetime of at least 40 years, which involves a variety of different actors. In brief, a typical district heating system has:

- A large number of private and commercial consumers
- A natural monopoly in the form of the piping network
- A variety of private, municipal, or consumer-owned heat producers such as power plants, waste incineration plants, or solar thermal plants (see Figure 6). These are also long term pieces of infrastructure with typical lifetimes of 20-30 years.
- A local network which usually does not expand beyond an urban region.

This illustrates why district heating needs to be considered as a long-term investment. Similarly, due to the technologies involved, district heating also requires a relatively high amount of capital funding in comparison to some of its alternatives. This leaves district heating with two key features which prohibit its development: long-term investment and high initial capital costs.

This structure of a district heating network investment does not fit with the priorities of a market economy. Developers or investors want a maximum of a 10-12 year payback on an investment, but the district heating pipes last for at least 40 years. Therefore, the majority of the technical lifetime of a district heating network is often disregarded when comparing it financially to other heating solutions under current investor requirements. The market economy is not including the full technical potential of district heating in its financial comparisons. Another type of economics needs to be considered to account for the long-term lifetime and high initial capital costs of a district heating system. In Heat Roadmap Europe we define this alternative as socio-economics.

When looking at socio-economic costs one should disregard the transactions between the different actors in society and look at what is beneficial for the actors as a whole. A socio-economic calculation includes many perspectives and theories which cannot be fully elaborated here. However, some concrete differences which illustrate the type of differences between socio-economics and conventional market economy would be:

- A socio-economic analysis considers the total lifetime of all technologies, which can be up to 50 years for hydropower plants for example, while an investor using market/business economy will only look for investments with a 10-12 year payback.
- A socio-economic analysis will look at the cost of the technology, while an investor will look at the cost of the technology with any subsidies from public support schemes minus any taxes or penalties due to other regulations. The principal here is that socio-economy is the underlining cost, but market economy is the 'adjusted' cost after current public regulation and market designs are applied to it.

It is important to note that district heating and heat demand reductions should not only be compared in terms of economy, regardless of whether it is socio or market based. There are also numerous other factors which should be taken into account during a feasibility study such as local jobs, security of supply, health, reduced fuel poverty, and improved comfort. This is critical for district heating since it is a piece of local infrastructure which often results in many local benefits, such as new local jobs. These feasibility studies must be the main focus when assessing where and where not to establish district heating.

Other economic perspectives are also important such as the fiscal budget and the private economic situation. When it has been established what is feasible from a socio-economic perspective, then as Figure 8 displays, the public regulation surrounding district heating networks should then be developed.

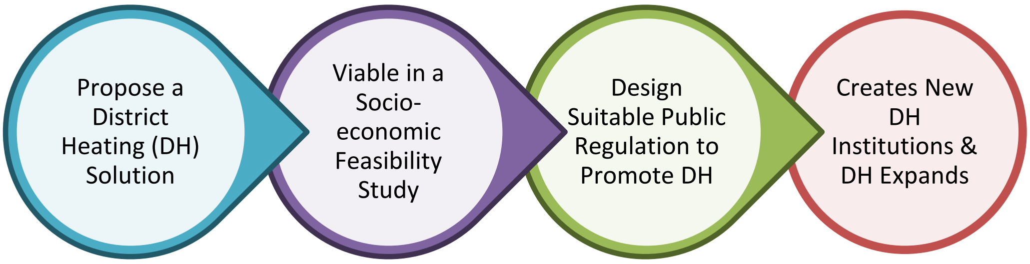

Figure 8: Fundamental changes required to stimulate growth in the district heating market.

The key technical characteristics of district heating (i.e. long lifetime and high initial capital) are very important to acknowledge, since they explain why a technology that it is often cheaper for society is still not implemented. This is an important context to remember when considering the new policies/public regulation discussed in the remainder of this chapter.

4.1 STRATEGY: THE NEED FOR A LONG-TERM STRATEGY AND EU WIDE GOALS

There is a need for a long-term strategy regarding district heating, in order to ensure that investments are considered and secured in the longer-term. A long term strategy usually results in long-term public regulation, which typically needs to be in place to implement district heating. Public regulation consists of many interrelated parts. For example, different EU directives already promote district heating and combined heat and power, directly or in directly, but these directives are not resulting in the implementation of district heating. Most MSs have implemented legislation to follow up on these directives, but in many cases legislation is put in place with no detailed institutions or guide on how this should then be implemented.

- There is a need for an overall EU goal for the implementation of district heating and supply by combined heat and power, surplus heat and/or renewable energy.
- There is a need for long-term public regulation which supports the long-term strategy for district heating.

This long-term strategy for district heating should consider the future energy system and not today's energy system. For example, heat savings should be implemented at the same time as the district heating network is being established so low heat demands are being met (see section 3.4.1 for more details). Similarly, if a district heating network is installed without heat savings, then the district heating owners should be incentivised to reduce the heat demand over time: by comparing the performance of different district heating systems. The long-term strategy should also fit with the Smart Energy System proposed in Figure 2. For example, surplus heat from biofuel plants could be used in the district heating system if there are large penetrations of biofuels in the transport sector, so:

- Any long term strategy should consider the supply and demand for heat in this future smart energy system context (Figure 2).

This can be implemented with policies which favour the use of surplus heat. For example, any new power plant constructed in the EU must use its surplus heat. Similarly, new policies could favour specific fuels by putting high taxes on oil for heating and low tax on the use of surplus heat or surplus electricity.

