Project No: IEE/13/650

Stratego

ENHANCED HEATING & COOLING PLANS

Creating National Energy Models for 2010 and 2050

Work Package 2

Background Report 1

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: David Connolly, Work Package 2 Coordinator
Kenneth Hansen
David Drysdale
Contact: Aalborg University, Denmark
A.C. Meyers Vænge 15
DK- 2450 Copenhagen
T: +45 9940 2483
E-mail: david@plan.aau.dk
Web: www.en.aau.dk

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

Nomenclature

CHP	Combined heat and power
CO_2	Carbon dioxide
IEA	International Energy Agency
JRC	Joint Research Centre
O&M	Operation and Maintenance
PES	Primary Energy Supply
NTC	Net Transfer Capacity
NHCPs	National heating and cooling plans
IRES	Intermittent Renewable Energy Sources
EC	European Commission
BAU	Business-as-usual
RES	Renewable Energy Sources

1 Introduction

The future energy system will be a lot more complex than energy systems from the past. One of the most significant changes in the future will be the high proportion of renewable energy, which will transform the dynamics of the energy system. Renewable resources such as wind, solar, and wave power are intermittent so their production varies significantly over relatively short time-horizons, such as minutes and hours. Therefore, when we design and analyse the future energy system, it is essential to consider these short-term variations that can occur.

To do so, it is very common to apply energy system analysis computer programs. These can account for the complex interactions that occur within the many sectors of an energy system to identify how different technologies can work together in a sustainable way. In this report, one such computer tool is presented and subsequently, an hourly energy model is created for five of the STRATEGO countries: Croatia, Czech Republic, Italy, Romania, and the United Kingdom. The modelling represents each country under three difference contexts:

- The current situation, which is represented by the year 2010 and called the '**reference'** model
- A future situation for the year 2050, which is based on the European Commission's current projects for that member state. This is referred to as the '**business-as-usual**' model
- Alternative heating and cooling scenarios based on the new knowledge created in STRATEGO WP2 such as the potential for energy savings (see Background report 3a & 3b), district heating and district cooling (see Background report 4, 5, 6 & 7), and renewable energy (see Background report 8 & 9). These scenarios are based on the reference and business-as-usual models created here, but they are presented and analysed in the Main Report titled "Enhanced Heating and Cooling Plans to Quantify the Impact of Increased energy Efficiency in EU Member States".

The main objective here is to present the methodology and results applied to create the 2010 reference and 2050 business-as-usual scenarios. This report begins by outlining the methodology applied (section 2): this describes the modelling tool and the key characteristics inherent within it, followed by a description of the key assumptions applied to the data when creating a model of the existing and future situations, which are represented by the years 2010 and 2050 respectively. Section 3 then presents some of the key results obtained after these models were complete such as the energy consumed, cost of energy supply, and the carbon dioxide emissions. Based on these results, some initial reflections are reported for each country in section 3.1.9.

2 Methodology

The methodology describes how new hourly models of electricity, heat, cooling and transport were created in STRATEGO WP2 for different EU member states. It begins by outlining the key principals defined to create suitable national heating and cooling strategies for the STRATEGO project (section 2.1). These key principals are essential to ensure the most sustainable and cost-effective solutions are implemented in society. Based on these key principals a suitable energy systems analysis tool is identified to carry out the study, which is called EnergyPLAN (section 2.2). Afterwards, the methodology describes how a new hourly model is created in EnergyPLAN for an EU member state (section 2.3). Finally, the methodology ends with a detailed discussion about some specific issues that became apparent during the analysis relating to both the 2010 reference (section 2.4) and 2050 business-as-usual models (section 2.5).

2.1 Key Principles

There are a wide variety of energy tools available to analyse various technologies and their impacts [1]. Naturally there are numerous assumptions and perspectives built in to these tools during their development. These have a significant impact on the results a model produces and thus the recommendations that are made based on them. In this section, some of the most significant pre-conditions defining the model that is chosen is this study are presented, which are:

- The analysis should consider the whole energy system.
- The model should account for short-term variations in production, long-term transitions in technology, and radical technological change.
- The results should include a socio-economic perspective.

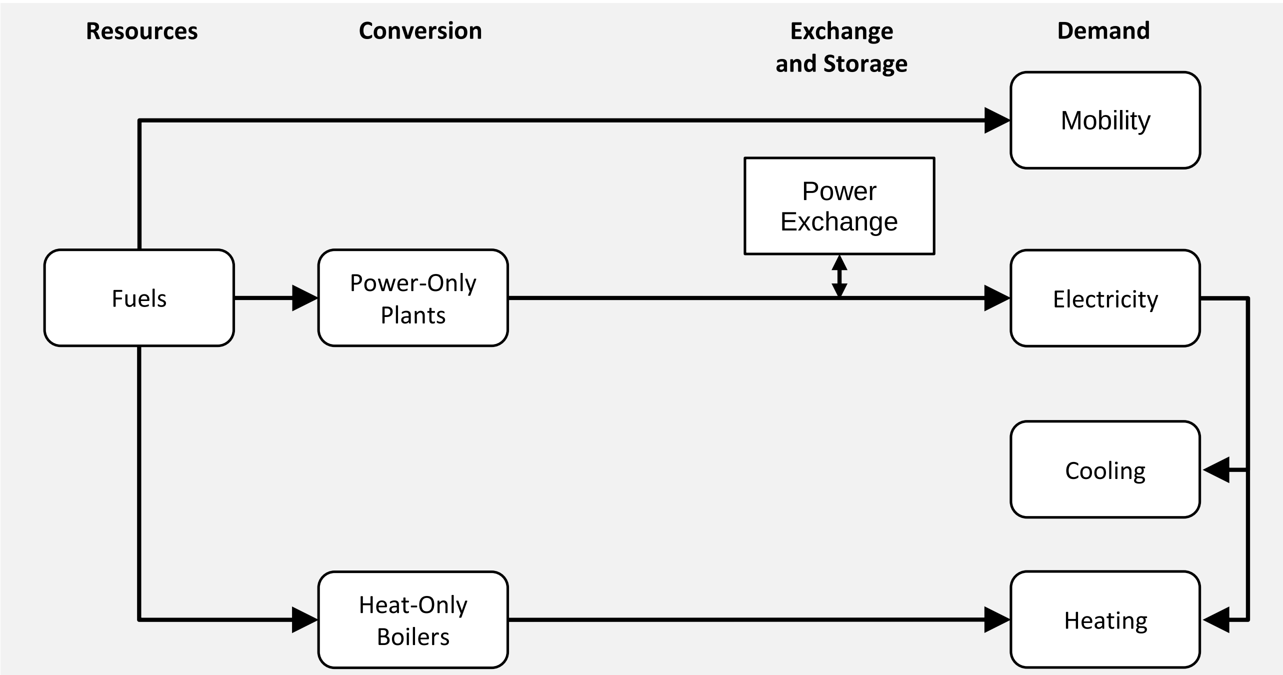


Figure 1: Interaction between sectors and technologies in today's energy system.

The methodology designed in this study to assess heating and cooling strategies for EU members includes the whole energy system (not just one energy sector); the reason being that the scenarios will be designed for a future energy system which will differ from today. Today's energy system (Figure 1) is largely a linear system with direct relationships between resources and demand; whereas in the future the energy system will consist of more interactions between resources, conversion technologies, and demands, in a less linear system. Therefore when making a change to one energy sector in the scenario analysis it is critical to understand how this will influence the other energy sectors, for example like the 100% renewable energy system structure displayed in Figure 2.

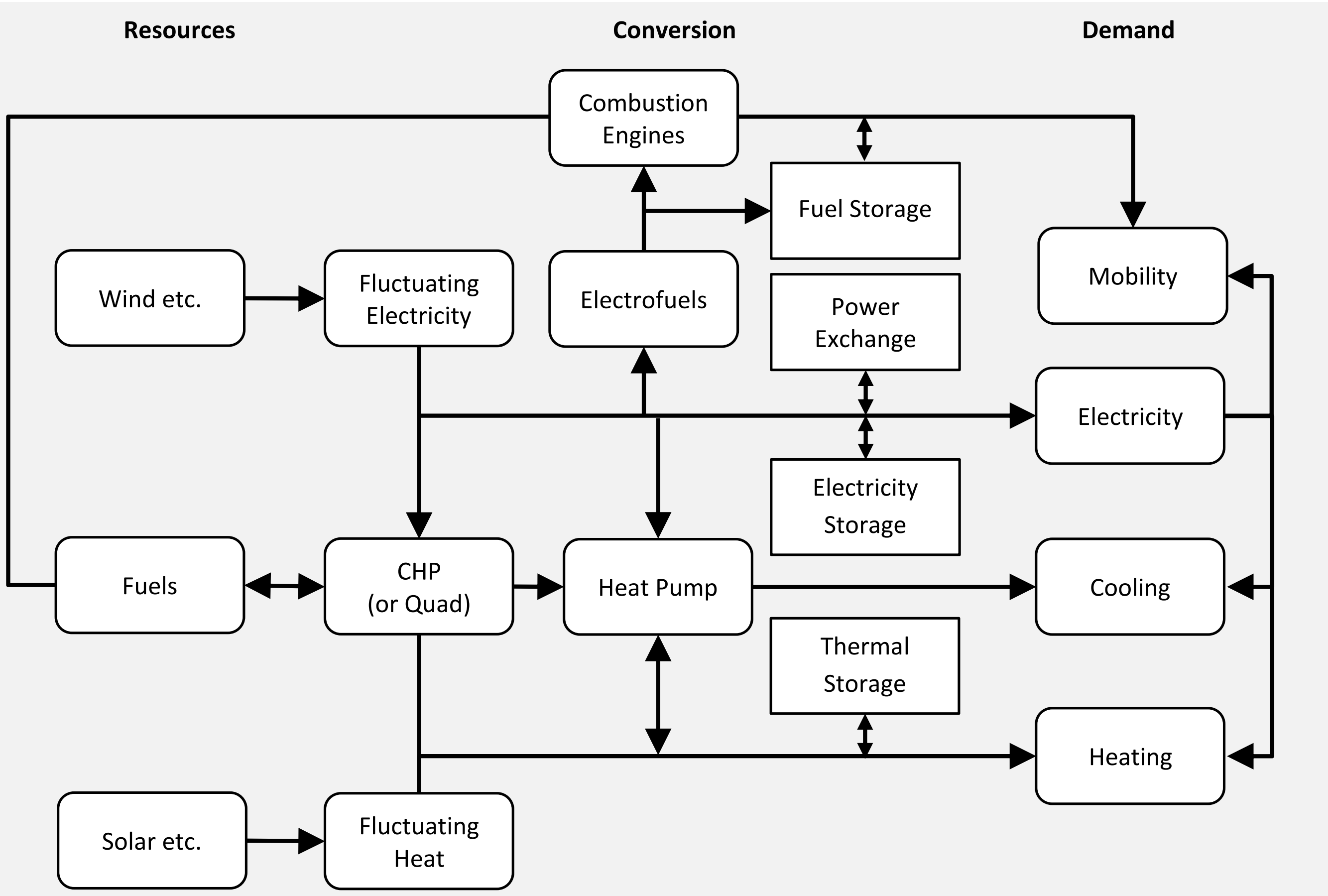


Figure 2: Interaction between sectors and technologies in a future smart energy system (a 100% renewable energy concept [2].

Over time fluctuating renewable energy, such as wind and solar, will become more dominant in the energy system meaning that there will be more short-term fluctuations of intermittent renewable energy sources (IRES). Therefore in this study, the heating and cooling strategies need to be analysed in short time periods of one hour intervals. By modelling the scenarios in one hour intervals, it is possible to understand how the energy system will operate realistically while ensuring that the demand for electricity, heat, cooling, and transport is always met, even when different parameters are modified.

In addition to these short-term time steps, the analysis must also consider long-term horizons so that there is time for the technologies in the energy system to change. For example, many power plants have lifetimes in excess of 25-30 years, so to allow change to occur time horizons often need to exceed these lifetimes. In this study, the heating and cooling strategies will be analysed for a time horizon as far as 2050, thus leaving sufficient time for these changes. Furthermore, the type of technological change required in the future is not minor alternatives, but radical technological change. This has already been demonstrated by the difference between today's energy system and the future energy system (Figure 1 and Figure 2 respectively). For example, building an energy system around fossil fuels is radically different to an energy system based on intermittent renewable energy such as wind and solar power. The model used to analysed different heating and cooling strategies in STRATEGO must therefore be able to account for these radical changes. Otherwise it is locked in to the existing way of doing things.

One of the most important outputs from the scenario analysis is economic costs. In this study the socio-economic cost of the energy system as a whole is assessed. The heating and cooling sectors are components of this total cost. The socio-economic cost is assessed because it is assumed that the future energy markets will reflect more than today the benefits from less pollution, lower GHG emissions, resource depletion, land-use change, waste, and security of supply, and this can be included and reflected in socio-economic cost results.

Furthermore in today's energy system the costs are largely from fuels, for power stations, transport and so on. These fuels are often traded on markets with a focus on profit generation. However in the future energy system it is expected that a renewable energy system will be based largely on investments rather than fuels. This is expected to cause a modification of organization types involved in the energy system; potentially opening up opportunities for different investment types for example energy investment co-operatives. The idea of the scenario analysis is therefore to design the energy system not for profits of one organization but for the citizens in society. The main focus for society is on the overall cost for energy, the types of resources being used (directly related to the environmental impact), the number of jobs created, and the balance of payment for the country (debt burden to society), among other interests. These are some main examples of the metrics of concern to society, and that can be used to determine a good or bad energy system.

This study will not consider the limitations associated with existing institutional arrangements. This is a critical component in a transition to a 100% renewable energy system and will need to be analysed further.

In order to complete the scenarios focusing on the factors mentioned above, a number of complex technical and economic analyses need to be carried out: for example, assessing the relationships between different energy sectors within the context of short term and long term time horizons. To do the analysis in line with these key considerations, the EnergyPLAN tool will be utilised.

2.2 Energy system analysis tool: EnergyPLAN

The EnergyPLAN tool is an energy system analysis tool that has been designed explicitly to assist the design of national or regional energy systems. Different planning strategies can be modelled in the tool, and analysed. The tool was introduced in 1999 at Aalborg University, Denmark, and has been continually developed since this time, and has been used for numerous energy system analyses, ranging from entire energy systems for whole countries, to specific technologies, and on a regional basis. It is now a very complex tool that is capable of handling a wide range of technologies, costs, and regulation strategies related to an energy system. The tool is freeware and can be downloaded www.EnergyPLAN.eu. The algorithms used to create the tools are described in detail in the user manual found at the same website. The algorithms are not discussed here.

EnergyPLAN was developed within the conceptual framework of a 100% renewable energy system. In this context the tool is designed to allow all energy sectors to be modelled as 100% renewable, and this can be achieved by any pathway envisioned by the user. For all users of the tool, EnergyPLAN considers all sectors in the energy system being: electricity, heating, industry, cooling and transport, as outlined in Figure 3. It is up to the user to determine how each sector is modelled within a 100% renewable energy system, producing results for socio-economic costs, technical feasibility, and so on.

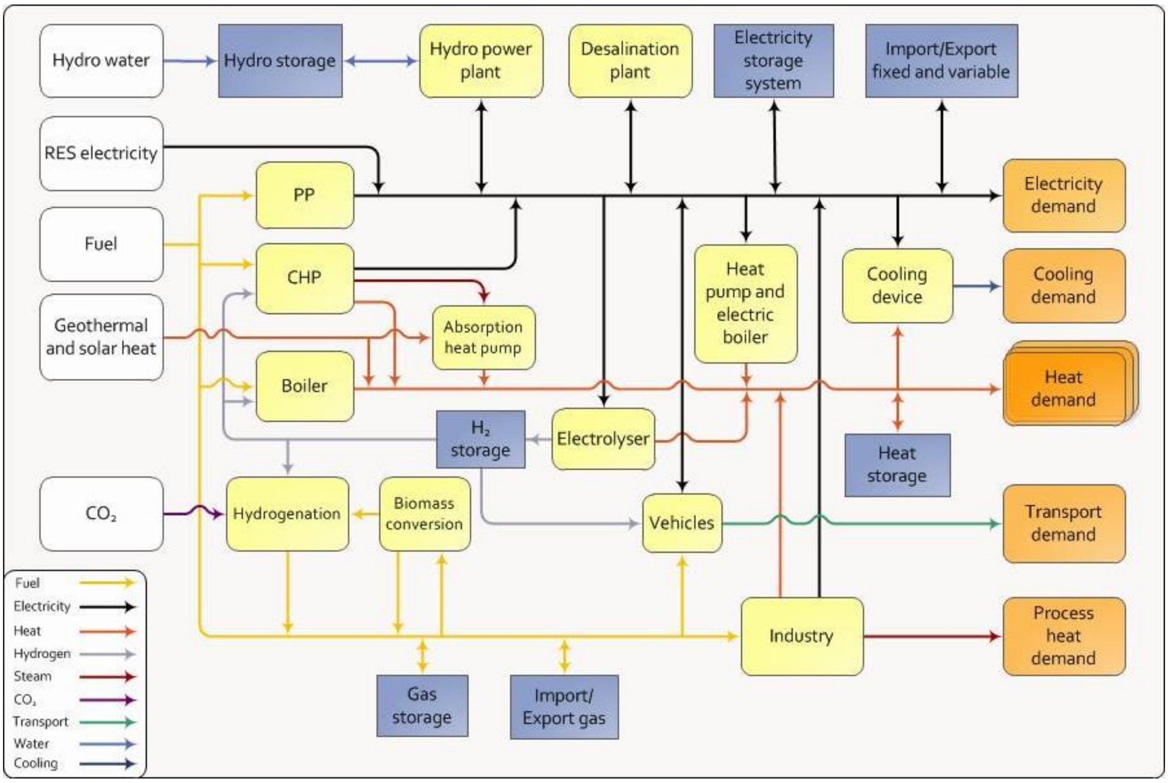


Figure 3: Flow chart of resources, conversion technologies, and demands considered in EnergyPLAN

One unique feature of the tool is that it includes all the new renewable energy technologies that are already on the market or are currently in development, since its main purpose is for research and for forecasting long-term scenarios. This means it is not locked into current technology options and is capable of assessing radical technological changes, which will likely become feasible in the future.

The core functionality of EnergyPLAN is to model energy systems as they operate in the real world, by simulating the energy system on an hourly basis over time. This functionality is essential in order to ensure that the intermittent nature of renewable energy is able to fit appropriately and reliably in the modelled energy systems; ensuring that the energy system component requirements, including electricity production and demand, heating, cooling, and transport, are satisfied.

The results generated from EnergyPLAN include among others: Primary Energy Supply (PES); renewable energy penetrations; greenhouse gas (GHG) emissions; energy system costs. EnergyPLAN can calculate costs from both a business-economic and socio-economic perspective, however in this study, socio-economic costs will be assessed. These are estimated by annualising all costs in the energy sytem using Equation 1 below.

$$I_{Annual} = (IC)\left\{\left[\frac{i}{1-(1+i)^{-n}}\right] + O\,\&\,M_{Fixed}\right\} \qquad (1)$$

The formula consists of total Investment costs (I), the installed capacities (C), lifetimes (n); interest rate (i) (assumed to be 3% in this study); and the annual fixed operation and maintenance costs ($O\&M_{Fixed}$) as a percentage of the total investment. Applying this formula allows for various scenario analyses where different combinations of technologies can be modelled and the costs can be compared with each other. The key issue here is that the socio-economic costs represent the cost to all of society as a collective and not to a single individual or organisation within society. In this way, EnergyPLAN identifies the costs to society so that suitable regulations and policies can be identified to replicate this 'optimum' situation in reality.

A key difference between EnergyPLAN and other energy planning tools is that EnergyPLAN can optimise the technical operation of a modelled energy system rather than identifying the optimum situation within regulations for an individual sector. This means that it can identify the total socio-economic cost of the entire energy system on an optimal technical operation with all sectors operating. The tool analyses how the overall system operates rather than focusing on maximizing specific investments within specific market frameworks. In addition, the tool does not analyse the system from only one technological viewpoint that operates in isolation.

The technical optimisation strategy minimizes the import and export of electricity and seeks to identify the least fuel-consuming option, which will also reduce the overall CO_2 emissions. If preferred, it is also possible to choose a 'market-economic' simulation strategy, which identifies the least-cost option based on the business-economic costs for each production unit (i.e. business economic profit) [5, pg.69].

The socio-economic costs can be calculated for the entire energy system, but with different operation strategies. In this report the technical optimisation strategy is applied because the aim is to identify the socio-economic consequences when creating an efficient renewable energy system of the future instead of optimising according to business-economic profits.

2.3 Creating EnergyPLAN country models

When developing reference energy system models for a number of countries, several phases are included. These are shown in Figure 4.

Figure 4: Steps to create a new model in EnergyPLAN

Firstly, data is collected from energy statistics in order to get a picture of how the energy system is structured. The second phase contains a reorganization and preparation of the statistical data in order to input it to the energy system modelling tool and after running the modelling tool output data is created. The data is then entered into the model in EnergyPLAN in the third phase. This data is then affected by all of the regulations and interpretations made within the model during the simulation. Hence, a fourth and important calibration phase is required aligning the statistical and modelled data in order to replicate the existing energy system as best as possible. A perfect replication is never possible because the model is affected by the data collected (its availability and accuracy) and the optimizations performed in the modelling tool. Hence, small differences between the original statistics and modelled data are expected.

2.3.1 Data collection

In this study a model of the current situation is necessary for each member state in order to define and understand the energy system being analysed such as the mix of power plants, types of boilers, and the vehicles in the system. This is referred to as the '**reference**' system and it forms the basis for future assumptions applied in the scenarios (see Main Report). In the reference system some key components of the energy system that are defined include the electricity, heat, cooling, and transport demands. These demands will need to be satisfied in each of the future scenarios.

To complete the reference scenarios data was collected from numerous sources across three main groups: energy demand and supply data; hourly energy distribution data; and cost data.

The type of data collected for energy demand and supply data include e.g. electricity demand, consumption and production by different plants. It includes energy data for transport, industry and heating as well. The purpose is to collect sufficient data to be able to create a model of the existing energy system for the various countries in an energy system analysis tool.

The primary source of energy demand and supply data was collected from the International Energy Agency [4], which provide energy balance data for each of the studied countries. The resolution of that data is sufficient to cover over 80% of the energy demand data required for the reference models. The remaining 20% was sourced from other sources such as EUROSTAT [5], ENTSO-E [6], Enerdata [7], Odyssee [8] and other sources (see Appendix C – Data). For example power plant capacities were unavailable from the IEA so this was sourced from Enerdata. For a full list of the types of data collected and the sources, including comments about some of the data see Appendix C – Data Sources.

To analyse an energy system on an hourly basis, hourly distributions must be obtained for demands and productions that vary from hour to hour. For example, this includes all demands such as electricity, heat, cooling, and transport as well as production from sources such as wind, solar, and wave power. This is a very large task since each year includes 8760 hours (or 8784 for a leap year) so the methodology required to build these hourly distributions are elaborated on in detail in Background Report 2.

Cost data is sourced from a cost database that is continuously maintained at Aalborg University and can be downloaded from www.energyplan.eu/costdatabase. This database covers costs for all the technologies in the energy system divided into investments, operation and maintenance (O&M) and lifetimes as well as costs for the purchase, transport, and handling of fuels. For certain technologies or costs specific methodologies had to be developed and these are described in Section 2.4. A summary of the fuel costs, investment costs, and operation and maintenance (O&M) costs used in this study are presented in Appendix B – EnergyPLAN Cost Database Version 3.0.

During the project, issues were encountered for data collection since the initial primary data source (Enerdata) was found to be inconsistent compared to other databases, such as the IEA energy balances. The Enerdata databases supplied the information required for most sectors and energy system phases, but after communication with the local partners and their feedback on the reference system data, a decision was made to switch to a different primary data source (the IEA energy balances [4]). The reason for this was that most of the local partners used the IEA data for their own national energy statistics and that the IEA data seemed more in accordance with other databases. This change required a significant restructuring of the reference models and prolonged the data collection phase. Other data sources, including Enerdata, were used to complement the IEA data to describe the complete energy system, which you can read more about in Section 2.4 - Specific issues for the reference models.

2.3.2 Boundary conditions

The data used in the STRATEGO reference models is governed by a set of boundary conditions in order to allocate the right amounts of energy demand and production to the right countries. These conditions apply to e.g. technologies and fuels, but also the geographical borders and import/export/transit of demands and fuels. These are explained in more detail below.

The technologies and fuels included in the energy system models can be illustrated by Figure 5 below.

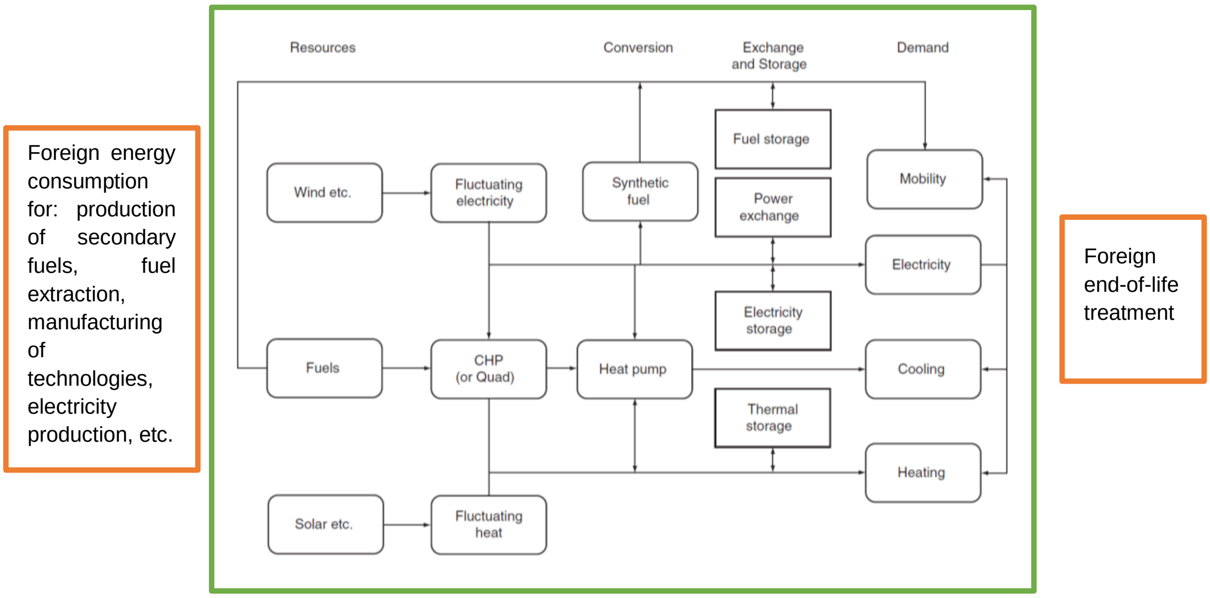


Figure 5: Boundary definition of the national energy system

The system includes the different phases of resources (fuel input), conversion/transformation, exchange and storage as well as the final demand. This means that phases taking place outside the country such as extraction of the fuels are not included and similarly that the phases after the final consumption in foreign countries (e.g. end-of-life treatments, etc.) are not included. This is not included as no data exists for these phases taking place outside of the countries. Furthermore, the energy consumed outside the country would be included in another country's energy balance.

Another issue that needs to be taken into account when using energy statistics concerns the methodology used for assessing issues such as trade of fuels and energy between countries. In the present study the general methodology described in [9] and used by IEA and Eurostat was applied. The method applied is the "physical energy content" and for clarification a few of the main assumptions are outlined below.

The focus in the study is on physical flows of electricity while less emphasis is put on the actual countries of origin and destination. Hence, transit electricity is included in the data inputs and the destination countries of the trade are assumed to be the neighbouring countries. The same applies for gas as it is difficult to keep track of origin and destinations when these energy carriers are transmitted over large distances.

The external energy trade data should be, at least partly, for domestic use, and hence the fuel data should exclude import and export if possible. The electricity and fuel limitations are therefore different.

The fuels included in the energy balances do not take into consideration how much primary fuel was consumed in country A for production of secondary fuels that are exported to country B. Examples of this can be the amount of biomass or crude oil that was consumed in country A to produce a fuel, such as biofuel or petrol, that is exported to country B. In this case only the import/export of the secondary fuel is included in the energy balances. This can make the fuel consumption seem higher in a country than it actually is due to e.g. large refinery industries that allocates the conversion losses from primary to secondary fuel to the country where it is located rather than where the secondary fuel is actually consumed.

For international marine bunkers fuel for "*All ships, irrespective of the country of registration, should be included but the ships must be undertaking international voyages*" [9]. In the study international aviation and navigation (sea) is included based on the IEA definitions, see more in [9].

2.4 Specific issues for the reference models

There are some additional key issues and definitions that were encountered in the methodology when constructing the reference models. These additional issues are described in this section along with an explanation of the solution chosen.

2.4.1 Definition of primary energy supply

Primary Energy Supply is a key metric when assessing an energy system, since it shows the energy consumed from primary energy sources in the country that are either renewable or non-renewable. Non-renewable primary energy is important to measure since it is only available once. Non-renewable primary energy is relatively simple to measure but the primary energy of renewable energy is more difficult to measure.

Table 1: Primary energy equivalents and conversion efficiencies for electricity generation (gross production) of renewable energy sources [10]

Energy source	Zero equivalent method	Direct equivalent method (as applied by UN statistics)	Physical energy content method (as applied by Eurostat and IEA)	Substitution method (as applied by US EIA)	Technical conversion efficiencies (as applied in LCA databases, e.g. GaBi 2012)
Hydro	n.a.	100%	100%	39.7%	85%
Wind	n.a.	100%	100%	39.7%	40%
Solar (photovoltaics)	n.a.	100%	100%	39.7%	13.4%
Solar (thermal electric)	n.a.	100%	33%	39.7%	12.4%
Geothermal	n.a.	100%	10%	39.7%	22.4%
Biomass (solid)	n.a.	28.6%			
Biogas & Bioliquids	n.a.	26.2%			
Waste	n.a.	17.7%			
Nuclear	n.a.	100%	33%	33%	33%
Imported electricity	n.a.	100%	100%	100%	Source specific, i.e. country specific

There are a number of methods to measure renewable primary energy and these measures have been compared with each other in a study prepared by PE International and Ecofys [10]. Table 1 taken from the report, presents the different approaches to applying primary energy for renewable energy.

This study follows the IEA method for quantifying primary energy supply, which is the physical energy content method. The method uses the normal physical energy value of the primary energy form for non-renewable fuels, or the “fuel input” basis [9]. For non-renewable fuels the primary energy is the total energy consumed at the secondary energy production plant; for example at a coal power plant. For primary electricity, which is produced by hydro, wind, solar etc. the primary energy is simply the gross electricity generation figure [9]. As shown in the Table 1 the primary energy equivalent values for most renewable electricity is 100%. Meaning that 1 MJ primary energy produces 1 MJ of electricity. In the case of electricity generation from primary heat (nuclear and geothermal), the heat is the primary energy form [9]. For solar (thermal electric) and nuclear plants the primary energy is inputted from the gross electricity generation using a thermal efficiency of 33% [9]. The thermal efficiency for geothermal is 10%, and this figure is only an approximate value and reflects the generally lower-quality steam available from geothermal sources [9].

In this study the total Primary Energy Supply is calculated using the following equation:

$$\begin{aligned} &\mathit{Total\ primary\ energy\ supply} \\ &\quad = \mathit{Primary\ energy\ production} + \mathit{Imports} - \mathit{Exports} + \mathit{Int.marine\ bunker\ fuels} \\ &\quad + \mathit{Int.aviation\ bunker\ fuels} + \mathit{stock\ changes} + \mathit{statistical\ difference} \end{aligned}$$

For electricity, the import and export is calculated based on the energy content in the electricity rather than based on the fuel consumed to produce this electricity.

International aviation and marine bunkers are added to the total primary energy supply in this study although in the IEA energy balance these numbers are excluded. This is to ensure that the fuel required for international aviation and marine transport is accounted for.

Stock changes refer to the amount of fuel that is provided from the stockpile for use in the particular year (this is a positive addition to total primary energy supply) or can be the amount that is added to the stockpile in the year, which would make the stock change value a negative number.

In general when data is collected both for total primary energy supply and for total primary energy consumption, these values should match. However this is often not the case, due to different parties collecting the data, reporting errors, or other unidentified reasons. This results in a statistical difference. In this study, any statistical difference was added to the primary energy supply in order to avoid under accounting.

2.4.2 Energy industry own use

The energy industry often consumes the fuels which they produce or import for secondary energy production, since they require energy and this is a quick and convenient source of energy for them.

The energy consumed by the enterprise may be purchased directly for consumption or be taken from the energy commodities it extracts or produces.

IEA define energy for own use as "*the quantities of energy commodities consumed within the fuel and energy enterprises that disappear from the account rather than appear as another energy commodity"* [9].

The energy is used in for example fuel extraction, or in the conversion or energy production plant and they do not enter into the transformation process of the main energy product that is sold from the plant. Examples include the use of charcoal to heat charcoal manufacture facilities and the use of biogases to heat sewage sludge or other biogas fermentation vessels. This energy own use can either be considered a loss to the system or a consumption. In this study energy industry own use of electricity, heat and fuels are included under total consumption since the energy industry is also an end-user of energy and if it did not consume this energy then it would import other energy from outside its operations. This is consistent with the IEA which explain that although the data is provided separate from the energy for main product, by its nature, it is part of the final consumption of the industry sector [9].

Pumped hydro is also included within the energy industry own use category by the IEA and in this study the net electricity consumed by pumped hydro is also included in total consumption.

2.4.3 Adjustments of CO_2 emissions

In this study the energy system of each country was modelled in EnergyPLAN which then calculates the CO_2 emissions of the energy system. The CO_2 emissions should be very similar to the data provided by IEA since the majority of energy data is from IEA. However in some instances the CO_2 emissions were different and this is most likely because EnergyPLAN uses average emission factors. For example, for coal there is only one emission factor in EnergyPLAN, but there can be numerous types of coal with different emission factors. Therefore for some countries the CO_2 emission factors for different fuels were modified in order to generate similar CO_2 emissions from EnergyPLAN compared with the IEA statistics. It is assumed that the differences in emission factors is due to the different fuel mixes in each category, for example, in the United Kingdom the proportion of different types of coal may be different meaning the average emission factor is different. In Table 2 the emission factors for the fuels for each country are presented, as well as the total CO_2 emissions of the energy system of each country.

Table 2: CO_2-emission factor applied in the different reference system models

Country (kg/GJ)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Coal	98.5	98.5	98.5	105	95
Fuel oil	72.9	72.9	72.9	72.9	70
Natural gas	56.9	56.9	56.9	56.9	53
LPG	59.64	59.64	59.64	59.64	59.64
Waste	90	90	90	90	90

The emission factors for the majority of the fuels are taken from [11]. For the changes to the emission factors the new values are still within possible realistic values that are reported by The Climate Registry [12]. The emission factor for waste is taken from the IPCC report on Greenhouse Gas Inventories [13].

2.4.4 Hydropower capacities and production

Hydropower is an important form of renewable electricity and it will become more important in the future, due to its abilities to work within a system with increasing fluctuating production. However collecting data for hydroelectricity is difficult, mainly because of the different definitions of hydropower especially between 'dammed' and 'run-of-river' hydro, which can lead to inconsistent reporting in different databases. In addition, quantifying hydro storage capacity is also difficult.

In this study, IEA provided the total hydropower production values and the pumped hydro losses, but hydropower capacities and pumped hydro storage and production data was provided by Enerdata, and run-of-river production data was provided by ENTSO-E. Overall, the IEA hydro production data was used as the basis for calculating any uncertain data points, such as the run-of-river production data when this data was unclear from ENTSO-E. Sometimes a specific piece of hydro data was unavailable from all the data sources; therefore additional data sources were required, for example for run-of-river hydro production for Italy.

When making adjustments to the hydro data due to inconsistencies between dammed and run-of-river data in the databases, the aim was to make all the changes so that the production data was within range of average hydroelectricity capacity factors. However, this often varied depending on the specific data available within a country.

In Italy run-of-river hydro capacity value was provided by Enerdata however no data was provided by ENTSO-E for electricity production. Therefore it was assumed that run-of-river hydro exists in Italy but ENTSO-E defines the power production as dam hydro. Therefore a production value needed to be quantified for run-of-river, and therefore for Italy the production value was determined by using data from another source which explained that run-of-river accounts for approximately 40% of total hydro production [14]. Therefore the run-of-river production data was increased and the dam hydro production was decreased by the same amount.

In Croatia, run-of-river production data was provided by ENTSO-E, as it was for the other countries, however a run-of-river production capacity was not provided by Enerdata. Therefore a production capacity was estimated for run-of-river hydro in Croatia. The capacity was estimated based on an average run-of-river capacity factor, and was assumed to be 300 MW with a capacity factor of 74%. The dam capacity was decreased to 1542 MW with a 47% capacity factor.

Another small adjustment was made for the United Kingdom hydro data where the dam production data was increased to 1.6 TWh in order to fit the IEA data. In Romania the run-of-river hydro capacity was too low to fit the production data therefore the capacity was increased by 2115 MW and thus the dam hydro was decreased by 2115 MW as well.

All the final data and assumptions are deemed to be suitable and accurate for the reference models, and and the data assumptions are presented in Appendix A - Technical Data and Appendix C – Data . The final capacity factors for hydro power in each country, after the adjustments is presented in Table 3.

Table 3: Hydro power capacity factors for the reference models

Capacity factors	2010 HR	2010 CZ	2010 IT	2010 RO	2010 UK
Run-of-river	74%	67%	50%	51%	90%
Dam	47%	16%	38%	27%	14%

Another important factor for hydro electricity production is the amount of water that can be stored for dammed hydro. This data is often difficult to find or simply not reported. Data was provided only for Croatia but for the other countries it was estimated. The energy storage capacity of the dammed hydro in each country was conservatively assumed to be a month of water as if operating at full capacity (31 days). The storage capacity was calculated simply by multiplying the production capacity of the dammed hydro by 744 hours in which it would operate at full capacity (31 days). This is deemed a conservative estimate since in the Nordic hydro system (Norway, Sweden, Finland) the average storage ranges from around 74 days in Finland up to around 110 days in Norway if operating at full capacity [15].

2.4.5 Pumped hydro and hydro storage

Although pumped hydro is often reported with other hydro data, it is not an electricity generation technology but rather an electricity storage technology. It is actually a net consumer of electricity as opposed to a producer.

If pumped hydro was included in electricity production it would be double counting since the electricity that pumped hydro produces when it operates was actually already produced elsewhere in the electricity system, for example by wind power. Therefore it cannot be included as a production source. It often runs according to economic reasons as opposed to technical reasons in which the main electricity system operates. The technology is typically used when the cost of the marginal thermal power station exceeds the cost of operating the pumped hydro.

When modelling the energy system in EnergyPLAN the pumped hydro production is sometimes different to reality. When using the technical simulation in EnergyPLAN, pumped hydro is often not even required in the models. This is because of the way pumped hydro is used in real-life versus the way it is modelled in EnergyPLAN, which determines its own ‘optimal’ technical operation. The most significant difference is most likely caused by EnergyPLAN’s lack of detailed modelling for peak load power plants, which are often the plants replaced by pumped hydro in today’s energy system.

In this study, the pumped hydro storage capacity was estimated since no data was available. It was estimated that the pumped hydro storage would be able to hold enough water to produce electricity for 10 hours at full capacity. This is a typical capacity for many pumped hydro plants today, since they were originally designed to allow baseload plants to continue operating during the low demand periods at night. For example, a large pumped storage plant in Germany has a 100 MW capacity and can hold 8.5 GWh of water [16], meaning that it could theatrically run at full capacity for 8.5 hours. Therefore in this study this is rounded up to 10 hours of storage.

2.4.6 Electric grid capacity and costs

The electric grid capacity data was collected from ENTSO-E using the national annual maximum load in each country as a proxy for electric grid capacity. The maximum load values of each country are specified in the System Adequacy Retrospect 2010 report [17], and represent the point of national maximum load at a specific date and hour during the 2010 year. Identifying an electric grid capacity and assigning a suitable cost is a very large task in itself, so this proxy is used in STRATEGO to reflect costs increases that will be required as electricity demand increases in the future. However, a more detailed investigation is required in the future to validate this, which is beyond the scope of this study.

2.4.7 Electricity interconnection capacities and costs

The capacities for interconnection cables between the study countries and other countries were collected from ENTSO-E [18]. The values are indicative values for Net Transfer Capacities (NTC). The values are for Winter 2010/2011 on a working day peak hours. There are usually two different values for capacities between countries due to the different load demand requirements of the countries. In these situations the highest value is used for the interconnection capacity.

Interconnections onshore are assumed to be equal to electric grid costs since onshore grid connections are essentially extensions of one grid to another grid. Offshore interconnection costs are based on current installed cables between €0.4-1.2 million per MWe and hence, 1.2 M€/MWe is applied as a conservative estimate based on real-world projects [[19], [20]]. The O&M costs were assumed to be 1% of the investment costs.

2.4.8 Individual boilers & costs

The individual boilers are located in residential and non-residential buildings. Residential buildings are split into single-family and multi-family buildings. In this study the number of buildings is used as a proxy for the number of individual boilers. The boiler capacities used for the different types and building sizes are presented in Table 4 below. The same boiler sizes were assumed for multi-family buildings and non-residential buildings, since both are likely located in similar sized urban buildings.

Table 4: Boiler capacities for different boiler types

		Oil burner (mineral oil fired, <10 % FAME)	Natural gas boiler	Biomass boiler (automatic stoking)
Average Heat production capacity for one unit (kW)	Single-family building	22.5	11.5	12.5
	Multi-family building	400	385	550
	Non-residential buildings	400	385	550

The number of single-family buildings and multi-family buildings are based on data from Entranze [21]. The different boiler types within the residential groups of individual boilers have been proportioned according by energy used for space heating of dwelling stock from Entranze database, for example between natural gas, coal, biomass.

The number of non-residential buildings in each country was used as a proxy for the number of boilers installed for the service heating. Non-residential buildings include buildings such as schools, hospitals, offices, hotels, shops, cultural buildings and so on. Industry buildings are not included. Data for the number of non-residential buildings was collected from numerous data sources. The number of non-residential buildings in the Czech Republic and Italy were collected from local data sources: the Ministry of Industry and Trade of the Czech Republic [22] and ENEA [23] respectively. The data for the UK was estimated based on the Carbon Reduction in Buildings (CaRB) project [24], which was carried out over four years by the Engineering and Physical Sciences Research Council (EPSRC) and the Carbon Trust. This project determined the number of non-residential buildings in the UK and from this an estimate of heated non-residential buildings was determined [24].

The number of non-residential buildings in Croatia were estimated based on the JRC data [25] and Odyssee data [8]. The data was calculated by using an average boiler capacity of 100 kW based on the JRC project. In addition the number of hours in which boilers are typically operated was taken from the Italian data from the JRC project, which is 1154 hours heating per year. The Odyssee database provided the total heat consumption from boilers for Croatia. This equalled 2.5 TWh (based on boiler efficiencies see Appendix A - Technical Data. The fuel mix for Croatia boilers was based on Czech Republic data from the JRC so the number of different non-residential boilers could be calculated by fuel. The resulting number of non-residential buildings in each country is presented in Table 5.

Table 5: Number of non-residential buildings in each country

	Croatia	Czech Republic	Italy	Romania	United Kingdom
Non-residential buildings	21,863	97,254	144,383	73,322	1,150,000

2.4.9 District heating definition

The heat and district heating data, in particular the production data, may differ from one source to the next due to how district heating is defined. In the IEA manual [9] the "*Gross production of heat is the amount produced and sold*". The IEA data includes all the heat and district heat that is produced at CHP plants, district heating boilers, waste incineration plants and industrial sites and is either used on-site or sold to other consumers (for example this could be to the public district heating network or to other industries). Heat for own use by energy industries is included in the total heat produced in a country and this is an additional heating demand that is consumed onsite and is not converted into another energy commodity.

An example that illustrates the importance of the heat and district heating definitions is for Italy. In the IEA data, the total heating production in 2010 was 57 TWh. This is the gross heat production. Around 18 TWh is consumed by the energy industry as own use. The remaining 39 TWh is produced and circulated via industrial CHP and CHP plants and boilers. It is consumed by industry and residential and service buildings (36 TWh and 3 TWh, respectively).

The net production of 39 TWh supplied from CHP and boilers and industry corresponds with data from Eurostat (that collects their data in the same way as IEA) [5].

In contrast, the total district heat production in 2011 according to EuroHeat & Power and ENEA (The Italian Government Energy Agency) was around 7.32-7.75 TWh, of which the industrial production is between 1.6-3.3 TWh [26]. Although IEA show that 57 TWh of heat is consumed in Italy we can assume that the sold heat data from the other databases is what is recorded as sold, and other heat trade has been excluded in the overall balance. In the IEA data 3 TWh of heat is sent to residential and service buildings which corresponds with the other databases. And the remaining proportion is assumed to be a small amount of the industrial heat which is recorded. It is assumed that the vast majority of heat produced in Italy remains officially unrecorded since it remains within industry.

Thus, the actual reason for the differences can be related to 1) whether the heat is supplied to the public district heating network or not and 2) where the measurements are taken in the district heating system. This may be the case for Euroheat & Power and ENEA's method for assessing the district heat production where only the district heat supplied to the public network is accounted for, hence leaving out the district heating that never reaches the public network as it is used onsite (own use) or supplied to other industries via more local and smaller scale district heating networks, such as those sometimes in an industrial area. However, it is important to notice that different data sources provide different district heating data and this should be taken into consideration when assessing the results of this study.

2.4.10 Centralised and decentralized district heating plants

Centralised and decentralised CHP plants have the ability to operate in different ways, which in turn has an impact on the rest of the energy system. Centralised plants are usually large CHP units which are located near a cooling source such as a river, the sea, or a cooling tower. Due to the presence of a cooling source, the centralised CHP plants can operate in condensing (i.e. electricity only) mode. In contrast, smaller decentralised plants typically don't have a cooling source so they must always produce heat when they are producing electricity.

All power plants and CHP plants were modelled as centralised plants, as opposed to decentralised plants, in the reference scenarios. The reason for this is that in the energy statistics only one type of plants are listed, so these were assumed to be centralised plants since the majority of electricity and heat production usually comes from centralised plants.

2.4.11 District heating boiler capacities

The district heating capacity plants consist of boilers, waste incineration plants, industrial plants and CHP plants. From the statistics it is generally possible to obtain data for thermal capacities for CHP plants and industrial CHP. However, it is more difficult to collect data for thermal capacities for boilers and waste incineration plants. The methodology for assessing district heating boiler capacities in this report is to identify the peak boiler demand (for any hour during the year) by running the given scenario and adding 20% capacity to this. Hence, the district heating boiler capacity is assumed to be peak demand multiplied by 120% for each model. No thermal capacities are required for waste incineration plants in EnergyPLAN as this is modelled by production (and waste input) rather than available capacities. Typically waste incineration plants are operated at baseload since their primary function is typically as a waste management service rather than energy production. Hence, production rather than capacity is sufficient for EnergyPLAN.

2.4.12 District heating pipe costs

District heating pipes are the pipes that distribute the hot water from heating plants throughout the city to end-users of the heat. The costs for district heating piping were determined by using the data from Table 6 below.

Table 6: District heating piping cost data [27]

Cost data	Conventional district heating network	Low-temperature district heating network
Specific Investment costs (1000 €/TWh)	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

In the reference scenarios the data for conventional district heating in existing buildings was used. In future scenarios, investment costs will be taken from the mapping work being carried out in STRATEGO which is in Background Report 6.

2.4.13 Cooling unit costs

There are two distinct types of cooling units: individual and network. Individual cooling systems are installed by an inhabitant independently of the people in the neighbouring area, and can be either small units (single-family) or large units (multi-family or non-residential). Today, individual cooling is provided predominantly by individual heat pumps. The investment cost of a small two kW individual heat pump for cooling in a single-family house is assumed to be €2,000 with a lifetime of 20 years [27]. For a larger 300 kW heat pump for an entire residential multi-family building or non-residential building the investment costs are assumed to be €195,000 and a lifetime of 15 years [28]. The number of homes with an individual cooling unit is based on the saturation rate for the cooling demand (see Background Report 4)

A network cooling solution is district cooling, where cold water is supplied by a central cooling system and subsequently shared between buildings using a common pipe and a heat exchanger in each building. There are very few large systems in operation in Europe today, with the larger systems in the cities of Stockholm, Helsinki, and Paris [29]. The cost for central cooling supply is based on Swedblom *et al.* [28], who reported an investment cost of €195,000 for a 300 kW air-cooled chiller plant. The number of full load hours is assumed to be 1200 hours/year, with a fixed O&M cost of 4% of the investment and variable O&M costs of 2 €/MWh. Also, a lifetime of 15 years is assumed [28]. The cost of the district cooling network is taken from the mapping work being carried out in STRATEGO which is in Background Report 6, while the cost of the heat exchanger for each building is assumed to be €5,500 in single-family homes and €22,000 in multi-family and services buildings both with a lifetime of 20 years based on similar costs for district heating equipment [27].

The district cooling costs therefore comprise of the three different parts, respectively the supply technology, network costs (pipes, etc.) and the energy transfer station (the heat exchanger in each building).

2.4.14 Renewable waste

In this study all waste fractions are included as renewable sources, even though in reality some waste fractions are based on oil products and therefore non-renewable. As a result, an average CO_2 emission factor was applied for the consumption of waste to acknowledge this non-renewable fraction.

This was not interrogated in detail here due to the small scale consumption of waste resources compared to the total energy resources. In the study, waste is hence included as a renewable source, but it still has CO_2-emissions, see Section 2.4.3 - Adjustments of CO2 emissions.

2.4.15 Vehicle numbers and costs

Vehicle stocks in each country were sourced from the Odyssee database [8]. Stocks were provided for motorcycles (petrol); cars (gasoline, diesel, LPG and electric); light vehicles 3 tonne payload (gasoline, diesel, LPG and electric); trucks (diesel); and buses (gasoline, diesel, LPG, electric). Data was unavailable for other vehicle types. In the United Kingdom the other vehicles account for 2%, but the types of vehicles they are and the fuels they consume are uncertain [30].

The number of vehicles is multiplied by the investment costs for the different types of vehicles. The investment, O&M and lifetimes are from the cost database, see Appendix B – EnergyPLAN Cost Database Version 3.0. A weighted average total investment cost, operation and maintenance cost, and vehicle lifetimes are quantified for all the vehicles.

2.4.16 Oil and gas storage capacities

Oil storage data for Czech Republic, Italy and United Kingdom was collected from the IEA document entitled “Energy Supply Security: The Emergency Response of IEA Countries - 2014 Edition” [31]. The oil storage for each country is presented in Appendix A - Technical Data. Oil storage sometimes includes crude oil plus oil products. Oil storage in Croatia was provided via the JANAF website that manages an oil pipeline in Croatia [32] and storage for Romania was estimated based on a 90 days reserve of net imports amount from the previous year [33]. Gas storage capacities are provided by the Enerdata database [7].

2.4.17 Manual adjustments during calibration

During the calibration of the reference system models several data issues were encountered and needed to be changed in order to calibrate the models towards an improved replication of the current energy systems. These are listed below along with an explanation of why they needed to be changed.

Croatia

- The Croatian CHP capacity was increased from 227 MW to 675 MW. This was required in order to deliver sufficient heating from CHP plants and this alteration was discussed with and approved by the local partner.

Italy

- The Italian CHP thermal capacity was increased from 4868 MW to 7000 MW in order to be able to produce sufficient CHP district heat. The electrical capacity of CHP plants remained the same.

Romania

- In Romania the full load hours for nuclear power were too high (above 100% capacity factor) and therefore it was assumed that the nuclear capacity of 1300 MW provided by Enerdata was too low. The capacity was increased to 1400 MW [34].

UK

- The UK CHP thermal capacity was changed to industrial CHP so that all district heat was assumed to be provided from industrial CHP (no district heat production from public CHP).
- Stock of electric cars in UK was reduced (originally 83600 based on Enerdata) to 8360 assuming it was a data entry error since the statistics reported almost no EV electricity consumption. This only affected the energy system costs.
- No data for offshore wind production was available, and since the UK has offshore wind capacity a production was calculated based on an average capacity factor of 30% [35]. This factor is lower than what might be expected in the future.

2.5 Specific issues for the business-as-usual models

This section contains a description of the methodology for projecting the 2010 reference models to the year 2050, based on a business-as-usual (BAU) scenario from the current modelling carried out by the European Commission [36].

The BAU models are used as a projection of what the future 2050 energy systems might look like if we continue on the path that we are currently following and implement existing policies, both nationally and internationally. It is hence used for both comparisons to the alternative 2050 energy system scenarios and as a baseline situation for the year of 2050. The alternative energy system models will therefore build on top of the 2050 BAU models in order to improve the energy systems, but with the 2050 demands and capacities.

2.5.1 Energy demand changes

The BAU models were based on the 2010 reference models for each country and projected towards 2050 based on the current modelling carried out by the European Commission [36]. A number of key changes were implemented in the 2010 models to reflect the 2050 situation, such as the demands within a number of sectors and the electric production capacities, since the electricity sector is undergoing the largest changes according to the projections applied. The demand changes were assessed within the sectors of electricity, heating and cooling, transport and industry according to the European Commission [36]. The methodology for developing the 2050 energy demands can be found in [36], but is generally based on already adopted national and international policies and agreements. The projections furthermore build on macroeconomic assumptions and population projections as well as developments in fuel prices and energy technologies. The changes that are applied to the 2010 reference models to reflect the 2050 BAU situation are listed in Table 7 below.

Table 7: Energy demand changes within electricity, district heating, individual heating, cooling, industry and transport between the 2010 references and the 2050 BAU systems [36]

Energy demand changes (%)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Electricity demand*	40%	33%	36%	62%	25%
Individual heating	12%	6%	-1%	14%	-6%
District heating**	16%	-1%	-3%	29%	39%
Cooling	6%	6%	-1%	7%	-6%
Industry***	30%	31%	6%	22%	-7%
Transport	7%	17%	1%	39%	-5%
Oil storage	-9%	3%	-21%	20%	-20%
Gas storage	14%	21%	1%	12%	-20%

* Electricity demand includes final consumption (e.g. electric heating, individual heat pumps, Centralised heat pumps, centralised electric boilers, PHES pumps), own use (industries) and electricity losses

** District heating demand includes own use (industries), residential and services, industry and heat losses

*** Industrial demand includes fuel for main product, own use and non-energy use

The largest changes take place in Romania and Croatia, which experience higher demands for all demand categories, while the United Kingdom experiences a reduction in demands for all categories except electricity and district heating demand. The electricity demand increases for all countries, including a 62% increase in Romania, and is the demand with the largest impact on the energy system.

The energy demand changes present by the European Commission [36] are either based on the sector (e.g. industry, residential) or fuel (heat, electricity, etc.). Hence, these have to be interpreted here to convert the 2010 reference models to 2050 models. The demand changes for electricity, district heating as well as cooling are all based on fuel changes, while the industrial energy demand and the transport energy demand are based on the changes for the sectors. The individual heating changes are based on the changes for both the residential and services sector and how large their share of the heating demand is in the 2010 reference model. No data was given for cooling by the European Commission [36] and hence best estimates based on the changes for individual heating and electricity were applied. The cooling demand is relatively limited compared to the overall energy system demands, so the impacts on fuel consumption and costs will not be influenced as much by cooling compared to other demand changes. All of the actual energy demands used to both the 2010 reference models and 2050 business-as-usual models are presented in Table 8.

Table 8: Energy demands for reference and BAU models broken down by category and country

Energy demands (TWh)	Croatia		Czech Republic		Italy		Romania		United Kingdom	
	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Electricity	18.8	26.3	70.4	94.0	343	467.4	58.1	93.8	381.3	476.6
Individual heating	15	16.7	61.4	64.8	369.2	367.1	64.6	73.8	477.1	448.7
District heating	3.5	4	35.9	35.5	57	55.3	27.5	35.6	15.8	22
Cooling	1.3	1.4	1.6	1.6	49.3	48.9	1.8	1.9	6.1	5.7
Industry	28	36	125	156	451	474	104	124	531	644
Transport	23.7	25.5	67.9	79.3	503.6	506.4	54.9	76.1	621.9	591

2.5.2 Electricity capacity changes

When changing the demands it was found that the electricity capacities installed in the 2010 reference models were insufficient to meet the future demands. Hence, the electricity producing technology capacities were also projected towards 2050 based on data from the European Commission [36]. The technologies and how they might develop until 2050 is included in Table 9 below.

Table 9: The changes in electricity capacities for different technologies in the STRATEGO countries [36]

Electricity capacity changes (%)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Condensing power plants	86%	-15%	-37%	-41%	-23%
Centralised CHP	118%	43%	29%	42%	>2000%
Nuclear power plants	0%	110%	0%	62%	-8%
Geothermal power plants	0%	0%	96%	0%	>2000%
Wind power plants	1112%	118%	434%	935%	1194%
Hydro (excluding pumped)	23%	24%	10%	25%	11%
Water supply	23%	24%	10%	25%	11%
Solar	>2000%	11%	1298%	>2000%	>2000%

The actual electric capacities for the reference models and the BAU models are listed in Table 10. The changes in Table 9 are based on the changes presented by the European Commission [36], but the actual capacities applied in the reference models are based on Enerdata data [7]. Hence, the changes have been applied to the original data using the changes from the European Commission to project the BAU models.

Table 10: Electricity capacities for different technologies for the reference and BAU models

Electricity capacities (MW)	Croatia		Czech Republic		Italy		Romania		United Kingdom	
	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Condensing power plants	1454	2702	7767	6572	52806	33240	8138	4839	66560	51034
Centralised CHP	675	1471	2688	3846	17443	22587	3079	4370	0	7155
Nuclear power plants	0	0	3900	8177	0	0	1400	2264	10865	10030
Geothermal power plants	0	0	0	0	728	1429	0	0	0	0
Wind power plants	89	990	215	468	5814	31043	462	4783	5378	69586
Hydro (excluding pumped)	1842	2274	1056	1305	13977	15385	6382	7970	1524	1690
Water supply (TWh)	7.11	8.78	1.15	1.43	34.13	37.57	9.87	12.33	1.75	1.94
Solar	0	606	1959	2179	3484	48694	2	3132	77	9193
Wave and tidal	0	0	0	0	0	0	0	0	0	3536

All the STRATEGO countries increase their electric capacities, which is in accordance with the increasing demands that were previously identified. The largest changes in electricity capacities take place in Croatia where all technologies present in the 2010 reference experience growth and results in a doubling of the 2010 capacity. The smallest increase takes place in the Czech Republic, with the overall electric capacity increasing by 26%, while the remaining countries are somewhere in between those two countries. For most countries the power plant capacity decreases and is replaced by more CHP plant capacity making the overall thermal capacities more or less similar to the 2010 reference models. The large-scale boilers which are associated with the CHP plants the capacity is changed according to peak demand during the BAU year, multiplied by 120% (see section 2.4.11). The nuclear capacities increase for the Czech Republic and Romania while it decreases for the United Kingdom.

For renewable sources such as solar and wind, large increases in capacity are present in all countries. Wind capacities in all countries increase by at least 100% compared to the 2010 capacity, while the solar capacity increases by more than 2000% for some countries, but should also be seen in the light of the very low capacities in the 2010 models. It is assumed that all the wind power changes in Romania, Czech Republic and Italy are onshore wind [36] while the wind power changes in Croatia and United Kingdom consists of both onshore and offshore capacities.

For hydro power capacities, the data applied was only for river-hydro and dammed hydro leaving pumped hydro as constant compared to the 2010 reference. This is both due to the data availability, but also because pumped hydro in this study is viewed upon as a storage technology rather than an electricity production technology, and storage capacity changes were not assessed in the BAU scenario. In order to utilize the increased dammed hydro capacity the water supply was increased accordingly with the same change.

The industrial electricity capacity did not change compared to the 2010 reference models as this is more related to the change in the industrial sector rather than the electricity demand as such. The same applies for the waste incineration plants that have the same capacity as in the reference models.

For the BAU models a few other assumptions had to be implemented regarding the minimum grid stabilization capacity and the import/export of electricity. For the minimum grid stabilization capacity of power plants and CHP plants, it is assumed that a similar capacity must remain online as in the 2010 reference models. This resulted in very similar capacities to the reference models. However, due to the changing electricity demands new problems regarding the grid stabilization were identified. The import and export in the reference models were calibrated to replicate the actual net import/export for 2010 for the different countries, but as the BAU models are supposed to represent an energy system in 2050, the EnergyPLAN tool was allowed to control the amount of import and export that should take place in 2050.

In the 2050 BAU models the fuel distributions remain the same as in the 2010 reference models. This means for example, that a country with a higher CHP production will have the same fuel ratio between the different types of fuel, but the consumption of each fuel will increase proportionately. A detailed breakdown of the new 2050 business-as-usual models is provided in Appendix A - Technical Data.

2.5.3 Cost changes in the BAU

The socio-economic costs are updated automatically when EnergyPLAN is run with the new energy demands and components. However, to reflect developments in the various technologies simulated, new costs based on projections for the year 2050 are using in the 2050 BAU models. The new costs for the year 2050 are presented in Appendix B – EnergyPLAN Cost Database Version 3.0.

3 Hourly EnergyPLAN models for each country

In this section the results for each country are presented for the reference model and the business as usual (BAU) scenario, by presenting various capacities, demands, and production results from EnergyPLAN after the models are run.

3.1 2010 Reference models

The reference model results are presented below in order to understand how the different energy systems are constructed and what the key characteristics and issues of the energy systems of the countries are. The results presented include the primary energy supply, electricity demand and production, electricity capacities, heating and cooling demand and production, transport energy demand, industry, CO_2-emissions as well as an overview of the socio-economic costs. A list of some of the inputs and results are displayed in Table 11, while more detailed data can be found in Appendix A - Technical Data.

Table 11: Summary table of key inputs and results from the different energy systems

Category	**Unit**	**Croatia**	**Czech Republic**	**Italy**	**Romania**	**United Kingdom**
Total domestic electricity demand	TWh	19	70	343	58	381
Total heat demand	TWh	22	109	498	113	569
District heat demand	TWh	3	36	57	28	16
Transport demand	TWh	24	73	520	56	636
Average power plant efficiency	%	45	38	27	31	40
CHP electricity efficiency	%	35	19	43	25	10
CHP heat efficiency	%	35	40	12*	48	0**
Hydro capacity	MW	2135	2203	21,521	6474	4268
Hydro production	TWh	8	3	51	20	4
Industrial electricity production	TWh	0	9	25	2	39
Industrial district heating production	TWh	0	4	31	3	16
Interconnections	MW	3250	7300	8105	1900	2450
Number of buildings (residential and services)	1000s	998	1976	8989	4353	22103
Number of light vehicles	1000s	1,517	4,496	36,751	4,320	28,346
Number of busses/trucks	1000s	41	105	1,220	134	580

* The Italian CHP heat efficiency is lower than what might be expected in reality. This might be due to the way the fuels and energy production from CHP plants are reported as the CHP plants should be reported according to operation mode. However, in some cases the statistics might have been reported according to plants instead and this might include condensing operation at a CHP plant which would improve the electric efficiency and reduce the heating efficiency.

** This value is 0 as there is no CHP heating production, only industrial district heating production

3.1.1 Primary energy supply

The primary energy supply (PES) is a measure of the energy consumed in a country before any conversion or transformation processes. The total Primary Energy Supply is presented in Table 12 below, and a breakdown into primary energy supply by fuel mix, for each country can be seen below in Figure 6.

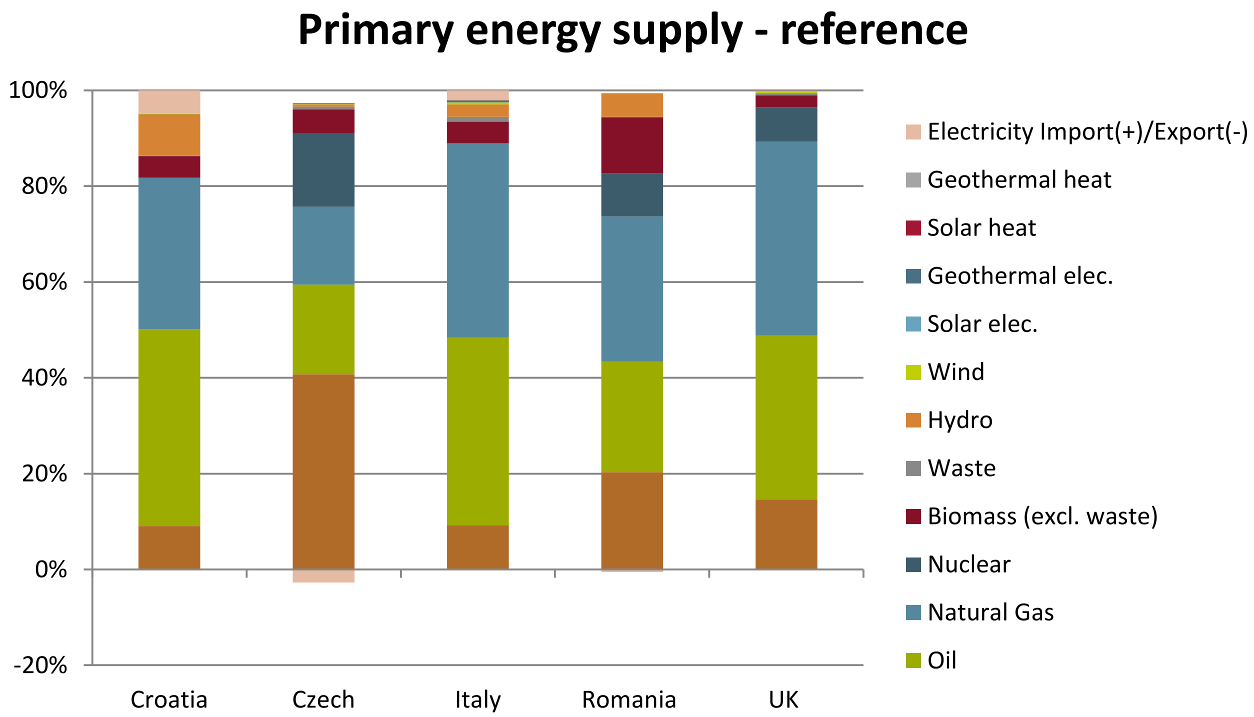


Figure 6: Primary energy supply shares out of the total for each country by fuel types. *A negative value for net import/export electricity indicates export while a positive is import.

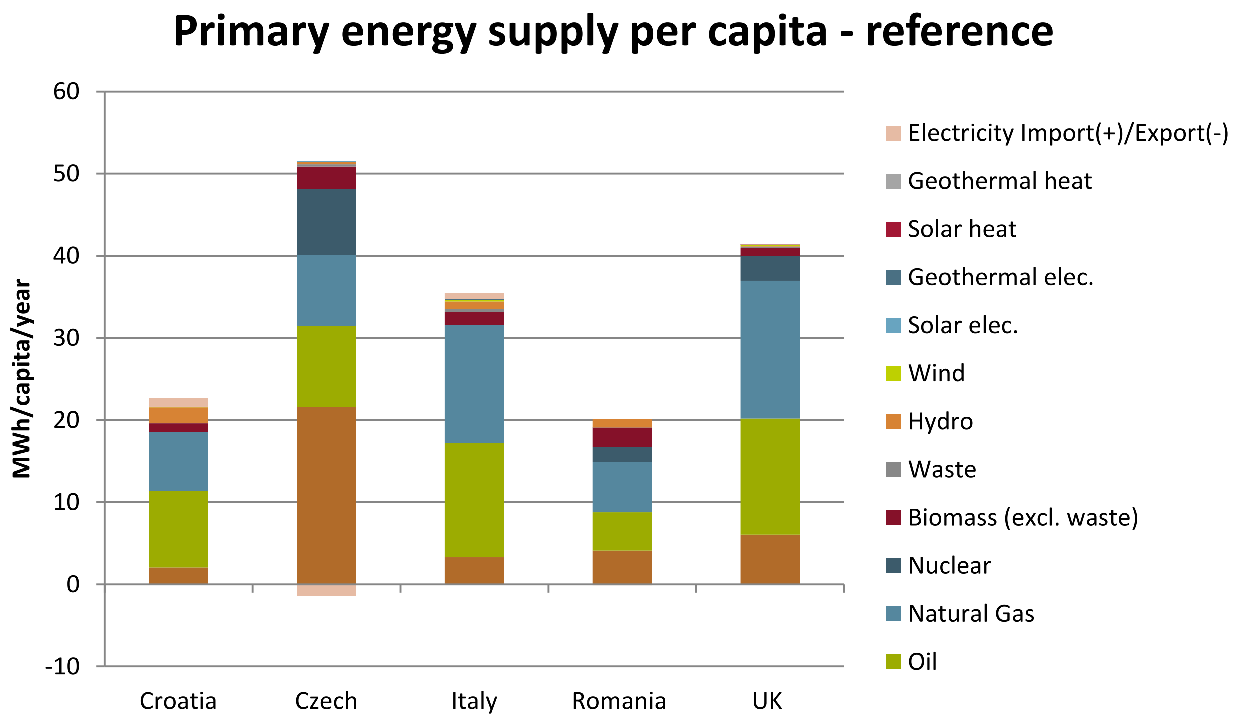


Figure 7: Primary energy supply per capita by fuel type for the STRATEGO countries

Table 12: Total Primary Energy Supply for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Primary Energy Supply	TWh	98	524	2100	406	2588

The results show that the majority of energy resources are from fossil fuels (coal, oil, natural gas). The Czech Republic has a particular large share from coal. The renewable shares (including hydro power) for the countries are 14% for Croatia, 7% for Czech Republic, 9% for Italy, 17% for Romania and the share for the United Kingdom is 3%. The primary energy supply per capita is shown in Figure 7 below.

The primary energy supply per capita shows that the least amount of energy per capita is consumed in Romania and Croatia with around 20 MWh/capita/year, while the Czech Republic has the highest consumption of around 50 MWh/capita/year of which the largest share is coal. In Italy and UK large shares of gas and oil are consumed.

3.1.2 Electricity capacities and production

The total electricity capacities for each country are presented in Table 13 below, and the split between the different electricity production technologies are shown for each country in Figure 8 below. The results show that the majority of the capacity is placed in condensing power plants in all the countries. The Czech Republic and the UK have the highest share of nuclear capacity. Croatia and Romania also have a significant share of hydro capacity while all the countries have small shares of wind power. The renewable capacity in the UK is the lowest of all the countries.

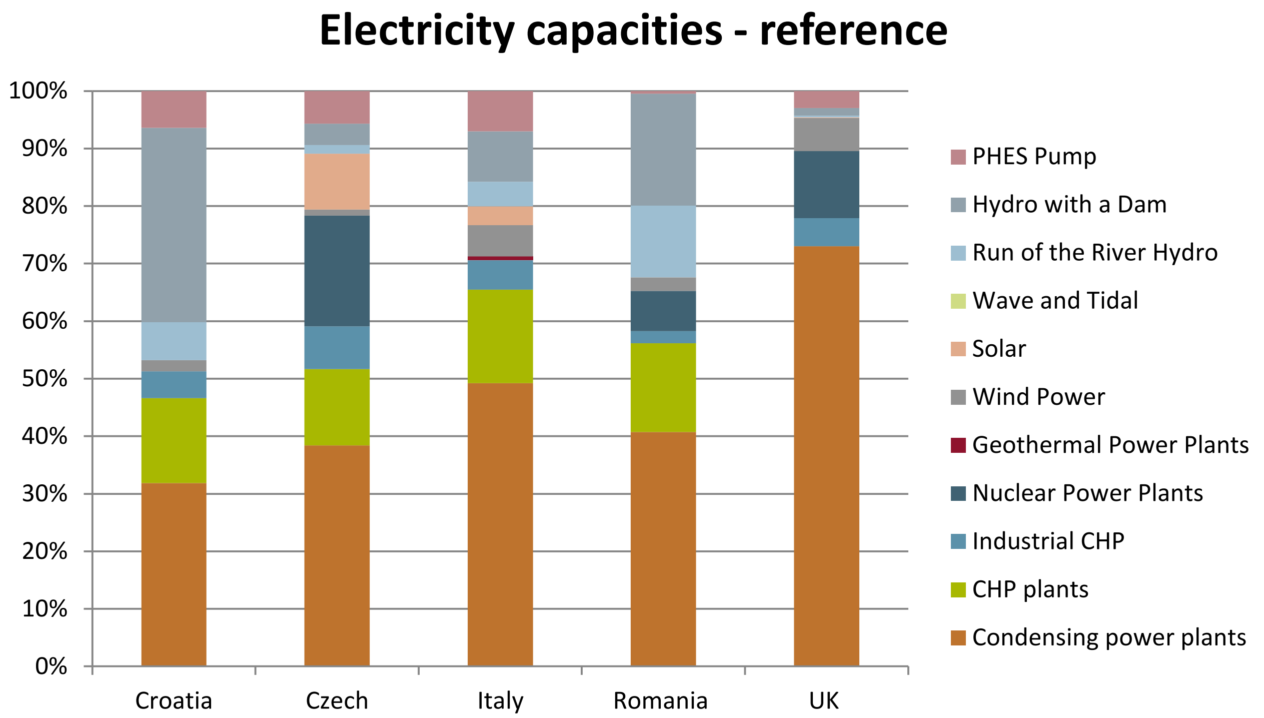


Figure 8: Electricity capacity shares out of the total capacity divided by technology type for the STRATEGO countries

Table 13: Total electricity capacity for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Electricity capacities	MW	4,565	20,232	107,251	19,976	93,201

The electricity capacity per capita is shown in Figure 9 below. As shown, the Czech Republic has the highest installed electricity capacity per capita with just below 2 kW installed per person. Croatia has the least installed electricity capacity at just around 1 kW installed per person.

The total domestic electricity production for the different countries is presented in Table 14, and the production is split between the different production technologies for each country in Figure 10 below. The electricity production structure is rather different between the STRATEGO countries, and there are no general trends for the electricity production structures of the STRATEGO countries. For example, Croatia has a large share of hydro production supplemented by import, power plants and CHP production. In a very different system the UK is dominated by a large share of thermal power production at condensing power plants supplemented by some industrial production and nuclear power. The renewable electricity shares for the different countries, assuming that all the import is non-renewable, are: Croatia 45%, Czech Republic 4%, Italy 20%, Romania 32% and UK 4%. The high renewable electricity shares for Croatia and Czech Republic are due to hydro power. Overall, the electricity production structure has a large influence on the overall fuel consumption and primary energy supply for each country.

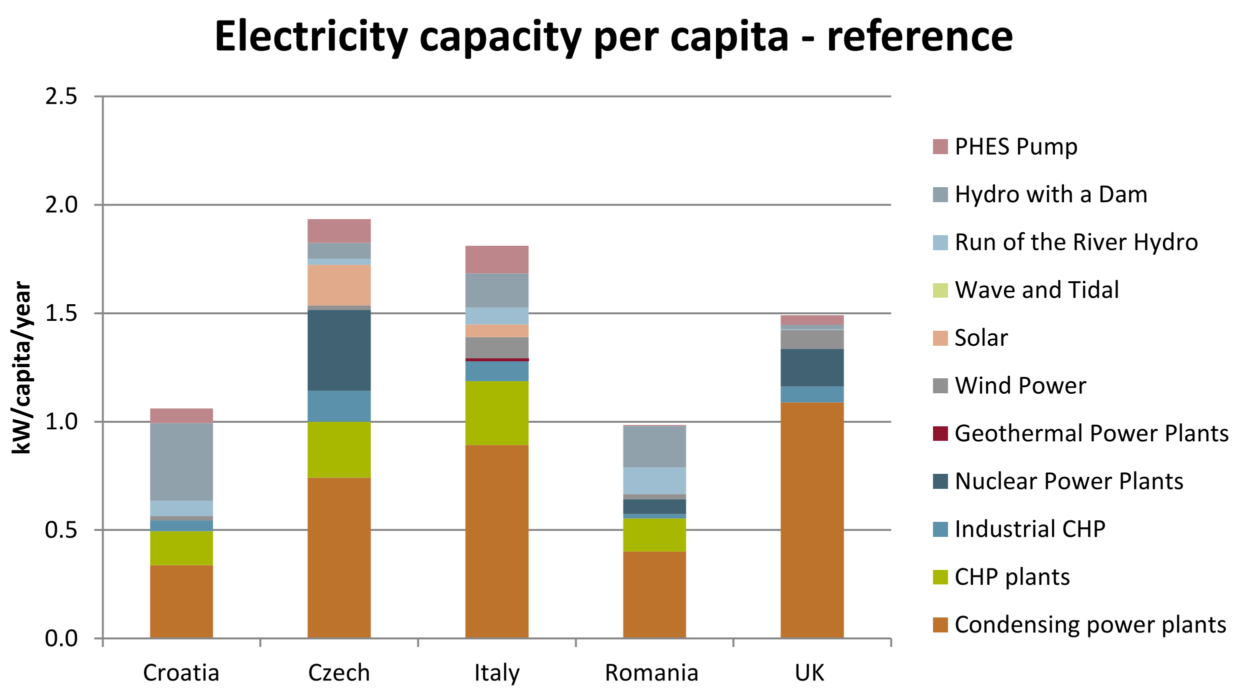


Figure 9: Electricity capacity per capita by technology type for the STRATEGO countries

Table 14: Total electricity production and net import/export

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total electricity production*	TWh	14	92.5	348	63	434
Net import (import minus export)	TWh	4.8	-15	44.2	-2.3	2.7

*Electricity production includes the electricity produced for export

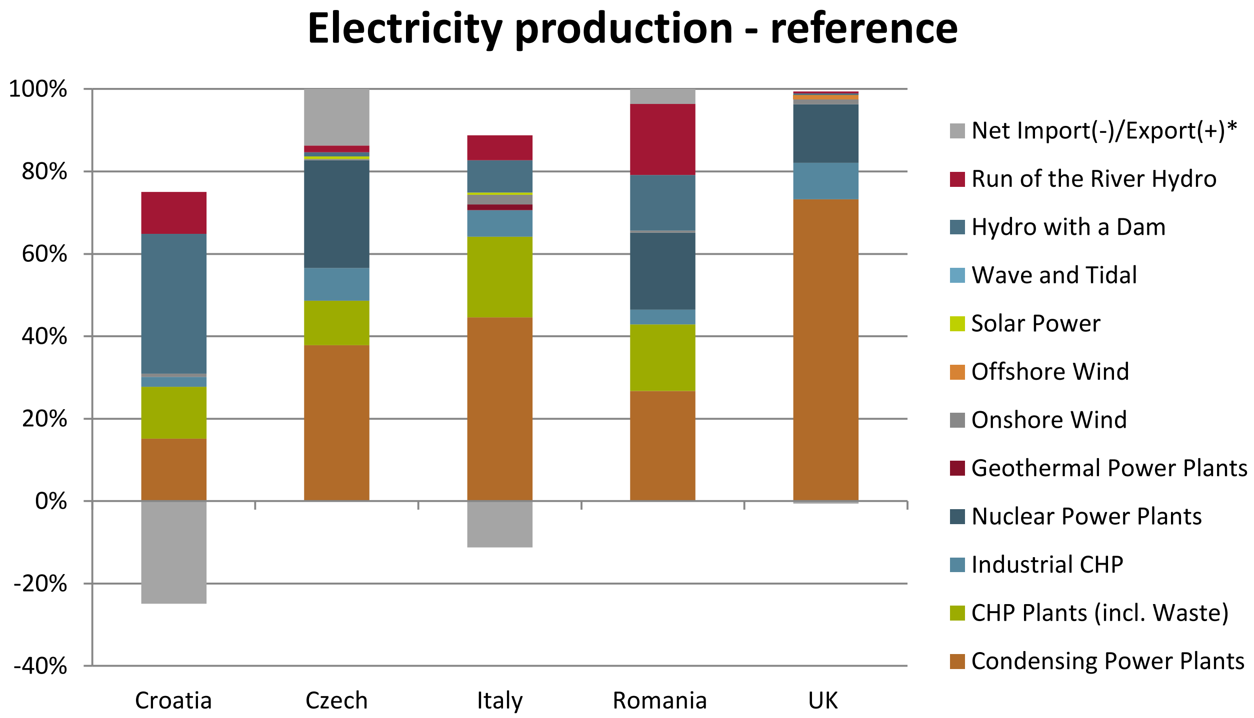


Figure 10: Electricity production shares out of the total production divided by technology type for the STRATEGO countries. *A negative value for net import/export indicates import while a positive is export. It is hence possible to see how large a share of the total electricity demand is covered from import of electricity or how large a share of the total production is exported to other countries.

The electricity capacity per capita is shown in Figure 11 below. As shown, the Czech Republic consumes the most electricity per capita. Excluding net exported electricity the country consumes around 8 MWh per person per year. Around 1.4 MWh is net exported. Romania has the lowest electricity production per capita of around 3 MWh per person. A small amount of this is net exported electricity. Croatia produces around 3.3 MWh and it has a net import of around 1.1 MWh.

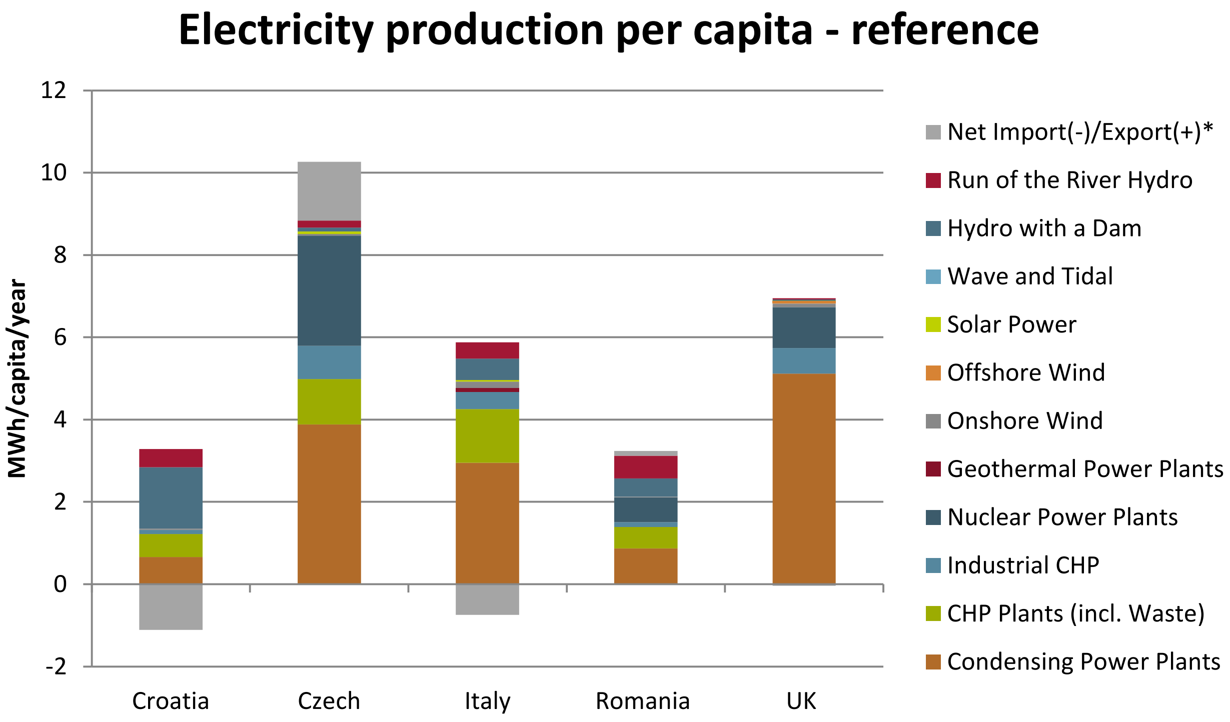


Figure 11: Electricity production per capita by technology type for the STRATEGO countries. *A negative value for net import/export indicates import while a positive is export. It is hence also possible to see how large a share of the total electricity demand is covered from import of electricity or how large a share of the total production is exported to other countries.

3.1.3 Heating and cooling production

The total heating production is presented in Table 15, and the heating production breakdown into different heat sources is shown for each country in Figure 12 below. In all the STRATEGO countries the heating production is produced mainly from individual units rather than collective systems. The largest share of district heating is in the Czech Republic where 34% of the total heat is supplied via district heating systems. On the opposite side the UK has a district heating share of around 10% of the total heat supply, including the industrial sector. For all the countries a large share of individual gas boilers is present, especially in the UK where 79% (437 TWh) of the total heat is supplied in this manner. Furthermore, only relatively small shares of electric heating are used for meeting the heat demand. Biomass boilers also supply significant shares of the heating in some countries (38% of the total heat supply in Romania), and it is important to note that biomass may be underrepresented in some statistics due to its local nature. For example, wood consumed from local forests that are owned by individual consumers can be missed in the statistics.

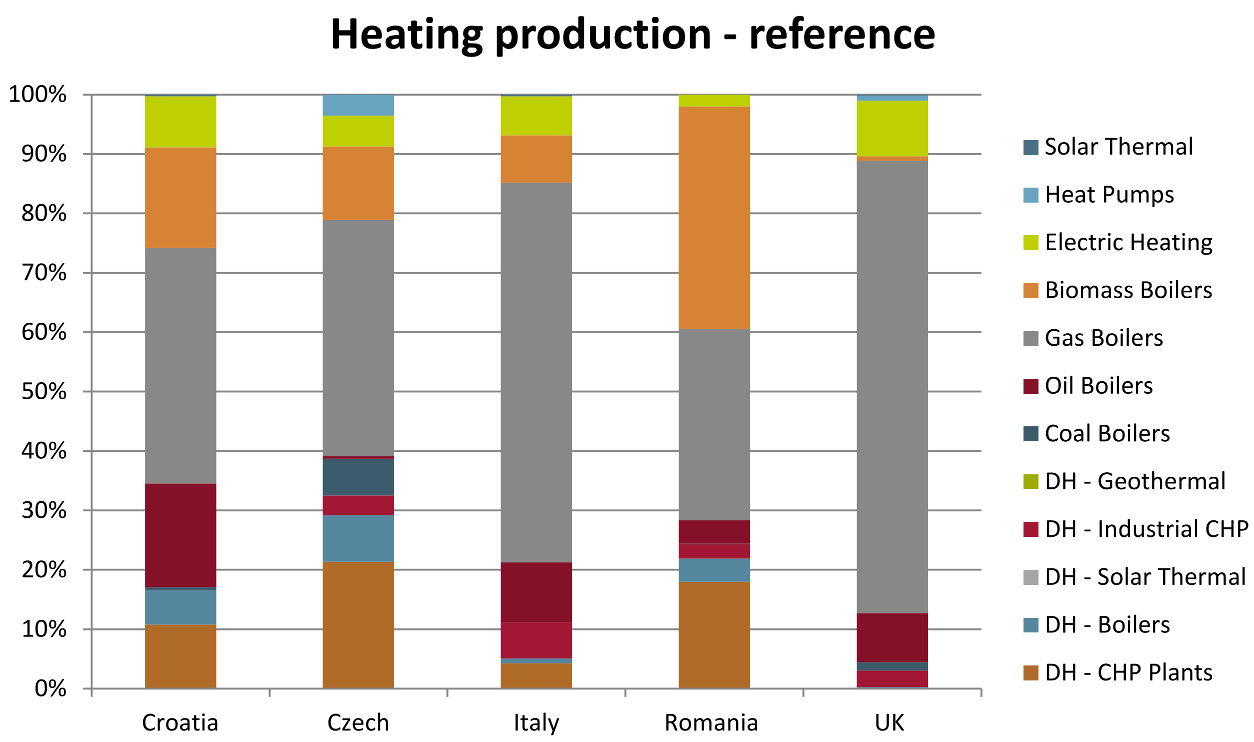


Figure 12: Heating production shares out of the total production divided by technology type for the STRATEGO countries

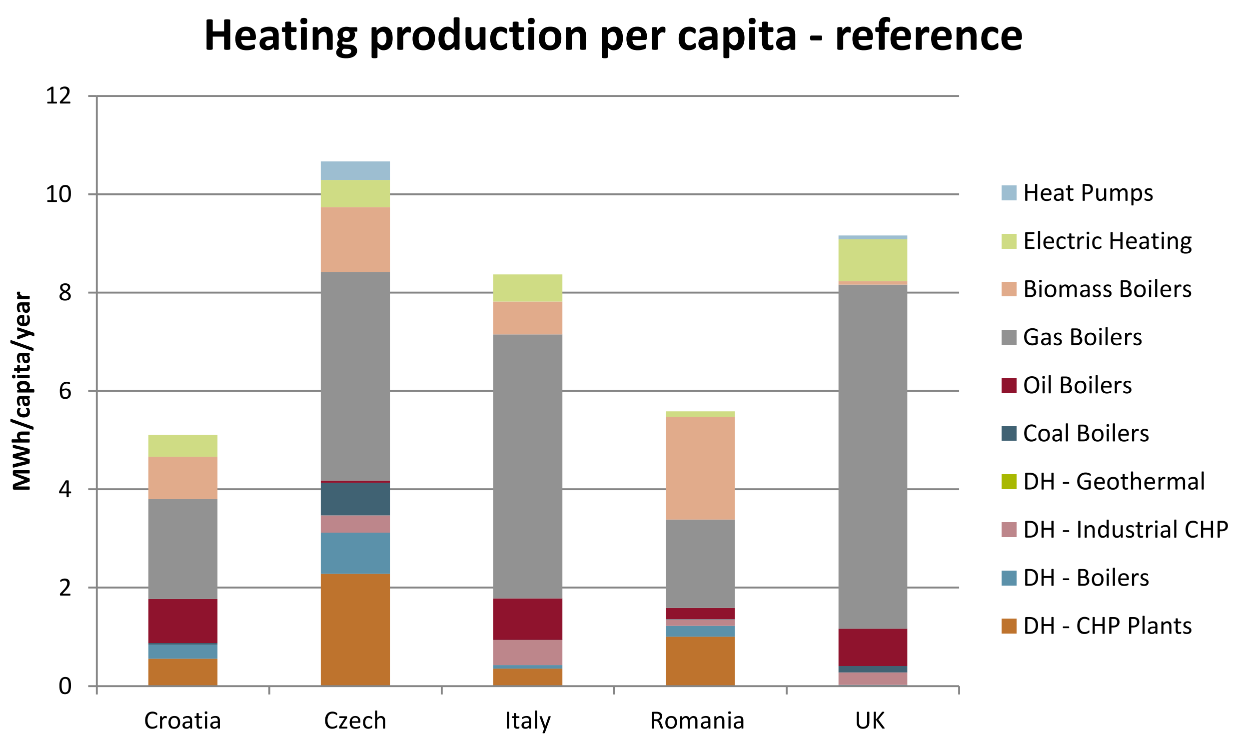


Figure 13: The heating supply per capita for the STRATEGO countries

Table 15: Total heat production for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total heat production	TWh	22	112	498	113	574

The heating supply per capita is presented for each country in Figure 13 below. The results show that the Czech Republic has the highest demand per capita and that he UK and Italian heating supply per capita are similar despite the differences in climate. The lowest heating per capita is in Romania and Croatia, which are around half the supply of the Czech Republic.

The district heating production is broken down by technologies in Table 16 and Figure 14 below to demonstrate the large variations between the countries. In Croatia, Czech Republic and Romania CHP plants deliver the majority of the district heating while district heating produced at industrial sites produce more than 50% of the total production in Italy and the majority in the UK.

Table 16: Total district heat production for each country, including district heat for residential, services, and industry

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total district heat production	TWh	3.6	36.5	60	27.5	17.5

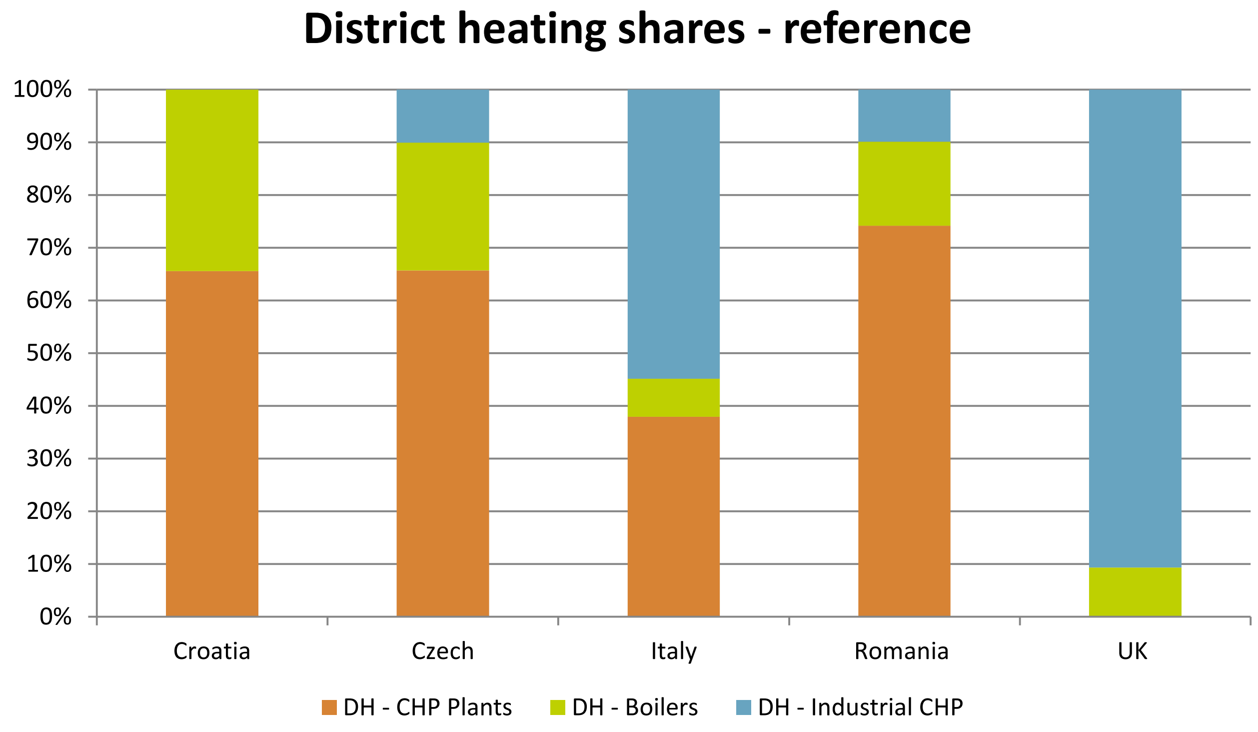


Figure 14: District heating shares out of the total district heating supply. The numbers in the figure represents the annual district heating production in TWh for the different technology types.

The total cooling production is presented in Table 17 below, and the breakdown into individual cooling and district cooling is presented in Figure 15 for each country. The cooling production (only for space cooling) is at a much lower level compared to the heating supply, varying between 1-49

TWh/year for the different STRATEGO countries. Italy is the country with the highest cooling demand around 49 TWh/year and almost all of it is supplied via individual cooling.

Table 17: Total cooling production for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total cooling production	TWh	1	2	49	2	6

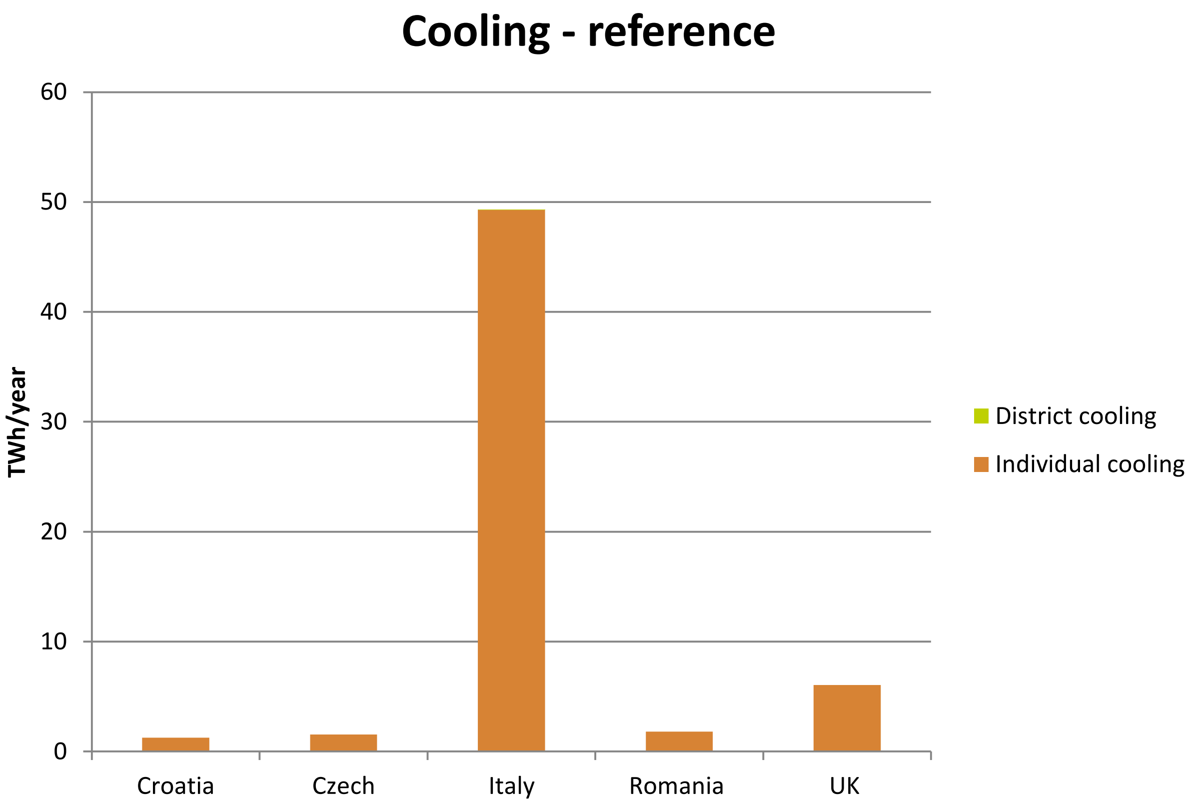


Figure 15: Cooling supply for the STRATEGO countries

The cooling demand per capita is shown for each country in Figure 16 below. When comparing the cooling supply per capita Italy also has the highest demand followed by Croatia, while the three other countries have demands that are far lower. These differences in cooling demands could also be expected due to different climatic conditions. Cooling is a service that can be seen more as a comfort service compared to heating, which in many cases in European is more of a necessity.

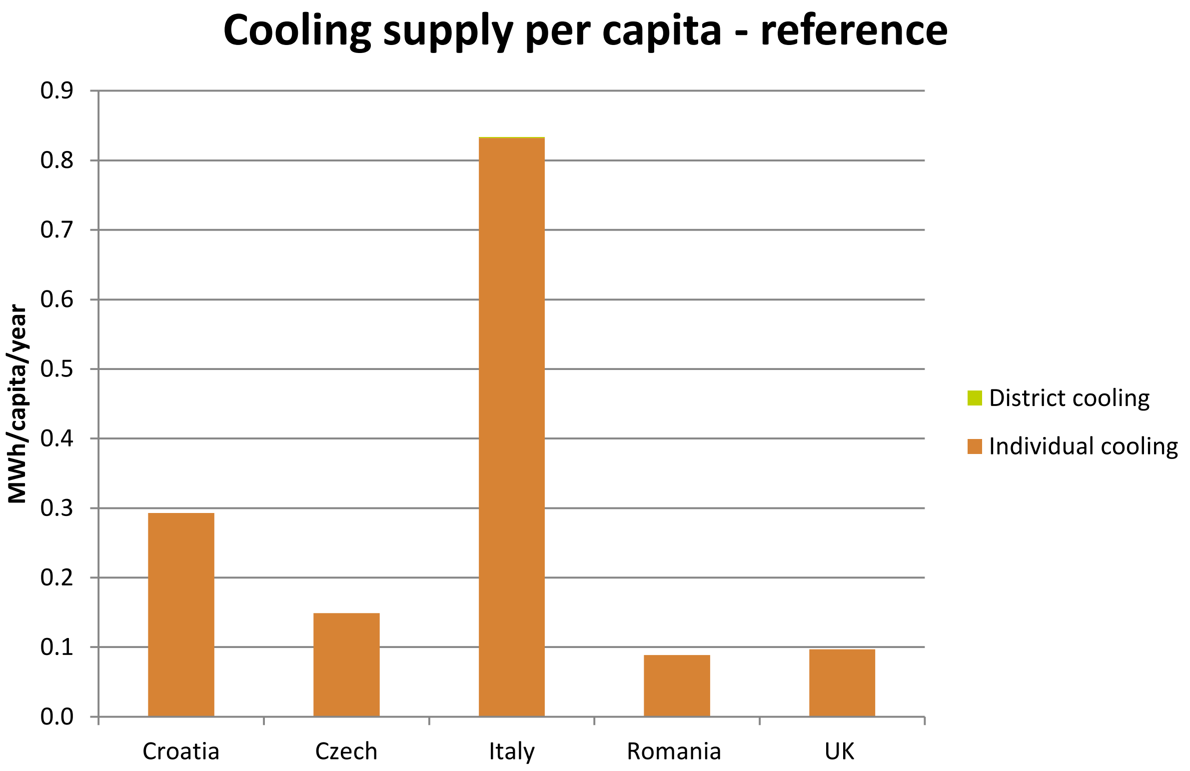


Figure 16: Cooling supply per capita for each of the countries

3.1.4 Transport energy demand

The total transport energy demand is presented in Table 18 below, and the breakdown of transport energy into different fuels is shown in Figure 17 for each country below. The transport energy is almost solely delivered from fossil fuels (between 96-99%). The most common fuel is diesel followed by petrol and jet fuel. The jet fuel in the UK is higher than for other countries, most likely due to the high volumes of visitors from other countries since 94% of the total jet fuel is for international aviation. Only small shares of biofuels and electricity (for rail) are consumed in the transport sector. The transport sector energy demands do prove certain general trends unlike other sectors, such as heating and electricity, since the fuel shares to a large degree are similar between the countries. The transport energy demand is strongly correlated with the population, but differences do occur when looking at the demand per capita, see Figure 18 below. The UK and Italy have the highest demand that is almost three times higher than the Romanian demand per capita.

Table 18: Total transport energy demand for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total transport energy demand	TWh	24	73	531	58	640

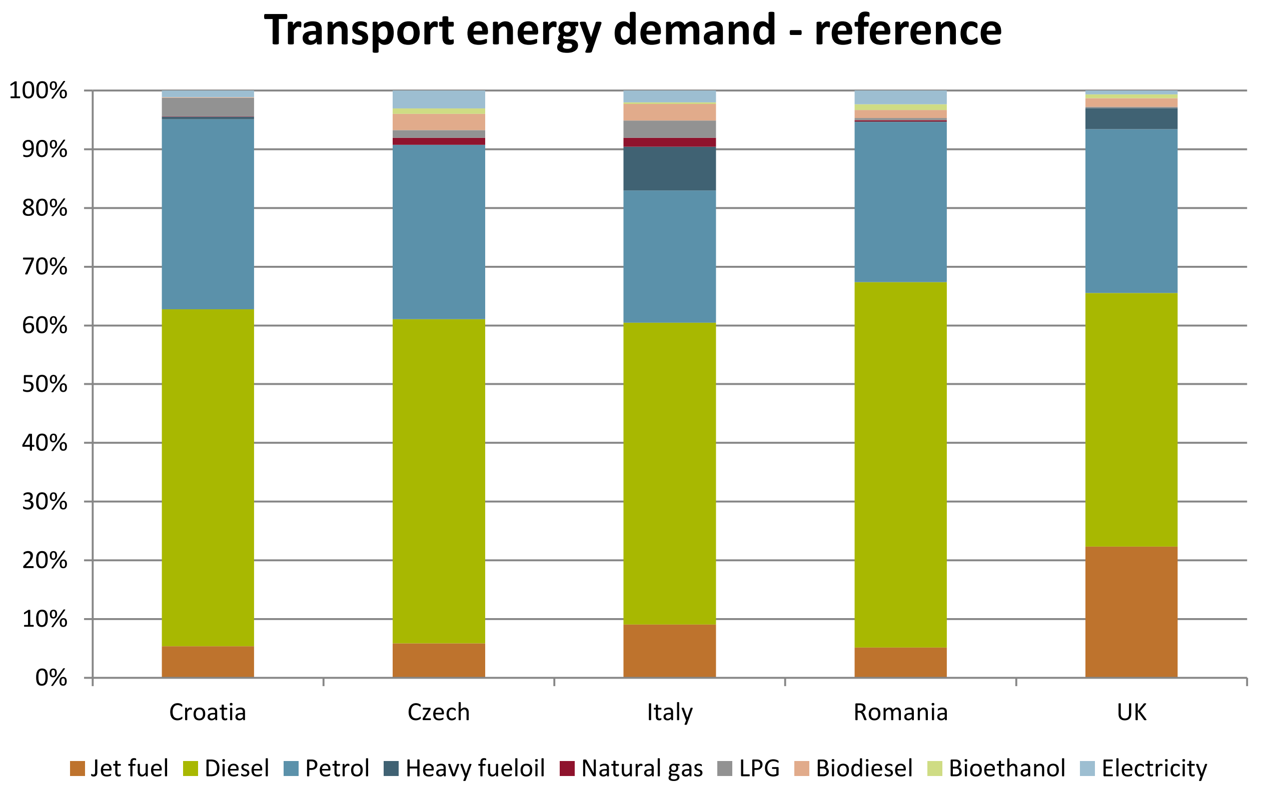


Figure 17: Transport energy demand shares out of the total demand by fuel types for the STRATEGO countries

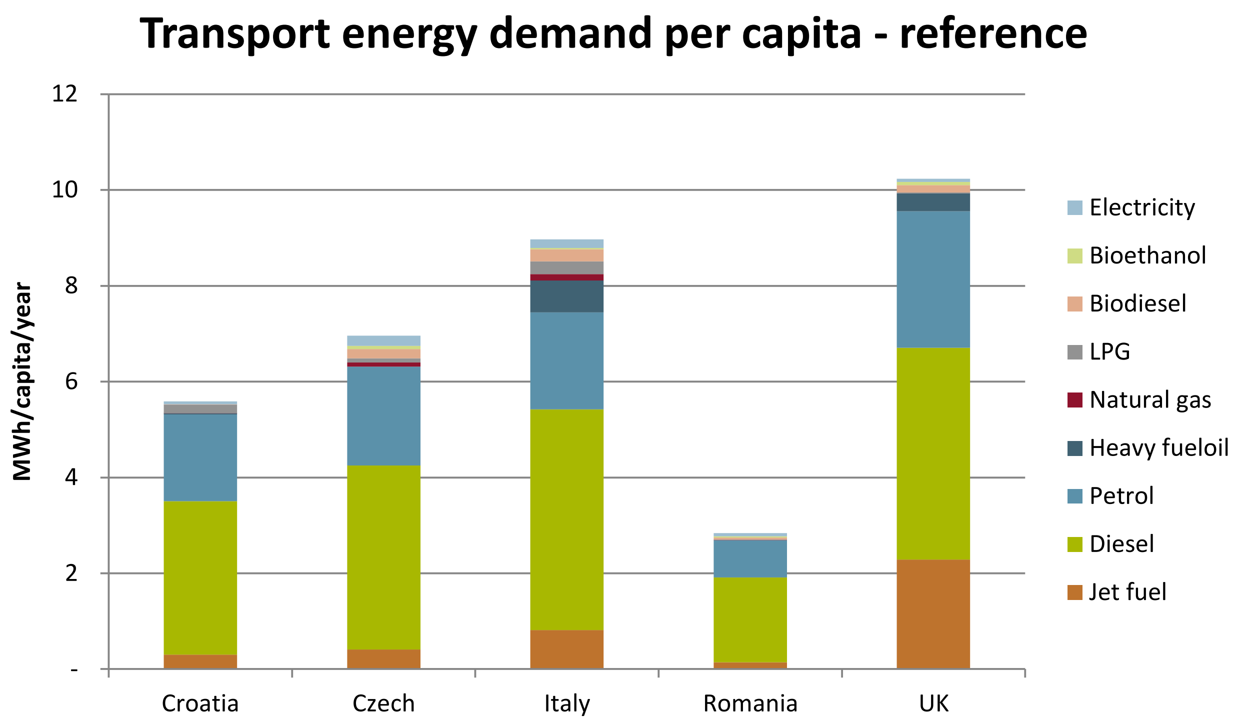


Figure 18: Transport energy demand per capita for the different STRATEGO countries

3.1.5 Industry energy demand

The total industrial energy demand is presented in Table 19 below, and the breakdown in to different energy sources for industry is presented in Figure 19. The figure indicates that oil, gas and electricity (produced from other energy resources) are the most common fuels. A substantial share of coal is consumed in the industrial sector in the Czech Republic compared to the other countries, which was also reflected by the primary energy supply. The industrial energy demand in the energy statistics is categorized within different categories (production of their main products, own use, sold heat and electricity and non-energy use). The main products consume between 50-65% of the total fuels for the different countries, the own use is responsible for between 11-27% of the total fuels, the sold heat and electricity consumes between 1-16% of the total fuels while the non-energy purposes consume between 12-21% of the total fuels, see also Appendix A - Technical Data. It should be noted that for industries waste consumption was classified as biomass. The industrial energy demand per capita indicates that the largest fuel consumption is in the Czech Republic while the other countries have a demand in the same range.

Table 19: Total industrial energy demand for each country

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total industrial energy demand	TWh	33	152	657	135	673

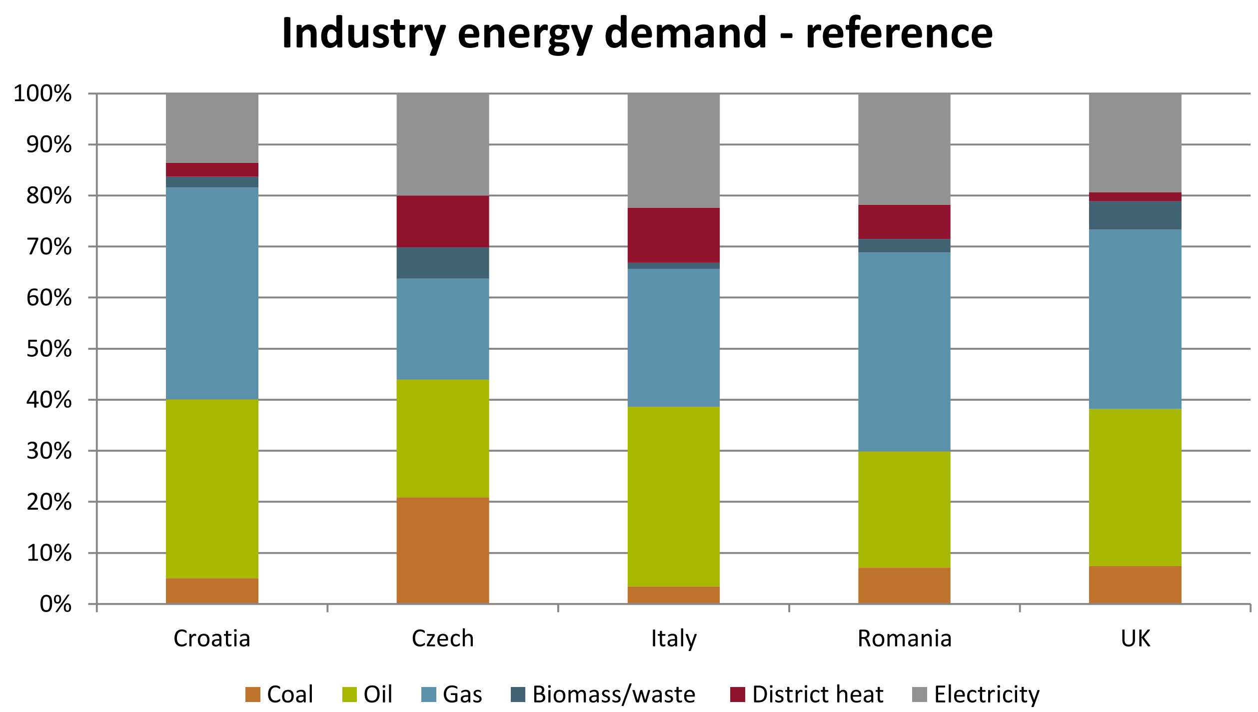


Figure 19: Industrial energy demand out of the total industrial energy demand by fuel types for the STRATEGO countries

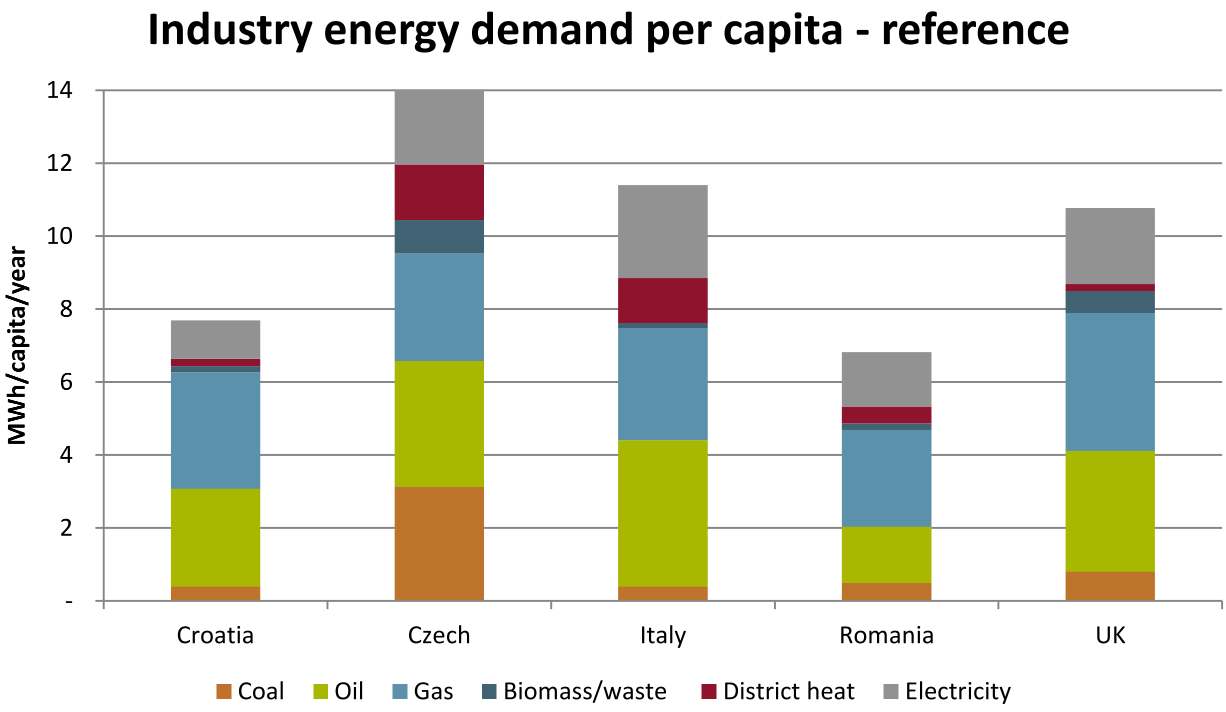


Figure 20: The industrial energy demand per capita in the reference models

3.1.6 CO_2 emissions

The total CO_2 emissions from the energy system and per capita are shown in Table 20 and Figure 21 below, respectively. The CO_2-emissions in the STRATEGO countries vary according to the fossil fuel consumption in the country. The lowest amount of CO_2 per capita is emitted in Romania emitting around 4 t/capita/year followed by Croatia while the Czech Republic by far has the largest emission per capita around 12 t/capita. Compared to the average EU28 emissions of 8.2 t/capita, only Czech Republic have higher emissions. The UK and Italy's emissions are around the same level per capita and the other countries have lower emissions [37]. The high Czech Republic emissions are due to the large amounts of coal consumed in the country.

Table 20: Total CO_2-emissions for each country

Emissions (Mt)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total CO_2	20	126	461	82	552

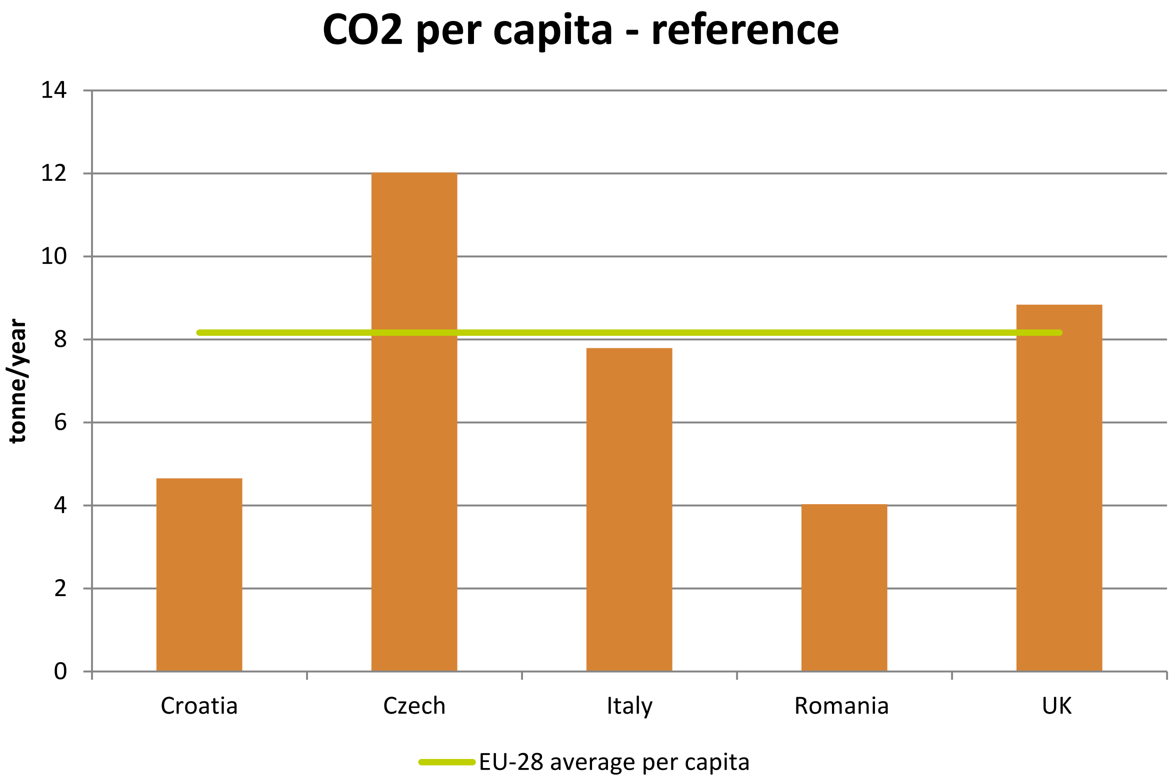


Figure 21: Average CO2-emissions per capita for the STRATEGO countries

3.1.7 Socio-economic costs

The total socio-economic costs of the energy system in each country are presented in Table 21 below, and the breakdown into different cost components is presented in Figure 22 below. The socio-economic costs are noticeably different between the STRATEGO countries in terms of absolute total costs (Table 21). However, the socio-economic costs composition is rather similar between the countries as around 40-50% is from investments, around 20% from operation and maintenance, 20-30% is from fuel costs while the remainder (less than 5%) is from CO_2 costs (Figure 22).

Table 21: Total socio-economic costs

Category	Unit	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total socio-economic costs	Billion Euro/year	11	39	264	41	250

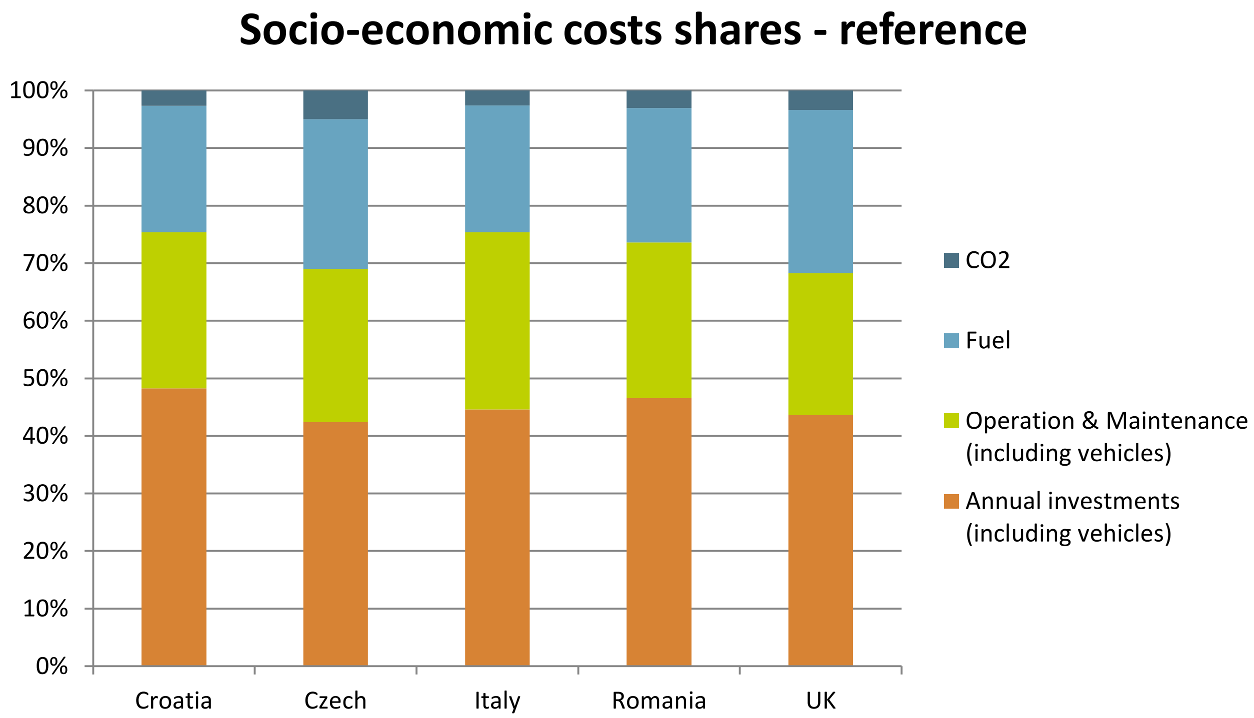


Figure 22: Annual socio-economic cost shares out of the total costs by cost type

When only investigating the investments and O&M costs for the various countries it is clear that the vehicle costs associated with all the transport vehicles make up a large share of the total costs (between 20-40%). Costs for individual heating solutions (e.g. boilers, HP, solar thermal) are responsible for 5-30% of the total costs and the collective electricity and heating production technologies are between 10-60% of the total costs (collective here refers to centralised plants, distinguishing them from individual plants in the building, such as a boiler for example). The district heating pipes are for all countries less than 1% of the total costs despite having a district heating share of up to 34% in the Czech Republic. The socio-economic costs per capita for each country are presented in Figure 23 below. Although the composition of the socio-economic costs is rather similar, the overall costs per capita are significantly higher in Italy, Czech Republic and UK than in Romania and Croatia.

When comparing the socio-economic costs per capita, Romania comes out as the country with the lowest costs around 2000 EUR/capita/year while Italy, UK and Czech Republic all have annual costs of 3500-4500 EUR/capita/year. The explanation for this difference is twofold; the first reason is that Romania consumes less energy per capita (see the description of the primary energy supply) compared to most of the other countries and the other reason is that inhabitants in Romania own fewer transport vehicles in average than inhabitants in the other STRATEGO countries. The number of average vehicles (including motor cycles, cars, light vehicles, trucks and busses) in Romania is 0.29 per capita while it is 0.47 in Croatia, 0.59 in UK, 0.63 in Czech Republic and it is as high as 0.94 vehicles/capita in Italy. This has a significant impact on the overall costs, since vehicle investments compose a large share of the total costs in an energy system.

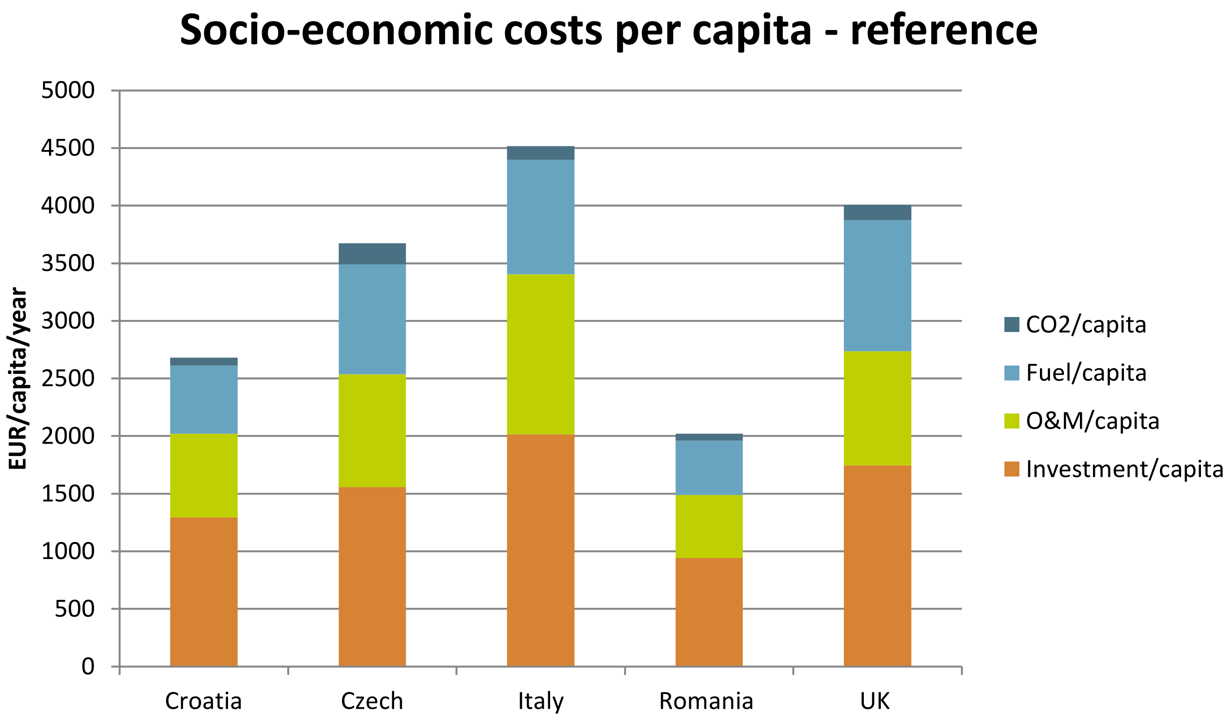


Figure 23: Socio-economic costs per capita by cost type for the STRATEGO countries

3.1.8 Comparison between the STRATEGO models and the 2010 statistics

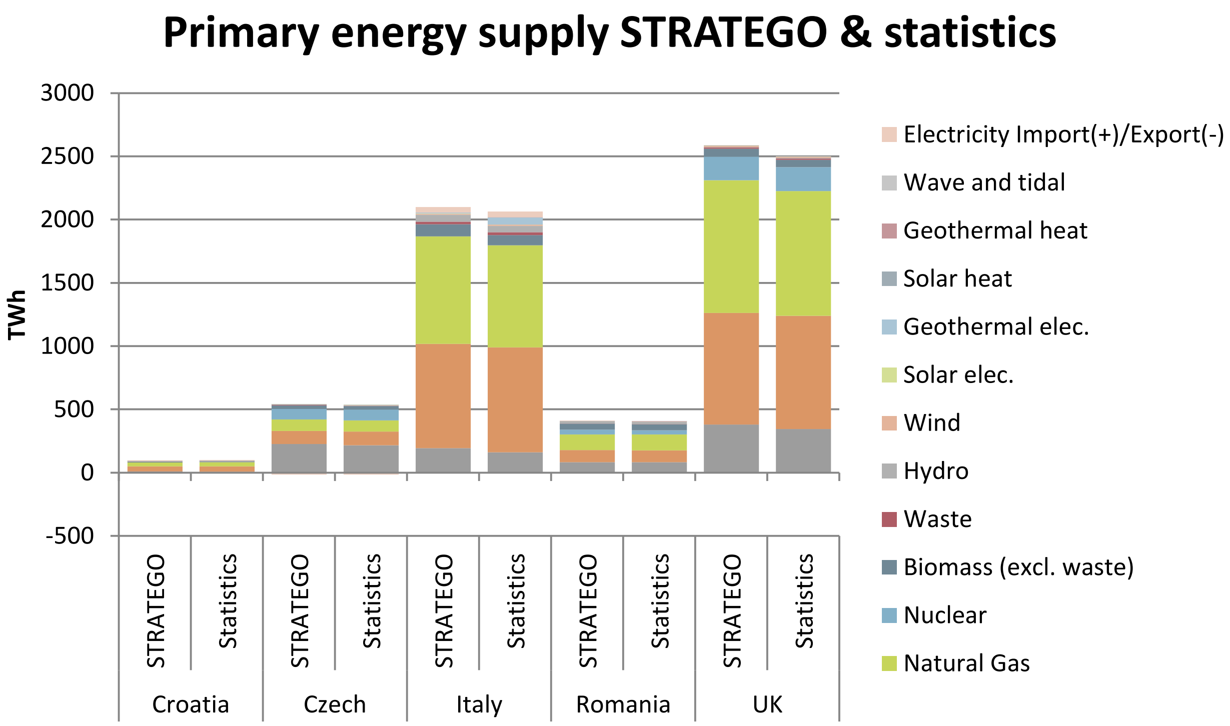


Figure 24: Primary energy supply for all STRATEGO countries based on statistical data and STRATEGO scenarios

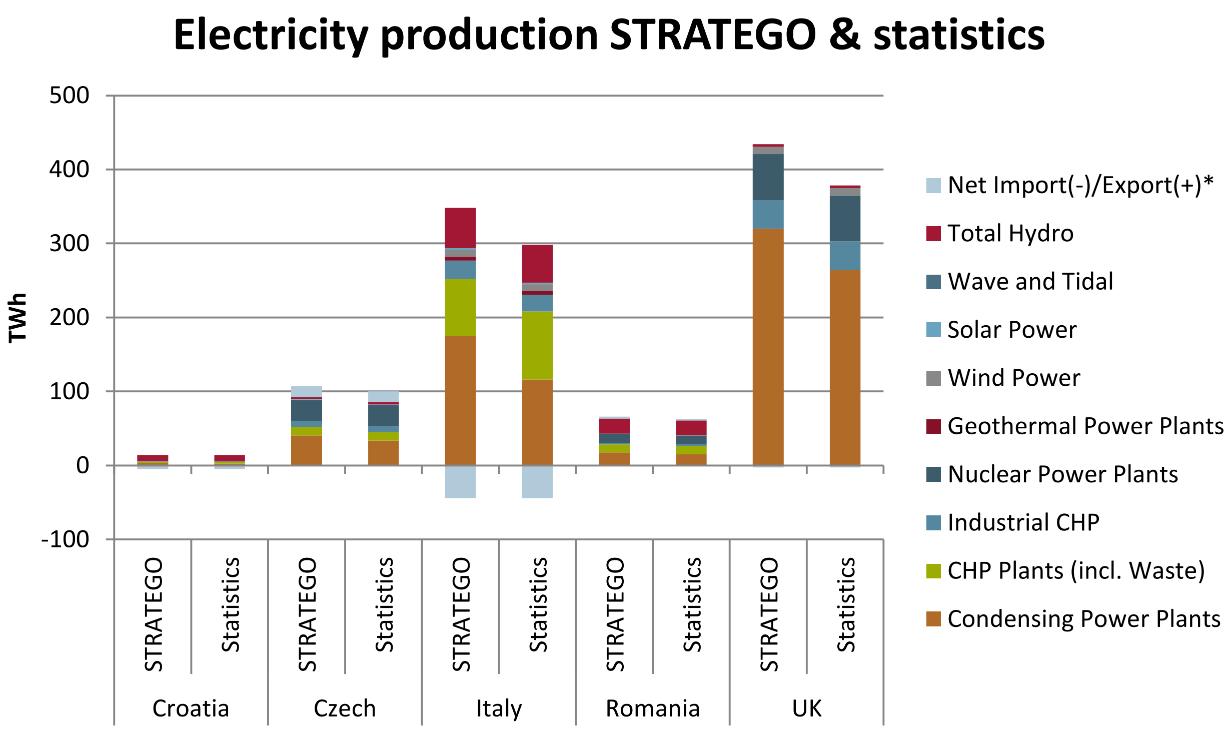


Figure 25: Electricity production for all STRATEGO countries based on statistical data and STRATEGO scenarios

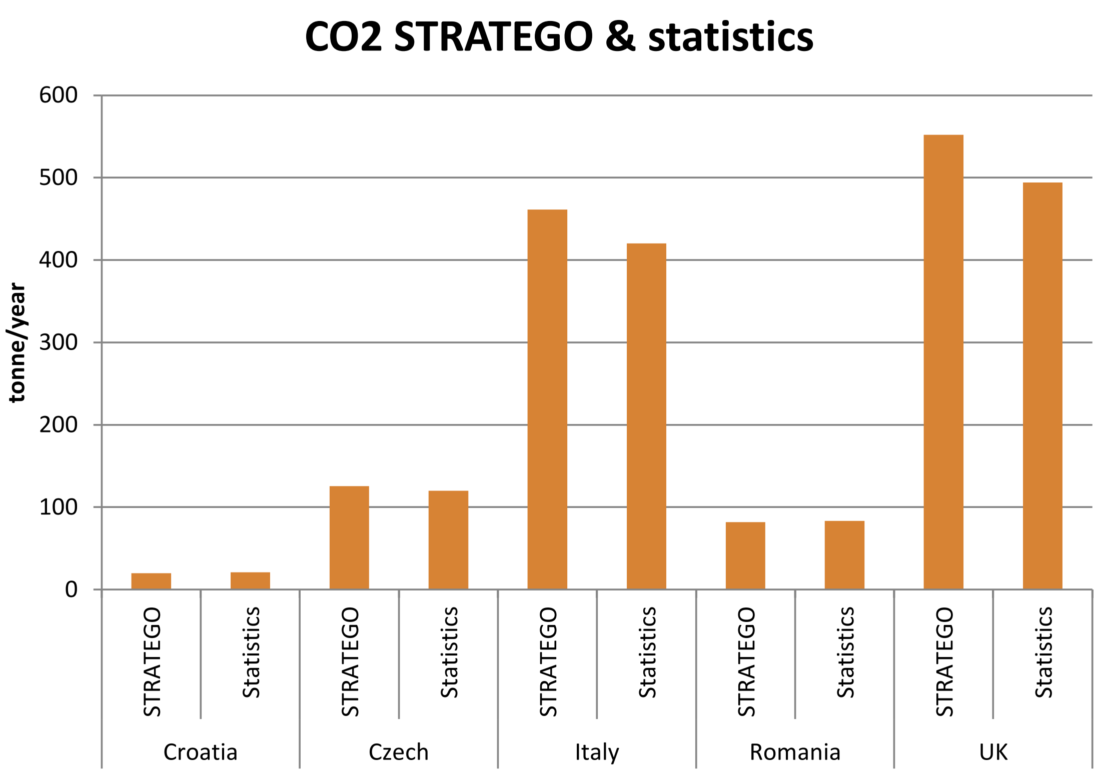


Figure 26: CO_2 emissions for STRATEGO models and statistical data for the reference models for the five STRATEGO countries

When modelling the data for generating the results a calibration phase is required to align the statistics and modelled data in order to replicate the existing energy system as best as possible, but a perfect replication is rarely possible since the model is affected by the data collected (its availability and accuracy) and the simulations performed in the modelling tool. An example of the differences between the statistics and modelled data can be seen below in Figure 24 and Figure 25 for all the STRATEGO countries: illustrating the differences between statistical data and modelled data within the areas of primary energy supply and electricity production.

The percentage differences for the reference models between statistical data and STRATEGO models can be seen for primary energy supply in the Table 22 below.

Table 22: The difference in percentage between the primary energy supply based on the statistical data and the STRATEGO models (a negative number indicates that the STRATEGO data is lower than the statistical data)

Primary energy supply differences (%)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Coal	-3%	1%	4%	1%	4%
Oil	11%	4%	18%	2%	9%
Natural Gas	-7%	-4%	-1%	2%	-1%
Nuclear	-1%	1%	5%	-1%	6%
Biomass (excl. waste)	-2%	2%	14%	1%	8%
Waste	0%	0%	0%	0%	0%
Hydro power	0%	0%	6%	2%	-1%
Wind	1%	4%	1%	1%	-2%
Solar elec.	0%	5%	5%	0%	69%*
Geothermal elec.	0%	0%	0%	0%	0%
Solar heat	-1%	0%	-11%	0%	0%
Geothermal heat	0%	0%	0%	0%	0%
Total	-3%	-3%	-1%	-1%	-1%

* The solar electricity production in UK is almost negligible (0.05 TWh/year) and hence the large differences

In the same manner are calibrations carried out for electric capacities, electricity production, heating and cooling supply and transport energy demand for all the five STRATEGO countries. The data used in the models is presented in Appendix A - Technical Data. These aspects all influence the overall primary energy supply as illustrated above. For the remainder of the report the EnergyPLAN model results will be presented unless otherwise stated.

3.1.9 Summary of the 2010 reference models

The reference energy systems for each country inform the research about the specific characteristics. Important characteristics from the reference scenario for each country are presented below.

All countries

- Fossil fuels are more than 80% of the total primary energy supply for all the countries
- Oil derived fuels dominate the transport energy demand, with very small contributions from biofuels and electric vehicles
- The largest renewable source in the five countries is hydro power, which is especially present in Croatia and Romania
- Industrial primary energy supply is sourced mostly from fossil fuels, and around 20% from electricity
- CO_2-emissions are between 4-12 t/capita/year, while the EU28-average is around 8t/capita/year
- Electricity production is dominated by thermal production in most of the countries, except for in Croatia that has a large share of hydropower
- All countries have more individual heating than district heating with the highest district heating share in buildings being 33% in Czech Republic and the lowest is 3% in UK
- Investment costs account for between 40 - 50% of socio-economic costs. Fuel costs account for 20 – 30% of the total socio-economic costs.
- Vehicle costs account for between 30-40% of the total investment and operation & maintenance costs.
- The electricity and collective district heat production technologies and grids account for between 40-60 % of the total investment and operation & maintenance costs.
- District heating pipes account for less than 1% of the total socio-economic costs

Croatia

- The renewable share of the PES in Croatia is 14%
- Croatia has the lowest total primary energy supply of all the countries. However it only has the second lowest primary energy supply per capita after Romania
- The majority of PES is sourced from oil and natural gas
- Croatia has a net import of electricity of 25% of its total consumption
- Croatia has large condensing power plant and dammed hydroelectric power capacities
- Croatia has 61% domestic renewable electricity production, excluding import
- Croatia sources heat mostly from individual gas boilers followed by oil and biomass boilers, and district heat
- Croatia has the second lowest CO_2 emissions per capita

Czech Republic

- The renewable share of PES in Czech republic is 7%
- The Czech Republic has the highest PES per capita of all the countries.
- The majority of PES is sourced from coal followed by oil, natural gas, and nuclear
- The Czech Republic has a net export of 15% of its produced electricity
- The Czech Republic has a high condensing power plant and nuclear capacity
- The Czech Republic has 4% domestic renewable electricity production
- The Czech Republic source heat mostly from individual gas boilers followed by district heating
- The Czech Republic has the highest CO_2 emissions per capita

Italy

- The renewable share of PES in Italy is 11%
- Italy has the second highest PES of all the countries, and third highest PES per capita
- The majority of PES is sourced from oil and natural gas
- Italy has a net import of 13% of its electricity consumption
- Italy has a high condensing power plant capacity,
- Italy has 23% domestic renewable electricity production
- Italy sources heat mostly from individual gas boilers with smaller shares from oil and biomass boilers and district heating
- Italy has a comparatively large cooling demand than the other countries

Romania

- The renewable share of PES in Romania is 17%
- Romania has the lowest PES per capita of all the countries
- Romania has a net export of 4% of its electricity production
- Romania has the highest amount of biomass PES of all the countries but the majority of PES is from coal, oil, and natural gas,
- Romania has 34% domestic renewable electricity production
- Romania sources heat mostly from biomass boilers, followed by gas boilers and district heating
- Romania has the lowest CO_2 emissions per capita

United Kingdom

- The renewable share of PES in the United Kingdom is 4%
- The United Kingdom has the highest PES of all the countries and the second highest PES per capita
- The United Kingdom has a net import of 1% of its electricity consumption
- The majority of PES is sourced from oil and natural gas,
- The United Kingdom has 4% domestic renewable electricity production
- The United Kingdom source heat mostly from natural gas boilers with minimal district heating
- The United Kingdom has the largest aviation fuel consumption, mostly from international aviation
- The United Kingdom has the second highest CO_2 emissions per capita

3.2 2050 Business-as-usual models

The results from the BAU models are described below in the same structure as for the reference models.

3.2.1 Population

Population forecasts according to [38]were applied to calculate the energy productions or demands per capita in 2050 in the BAU systems. The forecasts and differences compared to the reference data are shown in Table 23.

Table 23: Population for each country in 2010 (ref) and 2050 (BAU)

Population (million)	Croatia		Czech Republic		Italy		Romania		UK	
	Ref	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Total	4.30	3.83	10.46	11.07	59.19	67.06	20.30	17.97	62.51	77.18
% change		-11%		6%		13%		-11%		23%

The population in Croatia and Romania decreases by around 11%, while the other countries experience increases, especially in the UK where the population growth between 2010 and 2050 is expected to be 23%.

3.2.2 Primary energy supply

The primary energy supply for the BAU 2050 energy system scenario was calculated and the results are presented here. The non-renewable and renewable primary energy supply for each country is presented in Table 24.

Table 24: **Primary energy demand of the energy system of each country in reference and BAU scenarios**

Primary energy demand	Croatia		Czech Republic		Italy		Romania		UK	
TWh	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Non-renewable	80	107	504	563	1867	1864	339	429	2497	2128
Renewable	13	20	35	38	189	265	69	93	89	216
Electricity import/export	5	0	-15	9	44	10	-2	1	3	58
Total	**98**	**127**	**503**	**610**	**2100**	**2140**	**406**	**523**	**2588**	**2518**

The results show an increase of primary energy supply for each country. Although the primary energy supply from renewable energy sources increases for all countries, the non-renewable energy also increases. Overall the energy system of each country depends heavily on non-renewable energy in the BAU scenario. This is largely for transport, individual heating for residents and services, and industry. The breakdown of primary energy supply into the different energy carriers in the BAU 2050 scenario is shown in Figure 27 below.

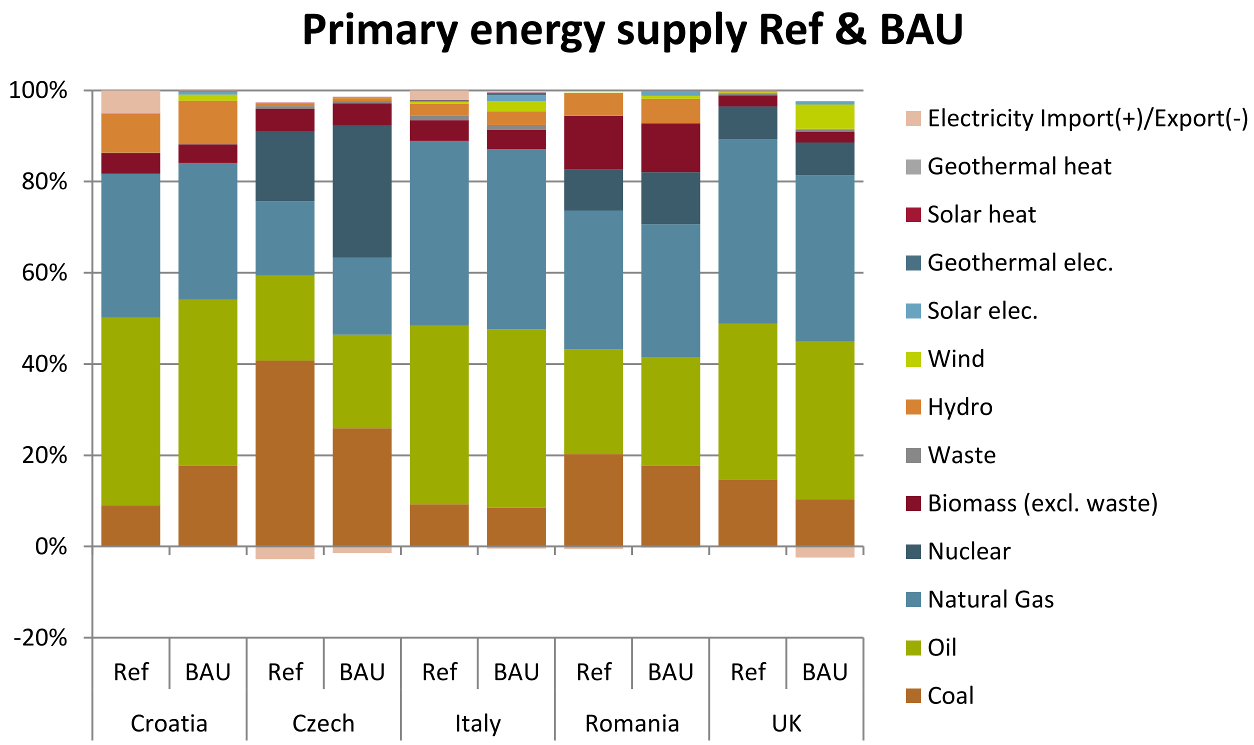


Figure 27: Mix of fuels in the primary energy supply for the 2010 reference and 2050 BAU models for each country

The results show that the majority of primary energy is from coal, oil and natural gas. Renewable energy has not penetrated the systems much in the BAU 2050 scenario. In the United Kingdom, electricity is exported since there is a lot of wind power and the system has not been altered to accommodate it. This electricity is exported as primary energy and since it leaves the system it is a negative value.

3.2.3 Electricity capacities and production

The changes in the BAU 2050 scenario are related to the electricity supply and capacities and the results are presented here. The electricity capacities are projected according to the changes in the European Commission's recent energy forecasts [36]. The electricity capacity for each STRATEGO country is illustrated in Table 25 and Figure 28.

Table 25: Electricity capacity of each country in reference and BAU scenarios

Electricity capacity	Croatia		Czech Republic		Italy		Romania		UK	
GW	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Total	4.6	8.6	20.2	25.2	107.2	165.4	20.0	27.9	93.2	160.7

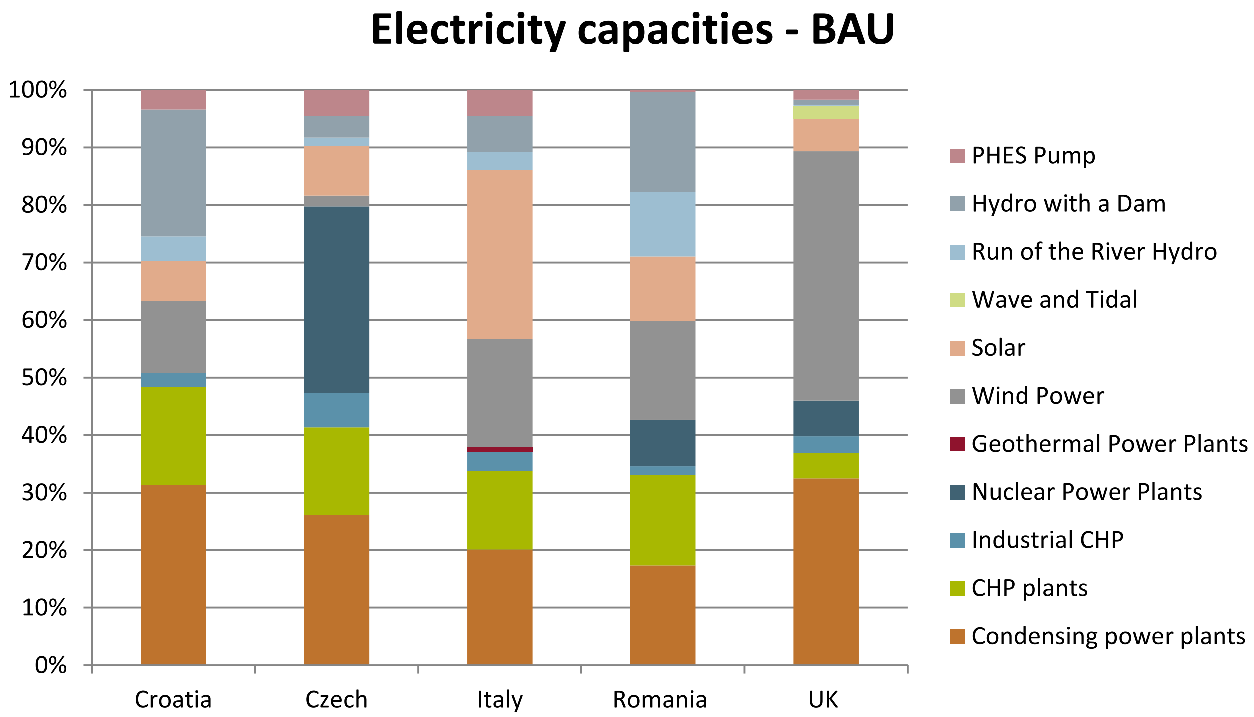


Figure 28: Electricity capacity for the 2050 Business-as-usual models

The figure shows that more renewables have been installed in all of the countries compared to the 2010 systems replacing thermal electricity power plants, except for in Croatia where both the renewable sources and the power plant capacities increase. Especially for wind and solar power large increases occur where wind capacities grow by a factor 10 in some of the countries while solar power increases even more, but from an almost non-existing capacity in 2010. In the UK the total wind capacity increases from around 5,000 MW in 2010 to almost 70,000 MW in 2050. In Italy the wind capacity is also larger in 2050 while the solar power capacity experiences the largest growth from around 6,000 MW in 2010 to around 30,000 MW in 2050. In Czech Republic the Nuclear capacity is assumed to double from 4,000 MW to around 8,000 MW with smaller increases in wind and solar capacity. Hydro power capacities increases in all countries between 10-25% compared to the 2010 capacities.

In Table 26 the results for each country for electricity production from non-renewable and renewable electricity technologies are presented for the reference and BAU models. The electricity production from different sources for each STRATEGO country is illustrated in Figure 29. The electricity production in 2050 is affected by the capacity changes, but is optimised in EnergyPLAN hour-by-hour for the full year.

Table 26: Electricity production from different technologies for each country in reference and BAU scenarios

Electricity production	Croatia		Czech		Italy		Romania		UK	
TWh	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Total thermal	5.7	11.9	60.6	32.8	277	264.7	30.6	35.2	358.6	236.8
Nuclear Power Plants	0.0	0.0	28.1	58.9	0.0	0.0	12.3	19.9	62.0	57.3
Renewable sources	8.5	14.8	3.8	5.2	71.1	151.2	20.5	36.4	13.6	161.2
Net import/export	4.8	0.0	-14.9	-8.9	44.2	10.2	-2.3	-1.1	2.7	-57.5
Total electricity production	**14.1**	**26.7**	**92.4**	**97**	**348.1**	**415.9**	**63.4**	**91.4**	**434.3**	**455.3**

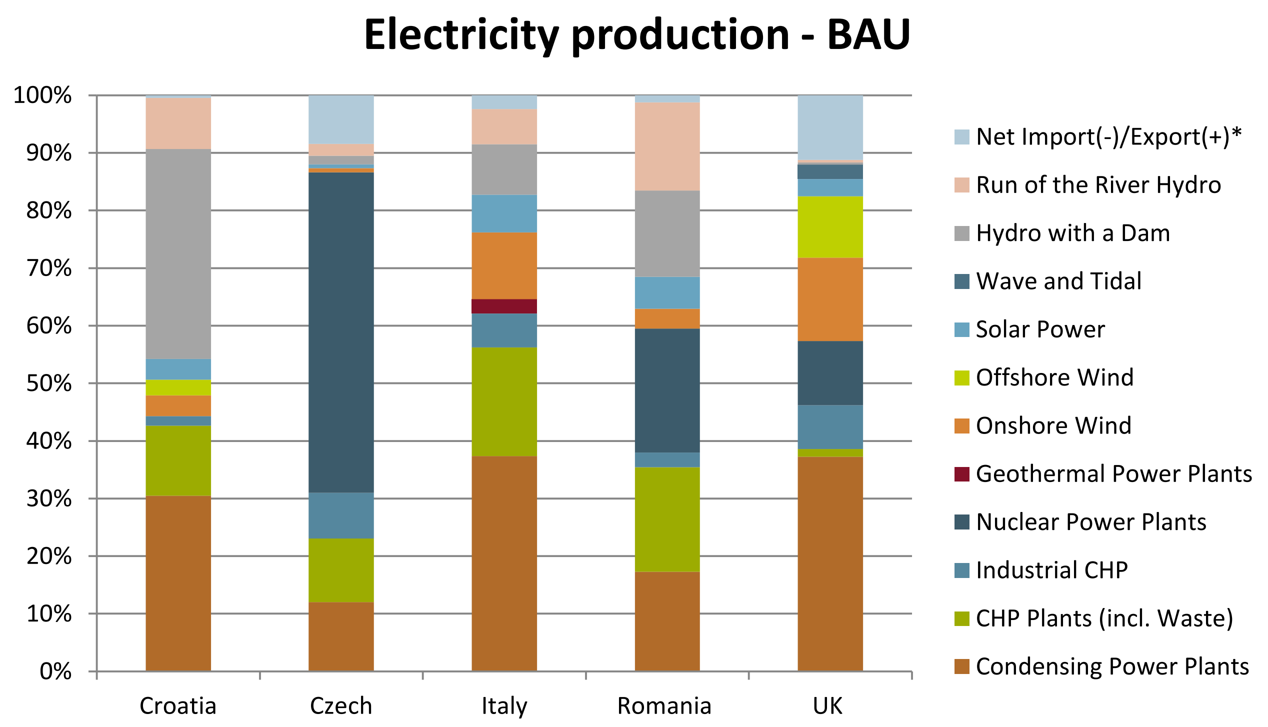


Figure 29: Electricity production in 2050 business-as-usual for the STRATEGO countries

The results show an increase in domestic electricity production for all countries. The largest changes occur in Croatia where the total electricity production is increased from 14 TWh to 27 TWh due to a reduced import of electricity and a growing electricity demand. In Czech Republic the nuclear production is increased significantly while the export of electricity is lower than in 2010. Smaller changes also occur in Italy and Romania while the largest change in the UK is related to the wind power production that increases from around 10 TWh in 2010 to almost 130 TWh in 2050 with 75 TWh of this being onshore wind power.

In the UK there is an increase in surplus electricity that would need to be exported or would be curtailed through wind for example. It is due to a large increase in wind capacity without adjusting the rest of the energy system to accommodate it, for example by implementing a Smart Energy System approach [39]. During the year the wind production exceeds the electricity demand on numerous occasions. An example of this is shown in Figure 30 for the first 400 hours of 2050 for the UK. This emphasises the importance of long-term strategic energy planning in the future, so that the entire energy system can work together to ensure that changes are made to account for variations in renewable energy output.