Any EU level strategy or public regulation also needs to be connected to the local communities where the district heating networks are being constructed. One proven method of doing so is to create a regional/national body that can coordinate where district heating should be implemented. A local authority also has to be able to identify areas where district heating is feasible. The planning is often very poor or non-existent in countries with small amounts of district heating, while it can be improved in mature district heating countries. In many MSs district heating is often not included in any strategies for improving energy efficiency or increasing the penetration of renewable energy.

- There is a need for local and regional/national authorities that have the power to ensure the development of district heating where district heating is feasible.
- On the national level there is a need for an organisation that can ensure that the socio-economy of district heating is assessed, so the infrastructure is only established where it is feasible for society. For example, this could be the development of a certain methodology which has to be used by the municipality, local authority or local utility to prove the feasibility and thus establish a local network.

In this way, a long-term EU strategy can be connected to the local implementation of district heating.

4.2 KNOWLEDGE: EXCHANGING SKILLS AND EXPERIENCES ACROSS MEMBER STATES

The EU has a key role to play as a facilitator of knowledge transfer in relation to district heating. District heating has evolved in many different ways around Europe. The Nordic countries have focused on the user's comfort and efficiency, the Eastern Europe countries focused on central planning and operation, and the central European countries have a key focus on industrial district heating networks. At the same time, many countries in Europe have no district heating systems. This means that the EU28 currently have extremely diverse experiences, skills, and most importantly perhaps, requirements in relation to district heating. The EU could play a central role in connected the knowledge spread across Europe together, to ensure that new district heating developments are developed in the 'right' way. Here, right is defined as a district heating system which fits with the smart energy system displayed in Figure 2. District heating will need to be efficient, account for reductions in the future heat demand, provide cheaper heat than its alternative, and use sustainable resources. To ensure that district heating develops in the 'right' way will require the exchange of knowledge between countries, particularly from experienced district heating countries to new district heating countries.

This encompasses all aspects of district heating, from the initial feasibility studies to the final operation of the heat plants. However, here are a few key areas where knowledge transfer is essential between MSs:

- Purpose of district heating: experience district heating countries should demonstrate how they have benefited from district heating in terms of fuel savings, carbon dioxide emissions, and costs. There is currently a major lack of knowledge in relation to the technology and consequences of using district heating.
- Feasibility studies: there is a shortage of consultancies and knowledge on how to assess a district heating scheme in countries without district heating. For example, many member states do not have heat atlas, which is fundamental for analysing a district heating system. There needs to be an exchange of training between new and experienced district heating countries, or at the very least, new district heating countries need to be connected to adequate skills in other countries.
- Identify local barriers: Help identify the individual barriers hindering the implementation of heat demand savings, district heating networks, and the use of waste heat and renewable heat in different MS.
- Planning: as discussed in section 4.1, a public authority needs to have the skills to identify the potential for district heating. Historically, many countries in Europe have very little experience with energy planning and in particular, district heating planning so this is another area of useful knowledge exchange.
- Share regulatory experiences: new district heating countries usually do not have a central district heating associations to enable new schemes to develop. As a result, new schemes face a lot of challenges such as developing the contractual agreements for customers, selling electricity from their CHP plants to the electricity grid, and connecting district heating systems to one another. Experienced countries could help to design the regulatory framework in new district heating countries.
- Support schemes: there was no direct policy supporting district heating in Sweden, but instead district heating was chosen as the best technology to meet indirect policies such as reducing their dependence on oil, improving energy efficiency, and utilising surplus heat from power plants. These experiences could be transferred to other countries to demonstrate the type of policies required for district heating.

These are only some suggestions for the type of knowledge exchange that could take place, since in practise all issues relating to district heating are applicable here.

4.3 FINANCING: FEASIBILITY STUDIES, CAPITAL SUPPORT AND DEMONSTRATION

The establishment of new district heating grids requires financing. There are usually two key periods in a district heating project when finance is required: a relatively small fund for a feasibility study and a relatively large amount to contribute to the initial construction.

Funding for feasibility studies are particularly difficult for district heating systems compared to other large-scale energy infrastructure such as natural gas and electricity grids. In inexperienced countries, this is primarily due to the lack of knowledge, skills, and awareness of the benefits of district heating. Usually there is no voice representing district heating in the debate in MS with low penetration levels and so funds are not prioritised for it. To prevent this, money could be set aside specifically for analysing the feasibility of district heating networks in all MS. Existing heating organisations could be required to pay a levy towards this fund:

for example, the PSO levy on electricity bills is sometimes used to raise money to carry out feasibility studies for wind farms.

There are many finance options which can help with the initial construction. For example, proven support schemes are loan guaranties by the local municipality or an initial investment subsidy by the local or national authority. For demonstrating the technology the EU could also provide some infrastructure investment support for part of the investments, for example via the new European Fund for Strategic Investment [25].

To ensure the maintenance of district heating systems is financed in the future, the district heating utility/organisation can be incentivised to keep its savings for a short period, such as five years. After this period, the operator must then either 1) Return the savings to the consumer by lower the heat prices or 2) Use the savings for reinvestments that improve the network and keep the prices low. Again it should be mentioned that any new networks or expansions need to be profitable from a societal perspective and approved by a local authority.