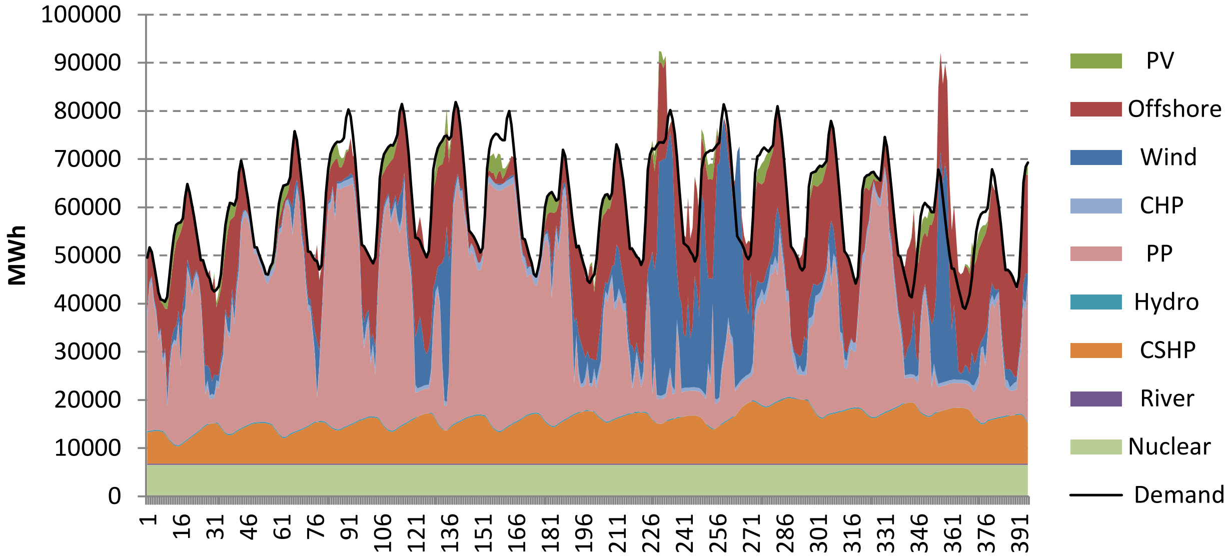


Figure 30: Hourly electricity production by plant type and the total electricity demand for the first 400 hours of the 2050 BAU model of the UK

3.2.4 Heating and cooling production

The heating and cooling sectors also changes compared to the 2010 reference models based on the changing demands. The total heating production in the reference and BAU scenarios can be seen in Table 27 and the technology shares in Figure 31. The changes are however smaller than in the electricity sector, but in general the heating production increases due to more district heating and rather constant production in individual production technologies. The total heat production actually decreases in the UK, but only by a small margin. The cooling production for the STRATEGO countries undertake smaller changes, but are almost similar to the production in the 2010 models, see Figure 32.

Table 27: Total heat production for the reference and BAU scenarios for each country

Heat production (TWh)	Croatia		Czech Republic		Italy		Romania		United Kingdom	
	Ref	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Total	22	25	112	117	498	493	113	133	574	551

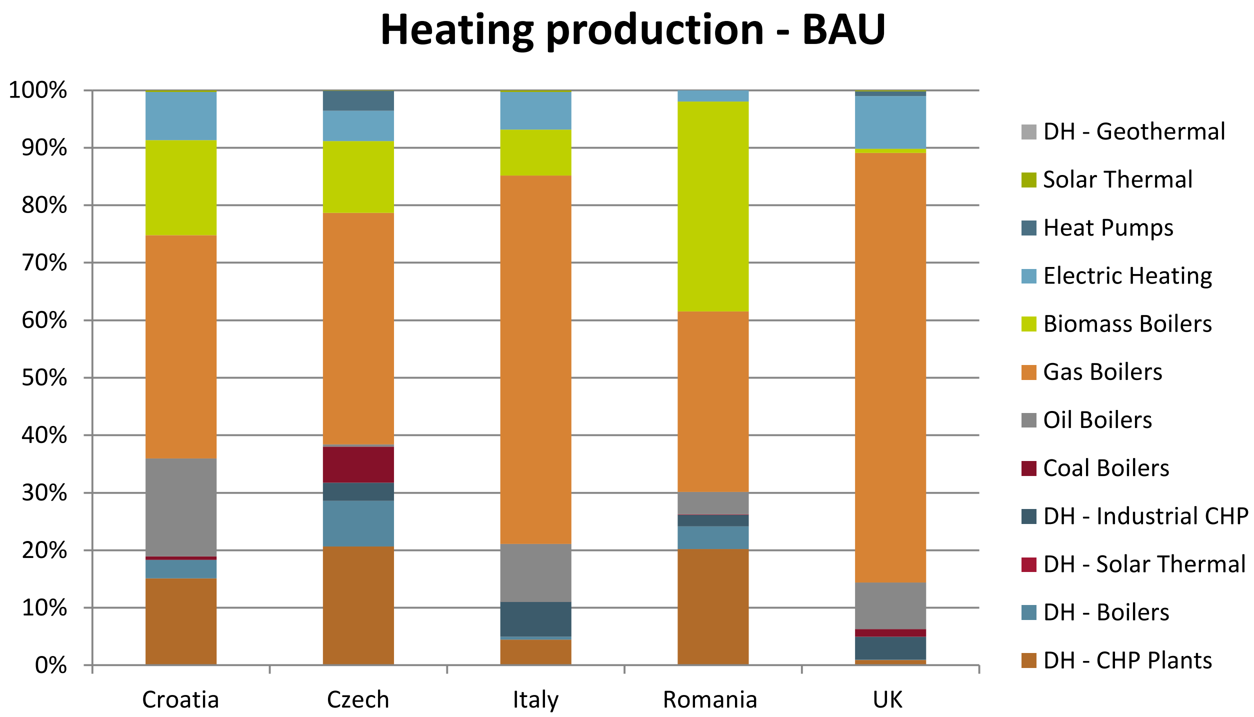


Figure 31: The heating production in the 2050 business-as-usual scenarios

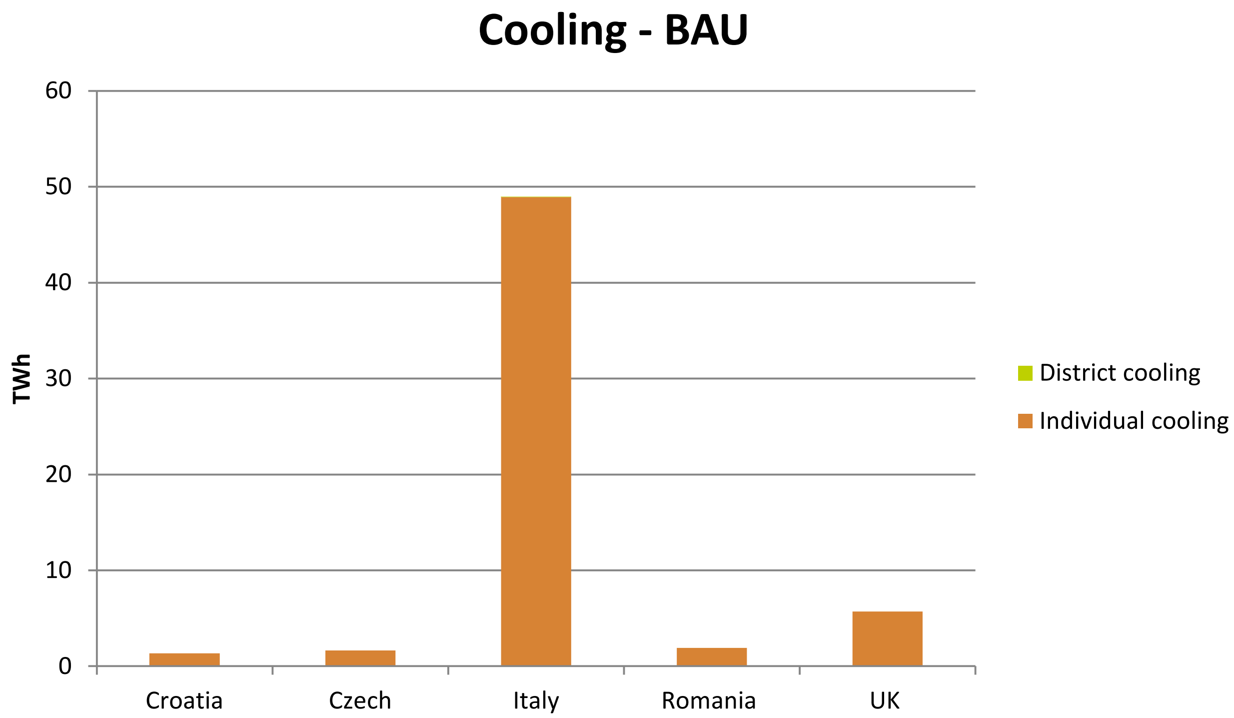


Figure 32: Cooling production in the STRATEGO countries in the business-as-usual models

3.2.5 Transport energy demand

When calculating the BAU transport changes, only the absolute transport energy demand is changed and the change is equally the same for each transport energy source. Therefore the proportion of energy sources for transport is the same as for the reference and therefore this is snot shown here. The change in total transport energy demand is shown in Table 28.

Table 28: Total transport energy demand for the reference and BAU scenarios for each country

Transport energy demand	**Croatia**		**Czech Republic**		**Italy**		**Romania**		**United Kingdom**	
TWh	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Total	24	26	73	85	531	534	58	80	640	608

Only the United Kingdom decreases in transport energy demand in the BAU scenario, and all the other countries increase in energy demand, with Romania increasing the most by 39%.

Since the population of each country changes in the BAU scenario the energy consumption per capita changes. And this is shown in Figure 33.

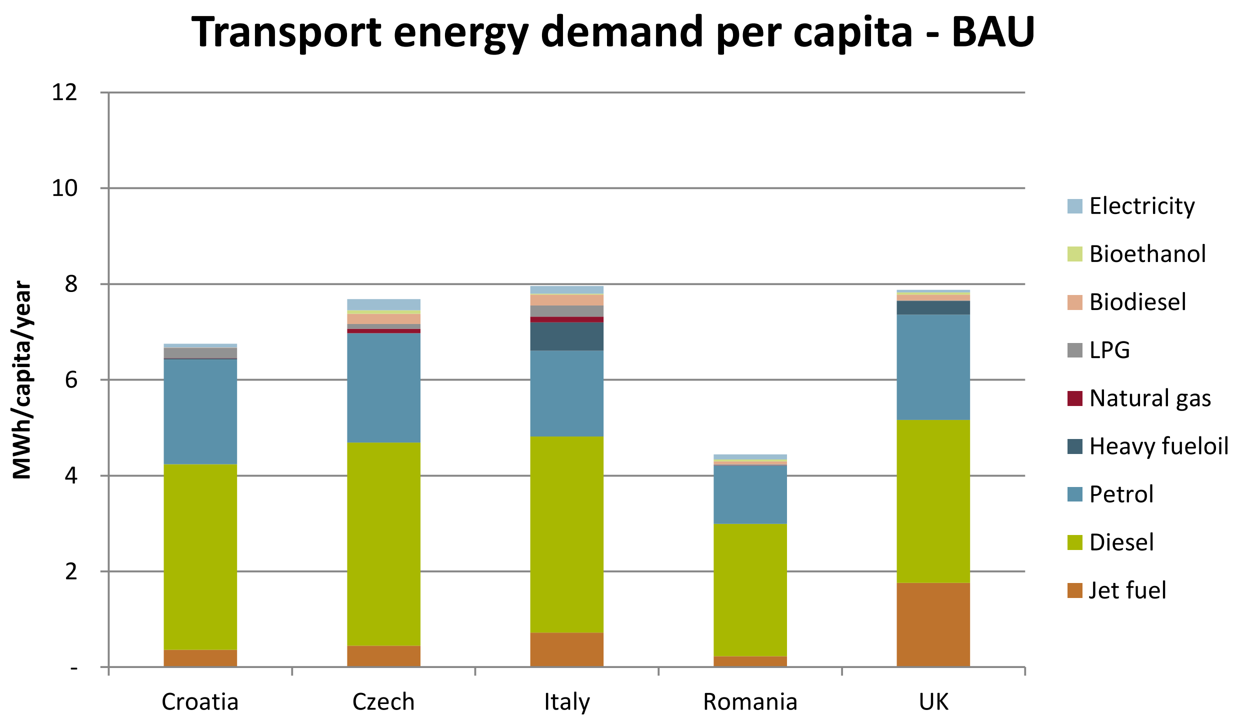


Figure 33: Transport energy demand per capita in the business-as-usual scenarios

The transport energy demand increases for most of the countries, except for the UK where the energy demand for transport decreases by 5%. At the same time the demand increases by up to 39% in Romania which makes the transport energy demand per capita more evened out in the 2050 BAU compared to the 2010 references. The energy demand per capita is between 6-8 MWh/capita/year for most countries while Romania‘s energy demand per capita is just above 4 TWh/capita/year.

3.2.6 Industry energy demand

When calculating the BAU industry changes, only the absolute industry energy demand is changed and the change is equally the same for each industry energy source. Therefore the proportion of energy sources for transport is the same as for the reference and therefore this is snot shown here. The change in total transport energy demand is shown in Table 29. The United Kingdom decreases industrial energy consumption by around 7%, whereas all the other countries increase their production by between 6% (Italy) and 31% (Czech Republic). Since the population of each country changes in the BAU scenario along with the changing demands the energy consumption per capita changes, which is shown in Figure 34.

The industrial energy demand increases slightly in Italy and by more than 30% in Croatia, Czech Republic and Romania. In the UK however the industrial energy demand decreases by 7% making it the country with the lowest energy demand in the industrial sector. The fuel shares of the total demand are unchanged compared to the 2010 fuel demands.

Table 29: Total industry energy demand for the reference and BAU scenarios for each country

Industry energy demand	Croatia		Czech Republic		Italy		Romania		United Kingdom	
TWh	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Total	33	41	156	187	675	696	138	160	673	648

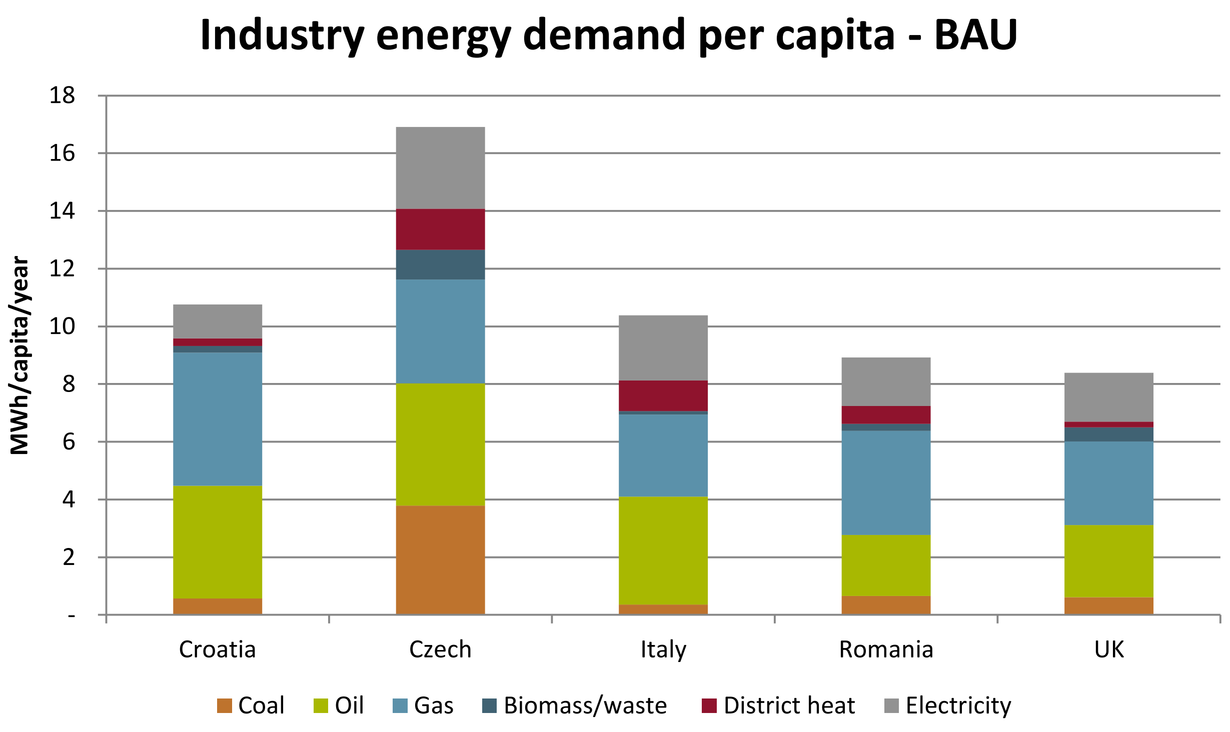


Figure 34: Industry energy demand per capita in the 2050 business-as-usual scenarios

3.2.7 CO_2 emissions

CO2 emissions from the BAU 2050 scenario are presented in Table 30 below for each country. The results show that for Croatia, Italy, and Romania, the CO_2 emissions increase in the BAU scenario. The emission reduction from increasing the renewable electricity in these countries is not enough to counter the increase in emissions from the fossil dependent power plants, and from increased emissions in transport, industry and heating. In the Czech Republic, the United Kingdom and Italy the emissions decrease; the Czech Republic decreases CO_2 emissions due to an increase of nuclear power and decrease of fossil power plants. The UK decreases emissions due to a significant increase in renewable electricity, particularly wind, and reductions in overall transport energy demand. For all countries there are still a high proportion of emissions coming from transport, individual heating from residents, and industry.

Table 30: Total CO_2 emissions from the energy system of each country

CO_2 emissions	Croatia		Czech Republic		Italy		Romania		United Kingdom	
Mt	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**	**Ref**	**BAU**
Total	20	28	126	110	461	459	82	99	522	462

The CO_2 emissions per capita are depicted in Figure 35 below.

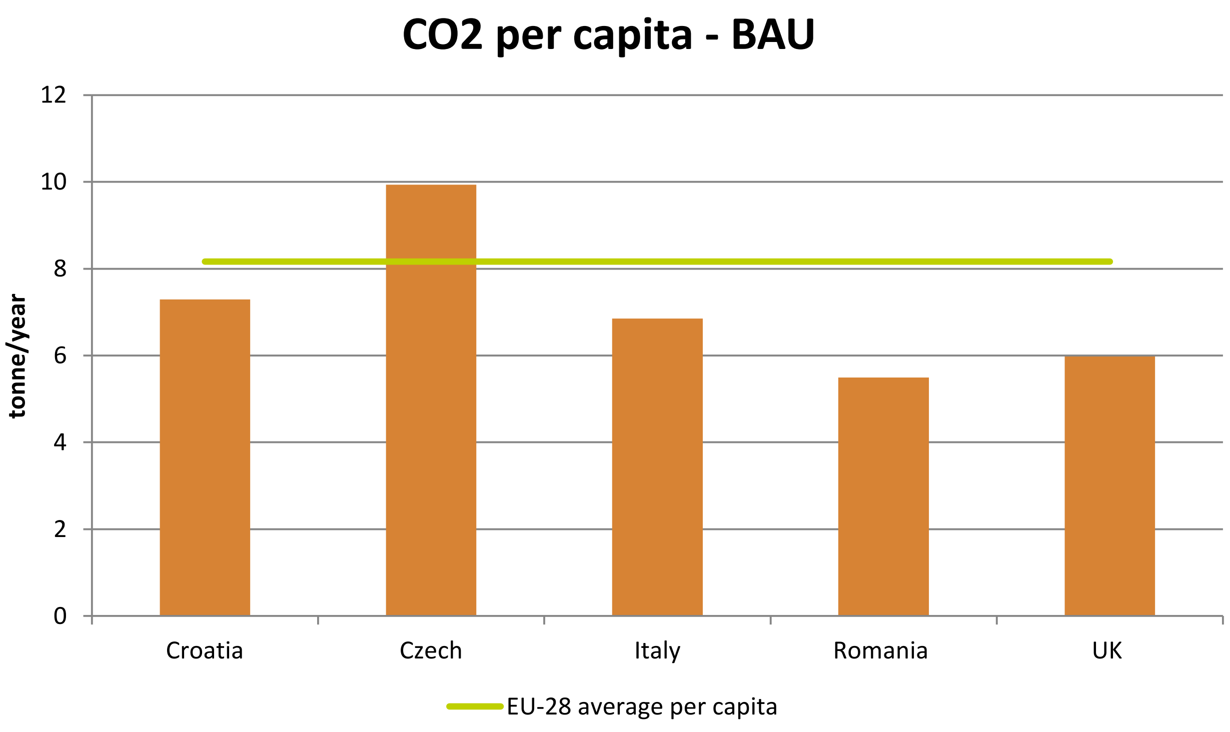


Figure 35: CO_2 emissions per capita in the 2050 business-as-usual scenarios

It shows that the CO_2 emissions per capita increases for Croatia and Romania while it decreases in the remaining three countries. The explanation is a combination of the fuel consumption in the 2050 BAUs (see 3.2.2) and the population forecasts. For both Croatia and Romania the population forecasts assume that the population will decline by 11% in 2050 compared to 2010 while the other countries will experience an increase between 6-23% [38]. This affects the CO_2 emitted per capita while also the increasing amount of renewables and the nuclear production in Czech contributes to the CO_2 reductions per capita.

3.2.8 Socio-economic cost

The socio-economic costs were quantified for the BAU 2050 system using updated 2050 prices to reflect developments in the different technologies and infrastructures (see Appendix B – EnergyPLAN Cost Database Version 3.0). The annual socio-economic cost for the reference and BAU scenarios are presented in Table 31 below. The annual cost for all countries increases. The cost is distributed between investments, fuels and O&M etc. in the same way as for the reference system. Fuels account for between 35% - 40% of the total cost, and investments account for between 30% - 40% of the cost.

Table 31: Total annual socio-economic cost of the energy system of each country

Annual cost based on 2011 prices	Croatia		Czech Republic		Italy		Romania		United Kingdom	
Billion €	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Total	11.4	16.6	39.0	54.3	264.5	331	41.1	62.1	250.3	281.1

The breakdown of socio-economic costs in the BAU scenario for each country is shown in Figure 36. As shown, the socio-economic cost shift from investment costs to higher fuel and CO_2 costs for most countries.

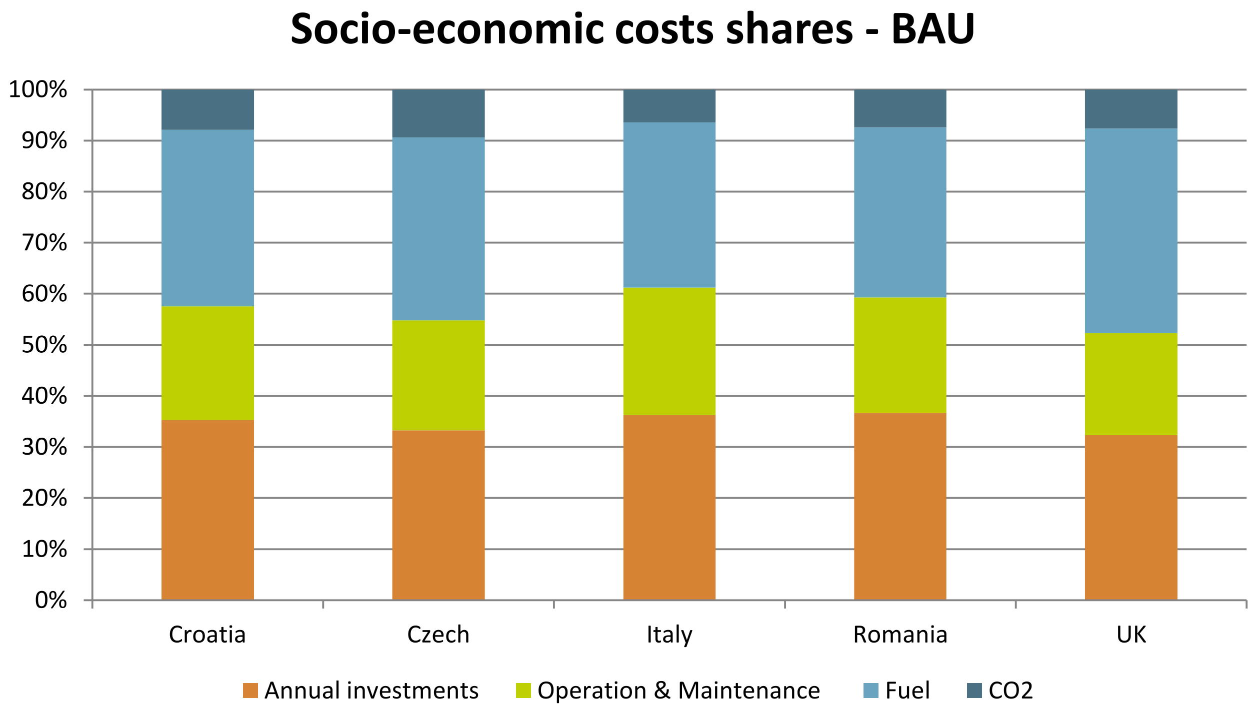


Figure 36: Breakdown of socio-economic cost for each country in the BAU scenario

The socio-economic cost per capita in the BAU scenario for each country is shown in Figure 37. As shown, the socio-economic cost per capita for each country change where the Romanian cost increases per person since the population decreases by around 11% by 2050. Whereas the socio-economic cost per person in Italy and the United Kingdom decrease and this is due to higher populations of 13% and 23%, respectively.

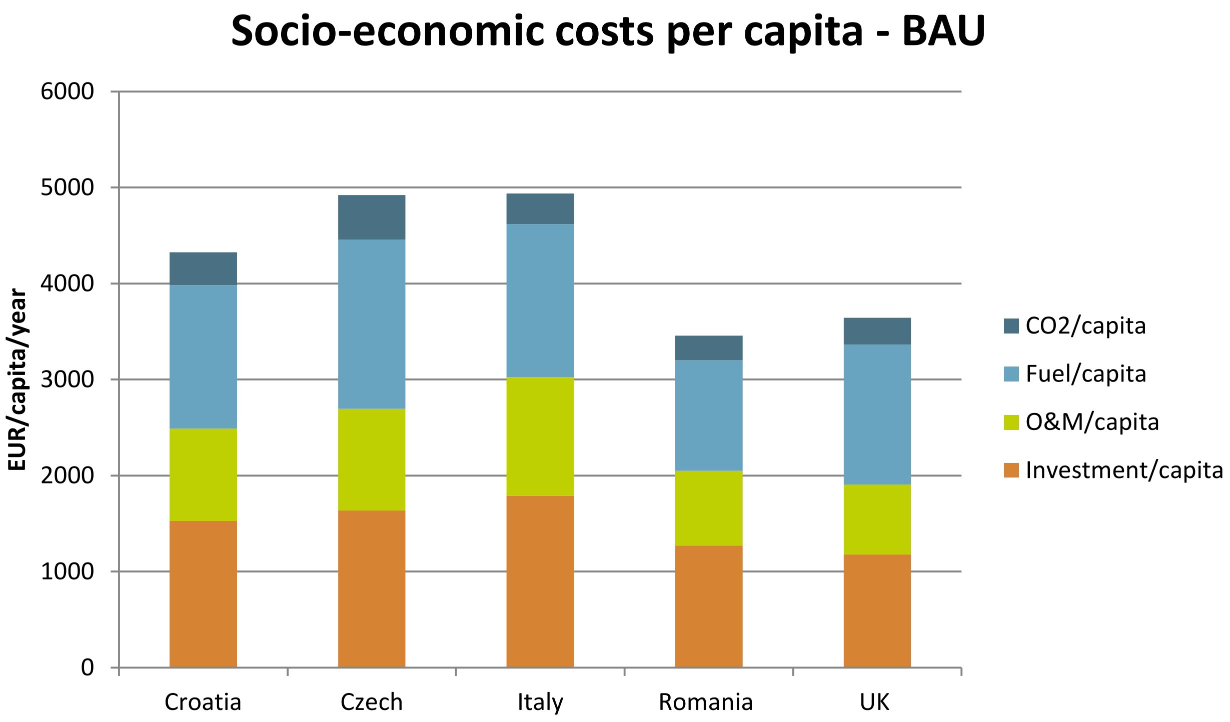


Figure 37: Socio-economic cost per capita for each country in the BAU scenario

3.2.9 Comparison between the STRATEGO models and the 2050 statistics

This section includes a comparison for the years 2010 and 2050 between the STRATEGO models in this study and the European Commission's recent energy forecasts [36]. These energy forecasts were used as the source for projecting the 2010 data in this study to 2050 for both energy demands and electricity production capacities, so a comparison is therefore relevant between the resulting 2050 energy systems.

The comparison of the total primary energy supply shows that the 2010 models are very similar, with the average difference in the region of 2%. For the 2050 models the differences are larger, especially for the UK where the EC model projects a large decrease in coal consumption. Generally, the primary energy supply is somewhat smaller in the 2050 EC models than in the 2050 STRATEGO BAU scenarios modelled here with an average difference in the region of 13%. Possible reasons for the differences can be different fuel distributions (e.g. the amount of coal consumed in thermal power plants), energy technology efficiencies and differences due to the time-steps considered: EnergyPLAN is an hour-by-hour model whereas PRIMES looks at the annual energy balance.

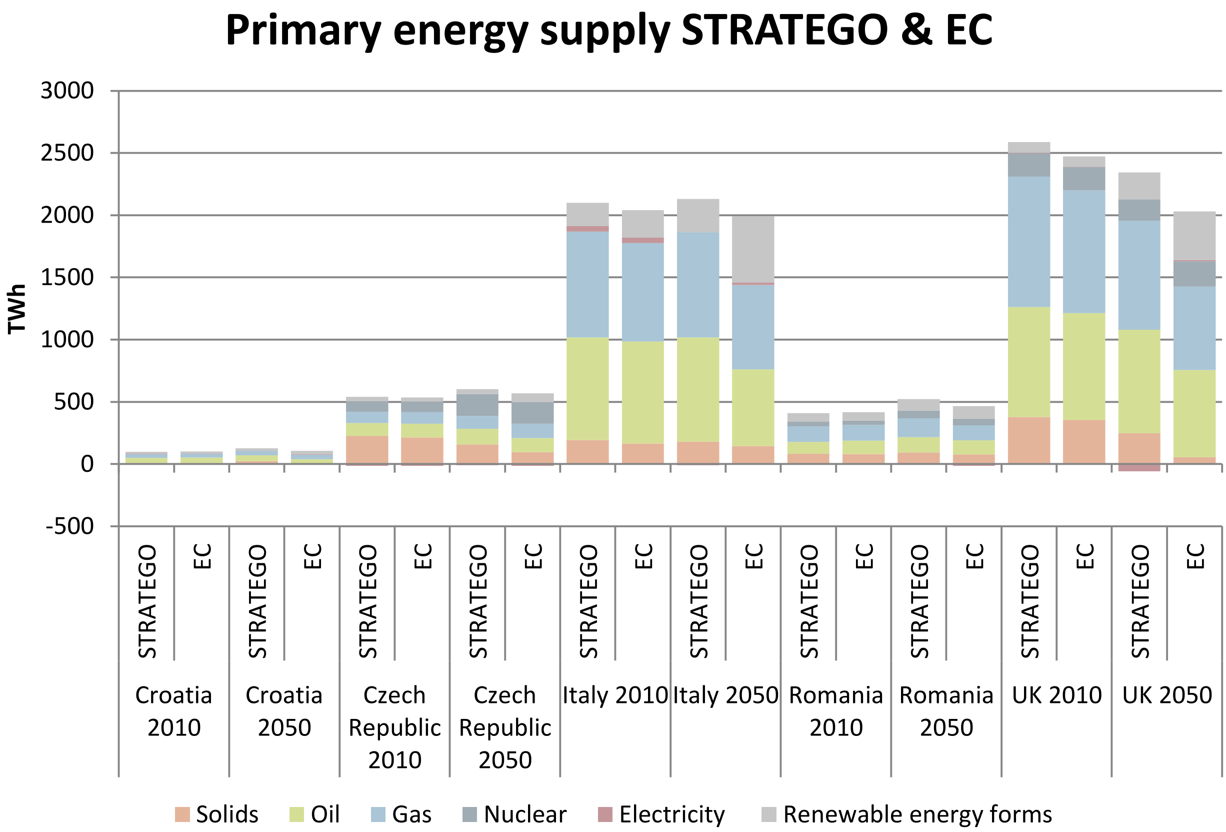


Figure 38: Primary energy for STRATEGO and EC scenarios for 2010 and 2050

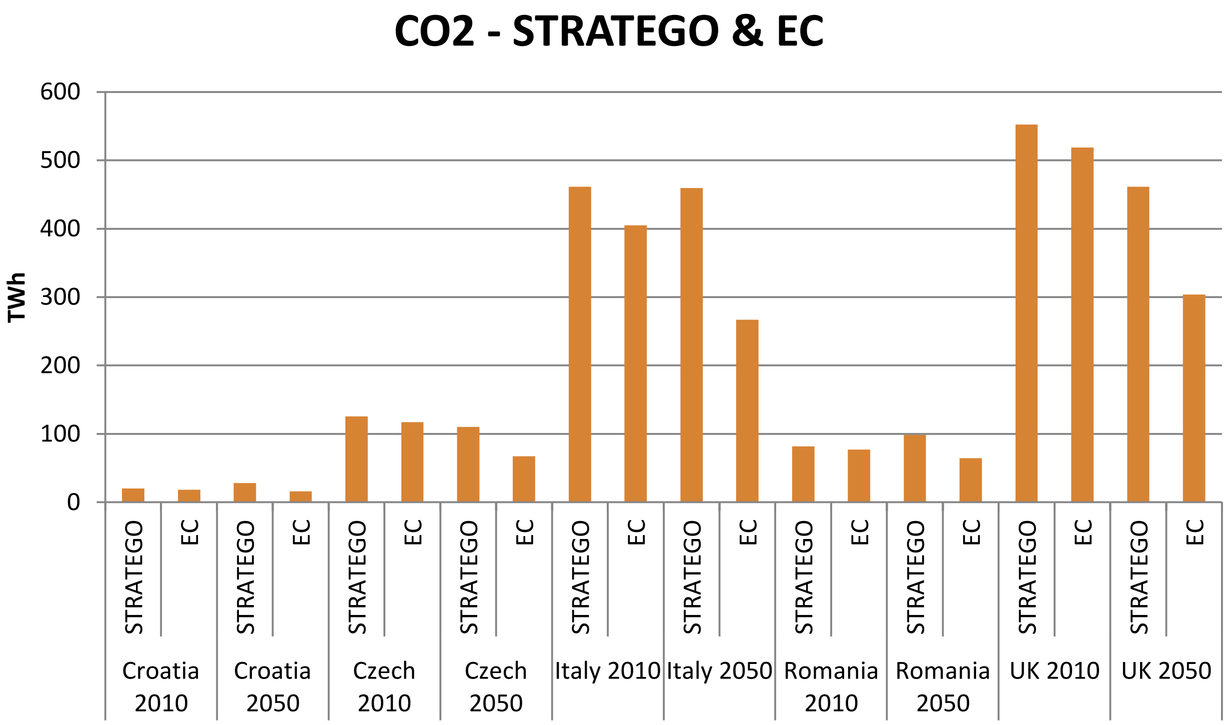


Figure 39: CO_2-emissions for STRATEGO and EC scenarios for 2010 and 2050

The differences in primary energy supply also affect the CO_2 emissions for 2050. For the scenarios in this study, the 2010 and 2050 emissions are rather similar, but there are significant reductions for EC projections, in particular for Italy and the UK. This is most likely due to the same reasons that the primary energy supply varies in both studies.

When comparing the demand side between the two types of models, STRATEGO and EC, they align to a large degree. Below in Figure 40 is the final electricity demand for each country in 2010 and 2050 illustrated showing that the STRATEGO and EC models are almost identical with the average difference being less than 0.1%.

In relation to transport (Figure 41), the differences are somewhat larger than for electricity and district heating where the overall average difference is 0.5%. The extreme high is in Italy, where fuel consumption for transport is 6% higher in the STRATEGO models than in the EC model.

The objective when forecasting energy demand and supply as far away as 2050 is not to identify exact quantities for demand and supply, but instead the main purpose is to create a context by answering questions such as:

- Is the energy demand increasing or decreasing?
- What is causing the energy demand to change? For example, this typically includes a breakdown of how the electricity, heating, cooling, industry, and transport sectors are changing.
- Is there more or less renewable energy?
- What type of power plants exist in 2050?

Based on the comparison between the STRATEGO and EC results, the key conclusions are that:

- The energy demands in STRATEGO and EC scenarios are rather similar for both 2010 and 2050
- The supply side (primary energy) is rather similar for 2010, but more than 10% different in 2050
- Differences in the supply side are most likely caused by factors such as differences in fuel distributions and technology efficiencies, which are not available in the report from the European Commission so they cannot be replicated, along with a different approach towards modelling the energy system (i.e. hour-by-hour vs. annual)
- Overall, the models produced in STRATEGO provide a sufficiently accurate context for the European energy system in 2050, based on the recent projections of the European Commission

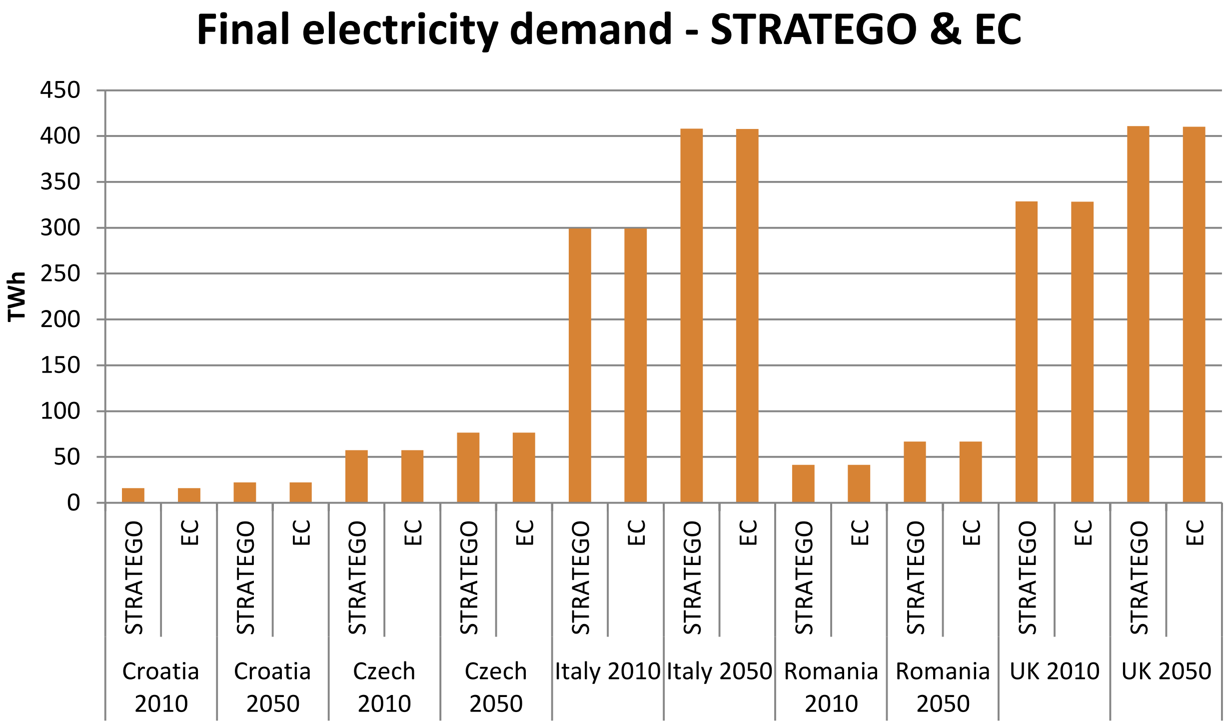


Figure 40: Final electricity demand for STRATEGO and EC scenarios for 2010 and 2050

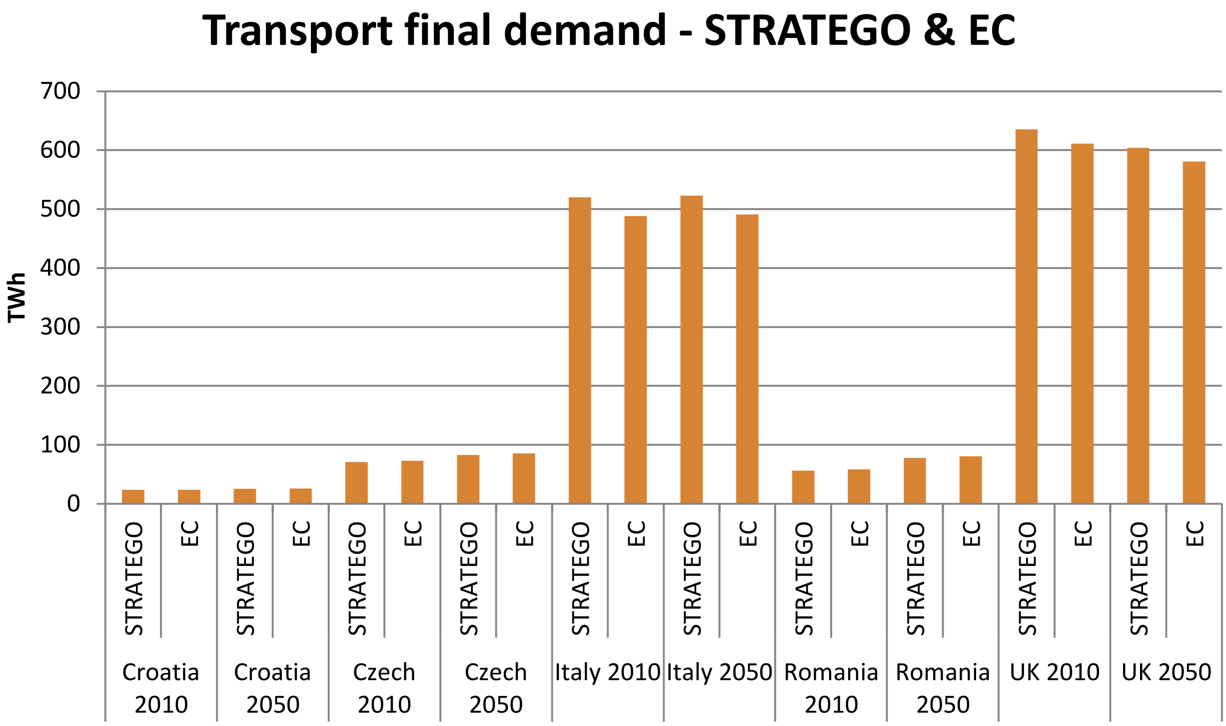


Figure 41: Fuel consumption for transport for the STRATEGO and EC scenarios for 2010 and 2050

3.2.10 Summary of the 2050 business-as-usual models

A business-as-usual (BAU) scenario is re-created here based on the current modelling carried out by the European Commission [36]. Energy demands have been updated to reflect this future scenario along with electricity production capacities. Only the electricity supply is updated since the electricity system undergoes radical change between now and 2050, primarily due to the introduction of wind and solar power. Other energy supply mixes have been kept very similar to the original design in the 2010 reference models, as the data required for 2050 was not available. New supply units are only added when it is necessary for the secure operation of the new energy system. For example, additional boiler capacity is added to the district heating system if the heat demand increases, to ensure that there is not a shortfall in heat supply.

This means that in terms of demand, the 2050 models developed here change by the same proportion as those proposed by the European Commission, but on the supply side there are minor differences since it is only the electricity system that is updated. These new 2050 BAU models will act as a starting point when analysing the new heating and cooling strategies in STRATEGO.

Also, there are some key differences between the 2010 and 2050 models developed in this study which is outlined below for all countries.

All countries

- Electricity demand increases between 25-62%
- There are less power plants in all countries except Croatia
- CHP capacities increase in all countries
- There is a large increase in fluctuating renewables such as wind and solar power
- For all countries there are still a high proportion of emissions coming from transport, individual heating for buildings, and industry

Croatia

- Demand for all fuel types increase due to increasing demands for electricity, heating, cooling and transport and industry
- The thermal power capacity almost doubles between 2010 and 2050 with large increases for both condensing power plants and CHP plants
- Carbon dioxide emissions increase in Croatia in 2050 due to the additional fossil fuel consumption
- Fluctuating renewable capacity in wind and solar power increases to a combined share of 20% of the total electricity capacity

Czech Republic

- There is less coal in the Czech Republic's electricity supply in 2050, primarily due to a growth in nuclear power which replaces some thermal plant production.
- Carbon dioxide emissions decrease in 2050, most likely due to the conversion from coal to nuclear power in the electricity sector
- Transport energy demand increases leading to a higher overall demand for oil products

Italy

- The renewable electricity production increases in the form of wind, solar and geothermal power
- Carbon dioxide stays almost constant due to the higher share of renewable sources despite the overall growing fuel demand
- Renewable electricity capacities increase to 63% of the total capacity while the overall share of renewable fuels of the total fuel consumption is only 15%

Romania

- The overall fuel demand increases primarily based on fossil fuel consumption for transportation
- More renewable sources are installed for electricity production in the form of wind and solar power
- Transport demand grows by around 40% between 2010 and 2050

United Kingdom

- There is a very large growth in wind power in the UK in 2050. The rest of the system is not altered sufficiently to support it, so there is some surplus electricity production which must be exported or curtailed.
- Carbon dioxide emissions decrease in 2050 as wind power is installed in the electricity sector replacing fossil fuel consumption at thermal plants.
- UK is the only country experiencing a decreasing transport demand while also the heating demand is reduced slightly compared to 2010

4 Conclusion

The EnergyPLAN model was able to accurately model the current 2010 and future 2050 energy systems in each of the STRATEGO countries based on statistical inputs and projections. Small deviations did appear in some of the sectors for the reference models, but these are deemed negligible in comparison to the overall energy system. For the 2050 BAU models larger differences occurred for some countries due to the methodology applied to develop these, i.e. the final demands and electricity capacities were projected while other factors such as fuel distributions at thermal plants and CO_2-emissions per energy unit remained similar to the 2010 inputs.

The 2010 and 2050 STRATEGO models provided a detailed overview of the heating and cooling sectors in each of the countries that enable further analysis and scenarios. It became clear that the heating sectors are significantly larger than the cooling sectors in terms of energy demand in all the countries.

The models demonstrate that each of the countries rely on different production technologies to meet their heating and electricity demands: for example, the UK almost solely relies on individual natural gas boilers to provide heating while a larger share of district heating is installed in the Czech Republic. It is therefore important to focus the analysis and create scenarios based on the specific country context rather than implementing common solutions across countries.

Some of the main results from the 2010 reference models are that:

- Fossil fuels represent the majority of the energy demand with a share above 80% of the primary energy supply in all of the STRATEGO countries;
- The largest renewable source is hydro power that produces a large share of the electricity demand in some of the countries;
- All the STRATEGO countries have more individual heating than district heating with the highest district heating share being 33% in Czech Republic and the lowest representing 10% in the UK
- The fuels for transportation and industry sectors are dominated by fossil fuels where oil delivers the majority of the energy demand in the transport sector and oil, gas and electricity are important in the industrial sector.
- The renewable share of electricity can be rather high for some countries, but as a share of the total primary energy renewables are still limited

For the 2050 BAU models some of the main results are that:

- Electricity demand is projected to increase significantly by between 25-62% in the STRATEGO countries
- In 2050 the fluctuating renewable sources such as wind and solar power increases and replaces condensing power plants in most of the countries while the CHP plant capacities also increase in all countries
- The EnergyPLAN model can accurately model the future 2050 situation in each of the STRATEGO countries. There are small differences on the supply side in 2050, which are

most likely caused by factors such as differences in fuel distributions and technology efficiencies, which are not available in the report from the European Commission so they cannot be replicated, along with a different approach towards modelling the energy system (i.e. hour-by-hour vs. annual). However, changes in the overall context of the energy system are captured by the model, so these smaller changes on the supply side are unlikely to have a significant impact during the next part of the analysis.

The hourly energy models from the year 2010 and 2050 will form the basis for the remaining analysis in the STRATEGO project. These will act as a starting point, so that the energy system can be combined with inputs from the other work streams in STRATEGO to create long-term heat strategies for each of Croatia, Czech Republic, Italy, Romania, and the United Kingdom (See Background Report 2).

5 References

[1] D. Connolly, H. Lund, B. V. Mathiesen, and M. Leahy, “A review of computer tools for analysing the integration of renewable energy into various energy systems,” *Appl. Energy*, vol. 87, pp. 1059–1082, 2010.

[2] D. of D. and Planning, “Smart Energy Systems,” 2015. [Online]. Available: http://www.energyplan.eu/smartenergysystems/. [Accessed: 14-Sep-2010].

[3] H. Lund, *Renewable energy systems - A smart energy systems approach to the choice and modelling of 100% renewable solutions*, Second edi. ELSEVIER, 2014, p. 362.

[4] International Energy Agency, “Energy balances of OECD countries,” 2014.

[5] E. Commission, “Eurostat - Statistics database,” 2014. [Online]. Available: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.

[6] ENTSO-E, “ENTSO-E - Statistical database,” 2014. [Online]. Available: https://www.entsoe.eu/data/data-portal/Pages/default.aspx.

[7] Enerdata, “Energy Research Services,” 2014. [Online]. Available: http://services.enerdata.net/user?destination=home_services#.

[8] Enerdata, Ademe, and European Energy Network, “ODYSSEE database on energy efficiency data & indicators,” 2014. [Online]. Available: http://odyssee.enerdata.net/nrd_web/site/.

[9] J. Garnier, L. Metzroth, M. Reece, K. Treanton, J. Elliott, B. Castellano, C. Gavay, V. Kubecek, J. Kuchta, O. L. D’Ortigue, P. Tavoularidis, N. Roubanis, and P. Loesoenen, “Energy Statistics Manual,” 2005.

[10] PE International and Ecofys, “Primary Energy Demand of Renewable Energy Carriers Part 1,” pp. 1–18, 2014.

[11] Ó. B. Howley M, Dennehy E, “Energy in Ireland 1990 - 2009,” 2010.

[12] The Climate Registry, “Climate Registry Default Emissions Factors,” pp. 1–34, 2012.

[13] B. Johnke, “Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,” 2001.

[14] Terna, “Terna - electricity production,” *Electricity production*, 2010. [Online]. Available: http://www.terna.it/LinkClick.aspx?fileticket=ZvzvQmkY2yg=&tabid=670&mid=13878.

[15] Nordpool, “Nordpool - hydro reservoir,” 2014. [Online]. Available: http://www.nordpoolspot.com/#/nordic/table.

[16] T. Beyer, “Goldisthal Pumped-Storage Plant: More than Power Production,” *Hydro Review Worldwide*, 2007. [Online]. Available: http://www.hydroworld.com/articles/print/volume-15/issue-1/articles/goldisthal-pumped-storage-plant-more-than-power-production.html.

[17] ENTSO-E, “System Adequacy Retrospect 2010 report,” 2010.

[18] ENTSO-E, “Indicative values for Net Transfer Capacities (NTC) in Continental Europe,” 2011. [Online]. Available: https://www.entsoe.eu/fileadmin/.../NTC-Values-Winter-2010-2011.pdf.

[19] Pöyry Energy Consulting, “Low Carbon Generation Options for the All-Island Market,” 2010.

[20] B. R. M.-T. Normark B, Heoelsaeter O-H, “Review by the International Expert Commission. Department of Communications, Energy, and Natural Resources (Ireland),” 2011.

[21] Entranze, “Share of single-family dwellings in total stock,” 2013. [Online]. Available: http://www.entranze.enerdata.eu/#/share-of-single-family-dwellings-in-total-stock.html.

[22] Ministry of Industry and Trade of the Czech Republic, “National Energy Efficiency Action Plan according to EED Art. 24 (2).”

[23] ENEA, “Piano d’azione italiano per l'efficienza energetica 2014,” 2014. [Online]. Available: http://www.enea.it/it.

[24] K. Lomas, T. Oreszcyn, D. Shipworth, A. Wright, and A. Summerfield, “Carbon Reduction in Buildings (CaRB) - Understanding the social and technical factors that influence energy use in UK homes,” 2006.

[25] European Union, “JRC IE Heat and Cooling market database,” 2013.

[26] Euroheat & Power, “DHC & Statistics,” 2011. [Online]. Available: http://www.euroheat.org/Italy-82.aspx.

[27] Danish Energy Agency, “Technology Data for Energy Plants: Individual Heating Plants and Energy Transport,” 2012.

[28] M. Swedblom, P. Mattsson, A. Tvärne, H. Frohm, and A. Rubenhag, “District cooling and the customers’ alternative cost,” 2014.

[29] M. Swedblom, M. Peter, T. Anders, H. Frohm, and A. Rubenhag, “District Cooling and the Customers’ Alternative Costs (RESCUE WP2),” 2014.

[30] UK Department for Transport, “Vehicle licensing statistics 2012,” 2012. [Online]. Available: https://www.gov.uk/government/statistics/vehicle-licensing-statistics-2012.

[31] International Energy Agency, "Energy Supply Security: The Emergency Response of IEA Countries - 2014 Edition," 2014.

[32] JANAF, "The JANAF system," 2014. [Online]. Available: http://www.janaf.hr/sustav-janafa/sustav-jadranskog-naftovoda.

[33] EIA, "U.S. Energy Information Administration," 2014. [Online]. Available: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=54&aid=3&cid=RO,&syid=2008&eyid=2012&unit=TBPD.

[34] Hotnews.ro, "Reactorul 2 de la Cernavoda a ajuns la capacitate maxima," 2007. [Online]. Available: http://www.hotnews.ro/stiri-arhiva-1029314-reactorul-2-cernavoda-ajuns-capacitate-maxima.htm.

[35] G. Hughes, "The Performance of Wind Farms in the United Kingdom and Denmark," 2012.

[36] P. Capros, A. De Vita, N. Tasios, D. Papadopoulos, P. Siskos, E. Apostolaki, M. Zampara, L. Paroussos, K. Fragiadakis, and N. Kouvariatakis, "E3M-Lab, IIASA-GAINS model, IIASA-GLOBIOM model, and EuroCARE, EU energy, transport and GHG emissions trends to 2050 - reference scenario 2013," 2014.

[37] EUROSTAT, "Air emissions accounts totals in NACE Rev. 2 bridging to emission inventory totals," 2014. [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

[38] EUROSTAT, "Main scenario - Population on 1st January by sex and single year age," 2015. [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=proj_13npms&lang=en.

[39] Aalborg University - Department of Development and Planning, "Smart Energy Systems," 2015. [Online]. Available: http://www.smartenergysystem.eu/.

6 Appendices

6.1 Appendix A - Technical Data

This appendix presents a compilation of the data that was produced from the reference system models.

6.1.1 2010 Reference Models

Primary energy supply

Table 1: The primary energy supply for the STRATEGO countries divided by fuel types

Primary energy supply (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Fossil fuels	**79.9**	**419.5**	**1867.3**	**302.5**	**2310.2**
Coal	8.9	225.9	194.1	83.3	379.4
Oil	40.1	103.3	822.8	94.6	883.3
Natural Gas	30.9	90.3	850.4	124.6	1047.5
Nuclear	**0.0**	**84.4**	**0.0**	**36.9**	**186.3**
Renewable sources	**13.1**	**35.1**	**188.9**	**69.1**	**88.7**
Biomass (excl. waste)	4.4	28.2	95.2	48.2	63.1
Waste	0.1	3.08	21.17	0.36	10.90
Hydro	8.3	2.8	54.4	20.2	3.5
Wind	0.1	0.35	9.23	0.31	9.96
Solar elec.	0.0	0.65	2.00	0.00	0.13
Geothermal elec.	0.0	0.0	5.4	0.0	0.0
Solar heat	0.1	0.05	1.40	0.00	1.13
Geothermal heat	0.0	0.0	0.0	0.0	0.0
Wave and tidal	0.0	0.0	0.0	0.0	0.0
Import/export electricity	4.8	-15.17	44.17	-2.15	2.66
Total	**97.8**	**523.8**	**2100.4**	**406.3**	**2587.9**

Electricity and heating demands

Table 2: Annual electricity and heating demands and district heating losses

Demands (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Electricity	**18.83**	**77.72**	**392.24**	**61.04**	**436.93**
Including electric heating	1.9	5.8	32.59	2.29	53.45
Including electric cooling	0.42	0.52	16.42	0.6	2.02
District heating for residential. services & other	2.33	19.16	2.36	15.89	5.17
District heating for industry	0.72	11.62	54.67	6.12	10.66
District heating transmission and distribution losses	0.45	5.97	0.85	5.75	0.16
Total district heating consumption	**3.05**	**30.77**	**57.03**	**22.01**	**15.82**
Total district heating production	**3.50**	**36.74**	**57.88**	**27.76**	**15.98**

Electricity capacities and production

Table 3: Electricity capacities by technologies for the STRATEGO countries

Electric capacities (MW)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Thermal plants	**2341**	**11955**	**75704**	**11638**	**71113**
Condensing power plants	1454	7767	52806	8138	66560
CHP plants	675	2688	17443	3079	0
Industrial CHP	212	1500	5455	421	4553
Nuclear Power Plants	**0**	**3900**	**0**	**1400**	**10865**
Renewable sources	**2224**	**4377**	**31547**	**6938**	**9723**
Geothermal Power Plants	0	0	728	0	0
Wind Power	89	215	5814	462	5378
Solar	0	1959	3484	2	77
Wave and Tidal	0	0	0	0	0
Run of the River Hydro	300	297	4633	2500	255
Hydro with a Dam	1542	759	9344	3882	1269
PHES Pump	293	1147	7544	92	2744
Total	**4565**	**20232**	**107251**	**19976**	**91701**

Table 4: Electricity production divided by technologies

Electricity production (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Total thermal	**5.68**	**60.57**	**276.97**	**30.60**	**358.61**
Condensing power plants	2.85	40.59	174.84	17.58	319.88
CHP plants (incl. Waste)	2.38	11.55	76.96	10.64	0.00
Industrial	0.45	8.43	25.17	2.38	38.73
Nuclear Power Plants	**0.00**	**28.09**	**0.00**	**12.30**	**62.03**
Renewable sources	**8.46**	**3.79**	**71.10**	**20.53**	**13.63**
Geothermal Power Plants	0.00	0.00	5.44	0.00	0.00
Wind Power	0.14	0.35	9.23	0.31	9.96
Onshore	0.14	0.35	9.23	0.31	5.74
Offshore	0	0	0	0	4.22
Solar	0.00	0.65	2.00	0.00	0.13
Wave and Tidal	0.00	0.00	0.00	0.00	0.00
Total hydro	8.32	2.79	54.43	20.22	3.54
Hydro with a Dam	6.40	1.04	30.72	8.88	1.58
Run of the River Hydro	1.92	1.75	23.71	11.34	1.96
PHES Pump	0.00	0.00	0.00	0.00	0.00
Net import*	4.70	-14.73	44.17	-2.39	2.66
Total. excl import/export	**14.14**	**92.45**	**348.07**	**63.43**	**434.27**

* A negative number indicates export while a positive is import

Heating and cooling supply

Table 5: Heating and cooling supply by technologies

Heating supply (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
District Heating Supply	**3.63**	**36.52**	**56.95**	**27.53**	**17.45**
DH - CHP Plants	2.38	23.85	21.12	20.42	0.00
DH - Geothermal	0.00	0.00	0.00	0.00	0.00
DH - Boilers	1.25	8.78	4.02	4.39	1.63
DH - Solar Thermal	0.00	0.00	0.00	0.00	0.00
DH - Industrial CHP	0.00	3.67	30.53	2.72	15.82
DH - Waste	0.00	0.22	1.28	0.00	0.00
DH - Industrial Excess	0.00	0.00	0.00	0.00	0.00
DH - Heat Pumps	0.00	0.00	0.00	0.00	0.00
Individual Heating	**18.39**	**75.35**	**441.12**	**85.88**	**556.50**
Coal Boilers	0.13	6.92	0.04	0.12	7.91
Oil Boilers	3.84	0.45	49.92	4.51	47.41
Gas Boilers	8.74	44.43	317.54	36.52	437.45
Biomass Boilers	3.72	13.79	39.63	42.44	4.31
Heat Pumps	0.00	3.91	0.00	0.00	4.84
Electric Heating	1.9	5.8	32.59	2.29	53.45
Solar Thermal	0.06	0.05	1.40	0.00	1.13
Total Heat Production	**22.02**	**111.87**	**498.07**	**113.41**	**573.95**
		Cooling supply (TWh)			
Individual cooling	1.26	1.56	49.26	1.8	6.06
District cooling	0.00	0.00	0.04	0.0	0.00
Total cooling	**1.26**	**1.56**	**49.30**	**1.8**	**6.06**

Transport energy demand

Table 6: Transport energy demand divided by fossil fuels, biofuels and electricity

Transport (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Fossil fuels	**23.75**	**67.89**	**503.57**	**54.93**	**621.88**
Jet fuel	1.29	4.25	48.07	2.95	142.90
Diesel	13.80	40.20	272.88	35.87	276.14
Petrol	7.79	21.61	119.51	15.72	178.42
Heavy fueloil	0.09	0.00	39.51	0.05	23.06
Natural gas	0.02	0.86	8.08	0.12	0.00
LPG	0.75	0.97	15.51	0.22	1.35
Biofuels	**0.03**	**2.69**	**16.51**	**1.34**	**13.65**
Biodiesel	0.03	2.01	15.09	0.80	9.54
Bioethanol	0.00	0.68	1.42	0.54	4.11
Electricity	**0.27**	**2.20**	**10.67**	**1.36**	**4.08**
Total	**24.04**	**72.78**	**530.74**	**57.63**	**639.60**

Vehicle stocks and types

Table 7: Stock of vehicles by motorcycles, light vehicles, trucks and busses

Vehicle type	Fuel type	Croatia	Czech Republic	Italy	Romania	United Kingdom
Motorcycles	Petrol	160,000	920,000	9,570,000	90,000	1,230,000
Light vehicles (cars, 3t	Petrol	945,400	3,386,100	20,716,600	2,609,800	20,253,100
	Diesel	649,400	1,618,000	17,234,600	2,261,500	11,225,300
	LPG	47,100	4,600	2,412,800	25,900	51,400

payload vehicle)	Electric	200	0	8,800	0	12,260
Trucks	Diesel	36,400	85,700	1,124,900	93,400	470,100
Busses	Petrol	0	2,000	600	0	600
	Diesel	4,800	17,300	94,800	40,900	109,700
TOTAL		**1,843,300**	**6,033,700**	**51,163,100**	**5,121,500**	**33,352,460**

Industrial energy demand

Table 8: Industrial energy demand broken down by fuels for industrial products, own use, sold heat and electricity, and non-energy use

Industry (TWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Industrial products	**16**	**95**	**369**	**78**	**300**
Coal	2	23	21	8	23
Oil	4	5	40	8	55
Gas	6	27	120	32	103
Biomass/waste	1	6	5	3	4
District heat	1	11	55	6	11
Electricity	4	23	128	20	105
Industrial own use	**9**	**21**	**111**	**37**	**155**
Coal	0	4	0	1	8
Oil	5	3	62	14	58
Gas	2	1	8	10	62
Biomass/waste	0	0	0	0	0
District heat	0	5	18	3	1
Electricity	1	9	23	10	26
Industrial sold heat & electricity	**1**	**8**	**84**	**5**	**124**
Coal	0	2	0	1	20
Oil	0	0	33	1	7
Gas	1	2	48	3	64
Biomass/waste	0	3	3	0	33
Non-energy use	**7**	**32**	**111**	**18**	**95**
Coal	0	3	2	0	0
Oil	2	28	103	9	88
Gas	5	1	7	9	7
Biomass/waste	0	0	0	0	0
Total	**33**	**156**	**675**	**138**	**673**
Coal	2	33	23	10	50
Oil	12	36	238	31	207
Gas	14	31	182	54	236
Biomass/waste	1	10	8	4	37
District heat	1	16	73	9	12
Electricity	4	31	151	30	130

Socio-economic costs

Table 9: Annual socio-economic costs by cost type

Socio-economic costs (Billion EUR/year)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Annual investments	5.56	16.30	119.23	19.10	109.19
Operation & Maintenance	3.12	10.21	82.3	11.08	61.87
Fuel	2.53	9.99	58.77	9.58	70.98
CO2	0.30	1.91	7.00	1.24	8.39
Electricity Trading	-0.18	0.60	-2.80	0.08	-0.11
Total	**11.35**	**39.03**	**264.51**	**41.10**	**250.3**

Electricity and heating efficiencies

Table 11. Efficiencies for heating and electricity units

Efficiencies (%)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Collective units					
Condensing power plants	38	35	44	33	46
CHP – electricity	35	19	43	25	10
CHP - thermal	35	40	12	48	0
Waste incineration - electricity	0	8	23	0	0
Waste incineration - thermal	0	85	7	0	0
District heating boilers	76	86	66	64	0
Heat pumps	300				
Nuclear power plants	33				
Geothermal power plants	10				
Other Renewable sources	100				
Individual units					
Coal boiler	65				
Oil boiler	80				
Gas boiler	85				
Biomass boiler	65				
Heat Pump Electricity	300				
Direct Electricity	100				
Solar	100				

Electricity, heat and fuel losses

Table 12: Electricity, heating and fuel losses for the different STRATEGO countries

Losses (%)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Coal	0.01	0.28	0	0.33	0.55
Oil	0	0	0	0.14	0
Gas	1.8	1.7	0.7	3.1	1.7
Waste	0	0	0	0	0
Biomass	0	0	0	0	0
Electricity	11	6	6	12	7
District heating	12	15	0	19	0

Hydropower capacities and production

Table 13: The hydropower capacities and capacity factors for the different STRATEGO countries

	Run-of-river		Dam (excl. pumped hydro)		Pumped hydro	
Country	**Capacity (MW)**	**Capacity factor**	**Capacity (MW)**	**Capacity factor**	**Capacity (MW)**	**Capacity factor**
Croatia	300	74%	1542	47%	293	5%
Czech Republic	297	67%	759	16%	1147	8%
Italy	4633	50%	9344	38%	7544	7%
Romania	2500	51%	3882	27%	92	33%
United Kingdom	255	90%	1269	14%	2744	13%

Table 14: Hydropower production by type and sources for data

	Hydropower type & production (TWh)			Pumped hydro storage			
Country	**TOTAL**	**Dam**	**Run-of-river**	**Production (TWh)**	**Electricity loss (TWh)**	**Efficiency**	**Source & notes**
Czech	**2.8**	1.0	1.8	0.8	**-0.2**	80%	Total is from IEA and dam & run-of-river is from ENTSO-E
Italy	**51.1**	30.7	20.4	4.5	**-1.2**	79%	Total is from IEA and dam and run-of-river (40%) is from Terna (Italian electricity transmission grid operator)
United Kingdom	**3.6**	1.6	2	3	**-1.1**	73%	Total hydro is from IEA and dam is calculated from run-of-river (ENTSO-E) and IEA total
Croatia	**8.3**	6.4	1.9	0.14	**-0.05**	75%	Total is from IEA and dam & run-of-river is from ENTSO-E
Romania	**20**	9	11	0.3	**0**	unknown	Total is from IEA and dam & run-of-river is from ENTSO-E

Thermal storage

Thermal storage for district heating is based on an assumption of four hours of average district heat demand.

Table 15: Thermal storage and average district heating demand for the STRATEGO countries

Thermal storage	Croatia	Czech Republic	Italy	Romania	United Kingdom
Thermal storage(GWh)	4.4	44.5	71.4	34.6	19.9
Average district heating demand (MWh)	395	3621	3007	2823	589

Hydro storage

Table 16: Dammed and pumped storage capacities in GWh

Hydro storage (GWh)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Dammed storage	4100	1425	12667	4575	3000
Pumped storage	2.9	11.5	75.4	0.9	27.4

Oil storage

Table 17: Oil storage for the STRATEGO countries

Country	Unit	Amount	Notes
Czech	Million barrel	26.3	Split between crude oil and refined products
Italy	Million barrel	163.5	Converted from 26 mcm using US barrels. Split into one-third crude and two-thirds finished products
United Kingdom	Million barrel	83	Includes Oil and product stocks. Main storage facilities for crude and oil products in the United Kingdom are located at refineries.
Croatia	Million barrel	11	Strategic oil storage capacity of 1,540,000 m3 and 202,000 m3 of petroleum derivatives (http://www.janaf.hr/sustav-janafa/sustav-jadranskog-naftovoda/).
Romania	Million barrel	11	Based on 90 days reserve of net imports amount from the previous year

Gas storage

Gas storage data was collected from the Enerdata database. Data was collected for the underground natural gas storage capacity.

Table 18: Gas storage capacities for the STRATEGO countries

Country	Unit	Amount
Czech	Billion cubic metre	3.1
Italy	Billion cubic metre	14.3
United Kingdom	Billion cubic metre	3.9
Croatia	Billion cubic metre	0.6
Romania	Billion cubic metre	2.7

Grid capacities

Table 19: Electric grid capacities based on the national annual maximum load for 2010

Country	Unit	Electric grid capacity (national annual maximum load)
Czech	MW	10,384
Italy	MW	56,425
United Kingdom	MW	60,100
Croatia	MW	3,121
Romania	MW	8,464

Interconnections

Table 20: Onshore and offshore electricity transmission interconnections

Country	Onshore cable (MW)	Offshore cable (MW)
Czech	7300	N/A
Italy	7605	500
United Kingdom	N/A	2450
Croatia	3250	N/A
Romania	1900	N/A

Heating units in buildings

The number of individual boilers (excluding boilers for district heating production), district heating substations and electric heating units.

Table 21: Number of heating units divided by the building types (single-family residential, multi-family residential, non-residential)

Units (1,000)	Croatia	Czech Republic	Italy	Romania	United Kingdom
Residential – single-family	**936**	**1699**	**6899**	**4189**	**20737**
Coal	5	95	1	4	221
Oil	166	7	739	188	1631
Gas	403	797	5006	1615	15988
Biomass	131	189	478	1436	121
District heating substations	126	404	44	827	222
Electric heating	103	122	604	119	2298
Residential – multi-family	**43**	**193**	**2045**	**91**	**239**
Coal	0	11	0	0	3
Oil	8	1	219	4	19
Gas	18	90	1484	35	184
Biomass	6	21	142	31	1
District heating substations	6	46	13	18	3
Electric heating	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Non-residential	**22**	**97**	**144**	**73**	**1150**
Coal	0	5	0	0	12
Oil	4	0	15	3	90
Gas	9	46	105	28	887
Biomass	3	11	10	25	7
District heating substations	3	23	1	14	12
Electric heating	2	8	13	2	12

Minimum power plant and CHP operation

Table 22: Minimum power plant and CHP operation in the reference models in order to ensure a stable electricity supply

Minimum operation	Croatia	Czech Republic	Italy	Romania	United Kingdom
Minimum grid stabilisation production share (%)	50	50	50	50	50
Minimum power plant operation (MW)	291	1553	10561	1628	13612
Minimum power plant operation (% of total)	20	20	20	20	20
Minimum CHP operation (MW)	68	269	1744	308	0
Minimum CHP operation (% of total)	10	10	10	10	0

6.1.2 2050 Business-As-Usual Models

Primary energy supply BAU

Table 25: The primary energy supply for the STRATEGO countries in the BAU scenario divided by fuel types

Primary energy supply (TWh)	Croatia		Czech Republic		Italy		Romania		United Kingdom	
	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Fossil fuels	**79.9**	**106.9**	**419.5**	**385.9**	**1867.3**	**1863.9**	**302.5**	**369.2**	**2310.2**	**1955.7**
Coal	8.9	22.5	225.9	158.2	194.1	181.4	83.3	92.5	379.4	247.5
Oil	40.1	46.3	103.3	125.3	822.8	837.4	94.6	124.2	883.3	831.8
Natural Gas	30.9	38.1	90.3	102.5	850.4	845.1	124.6	152.6	1047.5	876.5
Nuclear	**0.0**	**0.0**	**84.4**	**176.9**	**0.0**	**0.0**	**36.9**	**59.7**	**186.3**	**172.0**
Renewable sources	**13.1**	**20.1**	**35.1**	**38.3**	**188.9**	**265.4**	**69.1**	**92.5**	**88.7**	**216.4**
Biomass (excl. waste)	4.4	5.1	28.2	29.9	95.2	91.6	48.2	55.7	63.1	56.3
Waste	0.1	0.09	3.08	3.08	21.17	21.17	0.36	0.36	10.90	10.90
Hydro	8.3	12.1	2.8	3.7	54.4	63.3	20.2	28.0	3.5	4.1
Wind	0.1	1.69	0.35	0.75	9.23	49.29	0.31	3.19	9.96	128.93
Solar elec.	0.0	0.97	0.65	0.73	2.00	27.94	0.00	5.17	0.13	15.14
Geothermal elec.	0.0	0.0	0.0	0.0	5.4	10.7	0.0	0.0	0.0	0.0
Solar heat	0.1	0.07	0.05	0.06	1.40	1.39	0.00	0.00	1.13	1.07
Geothermal heat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wave and tidal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
Import/export electricity	4.8	0.12	-15.17	8.95	44.17	10.19	-2.15	1.14	2.66	57.52
Total	**97.8**	**127.0**	**523.8**	**610.0**	**2100.4**	**2139.5**	**406.3**	**522.5**	**2587.9**	**2401.7**

Electricity production BAU

Table 4: Electricity production divided by technologies

Electricity production (TWh)	Croatia		Czech Republic		Italy		Romania		United Kingdom	
	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU	Ref	BAU
Total thermal	**5.68**	**11.86**	**60.57**	**32.83**	**276.97**	**264.71**	**30.60**	**35.18**	**358.61**	**236.76**
Condensing power plants	2.85	8.16	40.59	12.75	174.84	159.19	17.58	16.03	319.88	191.16
CHP plants (incl. Waste)	2.38	3.25	11.55	11.65	76.96	80.31	10.64	16.77	0.00	6.87
Industrial	0.45	0.45	8.43	8.43	25.17	25.21	2.38	2.38	38.73	38.73
Nuclear Power Plants	**0.00**	**0.00**	**28.09**	**58.90**	**0.00**	**0.00**	**12.30**	**19.89**	**62.03**	**57.27**
Renewable sources	**8.46**	**14.79**	**3.79**	**5.22**	**71.10**	**151.21**	**20.53**	**36.37**	**13.63**	**161.22**
Geothermal Power Plants	0.00	0.00	0.00	0.00	5.44	10.67	0.00	0.00	0.00	0.00
Wind Power	0.14	1.69	0.35	0.75	9.23	49.29	0.31	3.19	9.96	128.93
Onshore	0.14	0.96	0.35	0.75	9.23	49.29	0.31	3.19	5.74	74.32
Offshore	0	0.73	0	0	0	0	0	0	4.22	54.61
Solar	0.00	0.97	0.65	0.73	2.00	27.94	0.00	5.17	0.13	15.14
Wave and Tidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.04
Total hydro	8.32	12.13	2.79	3.74	54.43	63.31	20.22	28.01	3.54	4.11
Hydro with a Dam	6.40	9.76	1.04	1.58	30.72	37.21	8.88	13.85	1.58	1.94
Run of the River Hydro	1.92	2.37	1.75	2.16	23.71	26.10	11.34	14.16	1.96	2.17
PHES Pump	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net import*	4.70	-0.12	-14.73	-8.95	44.17	-10.19	-2.39	-1.14	2.66	-57.52
Total, excl. import/export	**14.14**	**26.65**	**92.45**	**96.95**	**348.07**	**415.92**	**63.43**	**91.44**	**434.27**	**455.25**

* A negative number indicates export while a positive is import

6.2 Appendix B – EnergyPLAN Cost Database Version 3.0

Energy cost database as of 30th January 2015 freely downloadable from www.EnergyPLAN.eu/costdatabase/

Preface

The EnergyPLAN cost database is created and maintained by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. It is constructed based on data from a wide variety of sources, with many of the inputs adjusted to fit with the required fields in the EnergyPLAN model. Below is a list of all the different sources currently used to construct the cost database. The result is a collection of investment, operation & maintenance, and lifetimes for all technologies for the years 2020, 2030, and 2050. Where data could not be obtained for 2030 or 2050, a 2020 cost is often assumed.

- Danish Energy Agency. Energistyrelsen. Available from: http://www.ens.dk/ [accessed 25 June 2012].
- International Energy Agency. World Energy Outlook 2010. International Energy Agency, 2010. Available from: http://www.iea.org/weo/2010.asp.
- Danish Energy Agency. Forudsætninger for samfundsøkonomiske analyser på energiområdet (Assumptions for socio-economic analysis on energy). Danish Energy Agency, 2011. Available from: http://www.ens.dk.
- Howley M, Dennehy E, Ó'Gallachóir B. Energy in Ireland 1990 - 2009. Energy Policy Statistical Unit, Sustainable Energy Authority of Ireland, 2010. Available from: http://www.seai.ie/Publications/Statistics_Publications/Energy_in_Ireland/.
- Lund H, Möller B, Mathiesen BV, Dyrelund A. The role of district heating in future renewable energy systems. Energy 2010;35(3):1381-1390.
- Bøckman T, Fleten S-E, Juliussen E, Langhammer HJ, Revdal I. Investment timing and optimal capacity choice for small hydropower projects. European Journal of Operational Research 2008;190(1):255-267.
- Danish Energy Agency, Energinet.dk. Technology Data for Energy Plants. Danish Energy Agency, Energinet.dk, 2010. Available from: http://ens.dk/da-DK/Info/TalOgKort/Fremskrivninger/Fremskrivninger/Documents/Teknologikatalog%20Juni%202010.pdf.
- Motherway B, Walker N. Ireland's Low-Carbon Opportunity: An analysis of the costs and benefits of reducing greenhouse gas emissions. Sustainable Energy Authority of Ireland, 2009. Available from: http://www.seai.ie/Publications/Low_Carbon_Opportunity_Study/.
- International Energy Agency. Energy Technology Data Source. Available from: http://www.iea-etsap.org/web/E-TechDS.asp [accessed 15 March 2012].
- Narional Renewable Energy Laboratory. Technology Brief: Analysis of Current-Day Commercial Electrolyzers. Narional Renewable Energy Laboratory, 2004. Available from: http://www.nrel.gov/docs/fy04osti/36705.pdf.
- Mathiesen BV, Blarke MB, Hansen K, Connolly D. The role of large-scale heat pumps for short term integration of renewable energy. Department of Development and Planning, Aalborg University, 2011. Available from: http://vbn.aau.dk.
- Danish Energy Agency and Energinet.dk. Technology Data for Energy Plants: Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion. Danish Energy Agency and Energinet.dk, 2012. Available from: http://www.ens.dk/.

- Joint Research Centre. Technology Map of the European Strategic Energy Technology Plan (SET-Plan): Technology Descriptions. European Union, 2011. Available from: http://setis.ec.europa.eu/.
- Gonzalez A, Ó'Gallachóir B, McKeogh E, Lynch K. Study of Electricity Storage Technologies and Their Potential to Address Wind Energy Intermittency in Ireland. Sustainable Energy Authority of Ireland, 2004. Available from: http://www.seai.ie/Grants/Renewable_Energy_RD_D/Projects_funded_to_date/Wind/Study_of_Elec_Storage_Technologies_their_Potential_to_Address_Wind_Energy_Intermittency_in_Irl.
- Mathiesen BV, Ridjan I, Connolly D, Nielsen MP, Hendriksen PV, Mogensen MB, Jensen SH, Ebbesen SD. Technology data for high temperature solid oxide electrolyser cells, alkali and PEM electrolysers. Aalborg University, 2013. Available from: http://vbn.aau.dk/.
- Washglade Ltd. Heat Merchants. Available from: http://heatmerchants.ie/ [accessed 12 September 2012].
- Danish Energy Agency and Energinet.dk. Technology Data for Energy Plants: Individual Heating Plants and Technology Transport. Danish Energy Agency and Energinet.dk, 2012. Available from: http://www.ens.dk/.
- COWI. Technology Data for Energy Plants: Individual Heating Plants and Energy Transport. Danish Energy Agency, 2013. Available from: http://www.ens.dk/.
- Department for Biomass & Waste, FORCE Technology. Technology Data for Advanced Bioenergy Fuels. Danish Energy Agency, 2013. Available from: http://www.ens.dk/.
- COWI. Alternative drivmidler i transportsektoren (Alternative Fuels for Transport). Danish Energy Agency, 2012. Available from: http://www.ens.dk/.
- IRENA. Renewable Energy Technologies: Cost Analysis Series - Concentrating Solar Power. IRENA, 2012. Available from: http://www.irena.org/.
- COWI. Alternative drivmidler i transportsektoren (Alternative Fuels for Transport). Danish Energy Agency, 2013. Available from: http://www.ens.dk/.
- Mathiesen BV, Connolly D, Lund H, Nielsen MP, Schaltz E, Wenzel H, Bentsen NS, Felby C, Kaspersen P, Hansen K. CEESA 100% Renewable Energy Transport Scenarios towards 2050. Aalborg University, 2014. Available from: http://www.ceesa.plan.aau.dk/.
- COWI. Alternative drivmidler i transportsektoren (Alternative Fuels for Transport). Danish Energy Agency, 2008. Available from: http://www.ens.dk/.

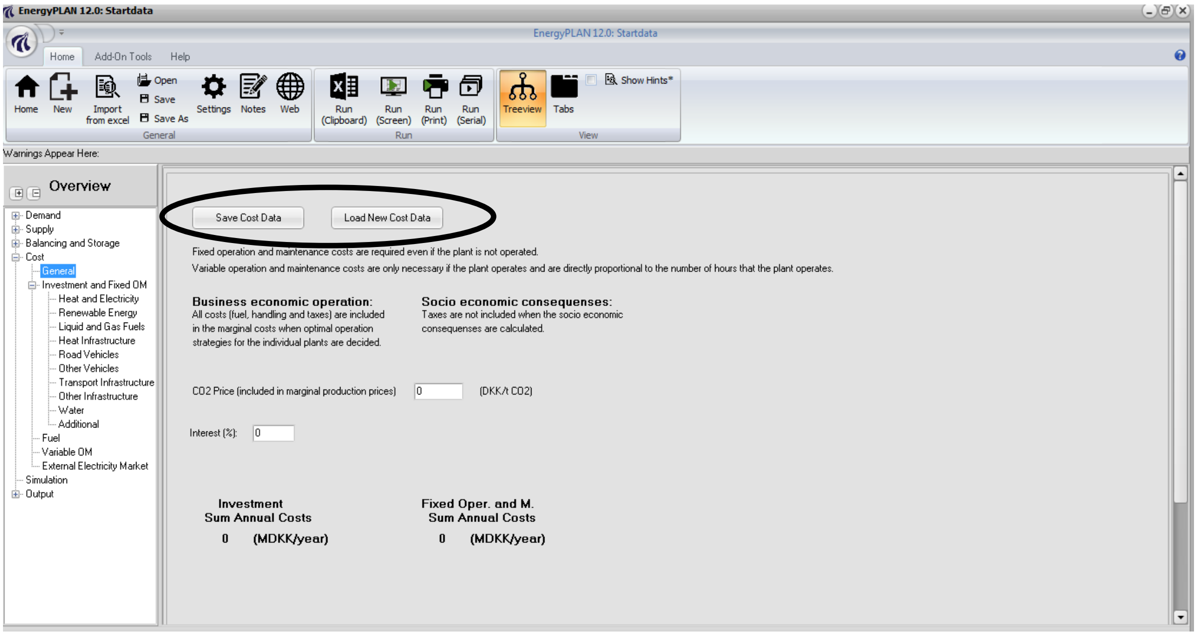
1 Introduction

The EnergyPLAN tool contains five tabsheets under the main 'Cost' tabsheet, which are:

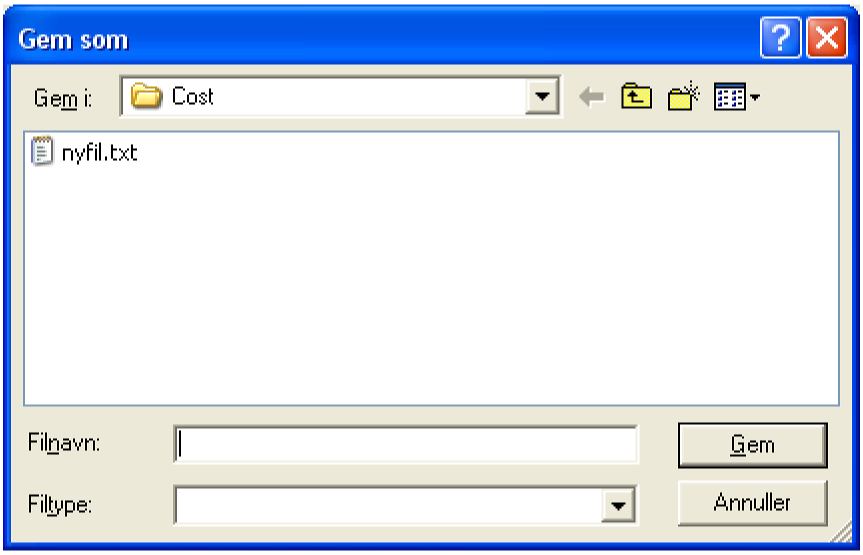
- General
- Investment and Fixed OM
- Fuel
- Variable OM
- External electricity market

The Investment and Fixed OM tabsheet further contains ten sub-tabsheets that relates to different technology groups such as Heat and Electricity, Renewable Energy, Heat infrastructure, Road vehicles, Additional, etc.

Within each of these, the user can enter over 200 inputs depending on the range of technologies being considered in an analysis. When completing an energy systems analysis, it is often necessary to change the cost data in EnergyPLAN for a variety of reasons: for example, to analyse the same system for a different year or to analyse the sensitivity of the system to different costs. To accommodate this, EnergyPLAN enables the user to change the cost data within a model, without changing any of the data under the other tabsheets. To do so, one has to go to the Cost-> General tabsheet and activate one of the two buttons "Save Cost Data" or "Load New Cost Data".



When activating one of these buttons, the user will be brought to the 'Cost' folder where one can either save a new cost data file or load an existing one. It is important to note that when you are saving a file, you should always specify a filename with .txt at the end of the name, as otherwise it may not save correctly.



Even with this function, collecting cost data is still a very time-consuming task and hence, the EnergyPLAN Cost Database has been developed. This database includes cost data for almost all of the technologies included in EnergyPLAN based primarily on publications released by the Danish Energy Agency. This document gives a brief overview of this data.

2 EnergyPLAN Cost Database

To date, the EnergyPLAN Cost Database consists of the following files:

- 2020EnergyPLANCosts.txt
- 2030EnergyPLANCosts.txt
- 2050EnergyPLANCosts.txt

The file name represents the year which the costs are for. These are recommended based on the literature reviewed by the EnergyPLAN team and it is the users responsibility to verify or adjust them accordingly. To date, the principal source for the cost data has been the Danish Energy Agency (DEA) [1], although a variety of other sources have been used where the data necessary is not available. Below is an overview of the data used to create the EnergyPLAN Cost Database, although it should be noted that this data is updated regularly, so there may be slight differences in the files provided.

2.1 Fuel Costs

The fuel prices assumed in the EnergyPLAN Cost Database are outlined in Table 32. Since the DEA only project fuel prices to 2030, the fuel prices in 2040 and 2050 were forecasted by assuming the same trends as experiences in the period between 2020 and 2030. These forecasts can change dramatically from one year to the next. For example, between January and August of 2012, the average oil price was $106/bbl, which is much closer to the oil price forecasted for 2020 than for the 2011 oil price.

Table 32: Fuel prices for 2011, 2020, 2030, 2040, and 2050 in the EnergyPLAN Cost Database [2, 3].

(2009-€/GJ) Year	Oil (US$/bbl)	Natural Gas	Coal	Fuel Oil	Diesel	Petrol	Jet Fuel	Straw	Wood Chips	Wood Pellets	Energy Crops	Nuclear
2011	82.0	5.9	2.7	8.8	11.7	11.9	12.7	3.5	4.5	9.6	4.7	1.5
2020	107.4	9.1	3.1	11.9	15.0	15.2	16.1	3.9	5.1	10.2	4.7	1.5
2030	118.9	10.2	3.2	13.3	16.6	16.7	17.6	4.3	6.0	10.9	5.2	1.5
	Projected assuming the same trends as in 2020-2030											
2040	130.5	11.2	3.3	14.7	18.1	18.2	19.1	4.7	6.8	11.5	5.7	1.5
2050	142.0	12.2	3.4	16.1	19.6	19.7	20.6	5.1	7.6	12.2	6.3	1.5

Fuel handling costs were obtained from the Danish Energy Agency [3]. They represent the additional costs of handling and storing fuels for different types of consumers as well as expected profit margins.

Table 33: Fuel handling costs for 2020 in the EnergyPLAN Cost Database [3].

2009 - €/GJ	Centralised Power Plants	Decentralised Power Plants & Industry	Consumer
Fuel			
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	

The cost of emitting carbon dioxide is displayed in Table 34 and the CO_2 emission factors used for each fuel are outlined in Table 35.

2.2 Carbon Dioxide Costs and Emissions

Table 34: Carbon dioxide prices for 2011, 2020, 2030, 2040, and 2050 in the EnergyPLAN Cost Database [3].

2009-€/Ton	**CO2 Price**
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 35: Carbon dioxide emission factors for different fuels in the EnergyPLAN Cost Database [4].

Fuel	Coal/Peat	Oil	Natural Gas	Waste	LPG
Emission Factor (kg/GJ)	98.5	72.9	56.9	32.5	59.64

2.3 Variable Operation and Maintenance Costs

In the Operation tabsheet, the user inputs the variable operation and maintenance costs for a range of technologies. Variable O&M costs account for the additional costs incurred at a plant when the plant has to run such as more replacement parts and more labour. Those available in the EnergyPLAN Cost Database are outlined in Table 36.

Table 36: Variable operation and maintenance costs assumed for 2020 in the EnergyPLAN Cost Database.

Sector	Unit	Variable O&M Cost (€/MWh)
District Heating and CHP Systems	Boiler*	0.15
	CHP*	2.7
	Heat Pump	0.27
	Electric Heating	0.5
Power Plants	Hydro Power	1.19
	Condensing*	2.654
	Geothermal	15
	GTL M1	1.8
	GTL M2	1.008
Storage	Electrolyser	0
	Pump	1.19
	Turbine	1.19
	V2G Discharge	
	Hydro Power Pump	1.19
Individual	Boiler	Accounted for under individual heating costs in the Additional tabsheet
	CHP	
	Heat Pump	
	Electric Heating	

***These costs need to be calculated based on the mix of technologies in the energy system, which can vary substantially from one system to the next.**

2.4 Investment Costs

Table 37 outlines the investment costs in the EnergyPLAN Cost Database for the different technologies considered in EnergyPLAN. Note that different technology costs are expressed in different units, so when defining the capacity of a technology, it is important to use the same unit in for the technical input as in the cost input.

Table 37: Investment costs for 2020, 2030, and 2050 in the EnergyPLAN Cost Database.

	Unit: M€/Unit	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	1.2	1.2	1.2
	Large CHP	MWe	0.8	0.8	0.8
	Heat Storage CHP	GWh	3.0	3.0	3.0
	Waste CHP	TWh/year	215.6	215.6	215.6
	Absorption Heat Pump	MWth	0.4	0.4	0.4

	Heat Pump Group 2	MWe	3.4	3.4	2.9
	Heat Pump Group 3	MWe	3.4	3.3	2.9
	DHP Boiler Group 1	MWth	0.100	0.100	0.100
	Boilers Group 2 & 3	MWth	0.075	0.100	0.100
	Electric Boiler	MWth	0.100	0.075	0.075
	Large Power Plants	MWe	0.99	0.98	0.9
	Nuclear	MWe	3.6	3.6	3.0
	Interconnection	MWe	1.2	1.2	1.2
	Pump	MWe	0.6	0.6	0.6
	Turbine	MWe	0.6	0.6	0.6
	Pump Storage	GWh	7.5	7.5	7.5
	Industrial CHP Electricity	TWh/year	68.3	68.3	68.3
	Industrial CHP Heat	TWh/year	68.3	68.3	68.3
Renewable Energy	Wind Onshore	MWe	1.3	1.3	1.2
	Wind Offshore	MWe	2.4	2.3	2.1
	Photovoltaic	MWe	1.3	1.1	0.9
	Wave Power	MWe	6.4	3.4	1.6
	Tidal	MWe	6.5	5.3	5.3
	CSP Solar Power	MWe	6.0	6.0	6.0
	River Hydro	MWe	3.3	3.3	3.3
	Hydro Power	MWe	3.3	3.3	3.3
	Hydro Storage	GWh	7.5	7.5	7.5
	Hydro Pump	MWe	0.6	0.6	0.6
	Geothermal Electricity	MWe	4.6	4.0	4.0
	Geothermal Heat	TWh/year	0.0	0.0	0.0
	Solar Thermal	TWh/year	386.0	307.0	307.0
	Heat Storage Solar	GWh	3.0	3.0	3.0
	Industrial Excess Heat	TWh/year	40.0	40.0	40.0
Liquid and Gas Fuels	Biogas Plant	TWh/year	240	240	240
	Gasification Plant	MW Syngas	0.4	0.3	0.3
	Biogas Upgrade	MW Gas Out	0.3	0.3	0.3
	Gasification Gas Upgrade	MW Gas Out	0.3	0.3	0.3
	2nd Generation Biodiesel Plant	MW-Bio	3.4	2.5	1.9
	Biopetrol Plant	MW-Bio	0.8	0.6	0.4
	Biojetpetrol Plant	MW-Bio	0.8	0.6	0.4
	CO2 Hydrogenation Electrolyser	MW-Fuel	0.9	0.6	0.4
	Synthetic Methane Electrolyser	MW-Fuel	0.0	0.0	0.0
	Chemical Synthesis MeOH	MW-Fuel	0.6	0.6	0.6
	Alkaline Electrolyser	MWe	2.5	0.9	0.9
	SOEC Electrolyser	MWe	0.6	0.4	0.3
	Hydrogen Storage	GWh	20.0	20.0	20.0

	Gas Storage	GWh	0.1	0.1	0.1
	Oil Storage	GWh	0.0	0.0	0.0
	Methanol Storage	GWh	0.1	0.1	0.1
Heat Infrastructure	Individual Boilers	1000 Units	6.1	0.0	0.0
	Individual CHP	1000 Units	12.0	0.0	0.0
	Individual Heat Pump	1000 Units	14.0	0.0	14.0
	Individual Electric Heat	1000 Units	8.0	0.0	0.0
	Individual Solar Thermal	TWh/year	1700.0	1533.3	1233.3
Road Vehicles	Bicycles	1000 Vehicles	0.0	0.0	0.0
	Motorbikes	1000 Vehicles	6.0	6.0	6.0
	Electric Cars	1000 Vehicles	18.1	18.1	18.1
	Conventional Cars	1000 Vehicles	20.6	20.6	20.6
	Methanol/DME Busses	1000 Vehicles	177.2	177.2	177.2
	Diesel Busses	1000 Vehicles	177.2	177.2	177.2
	Methanol/DME Trucks	1000 Vehicles	99.2	99.2	99.2
	Diesel Trucks	1000 Vehicles	99.2	99.2	99.2
Water	Desalination	1000 m3 Fresh Water/hour	0.1	0.1	0.1
	Water Storage	Mm3	0.0	0.0	0.0

***Power plant costs need to be calculated based on the mix of technologies in the energy system, which can vary substantially from one system to the next.**

2.5 Fixed Operation and Maintenance Costs

	Unit: % of Investment	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	3.75	3.75	3.75
	Large CHP	MWe	3.66	3.66	3.80
	Heat Storage CHP	GWh	0.70	0.70	0.70
	Waste CHP	TWh/year	7.37	7.37	7.37
	Absorption Heat Pump	MWth	4.68	4.68	4.68
	Heat Pump Group 2	MWe	2.00	2.00	2.00
	Heat Pump Group 3	MWe	2.00	2.00	2.00
	DHP Boiler Group 1	MWth	3.70	3.70	3.70
	Boilers Group 2 & 3	MWth	1.47	3.70	3.70
	Electric Boiler	MWth	3.70	1.47	1.47
	Large Power Plants	MWe	3.12	3.16	3.26
	Nuclear	MWe	2.53	2.49	1.96
	Interconnection	MWe	1.00	1.00	1.00
	Pump	MWe	1.50	1.50	1.50
	Turbine	MWe	1.50	1.50	1.50
	Pump Storage	GWh	1.50	1.50	1.50
	Industrial CHP Electricity	TWh/year	7.32	7.32	7.32

	Industrial CHP Heat	TWh/year	7.32	7.32	7.32
Renewable Energy	Wind Onshore	MWe	3.05	2.97	3.20
	Wind Offshore	MWe	2.97	3.06	3.21
	Photovoltaic	MWe	2.09	1.38	1.15
	Wave Power	MWe	0.59	1.04	1.97
	Tidal	MWe	3.00	3.66	3.66
	CSP Solar Power	MWe	8.21	8.21	8.21
	River Hydro	MWe	2.00	2.00	2.00
	Hydro Power	MWe	2.00	2.00	2.00
	Hydro Storage	GWh	1.50	1.50	1.50
	Hydro Pump	MWe	1.50	1.50	1.50
	Geothermal Electricity	MWe	3.50	3.50	3.50
	Geothermal Heat	TWh/year	0.00	0.00	0.00
	Solar Thermal	TWh/year	0.13	0.15	0.15
	Heat Storage Solar	GWh	0.70	0.70	0.70
	Industrial Excess Heat	TWh/year	1.00	1.00	1.00
Liquid and Gas Fuels	Biogas Plant	TWh/year	6.96	6.96	6.96
	Gasification Plant	MW Syngas	5.30	7.00	7.00
	Biogas Upgrade	MW Gas Out	15.79	17.65	18.75
	Gasification Gas Upgrade	MW Gas Out	15.79	17.65	18.75
	2nd Generation Biodiesel Plant	MW-Bio	3.01	3.01	3.01
	Biopetrol Plant	MW-Bio	7.68	7.68	7.68
	Biojetpetrol Plant	MW-Bio	7.68	7.68	7.68
	CO2 Hydrogenation Electrolyser	MW-Fuel	2.46	3.00	3.00
	Synthetic Methane Electrolyser	MW-Fuel	0.00	0.00	0.00
	Chemical Synthesis MeOH	MW-Fuel	3.48	3.48	3.48
	Alkaline Electrolyser	MWe	4.00	4.00	4.00
	SOEC Electrolyser	MWe	2.46	3.00	3.00
	Hydrogen Storage	GWh	0.50	0.50	0.50
	Gas Storage	GWh	1.00	1.00	1.00
	Oil Storage	GWh	0.63	0.63	0.63
	Methanol Storage	GWh	0.63	0.63	0.63
Heat Infrastructure	Individual Boilers	1000 Units	1.79	0.00	0.00
	Individual CHP	1000 Units	0.00	0.00	0.00
	Individual Heat Pump	1000 Units	0.98	0.00	0.98
	Individual Electric Heat	1000 Units	1.00	0.00	0.00
	Individual Solar Thermal	TWh/year	1.22	1.35	1.68
Road Vehicles	Bicycles	1000 Vehicles	0.00	0.00	0.00
	Motorbikes	1000 Vehicles	5.00	5.00	5.00
	Electric Cars	1000 Vehicles	6.99	4.34	4.34
	Conventional Cars	1000 Vehicles	4.09	4.09	4.09

	Methanol/DME Busses	1000 Vehicles	9.14	9.14	9.14
	Diesel Busses	1000 Vehicles	9.14	9.14	9.14
	Methanol/DME Trucks	1000 Vehicles	21.10	21.10	21.10
	Diesel Trucks	1000 Vehicles	21.10	21.10	21.10

2.6 Lifetimes

	Unit: Years	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	25	25	25
	Large CHP	MWe	25	25	25
	Heat Storage CHP	GWh	20	20	20
	Waste CHP	TWh/year	20	20	20
	Absorption Heat Pump	MWth	20	20	20
	Heat Pump Group 2	MWe	25	25	25
	Heat Pump Group 3	MWe	25	25	25
	DHP Boiler Group 1	MWth	35	35	35
	Boilers Group 2 & 3	MWth	20	35	35
	Electric Boiler	MWth	35	20	20
	Large Power Plants	MWe	27	27	27
	Nuclear	MWe	30	30	30
	Interconnection	MWe	40	40	40
	Pump	MWe	50	50	50
	Turbine	MWe	50	50	50
	Pump Storage	GWh	50	50	50
	Industrial CHP Electricity	TWh/year	25	25	25
	Industrial CHP Heat	TWh/year	25	25	25
Renewable Energy	Wind Onshore	MWe	20	25	30
	Wind Offshore	MWe	20	25	30
	Photovoltaic	MWe	30	30	40
	Wave Power	MWe	20	25	30
	Tidal	MWe	20	20	20
	CSP Solar Power	MWe	25	25	25
	River Hydro	MWe	50	50	50
	Hydro Power	MWe	50	50	50
	Hydro Storage	GWh	50	50	50
	Hydro Pump	MWe	50	50	50
	Geothermal Electricity	MWe	20	20	20
	Geothermal Heat	TWh/year	0	0	0
	Solar Thermal	TWh/year	30	30	30

	Heat Storage Solar	GWh	20	20	20
	Industrial Excess Heat	TWh/year	30	30	30
Liquid and Gas Fuels	Biogas Plant	TWh/year	20	20	20
	Gasification Plant	MW Syngas	25	25	25
	Biogas Upgrade	MW Gas Out	15	15	15
	Gasification Gas Upgrade	MW Gas Out	15	15	15
	2nd Generation Biodiesel Plant	MW-Bio	20	20	20
	Biopetrol Plant	MW-Bio	20	20	20
	Biojetpetrol Plant	MW-Bio	20	20	20
	CO2 Hydrogenation Electrolyser	MW-Fuel	20	15	15
	Synthetic Methane Electrolyser	MW-Fuel	0	0	0
	Chemical Synthesis MeOH	MW-Fuel	20	20	20
	Alkaline Electrolyser	MWe	28	28	28
	SOEC Electrolyser	MWe	20	15	15
	Hydrogen Storage	GWh	30	30	30
	Gas Storage	GWh	50	50	50
	Oil Storage	GWh	50	50	50
	Methanol Storage	GWh	50	50	50
Heat Infrastructure	Individual Boilers	1000 Units	21	0	0
	Individual CHP	1000 Units	10	0	0
	Individual Heat Pump	1000 Units	20	0	20
	Individual Electric Heat	1000 Units	30	0	0
	Individual Solar Thermal	TWh/year	25	30	30
Road Vehicles	Bicycles	1000 Vehicles	0	0	0
	Motorbikes	1000 Vehicles	15	0	15
	Electric Cars	1000 Vehicles	16	16	16
	Conventional Cars	1000 Vehicles	16	16	16
	Methanol/DME Busses	1000 Vehicles	6	6	6
	Diesel Busses	1000 Vehicles	6	6	6
	Methanol/DME Trucks	1000 Vehicles	6	6	6
	Diesel Trucks	1000 Vehicles	6	6	6

2.7 Additional Tabsheet

The additional tabsheet under the Investment and Fixed OM tabsheet can be used to account for costs which are not included in the list of technologies provided in the other tabsheets. Typically these costs are calculated outside of the EnergyPLAN tool and subsequently inputted as a total. In the past, this section has been used to include the costs of the following technologies:

- Energy efficiency measures
- Electric grid costs
- Individual heating costs

- Interconnection costs
- Costs for expansion of district heating and cooling

Some of these costs vary dramatically from one energy system to the next and hence they are not included in the cost files which can be loaded into EnergyPLAN. However, below are some costs which may provide a useful starting point if additional costs need to be estimated.

2.7.1 Heating

Individual heating can be considered automatically by EnergyPLAN or added as an additional cost. To use the automatic function, you must specify an average heat demand per building in the Individual heating tabsheet. Using this, in combination with the total heat demand, EnergyPLAN estimates the total number of buildings in the energy system. This is illustrated in the Cost->Investment and Fixed OM ->Heat infrastructures window. The price presented in Table 37 above represents the average cost of a boiler in a single house, which is used to automatically estimate the cost of the heating infrastructure. This is a fast method, but it can overlook variations in the type of boilers in the system. For example, some boilers will be large common boilers in the basement of a building rather than an individual boiler in each house.

To capture these details, we recommend that you build a profile of the heating infrastructure outside of the EnergyPLAN tool and insert the costs as an additional cost. Below in Table 38 are a list of cost assumptions you can use if you do this.

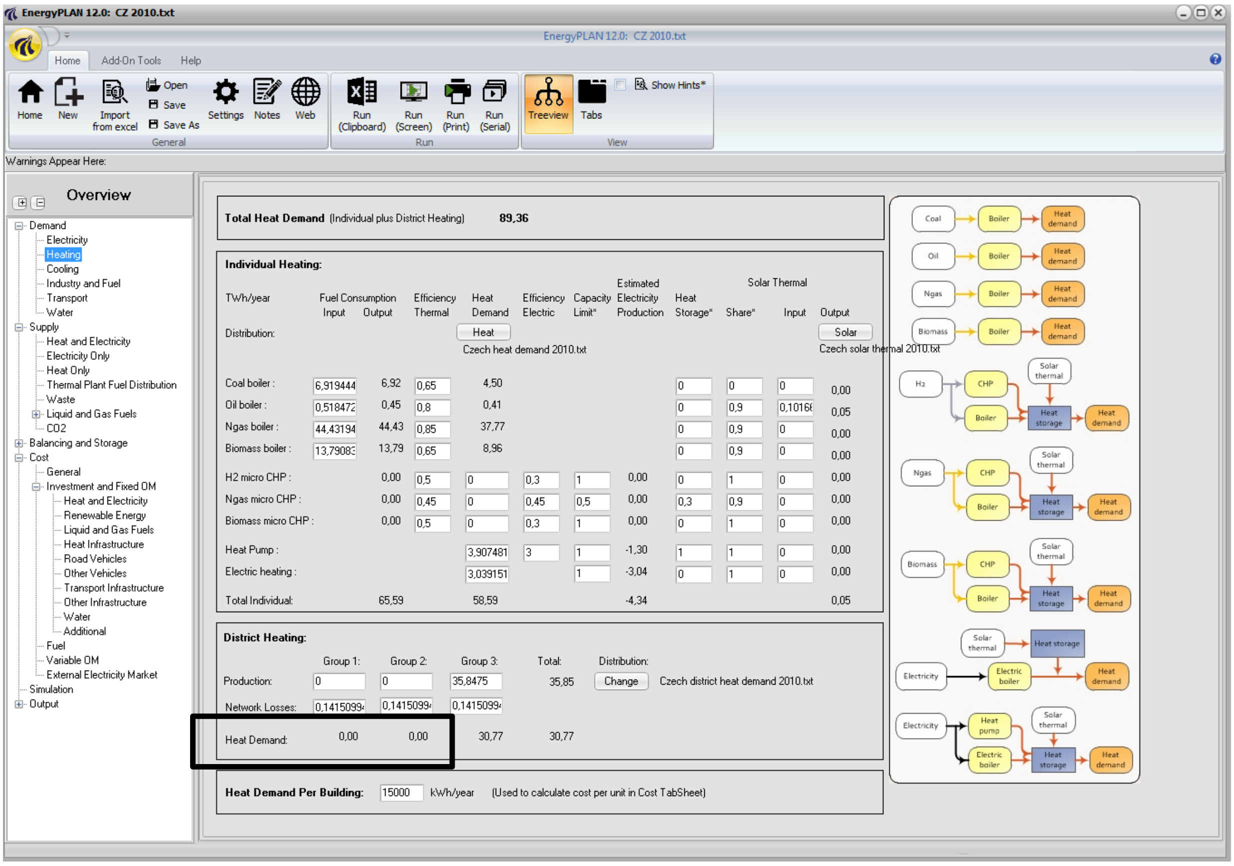


Table 38: Individual heating unit costs for 2020 in the EnergyPLAN Cost Database [5].

Parameter	Oil boiler	Natural gas boiler	Biomass boiler	Heat pump air-to-water	Heat pump brine-to-water	Electric heating	District heating substation
Capacity of one unit (kW_{th})	15-30	3-20	5-20	10	10	5	10
Annual average efficiency (%)	100	100-104	87	330	350	100	98
Technical lifetime (years)	20	22	20	20	20	30	20
Specific investment (1000€/unit)	6.6	5	6.75	12	16	4	2.5
Fixed O&M (€/unit/year)	270	46	25	135	135	50	150
Variable O&M (€/MWh)	0.0	7.2	0.0	0.0	0.0	0.0	0.0

Table 39: District heating network costs for 2020 in the EnergyPLAN Cost Database [5].

Technology	Low-temperature DH network
Heat density an consumer (TJ/km^2 land area)	45-50
Net loss (%)	13-16
Average Technical lifetime (years)	40
Average Investment costs (1000 €/TJ)	145
Average Fixed O&M (€/TJ/year)	1100
Branch Piping (1000€/substation)	3

3 References

[1] Danish Energy Agency. Energistyrelsen. Available from: http://www.ens.dk/ [accessed 25 June 2012].

[2] International Energy Agency. World Energy Outlook 2010. International Energy Agency, 2010. Available from: http://www.iea.org/weo/2010.asp.

[3] Danish Energy Agency. Forudsætninger for samfundsøkonomiske analyser på energiområdet (Assumptions for socio-economic analysis on energy). Danish Energy Agency, 2011. Available from: http://www.ens.dk.

[4] Howley M, Dennehy E, Ó'Gallachóir B. Energy in Ireland 1990 - 2009. Energy Policy Statistical Unit, Sustainable Energy Authority of Ireland, 2010. Available from: http://www.seai.ie/Publications/Statistics_Publications/Energy_in_Ireland/.

[5] Danish Energy Agency and Energinet.dk. Technology Data for Energy Plants: Individual Heating Plants and Technology Transport. Danish Energy Agency and Energinet.dk, 2012. Available from: http://www.ens.dk/.

6.3 Appendix C – Data Sources

In this appendix is a table that provides overview of most of the data categories, the sources and relevant comments.

Data category	Sub-category	Source	Comments
Primary energy supply	Total	IEA, 2010	
	Fuels	IEA, 2010	
	Statistical differences	IEA, 2010	
Electricity production	Total	IEA, 2010	
	Offshore wind	No data available	No data - calculated by using an average offshore capacity factor of 30%
	Onshore wind	IEA, 2010	The capacity factors for onshore wind is between 8% (RO) and 18% (UK). Around 18% for most countries.
	Solar PV	IEA, 2010	
	Hydro Total	IEA, 2010	In IEA only a total hydro production number and not separated into different types. Other sources for the individual hydro types - the overall production however matches
	Hydro dam	IEA, 2010	The efficiency for hydro dam is assumed to be 90% and this is used to calculate the water supply so that it matches with the production data.
	Hydro run-of-river	ENTSO-E country packages	https://www.entsoe.eu/data/data-portal/country-packages/Pages/default.aspx
	Hydro Pumped	IEA, 2010	We subtract the pumped hydro because of the methodology that IEA uses for pumped hydro. In IEA the electricity consumed for pumped hydro is only the loss (difference between electricity for pumping it up and the production) while in other places the electricity consumption is higher (the pumping up) and therefore the production is also higher (production when the water is released).
	Hydro storage	Calculated; Croatia personal communication	Croatia was provided by Tomislav Novosal worked out by Goran Krajacic. The hydro dam storage is calculated as 31 days of storage
	Geothermal	IEA, 2010	Enerdata and IEA are similar for geothermal production
	Nuclear	IEA, 2010	Nuclear production too high for Romanian capacity of 1300 MW at 33% efficiency therefore capacity scaled up to 1400MW
	Thermal production	IEA, 2010	The total thermal for IEA and Enerdata total electricity production are almost identical

	CHP	IEA, 2010	
	PP	IEA, 2010	
	Industrial (CHP + power only)	IEA, 2010	Also includes electricity produced from waste in auto-producer. This waste is not included in the waste incineration plants. Small amount.
	Import/export	IEA, 2010	
Electricity consumption	Total	IEA, 2010	
	Individual electric heating and Heat pumps	Mapping team (Urban)	Calculated by mapping team about heat markets. It is based on the share of electric heating out of the total heating demand and then proportioned between heat pumps and direct heating.
	Electric cooling	Mapping team (Sven)	We use the data from the mapping team. Some difference when comparing to the JRC numbers. Electricity consumption based on a COP of 3.
	Centralised heat pump and electric boiler	IEA	Almost nothing for all countries
	Transport	IEA	Road and rail electricity - for rail also the "non-specified" and "pipeline transport"
	PHES pump	IEA	Only the loss from pumped is included as a storage method (electricity consumed minus production). This is how IEA does it. It is different for other sources (ENTSO-E and Enerdata) that accounts the total electricity consumed to "pump up" the water.
	Losses	IEA, 2010	Includes only losses values as defined by IEA
	Bioenergy	EnergyPLAN model	The electricity consumption for bioenergy plants is based on the EnergyPLAN outputs as no other data is available. Small amounts.
	Electricity demand	Own calculation	The electricity demand is the total consumption + own use + losses (including the statistical difference)
Electricity production capacities	Thermal	Enerdata	
	CHP	Enerdata	
	PP	Enerdata	
	Hydro total	Enerdata	2010 was a very high hydro year in Romania.
	Hydro (dam)	Enerdata	Assuming that the PHES is part of this group as well. Hence we subtract the PHES from the Enerdata dam number.
	Hydro (run-of-river)	Enerdata/own calculation	No data for Croatia and Romania, hence we calculated it by estimating a typical capacity factor

	Hydro (pump)	Enerdata	
	Solar	Enerdata	
	Wind onshore	Enerdata	
	Wind offshore	Enerdata	
	Geothermal	Enerdata	Assuming an efficiency of 100% between production and "fuel used" in PES
	Nuclear	IEA	Assuming an efficiency of 33% to calculate the "fuels" used in nuclear
Thermal production efficiencies	Thermal efficiencies	IEA, 2010	Electric efficiencies for PP and CHP are calculated based on the fuel input and electricity output from plants in IEA
	Centralised boilers	IEA, 2010	Based on fuel input and heat output
	CHP - thermal	IEA, 2010	Based on fuel input and heat output
	Individual boilers, HP	Danish Energy Agency, ECOHEATCOOL	Based on different projects and state of the art knowledge
Fuel input distributions	Thermal production	IEA, 2010	Fuel mix is based on IEA fuel input. Available for the required technologies (Power plants, CHP, boiler and industrial production).
Electricity exchange	Import/export	IEA, 2010	We use a fixed net import/export based on the monthly data
Heating demand	Total	IEA, 2010	Adding up the heat "delivered" to the consumer, including individual heating + solar + geothermal + DH
	Individual	IEA, 2010	Based on data from the mapping team and the efficiencies we assume
	District heating	IEA, 2010	
Heating production	Total	IEA, 2010	Adding up the heat produced at the plant, including individual heating + solar + geothermal + DH
	Individual boilers	IEA, 2010, Halmstad University	IEA for both individual heat demand (heat market) and fuel consumption
	Ind. Electric heating	IEA, 2010, Halmstad University	
	Individual HP	IEA, 2010, Halmstad University	

	CHP District heating	IEA, 2010	
	Boiler District heating	IEA, 2010	
	Heat pump District heating	IEA, 2011	
	Electric boilers	IEA, 2012	
	District heating losses	IEA, 2010	It is assumed that all the DH losses are in CHP, while some in reality also might happen at boilers, but only one total number from IEA.
	Waste	IEA, 2010	Adding up waste input for heating plants + CHP and calculating the elec and thermal efficiency based on the outputs
	Losses	IEA, 2010	District heating losses given in IEA database
	Geothermal heating	IEA, 2010	Not included in the model now as the tool needs to be updated to be able to include this
	Industrial DH	IEA, 2010	The IEA data provides industrial heating that is sold to the network.
Cooling demand & production	Individual cooling demand	Halmsted University; University of Flensburg	Includes both residential and services
	District cooling	JRC report (Heat and cooling demand and market perspective, 2012)	Very low amounts
	Cooling COP	JRC number	We use a COP of 3 to calculate the cooling electricity demand in individual cooling
Industry energy demand	Total	IEA, 2010	
	Fuels	IEA, 2010	
	Various	IEA, 2010	Non-energy use
Transport	Total	IEA, 2010	
	Petrol	IEA, 2010	
	Diesel	IEA, 2010	

	Aviation fuel	IEA, 2010 + IEA online	Domestic aviation fuel from IEA, 2010 while the international aviation fuel is from the online database.
	Navigation (sea) fuel	IEA, 2010 + IEA online	Domestic navigation fuel from IEA, 2010 while the international navigation fuel (marine bunker) is from the online database.
	Electricity	IEA, 2010	Divided into road and rail (rail also includes non specified and pipeline transport)
	EV characteristics (battery and grid capacity)	Nissan LEAF model	The EV characteristics are based on a Nissan LEAF model
Fuel losses	Coal, oil, gas, biomass losses	IEA, 2010	Fuel losses are the difference between total primary energy supply (including statistical difference) and fuel input to energy transformation plants and final consumption (e.g. industry, residential etc.)
	Biogas production	IEA, 2010	The biogas production is based on the input to transformation plants rather than the total production in the country, hence we do not include the (rather small) biogas loss when it is transmitted from production to consumption at the plants
CO2	Total emission	Enerdata	No data from IEA
	CO2 content for different fuels	Howley M, Dennehy E, Ó'Gallachóir B. Energy in Ireland 1990 - 2009. Energy Policy Statistical Unit, Sustainable Energy Authority of Ireland, 2010	When the PES matches the statistics we calibrate the model by changing the CO2 content in the fuel types.
Storage	Thermal storage	Gadd H, Werner S. Daily Heat Load Variations in Swedish District Heating Systems. In Review 2013	We calculate it by using 4 hours of average DH demand based on the DH demand from EP (a mix of the distribution and the demand)

	Oil storage	IEA report on energy security of supply	RO is based on 90 days of storage
	Gas storage	Enerdata	
	Hydro pumped storage	Enerdata	The Pumped hydro is only used as a storage option in IEA, but the capacities and actual storage is from Enerdata.
	Dam hydro storage	Calculated	The dam hydro capacity is assumed to be 31 days of full operation
regulations	min CHP, grid stabilisation	Estimations	For min CHP and PP we use around 10% as default. It is changed for some countries during the calibration in order to create a system in balance. Minimum grid stabilisation production share of 50% for all countries.
Distributions	Electricity demand	University of Zagreb; Aalborg University	
	Heat demand	University of Zagreb; Aalborg University	
	District heating	University of Zagreb; Aalborg University	
	Import/export of electricity	University of Zagreb; Aalborg University	
	Cooling demand	University of Zagreb; Aalborg University	
	Natural cooling	University of Zagreb; Aalborg University	
	Solar thermal	University of Zagreb; Aalborg University	
	Onshore wind	University of Zagreb; Aalborg University	

	Offshore wind	University of Zagreb; Aalborg University	
	PV	University of Zagreb; Aalborg University	
	Hydro water inflow	University of Zagreb; Aalborg University	
	Hydro production	University of Zagreb; Aalborg University	
	Transport	University of Zagreb; Aalborg University	
	Price distributions	Aalborg University	Historical 2009 price distributions are used. UK uses distribution for UK, while HR, CZ, RO uses AT distribution. IT uses IT.
	Geothermal power	University of Zagreb	Constant production throughout the year
	Industry district heat production	Aalborg University	Constant for all countries.
Costs	Investments, O&M, lifetime	From AAU cost database	All the sources, numbers, etc., can be found in the cost database. In general the costs include investments, O&M and the lifetime of the technology, CO2 and ngas and electricity exchange according to the model. No taxes are included.
	Ind. Boilers	JRC, ENTRANZE, CaRB	calculating the amount (single-family, multi-family and services) and the costs
	Interconnections	ENTSO-E, P.51 Poyry Report for EirGrid	Split between onshore/offshore interconnections and with around 10 times higher costs for offshore than onshore. The onshore interconnections are assumed to have similar costs to electric grid.
	Electricity grid	DEA (cost database)	

	Transport vehicles	Danish Energy Agency (Alternative drivmidler) and stock from Enerdata	The costs are based on the stock of different types of vehicles, (cars, trucks, busses driven by different fuels) and the investments, O&M and the associated lifetimes
	EV charging stations	Danish Energy Agency	It is assumed that the EV charging station costs are 1,000 EUR/EV
	District heating pipes	University of Flensburg	
	Large power plants and centralised boilers	Cost database	These are calculated by proportioning the total capacity by fuel consumption and thereby creating different plant types with different costs

Project No: IEE/13/650

Creating Hourly Profiles to Model both Demand and Supply

Work Package 2

Background Report 2

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: David Connolly, Work Package 2 Coordinator, Aalborg University
David Drysdale, Aalborg University
Kenneth Hansen, Aalborg University
Tomislav Novosel, FAMENA, University of Zagreb
Contact: Aalborg University, Denmark
A.C. Meyers Vænge 15
DK- 2450 Copenhagen
T: +45 9940 2483
E-mail: david@plan.aau.dk
Web: www.en.aau.dk

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

Nomenclature

Variable	Description
ABM	Agent based modelling
CDD	Cooling degree day
EV	Electric vehicle
HDD	Heating degree day
HW_H	Hourly hot water demand
HW_Y	Yearly hot water demand
MW	Megawatt
PJ	Petajoule
PV	Photovoltaic
SH_H	Hourly space heating demand
SH_Y	Yearly space heating demand
TH_H	Hourly total heat demand
TH_Y	Yearly total heat demand
TSO	Transmission System Operator

1 Introduction

To analyse an energy system on an hourly basis, hourly distributions must be obtained for demands and productions that vary from hour to hour. For example, this includes all demands such as electricity, heat, cooling, and transport as well as production from sources such as wind, solar, and wave power. This is a very large task since each year includes 8760 hours (or 8784 for a leap year) so a methodology required to build these hourly distributions needs to be applied and a specific methodology is elaborated in detail in this report.

The focus here is at the national level, rather than for example at the building level. Many studies in the past have developed hourly distributions for electricity, heating, and cooling demands at the building level [1-4], but the novelty of this methodology is to develop these distributions at a national level. These are necessary for national energy strategies that are often carried out to investigate issues such as new technologies, targets, and policies [5-7].

The main distributions for non-dispatchable components in the energy system are presented in Table 1. All of the major branches on the demand side of the energy system are non-dispatchable, since the consumer expects their energy demands to be met at the time required. On the supply side, the non-dispatchable components considered here are wind, solar, and waves. This is not a complete list, since other distributions could be necessary depending on the capabilities of the energy systems analysis tool. However, the aim here is to cover the key sectors that are usually non-dispatchable. The complexity associated with each distribution varied significantly depending on the type and availability of data, but even if the distribution is relatively simple to create, a brief description is included here for completion.

Table 1: Distributions created in this study for non-dispatchable components in the energy system.

Demand	Supply
Electricity	Wind Power
Heating	Solar Electricity (Photovoltaic)
Cooling	Solar Thermal
Transport	Wave Power

After creating the distributions, some are compared against existing data: these are the distributions for heating, wind, and solar (PV and thermal). The results suggest that each technique provides a good approximation of the demand or supply that it presents. To quantify this, the distributions were calculated using the methodology defined here for different countries. Subsequently, they were compared with historical data, to examine if the distributions created here produced similar results to the data measured locally. Overall, the distributions that could be validated demonstrated very similar trends to the historical data, but there are differences in the exact values at each hour. The similarly was quantified using a regression analysis, but the values did not correlate very well with a visual comparison of the distributions, so this should only be seen as a guide. Considering the original purpose, which was to develop hourly distributions for national energy modelling, we concluded that these distributions are sufficiently accurate for creating and evaluation national energy strategies. The electricity demand is based on measured data, so this did not need to be validated, while the remaining distributions, which are transport and wave power, were not validated since no local measurement data was obtained to do so.

2 Methodology and Results

Each distribution has a single value representing each hour of the year, which results in a total of 8760 hours (or 8784 if it is a leap year). Each data point represents a value between 0-100% of the maximum hourly value over the year. For example, Figure 1 illustrates how an hourly distribution of the Irish electricity demand for January 2007 is distributed over the month. By normalising the data in this way, it is possible to use the hourly distribution for different total values. For example, Figure 2 illustrates how the normalised distribution in Figure 1 is used to represent three different total electricity demands over the month of January. This enables various different scenarios to be easily compared using the same distribution in an energy system analysis tool. Similarly, the normalised distribution can be adjusted based on an installed capacity by adjusting the peak hourly value recorded during the year, which can also be required depending on the methodology in the energy system analysis. Finally, by normalising the distributions it is also possible to compare different countries with one another, independent of scale or annual totals. This can expose the different challenges facing countries, depending on the resources and demands that are present. In the following section, the data collected and any proceeding adjustments applied are described for each hourly distribution. Once again, these distributions are designed for national energy system analysis tools, and hence the focus is on national data and behaviour rather than the building level for example. Therefore, after describing the methodology, it has been applied here to different EU member states to demonstrate how the hourly distributions can be applied and to validate the results. The member states considered at different points in the study are Croatia, Czech Republic, Denmark, Germany, Italy, Romania, and the United Kingdom.

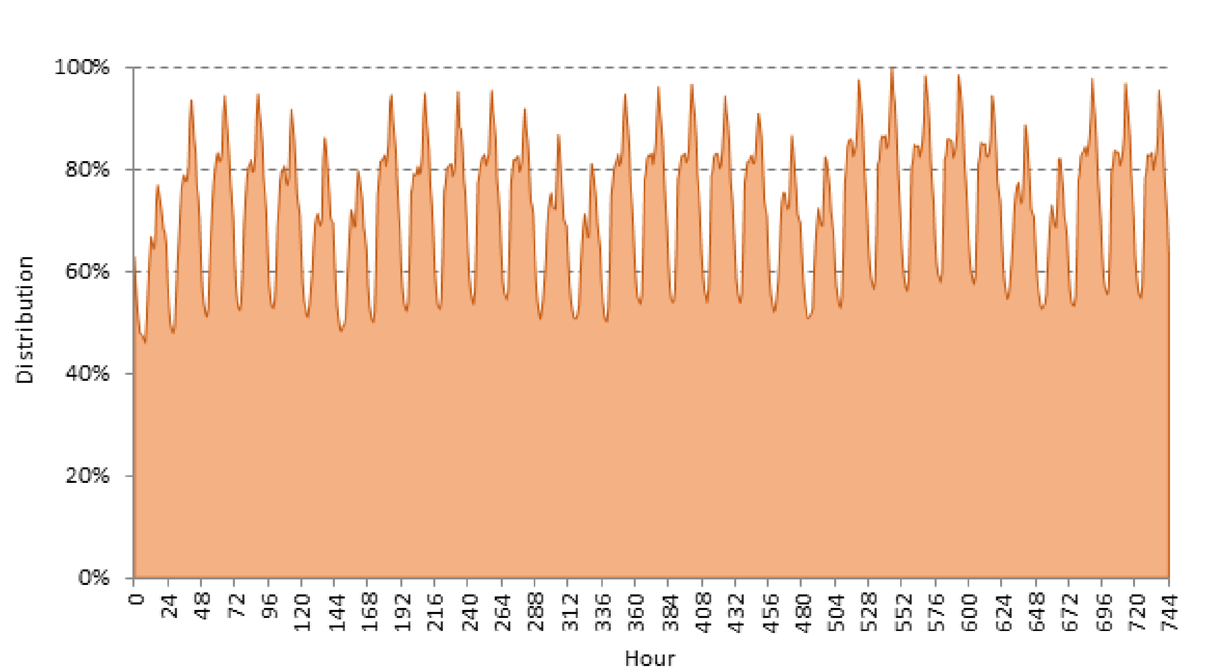


Figure 1: Distribution of Irish electricity demand for January 2007 [8].

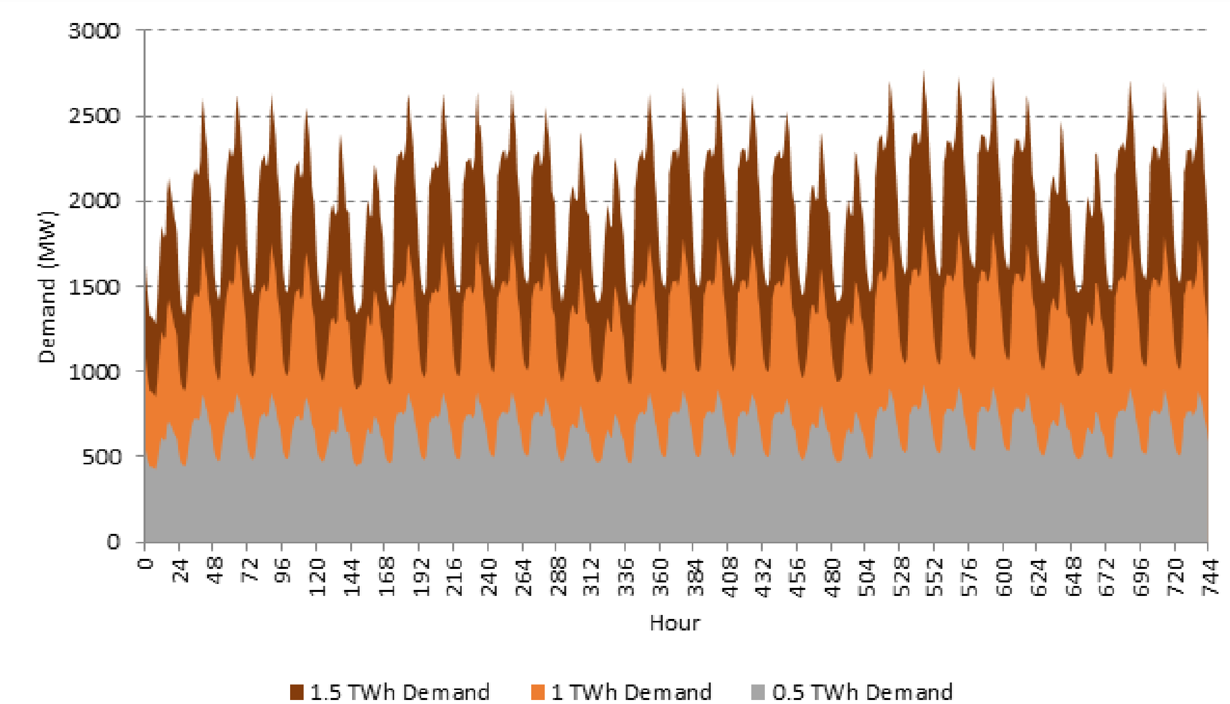


Figure 2: Distribution modified by the total Irish electricity demand required for January 2007 [8].

After describing the method for each distribution the authors attempt to validate the results based on case studies that have some existing data. It is very difficult to verify the hourly data produced in this study, since in almost all cases the hourly data is not available for a variety of reasons, such as 1) it is not measured, 2) it is not publicly available or 3) it is measured at an individual plant level and not at a national aggregation. As a result the validation is only done for the heat demand, wind power, solar photovoltaic, and solar thermal supply. For these validated distributions, the comparisons are made based on qualitative visual comparison as well as by carrying out a regression analysis comparing the two distributions in order to quantify the correlation. However the regression analysis is only used as an additional test where the visual test is the main comparison. The regression analysis cannot capture the distribution behaviour in which we try to compare such as long term trends and likeness. The regression analysis determines absolute correlation which is not necessary in the tests since we only need generic behavioural distributions during the year, we are not trying to replicate old data with the distributions, but rather we try to create model distributions for future application.

The electricity demand does not need to be validated since it is based on measured data from the various transmission system operators (TSOs) around Europe, while it is not possible at present to validate the cooling demand, transport demand, or wave power since no verified hourly production data could be obtained. In this way, the hourly distributions should be seen as a best estimate based on existing knowledge of what type of hourly variations can be expected in the future, rather than a recreation of what is being recorded today.

2.1 Demands

A different hourly distribution is typically required for each of the main end-user sectors: electricity, heating, cooling, and transport.

2.1.1 Electricity

Both the annual and hourly electricity demand is available and easily accessible for all EU countries and most European countries outside the Union. The annual electricity demand can be obtained from several sources like the International Energy Agency [9], national reports and the European Network of Transmission System Operators for Electricity [10]. Hourly electricity demand can usually only be obtained from two sources, either from the national TSO or, if the data is available for the modelled country, from the European Network of Transmission System Operators for Electricity [10]. For the purpose of this report the second option was used. The hourly data is publicly available online for all of the observed countries. Figure 3 demonstrates the electricity demand for Romania for the first week of January and June.

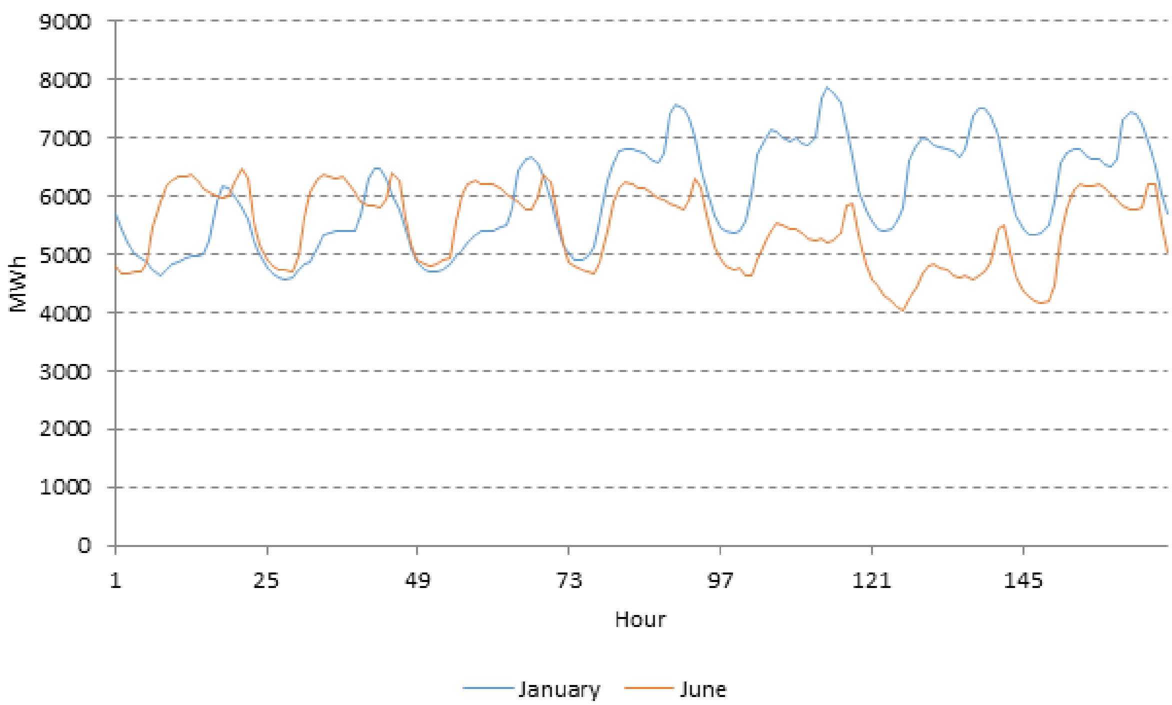


Figure 3 Hourly distribution curve for electricity demand

2.1.2 Heat

Hourly heat demand data is usually only available in countries with district heating systems and even in this case, it is usually not publicly available information. To overcome this, heat degree days (HDD) are typically used to evaluate variations in heating demands at different locations.

HDD are measured based on the outside temperature at a specific location. The temperature within a building is usually 2-3°C more than the temperature outside, so when the outside temperature is for example 15°C, then the inside temperature of a building is usually 17-18°C. Therefore, once the outside temperature drops below 15°C outside, then the inside temperature drops below 17-18°C and the space heating within a building is usually turned on. The outside temperature used to estimate the space heating demand, for example, in this case 15°C, is referred to as the set-point. HDD are calculated based on the difference between the set-point and the outside temperature, with the difference reflecting the amount of heat that is required at that time [11, 12]. To create an hourly distribution, the same methodology is applied for each hour of the year by comparing the temperature measured outside with the set-point. If the outside temperature is above the set-point, then the HDD for that hour is assumed to be zero. As a result, the results are very sensitive to the set-point that is assumed. Different values are typically used depending on a number of factors such as the climate and the typical level of house insulation in the area [11].

Space heating is usually not required during the summer months of the year, since the heat absorbed during the warm days and hours is enough to keep the buildings warm during colder periods. Once again, this is evident on district heating systems, as their operators often shut down the supply of space heating in the summer months. For example, district heating systems in the Czech Republic usually stop supplying space heating for June, July and August (see Appendix A). When the hourly distribution is created based on outside temperature data, there can be some hours in the summer where the outside temperature is above the set point, even though it is very unlikely that people use their heat systems during these hours. To account for this, the space heating demand is set to zero for all hours outside of the typical heating season. The result is an hourly distribution of space heating which can be replicated for any location in the world that records outside temperature, which is very common and publicly available information. However, HDD only represent variations in the hourly space heating demand (SH_H) and not in the hot water demand.

Hot water is required for cooking, cleaning, showering, and bathing in buildings. Unlike space heating, hot water demands do not vary significantly over the year. This is evident during the summer months on district heating systems, when the space heating is switched off and the only demand being met is hot water [13, 14]. Based on these experiences, it is assumed here that hot water is a constant demand over the entire year. The demand for hot water is estimated here by identifying what percentage of the total annual heat demand, TH_Y, is hot water, $HW_{Y\%}$. This data is currently available from the ENTRANZE database [15]. This total demand for hot water is then evenly distributed over each hour of the year, to identify the hourly demand for hot water, HW_H. It is assumed that each hour in the year has the same constant demand for hot water. This can then be added to hourly space heating demand, SH_H, developed with the HDD data, to provide an hourly distribution for the total heat demand (TH_H).

$$HW_H = \frac{\frac{SH_Y}{1 - HW_{Y\%}} \cdot HW_{Y\%}}{h} \tag{1}$$

This methodology has been applied to the five EU member states based on the assumptions outlined in Table 2. An example of the resulting hourly distributions is presented in Figure 4 for the United Kingdom, demonstrating the short-term hourly variations that occurs over the year.

Many of the extreme changes are concealed if hourly data is replaced with daily average, as displayed in Figure 5, outlining the importance of hourly considerations when simulating the heating sector.

Table 2: Assumptions for the hourly heat distributions developed in this study to apply the methodology.

Country	Space Heating Assumptions		Hot Water Assumptions		District heating distribution
	Set-point (^{O}C)	Heating Season	Annual Hot Water Demand (% of total heat demand)	Resulting Ratio of Peak to Baseload Demand (from equation 1)	Network Losses (% of annual heat production)
Croatia	16	15th September to 15th May	16%	22	14%
Czech Republic	16	Conditional: see Appendix A	18%	15	16%
Italy	16	All Year: see Appendix A	13%	34	n/a (assume 15%)
Romania	16	Conditional: see Appendix A	28%	14	19%
United Kingdom	16	1st October – 30th April	20%	15	n/a (assumed 15%)

Finally, when this heating distribution is used to model future heating scenarios, it is likely that heat savings will need to be taken into account due to measures such as better insulation, doors, and windows. In these future scenarios, the relationship between space heating and hot water demands will need to be recalculated based on the new demands after these savings are implemented.

These hourly distributions represent the heat demand in the building, so it does not reflect the demand for heat from a district heating system. If an hourly profile is required to represent the demand form district heating plants, then network losses must also be considered. These are added as an additional baseload demand in the same way as hot water, but this time using the annual network losses over the year. Typically these network losses are in the region of 15% [16], but can sometimes be calculated for different countries from annual energy balances [9]. As displayed in Table 2, the data required is not always available to do so.

In order to validate the methodology used for the creation of the heat demand distribution, hourly values for a district heating plant in Italy have been used. Using the method described above a calculated hourly heat distribution was calculated for Italy. This calculated demand is compared with the reference real world demand.

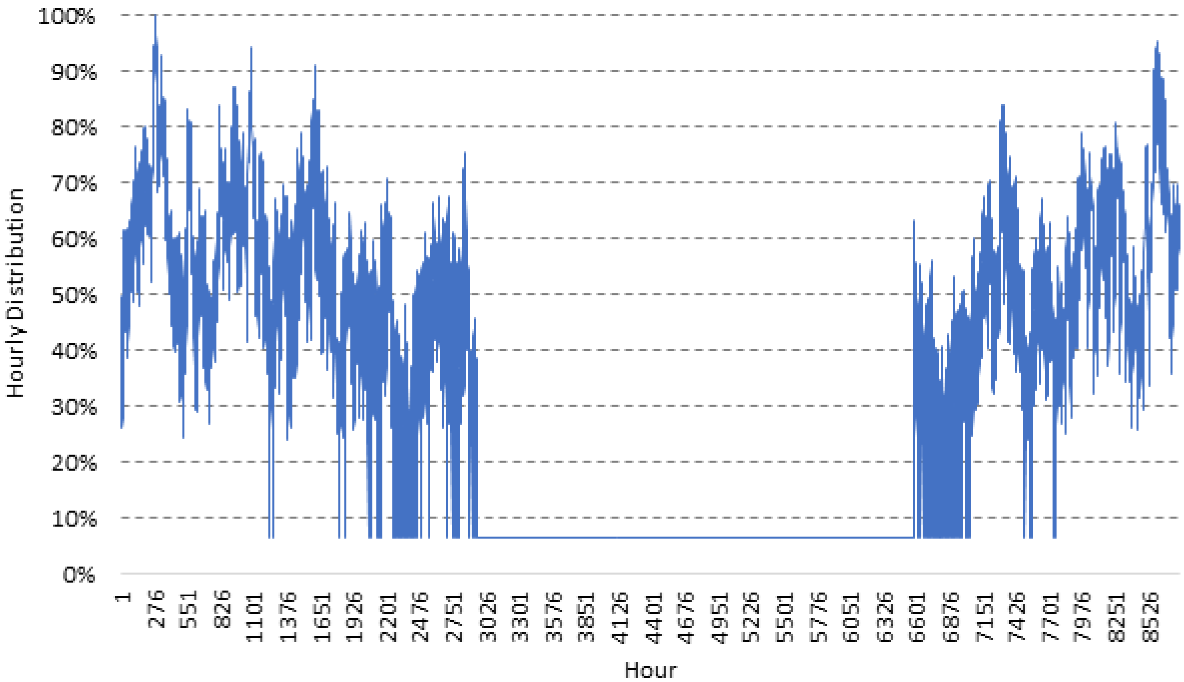


Figure 4: Hourly heat demand distribution for the United Kingdom.

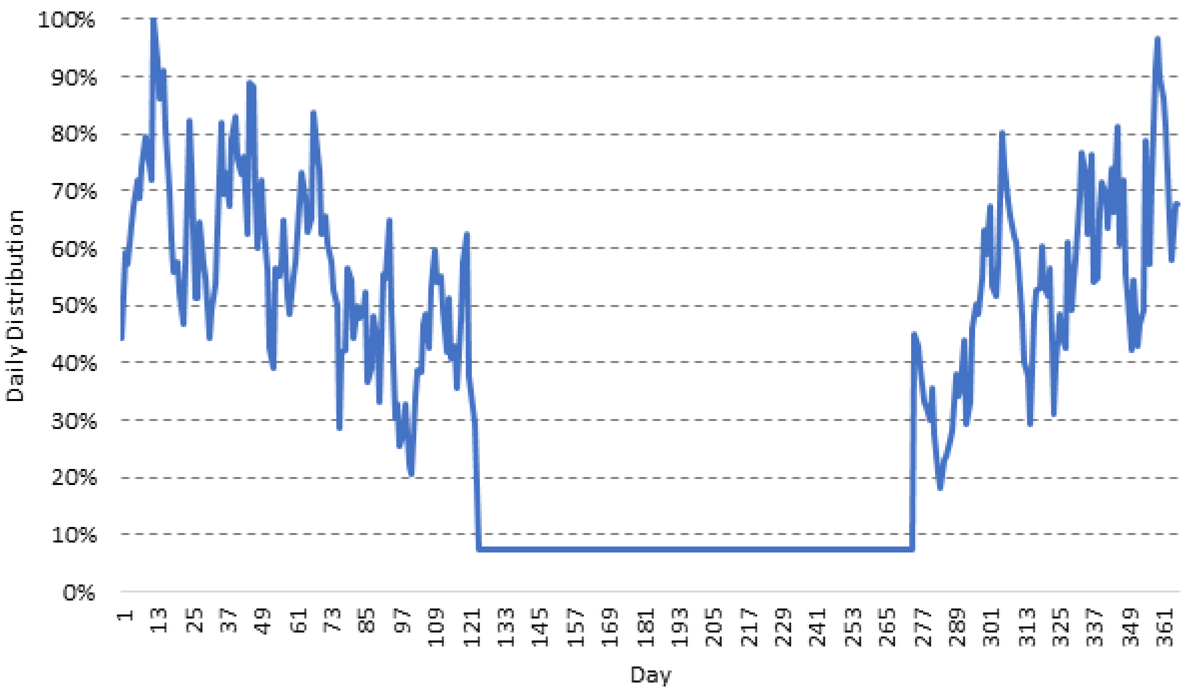


Figure 5: Daily heat demand distribution for the United Kingdom.

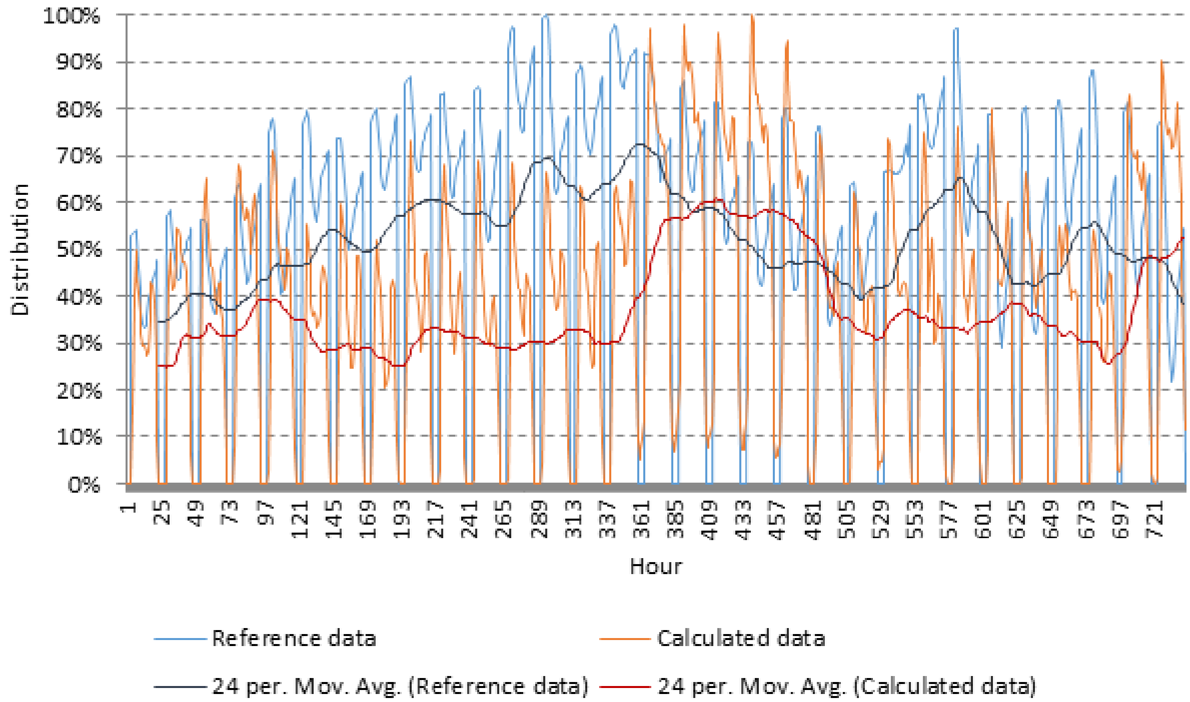


Figure 6: Comparison of reference and calculated heat demand in Brescia in Italy for January 2012.

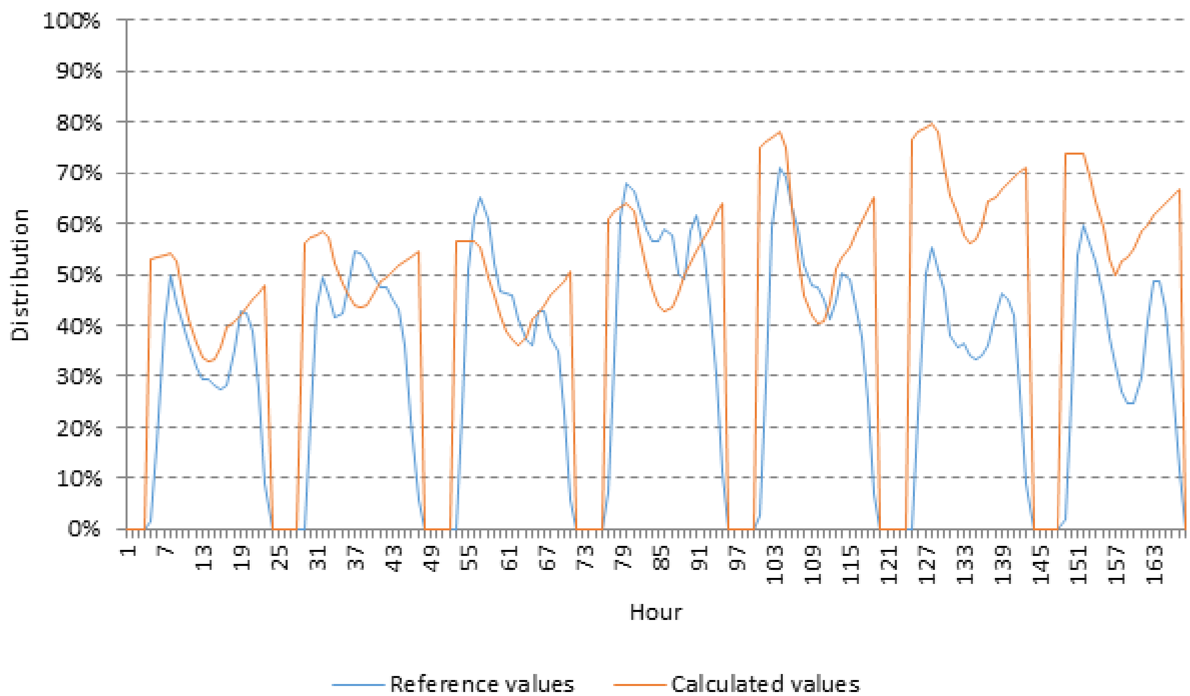


Figure 7: Hourly comparison of the heat demand on an Italian district heating system. The identity of city cannot be revealed due to a data confidentiality agreement.

Figure 6 shows the heat demand in January 2012 (744 hours) for the calculated and reference distributions, on an hourly basis. The 24-hour moving average is also shown for both distributions. The reference distribution is based on heat demand in Brescia in Italy for the year 2012. In order to compare the two curves, the original data provided by the district heating plant had to be separated into the hot water and space heating demands. The calculated hourly distribution also had to be modified in order to accommodate to the heating regulations of Italy where the heating is active from 05:00 to 23:00 (see Appendix A: Typical Heating Season in each STRATEGO Country). The results show that there is some correlation between the hourly distributions with an R2-value of 0.36.

Figure 7 demonstrates the comparison between the reference and the calculated data sets for the first week of January (168 hours). It can be seen that the two data sets follow similar trends, with a slightly higher difference in the last two days. The R^2-value comparing the two distributions is 0.44. This is because the peaks and troughs during the period are at slightly different times and locations in the figure.

2.1.3 Cooling

The cooling distribution is created using a similar methodology as the heating distribution. The Cooling Degree Days (CDD) are estimated using the same approach as HDD, but the set-point is usually different and the cooling demand occurs when the outside temperature is above the set-point, rather than below. The key challenge when applying the CDD methodology to create an hourly distribution is the lack of knowledge about cooling demands. Today cooling is mostly provided using air-conditioner units (heat pumps) that consume electricity. As a result, cooling demand is usually measured in terms of how much electricity is consumed by these air-conditioning units, rather than based on the cooling demand within the buildings. The only true measure of cooling demand is available from district cooling networks, but currently there are relatively few large-scale district cooling networks in place. In total there are approximately 100 district cooling systems in Europe, but these are still relatively small compared to the overall demand: in 2009 the verified district cooling demand was approximately 9 PJ compared to a total cooling demand of approximately 700 PJ in Europe [13]. It was not possible to obtain hourly demand data from the existing district cooling systems during this work, but general characteristics of cooling demands have recently been reported by Frederiksen and Werner [13] and also in the RESCUE project [17].

The RESCUE project analysed hourly cooling demand from approximately 50 buildings spread across different district cooling systems in Europe. Surprisingly, their results indicated that the demand for ‘comfort cooling’ began at temperatures as low as 9^{O}C, and became fully linear to ambient temperature at approximately 15-17^{O}C. As a result, the set-point for estimating the district cooling distribution should be in this region when calculating the CDD.

The RESCUE analysis also indicated that on average 56% of the cooling demand was identified as baseload (i.e. non-weather dependent) [17], indicating that very large proportions of cooling are required throughout the year. This is likely due to the high number of services buildings that make up the cooling demand, which require cooling for non-weather dependent applications such as offices and IT applications. The non-weather dependent share can be used in the same way as the hot water share for heating in equation 1.

Table 3: Assumptions for the hourly cooling distributions developed in this study to apply the methodology.

Country	Space Cooling Assumptions		Baseload Assumptions	
	Set-point (^{O}C)	Peak Cooling Demand (% of peak after CDD methodology)	Annual Baseload Demand (% of total cooling demand)	Resulting Ratio of Peak to Baseload Demand (from equation 1)
Croatia	17	100%	56%	7
Czech Republic	16	100%	56%	13
Italy	17	100%	56%	7
Romania	17	100%	56%	10
United Kingdom*	15	85%*	56%	10

*A peak was removed from the UK data since it was considered an outlier: it represented a day where the average temperature from the six locations across the UK was 29˚C, primarily due to a temperature of 39˚C recorded in Glasgow. This is an extremely high temperature for the UK so it is unlikely that cooling units will be designed to meet this once-off peak demand.

Once again, this methodology is applied here to the five different countries using the key assumptions outlined in Table 3. The set-point was varied between the countries depending on their climate since it is assumed that the buildings in warmer countries have better natural cooling than the buildings in colder countries. This was monitored by calculating the ratio between the peak cooling demand and the baseload cooling demand during the year. Data reported by Frederiksen and Werner for the district cooling system in Helsingborg (Sweden) indicates that this ratio is approximately 8 [13], and hence a similar scale was purposely maintained here. An example of the resulting hourly distribution is presented in Figure 8 for the Czech Republic. As expected the cooling demand is baseload during the winter months and peaks in the middle of summer. Once again, the hourly distribution in Figure 8 displays much larger variations than the daily distribution equivalent displayed in Figure 9. Many buildings use electricity to supply this cooling demand so accounting for these variations is important for the short-term balancing of the electricity grid. If district cooling is used instead of electricity to meet the cooling demand, then district cooling network losses of approximately 10% of the annual district cooling production should be added [13]. Validation for the cooling distribution method is not possible in this study due to a lack of reference data.