- In summary, funding for feasibility studies, support schemes in the form of loan guaranties, direct support for part of the investment, support for demonstration projects, and suitable public regulation to finance the quality of the network needs to be established by the local and national authorities, which can be coordinated and/or supported by the EU.

4.4 REGULATION: CREATING AND OPERATING DISTRICT HEATING NETWORKS

District heating network is a natural monopoly, similar to gas networks and electricity grids. This means that there is a need for the creation and regulation of institutions and ownership models which enable the establishment and maintenance of the networks, while also ensuring that consumers are not subjected to inflated heating costs. From a societal perspective district heating is usually a lower-cost and more efficient heating solution, and as mentioned a public body needs to ensure district heating is implemented where this is the case. This also means that in high heat density areas, the actual cost of producing district heating is usually lower than the alternative individual heating solutions. The public institutions should ensure that customers have low district heating prices and that the owners of the grid do not take advantage of the natural monopoly:

- The owners of the district heating grid should ensure lower heating prices for consumer's compared to individual solutions such as oil boilers.
- The owners should be encouraged to implement heat savings. For example, the performance of the system can be measured and compared to others, or the owners can incentivised to reinvest in improvements.
- Public institutions should ensure that consumers have low costs for district heating and that the natural monopolies are not taken advantage of.
- Rules for setting up utilities/organisations that establish district heating needs to be established.

The natural monopoly is mostly related to the district heating grid, so whoever is the owner of this requires a different business economic framework to function to ensure that prices remain fair, such as that suggested in Figure 9. These goals are usually easier to regulate through ownership by the local municipality or with a consumer-owned non-profit model. A key advantage of publicly owned or consumer-owned district heating systems can be the lower incentive for profit maximization, which can lead to fairer consumer prices. This is specifically related to the grid, since there can be numerous owners providing heat from different plants to the grid. However, public authorities need to make sure that there are different institutions owning the district heating networks and on the other side producing district heating for the grid.

Ownership structures are also very important for the development of the district heating girds. A district heating system usually begins with a number of smaller networks. It should be possible, from both a technical and regulatory perspective, to allow these networks to connect to one another as they expand. A local authority needs to ensure that district heating grids are established and developed in a coherent way: for example, by ensuring that two district heating grids are not built over one another in the same area and/or ensuring that grids work together when they are connected.

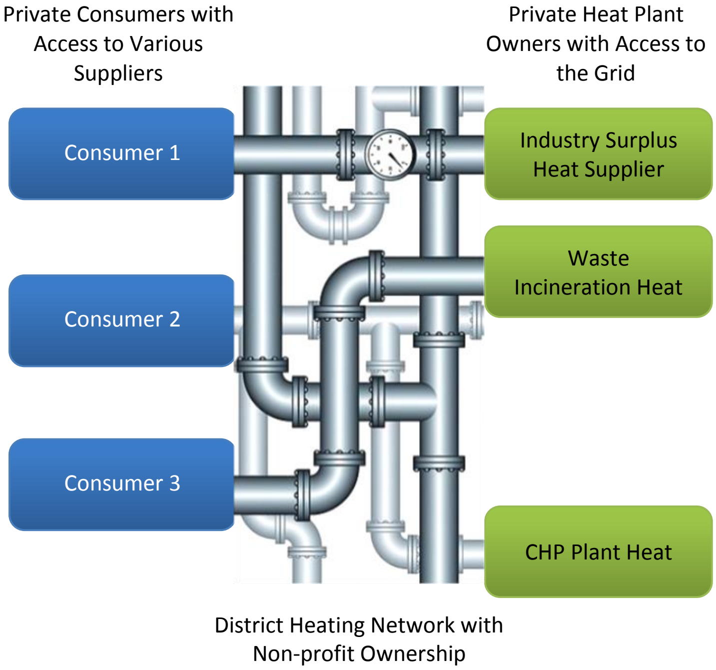

Figure 9: A hypothetical example of a district heating network and its ownership structure.

4.5 COMMUNICATION: EXPLAING THE BENEFITS AND INVOLVING THE LOCAL COMMUNITY

A key challenge for district is communicating the benefits. Many people attribute this to the historical development of district heating, with many member states experiencing smaller one-off projects in the past that were not operated efficiently or with the user's comfort as a priority. Many of these cases are from more than 20 years ago, but even though many other countries have developed successful systems and the technology has improved, the perception still remains.

This is a key challenge for district heating because it makes it relatively difficult to communicate the benefits to consumers, local authorities, politicians, and investors. This creates a cycle: new district heating systems need to be developed in order to change the current perception, but new systems are not succeeding while the perception remains.

Due to the varied experiences in Europe with district heating, the EU could play a key role in communicating its benefits. Firstly, the authorities that exist in member states without district heating could be shown the benefits in member states that have district heating and secondly, the public actors involved such as the politicians, local authorities, and the end consumers should be informed about how it benefits them directly. If people are aware of the developments and the mainstream use of district heating today, then it is likely that many of the perceptions about district heating can be overcome.

It is very important that local citizens understand the benefits of the district heating since the local community need to be involved to implement a district heating network. The institutions and organisations that own and establish the district heating system are important to allow the community to be involved. Here is a sample of recommendations that could encourage the support and/or involvement of local communities:

- The district heating alternative needs to have lower costs for the consumer and it should be seen as a secure installation: it should not be seen as a trap with a forced connection to one private producer (see section 4.4 above in relation to public regulation and prices).
- The district heating operator should be supporting energy savings to avoid over investments in the district heating networks and the production facilities. For example, there should be a low fixed-rate annual payment for the consumer and high variable rate, which is linked to consumption.
- The consumers should be aware that there are benefits for the end consumer apart from the possibility of lower heating costs, such as more stable heating costs in the long term, better comfort, no local emissions, the potential for better health, and a potential for lower fuel poverty levels.