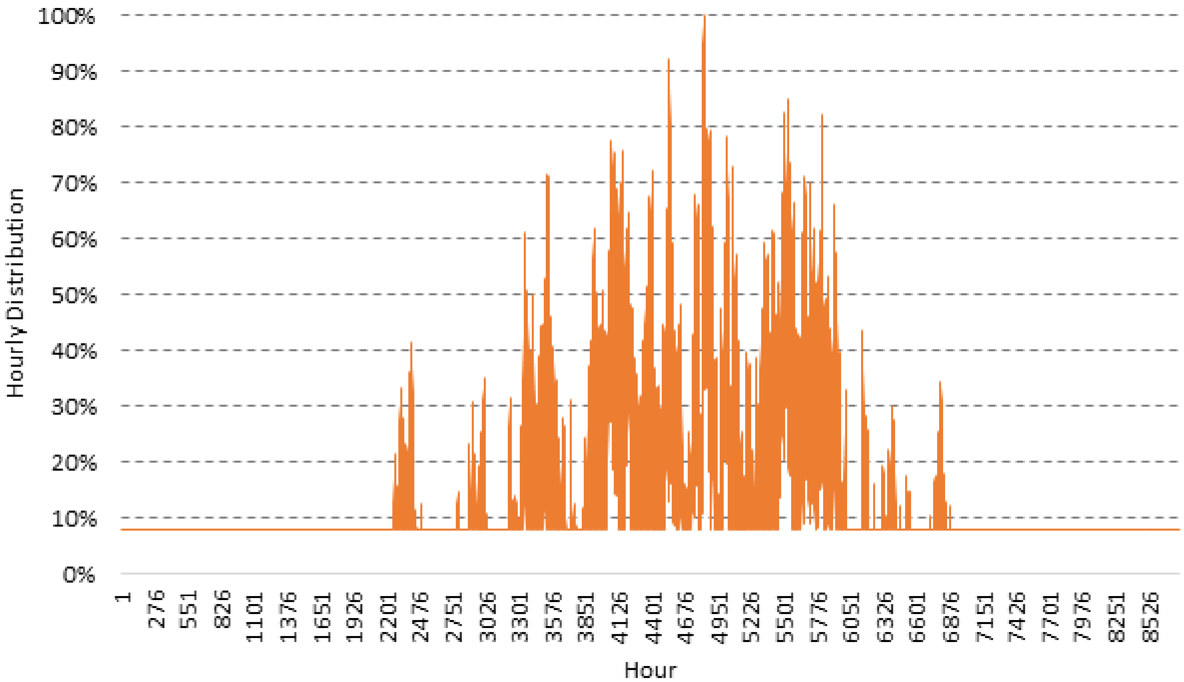


Figure 8: Hourly cooling demand distribution for the Czech Republic.

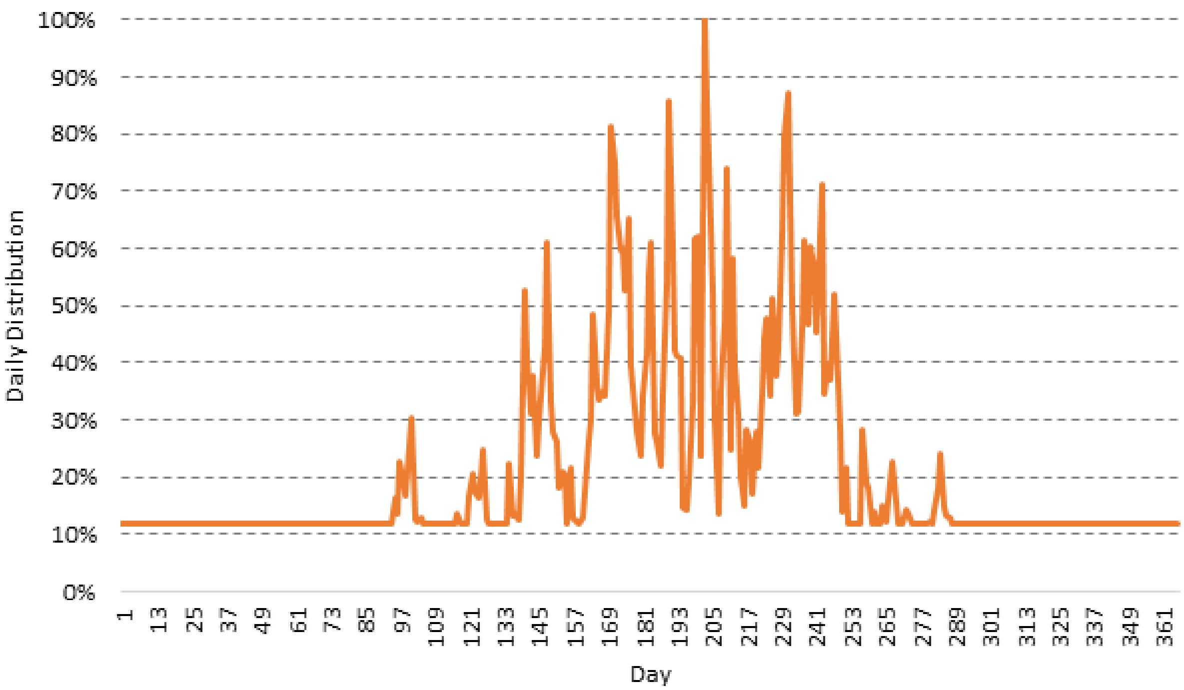


Figure 9: Daily cooling demand distribution for the Czech Republic.

2.1.4 Transport

A variety of approaches for the creation of annual energy consumption of the transport sector have already been described in the past [18-20]. Hourly data is usually more difficult to obtain, especially data adequate for energy planning. The agent based modelling (ABM) tool MATSim [21] has been used in this work for this purpose. The hourly distribution curve for the energy consumption of the transport sector has been created based on a case study for Croatia. MATSim is a data intensive tool requiring a broad range of input data from demographic information, activity plans, detailed transportation network and the definition of facilities. The created case study has been focused on Croatia's four largest cities namely Zagreb, Split, Rijeka and Osijek which together encompass the majority of the total population. The quality of the obtained results is very sensitive to the quality of the provided inputs. The best possible would be if each single agent represented one surveyed person, but this would be highly impractical and the data would be impossible to get. Therefore the inputs have to rely on surveys conducted amongst a limited number of participants and set of data that is usually available in an aggregated form. In order to reduce the number of input data and simplify the preparation of MATSim inputs some assumptions had to be made. The only two activities foreseen by the model are work and home and there are no holydays throughout the year. Figure 10 represents the distribution of work and home locations for the four modelled cities and the created network.

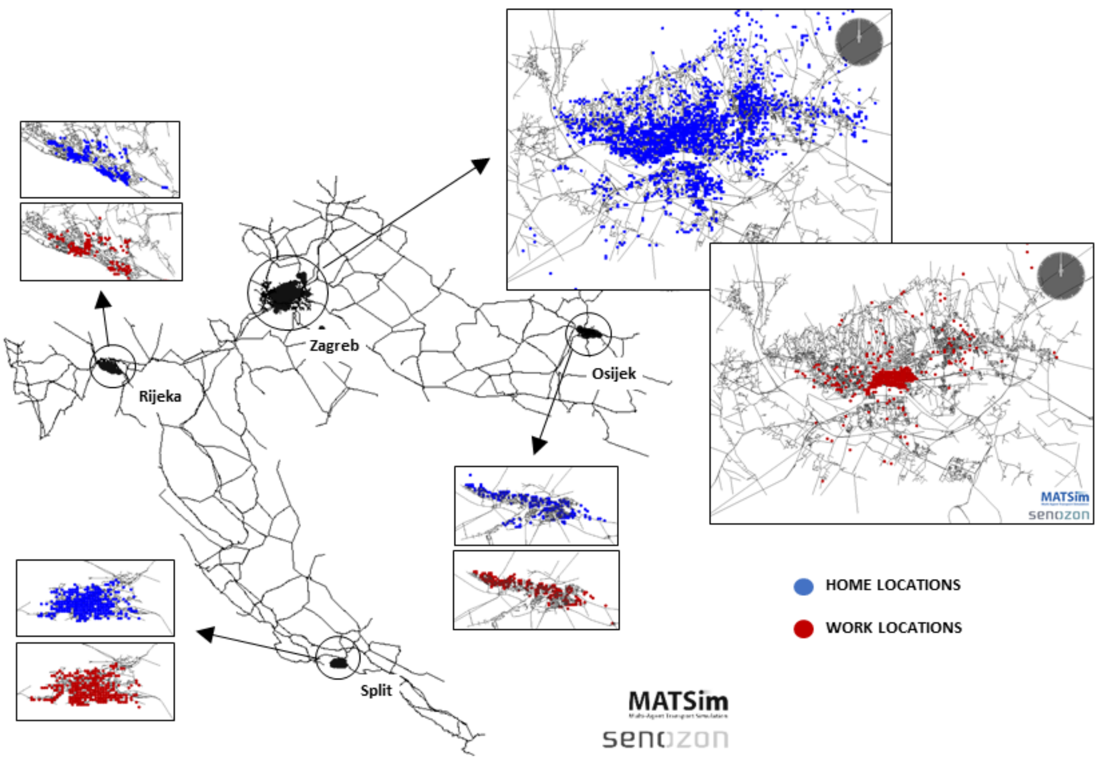


Figure 10: Distribution of home and work locations.

The detailed explanation of the methodology is available in our previous work [22]. The obtained distributions for the four individual cities as well as the aggregated curve are presented in Figure 11. It is not possible to validate the transport distribution method in this study due to a lack of data.

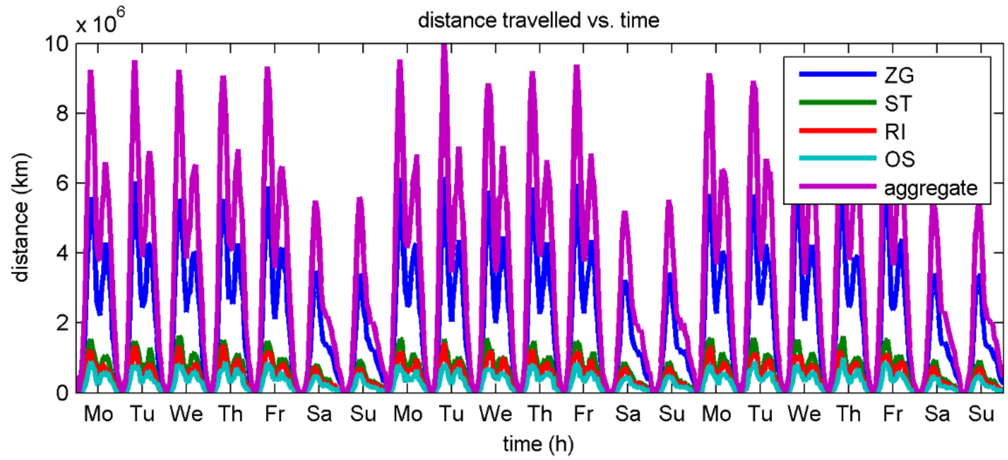


Figure 11: Hourly distribution of energy demand in transport.

2.2 Supply

Hourly distribution files are developed for three different types of renewable resources: wind, solar, and wave power. For solar, both solar PV and solar thermal are created separately.

2.2.1 Wind Power

In order to create an hourly distribution of electricity production from wind, hourly wind speed data has to be gathered first. These data can be obtained from measurements, computer tools like Meteonorm [23], national databases [24, 25] or similar sources.

For the purpose of this work, hourly wind speeds for one year have been gathered for six locations within every modelled country using the Meteonorm tool [23]. If we take the UK as an example, the data has been collected for Belfast, Bristol, Cardiff, London, Edinburgh and Glasgow. The gathered values represent hourly wind speeds at an elevation of 10m above ground. Figure 12 presents the gathered raw data for the six selected locations in the UK for the first week of July.

In order to utilize the gathered data in an energy system modelling tool such as EnergyPLAN, the wind speeds had to be converted into energy production. To accomplish this, power curves for three different wind turbines have been used, one 2MW turbine at an elevation of 80m and a 3MW and a 5MW turbine at elevations of 100m. Power curves of different wind turbines are readily available online [25-27]. The three utilized power curves are presented in Figure 13. Equation 2 has been used to calculate the wind speeds at the elevations of 80m and 100m based on the ones collected from Meteonorm.

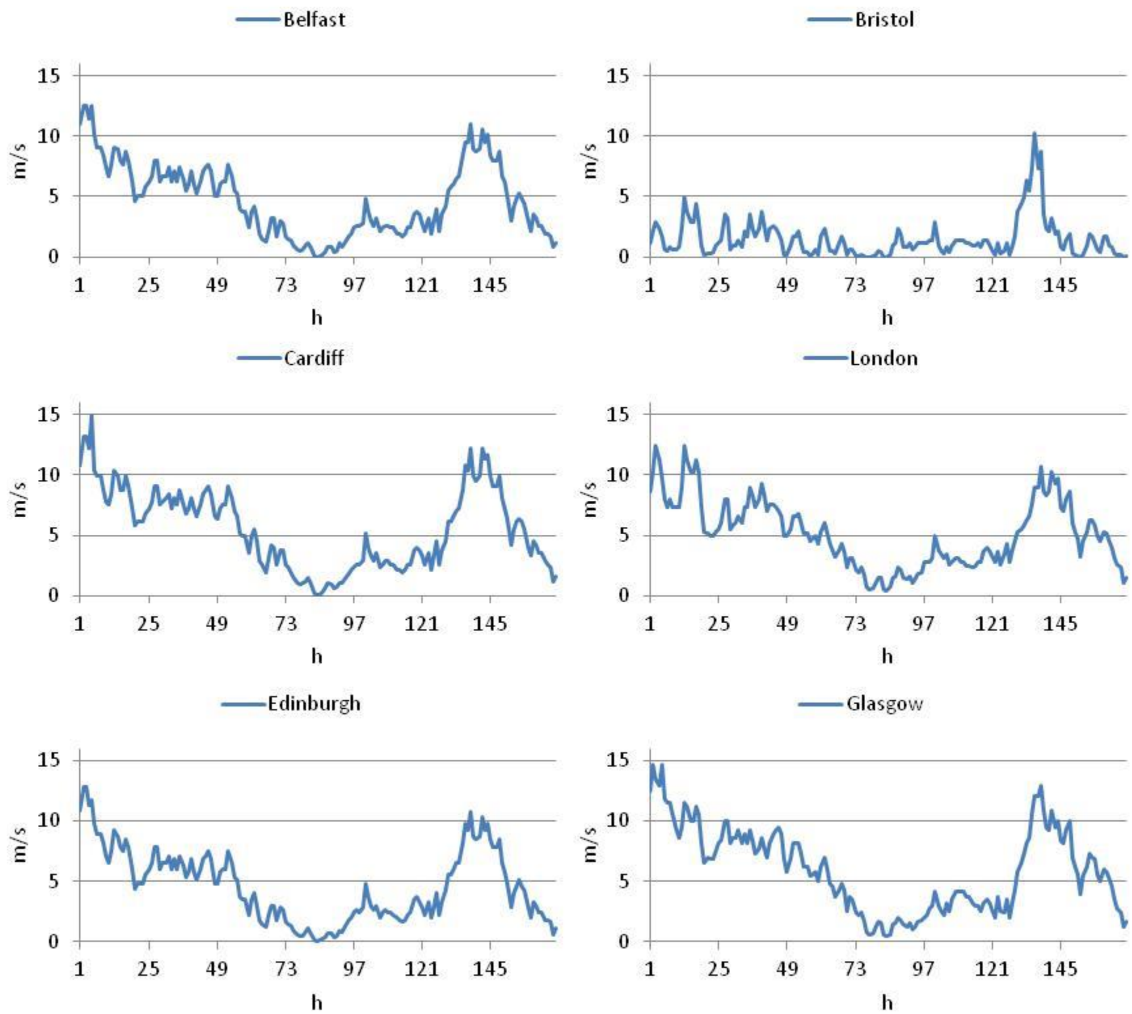


Figure 12: Raw wind speed data.

Using Equation 2 and the presented power curves, the electricity production for every individual location is calculated. The aggregated distribution curves for the whole countries are then calculated as an average of the six individual ones. Figure 14 presents the average wind speeds at 100m and the aggregated distribution curve for electricity production from wind for the UK for the first week of July.

$$
\begin{aligned}
&ws_h = ws_{10} \cdot \left(\frac{h}{10}\right)^{\alpha} \\
&\mathrm{ws}_h - \textit{wind speed at desired height}\ [m/s] \\
&\mathrm{ws}_{10} - \textit{wind speed at}\ 10m\ [m/s] \\
&h - \textit{height at which the wind speed is being calculated}\ [m] \\
&\alpha - \textit{roughness of terrain coefficient}
\end{aligned}
\qquad (2)
$$

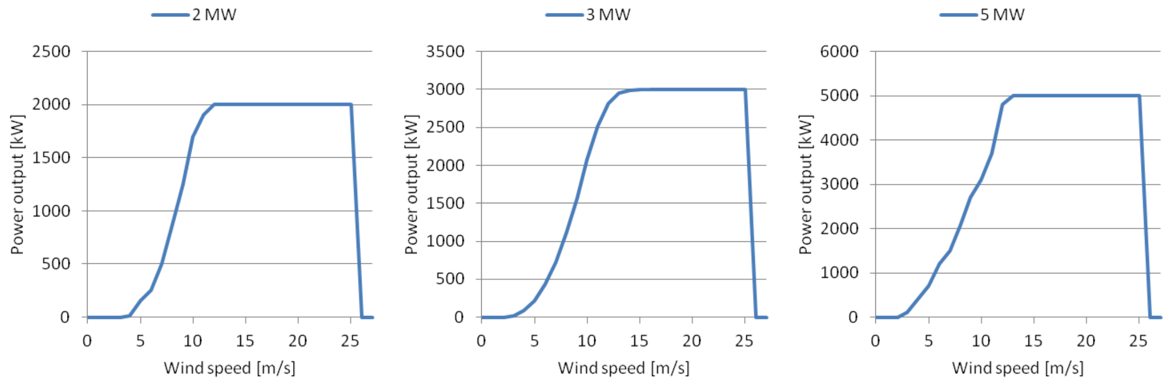


Figure 13: Power curves for different wind turbines.

Electricity production from offshore wind power is handled in much the same way with the exception that offshore wind data is used and there is less available data for these cases. Data measured on islands, offshore platforms or buoys has been used here. If we take Italy as an example, the offshore wind data for 4 locations has been used. The hourly data has again been recalculated to fit the necessary heights and the appropriate power curves have again been utilized to calculate the electricity production. Figure 15 presents the average wind speeds and the aggregated electricity production curve for the four available locations in Italy for the first week of June.

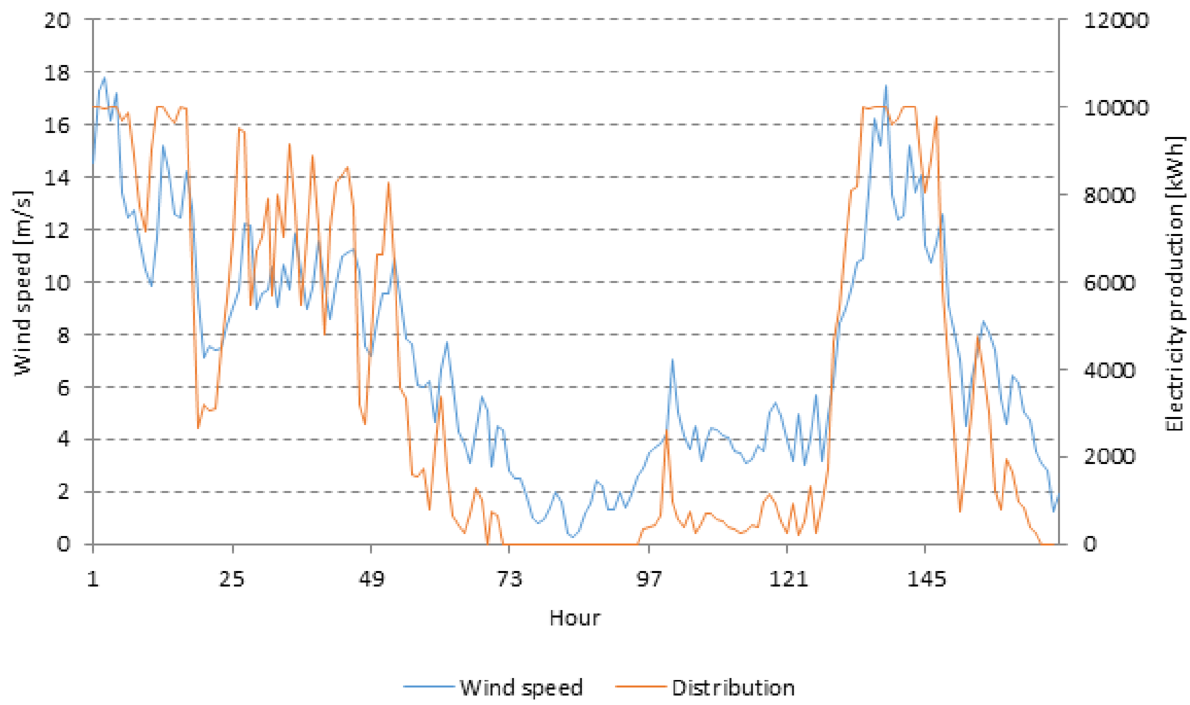


Figure 14: Comparison of the average wind speed and aggregated distribution curve.

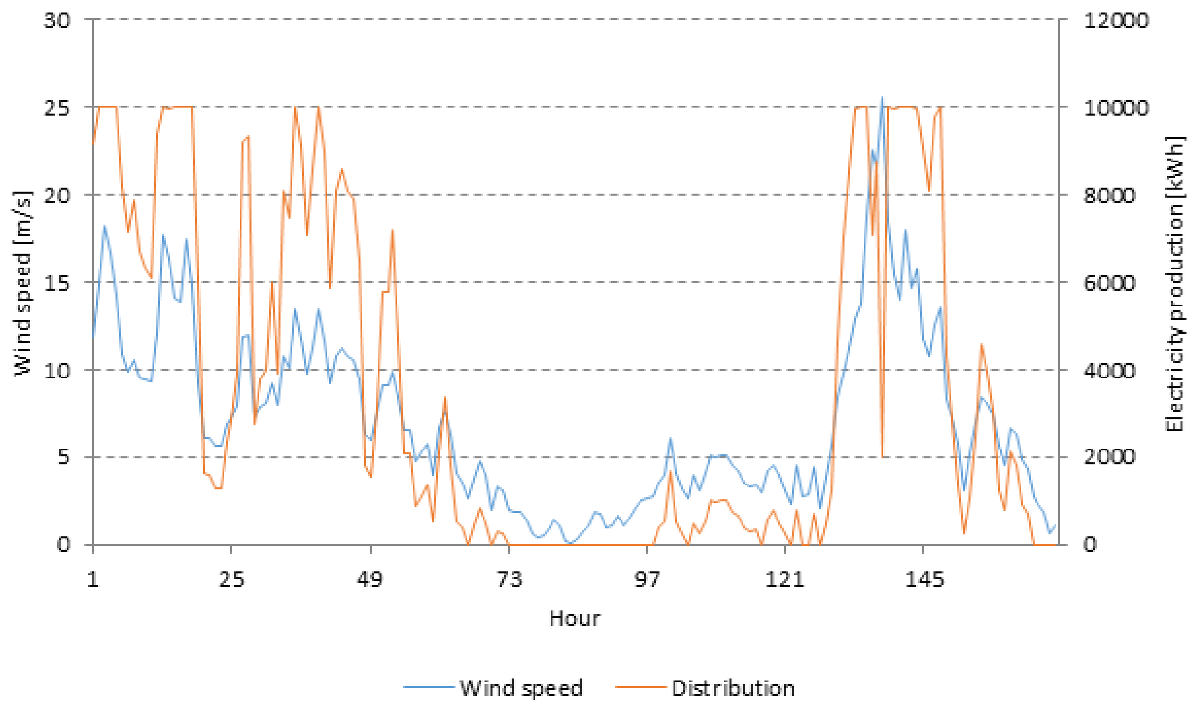


Figure 15: Comparison of offshore wind speeds and the aggregated distribution curve.

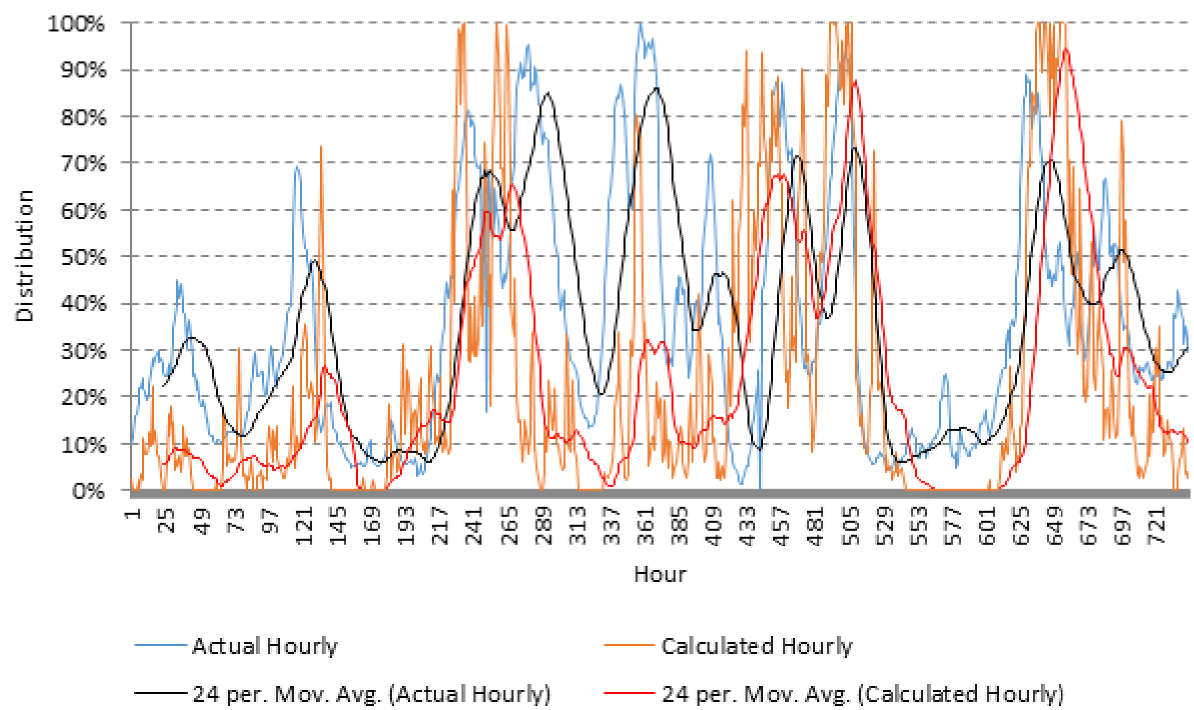


Figure 16: Comparison of actual wind electricity generation with calculated generation for January 2010 in the UK (excluding Northern Ireland).

The UK is used as a case study to validate the wind power distribution. To validate the accuracy of the calculated distribution with actual real world electricity generation, data was extracted from the Elexon database [28]. Elexon is involved in the operation of the wholesale electricity market in the UK. They collect 5 minute interval electricity generation for wind for the UK, excluding Northern Ireland. Figure 16 below compares a calculated distribution with the Elexon data on an hourly basis in January 2010. A moving average over 24 hours is also shown for each distribution. This shows the daily trend and this distribution is used for the comparison. January was selected because later in 2010 numerous wind farms began operation and this skews the comparison. This is because when the distribution is calculated, the total electricity capacity for that year is included from January to December, even if the capacity was not operating in January.

As shown in the figure, on a 24 hour moving average distribution the areas where there are peaks and troughs in wind production is relatively similar between the distributions. The R^2-value comparing the two 24-hour distributions for January is 0.38 showing that there is some correlation between the two distributions. This correlation is not higher since the peaks and troughs in wind occur at slightly different times and locations in the figure. But the important comparison in this study is that the general trend is followed even if at slightly different times. The hourly R^2-value over the month is 0,22, and this is also because the peaks and troughs do not match within the exact same hour, but the trend is similar.

2.2.2 Solar

When it comes to solar power there are two aspects that need to be considered, solar thermal collectors and photovoltaics (PV). The idea behind the generation of the hourly distribution of energy production from both is very similar. For the case of PV, the electricity output will match the solar insolation quite well. For this reason, hourly solar insolation is used to develop the hourly distribution. This data can be obtained from tools like Meteonorm [23]. The insolations are usually available for flat surfaces and tilted plains. The optimal slope and also the optimal azimuth of the surface for maximum annual solar insolation can be obtained from PVGIS for Europe and Asia [29].

The average insolation, and with that the average PV distribution curve, can be created as a combination of the two. For the Czech Republic as an example, solar insolations on flat surfaces and surfaces tilted to the optimal angle obtained from PVGIS have been collected for 6 locations using Meteonorm. The distribution is then created for every location individually as an average of the insolation on the tilted and flat planes. The aggregated distribution curve is calculated as an average of the 6 individual ones. The curves can be calibrated according to the calculated total annual electricity production varying the ratios between the two types of insolation (flat surface and tilted plane). The aggregated curve for the Czech Republic for the first week of January and July are presented in Figure 17.

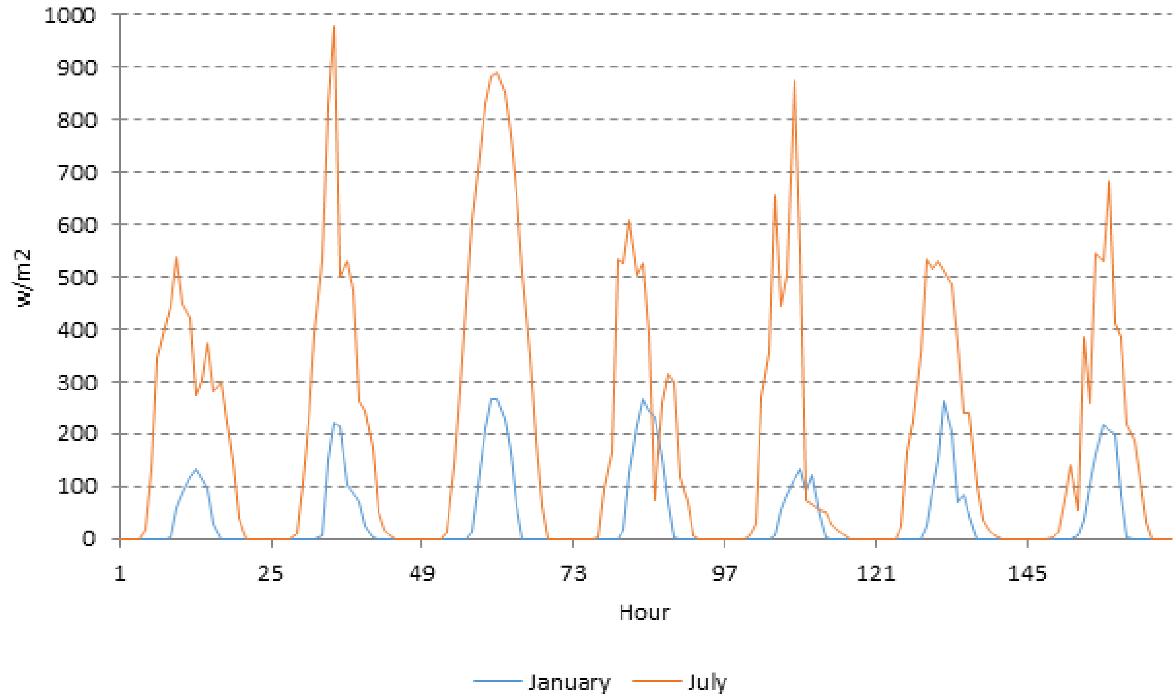


Figure 17: PV distribution for the Czech Republic.

The solar thermal distribution can usually be created the same way as PV if the tool used to model the system handles thermal storage separately from the hourly distribution curve. If the tool uses the hourly distribution of solar thermal production as an input into the energy storage and the heat demand as an output, for example as the tool EnergyPLAN does, the hourly distribution for solar thermal can again be modelled as a function of the hourly solar insolation on a flat and tilted surface.

In order to validate the methodology related to the distribution of energy production from PV, a calculated distribution was compared with actual real world electricity generation using German solar data. Real world data was extracted from the Amprion database. Amprion GmbH is a transmission system operator and operates the German extra-high voltage grid from Lower Saxony down to the Alps. Amprion collect solar production data every 15 minutes in West Germany. Data collected for Hanover and Frankfurt for the calculated distribution was compared with the Amprion data and this is shown in Figure 18 and Figure 21. Data was only available for the second half of 2010 (July 1 to December 31 2010).

In Figure 18 the hourly solar distribution is shown for the reference and calculated distributions. In addition, a moving average over one week (168 hours) is shown for each distribution in order to demonstrate the longer term trend.

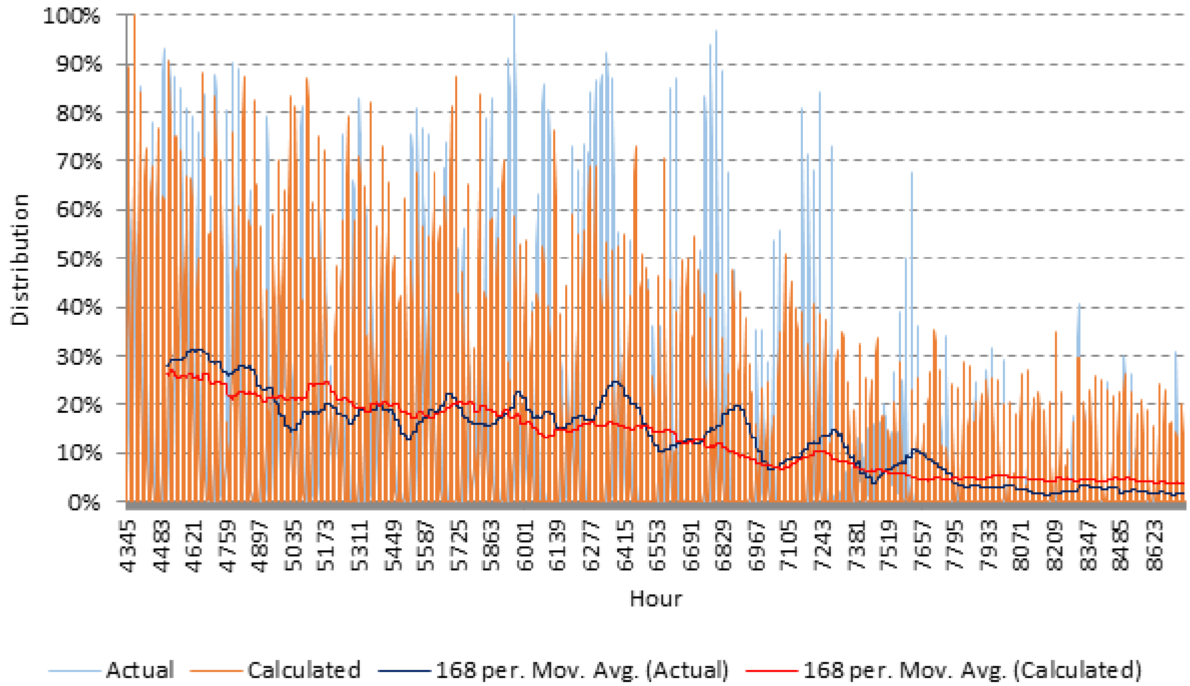


Figure 18: Comparison of reference solar electricity generation with calculated generation for July 1st to December 31st in 2010 for West Germany.

Overall the figure shows a general downward trend in solar production from July to December for both distributions. This is expected as the seasons shift from summer to winter. For the hourly distribution from July to December there is a similar trend and the R^2-value is 0.67, but there are some additional peaks in the reference distribution. Since the actual distribution includes most of West Germany and covers a broader area, the solar capacity is higher than compared with the calculated distribution which only includes two cities. But in general the trends follow each other and there are peaks and troughs occurring around the same periods. The weekly average production (168 hours) comparison shows a similarity between the distributions with an R^2-value of 0.83. If all solar data from this area in Germany was included in the calculated distribution (like it is in the Amprion dataset) then it is likely that the distributions would be closer.

The hourly distributions over the July month over 744 hours are shown in Figure 21 below. The R^2-value for the hourly comparison in this month is 0.55. As explained above, the peaks of the reference distribution are higher since the dataset covers a broader area in Germany and thus has a higher production capacity, increasing the peaks. But in general the trend is similar.

The methodology related to the creation of the solar thermal distributions has been validated on a case of the Marstal plant in Denmark. Hourly values for the solar heat available has been obtained from [30] and compared to the distribution created using the described methodology. It should be noted that hourly solar radiation values were not available for the exact location of the plant and the closest available point has been used, Sydfyns in Demark.

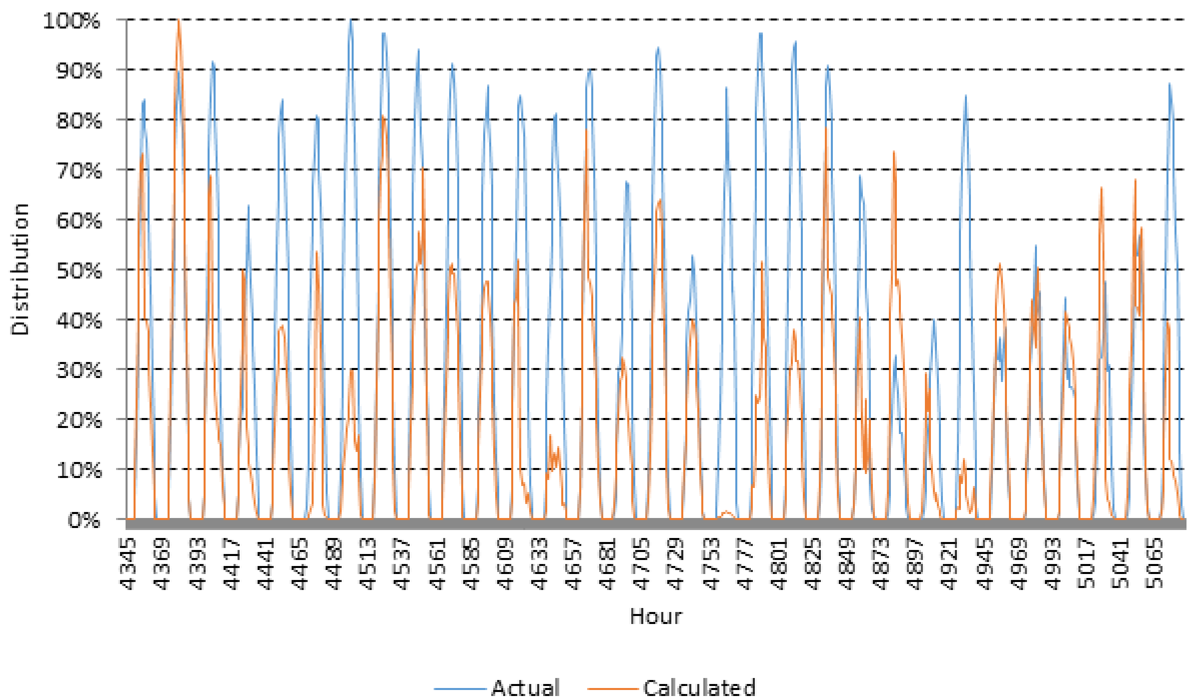


Figure 19: Comparison of reference solar electricity generation with calculated generation for July 1st to July 31st in 2010 for West Germany.

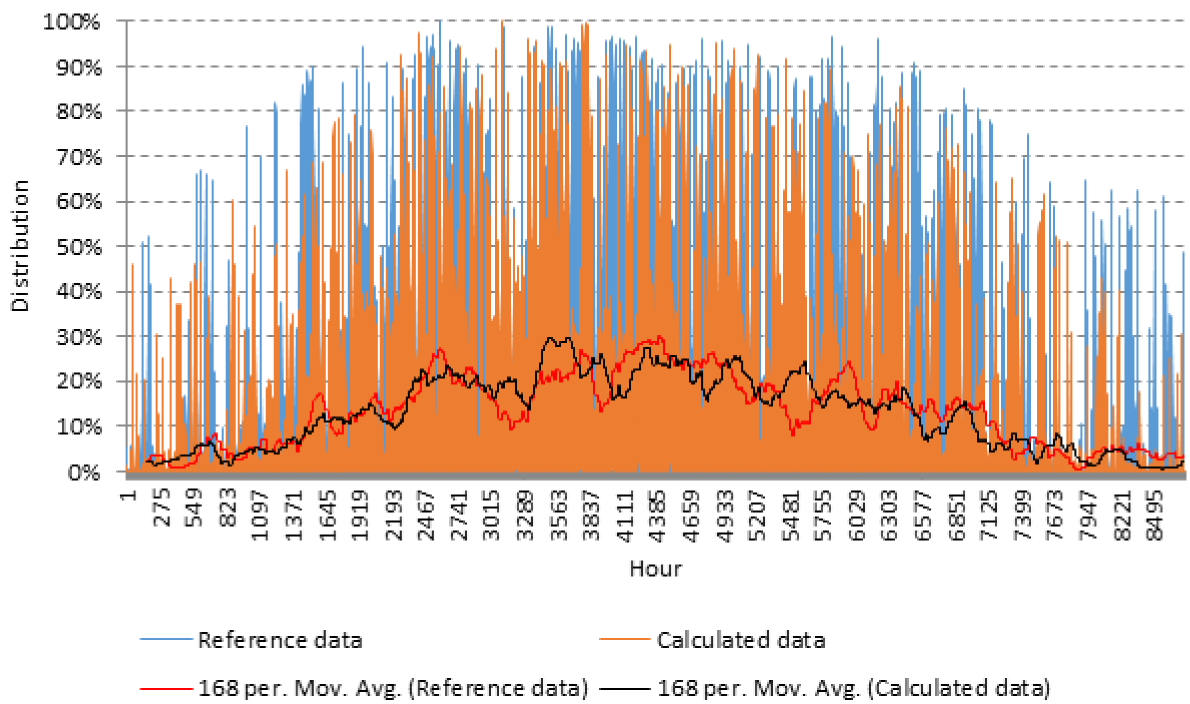


Figure 20: Comparison of reference solar thermal generation with calculated generation for 2010.

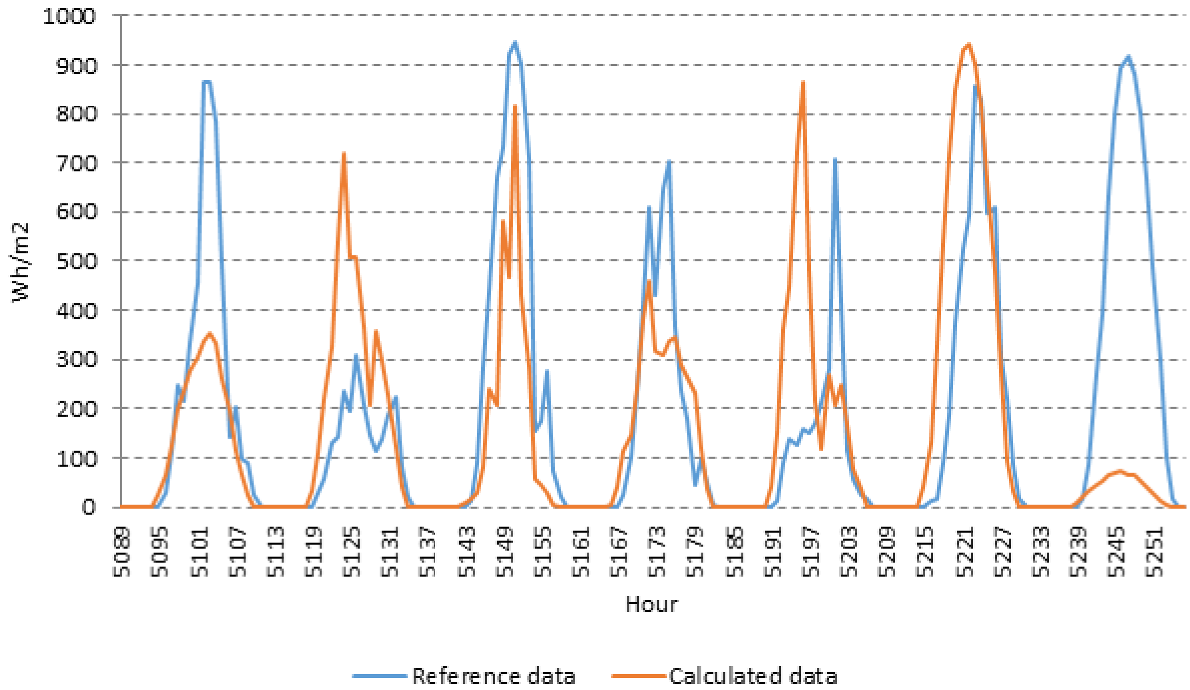


Figure 21: Hourly comparison of the reference and calculated distributions.

The hourly solar thermal distribution in 2010 is shown in Figure 22. The hourly distributions are shown along with the weekly moving average distribution over 168 hours.

It can be seen that the distributions over a weekly moving average are similar during the year with an R^2 value of 0.79. The R^2-value for the hourly distribution over the entire year is 0.42. The reason for this low value is due to the different timing and location on the figure of the peaks and troughs, but in general the trend is similar.

Figure 21 presents the comparison of the first week of August for the reference and the calculated data. The two data distributions demonstrate the same trends and similar peeks for most of the observed days. The R^2-value between the two hourly distributions is 0.3 showing a small correlation, due to different locations and peaks and troughs in the timing and figure. Greater differences can be noted in the first and the last day in the week. Overall the trend appears similar between the two distributions.

2.2.3 Wave Power

Unlike wind power where the three-bladed turbine has become the primary technology, it is very unlikely that there will be a standard design for future wave generators. This is due to the fact that wave power depends on two parameters: wave height and wave period. It is difficult to develop a wave generator that is able to operate across locations, since the relationship between these two parameters can vary depending on the local wave conditions.

Significant wave height (H_{sig}, m) \ Power period (T_{pow}, s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

(a) (b)

Figure 22: Pelamis wave generator (a) and its power matrix: output in kW (b).

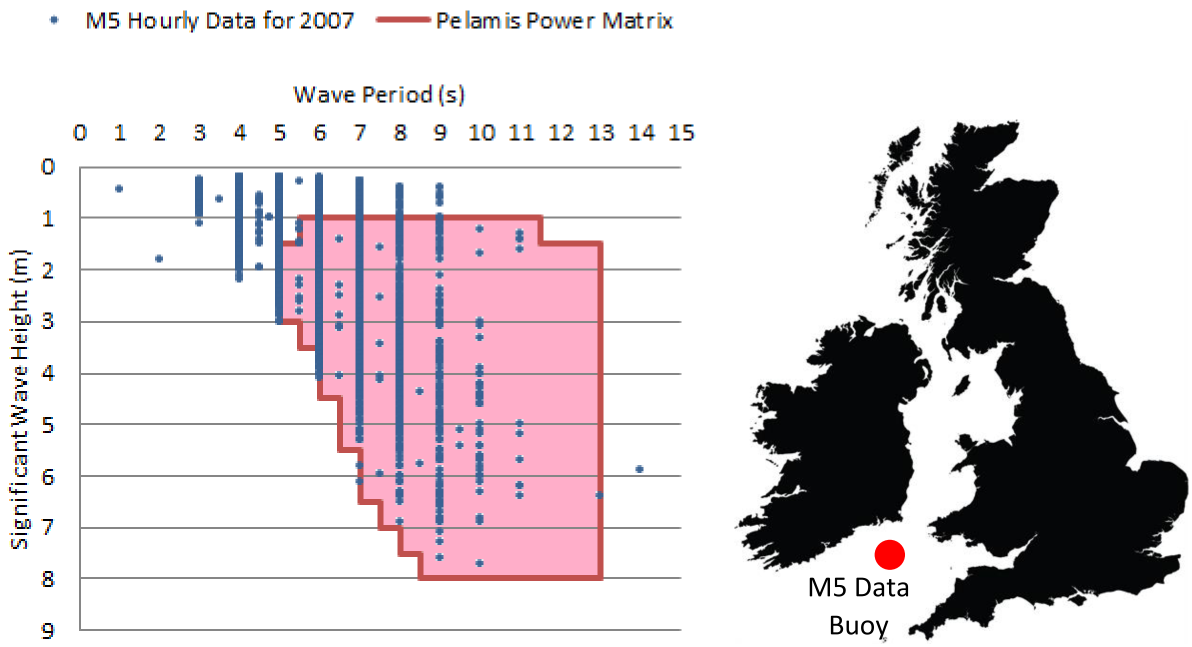


Figure 23: Scatter diagram for M5 data buoy off the coast of the United Kingdom. The data was gathered by the Marine Institute in Ireland [32].

Currently, the expected electricity production from a wave power device across a variety of wave periods and wave heights is reported using a power matrix [31]. For example, Figure 22 presents a wave power matrix for the Pelamis device. It is important to note that the wave height and wave period can vary and it is important to make sure that the data being measured is the same as required by the power matrix. For example, the wave period can often be the peak period (T_p), energy period (T_e), or mean period (T_z), while the wave height can often be the deterministic significant wave height ($H_{1/3}$), spectral significant wave height (H_{m0}), or maximum wave height (H_{max}).

When multiple power matrices are available, the suitability of the device for a particular site can be evaluated by completing a scatter diagram of the data. The hourly wave height and hourly wave period recorded at the site in question should be plotted against one another as illustrated in Figure 23. If the power matrix and recorded data from the site in question overlap each other significantly on the scatter diagram, then the wave energy generator being investigated is a good choice for that particular location. As seen in Figure 23, the Pelamis is a good match for the M5 site available here.

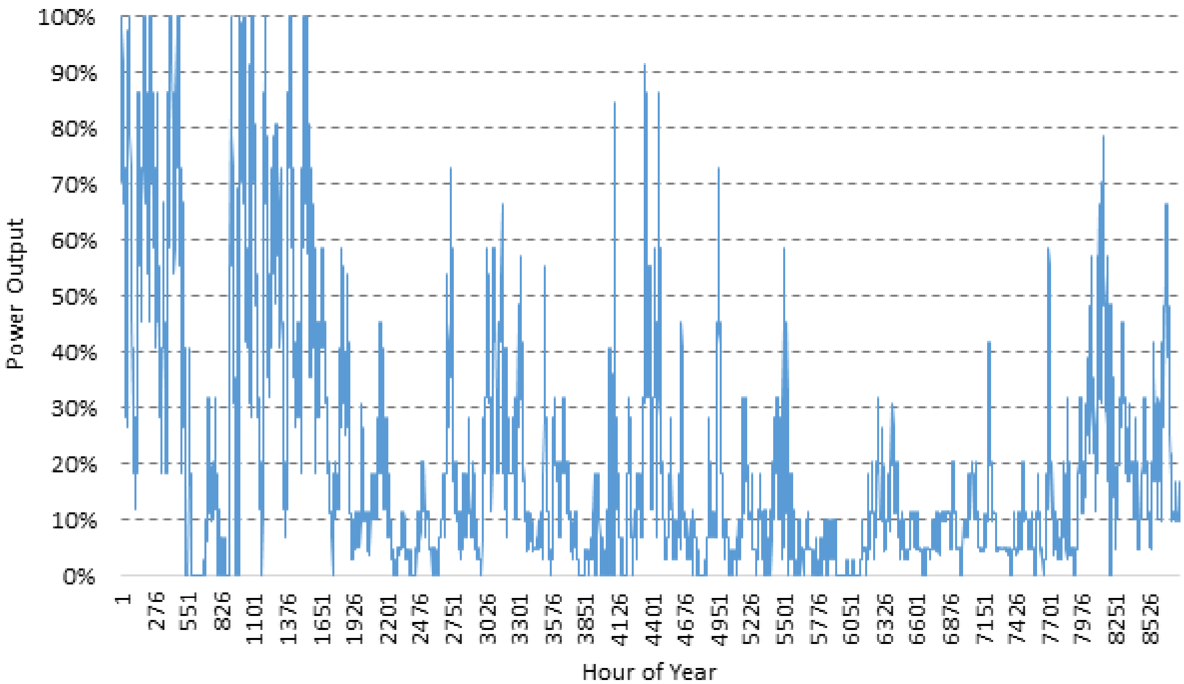


Figure 24: Hourly wave power output for the UK based on the Pelamis wave device (Figure 22) and wave data from the M5 data buoy (Figure 23).

Once the most suitable wave power device has been chosen, and the power matrix obtained, the hourly wave height and wave period data recorded at the site must be converted into an hourly power output. This was carried out here using a freeware tool developed as part of this study called WavePLAN, which can be downloaded as part of the EnergyPLAN tool [33]. An example of the hourly power production from the Pelamis wave device is provided in Figure 24. This curve represents the power for a single type of device at a single location. At present the key limitation for hourly wave power output is the availability of more hourly wave data across more locations. Additional data could not be obtained in this study since it was either unavailable or required a fee to be provided.

3 Discussion and Conclusion

In the future intermittent renewable energy will provide much larger shares of the primary energy supply and therefore this needs to be accommodated in future energy system modelling. The challenge is to determine how the energy demand and supply will fluctuate in the future. This study aimed to develop a methodology for developing energy demand and supply hourly distributions for different sectors of the energy system of a country. A methodology was developed for calculating demand and supply side distributions. The demand side included electricity, heat, cooling and transport. And the supply side included wind power, solar PV and solar thermal, and wave power.

Where possible the methodology was tested and validated using real world data compared with calculated data using the methodology. This was carried out for heat demand, wind power, and solar PV and solar thermal. Validation was not necessary for the electricity distribution, and for the cooling and transport demand it was not possible to validate since there is very limited real world data available.

Overall the validation showed that the main trends between the reference and calculated distributions were similar. There were variations between the distributions which are expected, but the main aim was to capture the key characteristics in the distributions over time, for example between seasons, in different weather events and in day-night shifts. Therefore, this methodology can provide a general picture of the short-term hourly variations that can be expected for supply and demand of a national energy system. However, if local bottom up data is available then it should be prioritised since there are differences between the exact values during each hour.

This is the first study of its type carried out for European countries and therefore the hourly distributions created using this methodology should be seen as a best estimate. The main purpose of the distributions is to determine what type of hourly variations can be expected in the future based on existing knowledge, rather than a recreation of what is being recorded today, which was done in the validation.

The methodology developed in this study has been used to calculate demand and supply distributions for five European countries in the Main Report of this STRATEGO project (UK, Romania, Italy, Czech Republic, and Croatia). Depending on the results from these countries the methodology developed in this may be refined further.

References

[1] Pagliarini G, Rainieri S. Restoration of the building hourly space heating and cooling loads from the monthly energy consumption. Energy and Buildings 2012;49(0):348-355.

[2] Fabrizio E, Filippi M, Virgone J. An hourly modelling framework for the assessment of energy sources exploitation and energy converters selection and sizing in buildings. Energy and Buildings 2009;41(10):1037-1050.

[3] Duanmu L, Wang Z, Zhai ZJ, Li X. A simplified method to predict hourly building cooling load for urban energy planning. Energy and Buildings 2013;58(0):281-291.

[4] Pedersen L, Stang J, Ulseth R. Load prediction method for heat and electricity demand in buildings for the purpose of planning for mixed energy distribution systems. Energy and Buildings 2008;40(7):1124-1134.

[5] Meibom P, Barth R, Brand H, Hasche B, Ravn H, Weber C. All-Island Grid Study: Wind Variability Management Studies. Department of Communications Energy and Natural Resources (Ireland), 2008. Available from: http://www.dcenr.gov.ie/Energy/Latest+News/All-Island+Grid+Study+Published.htm.

[6] Danish Commission on Climate Change. Energy Strategy 2050: from coal, oil and gas to green energy. The Danish Government, 2011. Available from: http://www.ens.dk/en-US/policy/danish-climate-and-energy-policy/danishclimatecommission/aboutthecommission/Documents/Energy%20Strategy%202050%20web.pdf.

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

[8] EirGrid. Welcome to EirGrid. Available from: http://www.eirgrid.com/ [accessed 8th November 2010].

[9] International Energy Agency. Energy Balances of OECD Countries. International Energy Agency, 2014. Available from: http://www.iea.org/.

[10] ENTSO-E. European Network of Transmission Systems Operators for Electricity. Available from: http://www.entsoe.eu/ [accessed 11 November 2014].

[11] Met Eireann. Degree Days. Available from: http://www.met.ie/climate/degree-day.asp [accessed 18th January 2012].

[12] The Chartered Institution of Building Services Engineers. Degree-days: theory and application. The Chartered Institution of Building Services Engineers, 2006. Available from: http://www.cibse.org/.

[13] Frederiksen S, Werner S. District Heating and Cooling. (planned for publication), Lund, Sweden, 2012.

[14] Gadd H, Werner S. Heat load patterns in district heating substations. Applied Energy 2013;108(0):176-183.

[15] ENTRANZE Project. Policies to ENforce the TRansition to Nearly Zero Energy Buildings in the EU27. Available from: http://www.entranze.eu/ [accessed 13 November 2014].

[16] COWI. Technology Data for Energy Plants: Individual Heating Plants and Energy Transport. Danish Energy Agency, 2013. Available from: http://www.ens.dk/.

[17] Swedblom M, Tvärne A, Frohm H, Rubenhag A. District Cooling Customer Measurement Analysis: Verification of and ECI for Market Assessment. Capital Cooling Energy Service AB, 2014. Available from: http://www.rescue-project.eu/.

[18] Zhang M, Mu H, Li G, Ning Y. Forecasting the transport energy demand based on PLSR method in China. Energy 2009;34(9):1396-1400.

[19] Anable J, Brand C, Tran M, Eyre N. Modelling transport energy demand: A socio-technical approach. Energy Policy 2012;41(0):125-138.
[20] Geem ZW. Transport energy demand modeling of South Korea using artificial neural network. Energy Policy 2011;39(8):4644-4650.
[21] Matsim. Agent-Based Transport Simulations. Available from: http://www.matsim.org/ [accessed 13 November 2014].
[22] Novosel T, Perković L, Ban M, Keko H, Pukšec T, Krajačić G, Duić N. Hourly transport energy demand modelling – Impact of EVs on the Croatian electricity grid. In: Proceedings of the 1st South East European Conference on Sustainable Development of Energy, Water and Environment Systems. Ohrid, Macedonia, 29 June - 3 July, 2014.
[23] Meteotest. METEONORM. Available from: http://meteonorm.com/ [accessed 12 November 2014].
[24] Stoutenburg ED, Jenkins N, Jacobson MZ. Power output variations of co-located offshore wind turbines and wave energy converters in California. Renewable Energy 2010;35(12):2781-2791.
[25] Fusco F, Nolan G, Ringwood JV. Variability reduction through optimal combination of wind/wave resources – An Irish case study. Energy 2010;35(1):314-325.
[26] Santos-Alamillos FJ, Pozo-Vázquez D, Ruiz-Arias JA, Lara-Fanego V, Tovar-Pescador J. A methodology for evaluating the spatial variability of wind energy resources: Application to assess the potential contribution of wind energy to baseload power. Renewable Energy 2014;69(0):147-156.
[27] Nørgaard P, Holttinen H. A Multi-Turbine Power Curve. In: Proceedings of the Nordic Wind Power Conference. Gothenburg, Sweden, 1-2 March, 2004.
[28] ELEXON. Available from: https://www.elexon.co.uk/ [accessed 15 February 2015].
[29] European Commission. Photovoltaic Geographical Information System (PVGIS). Available from: http://re.jrc.ec.europa.eu/ [accessed 4 November 2014].
[30] SOLVARMEDATA. Solar Thermal Data. Available from: http://www.solvarmedata.dk [accessed 11 February 2015].
[31] Environmental Change Institute, University of Oxford. Variability of UK Marine Resources. Environmental Change Institute, University of Oxford, 2005. Available from: http://www.carbontrust.co.uk/NR/rdonlyres/EC293061-611D-4BC8-A75C-9F84138184D3/0/variability_uk_marine_energy_resources.pdf.
[32] Marine Institute. Marine Institute. Available from: http://www.marine.ie/Home/ [accessed 10th January 2009].
[33] Aalborg University. EnergyPLAN: Advanced Energy System Analysis Computer Model. Available from: http://www.energyplan.eu/ [accessed 8 September 2014].

Appendix A: Typical Heating Season in each STRATEGO Country

This information was collected from the local partners in STRATEGO.

Czech Republic

Two requirements need to be fulfilled to start delivering heat to customers:

1) The heating season is defined by law from 1st September to 31st May
2) Within this period, if the average daily outside temperature (at 7:00, 14:00 and two times at 21:00 hours) is below 13 degrees Celsius with stable weather forecast, then the district heating utilities starts delivering the heat. If the average temperature raises above 13 degree Celsius for 2 days (with stable forecast) then they stop delivering the heat.

Croatia

The heat season is usually from the 15th September to the 15th May.

Italy

Italy is quite a particular case in Europe regarding heating demand. While several north European Countries might be considered uniform regarding climatic zones, in Italy this cannot be the case. Its geography and extension in the north-south direction lead to a condition where cities located in the north require space heating for several months each year, while territories located in the south might not require space heating at all.

The operation of district heating in Italy is regulated by a law. The territory is divided into 6 climatic zones based on a degree days classification (degrees days are calculated considering 20°C as normal temperature):

- Zone A: territories presenting a number of degree-days not higher than 600
- Zone B: territories presenting a number of degree-days higher than 600 and lower than 900
- Zone C: territories presenting a number of degree-days higher than 900 and lower than 1400
- Zone D: territories with a number of degree-days higher than 1400 and lower than 2100
- Zone E: territories presenting a number of degree-days higher than 2100 and lower than 3000
- Zone F: territories presenting a number of degree-days higher than 3000

Space heating is permitted in each zone according to this calendar:

- Zone A: max 6 hours per day from December 1st to March 15th
- Zone B: max 8 hours per day from December 1st to March 31st
- Zone C: max 10 hours per day from November 15th to March 31st
- Zone D: max 12 hours per day from November 1st to April 15th
- Zone E: max 14 hours per day from October 15th to April 15th
- Area F: no limitation

The above permitted hours have to be between 5 am and 11 pm. For buildings connected to district heating (and other particular type of heating devices), the limitation regarding the max number of hours of daily operation does not apply. the limitation concerning the period of operation during the year is still applicable. If certain conditions apply, then the Mayor might extend the operating allowed period.

Romania

In Romania, the beginning of the period for district heating is considered after registration for 3 consecutive days, (between 06.00 pm - 06.00 am), the outside average daily air temperature of +10°C or less, but not later than November 1st.

Termination of district heating is done after 3 consecutive days in which the average outside air temperature exceeds +10°C, between 6.00 am, - 6.00 pm, but not earlier than April 15th.

United Kingdom

The heat season is usually from the 1st of October to the 30th April, usually beginning when a daytime peak temperatures of 16°C or less occurs for two or more consecutive days.

ECOFYS

sustainable energy for everyone

IEE EHP Stratego

Quantifying the Cost of Heat Savings in EU Member States

Background Report 3a

- Confidential –

IEE EHP Stratego

Report

- Confidential –

By: Dr. Kjell Bettgenhäuser, Willemijn Pouwels, Thomas Boermans
Date: 10 February 2015

Project number: BUIDE15000

ECOFYS Germany GmbH | Am Wassermann 36 | 50829 Cologne | **T** +49 (0)221 27070-100 | **F** +49 (0)221 27070-011 | **E** info@ecofys.com | **I** www.ecofys.com
Managing Director C. Petersdorff | **Register Court:** Local Court Cologne | **Chamber of commerce Cologne** HRB 28527 | **VAT ID** DE 187378615

ECOFYS
sustainable energy for everyone

Table of contents

ECOFYS Germany GmbH | Am Wassermann 36 | 50829 Cologne | **T** +49 (0)221 27070-100 | **F** +49 (0)221 27070-011 | **E** info@ecofys.com | **I** www.ecofys.com
Managing Director C. Petersdorff | **Register Court:** Local Court Cologne | **Chamber of commerce Cologne** HRB 28527 | **VAT ID** DE 187378615

1 Introduction

Euroheat & Power, through the DHC+ Technology Platform, is the coordinator of the STRATEGO project. The STRATEGO project is a European co-funding project developed in the framework of the Intelligent Energy Europe Programme, having the contract n°. IEE/13/650/SI2.675851.
The purpose of the project “Multi level actions for enhanced Heating and Cooling plans – STRATEGO” is to bridge the gap between EU policy, national objectives and effective actions taken at regional and local levels.
Ecofys contributed already, led by the University of Aalborg and in cooperation with Halmstad University and PlanEnergi, to the pre-study of the STRATEGO project, called “Heat Roadmap Europe 2050 – second pre-study for the EU-27” commissioned by Euroheat & Power.
After finalisation of the study and its publication in 2013, Ecofys was contracted in this STRATEGO project to calculate building stock energy demand paths for the countries Czech Republic, Italy, Romania and Croatia. Based on input from country experts we developed a reference path and an efficiency path for each of the countries.

1.1 Introduction to BEAM²

For the scenario calculation the **Built Environment Analysis Model BEAM²** is been used. Ecofys developed this model over the last years as model for international building stocks. Results of the model are energy demand, CO2-emissions and energy costs for space heating in the built environment, which then can be presented for different types of buildings, building ages, climate zones etc. Input to the model calculation is a database containing international building stock data distinguished by climatic regions, building type/size, building age, insulation level, energy supply, energy carrier, energy costs and emission factors. This can be applied in a scenario tool used for calculating the development over time of the building stock as a function of demolition rate, new building activity, refurbishments and energy-efficiency measures in retrofits. The tool is thereby fully flexible to be applied to any country world-wide, once the relevant input data are assessed and incorporated. The model was used so far in various projects (e.g. the European Commission, Eurima etc.) and contributed to the perception and reputation of Ecofys in Europe.
For more information on the BEAM² model also see *www.beam2.info*.

ECOFYS

sustainable energy for everyone

2 Overview of inputs

In the following paragraphs the input into BEAM² is shown per topic.

2.1 Age groups

For each country the experts have provided different building statistics per age group. These age groups differ per country also resulting in a different number of age groups per country. Table 1 shows the age groups used for each country.

Table 1 Age groups used for each country

Age Groups	Croatia	Czech Republic	Italy	Romania
Age group I	before 1945	before 1946	before 1946	before 1970
Age group II	1946 - 1969	1946 - 1980	1946-1990	1971-1990
Age group III	1970 - 1989	1981 - 2000	1991-2006	1991-2014
Age group IV	1990 - 1999	2001 - 2011	2007-2012	since 2015
Age group V	2000 - 2008	since 2012	since 2012	
Age group VI	since 2008			

2.2 Reference building geometries

Because of missing data from the country experts the dimensions of the reference buildings for the non-residential buildings are taken from an average European building and the same for each country. This counts as well for attached single family homes and small and large multifamily homes. For detached single family homes the dimensions for a Romanian or Czech Republic home are equal to each other as are the dimensions for an Hungarian and Italian dwelling. Values are again taken from a European average.

2.3 Thermal quality of building envelopes

In the following paragraphs the u-values for the different reference buildings per age group are shown per country. These values are taken from the country experts. The u-values used in the simulations for the reference efficiency scenario and the high efficiency scenario are shown in Table 2. These u-values are taken from *Renovation tracks for Europe up to 2050.*

Table 2 U-values for different envelope parts

	Croatia [W/m2.K]		Czech Republic [W/m2.K]		Italy [W/m2.K]		Romania [W/m2.K]	
	Ref	High Eff	Ref	High Eff	Ref	High Eff	Ref	High Eff
Wall	0.30	0.15	0.30	0.12	0.30	0.15	0.30	0.12
Roof	0.39	0.15	0.43	0.12	0.43	0.15	0.43	0.12
Floor	0.35	0.15	0.35	0.12	0.35	0.15	0.35	0.12
Windows	1.3	0.85	1.3	0.85	1.3	0.85	1.3	0.85

In order to connect the technical specifications to *real actions*, this paragraph gives a brief overview on retrofit and new building measures.

For *insulation* a u-values of 0,43 W/(m²K) is equivalent to approx. 9cm in standard insulation, while a u-value of 0,30 W/(m²K) means 12cm insulation and 0,15 W/(m²k) is equivalent to approx. 26cm of standard insulation (mineral wool or EPS/XPS).

Windows are either used in "standard" quality with an u-value of 1,3 W/(m²K), which is a standard triple-glazing with a simple wooden frame, or as "high performance" window with 0,85 W/(m²K), which is equivalent to a very good triple-glazing with a passive-house frame.

Concerning the assumed *ventilation* strategies a share of buildings in new buildings and renovations are assumed with ventilation systems and heat recovery. As starting point we assume that 90% of new buildings and 95% of all renovations are done without ventilations systems (and hence without heat recovery). The share of ventilations systems and heat recovery increases then in all countries and scenarios up to 25% in 2020 and remains constant. For the heat recovery systems a heat recovery rate of 85% is used.

2.3.1 Croatia

Building	Age	Wall [W/m2K]	Roof [W/m2K]	Floor [W/m2K]	Window [W/m2K]
SFH Detached	I	1.28	1.14	0.93	4.4
SFH Detached	II	1.46	1.14	0.93	4.4
SFH Detached	III	1.28	1.16	0.93	3
SFH Detached	IV	0.83	0.69	0.65	2.4
SFH Detached	V	0.34	0.29	0.65	1.8
SFH Attached	I	1.28	1.14	0.93	4.4
SFH Attached	II	1.46	1.14	0.93	4.4
SFH Attached	III	1.28	1.16	0.93	3
SFH Attached	IV	0.83	0.69	0.65	2.4
SFH Attached	V	0.34	0.29	0.65	1.8
MFH Small	I	1.28	1.14	0.93	4.4
MFH Small	II	1.46	1.14	0.93	4.4
MFH Small	III	1.28	1.16	0.93	3
MFH Small	IV	0.83	0.69	0.65	2.4

Building	Age	Wall [W/m2K]	Roof [W/m2K]	Floor [W/m2K]	Window [W/m2K]
MFH Small	V	0.34	0.29	0.65	1.8
MFH Large	I	1.28	1.14	0.93	4.4
MFH Large	II	1.46	1.14	0.93	4.4
MFH Large	III	1.28	1.16	0.93	3
MFH Large	IV	0.83	0.69	0.65	2.4
MFH Large	V	0.34	0.29	0.65	1.8
Office	I	1.28	1.14	0.93	4.4
Office	II	1.46	1.14	0.93	4.4
Office	III	1.28	1.16	0.93	3
Office	IV	0.83	0.69	0.65	2.4
Office	V	0.34	0.29	0.65	1.8
Wholesale and retail trade	I	1.28	1.14	0.93	4.4
Wholesale and retail trade	II	1.46	1.14	0.93	4.4
Wholesale and retail trade	III	1.28	1.16	0.93	3
Wholesale and retail trade	IV	0.83	0.69	0.65	2.4
Wholesale and retail trade	V	0.34	0.29	0.65	1.8
Education	I	1.28	1.14	0.93	4.4
Education	II	1.46	1.14	0.93	4.4
Education	III	1.28	1.16	0.93	3
Education	IV	0.83	0.69	0.65	2.4
Education	V	0.34	0.29	0.65	1.8
Hotels and restaurants	I	1.28	1.14	0.93	4.4
Hotels and restaurants	II	1.46	1.14	0.93	4.4
Hotels and restaurants	III	1.28	1.16	0.93	3
Hotels and restaurants	IV	0.83	0.69	0.65	2.4
Hotels and restaurants	V	0.34	0.29	0.65	1.8
Healthcare	I	1.28	1.14	0.93	4.4
Healthcare	II	1.46	1.14	0.93	4.4
Healthcare	III	1.28	1.16	0.93	3
Healthcare	IV	0.83	0.69	0.65	2.4
Healthcare	V	0.34	0.29	0.65	1.8
Other NonRes	I	1.28	1.14	0.93	4.4
Other NonRes	II	1.46	1.14	0.93	4.4
Other NonRes	III	1.28	1.16	0.93	3
Other NonRes	IV	0.83	0.69	0.65	2.4
Other NonRes	V	0.34	0.29	0.65	1.8

2.3.2 Czech Republic

Building	Age	Wall [W/m2K]		Roof [W/m2K]		Floor [W/m2K]		Window [W/m2K]	
Building		Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted
SFH Detached	I	1.47	0.93	1.39	0.95	2.35	1.43	2.85	1.8
SFH Detached	II	1.68	0.96	1.37	0.99	1.3	0.69	3.33	1.92
SFH Detached	III	0.59	0.38	0.57	0.38	1.2	0.37	2.9	1.5
SFH Detached	IV	0.3	0.19	0.43	0.19	0.59	0.33	1.54	0.83
SFH Attached	I	1.47	0.93	1.39	0.95	2.35	1.43	2.85	1.8
SFH Attached	II	1.68	0.96	1.37	0.99	1.3	0.69	3.33	3.33
SFH Attached	III	0.59	0.38	0.57	0.38	1.2	0.37	2.9	1.5
SFH Attached	IV	0.3	0.19	0.43	0.19	0.59	0.33	1.54	0.83
MFH Small	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
MFH Small	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
MFH Small	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
MFH Small	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
MFH Large	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
MFH Large	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
MFH Large	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
MFH Large	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Office	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Office	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
Office	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Office	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Wholesale and retail trade	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Wholesale and retail trade	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
Wholesale and retail trade	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Wholesale and retail trade	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Education	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Education	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
Education	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Education	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Hotels and restaurants	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Hotels and restaurants	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
Hotels and restaurants	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Hotels and restaurants	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Healthcare	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Healthcare	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01
Healthcare	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Healthcare	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2
Other NonRes	I	1.47	0.83	2.94	0.85	1.38	0.8	2.85	1.8
Other NonRes	II	1.56	0.88	1.51	0.91	1.47	0.85	3.33	2.01

Building	Age	Wall [W/m2K]		Roof [W/m2K]		Floor [W/m2K]		Window [W/m2K]	
Building		Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted	Not retrofit ted	Already retrofit ted
Other NonRes	III	0.9	0.55	0.57	0.56	0.87	0.54	3.44	2.03
Other NonRes	IV	0.59	0.19	0.39	0.19	0.58	0.19	1.9	1.2

2.3.3 Italy

Building	Age	Wall [W/m2K]	Roof [W/m2K]	Floor [W/m2K]	Window [W/m2K]
SFH Detached	I	1.3	1.1	1.1	1.1
SFH Detached	II	1.2	1.2	1.2	1.2
SFH Detached	III	1	1	1	1.1
SFH Detached	IV	0.7	0.7	0.7	0.8
SFH Attached	I	1.3	1.1	1.1	1.1
SFH Attached	II	1.2	1.2	1.2	1.2
SFH Attached	III	1	1	1	1.1
SFH Attached	IV	0.7	0.7	0.7	0.8
MFH Small	I	1.3	1.1	1.1	1.1
MFH Small	II	1.2	1.2	1.2	1.2
MFH Small	III	1	1	1	1.1
MFH Small	IV	0.7	0.7	0.7	0.8
MFH Large	I	1.3	1.1	1.1	1.1
MFH Large	II	1.2	1.2	1.2	1.2
MFH Large	III	1	1	1	1.1
MFH Large	IV	0.7	0.7	0.7	0.8
Office	I	1.3	1.1	1.1	1.1
Office	II	1.2	1.2	1.2	1.2
Office	III	1	1	1	1.1
Office	IV	0.7	0.7	0.7	0.8
Wholesale and retail trade	I	1.3	1.1	1.1	1.1
Wholesale and retail trade	II	1.2	1.2	1.2	1.2
Wholesale and retail trade	III	1	1	1	1.1
Wholesale and retail trade	IV	0.7	0.7	0.7	0.8
Education	I	1.3	1.1	1.1	1.1
Education	II	1.2	1.2	1.2	1.2
Education	III	1	1	1	1.1
Education	IV	0.7	0.7	0.7	0.8
Hotels and restaurants	I	1.3	1.1	1.1	1.1
Hotels and restaurants	II	1.2	1.2	1.2	1.2
Hotels and restaurants	III	1	1	1	1.1
Hotels and restaurants	IV	0.7	0.7	0.7	0.8

Building	Age	Wall [W/m2K]	Roof [W/m2K]	Floor [W/m2K]	Window [W/m2K]
Healthcare	I	1.3	1.1	1.1	1.1
Healthcare	II	1.2	1.2	1.2	1.2
Healthcare	III	1	1	1	1.1
Healthcare	IV	0.7	0.7	0.7	0.8
Other NonRes	I	1.3	1.1	1.1	1.1
Other NonRes	II	1.2	1.2	1.2	1.2
Other NonRes	III	1	1	1	1.1
Other NonRes	IV	0.7	0.7	0.7	0.8

2.3.4 Romania

Building	Age	Wall [W/m2K]	Roof [W/m2K]	Floor [W/m2K]	Window [W/m2K]
SFH Detached	I	0.83	0.5	0.5	2.56
SFH Detached	II	0.83	0.5	0.5	2.56
SFH Detached	III	0.71	0.33	0.42	2
SFH Attached	I	0.83	0.5	0.5	2.56
SFH Attached	II	0.83	0.5	0.5	2.56
SFH Attached	III	0.71	0.33	0.42	2
MFH Small	I	0.83	0.5	0.5	2.56
MFH Small	II	0.83	0.5	0.5	2.56
MFH Small	III	0.71	0.33	0.42	2
MFH Large	I	0.83	0.5	0.5	2.56
MFH Large	II	0.83	0.5	0.5	2.56
MFH Large	III	0.71	0.33	0.42	2
Office	I	0.83	0.5	0.5	2.56
Office	II	0.83	0.5	0.5	2.56
Office	III	0.71	0.33	0.42	2
Wholesale and retail trade	I	0.83	0.5	0.5	2.56
Wholesale and retail trade	II	0.83	0.5	0.5	2.56
Wholesale and retail trade	III	0.71	0.33	0.42	2
Education	I	0.83	0.5	0.5	2.56
Education	II	0.83	0.5	0.5	2.56
Education	III	0.71	0.33	0.42	2
Hotels and restaurants	I	0.83	0.5	0.5	2.56
Hotels and restaurants	II	0.83	0.5	0.5	2.56
Hotels and restaurants	III	0.71	0.33	0.42	2
Healthcare	I	0.83	0.5	0.5	2.56
Healthcare	II	0.83	0.5	0.5	2.56
Healthcare	III	0.71	0.33	0.42	2
Other NonRes	I	0.83	0.5	0.5	2.56
Other NonRes	II	0.83	0.5	0.5	2.56
Other NonRes	III	0.71	0.33	0.42	2

2.4 Investment costs

Similar to the insulation values the investment costs are taken from the report *Renovation tracks for Europe up to 2050.* The investment costs are shown in Table 3. The investment costs for insulation are split into a fixed and a variable part, the latter being dependent on the thickness of the insulation.

Table 3 Investment costs

	Croatia		Czech Republic		Italy		Romania	
	Fixed costs [€/m²]	Variable costs [€/m²/cm]	Fixed costs [€/m²]	Variable costs [€/m²/cm]	Fixed costs [€/m²]	Variable costs [€/m²/cm]	Fixed cost s[€/m²]	Variable costs [€/m²/cm]
Wall	16.3	1.1	17.5	1.2	18.8	1.3	17.5	1.2
Roof	14.1	1	15.1	1.1	16.3	1.2	15.1	1.1
Floor	17	1	18.2	1.1	19.3	1.2	18.2	1.1
Window Reference Efficiency	119.43	N.A.	187.5	N.A.	167.03	N.A.	187.5	N.A.
Window High Efficiency	140.5	N.A.	222	N.A.	196.5	N.A.	222	N.A.

2.5 Climate data

For each country a reference city is picked to provide the climate data used for the calculations.

Table 4 Reference city for climate data

Country	Reference city
Croatia	Zagreb
Czech Republic	Ostrava
Italy	Milan
Romania	Bucharest

2.5.1 Croatia

In its building legislation Croatia recognises two climate zones (continental and maritime). For the simulations in this model we have used Zagreb as it is quite centralized and has the largest population in the country. It also has a substantial heating and cooling demand. [1]

[1] Email Tomislav Novosel - University of Zagreb

2.5.2 Czech Republic

For the Czech Republic three cities where taken into account for the climate data; Ostrava, Plzeň or Prague. Prague is the in the warmest region of Czech Republic and was advised against. The data used is for Ostrava.

2.5.3 Italy

Milan was chosen as the reference city for Italy. In Milan energy demand is significant both for heating in winter and for cooling in summer. Other cities, located in southern regions, might have a demand for ambient heating during winter season not really significant for the scope of Stratego Project[2].

2.5.4 Romania

Romania has four climate zones of which the Stratego cities are located in two of them. Bucharest is also located in one of these two climate zones and is also part of an area with high population density. Therefor Bucharest is chosen as a reference city.[3]

2.6 Retrofit-, new building and demolition rates

Table 5 show the rates for retrofit, new construction and demolition used in the simulations. The rates are not different for the reference scenario or the high efficiency scenario and are based on information from the country experts.

Table 5 Rates per annum for retrofit, construction and demolition

Rates	Retrofit	New building	Demolition
Croatia	1,0% p.a. for all buildings	1,0% p.a. for all buildings	0,5% p.a. for all buildings
Czech Republic	For all components of the building envelope increasing from 1,0% p.a. to 1,5% p.a. (0,1% p.a. increase per year)	0,95% p.a. for SFH and 0,65% p.a. for MFH and non-residential buildings	0,2% p.a. for all buildings
Italy	3,0% p.a. for all buildings	1,0% p.a. for all buildings	0,35% p.a. for all buildings
Romania	For all components of the building envelope 1,7% p.a.	0,64% p.a. for residential buildings 2,0% p.a. for non-residential buildings	0,2% p.a. for all buildings

[2] Email Luca Bertagna - A2A Calore & Servizi S.r.L. - Gruppo A2A

[3] Email Gabriela Crisan-Badea – Tractabel Engineering

While new buildings and retrofits both have a direct positive impact on costs, energy demand is lowered by retrofitting buildings, but it increases by new builds. Therefore a high retrofit rate typically leads to increasing investments per energy saving over time (€/kWh saved), mainly due to the fact that the worst performing buildings are retrofitted at first and saving are decreasing over time, while a high new building rates increases both investments and energy use and hence influences this equation as well.

3 Output of the simulations

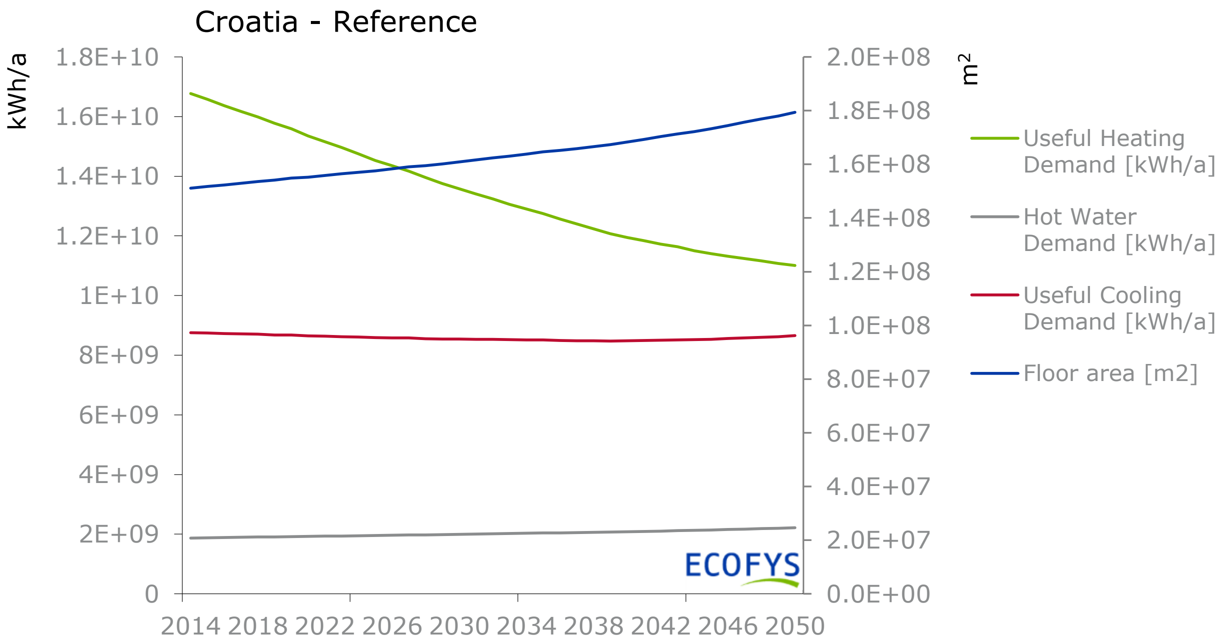
The simulations generate multiple results for each country, which are shown in the following graphs. Detailed information is given in the provided Excel output-file, this section just gives an overview over the output parameters per country:

- Floor area per building type
- Useful heating demand per building type
- Hot water demand per building type
- Useful cooing demand per building type
- Investment costs for the building envelope

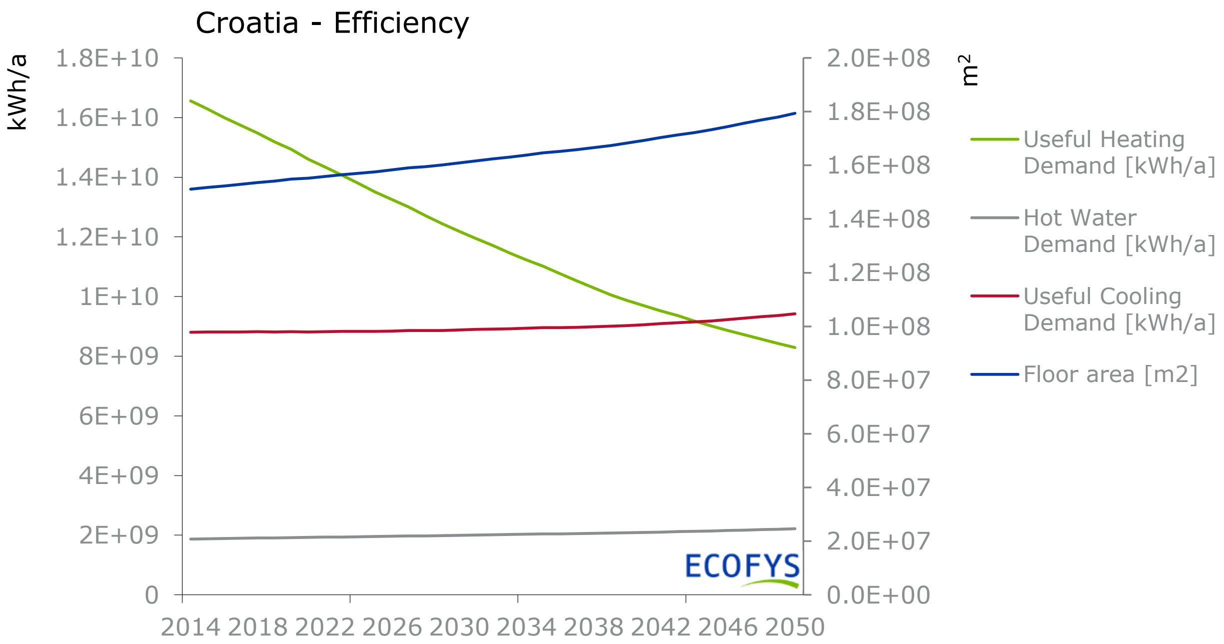
These results are provided for two scenarios, the reference path and the efficiency path, the difference coming from the different u-values and investment costs per path. For each path similar retrofit, new building and demolition rates are assumed.

3.1 Croatia

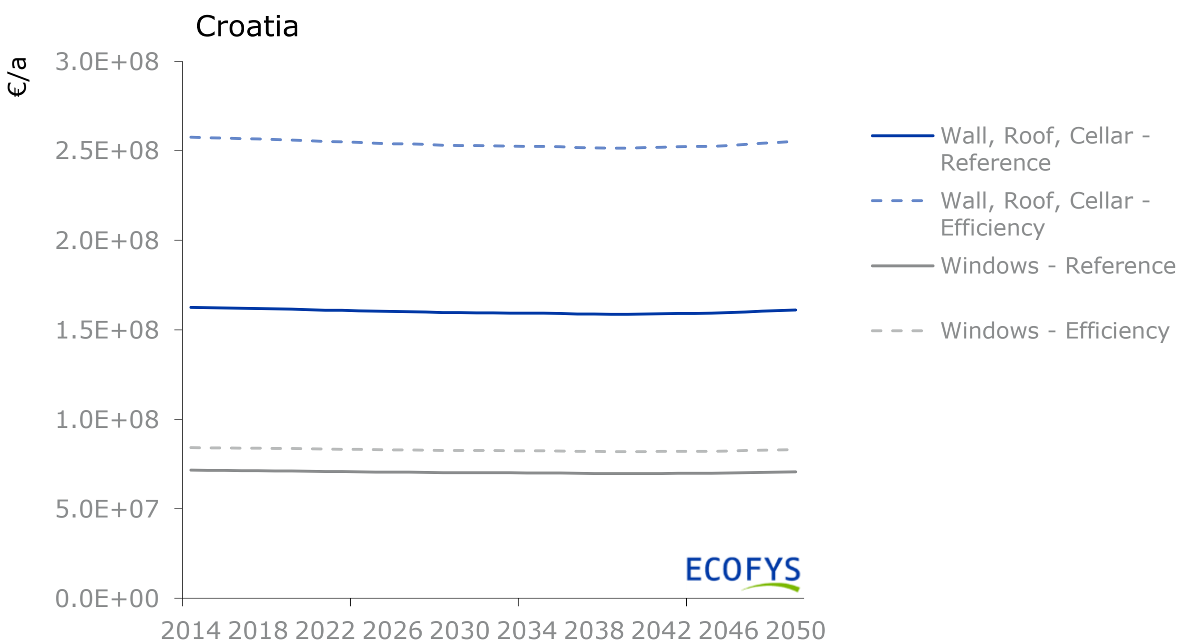
3.1.1 Reference path



3.1.2 Efficiency path

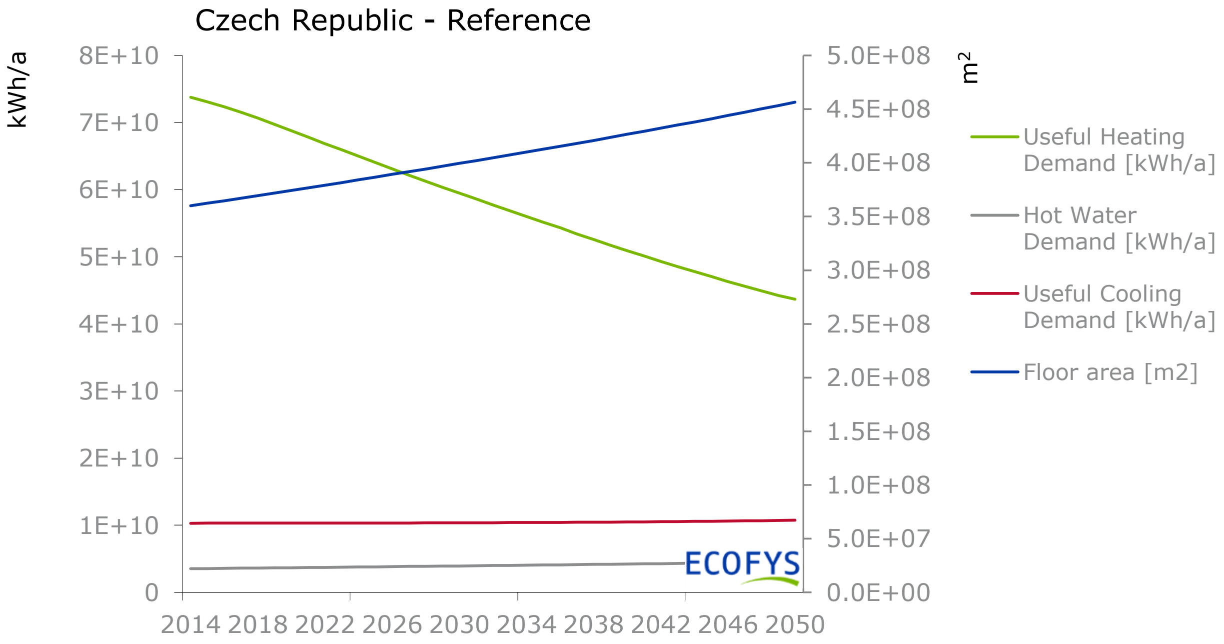


3.1.3 Investments

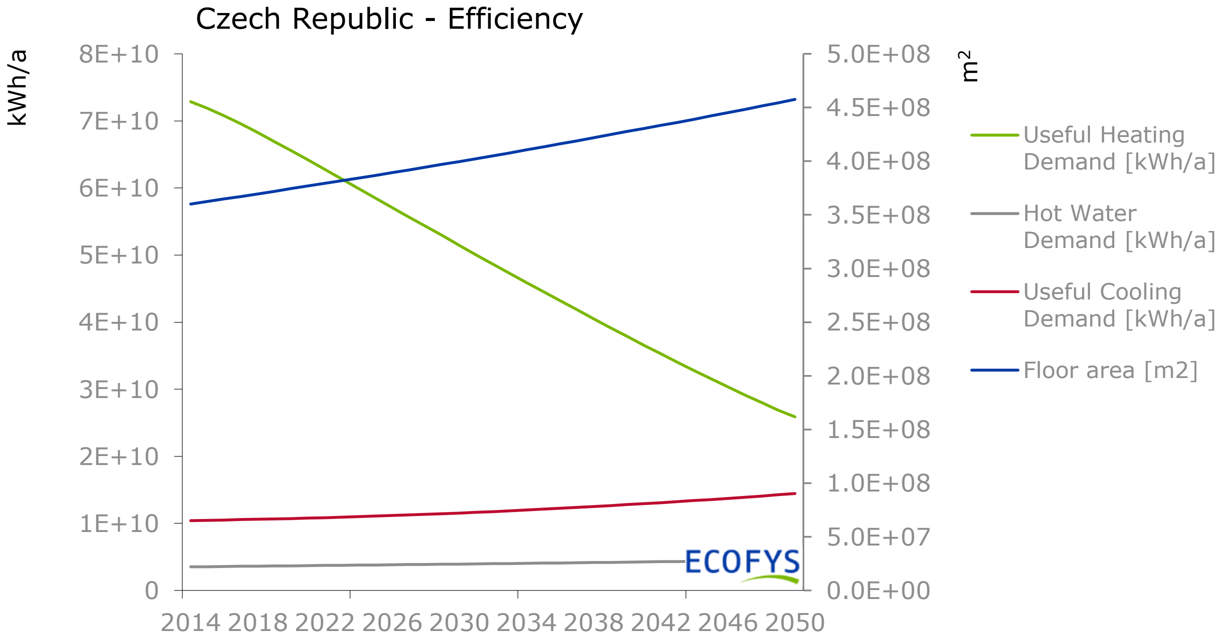


3.2 Czech Republic

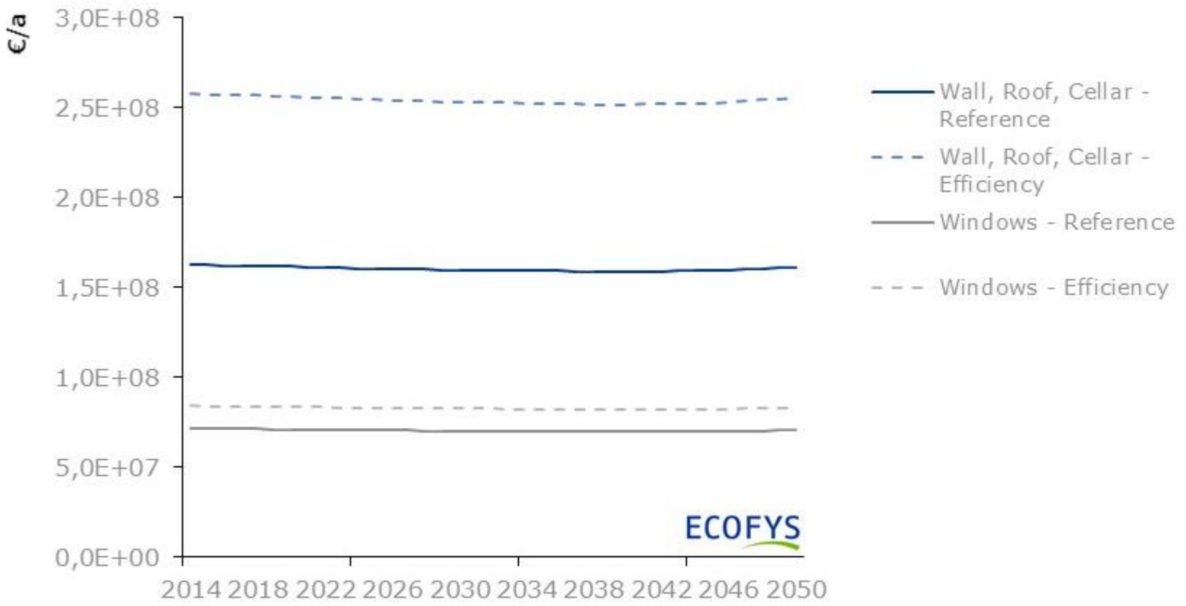
3.2.1 Reference path



3.2.2 Efficiency path

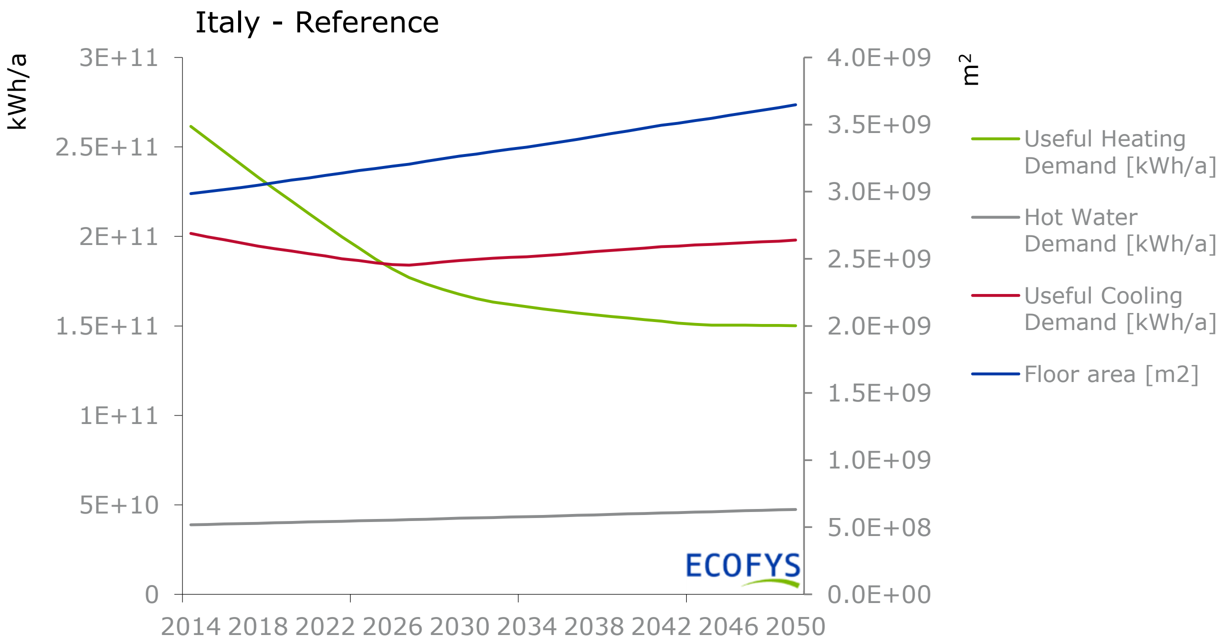


3.2.3 Investments

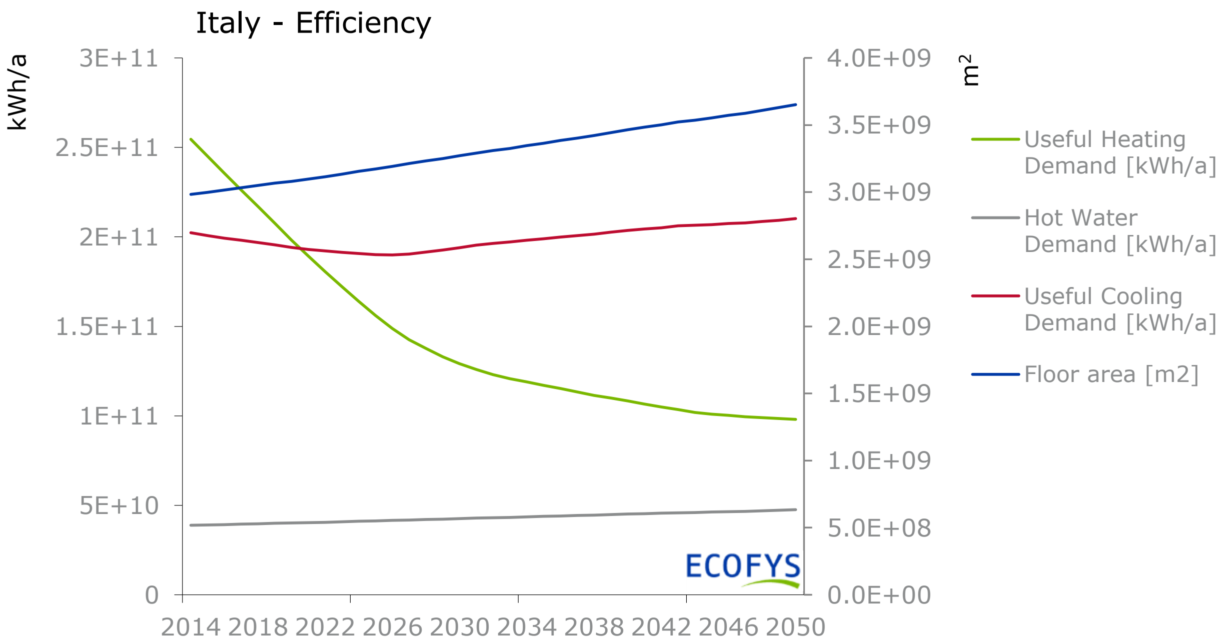


3.3 Italy

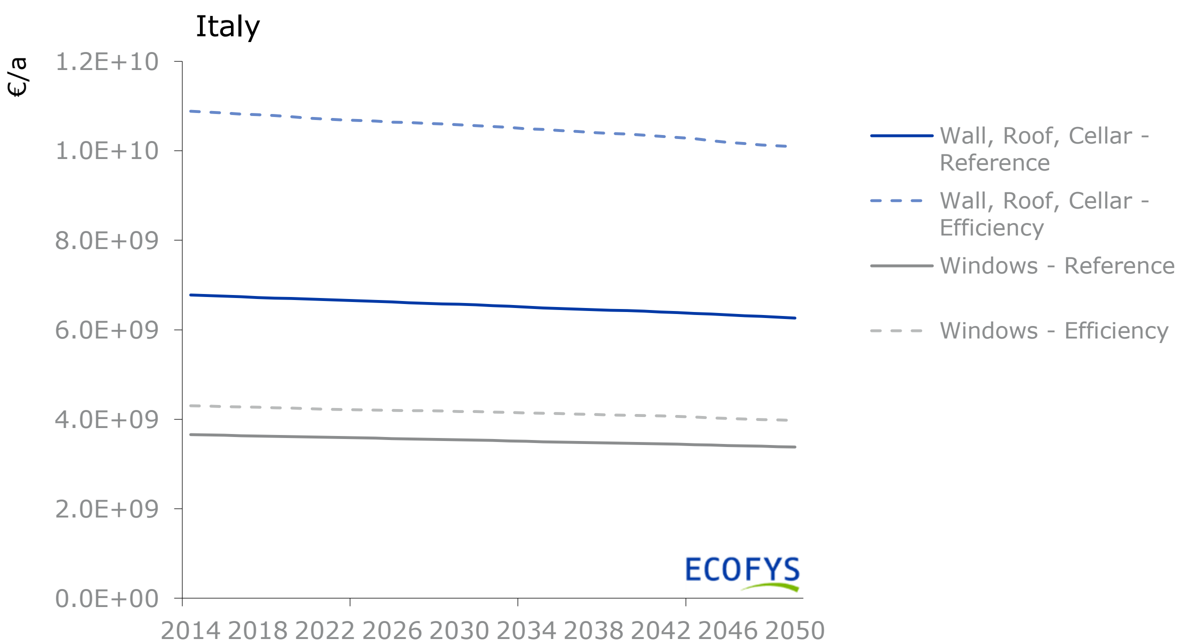
3.3.1 Reference path



3.3.2 Efficiency path

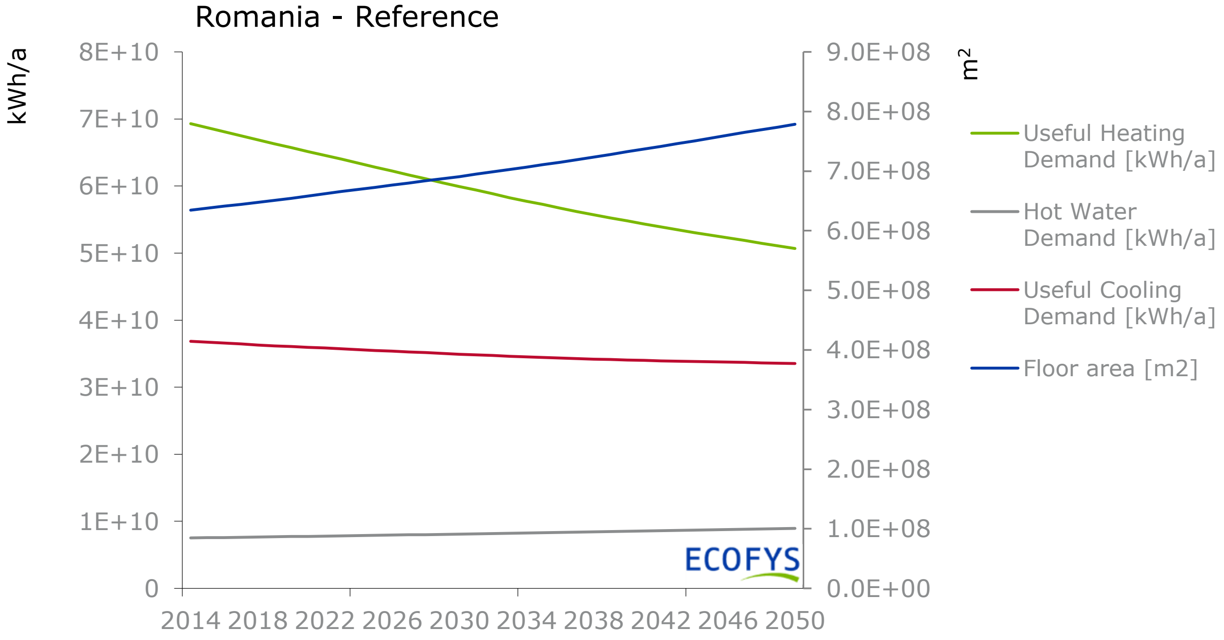


3.3.3 Investments

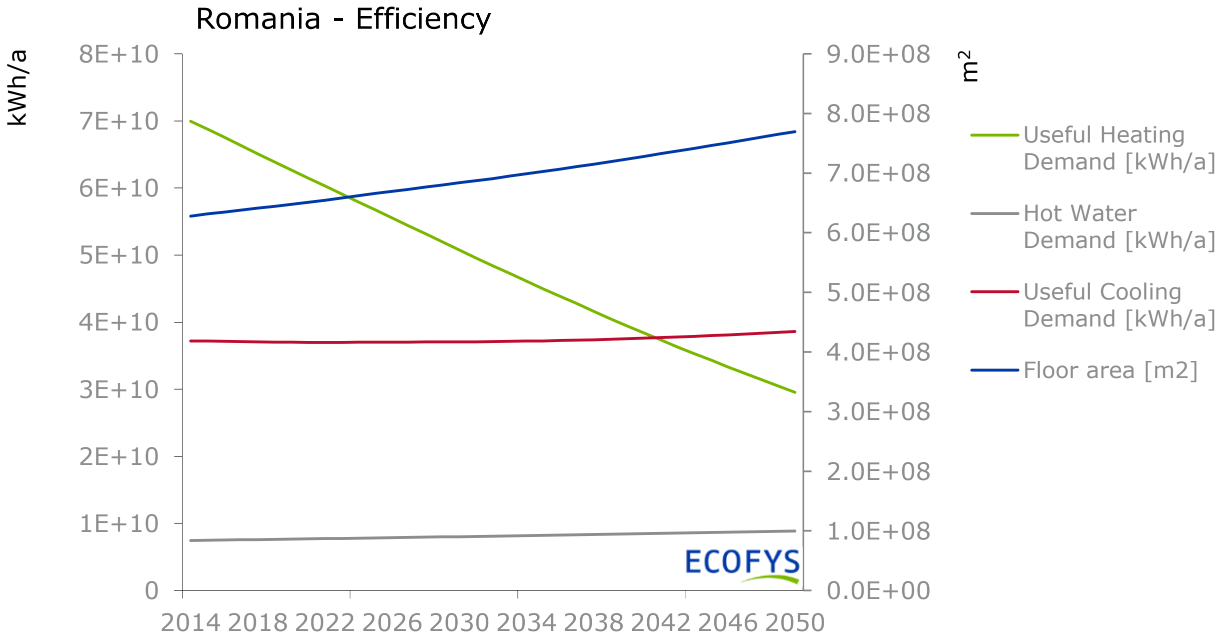


3.4 Romania

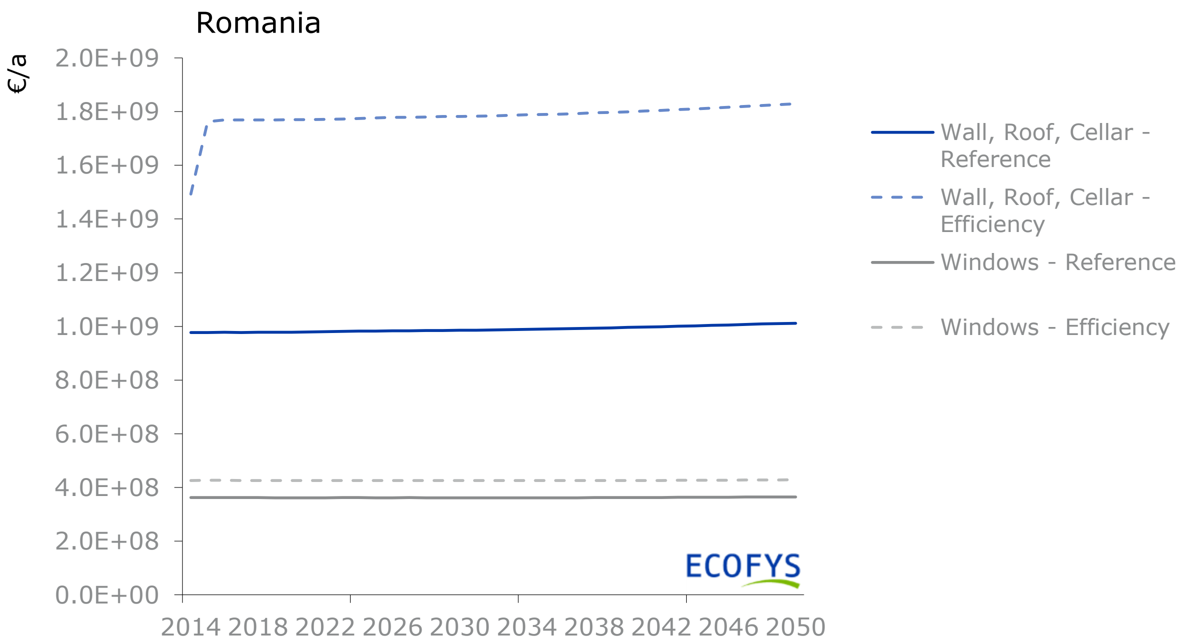
3.4.1 Reference path



3.4.2 Efficiency path



3.4.3 Investments



4 Conclusion

This sections gives a brief overview of the scenarios results.

The *floor area* development in all countries follows a linear path, since the new building and demolition rates are assumed as constant over the period until 2050. Furthermore there is no difference between the reference and the efficiency path, since the difference in retrofit depth is not visible in the total floor area development.

In contrast to this the *heating demand* is decreasing in all scenarios due to energy efficiency measures in the building stock. The additional energy demand of new buildings is overcompensated by the retrofit efficiency gains. In most countries the curve is almost linear, except for Italy. Here we see that building from the worst performing age group are fully retrofitted and then buildings form the next age group undergo renovation. Since the energy demand before renovation is lower for the second age group, the reduction in energy demand is decreasing over time. This is the effect we see here.

The *cooling demand* stays more less the same in all scenarios and sometimes is increasing a bit, especially for the efficiency paths. This is due to the fact that functions like night cooling needs to be optimized in high energy efficient buildings, otherwise the higher tightness and lower transmission leads to a situation where the buildings heats up especially during summertime and does not cool down again when it would be possible during night-time. Since this issue is not especially addressed in the scenarios the results are reasonable.

Hot water demands are increasing slowly due to new buildings being constructed.

The overall *investment costs* for the building envelope are split up by insulation and windows. In general the investments for the efficiency paths are between 50-100% higher than for the reference path due to higher efficiency standards.

sustainable energy for everyone

sustainable energy for everyone

ECOFYS Germany GmbH

Am Wassermann 36
50829 Cologne

T: +49 (0) 221 27070-100
F: +49 (0) 221 27070-011

E: info@ecofys.com
I: www.ecofys.com

Project No: IEE/13/650

Applying the Ecofys Results in the Energy Modelling and the Cost of Heat Savings for the United Kingdom

Work Package 2

Background Report 3b

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: David Connolly, Work Package 2 Coordinator
Kenneth Hansen
David Drysdale
Contact: Aalborg University, Denmark
A.C. Meyers Vænge 15
DK- 2450 Copenhagen
T: +45 9940 2483
E-mail: david@plan.aau.dk
Web: www.en.aau.dk

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

1 Introduction

Background Report 3a of the STRATEGO project calculated the cost of implementing heat savings for four different STRATEGO countries between now and the year 2050, along with the resulting heating and cooling demand. The four countries included in Background Report 3a are Czech Republic, Croatia, Italy, and Romania. These results are used as inputs for the energy modelling, when developing the heating and cooling strategies in the main STRATEGO report. This report explains how the results from Background Report 3a are interpreted for the energy modelling and afterwards, how they are used in combination with a literature review to estimate the costs of heat savings in the United Kingdom (Section 4), which is the fifth STRATEGO country.

2 Quantifying the Cost of Heat Savings in Buildings for the Czech Republic, Croatia, Italy and Romania

The Background Report 3a of the STRATEGO project presents the total investment costs required in the building envelope to reduce the heat demand between today (i.e. 2014) and the year 2050. Four countries, including Czech Republic, Croatia, Italy, and Romania are all calculated separately, with investments divided between measures 1) existing buildings and new buildings and 2) between investments in the walls/roof and investments in windows. An example for the Czech Republic is provided in Figure 1 and Figure 2 below, which display the heat demand and corresponding investments in heat savings respectively.

These total investment costs were annualised to include these in the energy modelling in the Main Report using a lifetime and an interest rate. It is assumed that the windows have a lifetime of 25 years, the walls/roof/cellar measures have a lifetime of 40 years, and the interest rate is 3%. The investment costs are annualised using equation 1 below, which includes the total investment costs (I), the lifetime (n), and the interest rate (i). The resulting annualised costs are presented for all four countries in Figure 3.

$$I_{Annual} = I\left[\frac{i}{1-(1+i)^{-n}}\right] \quad (1)$$

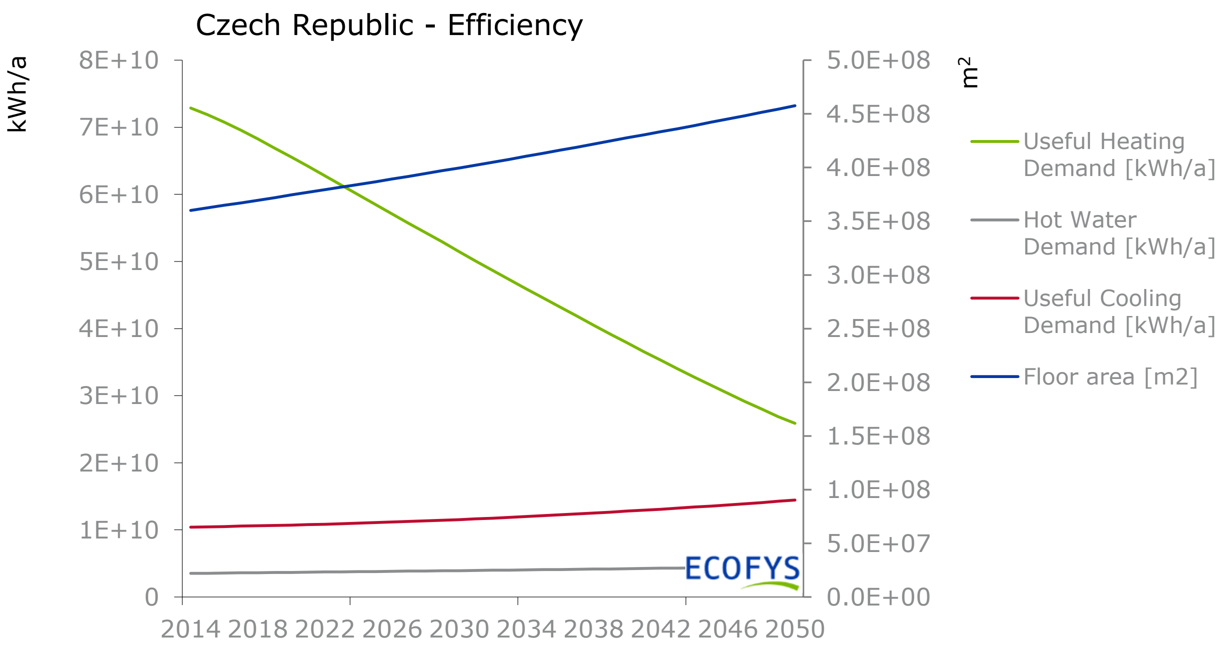


Figure 1: Efficiency pathway in Czech Republic.

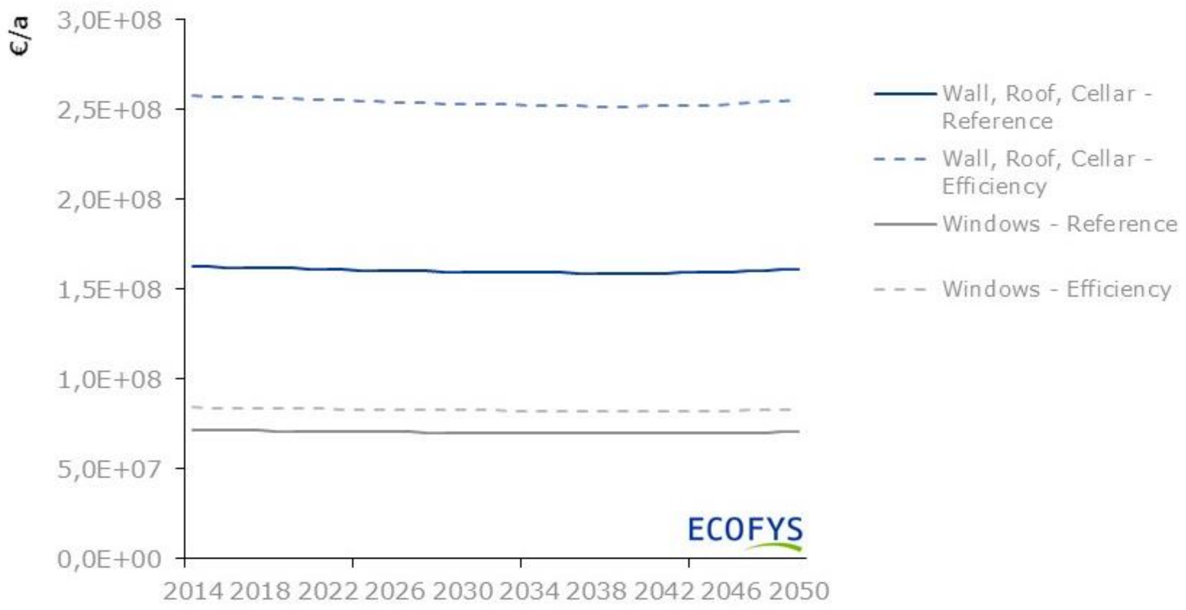


Figure 2: Investments in Czech Republic.

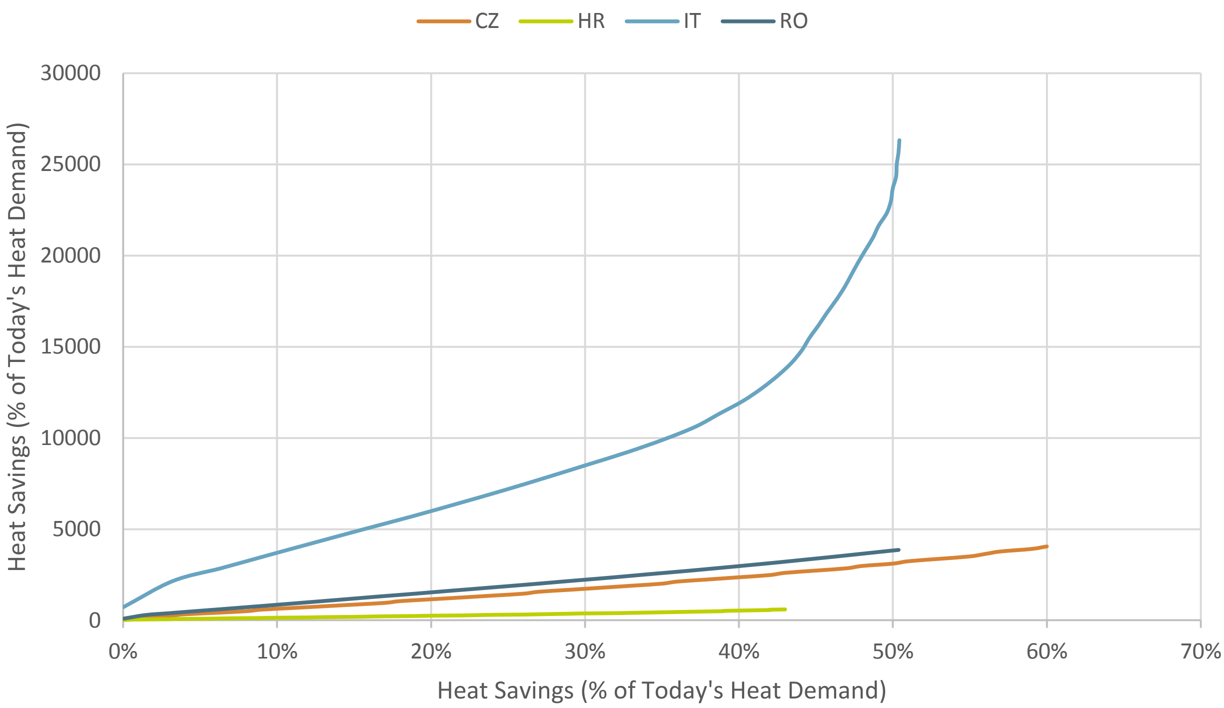


Figure 3: Accumulated Annualised costs for Czech Republic, Croatia, Italy, and Romania. Today's heating demand refers to the year 2014.

After quantifying the total costs for the energy savings, the levelised cost of heat savings (i.e. €/kWh of heat saved) was also calculated so the different countries could be compared with one another. The method used to calculate the cost of heat savings is described below using the Czech Republic efficiency path as an example (see Figure 1 and Figure 2).

1. We calculate the heat demand (space heat and hot water) per floor area (m^2) for every year from 2014 to 2050, by dividing the total square meters of all the buildings by the total heat demand of all the buildings.

For example, in 2015 the total floor space is calculated as being 362,422,144 m^2 (2,428,408 m^2 more than 2014). In 2015 the total space and hot water heat demand is 75.4 TWh (71.9 TWh space heating and 3.5 TWh hot water). Therefore in 2015 the heat demand per floor space is 208 kWh/m^2.

2. We then quantify the 'expected heat demand without savings' by multiplying the total floor area of 2015 (362,422,144 m^2) by the unit heat demand (i.e. kWh/m^2) from the previous year (2014).

For example, in 2014, the previous year, the heat demand was 212 kWh/m^2. This is multiplied by the total floor area of 2015 (362,422,144 m^2). This suggests that if no heat savings were implemented, then the heat demand would have been 76.9 TWh in 2015.

3. We then subtract the actual heat demand of 2015 from the expected heat demand, which is based on the 2015 floor area and the heat demand (kWh/m2) of the previous year (2014).

For example, the actual heat demand in 2015 is 75.4 TWh. The difference between the actual and the expected is 1.5 TWh, which is assumed to be the amount of heat saved in 2015 due to the investments made in heat savings in the year 2015.

4. For each year the total investment costs are also annualised as described earlier in equation 1 and as presented for each country in Figure 3.

In the Czech Republic example, the total investment in heat savings in 2015 is €1080 million (see Table 1). Annualised, this is a total investment cost of M€51/year.

Table 1: Example of total investment costs in renovations measures and the annualised cost for 2014

Component	Building type	Total investment in 2014 (M€)	Annualised cost in 2014 (M€)
Insulation	Wall, Roof, Cellar retrofit	410	32
	Wall, Roof, Cellar new buildings	333	
Windows	Windows retrofit	156	16
	Windows new buildings	123	
Total		1021	48

5. By dividing the annualised costs of the previous year (i.e. 2014) by the total savings in that year (i.e. 2015), it is possible to estimate the unit cost of heat saved (i.e. €/kWh)

For the Czech Republic, the investment in heat savings in 2014 is M€48/year in 2014, while the heat saved in 2015 equates to 1.5 TWh/year, so the levelised cost of heat saved is €0.033/kWh.

6. This process is repeated for all efficiency scenarios for all years in Czech Republic, Croatia, Italy and Romania.

7. Finally, the unit cost of heat saved (i.e. €/kWh) is plotted against the unit heat demand (i.e. kWh/m2) for each year, which is discussed in more detail in section 4.

The results for each country are shown below in Figure 4. The results suggest that heat savings are the most cost effective in the Czech Republic, then Croatia, and finally Italy and Romania have similar costs.

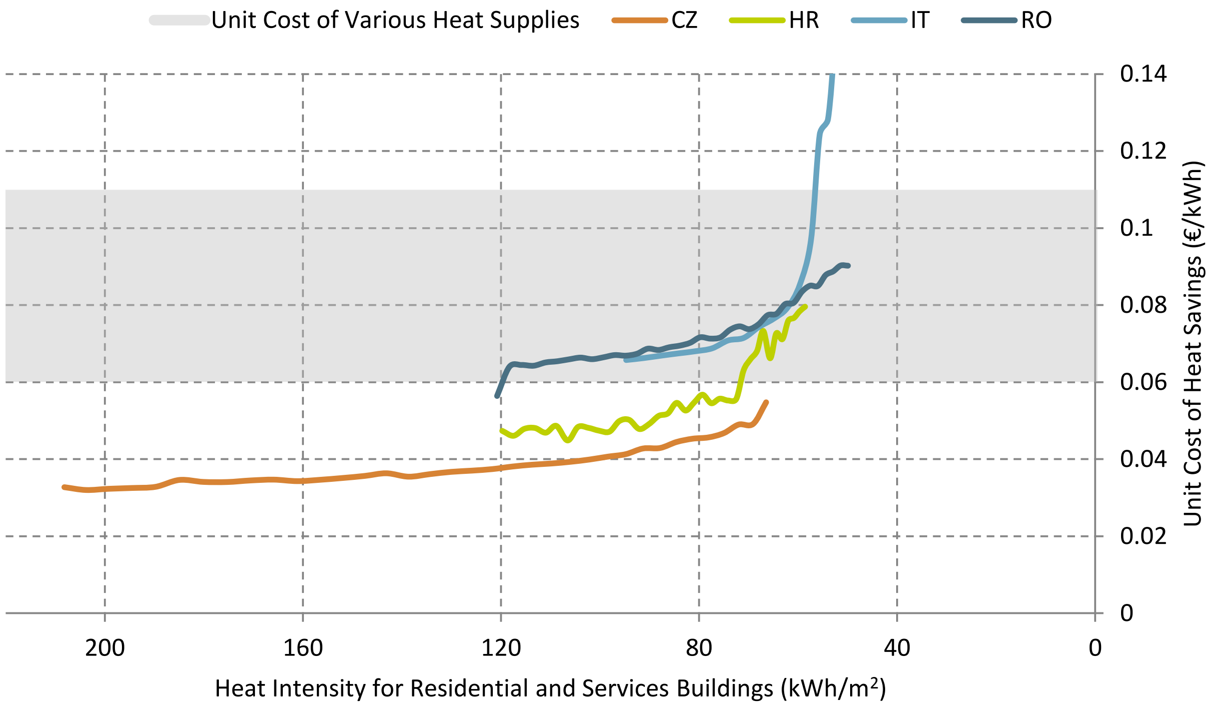


Figure 4: Heat intensity compared to the unit cost of heat savings and various forms of heat supply in the Czech Republic, Croatia, Italy, and Romania. The methodology used to estimate the unit cost of heat supply from various technologies is discussed in section 4.

3 Quantifying the Cost of Heat Savings in Buildings for the UK

The UK is not included in Background Report 3a, so a literature review was carried out to establish if the cost of heat savings is already reported for the UK. This led to a study by Element Energy called “*Review of potential for carbon savings from residential energy efficiency*” written for The Committee on Climate Change [1].

This study only considers the residential sector whereas the Ecofys analysis included both residential and services buildings.

According to the main data source used in the Element Energy study, in the United Kingdom the heating energy demand for residential space heating and hot water was approximately 400 TWh in 2010 [2], of which ~80% was supplied by natural gas. Based on 27.4 million dwellings, the average household heat consumption equates to 15,150 kWh of heating each year. The average residential dwelling floor area in the UK in 2010 was around 92 m^2 [3], so the average unit heat consumption was estimated as 161 kWh/m^2.

In the Element Energy study, heat saving potentials were determined for different measures in the UK. Since housing types are varied in the UK and not all measures are relevant for each housing type, the extent of heat savings were quantified for each measure for a range of different UK house types. The UK residential building stock was segmented into groups in order to carry out this study. In total there were 135 different house types. The Standard Assessment Procedure (SAP) was applied for the calculation of the residential heating [1][4].

The SAP methodology calculates the annual heating (space and hot water) and electricity consumption (excluding consumer appliances) demand for each of the different house types before and after the energy saving measure is introduced [1]. The disaggregation and segmentation of the housing stock was determined from the English Housing Survey (EHS), which determined the different types of homes in the UK. The house types vary in terms of size, tenure and fuel.

Element Energy developed a Housing Energy Model (HEM) that was used to calculate the heat savings from each measure. HEM calculates the technical potential for each measure and this is used to determine the potential for heat energy savings associated with each specific measure, which can vary across the house types. The assessment was carried out for each building segment in the stock, but the heat savings were only measured for the housing segments in which they were installed.

The results from the study are used as the basis for the calculations in this report. There are two main components in the calculations, being 1) the additional cost for additional measures and their corresponding heat savings (i.e. €/kWh saved) and 2) the cumulative reduction of the country’s domestic residential unit heat demand (i.e. kWh/m^2). This ensures that the results for the UK can be directly compared with those obtained for the other STRATEGO countries in Figure 4.

The weighted average cost from each measure across the total UK stock is presented in Figure 5. The installation cost of the measure is different for different house types. Therefore the cost is determined based on the house type attributes such as wall area, loft area and thickness, glazing area [1], with the results converted into a weighted average. The different house types also affect the annual fuel savings for each measure which are also weighted, which is shown in Figure 6.

After the weighted average cost of each measure is determined, then they are annualised in order to compare each measure with one another, which is also shown in Figure 7. These annualised costs are used in in this study to determine the unit cost of heat savings (i.e. €/kWh). These costs are per measure so they are multiplied by the total number of dwellings to establish the impact at a national level.

To determine the unit cost of heat savings (i.e. €/kWh saved) for each measure, the following steps are carried out:

1. The "number of houses with each measure" was estimated based on the total heat savings for each measure (Figure 8) and the average heat savings for each dwelling (Figure 6).

$$number\ of\ houses\ with\ the\ measure = \frac{total\ heat\ energy\ savings\ by\ the\ measure\ in\ the\ UK}{weighted\ average\ heat\ energy\ savings\ by\ the\ measure} \quad (2)$$

2. The "total annualised cost of the measure in the UK" is determined by multiplying the cost per household for each measure (Figure 7) by the number of houses with the measure (equation 2):

$$total\ annualised\ cost\ of\ the\ measure\ in\ the\ UK = (annualised\ cost\ per\ installation) \cdot (number\ of\ houses\ with\ the\ measure) \quad (3)$$

3. Finally, the unit cost of heat savings is calculated based on the total annualised costs (equation 3) divided by the total annual energy savings due to the measure (Figure 8). As shown in Figure 8, the results are presented in terms of fuel savings, as opposed to heat savings. Since this study focuses on reductions in the heat demand, the fuel savings are converted into heat savings. Different efficiencies are assumed for the different types of heating units, depending on the fuel they consumed. The same efficiencies are used here as in Background Report 4, which are 65% for solid fuel, 85% for natural gas, 80% for oil, and 100% for direct electric heating. The different fuel mix used in the Element Energy study was extracted from the UK Energy Data file [2]. Using this fuel mix and the efficiencies, the average efficiency was calculated as 85%. This efficiency is assumed when converting from fuel savings to heat savings for the individual measures.

$$cost\ per\ kWh\ saved = \frac{total\ annualised\ cost\ of\ the\ measure\ in\ the\ UK}{total\ annual\ heat\ savings\ of\ the\ measurein\ the\ UK} \quad (4)$$

The resulting weighted average heat energy savings per measure, total annual heat energy savings by each measure, the number of houses with each measure, and the corresponding costs are presented in Table 3.

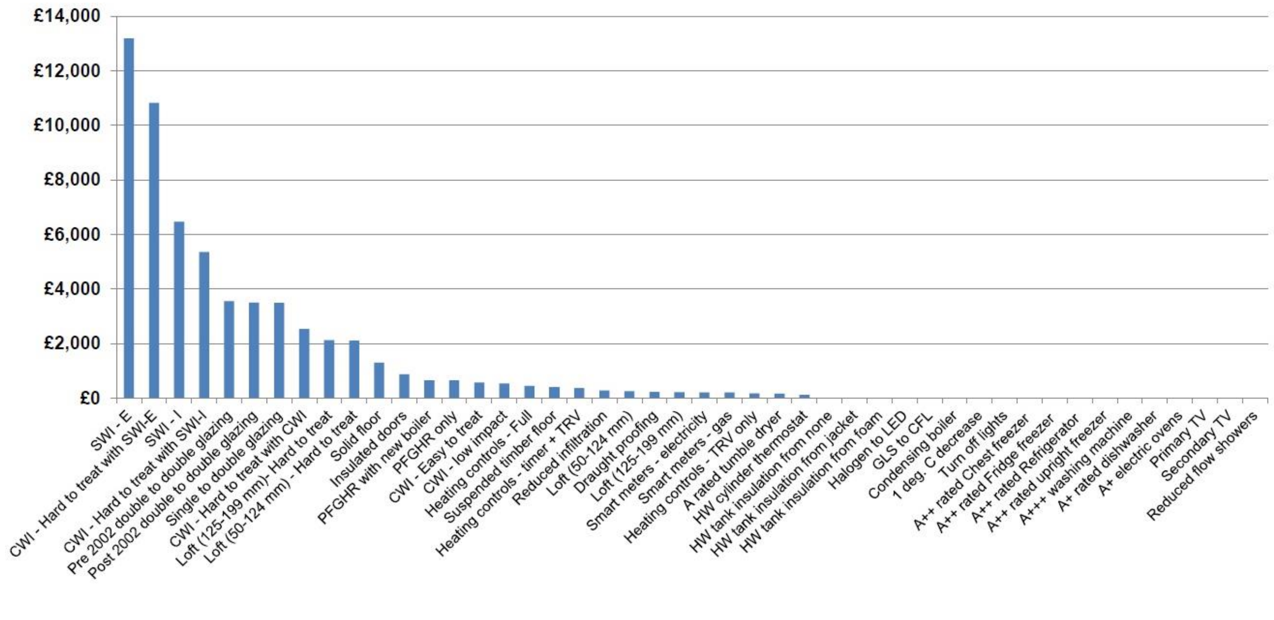


Figure 5: Breakdown of weighted average cost of installation of measures [1]**.**

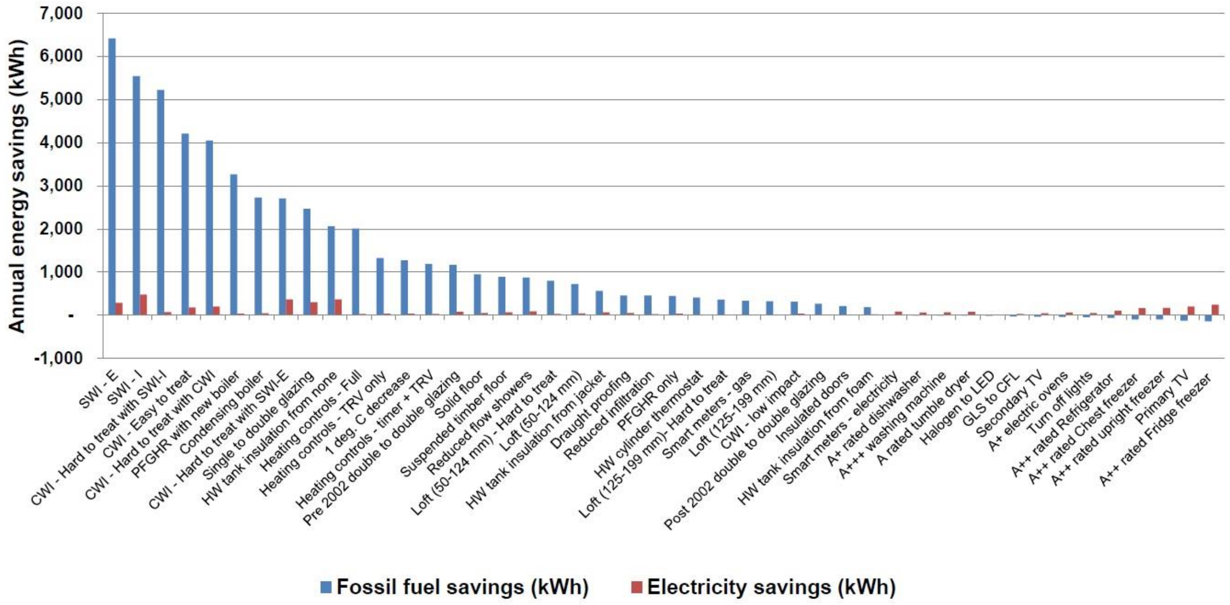


Figure 6: Breakdown of weighted average fossil fuel and electricity savings [1]**.**

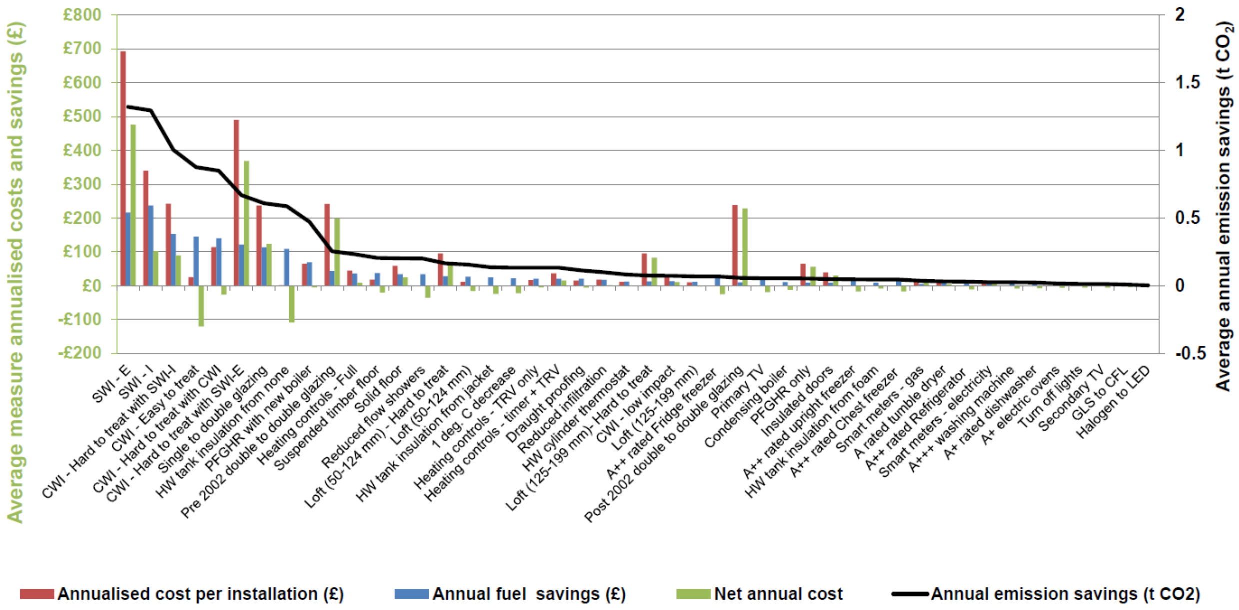


Figure 7: Annualised cost per installation of measure [1].

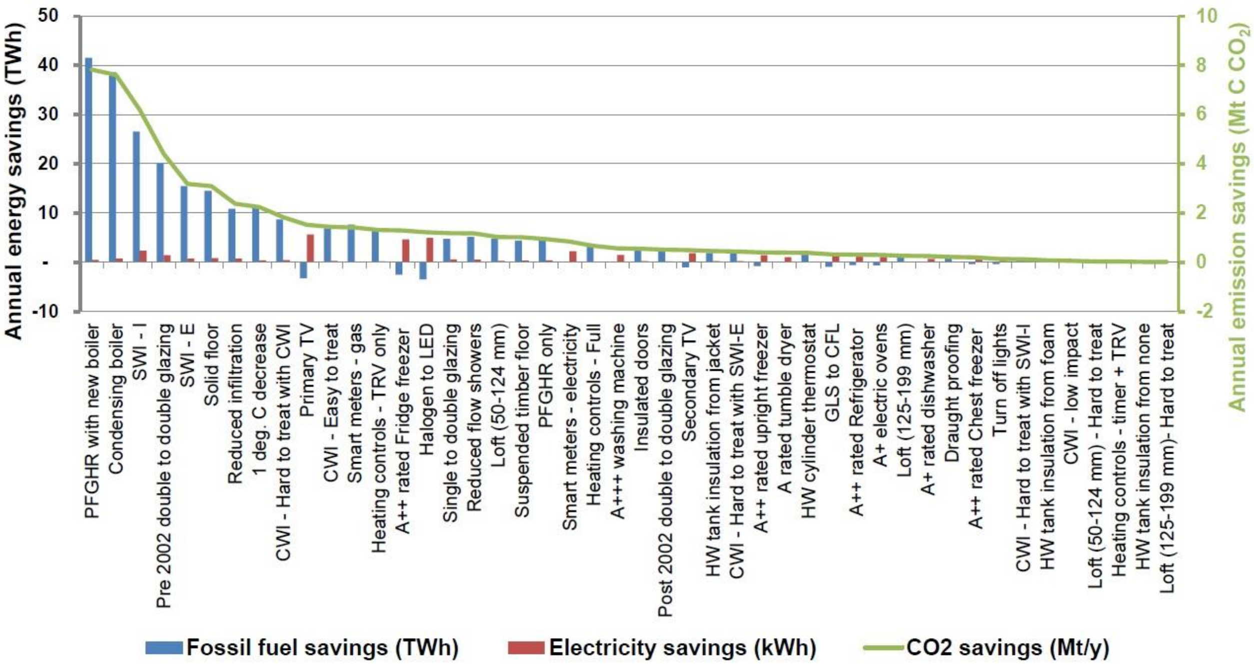


Figure 8: Total potential for annual energy savings across stock [1]

An important note is that this study excludes all of the behavioural and heating supply measures, such as installing a condensing boiler and decreasing the temperature by 1°C. To be in line with the analysis in Background Report 3a, only measures relating to the building envelope were included such as insulation and improvements to the windows. The resulting measures included are outlined in Table 2. Also, Figure 9 presents the overlapping savings data which corrects the savings when different measures are combined in one dwelling, so they can counteract some of the savings by each other, thus lowering the overall savings. The figure shows that this is only occurs for the boilers, and so all the measures included in this study do not have an overlapping effect. As a result, the overlapping affect is not considered here.

Table 2: Measures included in the study.

Component	Measure
Hot water tank	Hot Water tank insulation from none Hot Water tank insulation from jacket Hot Water tank insulation from foam
Walls & doors	Cavity Wall Insulation - Easy to treat Cavity Wall Insulation - Hard to treat with Cavity Wall Insulation Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - Internal Solid wall insulation - Internal Cavity Wall Insulation - low impact Solid wall insulation - External Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - External Insulated doors
Ceiling	Loft (50-124mm) Loft (125-199mm) Loft (50-124mm) - Hard to treat Loft (125-199mm) - Hard to treat
Floors	Suspended timber floor Solid floor
Windows	Single to double glazing Pre 2002 double to double glazing Post 2002 double to double glazing
Building air tightness	Draught proofing Reduced infiltration

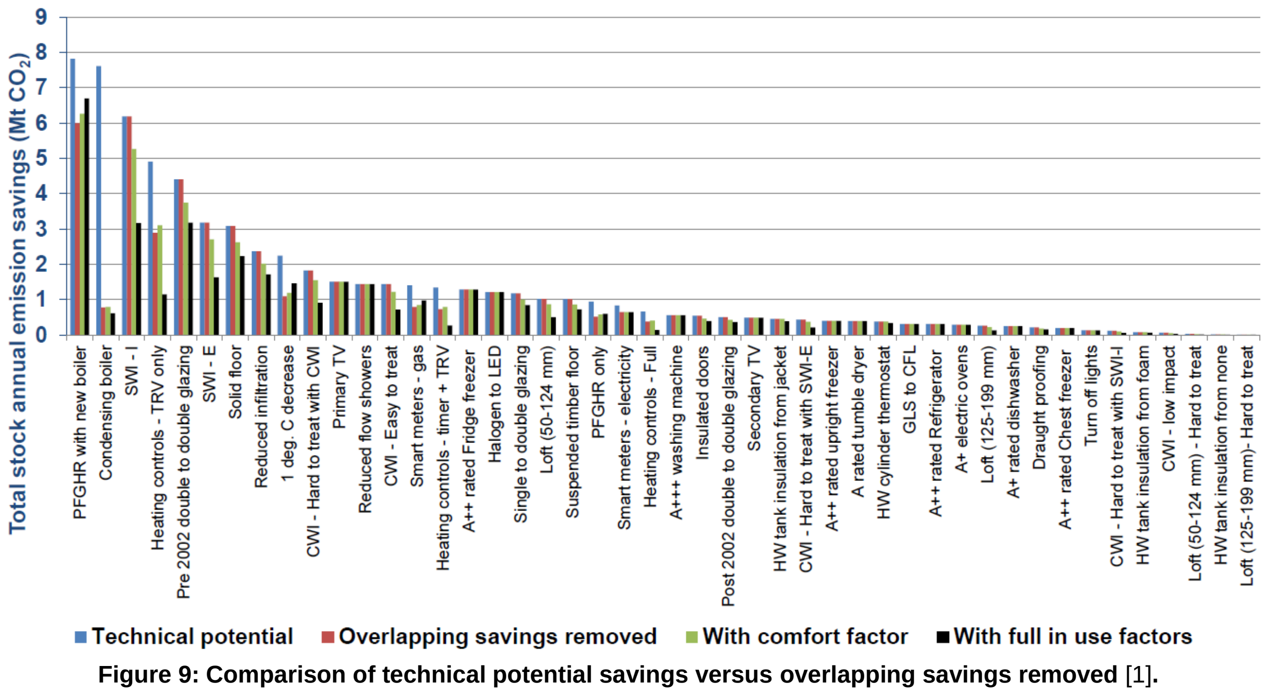


Figure 9: Comparison of technical potential savings versus overlapping savings removed [1].

Table 3: Heat savings per measure in the UK, including number of dwellings receiving each measure along with the corresponding cost for each measure, including unit cost of heat savings.

Component	Measure	Weighted average annual heat savings per measure (kWh)	Annual heat savings in UK (TWh)	Number of dwellings receiving measure in UK	Total annualised cost for the UK (€ Million)	Unit cost (€/kWh saved)
Hot water tank	Hot Water tank insulation from none	2067	0.09	41,152	0.06	0.0007
	Hot Water tank insulation from jacket	519	1.3	2,459,016	3.4	0.003
	Hot Water tank insulation from foam	162	0.3	1,578,947	2.2	0.008
Walls & doors	Cavity Wall Insulation - Easy to treat	3726	6.4	1,712,329	58.7	0.009
	Cavity Wall Insulation - Hard to treat with Cavity Wall Insulation	3573	8.1	2,261,905	77.5	0.01
	Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - Internal	4475	0.3	76,046	23.9	0.07
	Solid wall insulation - Internal	5062	24.3	4,789,916	2,165.5	0.09
	Cavity Wall Insulation - low impact	281	0.2	606,061	24.9	0.15
	Solid wall insulation - External	5657	13.2	2,330,827	2203.3	0.17
	Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - External	2637	1.3	483,871	324.8	0.25
	Insulated doors	179	1.7	9,523,810	391.4	0.23
Ceiling	Loft (50-124mm)	676	4.3	6,289,308	86.2	0.02
	Loft (125-199mm)	272	0.1	312,500	4.3	0.05
	Loft (50-124mm) - Hard to treat	736	0.1	115,607	15.8	0.19
	Loft (125-199mm) - Hard to treat	349	0.04	121,951	16.7	0.39
Floors	Suspended timber floor	817	3.8	4,687,500	96.3	0.025
	Solid floor	851	12.8	15,000,000	1130.3	0.089
Windows	Single to double glazing	2340	4.7	2,000,000	630.2	0.13
	Pre 2002 double to double glazing	1038	17.9	17,213,115	5541.8	0.31
	Post 2002 double to double glazing	230	1.7	7,407,407	2334.1	1.37
Building air tightness	Draught proofing	451	0.4	943,396	19.4	0.046
	Reduced infiltration	434	9.4	21,568,627	443.2	0.05
TOTAL		N/A	112	N/A	N/A	N/A

Overall by implementing these measures the UK could save around 112 TWh (or 28%) of heat demand per year out of 400 TWh based on the 2010 demand, assuming that the floor area remains the same, at a total annualised cost of around €16 billion/year.

All the measures are ranked from cheapest to the most expensive. The results shown in Table 4 and Figure 10 show the cheapest measures first up to the most expensive. Table 4 provides the new heat density (kWh/m^2) after each measure is installed in the UK. Before any of the measures are installed the heat density is 161 kWh/m^2. Figure 10 shows the measures being installed one after the other in this order. On the x-axis the reduction in heat energy of the total UK heat demand is calculated as each measure is implemented. Each measure is added to the previous measure and the cumulative energy savings for the UK housing stock are determined until all the measures have been implemented. When plotting each measure on the chart, the measures are added to each other as if they are installed sequentially in the UK building stock and thus the energy savings keep accumulating. Although the energy savings accumulate along the x-axis, the unit cost of each measure is not accumulated on the y-axis. Instead, it reflects the cost of the measure individually.

Table 4: Unit heat demand (kWh/ m^2) as each measure is installed, starting with hot water tank insulation to post 2002 double to double glazing.

Hot Water tank insulation from none	**Hot Water tank insulation from jacket**	**Hot Water tank insulation from foam**	**Cavity Wall Insulation - Easy to treat**	**Cavity Wall Insulation - Hard to treat with Cavity Wall Insulation**	**Loft (50-124mm)**	**Suspended timber floor**	**Draught proofing**	**Reduced infiltration**	**Loft (125-199mm)**	**Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - Internal**
161	161	160	158	155	153	151	151	148	147	147
Solid floor	Solid wall insulation - Internal	Single to double glazing	Cavity Wall Insulation - low impact	Solid wall insulation - External	Loft (50-124mm) - Hard to treat	Insulated doors	Cavity Wall Insulation - Hard to treat with Solid Wall Insulation - External	Pre 2002 double to double glazing	Loft (125-199mm) - Hard to treat	Post 2002 double to double glazing
142	133	131	131	125	125	125	124	117	117	116

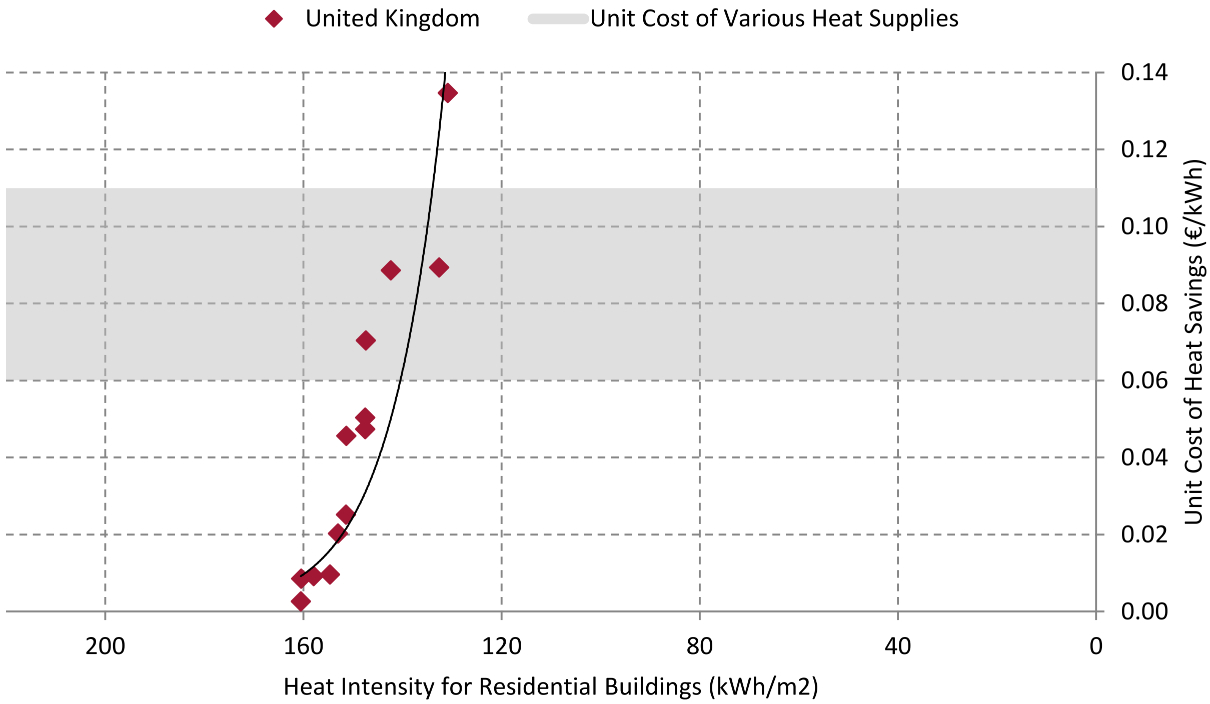


Figure 10: Heat demand per square metre against cost for marginal savings. Note that this does not include all of the savings presented in Table 3 since the scale on the axes is the same as in Figure 4.