5 ENERGY SYSTEM RECOMMENDATIONS BASED ON OTHER RESEARCH

Figure 2 has already outlined the structure of a smart energy system in the future, which will enable large penetrations of intermittent renewable energy in the future. The Smart Energy System concept has been quantified for the EU energy system in the Smart Energy Europe studies [26]. It is evident from this structure that district heating is only one of the major changes that is required in the EU energy system. There is already a good momentum and consensus in relation to the electricity sector, where wind and solar power continue to develop at a relatively fast pace. However, this section briefly presents the changes in two other parts of the energy system that are currently overlooked, which are:

- Individual heating
- Transport fuels with a high energy density for vehicles such as trucks and aeroplanes

5.1 INDIVIDUAL HEATING RECOMMENDATIONS BASED ON OTHER RESEARCH

The main focus of Heat Roadmap Europe has been on district heating. However, the individual heating sector was also a key consideration, particularly in the Heat Roadmap Europe Pre-Study 2 project and in subsequent research on the EU energy system. The strengths and weaknesses of individual heat solutions based on this research is presented briefly in Table 4.

Table 4: Overview of the strengths and weaknesses for individual heating solutions from a future smart energy system perspective. Natural gas is not included here since it is typical only viable in urban areas where the heat

density is high enough for a heat network. In these situations, district heating is advised instead of natural gas in the Heat Roadmap Europe studies.

Heating Unit	Sustainable Resources	Efficient	Cost-Effective	Robust Costs vs. Demand
Electric Heating	Yes	No	No	No
Heat Pumps	Yes	Yes	Mix	Mix
Oil Boilers	No	Mix	Mix	No
Biomass Boilers	Mix	No	Yes	No

The results indicate that heat pumps will be the primary form of individual heating the future. They use the most sustainable resource, in the form of renewable electricity, they are very efficient and they come at a reasonable cost that is relatively robust to changes in the assumptions.

Although biomass boilers are cheaper, the biomass resource needs to be prioritised for other sectors of the energy system, particularly transport. As the amount of biomass being consumed moves towards the residual biomass limit, the price of biomass is likely to increase. The biomass boiler solution is sensitive to the price of biomass, so even though it is the cheapest alternative under existing pricing forecasts, it is possible that in reality the price could be significantly higher if biomass boilers are the primary form of individual heating.

Electric heating is a sustainable solution, but its costs can be extremely high due to the inefficiency of converting electricity to heat. This could mean that a lot of new power plants need to be constructed and a lot of electricity needs to be generated, resulting in a very expensive solution.

Oil boilers are the worst solution since they are not the most sustainable, efficient or cost effective.

In brief, the authors recommend that heat pumps are implemented where individual heating units are required, which will primarily be in rural buildings. Biomass boilers also have a role to play where there is a sustainable supply of biomass available, which could occur in rural Sweden for example. Individual solar thermal can complement these individual solutions, but an exact penetration level has not been identified to date.

5.2 SUPPLYING ENERGY DENSE TRANSPORT FUELS

The transport sector is progressing towards a smart energy system, although at a slower rate than the electricity sector. The most important technical change currently underway is the introduction of electric vehicles, which are slowly gaining more momentum in the private car market. However, there are still significant concerns in relation to the use of biomass in the transport sector to replace oil in vehicles that require a high energy density fuel such as trucks and aeroplanes.

Based on research carried out by the authors [27-31], the most promising sustainable solution for the transport sector are electrofuels, which are defined here as the combination of a carbon dioxide source with hydrogen produced from an electrolyser. A high-level example of this is presented in Figure 10, where carbon is combined with hydrogen to produce approximately 1 TWh of methanol or dimethyl ether (DEM).

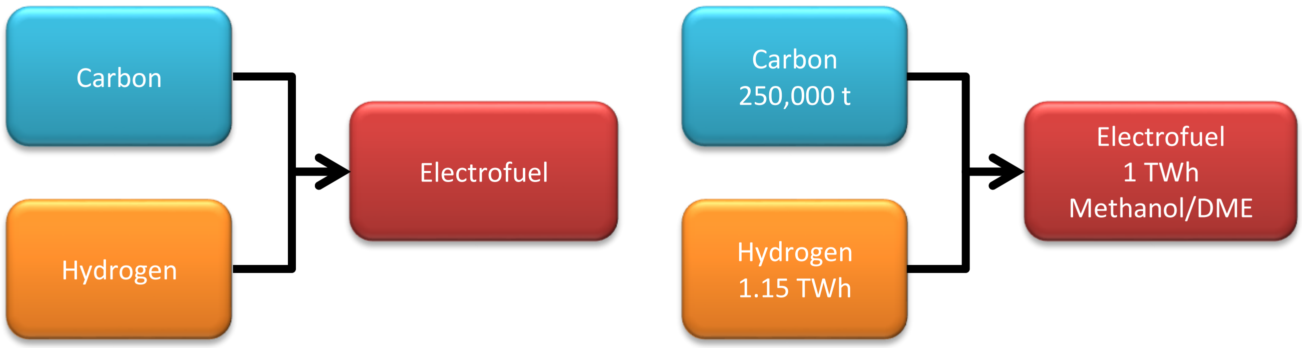

Figure 10: Producing an electrofuel by combining carbon dioxide and hydrogen, along with approximate numbers for the production of methanol of dimethyl ether (DME).