4 Comparing the Cost of Heat Savings and Heat Supply for Each STRATEGO Country

The building envelope is usually much more efficient in newer buildings than in older buildings, due to improved building regulations over time. Therefore, when heat savings are implemented in older buildings, there is usually a shorter payback than when buildings are implemented in newer buildings. As a result, heat savings are usually implemented in older buildings first, so in the beginning heat savings are extremely cost effective from a private and socio-economic perspective. However, over time the number of older buildings that need renovating becomes less and less, so the payback of heat savings reduces, with previous studies concluding that the cost of further heat savings will eventually surpass the cost of supply [5]. On the broader energy system level it is at this point that it is more cost-effective to consume heat within the building rather than to add a new heat saving measure. The key question remaining is at what point does the cost of heat savings exceed the cost of heat supply?

Here, the balance between the cost of heat savings and the cost of heat supply is compared for the STRATEGO countries. This comparison is based on the unit cost of heat savings obtained in sections 2 and 3, with the unit cost of heat supply. Therefore, the unit cost of heat supply has to be calculated. The levelised cost was determined for 1 kWh of heat for oil boilers, natural gas boilers, biomass boilers, air source heat pumps, ground source heat pumps, electric heating, and district heating. The assumptions used to estimate the levelised costs of heating are provided in Table 5, while the resulting levelised costs for heat are displayed in Figure 11.

Table 5: Cost assumptions to estimate the levelised cost from various individual heating technologies. These are the costs of single-family heating units for new buildings based on the year 2020 [6][7]**.**

Heating System	Oil Boiler	Natural gas Boiler	Biomass Boiler	Heat Pump Air Source	Heat Pump Ground Source	Electric Heating	District Heating
Specific investment (1000€/unit)	6.6	5	6.75	12	16	8	2.5
Technical lifetime (years)	20	22	20	20	20	30	20
Annual Investment* (€/year)	444	251	454	672	874	408	202
Fixed O&M (€/unit/year)	270	46	25	135	135	80	150
Efficiency	100%	102%	87%	330%	350%	100%	98%
Annual Fuel Consumption# (MWh/year)	15	15	17	4.5	4.3	15	15
2010 Fuel Cost+ (€/MWh)	32	36	32	65”	65”	65”	36”
2050 Fuel Cost+ (€/MWh)	65	54	41	83”	83”	83”	51”
Annual District Heating Pipe Costs (€/MWh)^							4

**Using equation 1 and assuming an interest rate of 3%*

#Annual a heat demand of 15 MWh/year

+Based on the cost from the Euroepan Commission [8]*, with the addition of fuel handling costs* [6]*. Carbon dioxide costs are not included here.*

^Based on the cost of conventional district heating networks in existing areas [7]*.*

”Assuming the electricity/heat is produced from a combined cycle gas turbine and based on the cost assumptions in the EnergyPLAN Cost Database [6]*.*

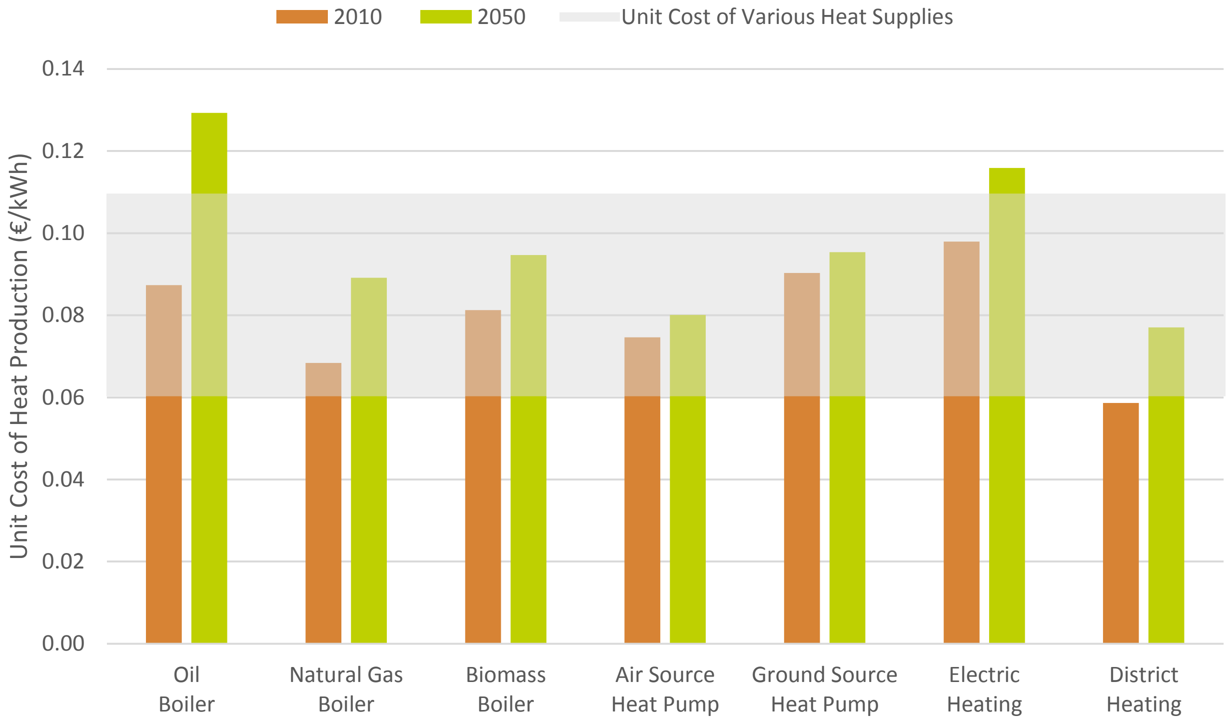


Figure 11: Unit cost for different years and costs for different heat sources.

The result suggest that the unit cost of heat supply is in the region of €0.06-0.11/kWh depending on the type of technology and the fuel price. These levelized costs are good for approximations, but they should only be seen as a guide since they do not account for the synergies that can be utilised in the energy system. For example, the electricity price for heat pumps and electric heating could vary significantly depending on the mix of technologies for electricity production. Here these unit prices are used as guide and compared with the unit cost of heat savings to establish an initial estimate for the level of heat savings feasible in each country.

Figure 12 displays these unit costs of heat supply against the unit costs of heat savings identified in sections 2 and 3. The results indicate the level of heat savings can vary dramatically depending on the specific cut-off point that is defined and the country that is being considered. For example, if the lowest estimated cost of heat supply is chosen, then the level of heat savings is 0-60% depending on the country chosen, while if it is the highest cost of heat supply, then the level is 20-60%. This illustrates the dangers of using a unit cost approach when defining a specific level. However, on the contrary, the unit costs approach also provides some valuable insights.

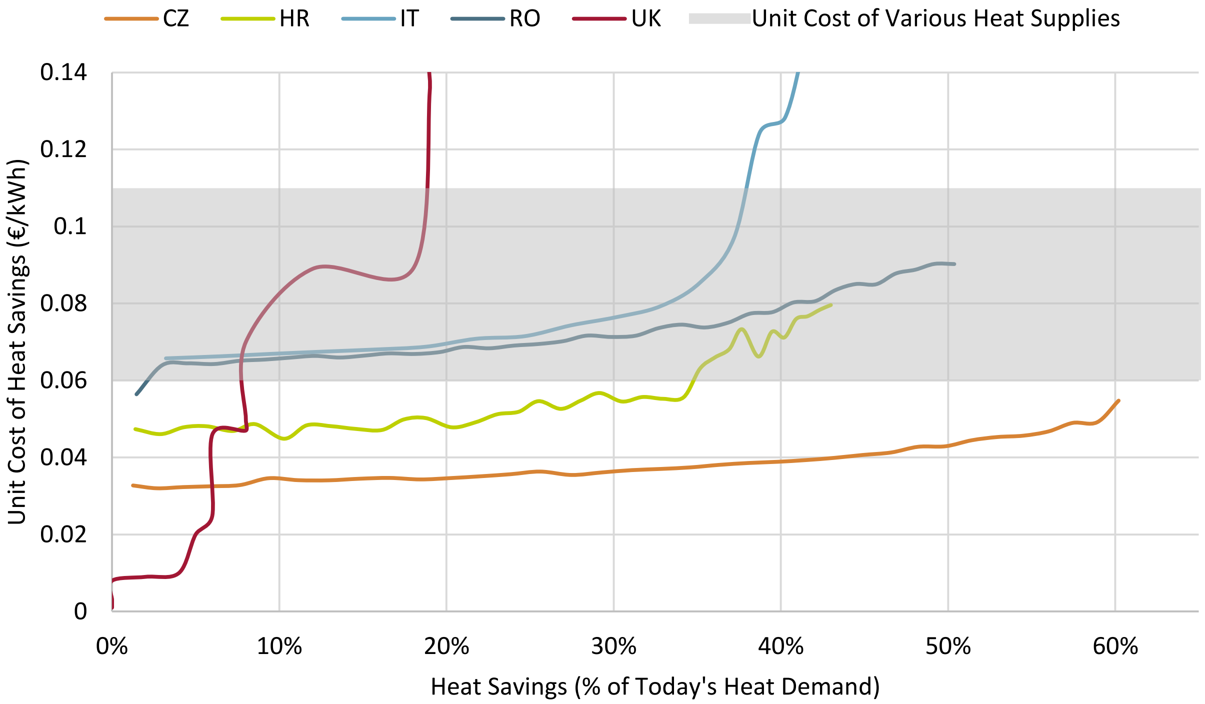


Figure 12: Comparison between the unit cost of heat supply and the unit cost of heat savings, along with the corresponding level of heat savings for each STRATEGO country. Note: today's heat demand refers to the year 2014 for Czech Republic, Croatia, Italy and Romania, but to the year 2010 for the UK.

Table 6: Heat Savings feasible in each country at based on the levelized cost of heat savings compared to the levelized cost of heat supply.

Heat Savings Feasible (% of Today's	Cost of Heat Supply €0.06/kWh	Heat Intensity (kWh/m^2)	Cost of Heat Supply €0.11/kWh	Heat Intensity (kWh/m^2)
CZ	60%	66	60%	66
HR	35%	70	45%	60
IT	0%	100	40%	55
RO	3%	120	50%	50
UK	10%	150	20%	130

**This is the maximum level of heat savings that is technically feasible even with very strong policy support between today and 2050 (see Background Report 3a).*

The results show that for four countries (UK, Croatia, Italy, Romania) the cost of renovations reaches a point in which it can be argued that it is cheaper to supply heat rather than install more heat saving measures. However, as shown in Figure 12, the Czech Republic is able to reduce its heat demand significantly at a relatively cheap cost, and it never crosses the threshold for the cost of supplying heat. There is a slight upward trend at the end of the modelled data, so if more heat saving measures are installed, then it is likely that the cost of heat savings would eventually surpass the cost of the heat supply for the Czech Republic, but this point is currently unknown,

For the four countries in the Ecofys analysis (see Background Report 3a), which are the Czech Republic, Croatia, Italy, and Romania, it is assumed as a starting point in the analysis that the level of heat savings is approximately 40-50%. Afterwards, the heat savings will be increased and decreased using an whole energy systems analysis approach with the EnergyPLAN tool, to establish the cheapest level of savings from an energy systems perspective.

The UK profile in Figure 12 is different to the other countries, since the cost of renovating the dwellings increases much faster, and overall less savings can be achieved with similar renovations measures (insulation and windows). The point at which the cost of heat savings surpasses the cheapest heat supply is at around 10% heat savings, which is at a heat intensity of 150 kWh/m^2, while it crosses the most expensive heat supply threshold at 20% heat savings, which is at a heat intensity of 130 kWh/m^2 (see Table 6). This is very different to the other countries, which is most likely related to the methodology. For example, some key considerations between the two methodologies are:

- The UK study does not consider new buildings or demolition of old buildings. The building stock remains the same in the study. In comparison, the Ecofys method increases the floor area every year since it considers demolition and new building rates, whereas the floor area in the UK remains the same
- The Ecofys method includes residential and service buildings, whereas the UK study includes only residential dwellings
- The Ecofys method calculates heat demand per year based on installation of insulation and windows every year, whereas the UK study calculates the savings from different measures as a total for the UK stock, and this does not consider the time horizon in which that occurs.
- The Ecofys study is based on a modelling tool that uses some key parameters, such as demolition rate, new build rate etc. Whereas the UK study is based on detailed analysis of the buildings stock and real-life potential for renovations and associated costs.

It is very unlikely that the UK varies this much from the other countries. In other words, it is unlikely that all other countries can potentially reach a heat intensity as low as 50-65 kWh/m^2, but the UK can only reach 130 kWh/m^2 (see Table 6). Due to these differences, the cost of heat savings in the UK is not based on the costs identified here in section 3. Instead, it will be assumed that the heat intensity in the UK can be reduced to a similar level as the other STRATEGO countries, which is conservatively assumed here to be 70 kWh/m^2, and that the cost of these savings measures in the UK is the average of the costs in the other four STRATEGO countries. Assuming a 70 kWh/m^2 corresponds to a total heat demand reduction in the UK of ~40%, while the average cost for the other four STRATEGO countries will only be available after the cheapest level of heat savings is identified in the energy system analysis in the main study for the other four countries. The level of UK savings will be varied at different levels in the same way as the other countries to see if this 40% level is a reasonable assumption from an energy system perspective, but again the corresponding costs will be the average of the other four countries and not the costs identified here in section 3.

5 Discussion and Conclusion

Identifying a balance between the cost of heat supply and heat savings is a very difficult task. When comparing unit costs, small changes in the assumptions can have a large impact of the level of heat savings defined as optimal. In addition, these numbers could potentially hide many of the challenges relating to the implementation. An extreme example could be an historical building where it is technically possible and economically viable to renovate from an energy perspective, but due to the cultural value of the building's façade, it is not possible to implement these measures. As a result, it is often important to go beyond the numbers when analysing the realistic level of heat savings that can be implemented in the future. Below are some reflections on the context of the numbers developed in this report.

Firstly, the numbers in Figure 12 and Table 6 are average numbers for the entire building stock, so there will be differences between the buildings in each country. For example, new buildings typically have a higher unit cost per heat saved than an existing building. For example, if you install a triple-glazing window with a very low insulation level in a new building, then it will be an improvement on the standard double-glazing window that usually goes into new buildings. However, if you put the same triple-glazed window into an existing building, then the window will cost the same price, but it will now most likely replace a single-glazed window in the exiting house rather than the double-glazed window that is typically in new houses. Therefore, for the same investment, you have obtained higher savings.

Furthermore, it is likely that more heat savings can be achieved in the rural areas than in urban areas, since the passive solar heat gain is usually higher for rural dwellings. For example, in the urban areas many buildings are located close together and the buildings can be four, five or more stories high, so the passive solar heat gain can be relatively low. Also, in rural areas it is easier to develop individual renewable heat sources such as solar thermal and solar PV, since there is more roof area per person available. This means that in the urban areas, there will likely be less heat savings on average, while in rural areas, there will likely be more heat savings on average.

Also, even if a lot of heat savings are implemented, it is still unlikely that the 'dispatchable' heat production unit can be removed completely (i.e. the boiler or heat pump). For example, to become a Net Zero Energy Building (NZEB) is not only a matter of heat savings, but it also typically requires some form heat supply. The main heat supply in a NZEB is often solar thermal or solar photovoltaic panels, but since their production is intermittent, some form of 'dispatchable' or 'controllable' heat supply is still necessary, since the space heating and/or hot water demands cannot rely solely on solar in the winter for example. For this, some typical options could be heat pumps, electric heating, boilers, or district heating. It is very unlikely that the 'backup' unit will ever be completely removed since there is a risk that the solar cannot supply the hot water when necessary. This is an important consideration since once the 'backup' unit is in place, the cost of supplying heat from the unit is much lower than if you also include the original investment cost.

Finally, it is important to appreciate that savings are usually an extremely economic solution for the energy system, since they eliminate the need for the rest of the supply chain, such as the fuel production, transportation, and maintenance. However, in some cases the heat supply available will take place with or without heat savings. For example, even if there is no heat demand in the buildings, there will still be excess heat available from the thermal power plants which could be used to heat the buildings. These synergies are only visible when the energy system is analysed from a holistic perspective in the main report.

In conclusion, the results in this study demonstrate that the cost of heat savings is likely to surpass the cost of heat supply as more heat savings are implemented. However, this economic balance between heat savings and heat supply is still unclear after comparing the unit cost of heat supply and the unit cost of heat savings. The balance varies significantly depending on the country and on the cut-off point defined for the cost of heat supply. Therefore, instead of defining an exact level here, the unit costs are used as a starting point when analysing different levels of heat savings in each of the STRATEGO countries.

Although a literature review was carried out to identify specific costs for the UK, these results were significantly different to those reported in Background Report 3a for the other four STRATEGO countries. Therefore, the scale and cost of heat savings in the UK is based on the average cost of heat savings from the other four countries.

6 References

[1] Element Energy, "Review of potential for carbon savings from residential energy efficiency. Final report for The Committee on Climate Change.," Cambridge, 2013.

[2] Department of Energy and Climate Change, "Energy Consumption in the UK (ECUK) Domestic data tables," 2014. [Online]. Available: https://www.gov.uk/government/collections/energy-consumption-in-the-uk. [Accessed: 20-Oct-2014].

[3] Enerdata, Ademe, and European Energy Network, "ODYSSEE database on energy efficiency data & indicators," 2014. [Online]. Available: http://odyssee.enerdata.net/nrd_web/site/.

[4] Department of Energy and Climate Change, "Guidance Standard Assessment Procedure," 2014. [Online]. Available: https://www.gov.uk/standard-assessment-procedure. [Accessed: 20-Oct-2014].

[5] D. Connolly, H. Lund, B. V Mathiesen, S. Werner, B. Möller, U. Persson, T. Boermans, D. Trier, P. A. Østergaard, and S. Nielsen, "Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system," *Energy Policy*, vol. 65, pp. 475–489, 2014.

[6] Aalborg University, "EnergyPLAN cost database," 2014. [Online]. Available: http://www.energyplan.eu/costdatabase/.

[7] Danish Energy Agency, "Technology Data for Energy Plants: Individual Heating Plants and Energy Transport," 2012.

[8] P. Capros, A. De Vita, N. Tasios, D. Papadopoulos, P. Siskos, E. Apostolaki, M. Zampara, L. Paroussos, K. Fragiadakis, and N. Kouvariatakis, "E3M-Lab, IIASA-GAINS model, IIASA-GLOBIOM model, and EuroCARE, EU energy, transport and GHG emissions trends to 2050 - reference scenario 2013," 2014.

Project No: IEE/13/650

Quantifying the Heating and Cooling Demand in Europe

Work Package 2

Background Report 4

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: Urban Persson
Sven Werner
Contact: Halmstad University
S-301 18 Halmstad, Sweden
T: +46 0 3516 7405
E-mail: urban.persson@hh.se
Web: www.hh.se/english

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

1 European heating demands

1.1 Background

Building heat demands for space heating and hot water preparation in residential and service sectors are quantified in the Stratego project by use of international energy statistics, a set of default conversion efficiencies for fuels used in final consumption, and a separate inquiry on electricity used for heating purposes. The assignment is to estimate the current heating demands in European buildings by country and by NUTS3 region using a top-down approach, partly to establish national and regional average values, partly to provide input data for the specific purpose of creating a high resolution heat demand density map for Europe in order to identify future possibilities for district heating systems. In the following, an account is given for the establishment of country and regional average values, while a separate section (see Background report 5 & 6) is dedicated to the approach and measures used to create the Pan-European heat demand density map.

Building heat demands account for significant shares of total energy use in European Union Member States today and the provision of energy services to meet these demands may utilise several different fuel supply sources and energy carriers. As will be presented in the following, fossil fuel supply sources are, on average, dominating alternatives in EU28 at current, where coal, oil products, and natural gas especially, represent 68% of the total supply to the building heat market (78% including electricity, which often is generated by use of fossil fuels). This indicates that the European building sector has an important role to play in the future decarbonisation of the European energy system, since there is plenty of room for improvements in this sector. One such improvement could be obtained by replacing some of the current fossil supply with recovered excess heat from energy and industry activities, as well as with renewable heat resources. District heating, which at current account for only a minor share of the total EU28 building heat market (12%), represent a key technology for the viability of such an approach.

One would perhaps think that building heat demands are a main issue mainly in Northern Member States, where colder climates and longer winter seasons emphasise the demand for these energy services, but since building heat demands reflect levels of building insulation, levels of energy services available and desired, levels of comfort etc., no such clear division exist in Europe today. Quite contrary, building heat demands are substantial also in central and, to some extent, as well in Southern Member States. In the future, by refurbishments of the current building stock and by new construction of low energy houses, the heat demands of European buildings are expected to decrease. However, since in parallel, specific buildings spaces and the use of domestic hot water are expected to increase, the future heat demands of European building remain difficult to predict. In this section, focus is on the current situation and the reference year for all statistical information used is 2010.

1.1.1 Method and data

To assess heat demands for space heating and hot water preparation in EU28 residential and service sector buildings, the approach within the Stratego project centres on the use of national level energy statistics (corrected energy balances for the year 2010 from the International Energy Agency (IEA, 2014)) and a separate survey on electricity used for heating purposes. The objective is to establish national volumes of fuel and energy supply to European buildings for heating purposes and, by use of default conversion efficiencies, assess the end-use heat demands to which this supply correspond (i.e. the EU28 building heat market). As can be seen in Table 1, default conversion efficiencies are set to reflect current average performance to be expected from individual boilers (using different fuel sources) and electrical appliances (heat pumps and resistance heaters) in contemporary building installations today. To facilitate a comprehensive understanding of the distribution between the residential and the commercial & public services sector, all data is in this context separated with respect to the residential sector (including non-specified (other) sector), the service sector, and the EU28 total.

Table 1. Fuel supply sources and energy carriers extracted from international energy statistics and anticipated average conversion efficiencies in local boilers and electrical appliances. Default values set to reflect average performance in contemporary building installations at current

Fuel supply sources and energy carriers	Average conversion efficiency
Coal and coal products	65%
Peat	60%
Crude, NGL, and feedstocks	80%
Oil Products	80%
Natural gas	85%
Geothermal (heat)	100%
Solar/wind/other	100%
Biofuels and waste	65%
Heat (District heat)	100%
Electricity for heat pumps (residential sector)	300%
Electricity for resistance heaters (residential sector)	100%

Table 2. Shares of electricity in residential sector heat demands (HD), by EU28 Member States, used data sources, and relative distribution of electrical heat demand in terms of heat pumps and other electric heating

Member States	Share of electricity in residential HD [%]	Data source, share of electricity in residential HD	Heat pumps[a] [%]	Other electric [%]
Austria	6	(Kranzl et al., 2012)	33	67
Belgium	3	(Entranze, 2014b)	0	100
Bulgaria	14	(Entranze, 2014b)	10	90
Croatia	6	(Entranze, 2014b)	0	100[b]
Cyprus	27	(CYSTAT, 2011)	0	100
Czech Republic	8	(Zahradník et al., 2012)	30	70
Denmark	3	(Entranze, 2014b)	14	86
Estonia	3	(Entranze, 2014b)	0	100
Finland	17	(Kiuru et al., 2012)	6	94[c]
France	13	(Entranze, 2014b)	2	98
Germany	7	(Kockat and Rohde, 2012)	17	83
Greece	7	(Entranze, 2014b)	0	100
Hungary	4	(Entranze, 2014b)	0	100
Ireland	5	(Entranze, 2014b)	0	100
Italy	6	(Zangheri et al., 2012)	0	100
Latvia	1	(Entranze, 2014b)	0	100
Lithuania	0	(Entranze, 2014b)	0	100
Luxembourg	5	(Entranze, 2014a)	0	100
Malta	77	(Valletta, 2014)	0	100[b]
Netherlands	2	(Entranze, 2014b)	82	18
Poland	1	(Entranze, 2014b)	1	99
Portugal	19	(Entranze, 2014b)	0	100
Romania	1	(Atanasiu et al., 2012)	0	100
Slovak Republic	3	(Entranze, 2014b)	30	70
Slovenia	1	(Entranze, 2014b)	0	100[b]
Spain	18	(Entranze, 2014b)	25	75
Sweden	26	(Entranze, 2014b)	68	32
United Kingdom	9	(Palmer and Cooper, 2012)	4	96

[a] *All data on relative shares, heat pumps versus Other electric, gathered from (Entranze, 2014a) unless otherwise noted*

[b] *No Entranze data available. Assumed distribution.*

[c] *No Entranze data available. Used data source: (Statistics Finland, 2008). NOTE; Shares refer to Residential and Service sector total.*

Since, in international energy statistics, electricity use in residential and service sectors never is specified in terms of electricity used for electrical or heating purposes, alternative information sources are used in the Stratego assessments to better estimate this share of the total building heat demand. For the residential sector assessments, the Entranze portal (Entranze, 2015) with associated country reports and publications (Atanasiu et al., 2012; Entranze, 2014a, b; Kiuru et al., 2012; Kockat and Rohde, 2012; Kranzl et al., 2012; Zahradník et al., 2012; Zangheri et al., 2014; Zangheri et al., 2012), have been the main information sources used for this end. Where available, also some national reports (CYSTAT, 2011; Palmer and Cooper, 2012; Statistics Finland, 2008; Valletta, 2014) were used. As detailed in

Table 2, national shares of electricity used for heating purposes in the residential sector are established by a selection of these sources, however mainly by use of (Entranze, 2014b).

Table 3. Electricity supply for final consumption in service sector, anticipated average electricity for heating purposes, total service sector heat market, and calculated electricity shares of service sector heat demands (HD), by EU28 Member States, data for 2010

Member States	Electricity supply[a] [EJ]	Electricity for heating (19.7%)[b] [EJ]	Total heat market - excluding electricity[c] [EJ]	Total heat market [EJ]	Share of electricity in service HD [%]
Austria	0.047	0.009	0.068	0.078	12
Belgium	0.080	0.016	0.109	0.125	13
Bulgaria	0.029	0.006	0.011	0.017	34
Croatia	0.019	0.004	0.011	0.015	25
Cyprus	0.008	0.002	0.002	0.003	46
Czech Republic	0.050	0.010	0.070	0.080	12
Denmark	0.039	0.008	0.047	0.055	14
Estonia	0.009	0.002	0.008	0.010	18
Finland	0.064	0.013	0.014	0.026	48
France	0.512	0.101	0.379	0.480	21
Germany	0.555	0.109	0.781	0.890	12
Greece	0.065	0.013	0.014	0.027	48
Hungary	0.041	0.008	0.078	0.086	9
Ireland	0.026	0.005	0.031	0.036	14
Italy	0.308	0.061	0.341	0.402	15
Latvia	0.009	0.002	0.014	0.016	11
Lithuania	0.010	0.002	0.013	0.015	13
Luxembourg	0.007	0.001	0.010	0.011	12
Malta	0.0023	0.0004	0.0000	0.0004	100
Netherlands	0.126	0.025	0.244	0.269	9
Poland	0.157	0.031	0.164	0.195	16
Portugal	0.059	0.012	0.016	0.028	41
Romania	0.027	0.005	0.045	0.050	11
Slovak Republic	0.029	0.006	0.049	0.055	10
Slovenia	0.011	0.002	0.009	0.011	19
Spain	0.302	0.060	0.088	0.148	40
Sweden	0.118	0.023	0.086	0.109	21
United Kingdom	0.351	0.069	0.278	0.347	20
EU28 Total	**3.061**	**0.604**	**2.982**	**3.586**	**17**

a As reported in (IEA, 2014).

b Average share for space and water heating of 19,7% for EU27 tertiary sector in 2007, according to (Bertoldi and Atanasiu, 2009).

c As reported in (IEA, 2014) and by use of default conversion efficiencies for fuel transformations according to Table 1.

An important piece of information for the residential sector assessments was also the division of electricity used for heating purposes with respect to heat pumps and “other electric” (mainly resistance heaters), available in (Entranze, 2014a). By this division at national level, it is possible in the Stratego assessment to estimate the often-obscure actual heat demand represented by heat supply from heat pumps. Since, according to Table 1, a default conversion efficiency of 300% is designated electrical heat pumps in this context, the corresponding heat demand satisfied by this technology is anticipated at three times the electrical supply.

For the Stratego service sector assessment, another approach was used since the Entranze data refers mainly to the residential sector only. Additionally, information on end use distributions of Member States service sector electricity use is very rare in general (no coherent data source seem to be available at current), which further necessitated an alternative approach. Based on a EU27 average value for the tertiary sector in 2007 (19.7% of all electricity use designated to space and water heating herein, according to (Bertoldi and Atanasiu, 2009)), electricity volumes for heating purposes are assessed by applying this share uniformly to total electricity supplies for final consumption per Member State (IEA, 2014), as detailed in Table 3. By subsequently adding hereby calculated volumes of electricity used for heating purposes to total Member State heat markets excluding electricity (IEA, 2014), assessments of total service sector heat markets are made available. From this, national shares of electricity use in service sector total heat demands, albeit somewhat granular, may be established.

Hereby, national level assessments of total fuel and energy volumes supplied and used for heating purposes in EU28 residential and service sector buildings are possible to estimate. Based on this, the next step involves national and regional population statistics, to assess specific heat demands (per-capita values), regional climate index factors (European Heating Index (EHI)), to adjust national values to regional conditions, and a proper regional division of the European continent to capture local conditions. Population statistics was gathered from Eurostat, on Member State level from (ES, 2014b) and on regional level from (ES, 2013), while geographical data on NUTS3 regions, the third level of European administrative units, were retrieved from the Eurostat/GISCO portal (ES, 2014a). According to 2010 (EU27) and 2008 NUTS classification, 35 European countries contain a total of 1453 defined regions today, among which 1302 are found in main land continental EU28 Member States (ES, 2010, 2011).

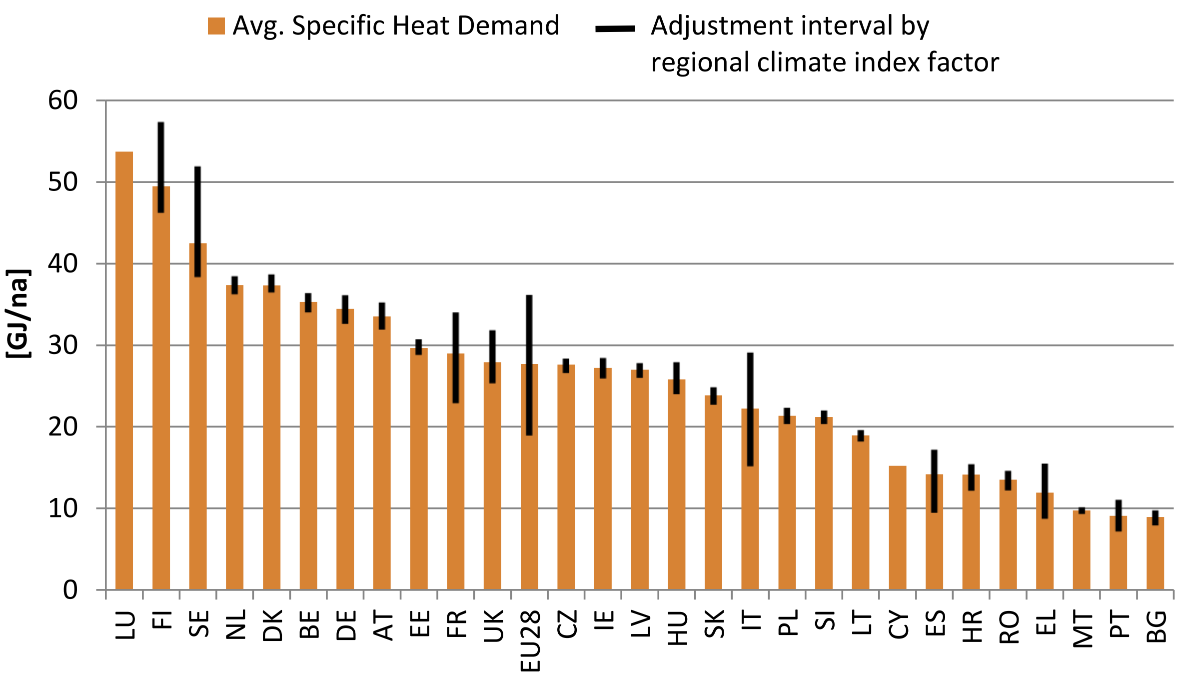


Figure 1. Average EU28 and Member State specific heat demands for final consumption of space heating and hot water preparation, with indicated adjustment interval by adaption of regional climate index factors. Data for year 2010.

To compensate for climatic variations within single Member States, present in countries with far north south stretches or large topological differences, regional climate conditions relative national climate conditions are anticipated by use of the European Heating Index (Werner, 2005). Typical index factor values range from ~0.6 in Southern Europe to ~1.5 in Northern

Scandinavia (relative average European conditions at 1.0). By this procedure, average national specific heat demands are increased by a factor ~1.3 (e.g. regions in northern Italy, Greece, and Sweden), and decreased by a factor ~0.7 (e.g. regions in southern Spain, Italy, Greece, and France), in most extreme instances, see Figure 1. (See also Figure 12 in the Appendix for a continental EU28 map of used index factors per NUTS3 region and Member State). Hereby, average national specific heat demands are adjusted and related to NUTS3 region population counts, whereby estimates of local climate adjusted regional heat demands are made available, as illustrated in Figure 13 in the Appendix.

As also visible in Figure 1, national average specific heat demand values range from approximately 10 to 50 GJ per-capita, with a EU28 national average at ~28 GJ per-capita. In preparation for visual representation, finally, all data was assembled in a relational database and spatially analysed within the ArcMap 10.1 GIS interface (ESRI, 2014).

1.1.2 Results

When compiling all reported fuel supplies and energy volumes from the considered sources and calculating the corresponding end use heat demand in EU28, the results show that a total annual energy supply of 15.5 EJ was supplied to buildings in residential and service sectors during the year 2010, as illustrated at left in Figure 2. Natural gas and oil products dominate the supply, followed by biofuels and waste, district heat, and electricity, respectively, while geothermal and other renewable sources are strictly marginal.

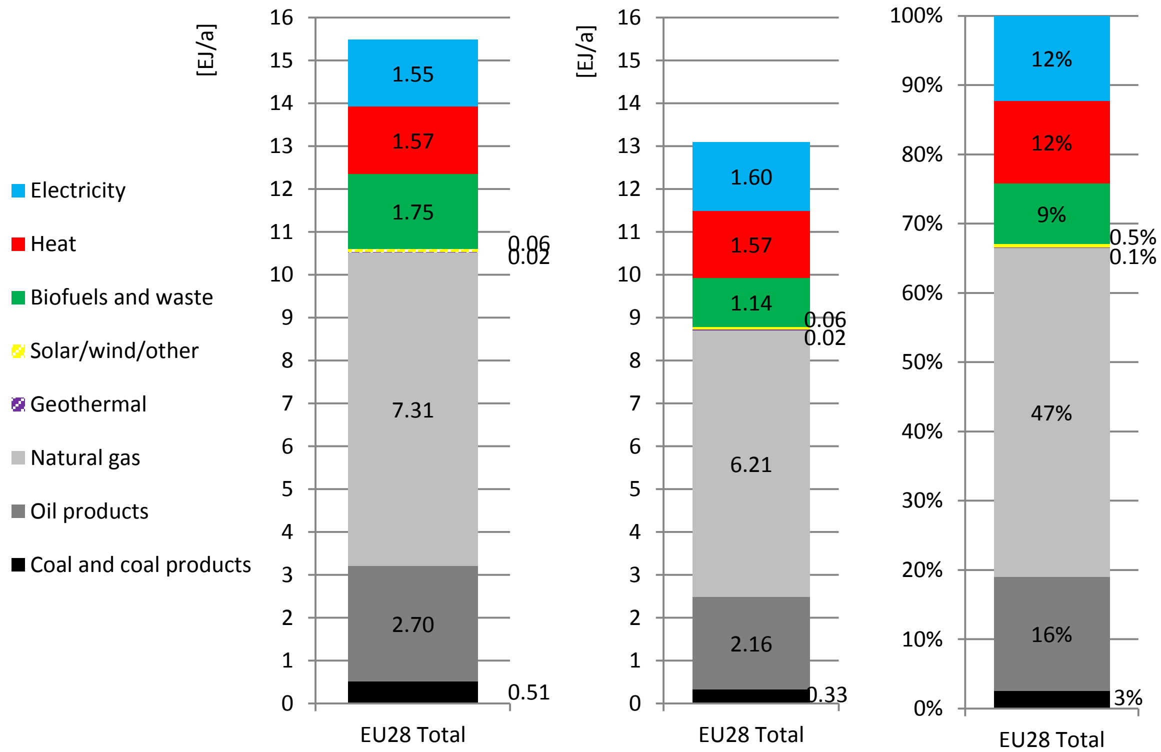


Figure 2. EU28 residential and service sector building heat market in 2010. At left, fuel and energy supply for final consumption to provide useful heat, by origin of fuel supply and energy sources. At centre, useful heat demand after local conversions. At right, distribution of residential and service sector building end use heat demands by fuel supply source and energy carrier.

In terms of useful heat demand, see Figure 2 at centre, the total residential and service sector building heat market constitute an energy volume of approximately 13.1 EJ, after e.g. conversion heat losses in local boilers and high thermal efficiencies of individual heat pumps.

This volume is higher than previous assessments performed in the Heat Roadmap Europe context ((Connolly et al., 2014; Connolly et al., 2013), where a corresponding EU27 end use heat demand of 11.8 EJ is assessed for the same year. Three plausible explanations for this difference are (i) use of corrected 2010 data, (ii) use of unique default conversion efficiencies per fuel and energy source (instead of uniform conversion efficiencies for all sources), and (iii) higher detail of electricity used for heating purposes.

Once more, it is apparent that fossil fuel supply sources dominate the European building heat market at current, representing some 66% of the total end use heat demand, while district heating represents 12% (with a useful heat volume of 1.57 EJ) and the electric heat demand accounting for 12% (1.60 EJ), as presented in Figure 2 at right.

In Figure 3, the total end use heat demand, i.e. the EU28 residential and service sector building heat market, is presented by fuel supply and energy volumes for each Member State, and it is clear that Germany, France, the United Kingdom, and Italy, represent largest national heat markets at current.

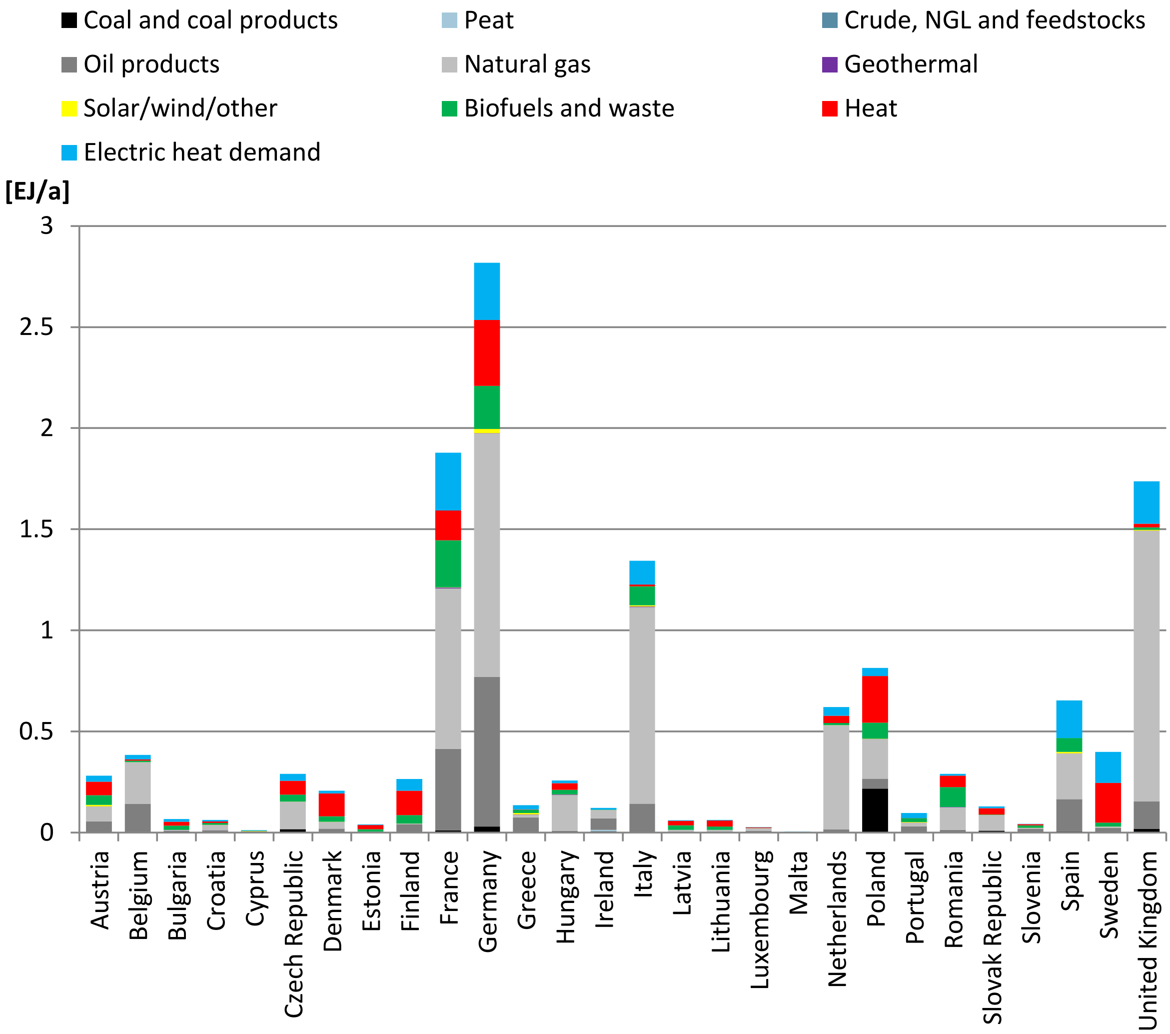


Figure 3. Stratego assessment of the EU28 residential and service sector building heat market in 2010, by Member States and fuel supply sources and energy carriers, data for year 2010.

As a complement to Figure 3, the results for the assessed EU28 residential and service sector building heat market is presented also in numerical form in Table 5 in the Appendix. If considering the relative shares of fuel supply sources and energy carriers used on respective

Member State heat markets, as depicted in Figure 4, a wide variety of national preferences is visible. The use of peat, for example, is limited essentially only to a few Member States (Ireland and the Baltic States), which is also the case for coal (however, approximately a 27% heat market share for coal in Poland). The use of oil products is pronounced in some instances (more than 50% national heat market share in Greece), while being a more or less abandoned alternative in e.g. the Czech Republic, the Slovak Republic, the Netherlands, Lithuania, and Hungary. Natural gas, on the other hand, account for substantial heat market shares in several countries today, especially so in the Netherlands (83%), the United Kingdom (77%), Italy (72%), and Hungary (69%), and the average national heat market share for natural gas among all EU28 Member States is 32%.

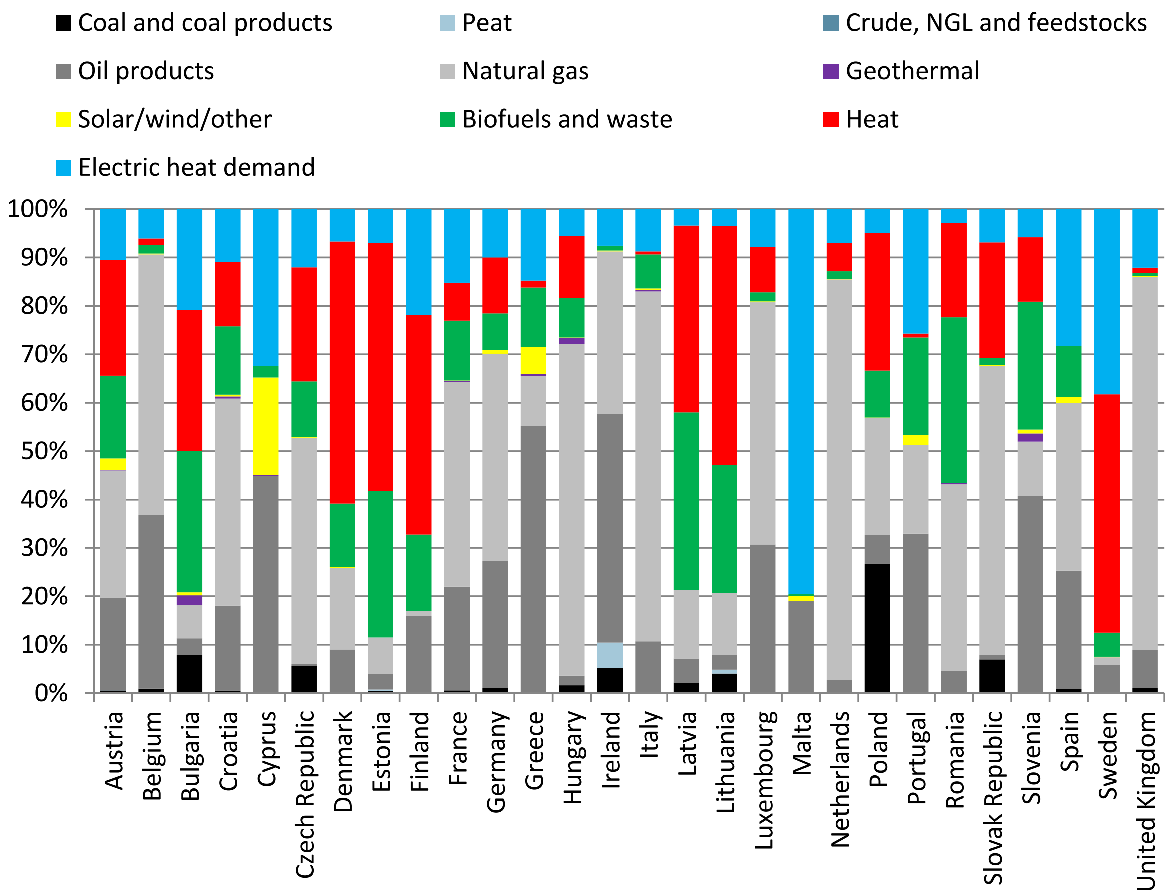


Figure 4. Distribution of EU28 Member States end use heat demands for space heating and hot water preparation in residential and service sector buildings. By fuel supply source and energy carrier, data for year 2010. Note that this is an updated version of the same graph, which was reference by the European Commission in October 2014 (EC, 2014).

In terms of renewable heat sources, geothermal heat reaches marginal heat market shares only in a couple of Member states today (e.g. Bulgaria, Hungary, and Slovenia), while largest volumes are found in France (~3.5 PJ annually). On national scale, the relative heat market share of 20% for solar/wind/other sources in Cyprus is without competition the highest in Europe today, although largest volumes of this category appear in Germany (20.3 PJ), Greece (7.7 PJ), and Spain (7.6 PJ). Biofuels and waste reaches highest national heat market shares in Latvia (37%), Romania (34%), and Estonia (30%), which is far above the average national heat market share of 13% for this environmentally important resource. Finally, district heating reaches half of total national heat market shares in some Northern Member States (54% in Denmark, 51% in Estonia, 49% in both Sweden and Lithuania), but account for significant national heat market shares also in Bulgaria (29%), Poland (28%), Austria, the Czech

Republic, and the Slovak Republic (all three at approximately 24%). Electricity for heating purposes on national European heat markets averages at 15% (12% of total EU28 building heat market) and is most pronounced in the Republic of Malta (80%), Sweden (38%), Cyprus (32%), and in Portugal (26%). However, largest electric heat demand volumes appear in France (285 PJ), Germany (282 PJ), the United Kingdom (210 PJ), and Spain (185 PJ).

1.1.3 Some conclusions

The major conclusions from these Stratego estimations to quantify building heat demands for space heating and hot water preparation in residential and service sectors are that:

1. Use of international energy statistics, default conversion efficiencies for fuels and energy carriers used in final consumption, and a separate inquiry on electricity used for heating purposes, allow estimations of the current building heat demands for space heating and hot water preparation in European residential and service sectors

2. The EU28 building heat market is anticipated at 13.1 EJ for the year 2010. Natural gas represents close to half of this market at current (47%) and fossil fuel sources dominate the useful heat demand in general (66%). District heating represents 12%, the electric heat demand 12%, biofuels and waste 9%, while coal and coal products, as well as geothermal and other renewable resources, are only marginally utilised

3. Residential and service sector building heat demands in 1302 EU28 NUTS3 regions, established by using a top-down approach based on national per-capita values and compensated for regional climate conditions, provides input data for creating a Pan-European heat demand density map at square kilometre grid cell resolution

4. Four Member States (Germany, France, the United Kingdom, and Italy) represent largest total heat demand volumes, all with national building heat markets above one EJ per year, while relative shares of fuel supply sources and energy carriers used on EU28 Member States national heat markets are widely distributed

5. Benchmarking to previous assessments performed in the Heat Roadmap Europe project suggests that the use of corrected 2010 data, unique default conversion efficiencies, and a deeper assessment of electricity used for heating purposes, provides a more realistic, and slightly higher, assessment of the EU28 building heat market

1.2 European cooling demands

1.2.1 Background

The assignment within the Stratego project is to estimate the current cooling demands in European buildings by country and by location by a bottom-up method for planning and modelling purposes. Another specific purpose is to provide input for creation of a detailed cold density map for Europe in order to identify the Pan-European possibilities for district cooling networks.

The main delimitation is that only space cooling demands for getting lower indoor temperatures in buildings during summers are considered. Other cold demands in buildings as refrigerators or freezers are not included in these estimations.

The cold currently generated for space cooling can either be generated in each room by individual cooling devices (room air-conditioners – RAC), by central cooling (central air-conditioning – CAC) in each building, or by district cooling systems in dense urban areas.

1.2.2 Method

The current cooling demand by country is the product of three parameters: the average specific cooling demands, the building spaces used, and the saturation rates. The latter are the proportions of building spaces currently having cooling devices installed.

The full cooling demands constitute of the products of the specific cooling demands (per building space area) and the building space areas. The current cooling supplies constitute of the products of the cooling demands and the saturation rates. Cooling supplies are almost always lower than the full cooling demands, since all cooling demands are not met by cooling supplies. Hence, higher indoor temperatures are mostly accepted during warm summer days.

Building spaces are divided into residential and service sector building spaces, since the average specific cooling demands in service sector buildings are normally higher than in residential buildings. Service sector buildings constitute of all buildings excluding residential, industrial, and agricultural buildings. Typical service sector buildings are used for offices, education, hotels, health care, trade, sports etc.

Specific cooling demands, building space floor areas, and saturation rates have been gathered from various literature sources. Aggregated estimations of the European cooling demands have earlier been very rare, but during 2014 several new estimations have been published, giving a possibility to benchmark the Stratego estimations obtained here with other independent estimations.

All cooling demands and supplies are here expressed as useful cold to be used inside buildings, except when otherwise is clearly stated. Cold is defined as heat removal. This cold use interface is equivalent to cold deliveries from chiller evaporators or from district cooling systems. Hereby, cooling demands and supplies are not generally expressed as electricity input to chiller compressors.

1.2.3 Intermediate estimations

1.2.3.1 Specific cooling demands

By tradition, cooling supplies as the output from cooling devices are seldom measured, making it difficult to estimate the actual cooling demands in buildings. This statement is also valid for the electricity supply used as input to these cooling devices. This electricity supply is normally just a part of all electricity delivered and measured for a building when cooling is applied.

Some literature information about cooling demands in Europe have been published, but many of these published demands are not measured, but theoretically estimated by combining climate data with standard efficiencies for cooling devices. Hence, gathering existing cooling demands in Europe is not an easy task and a proper Pan-European survey of cooling demands and supplies by countries and by locations has never been published before.

However, one exception exists with respect to measurements of cooling supplies. When district cooling systems are used, the cooling supplies are regularly measured in order to create invoices for these cold deliveries. Hereby, these systems can provide information about aggregated and average cooling demands. These systems deliver cold to mostly service sector buildings.

In total, twenty annual cold deliveries have been gathered from district cooling systems and these values consider both aggregated deliveries and deliveries to specific buildings. These values are presented in Figure 5 as red squares with the European Cooling Index (ECI) as independent variable. This index was defined and presented in (Dalin et al., 2005) as an indicator of local cooling demands at a time when proper actual specific cooling demands were not available. The values considering six specific buildings from (Swedblom et al., 2014) have also smaller diagonal black squares. These twenty values are grouped into three main clusters. The highest cluster consists of three highest values and these were obtained from one Spanish and two Italian district cooling systems. The intermediate cluster represents some French district cooling systems, while the remaining values with ECI values between 45 and 85 constitute the lowest cluster based on information from district cooling systems in Finland, Sweden, Norway, and Switzerland. The average red line represents the best linear fit to these twenty values.

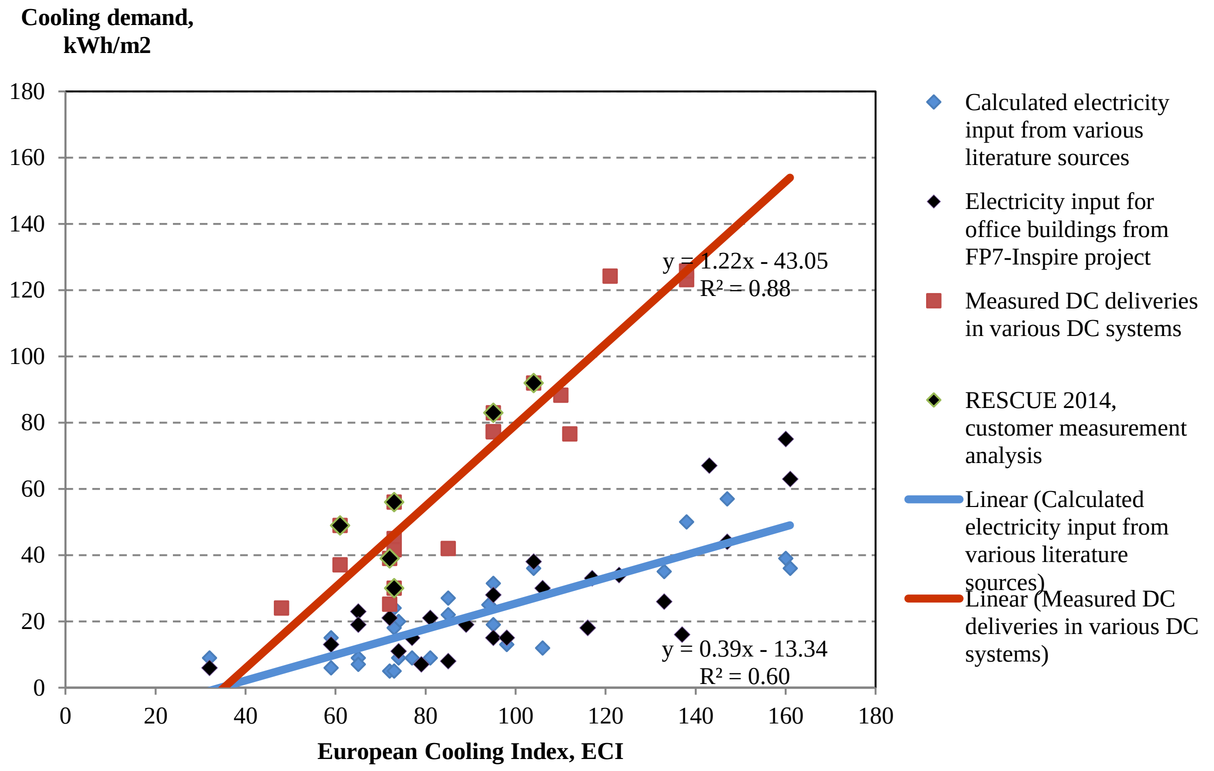


Figure 5. Estimated specific cooling demands for service sector buildings with direct use of district cooling or use of electricity input to compressor chillers.

Further fifty-three values have been gathered from various literature sources considering electricity input to cooling devices in service sector buildings for various locations or countries. These values are represented by the diagonal green squares in Figure 5. Twenty-seven of these values have been cited from (INSPIRE, 2014) and consider country averages. These values have also smaller diagonal black squares. The average green line represents the best linear fit to these fifty-three values.

Energy efficiency ratio (EER) is the performance indicator for cooling devices expressing the ratio between the output cooling energy from the evaporator and the input electricity to the compressor. The average seasonal ERR (SEER) can be estimated from Figure 5 by the ratio between the slopes for the two average lines. This SEER estimate amounts to 3.1 and this is a very plausible value. Hence, the two average lines in Figure 5 support each other. Hereby, the average red line in Figure 5 can be used to estimate the European cooling demands in service sector buildings.

The corresponding detailed information about specific cooling demands is currently not available for residential buildings in Europe. In both (Dalin et al., 2005) and (Tvärne et al., 2014), the residential cooling demands were assumed to be 45% of the service sector cooling demands. The same estimation of 45% was also obtained when comparing residential and office buildings in (INSPIRE, 2014). Therefore, the same ratio of 45% will also be used here in the Stratego project.

1.2.3.2 National building spaces

Areas of residential building spaces are rather well accessible from various national statistical authorities. They have gathered them for many years, since this information have had substantial political and governmental interests. The same has not been valid for service sector building areas, giving a considerable unavailability of information about these buildings.

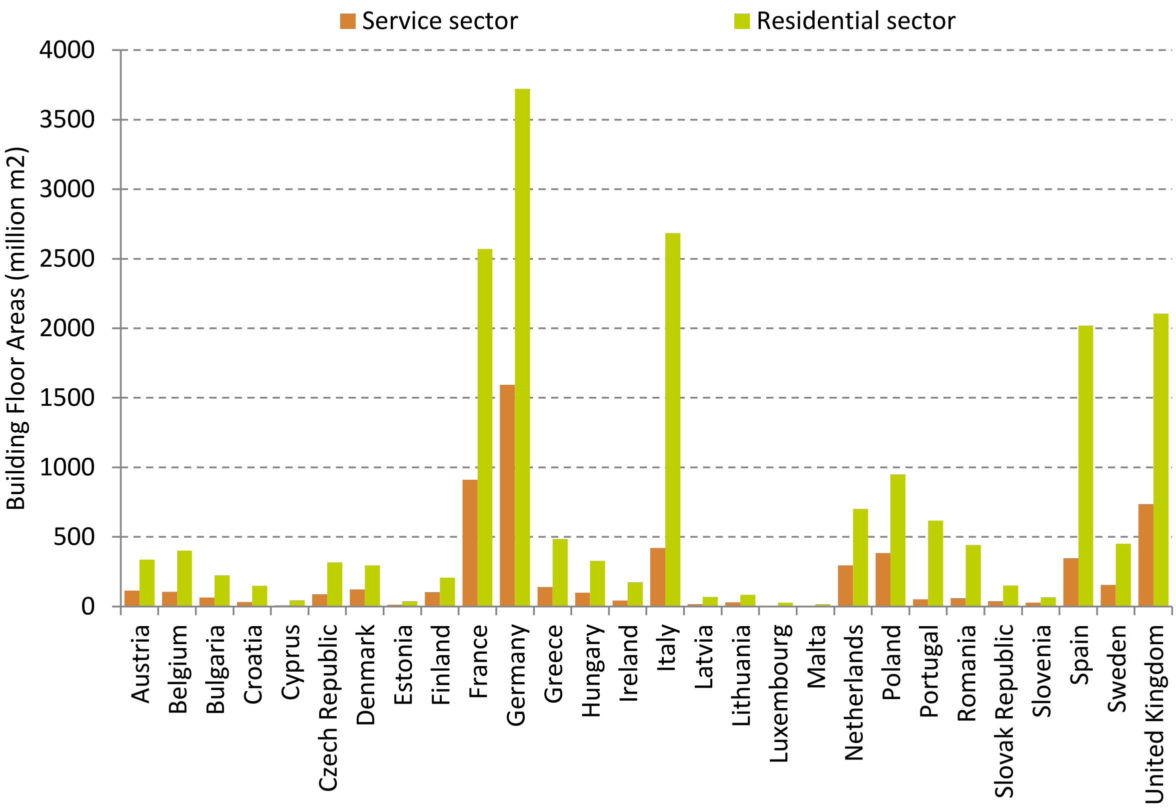


Figure 6. Estimated building space areas in residential and service sector buildings in the EU28 member states.

However, the European Energy Performance for Buildings Directive and the Ecodesign Directive has created a research demand for more information about the European buildings, including the service sector buildings. This has given a better supply of information about the European buildings from EU institutions, projects, and clusters as JRC, INSPIRE, BPIE, ENTRANZE, ODYSSEE, and EPISCOPE (formerly TABULA). However, the INSPIRE project did only review residential and office buildings, so the whole service sector was not reviewed. The quality of this new information is sometimes very low with no references to original information sources. Different sources are also quoting each other, giving some circulation of low quality information. Another problem is that the national rules and standards for calculating building space areas are different from country to country.

Estimated building floor areas are presented in Figure 6. The service sector areas have been estimated as the averages from six different groups of estimations, while the residential areas have been estimated as the averages from eight different groups of estimations.

1.2.3.3 National saturation rates

Gathered saturation rates are presented in Figure 7. Values for service sector buildings have been estimated as the averages from four different groups of estimations. Ten percent was assumed as a default value when no information was available at all for a specific country. Values for residential buildings have been estimated from averages of seven different groups of estimations.

Several of these estimations can be questioned and this reveals the low quality level for current saturation rates. This is also the explanation for many literature sources to only provide estimations of the European cooling demands on an aggregated European level, as in (Tvärne et al., 2014).

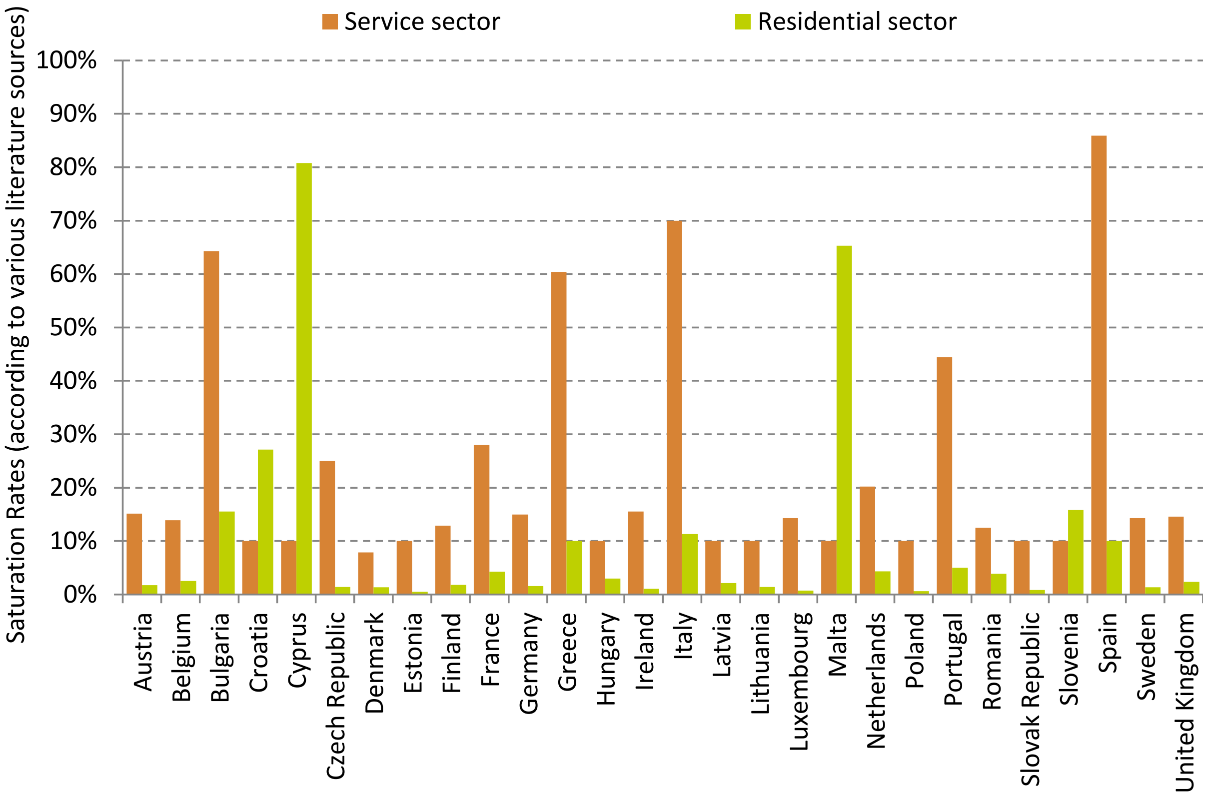


Figure 7. Estimated saturation rates for cooling supply to residential and service sector buildings in the EU28 member states.

1.2.4 Results

Country estimations of total floor areas, European cooling index, specific cooling demands, cooled areas, and the current cooling supplies are summarised inTable 4. The aggregated values for EU28 reveal that 10% of all building areas are cooled and that these cooling supplies cover 16% of the total cooling demand. The latter proportion is higher than the former since cooling supplies are more common when the cooling demands are high.

Table 4. Country estimations of total floor areas, European cooling index (ECI), specific cooling demands, cooled floor areas and current cooling demands by country. Each national ECI estimation considers the estimation for each capital city.

	Total floor areas				Specific cooling demands			Cooled floor areas			Current cooling supplies		
Country	Service sector	Residen-tial	Total	ECI	Service sector	Residen-tial	Average	Service sector	Residenti al	Total	Service sector	Residen-tial	Total
	Mm2	Mm2	Mm2		kWh/m2	kWh/m2	kWh/m2	Mm2	Mm2	Mm2	TWh	TWh	TWh
Austria	114	338	452	106	83	38	49	17	6	23	1	0	2
Belgium	105	402	507	77	50	23	28	15	10	25	1	0	1
Bulgaria	64	225	288	116	95	43	54	41	35	76	4	1	5
Croatia	32	149	181	85	59	27	32	3	40	44	0	1	1
Cyprus	8	44	52	160	145	65	77	1	36	37	0	2	2
Czech Republic	89	316	405	89	64	29	37	22	4	27	1	0	2
Denmark	122	295	418	59	30	13	18	10	4	14	0	0	0
Estonia	12	38	50	65	37	16	21	1	0	1	0	0	0
Finland	104	206	310	72	45	20	28	13	4	17	1	0	1
France	911	2571	3482	95	71	32	42	255	110	365	18	4	22
Germany	1594	3723	5317	98	74	33	46	239	58	297	18	2	20
Greece	141	486	627	161	146	66	84	85	49	134	12	3	16
Hungary	99	327	426	123	103	46	59	10	10	20	1	0	1
Ireland	43	174	216	32	0	0	0	7	2	8	0	0	0
Italy	421	2686	3107	133	114	51	60	295	304	599	34	16	49
Latvia	17	68	85	79	53	24	29	2	1	3	0	0	0
Lithuania	30	84	114	85	59	27	35	3	1	4	0	0	0
Luxembourg	5	27	32	81	55	25	29	1	0	1	0	0	0
Malta	4	17	21	143	126	57	70	0	11	11	0	1	1
Netherlands	295	702	997	65	37	16	22	60	30	90	2	0	3
Poland	385	951	1336	95	71	32	43	39	6	44	3	0	3
Portugal	52	619	671	104	81	36	40	23	31	54	2	1	3
Romania	59	442	501	137	119	53	61	7	17	24	1	1	2
Slovak Republic	38	150	188	117	96	43	54	4	1	5	0	0	0
Slovenia	28	67	95	116	95	43	58	3	11	13	0	0	1
Spain	349	2019	2368	147	130	59	69	299	202	501	39	12	51
Sweden	155	451	606	73	46	21	27	22	6	28	1	0	1
United Kingdom	736	2107	2843	74	47	21	28	107	50	157	5	1	6
EU28	6011	19684	25695	103	74	37	45	1584	1039	2623	145	47	192
								26%	5%	10%	33%	7%	16%

1.2.4.1 European cooling demand map

The information from Figure 5 about the correlation between the average specific cooling demands for service sector buildings and the European cooling index (ECI) makes it possible to generate a European map from locations with known estimations of ECI. This map is provided in Figure 8 based on 80 locations in Europe. It is important to understand that this map only presents average demands and that individual demands vary from these average demands. The highest demands of 140 kWh/m^2 are found in southeast Europe, while near zero demands are found in northwest Europe. Ireland should have no cooling demands, while the demands in the Nordic countries are around 30-40 kWh/m^2, explaining the basic conditions for the large district cooling systems in Stockholm and Helsinki.

The information from Figure 8 will be used to identify high agglomerations of cooling demands giving high cold densities in European cities in order to investigate the possibilities for extended and new district cooling systems.

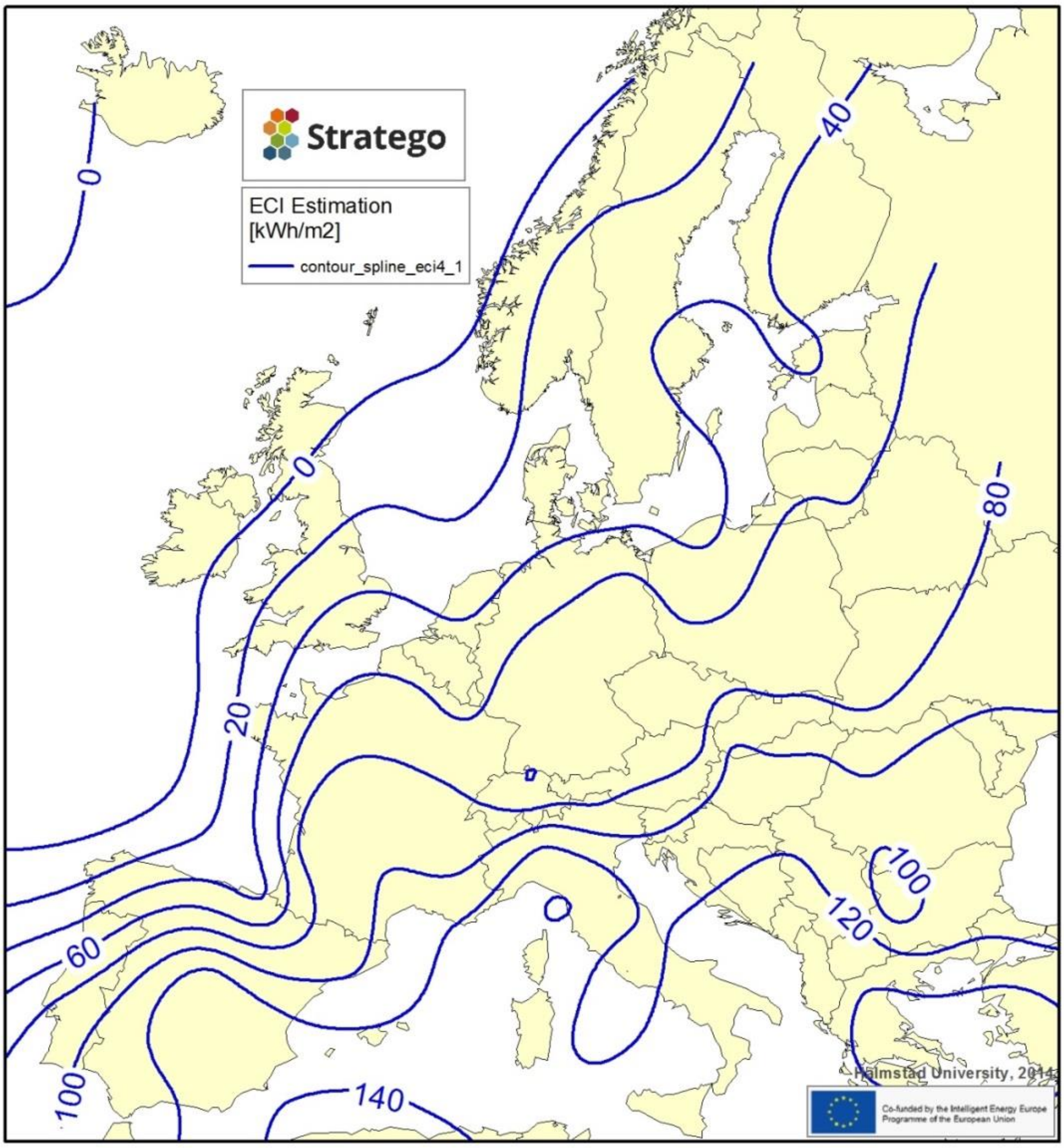


Figure 8. The average specific cooling demands in kWh/m^2 for service sector buildings for various locations in Europe. The map has been generated by using the red average line in Figure 5 together with estimated ECI for 80 different locations according to (Dalin et al., 2005).

1.2.4.2 Average annual specific cooling demands

The average annual specific demands estimated here in Stratego are benchmarked in Figure 9 with two other sources: (EURAC, 2014) and (Tvärne et al., 2014). The average specific demands from (EURAC, 2014) was estimated by multiplying the electricity inputs from that study (64 TWh/year for service sector buildings and 18 TWh/year for residential buildings) with the SEER estimate of 3.1 in this study and by dividing with the building floor spaces estimated in this study. The conclusion from the comparison in Figure 9 becomes that the Stratego estimations will be somewhat lower than in the two other studies.

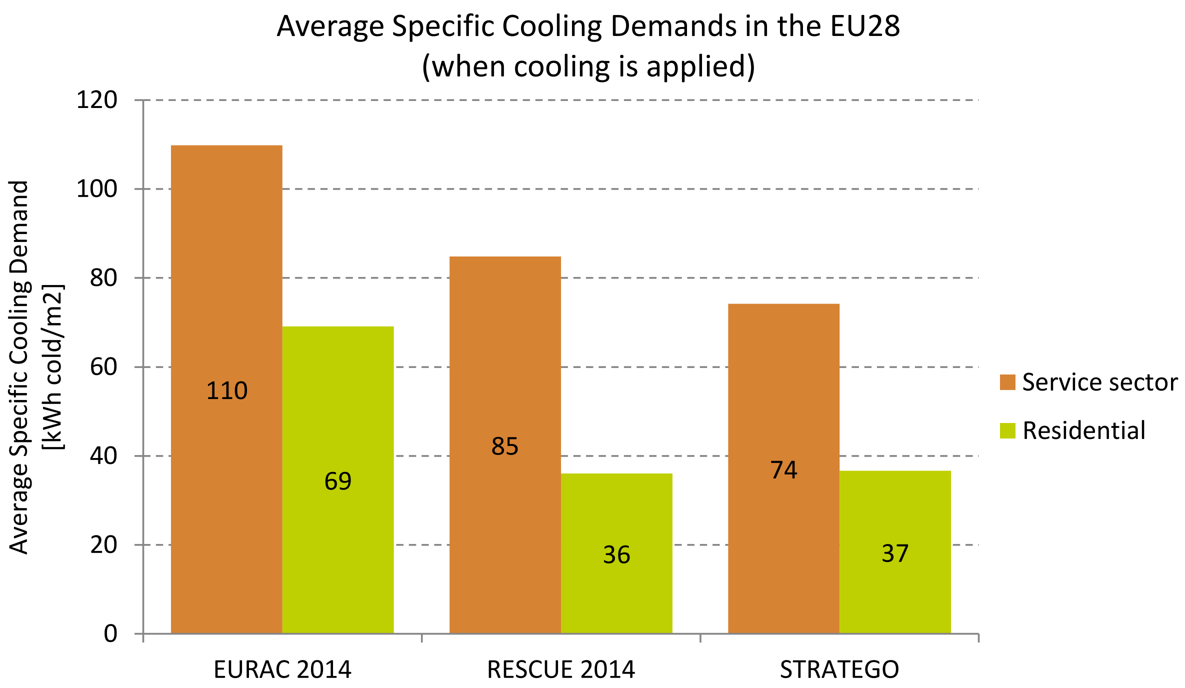


Figure 9. Three different estimations of the average annual specific cooling demands in EU28, when cooling is applied, from two external sources and this Stratego estimation.

1.2.4.3 Current annual European cooling supplies

The current annual European cooling supplies estimated here in Stratego are benchmarked in Figure 10 with four other sources: (EURAC, 2014; Kemna, 2014; Pardo et al., 2012 ; Tvärne et al., 2014). The conclusion from Figure 10 becomes that the Stratego estimations will be the lowest, somewhat lower than three other estimations, while (Pardo et al., 2012) have provided the highest estimations.