The carbon for this process can come from a variety sources such as:

- Biomass
- Industrial process, such as a cement factory
- Power plant, such as a coal plant via carbon capture
- Carbon trees

From our hourly analysis of the smart energy system, this type of electrofuel enables the electricity sector to produce approximately 80% of its electricity using intermittent renewable resources such as wind and solar. Once the carbon and hydrogen are combined with one another, it is possible to produce a variety of different fuels which are suitable for different vehicles such as trucks, aeroplanes, and ships. The key technological bottlenecks for synthetic fuels are:

- Cost effective electrolysers, which requires the development of solid oxide electrolysers (SOECs)
- Biomass gasification plants
- Carbon capture and recycling technologies

These electrofuels are likely to be more expensive than biofuels, but they are necessary since the residual biomass resource in Europe is unlikely to be high enough to enable the transport sector to function on biofuels alone. As mentioned previously, these issues are analysed in more detail in the Smart Energy Europe study [26].

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7 APPENDIX

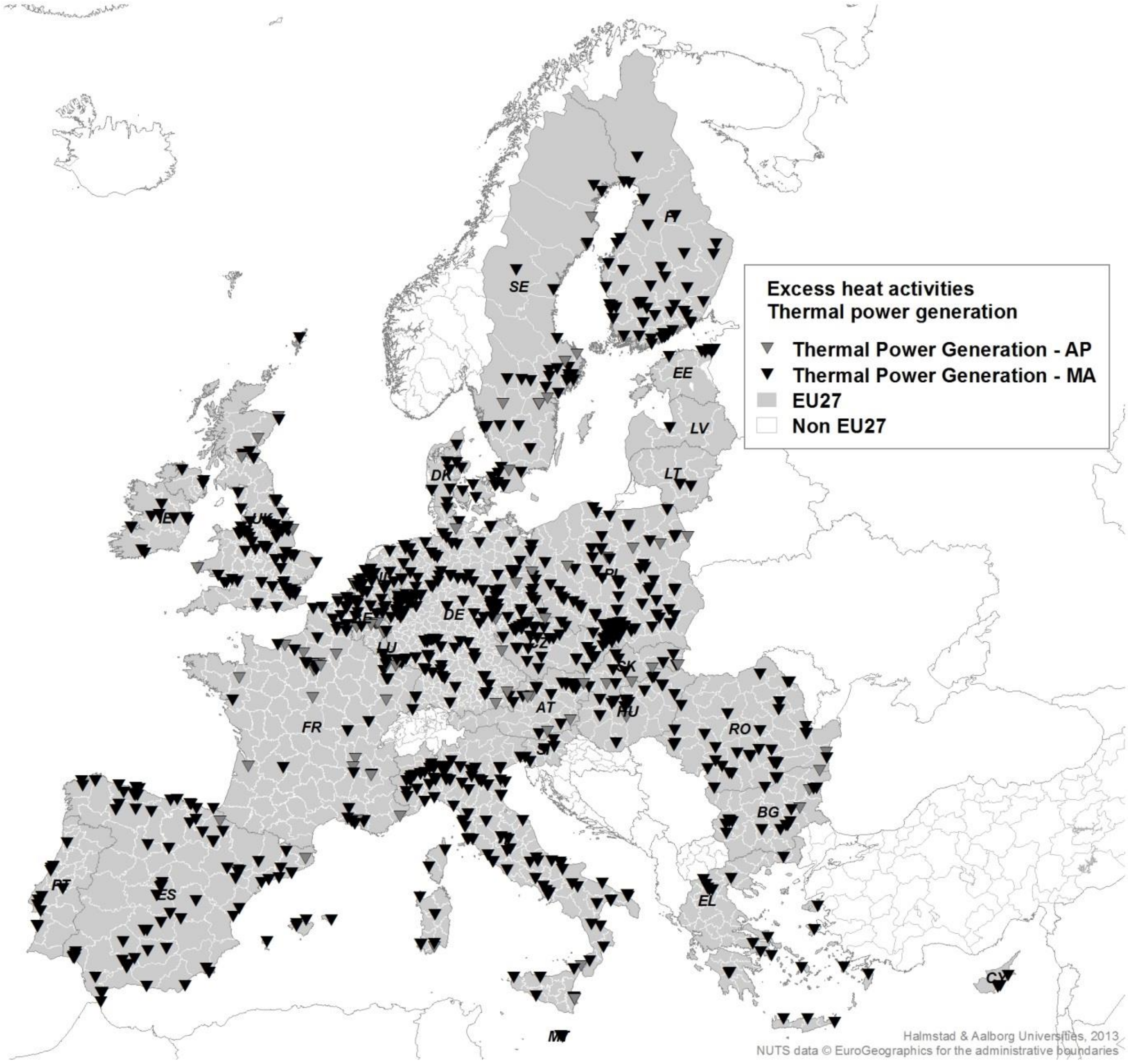

Figure 11: Major combustion installations above 50 MW for power and heat generation in Europe. Source: The E-PRTR database at EEA in Copenhagen.

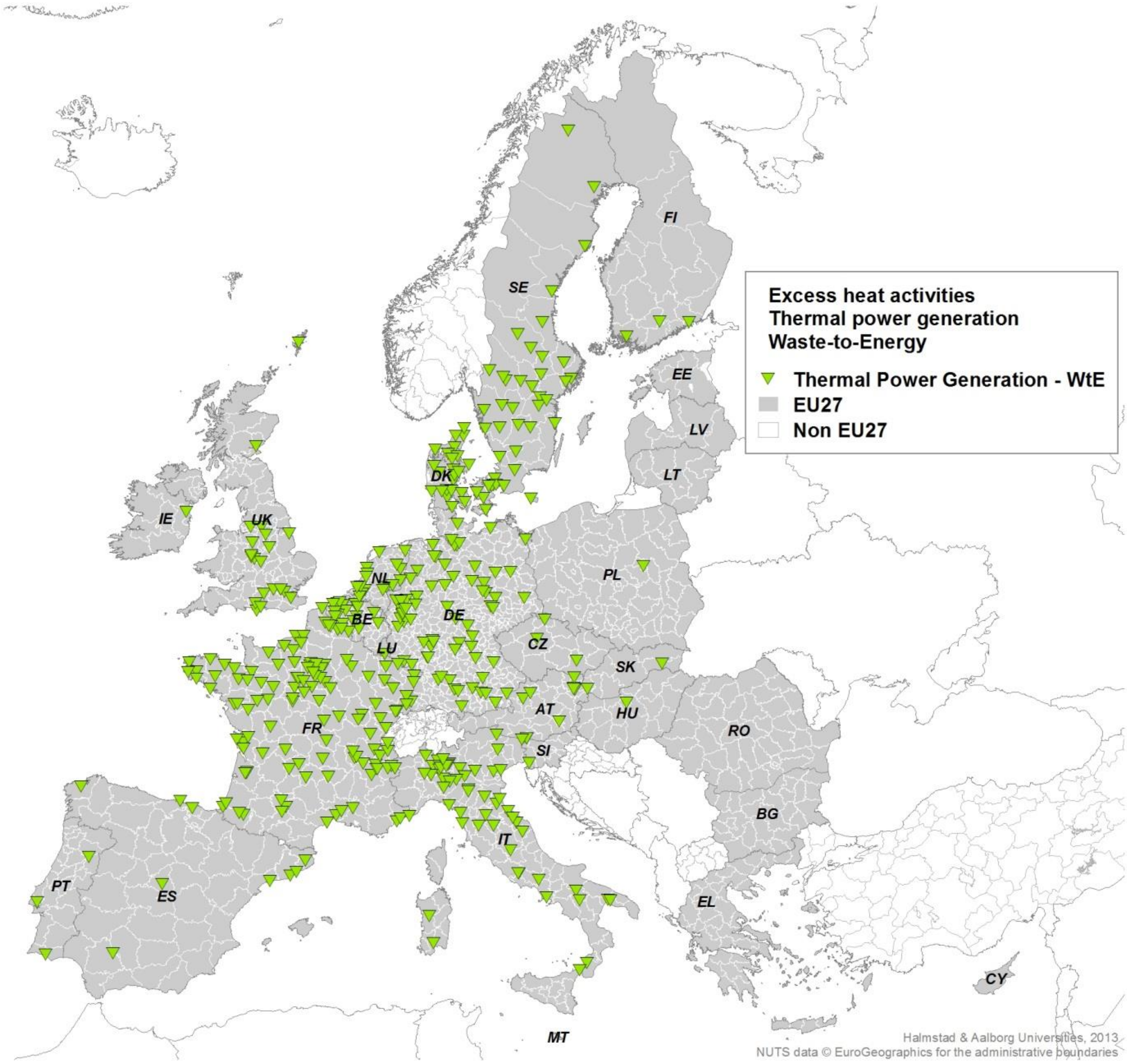

Figure 12: Locations of 410 waste incineration plants in Europe. Sources: CEWEP, E-PRTR, ISWA, and some national sources for Sweden, Denmark, and France.

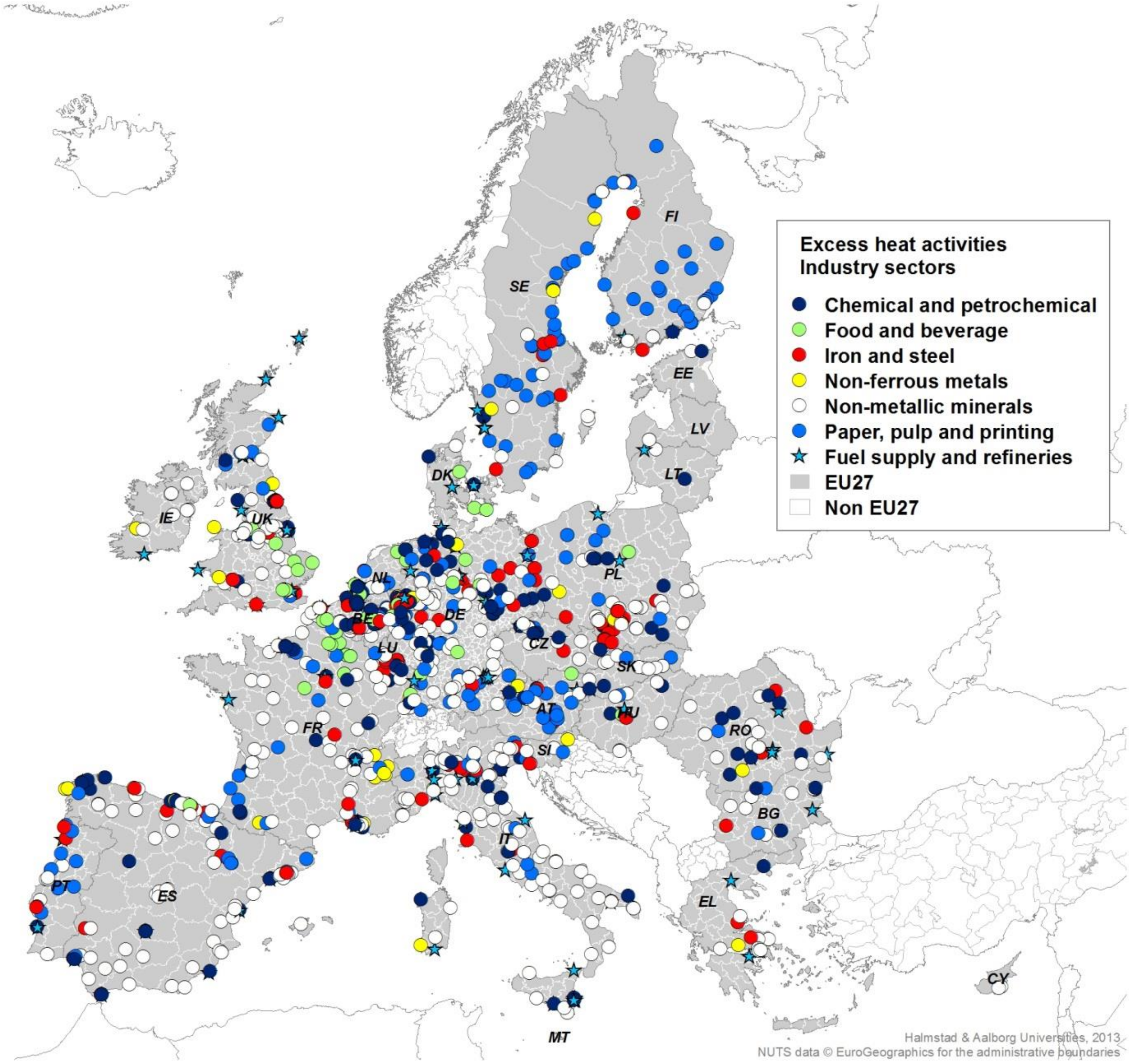

Figure 13: Locations of major energy intensive industries with considerable volumes of excess heat. Source: The E-PRTR database at EEA in Copenhagen.

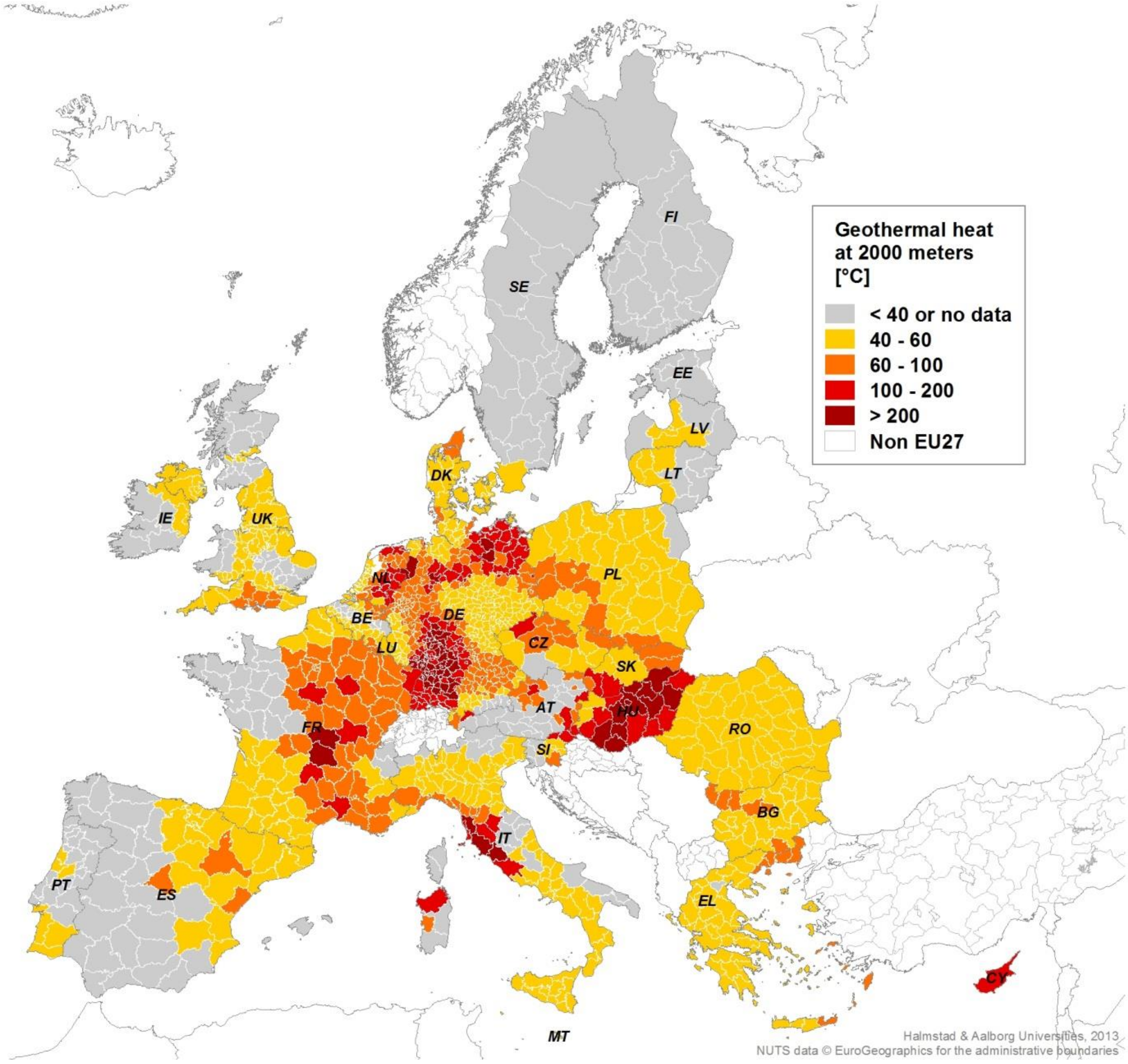

Figure 14: Identified geothermal heat resources by temperature at 2000 m depth by NUTS3 region. Source: European Commission, Atlas of Geothermal Resources in Europe. Publication EUR 17811, Luxembourg 2002.

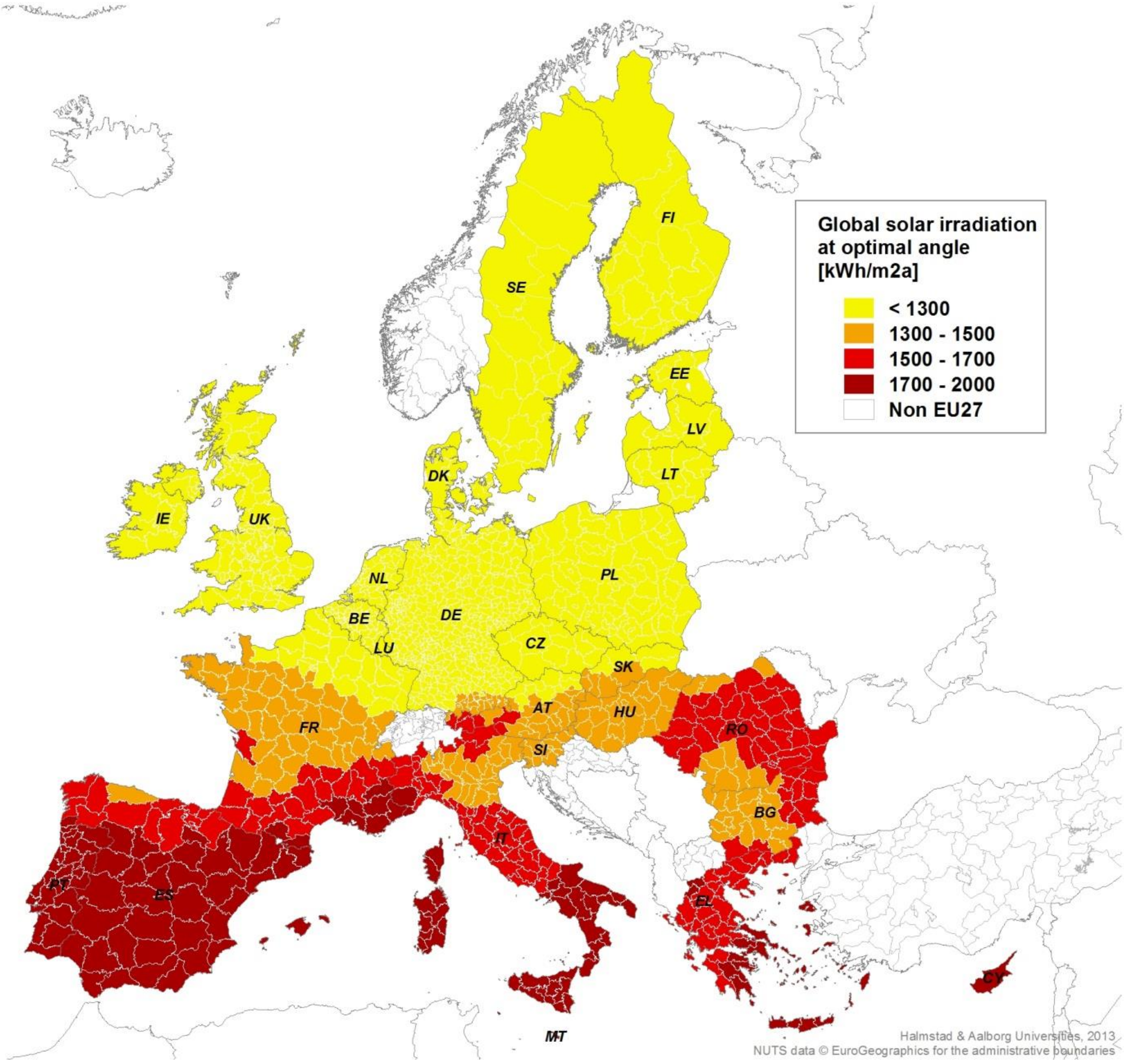

Figure 15: Annual solar irradiation on a south-oriented tilted surface at optimal angle by NUTS3 region.