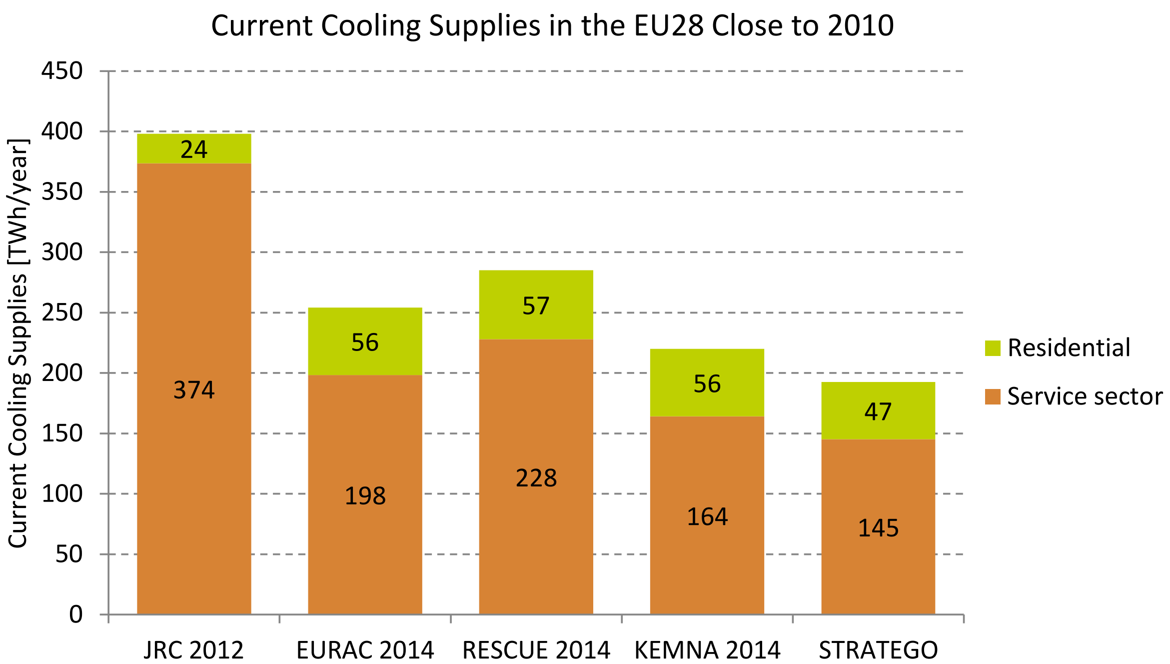


Figure 10. Five different estimations of the current cooling supplies in EU28 close to 2010 from four external sources and this Stratego estimation.

1.2.4.4 Annual full European cooling demands

The annual full European cooling demands estimated here in Stratego are benchmarked in Figure 11 with two other sources: (EURAC, 2014; Tvärne et al., 2014). The conclusion from Figure 11 becomes that the Stratego estimations will be about the same as the estimations as in (Tvärne et al., 2014), while (EURAC, 2014) have provided much higher estimations.

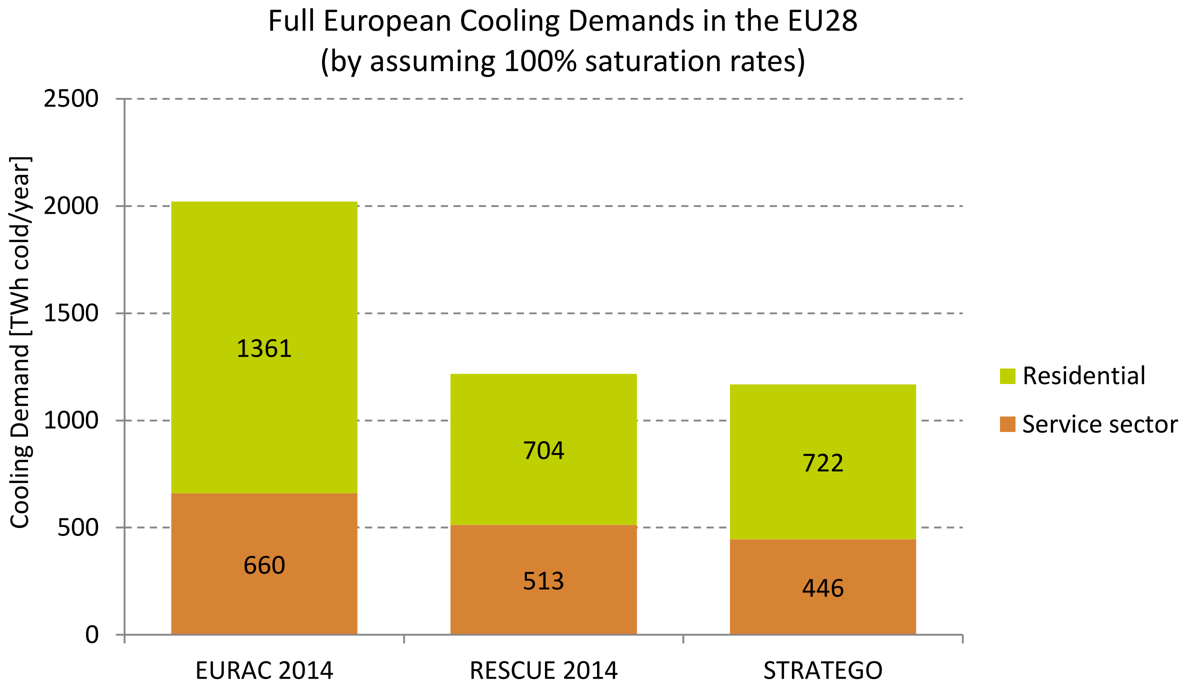


Figure 11. Three different estimations of full European cooling demands in EU28, by assuming all saturation rates to be 100%, from two external sources and this Stratego estimation.

1.2.5 Some conclusions

The four major conclusions from these Stratego estimations of European cooling demands become then:

1. Information about individual and aggregated cold deliveries in several European district cooling systems has made it possible to estimate the average annual cooling demands in Europe.
2. These estimations can for the first time ever provide cooling demands by countries and by locations in Europe.
3. The obtained estimations by locations can also be used to identify urban areas with high cold densities as input for studies of the possibilities for extended and new district cooling systems in Europe.
4. Benchmarking with other recent studies of aggregated European cooling demands reveals that the Stratego estimations will be somewhat lower than estimations obtained in other studies.

References

Atanasiu, B., Economidou, M., Maio, J., Sebi, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in Romania. D2.1 of WP2 from Entranze Project, Entranze.

Bertoldi, P., Atanasiu, B., 2009. Electricity Consumption and Efficiency Trends in European Union - Status Report 2009. EUR 24005 EN, European Commission, Joint Research Centre, Institute for Energy, Renewable Energy Unit. Luxembourg: Publications Office of the European Union.

Connolly, D., Lund, H., Mathiesen, B.V., Werner, S., Möller, B., Persson, U., Boermans, T., Trier, D., Østergaard, P.A., Nielsen, S., 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 65, 475-489.

Connolly, D., Vad Mathiesen, B., Alberg Östergaard, P., Möller, B., Nielsen, S., Lund, H., Persson, U., Werner, S., Grözinger, J., Boermans, T., Bosquet, M., Trier, D., 2013. Heat Roadmap Europe 2050 - Second pre-study for EU27. Euroheat & Power, Brussels. Available at: (http://www.euroheat.org/Heat-Roadmap-Europe-165.aspx).

CYSTAT, 2011. Final Energy Consumption in Households, 2009. Energy Consumption for Space Heating, Statistical Service, Republic of Cyprus

Dalin, P., Nilsson, J., Rubenhag, A., 2005. Ecoheatcool. Work Package 2. The European Cold Market. Final Report, Brussels. Available at (2015-01-22): (http://www.euroheat.org/files/filer/ecoheatcool/documents/Ecoheatcool_WP2_Web.pdf).

EC, 2014. Communication from the Commission to the European Parliament and the Council on the short term resilience of the European gas system. Preparedness for a possible disruption of supplies from the East during the fall and winter of 2014/2015, COM(2014) 654 final. European Commission. Availabe at (2015-02-19): (http://ec.europa.eu/energy/sites/ener/files/documents/2014_stresstests_com_en.pdf).

Entranze, 2014a. Policies to Enforce the Transition to Nearly Zero Energy Buildings in the EU-27. Downloaded data: Share of dwellings with electric systems, Enerdata. Available at (2014-09-16): (http://www.entranze.enerdata.eu/share-of-dwellings-with-electric-systems.html).

Entranze, 2014b. Policies to Enforce the Transition to Nearly Zero Energy Buildings in the EU-27. Downloaded data: Share of space heating in total residential consumption, Enerdata. Available at (2014-09-16): (http://www.entranze.enerdata.eu/share-of-dwellings-with-electric-systems.html#/share-of-space-heating-in-total-residential-consumption.html).

Entranze, 2015. Policies to Enforce the Transition to Nearly Zero Energy Buildings in the EU-27, Web page available at (2015-01-20): (http://www.entranze.eu/).

ES, 2010. European Regional and Urban Statistics - Reference Guide, 2010 Edition, Methodologies and Working papers. Eurostat, Luxembourg.

ES, 2011. Regions in the European Union - Nomenclature of territorial units for statistics NUTS 2010/EU-27, 2011 edition, Methodologies and Working papers. Eurostat, Luxembourg.

ES, 2013. Your key to European Statistics. Eurostat, Luxembourg. Downloaded data categories (2013-06-28): [demo_r_pjanaggr3], [demo_r_d3area], [demo_r_d3dens]. Available at: (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home).

ES, 2014a. Administrative units/Statistical units. Eurostat, Luxembourg. Available at (2014-11-14): (http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/administrative_units_statistical_units_1).

ES, 2014b. Your key to European Statistics. Eurostat, Luxembourg. Downloaded data category (2014-10-20): [demo_pjan]. Available at: (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home).

ESRI, 2014. Understanding our world, Environmental Systems Research Institute Inc. Available at: (http://www.esri.com/).

EURAC, 2014. Potential and actual space heating and cooling consumption in Europe (Sparber, W. and Pezzutto, S.). , RHC-Platform Annual Event, May 22, 2014. EURAC Research. Available at (2015-01-22): (http://www.rhc-platform.org/fileadmin/user_upload/members/Downloads/Pezzutto_.pdf)

IEA, 2014. Energy Balances of OECD and Non-OECD Countries (2014 Edition). Summary Energy Balances. International Energy Agency, Paris.

INSPIRE, 2014. Survey on the energy needs and architectural features of the EU building stock. Report D2.1a from the FP7-INSPIRE project, May 2014. , INSPIRE: Systemic Energy Renovation of Buildings. Available at (2015-01-22): (http://www.inspirefp7.eu/wp-content/uploads/2014/08/WP2_D2.1a_20140523_P18_Survey-on-the-energy-needs-and-architectural-features.pdf).

Kemna, R., 2014. Average EU building heat load for HVAC equipment, Van Holsteijn en Kemna B.V. (VHK), Delft, August 2014. Available at (2015-01-22): (https://ec.europa.eu/energy/sites/ener/files/documents/2014_final_report_eu_building_heat_demand.pdf).

Kiuru, J., Heiskanen, E., Sebi, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in Finland. D2.1 of WP2 from Entranze Project, Entranze.

Kockat, J., Rohde, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in Germany. D2.1 of WP2 from Entranze Project, Entranze.

Kranzl, L., Toleikyte, A., Moravac, Z., Müller, A., Sebi, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in Austria. D2.1 of WP2 from Entranze Project, Entranze.

Palmer, J., Cooper, I., 2012. United Kingdom housing energy fact file 2012. URN: 12D/354, Department of Energy and Climate Change.

Pardo, N., Vatopoulos, K., Krook-Riekkola, A., Moya, J.A., Perez, A., 2012 Heat and cooling demand and market perspective. JRC scientific and policy reports, EUR 25381, Intitute for Energy and Transport. Joint Research Centre. Available at (2015-01-22): (http://publications.jrc.ec.europa.eu/repository/handle/JRC70962)

Statistics Finland, 2008. Energy Sources for Heating Residential, Commercial and Public Buildings. Environment and energy. Calculation model for space heating, Statistics Finland.

Swedblom, M., Tvärne, A., Frohm, H., Rubenhag, A., 2014. District cooling customer measurement analysis verification of and ECI for market assessment. Rescue WP2.1 report, RESCUE: Renewable Smart Cooling for Urban Europe, Available at (2015-01-22): (http://www.rescue-project.eu/fileadmin/user_files/WP2_Reports/RESCUE_WP_2.1_DC_CUSTOMER_MEASUREMENT_ANALYSIS.pdf)

Tvärne, A., Frohm, H., Rubenhag, A., 2014. EU District cooling market and trends, Rescue WP2.3 report, RESCUE: Renewable Smart Cooling for Urban Europe, Available at (2015-01-22): (http://www.rescue-project.eu/fileadmin/user_files/WP2_Reports/RESCUE_WP_2.3_EU_COOLING_MARKET.pdf)

Valletta, 2014. Census of Population and Housing 2011. Final Report, National Statistics Office, Malta.

Werner, S., 2005. Ecoheatcool: The European heat market (WP1). Euroheat & Power, Brussels. Available at: (http://euroheat.org/ecoheatcool).

Zahradník, P., Karásek, J., Šestáková, Z., Sebi, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in the Czech Republic. D2.1 of WP2 from Entranze Project, Entranze.

Zangheri, P., Armani, R., Pietrobon, M., Pagliano, L., Boneta, M.F., Müller, A., 2014. Heating and cooling energy demand and loads for building types in different countries of the EU. D2.3. of WP2 of the Entranze Project, Entranze.

Zangheri, P., Pagliano, L., Sebi, C., 2012. The challenges, dynamics and activities in the building sector and its energy demand in Italy. D2.1 of WP2 from Entranze Project, Entranze.

Appendix

Table 5. Stratego assessment of the EU28 residential and service sector building heat market in 2010, by Member States and fuel supply sources and energy carriers. All values in PJ

Member States	Coal &Coal Products	Peat	Crude/NGL feedstocks	Oil Products	Natural Gas	Geothermal	Solar/Wind Other	Biofuels & Waste	Heat	Electricity	Total Heat Market
Austria	1.6	0.005	-	53.8	74.1	0.3	6.6	48.2	67.0	29.7	281
Belgium	3.6	-	-	137.8	207.1	-	0.5	7.1	4.9	23.4	384
Bulgaria	5.3	-	-	2.3	4.6	1.4	0.4	19.6	19.6	14.1	67
Croatia	0.3	-	-	11.0	26.7	0.3	0.2	8.8	8.3	6.8	63
Cyprus	0.003	-	-	5.6	-	0.03	2.5	0.3	-	4.1	13
Czech Republic	16.2	-	-	1.1	136.0	-	0.4	33.3	68.5	34.9	290
Denmark	0.3	-	-	18.4	34.8	-	0.5	27.0	112.0	13.9	207
Estonia	0.2	0.1	-	1.3	3.0	-	-	12.0	20.4	2.8	40
Finland	0.02	0.3	-	42.1	2.7	-	0.04	41.9	120.3	58.0	265
France	10.7	-	-	402.9	794.0	3.5	2.4	232.4	147.5	285.4	1879
Germany	29.6	-	-	739.5	1204.7	2.2	20.3	213.6	325.7	282.2	2818
Greece	0.1	-	-	74.4	14.0	0.5	7.7	16.5	1.9	19.9	135
Hungary	4.1	-	-	5.1	177.0	3.3	0.2	21.2	33.0	14.2	258
Ireland	6.3	6.4	-	57.5	40.8	-	0.3	1.2	-	9.2	122
Italy	0.1	-	-	143.5	971.7	3.2	5.3	94.1	8.4	117.3	1344
Latvia	1.3	0.01	-	3.1	8.5	-	-	22.2	23.3	2.0	60
Lithuania	2.5	0.5	-	1.9	8.0	-	-	16.5	30.7	2.2	62
Luxembourg	0.0	-	-	8.3	13.6	-	0.04	0.5	2.6	2.1	27
Malta	-	-	-	0.8	-	-	0.04	0.0	-	3.2	4
Netherlands	0.2	-	-	16.6	513.9	-	1.0	9.5	36.3	43.7	621
Poland	217.9	-	-	47.9	197.0	0.6	0.4	79.1	231.6	40.2	815
Portugal	-	-	-	31.8	17.6	0.04	2.0	19.4	0.8	24.8	97
Romania	0.3	0.005	-	13.0	111.8	0.8	0.0	99.3	56.5	8.3	290
Slovak Republic	9.0	-	-	1.1	77.4	0.05	0.2	1.8	31.0	8.9	129
Slovenia	-	-	-	17.7	4.9	0.7	0.3	11.5	5.8	2.5	43
Spain	5.8	-	-	159.6	225.9	0.5	7.6	68.7	-	184.9	653
Sweden	0.3	-	-	22.9	6.4	-	0.4	19.8	196.1	152.5	398
United Kingdom	18.5	-	-	136.5	1338.6	-	4.1	11.6	18.6	209.8	1738
EU28 Total	**334**	**7**	**0**	**2157**	**6215**	**17**	**63**	**1137**	**1571**	**1601**	**13104**
Shares [%]	3	0	0	16	47	0	0	9	12	12	100

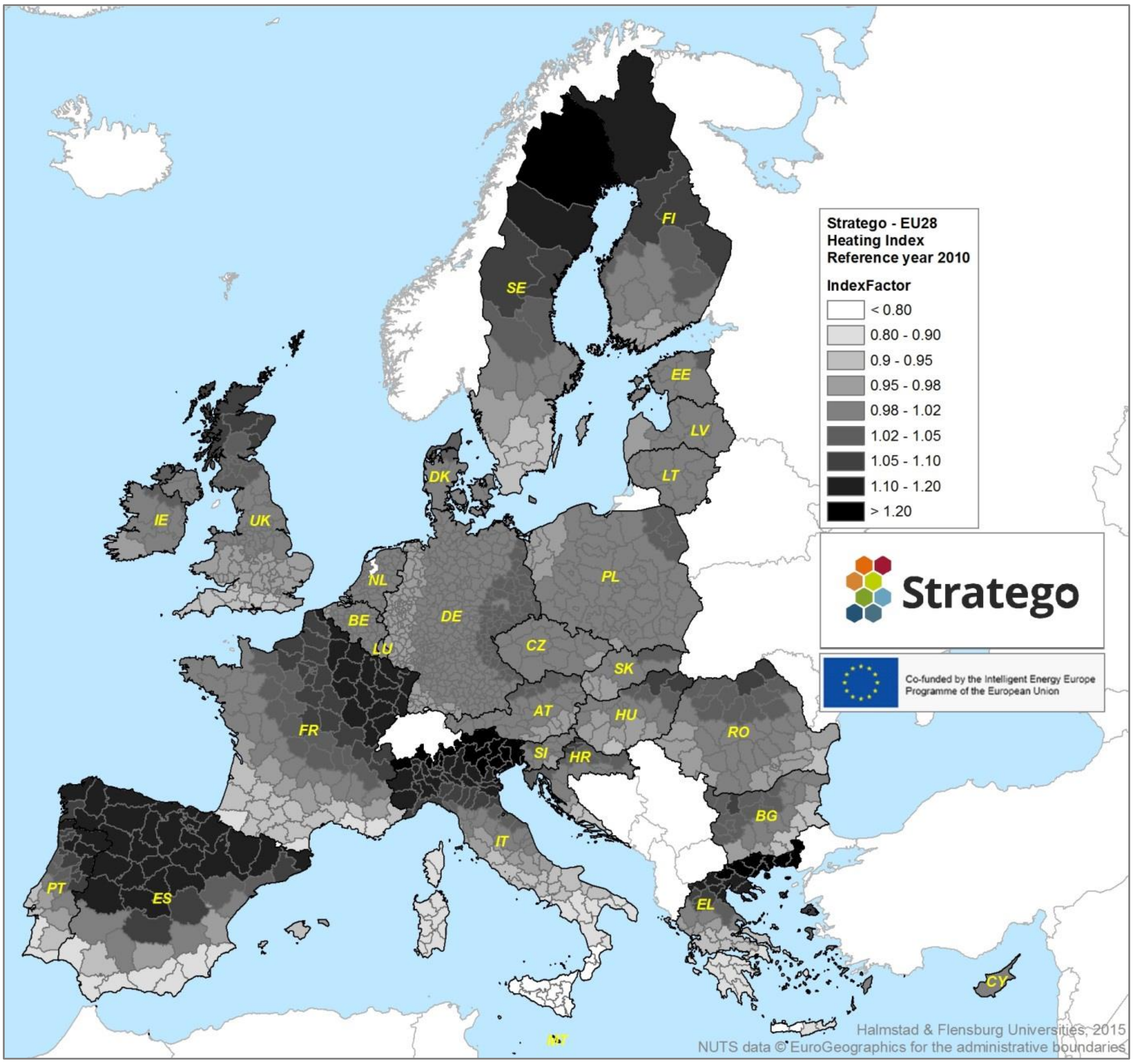


Figure 12. Regional climate index factors by NUTS3 regions in EU28 Member States. Based on the European Heating Index (EHI).

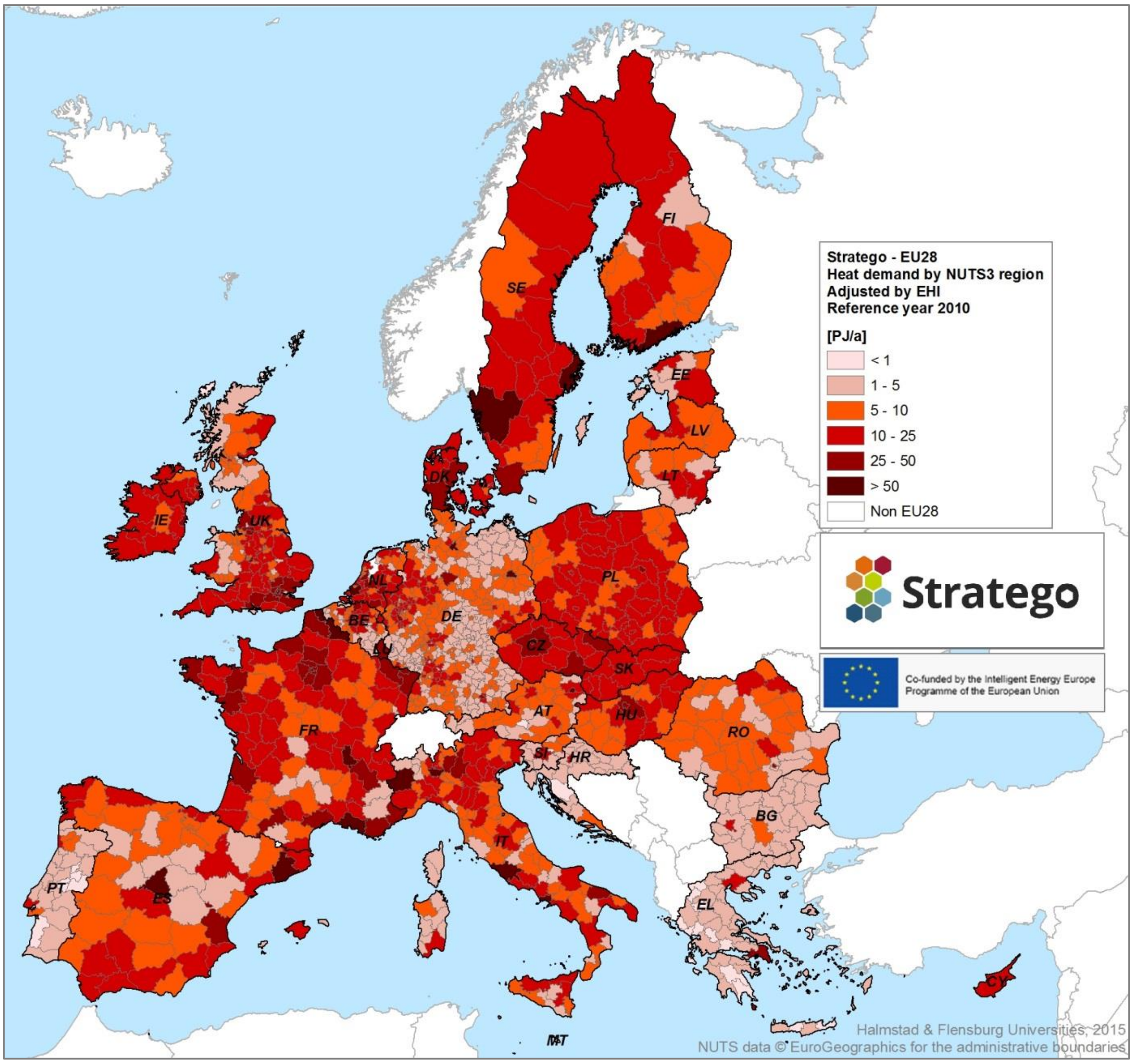


Figure 13. End use heat demands for space heating and domestic hot water preparation in residential and service sectors, by EU28 NUTS3 regions. Heat demands adjusted to local conditions by adaption of regional climate index factors based on the European Heating Index (EHI).

Project No: IEE/13/650

Stratego

ENHANCED HEATING & COOLING PLANS

Mapping the Heating and Cooling Demand in Europe

Work Package 2

Background Report 5

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: Bernd Möller
Contact: University of Flensburg
Munketoft 3b
Raum MV 014
24937 Flensburg
Tel: +49 (0) 461/805-2506
Fax: +49 (0) 461/805-2505

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

4DH
4th Generation District Heating Technologies and Systems

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Heat Roadmap Europe 2050

Contents

1. Mapping the Heating and Cooling Demand in Europe

Mapping the heating and cooling demand is a basic requirement and precondition for the formulation of energy policies as well as the implementation of directives that aim at the integration of energy systems by means of efficiency in end use and supply as well as renewable energy. It is required for the analysis of expansions of major energy infrastructures like gas or electric grids. Although the main focus in this project is the development of district heating and cooling systems, a thorough knowledge of the location and intensity of heating and cooling demands, as well as the efficiency potentials greatly facilitates the formulation of sustainable energy development policies and their follow-up measures.

Studies of the potentials of developing district heating and cooling (DHC) grids require a geographically explicit quantification of heating and cooling demands (Persson et al., 2014). The high costs of distribution networks, the investments in heat and cooling transmission, as well as the geographically determined sources of district energy require heating and cooling demands to be mapped. Further, while seeking to increase the energy efficiency of the built environment, the present location and amount of final energy demand cannot be granted. Finally, trends of urbanization and structural change make the location and distribution of heating and cooling demands even more interesting.

In previous studies (Connolly et al., 2013; Gils 2012) the potential for developing DH schemes was assessed using small-scale statistics as well as geographical representations of heating demands at a spatial resolution of $1km^2$, typically using a distribution of heat demand on population and specific land use. But within one km^2 the typical urban tissue of towns and cities varies, and smaller settlement structures disappear. Hence the actual geometry of district energy grids, their cost-determining densities and the connectivity between grids cannot be represented to a degree, which is needed for improved potential and cost assessments beyond the 1km resolution. While avoiding the Modifiable Area Unit Problem (Openshaw, 1984), which occurs if statistics are compared by using variable geographical entities, and offering a practical scale of analyses on the European level, the 1km2 grid studies did not allow for a precise delineation of DHC systems because most urban and semi-urban settlement structures show high variability within one square kilometer. Neither are they suitable for local and regional studies.

DHC distribution infrastructures follow the building and population distribution. Heating and cooling demand, within a country and for the residential sector, are the function of available building area per capita and specific thermal demand per area. Therefore, knowing these ratios, heating and cooling demand can be mapped taking departure in the location of buildings. Mapping the building matrix of all member states of the European Union in a limited study like the present necessitates a simple yet robust tool. The present Pan-European Atlas of sub-$1km^2$ resolution attempts to distribute the demand for cooling and heating in residential and service sector buildings on such a small scale, that the delineation of actual DHC grids becomes feasible. Along with demands the costs of such systems are being mapped in the same geographical entities, so that studies of marginal costs of a cumulative supply of thermal services become feasible. This has been realized on a smaller scale for Denmark (Möller and Nielsen, 2014), and has been attempted without a spatial explicit model of DHC demands in Europe (Persson and Werner, 2011).

A basic hypothesis is that district heating and cooling can be developed everywhere, where there is a sufficiently high demand density. All demands below a given threshold could be supplied at lower costs compared to individual heating and cooling solutions. So far, with the exemption of Denmark, Sweden and Finland, where more than half of the heat demand is covered by collective systems, most heat demand seems to be out of reach for such systems. Collective cooling systems do only exist in a few places yet. At the same time, assuming empirical cost data from the Scandinavian countries, somewhat near-optimal system designs and costs can be assumed and transferred to the rest of Europe.

Mapping of heating and cooling demand is the precondition to describe the possible supply and its costs for all urban areas (cities, towns, suburbs as well as villages larger than 1-2 km^2 and typically exceeding a population of 200. Furthermore, the agglomeration of such prospective DHC systems is to be analyzed, as there are economies of scale but also limitations of transport distances prevailing in this kind of studies.

1.1. Objectives

For the 5 target countries (CZ, HR, IT, RO and UK) the heat demand in residential and service sector buildings is to be mapped. Cooling demands are to be mapped for service sector buildings. Mapping is done on a sub-1km2 basis, which means that gridded data down to the 100m resolution are used to better describe what happens within the 1km scale, which is the output resolution for all subsequent studies. Publicly available geographical data compliant to the EU INSPIRE directive is to be used to the widest possible extent.

1.2. Method

Raster-based Geographical Information Systems (GIS) are used to model and map heating and cooling demand as distribution functions of population, land use and soil sealing in a combined top-down and bottom-up manner. National energy statistics, combined with small-scale statistics on the NUTS3-level are used to calculate specific or absolute heating and cooling demand values on a per-capita (heat) or per-m^2 (cooling) basis. Where HRE2 used a 1km resolution for the analysis, the computational basis used in the Stratego project is the 100m resolution, at which several publicly available datasets exist, which represent the small scale geography of urban areas. The results are re-aggregated to the 1km scale.

In the case of heat demand, population density per 1 km^2 is distributed to population densities per hectare (ha), derived by multi-linear regression modelling from a 1km^2 population grid as well as geographical data that describes the qualitative and quantitative pattern of settlements. Cooling demand is more complex to model because of several basic differences from heat demand. Firstly, a large part of the theoretical cooling demand is and will remain to be unmet, resulting in a cooling demand and a cooling consumption value for a specific building. Then, cooling demand currently mostly happens in service sector buildings such as shops and offices, whose locations cannot be mapped specifically on a European scale. The statistical model is therefore vital to find the likely distribution of service sector building areas within urban areas.

ArcGIS version 10.2.1 with Spatial Analyst was used to carry out the extensive analyses in the raster domain. All calculations were done using Model Builder, which is the graphical modelling interface in ArcGIS. All results were saved to a file-based Geodatabase. ArcGIS in its latest version is OGC-compliant, i.e. it follows the recommendations of the Open Geospatial Consortium Inc. for GIS interoperability, which allows users to "access data and services from many different sources, regardless of the technology used by those sources. In addition, users can share their content with others, including non-Esri users, thus contributing to the larger goals of the open data movement." (GeoCommunity, 2015).

1.3. Data input

Three central data themes form the data basis for representing the geographical distribution of heating and cooling demands within the European heating and cooling atlas. First, the population is mapped using the GEOSTAT 2011 1km population grid (GISCO, 2014). Second, the urban tissue is mapped qualitatively using Corine 2006 land use grid with 100m resolution (EEA, 2014a), while a quantitative measure for urban land use is the degree of soil sealing, mapped by the European Environment Agency at a 100m resolution grid (EEA, 2014b).

As a general spatial reference, a 1km grid by GEOSTAT (Eurostat, 2014), which is INSPIRE-compatible (IINSPIRE, 2014) and which uses the ETRS89 datum and a Lambert Azimuthal Equal Area projection to maintain area representation.

Additional data used is a NUTS3 administrative boundary layer originating from ESRI's ArcGIS Online service (ESRI, 2014), which had to be adjusted to the 2010 Eurostat data used in Background Report 6, plus the Open Street Map background layer service via ArcGIS (OSM, 2014).

Hence, all data used for distributing heat and cooling demand are either publicly available, owned by public institutions or the public domain.

1.4. Analysis of urban tissue: land use, settlement density and energy demand

An initial analysis was carried out to see if there is a spatial relation between land use and settlement density expressed by, among others, soil sealing. Soil sealing is mapped by the EEA and defined as the degree of imperviousness of surfaces, using a scale from 0 - 100% within a given geographical unit, here 1 hectare (ha).

By geo-statistically overlaying land cover and soil sealing it can be seen in Figure 1 that there is a close relation between soil sealing and urban land use associated to built-up areas, in particular the CORINE land cover classes 111 (Continuous urban fabric), 112 (Discontinuous urban fabric) and 121 (Industrial or commercial units). More than 90% in average of all soil sealing happens in urban built-up areas.

Within the 1 ha resolution, most details like the distribution of buildings and other sealed surfaces like roads etc. in smaller cities and in fringes of larger metropolitan areas would be leveled out by the coarse raster resolution. The overall urban structure, given by the boundaries to the lesser developed and green areas, is represented very well by the soil sealing grid, and explicitly by the land cover grid. It is here assumed that the population accounted for within a 1km2 raster cell is distributed only to the cells of 1 ha resolution, which have urban land cover (CORINE codes 111 and 112). Furthermore it has been assumed that the distribution of people follows the distribution of soil-sealing. Because the actual distribution between building footprint area and other sealed areas is different from one city to another, and from country to another, and specific heat demand is a function not only of the population density, but also building qualities and the available floor area per capita, the distribution has to be adjusted to actual data using small-scale statistics, see Background Report 6.

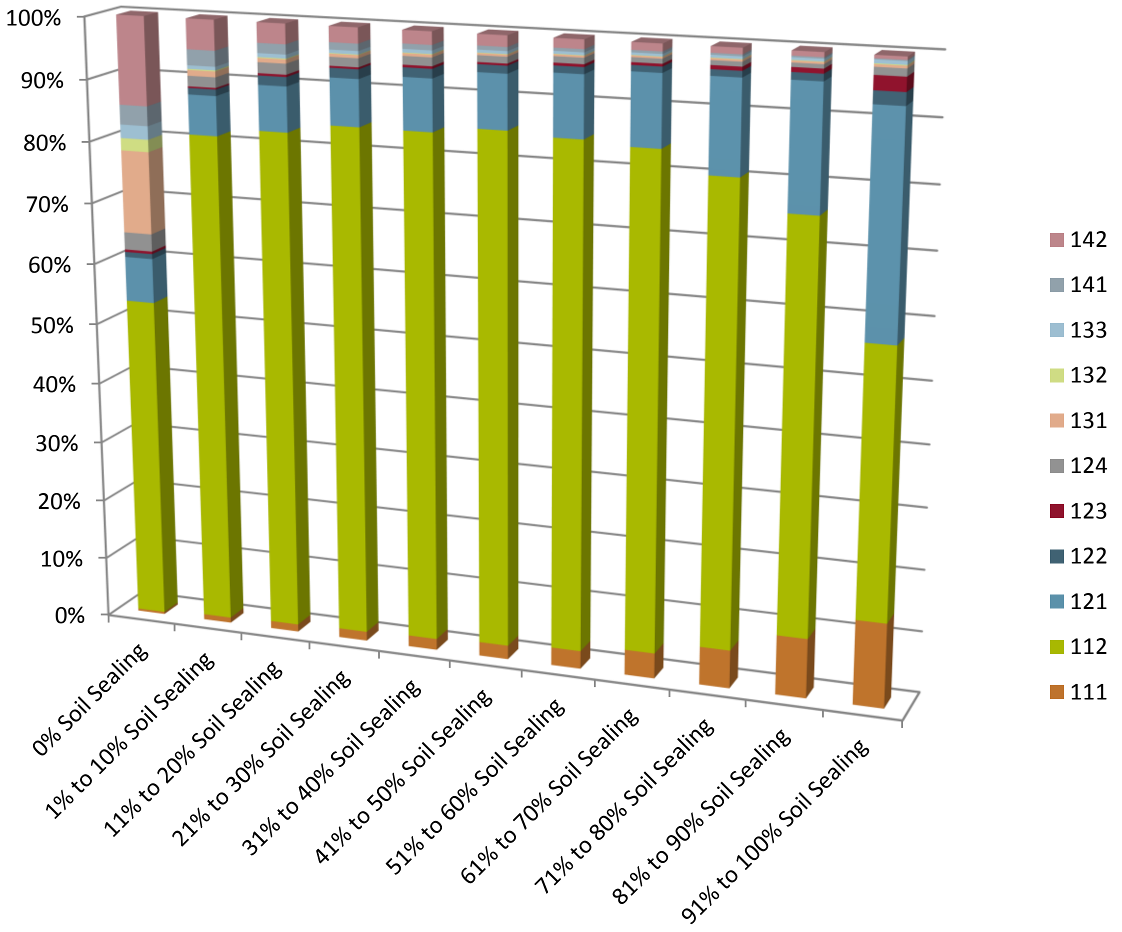


Figure 1: Percentage of CORINE land cover classes for bands of soil sealing. It can, among others, be seen that the urban land use class 111 (continuous urban) predominantly is featuring high percentages of soil sealing.

1.5. Heat demand model

Heat demand in buildings of the residential and service sectors are mapped separately. While the distribution of residential heat demand is assumed to be proportional to population, service sector heat demand typically can be located looking at urban functions.

First, the population represented by the GEOSTAT 2011 grid was distributed to 100m resolution. This is done using soil sealing as a proxy to the intensity of the built environment, which again follows population density. A regression done for the Netherlands shows the following relation between soil sealing and population (PDOK, 2015) it shows the average population density for each degree of soil sealing, see Figure 2. Please observe the values of the standard deviation also, which tell that in low and high density areas the deviation is higher.

According to the results for the analysis of urban tissue above, from the CORINE maps the land cover codes 111 (Continuous urban fabric), 112 (Discontinuous urban fabric) and 121 (Industrial or commercial units) were extracted to exclusively map built-up areas. Within these, as a proxy for building density the degree of soil sealing was used.

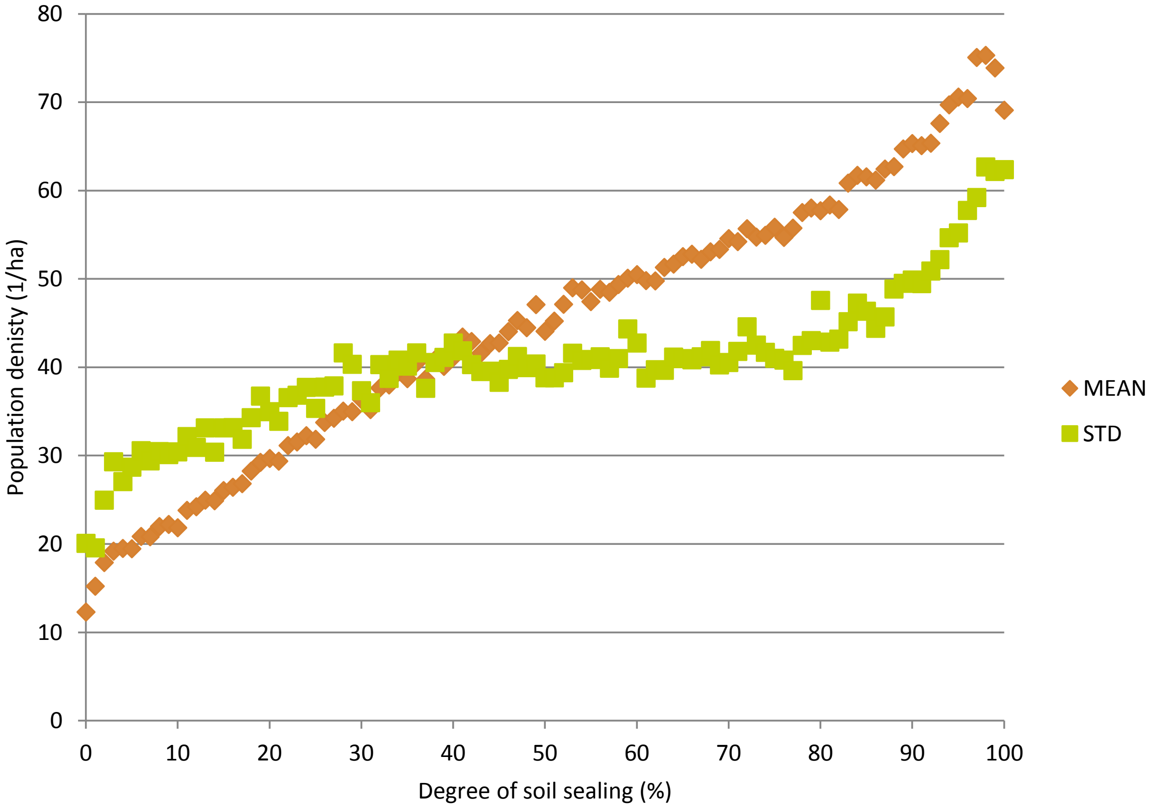


Figure 2: Average population density by degree of soil sealing for the Netherlands, where 100m population data is available.

As there are other urban land cover types with high degrees of soil sealing, such as roads, parking lots and public places, which may be larger than 0.5 to 1 ha and therefore show in a 100m grid, some adjustment has to be made. To remove linear structures such as roads, boundary cleaning was used, see Figure 3. The boundary cleaning was used twice. It also was effective at removing smaller groups of 1-4 cell clusters, which may represent larger non-built-up areas. The evaluation of effective removal of roads etc. was based on a spot checks in several urban areas followed by comparison to aerial photographs (various sources, ESRI).

To distribute population over built-up areas, population in a 100m cell is calculated multiplying the ratio of soil sealing in a 100m cell and the sum of soil sealing in a 1km cell with the population count per 1km cell. The result is an approximation of real population density, assuming that the population of the GEOSTAT grid lives in the above mentioned land use classes only. When re-aggregating the final results to 1km grid size, the original population and therefore heat demand is maintained, only the heat demand densities are adjusted to a better distribution of the built environment.

Figure 3: Effects of boundary cleaning of the soil sealing layer in Boolean prepresentation (left). The layer on the right hand side shows only the larger compounds of areas with urban development. The sealed road surfaces, which are visible in the original layer, as well as smaller built-up areas, are removed. The sample is from the Derby area, UK.

Residential heat demand for the 100m resolution model is modelled using the per-capita heat demand data on the NUTS3 level, see Background Report 4, using the population per 100m cell.

Service sector heat demand is modelled using a calculated plot ratio of service sector buildings. The plot ratio accounts for the building area per ground surface area. It is modelled using an ordinary least square statistical model, which applies three variables found by experiment using real building densities from the Danish heat atlas (Möller and Nielsen, 2013): population density has an influence on service sector density because it is assumed that services are located in the proximity of population, which is however not the case for very large office districts, such as parts of the city of Paris, or extensive shopping areas near large cities. Second, the degree of soil sealing reveals patterns of urbanity, which also is assumed to be related to the occurrence of service sector buildings. Thirdly, the average soil sealing density within a defined neighbourhood of 300m is another variable with influence on the service sector plot ratio. The resulting multi-linear regression model and its parameters are shown in Table 1. The overall adjusted R^2 value is 0.097, which seems very low, but if the resulting plot ratios are re-aggregated to 1km resolution, the R^2 becomes 0.616, which is very acceptable. This shows that the uncertainty lies in locating the actual service sector buildings exactly within the 100 possible 1-hectare cells of a 1 km2 grid. Here the model can only place 10 out of 100 cells correctly; placing the remaining cells almost at random. Comparing the 100m model with the actually registered buildings in Denmark it can be observed that the plot ratio is somewhat lower, hence the plot ratio and hereby the heating and cooling demand densities predicted are conservative.

The model has low standard errors, the probability and robustness values show highly significant p-values ($P < 0.01$). Low Variance Inflation Factor (VIF) values (< 7.5) indicate low redundancy among explanatory variables, even though soil sealing above 87% and the neighbourhood mean soil sealing are closely related, but that does not seem to have an effect on the small geographical scale applied here.

Table 1: Results from the multiple linear regression model of service building areas.

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	-19785	193032	######	0.000	1917	-10.35	0.000	-------
POP	31.167	1.612	19.32	0.000	1.654	18.84	0.000	1.086
SOILSEAL	228.96	21.04	10.87	0.000	22.05	10.38	0.000	1.108
GRIDCODE	46.672	5.133	9.091	0.000	6.079	7.678	0.000	1.197

As the model is based on the relations between population and soil sealing in Danish towns and cities, the resulting sums of building areas in the service sectors need to be adjusted for other member states to result in appropriate geographical distributions of service building areas. This is done using the data from Figure 13 in Background Report 4.

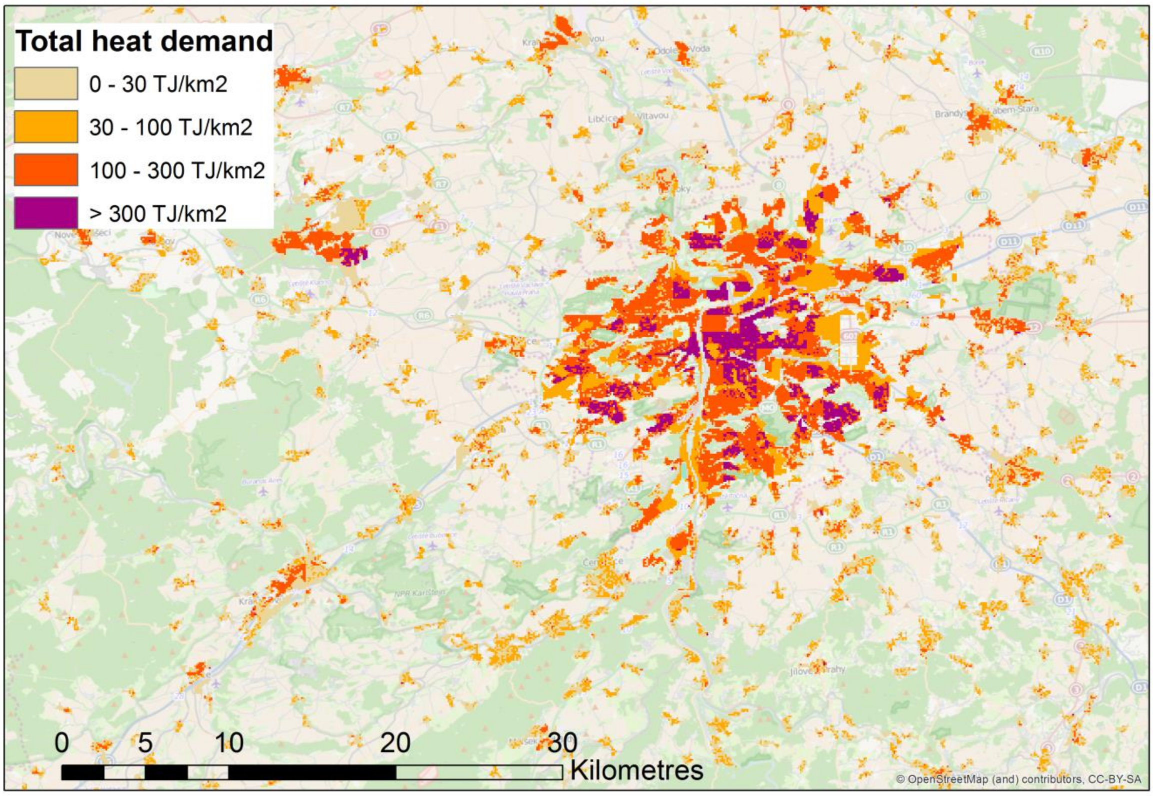


Figure 4: Extract from the 100m Heat Atlas showing heat demand in the Prague area, Czech Republic.

Using the model coefficients from Table 1, the service sector plot ratio is calculated for all EU28 member states and used to model the service sector heating and cooling (see below) demands. Finally, residential and service sector heat demands are added. The outcome is a heat demand map of 100m resolution, in GJ/ha or GJ/cell. It can be seen in Figure 4 how well the geographical delineation of towns and cities is replicated. However, great care has to be taken in using the data on a very local scale as the model only suggests high accuracy of this hitherto unprecedented scale. Nevertheless, the authors believe that the resulting Pan-European sub-1km Heat Atlas may be a further development of the 1km heat atlases of the

Heat Roadmap Europe Pre-study 2 as it better represents the geography of heat demand and collective heat supply areas.

1.6. Cooling demand model

The basis for calculating cooling demands form the statistics of service sector area and the European Cooling Index (ECI), see Background report 4. For the distribution of cooling demand the service sector plot ratios developed in the previous section are used, which are multiplied with the ECI values (in kWh/m^2).

It can be observed that service sector buildings and their cooling demands are confined to smaller areas predominantly in urban centres. The areas are often less coherent than the prospective district heating areas. Therefore great care has to be taken to model the potentials and costs of district cooling.

The cooling demand model is a first, rough estimate. First, the ECI values are based on average building efficiency and intensity of use. Second, the distribution of the service sector buildings is based on statistics from Denmark only, which is a small country where zonal planning is rather efficient, but also where accessibility and socio-economy is rather different from other EU countries.

Figure 5 shows the result of the model of service sector plot ratio compared to the mapped plot ratio using the Danish national building register used in the heat atlas by Möller and Nielsen (2013).

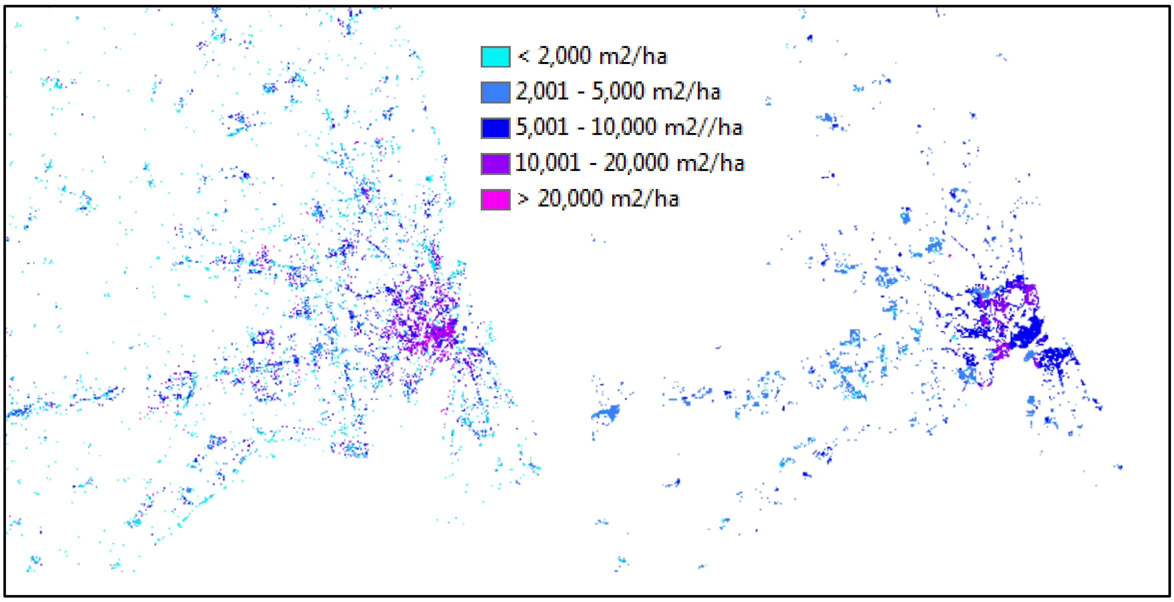


Figure 5: Comparison of registered plot ratio of service sector buildings (left) and modelled plot ratio (right) for Copenhagen, Denmark. The urban pattern is well represented by the model, although it may underestimate high-density areas, while increasing their area. Note that service sector buildings in rural areas are excluded because of the land cover mapping, which only includes urban areas.

Figure 6 shows an example of the cooling demand mapped at 100m resolution. The model suggests that cooling demand is much less coherently located than heat demand, which is because service sector buildings are confined to specific locations in urban and suburban centres as well as commercial zones. It has to be realized despite the high resolution that the model is not able to locate exactly where cooling demand is located within 1 km^2. Hence the cooling demand map will be aggregated to 1 km^2 resolution, while the cost-supply analysis uses the 100m resolution.

Finally, the large unknown is the difference between cooling demand and the actual rate of which it is met. The choice was therefore to only look at service sector buildings and to rather underestimate the cooling demand density.

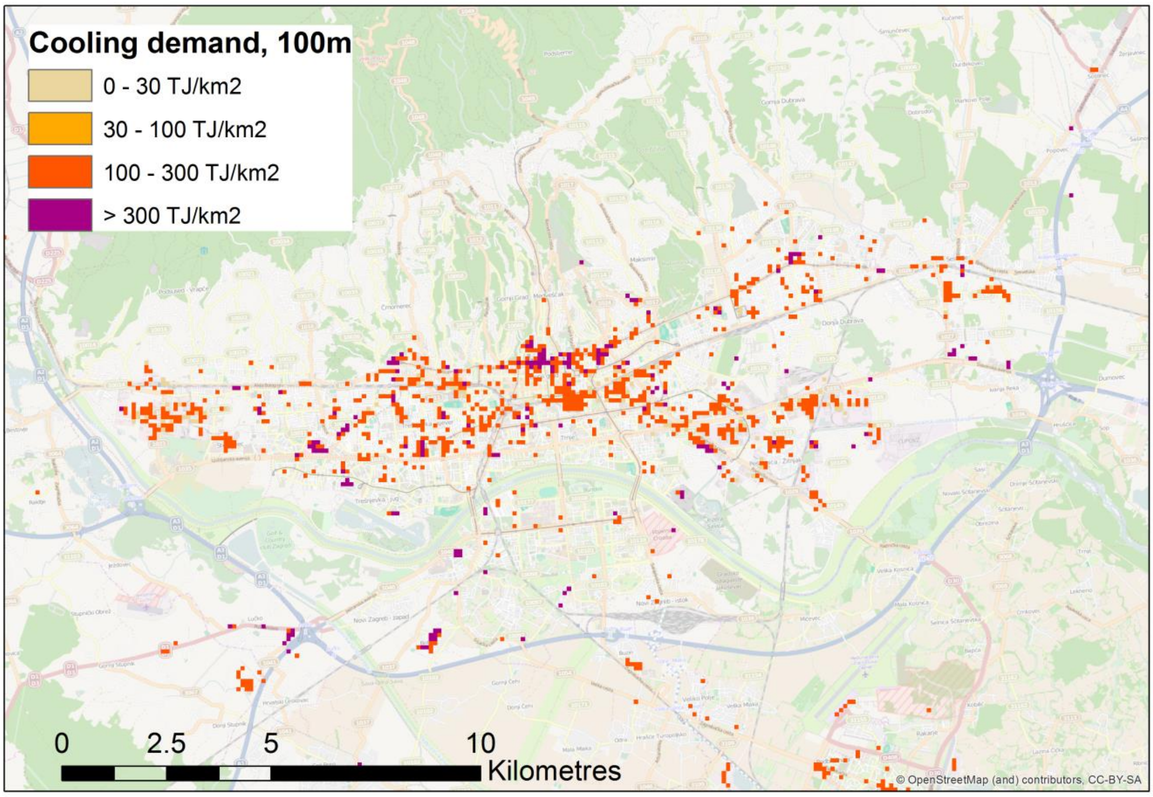


Figure 6: detail of the mapped cooling demand at 100m resolution for the city of Zagreb. Cooling demand is less coherent and confined to centres as well as service areas, it appears. It is not possible with the model to map exactly where cooling demand is located, but it gives a rather representative image of the distribution of urban cooling demand in the service sector.

References

Connolly D,Mathiesen BV, Østergaard PA, Möller B, Nielsen S, Lund H, Persson U, Werner S, Grözinger J, Boermans T, Bosquet M, Trier D, Heat Roadmap Europe 2050: Second pre-study for the EU27. Dept. of Development and Planning, Aalborg University, Denmark (2013)

EEA (European Environment Agency) Corine Land Cover 2006 raster data . http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-3 (Last accessed Nov. 13, 2014)

EEA (European Environment Agency) EEA Fast Track Service Precursor on Land Monitoring - Degree of soil sealing. http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing (last accessed Dec. 2, 2014).

ESRI, Environmental Systems Research Institute. ArcGIS Online http://www.esri.com/software/arcgis/arcgisonline (last accessed Jan. 20, 2015)

Eurostat, GEOSTAT project. http://ec.europa.eu/eurostat/c/portal/layout?p_l_id=4311216&p_v_l_s_g_id=0 (last accessed Nov 10th, 2014)

GeoCommunity Article on http://spatialnews.geocomm.com/dailynews/2015/jan/27/news1.html (last accessed Jan 28, 2015).

Gils HC, A GIS-based Assessment of the District Heating Potential in Europe. 12. Symposium Energieinnovation, 15 - 17.2.2012, Graz/Austria

GISCO, the Geographical Information System at the Commission, http://ec.europa.eu/eurostat/web/gisco (last accessed Nov. 10, 2014).

INSPIRE, Infrastructure for Spatial Information in the European Community. http://inspire.ec.europa.eu/ (Last accessed Jan. 30, 2015)

Möller B, Nielsen S, High resolution heat atlases for demand and supply mapping. International journal of Sustainable Energy Planning and Management 01 (2014) 41-58.

Openshaw S, *The Modifiable Areal Unit Problem*. Geobooks, Norwich, England (1984)

OSM, OpenStreetMap http://www.openstreetmap.org (last accessed Jan. 20, 2015)

PDOK, Publieke Dienstverlening Op de Kaart (public mapping services), https://www.pdok.nl/ (last accessed Jan. 30, 2015)

Persson U, Möller B, Werner S, Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74 (2014) 663-681.

Persson U, Werner S, Heat distribution and the future competitiveness of district heating. Applied Energy 88 (2011) 568-576.

Project No: IEE/13/650

Stratego
ENHANCED HEATING
& COOLING PLANS

Quantifying the Potential for District Heating and Cooling in EU Member States

Work Package 2

Background Report 6

Co-funded by the Intelligent Energy Europe
Programme of the European Union

Authors: Bernd Möller, University of Flensburg
Sven Werner, Halmstad University

Contact: University of Flensburg
Munketoft 3b
Raum MV 014
24937 Flensburg
Tel: +49 (0) 461/805-2506
Fax: +49 (0) 461/805-2505

Version 3 (additional data for each country with updated costs and description)

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

1. Potential for district heating and cooling and their corresponding distribution costs

1.1. Objectives

For the five Stratego target countries: CZ, HR, IT, RO and UK the prospective DH areas are to be delineated and their properties are to be mapped. The costs of establishing district heating and cooling grids are to be calculated on the basis of empirical, analytical cost models. Using the mapped potentials for district heating and cooling in combination with the cost mapping and the properties of prospective district heating and cooling grids, cost-supply analysis is to be carried out, which yields tabular results for export to energy systems analysis as well as a graphical representation of the economic constraints of utilizing the potential to develop district energy systems.

1.2. Potentials for district heat development

Potentials for the development of district heating are assessed initially using heat demand density as a single criterion. Where ever heat demand is falling into categories of 0 – 30, 30 – 100, 100 – 300 or above 300 TJ/km^2, it is being summarized for a whole country. This first assessment of potentials leaves out the connectedness of systems, the size of operations and its location relative to renewable energy sources. What can be seen in Table 1 is how the potentials are distributed for the five countries. With current district heating technology, which may require heat demand densities above 100 TJ/km^2, the potential is highest in the UK, in relative and absolute terms. A country like Croatia however has just 12% of is present heat demand located in sufficiently dense areas, and size and location of the country in a warmer climate also mean that the absolute heat market is very small. With advanced 4th generation district heating systems (4DH), the required heat demand densities are lower, increasing the shares of heat demand likely to be covered with 4DH systems to 57 to 86%.

Table 1: Heat demand by heat demand density classes, which explain the suitability for developing district heating, in PJ and in %.

Member State	CZ	HR	IT	RO	UK
Heat demand density 0 - 30 TJ/km^2 (PJ)	28	13	46	60	46
Heat demand density 30 - 100 TJ/km^2 (PJ)	95	28	321	91	306
Heat demand density 100 - 300 TJ/km^2 (PJ)	110	8	664	95	1,075
Heat demand density > 300 TJ/km^2 (PJ)	24	0	954	2	118
Heat demand in built-up areas, sum (PJ)	256	48	1,124	248	1,545
Heat demand, total (PJ)	290	63	1,344	290	1,738
Heat demand in rural areas (PJ)	34	14	219	42	192
Heat demand in rural areas, %	12%	23%	16%	14%	11%
DH Almost Impossible (0 - 30 TJ/km^2)	10%	20%	3%	21%	3%
Potential for 4DH (30 - 100 TJ/km^2)	33%	44%	24%	31%	18%
DH Currently Possible (100 - 300 TJ/km^2)	38%	12%	49%	33%	62%
DH Highly Feasible (>300 TJ/km^2)	8%	0%	7%	1%	7%
Cumulative Above 30 TJ/km^2	79%	57%	80%	65%	86%
Cumulative Above 100 TJ/km^2	46%	13%	56%	34%	69%

1.3. Identification of potential district heating systems

In order to find coherent areas with heat demands, which could comprise prospective district heating areas, a clustering process is required. By means of contingency mapping, connected cells are grouped to individual heat supply areas, see Figure 1. A threshold of 1 km is used to interconnect neighbouring areas. The result is a clustering of heat demand into larger, coherent areas, which may comprise prospective district heating systems, depending on their demand densities and the resulting costs of district heat supply.

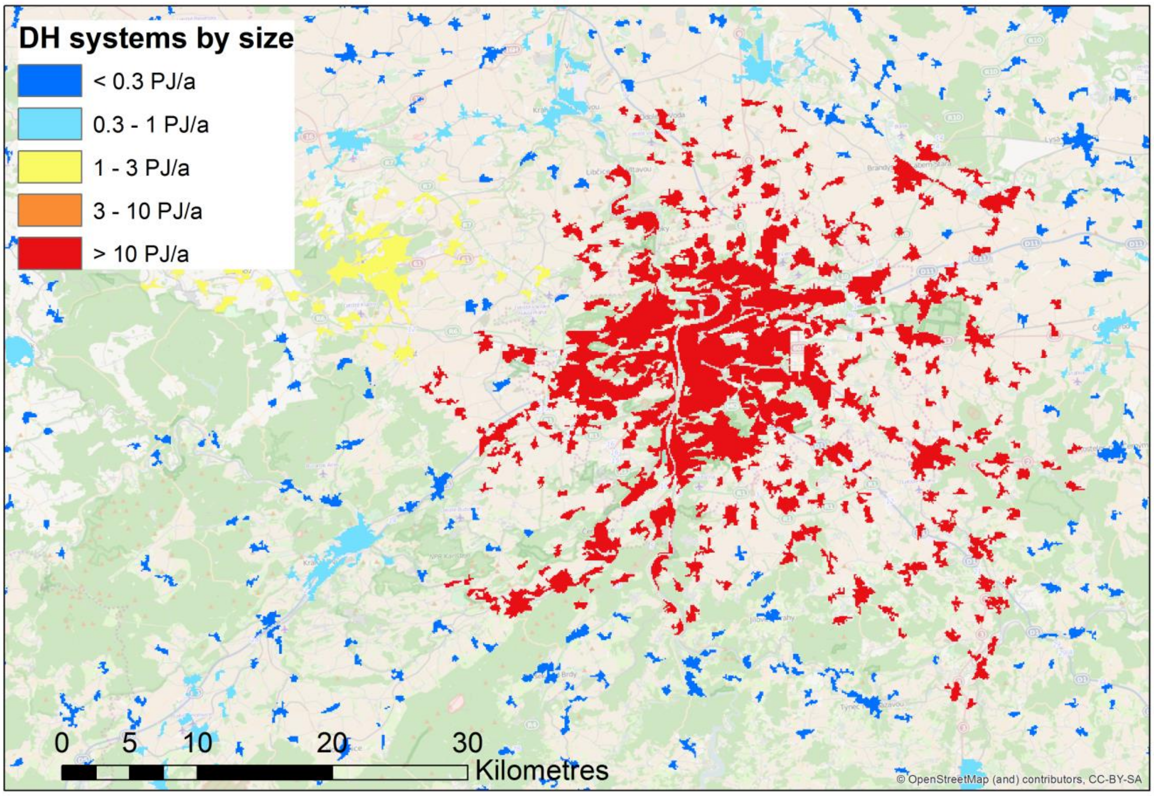


Figure 1: Prospective DH systems by size (sum of gross annual heat demand) around the city of Prague, Czech Republic. This mapping allows for a quantification of potentials and costs by several system variables, one of which is the size of a system, which may be related to the heat production technologies used. Furthermore, systems located less than 1 km apart are considered coherent, i.e. they could be connected to agglomerated systems.

For each of these areas a number of attributes can be derived from the map, or attached from other map layers using spatial analysis. By means of zonal statistics by district heat supply area, the sum of heat demand, the area and the average heat demand densities are fused to the heat supply area layer. The attributes are then used in the cost-supply areas in order to establish relationships of potentials and costs by various system properties, such as system size in terms of area or heat demand, as well as access to renewable energy sources etc.

Table 2 shows the heat demand of the five targeted countries by prospective DH system size, which is the sum of heat demand within each individual, coherent area. While very large systems above 10 PJ/a comprise about 20% of the non-rural heat demand in the Czech Republic, in the UK this is more than half. Romania is predominantly rural, which means that about half of the heat demand is located in areas, which have less than 0.3 PJ annual heat demand. Systems in the size of 3 to 10

PJ/a are underrepresented in all countries, where only about 10% of the heat demand is located in cities with a cumulative heat demand of this magnitude.

Table 2: Heat demand by district heating system size for the 5 Stratego countries, in PJ.

Heat demand by DH system size, PJ	CZ	HR	IT	RO	UK
< 0.3 PJ	87	20	283	116	155
0.3 - 1 PJ	51	8	152	38	138
1 - 3 PJ	38	8	140	36	176
3 - 10 PJ	25	-	99	30	196
> 10 PJ	55	12	451	28	881
Sum (excl. rural)	256	48	1,125	248	1,546

1.4. Potentials for district cooling development

District cooling is much less developed in Europe and also the potentials for developing district cooling systems are much lower, in general. From Table 3 it follows that Croatia and the UK have significant potentials for district cooling under current conditions, while with the advent of advanced district cooling systems by far the most cooling demand could be covered by these systems. Please observe that the threshold levels for possibility are different than for district heating.

Table 3: Cooling demand by cooling demand density as a means to identify potential district cooling areas, in PJ and in %.

Member State	CZ	HR	IT	RO	UK
Cooling Demand (PJ) by Cooling Density, < 30 TJ/km^2	1.41	0.19	0.83	0.01	0
Cooling Demand (PJ) by Cooling Density 30 - 100 TJ/km^2	18.65	0.26	23.27	12.21	8.70
Cooling Demand (PJ) by Cooling Density 100-300 TJ/km^2	0.53	9.16	133.58	0.03	42.28
Cooling Demand (PJ) by Cooling Density >300 TJ/km^2	0.00	2.00	1.93	0	18.64
Cooling Demand (PJ) by Cooling Density, sum	20.60	11.60	159.60	12.25	69.62
Cooling demand, rural areas (< 30 TJ/km^2)	7%	2%	1%	0%	0%
DC Almost Impossible (30 - 100 TJ/km^2)	91%	2%	15%	100%	12%
Potential for advanced DC (100 - 300 TJ/km^2)	3%	79%	84%	0%	61%
DC Currently Possible (> 300 TJ/km^2)	0%	17%	1%	0%	27%
Cumulative Above 30 TJ/km^2	93%	98%	99%	100%	100%
Cumulative Above 100 TJ/km^2	3%	96%	85%	0%	88%

2. Assessment of investment costs for heat and cold distribution

2.1. Background

The assignment is to estimate the average investment costs for heat and cold distribution as a function of the heat and cold densities for modelling and planning purposes. This aim is achieved by elaborating the basic theory of heat and cold distribution costs presented in section 11.4 of the international textbook of (Frederiksen & Werner, 2013).

2.2. Method

The expected output from this estimation analysis is to obtain the specific investment cost for heat and cold distribution as a function of heat and cold densities. This output is achieved in five steps:

- Estimation of the investment cost per metre of trench length by pipe dimension and ground conditions.
- Estimation of the average investment cost with respect to typical ground conditions.
- Estimation of the average pipe dimension from the linear heat density
- Estimation of the average investment cost from the average pipe dimension as a function of the land area density as heat or cold demand per land area
- Final estimation of the specific investment cost per heat and cold sold as a function of the heat and cold densities.

2.3. Intermediate estimations

The two first two steps are presented in Figure 2, showing the investment cost for district heating pipes per trench length. The information is based on the Swedish cost level of 2007. Hereby, the cost level includes also a learning process for putting the pipes efficiently into the ground as achieved in mature district heating countries. Small pipes are normally used in areas with single family areas, with a high proportion of green areas. Wider pipes are normally used in inner city areas with higher building densities and higher construction costs, as presented in Figure 2. These ground conditions are considered when creating the average cost line by using the marked dots in Figure 2. This estimated linear average cost line will have the following composition:

Average investment cost = 130 + 2858(average pipe diameter in m)* [EUR/m]

The third step will utilize the experienced relation between the linear heat densities and the average pipe dimensions in 134 Swedish heat distribution networks or parts of networks as presented in Figure 11.8 in (Frederiksen & Werner, 2013). The linear heat density is the heat sold annually divided by the corresponding trench length. This relation can be written as

*Average pipe dimension = 0.0486 * LN (linear heat density in MWh/m) + 0.063* [m]

The fourth step is obtained by combining the average cost line in Figure 2, the relation above for the average pipe dimension, and an effective width of 65 m. The latter assumption for the effective width is based on Figure 11.10 in (Frederiksen & Werner, 2013) showing that the effective width is almost constant at that level for plot ratios above 0.4. The effective width is needed since the linear densities are equal to the product of the effective width and the land area densities. The intermediate result from the fourth step is presented in Figure 3.

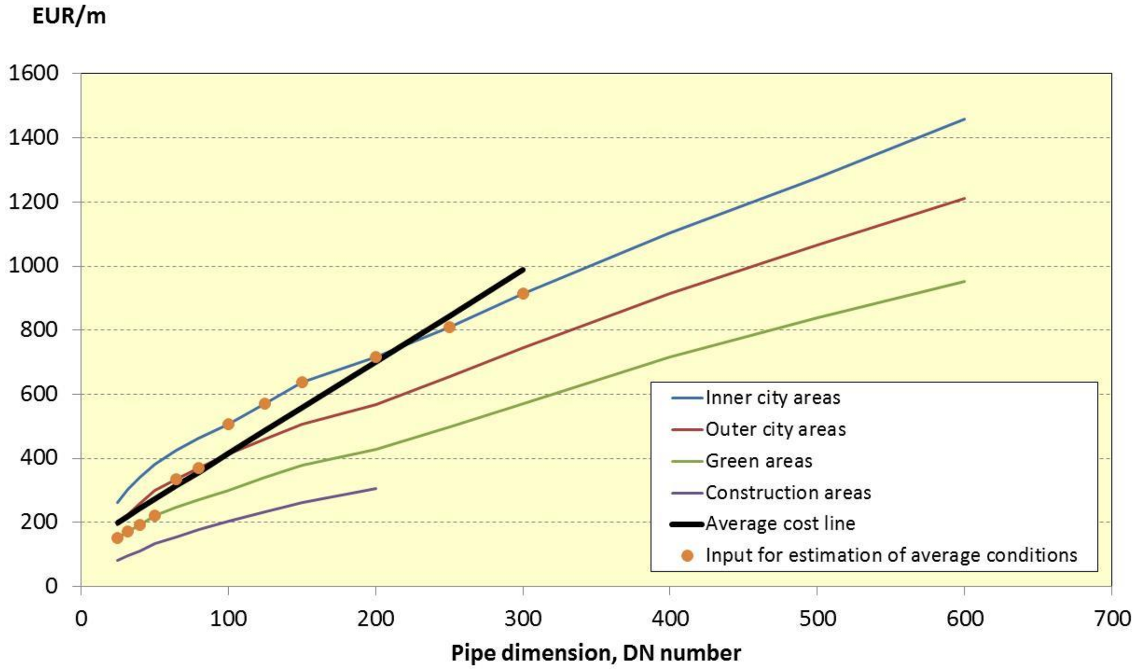


Figure 2: The investment cost for distribution pipes per trench length by pipe dimension and ground conditions based on Swedish experiences for the 2007 cost level.

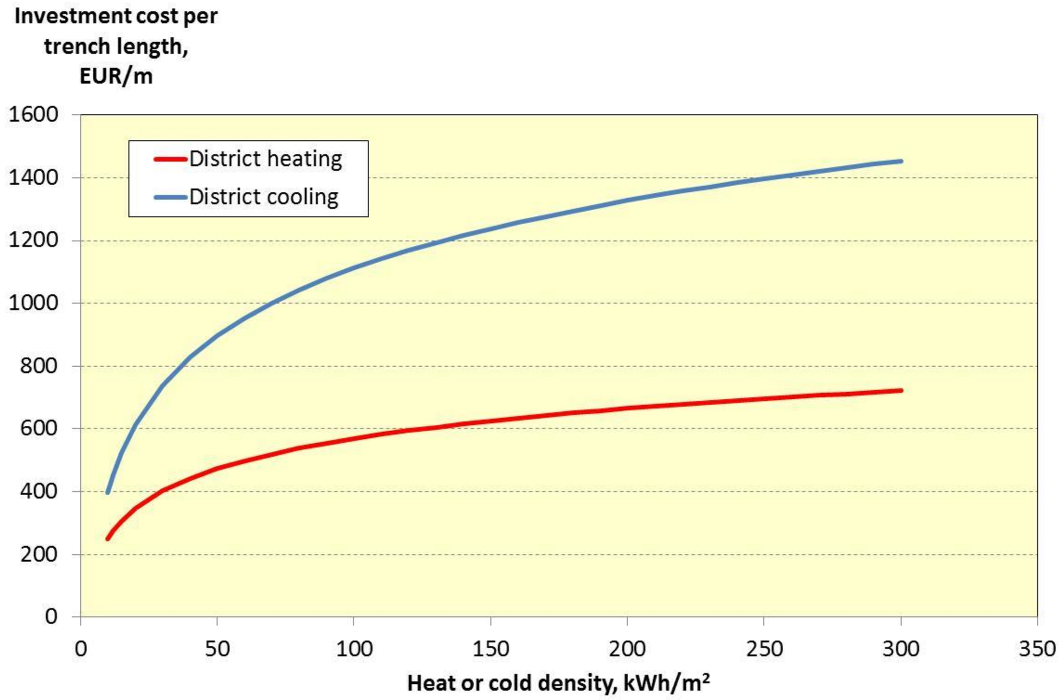


Figure 3: The estimated average distribution costs for district heating and district cooling as a function of the heat and cold densities, respectively.

The average cost line for district cooling was estimated with pipe dimensions that are wider than the corresponding pipe dimension for district heating. The used upscaling factor was the square root of five, since the flows in district cooling networks are about five times higher than in district heating networks at same demand levels. This higher flow level appear since the temperature differences in district cooling networks are about one fifth of the temperature differences in district heating networks.

2.4. Result

The final fifth and resulting step in the estimation is presented in Figure 3. The specific average investment costs were estimated by dividing the average investment costs in Figure 2 by the corresponding linear densities as defined in (Frederiksen & Werner, 2013). The linear densities were again estimated by the product of the land area densities with the assumed constant effective width of 65 m.

These specific average investment costs are consequentially being used within the STRATEGO project for overall assessments and feasibility studies for new or extended district heating and district cooling networks.

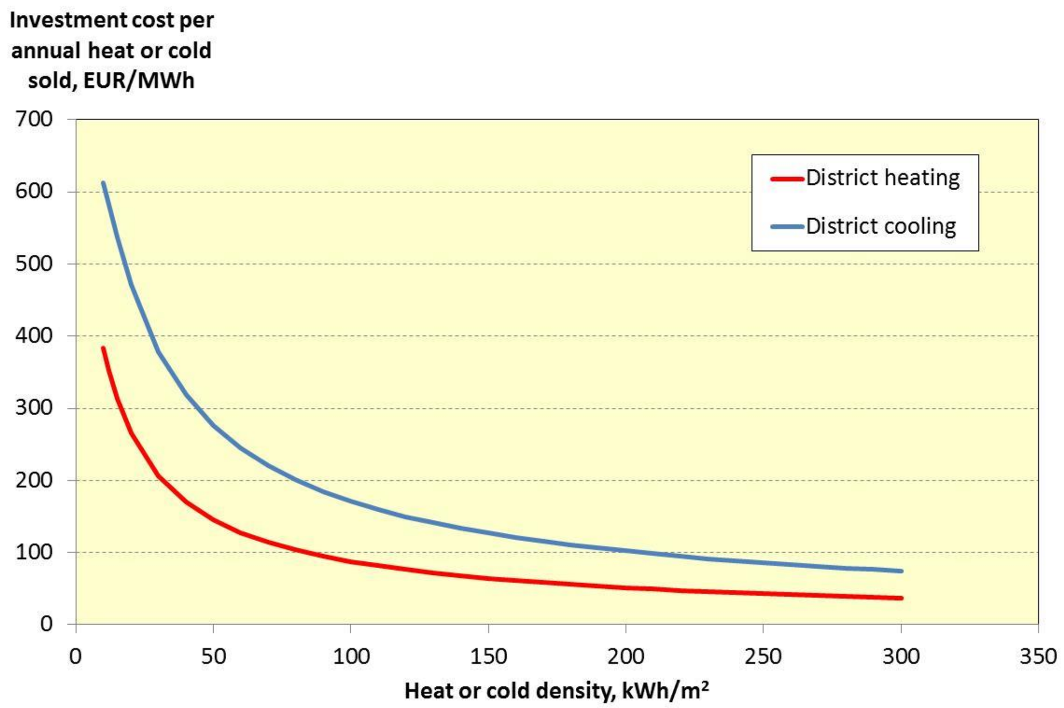


Figure 4. The specific investment cost per heat or cold annually sold as function of the heat and cold densities, both related to the corresponding land area.

From Figure 4 it follows that district cooling systems are more expensive to install for the same amount of energy delivered. The highest sensitivity to energy density is in the low density areas at the threshold to economic feasibility. It can be expected that the geographical boundaries between collective and individual heating or cooling systems are subject to high cost sensitivity also, as the cost curves suggest.

2.5. Cost-supply analysis

In cost-supply analysis, the marginal costs of cumulative utilization of a potential are given. A cost-supply curve establishes a mathematical relation between the amount of a given resource (in this case heating or cooling demand) and their costs (here the annualized investment costs to utilize the resource). The basic assumption is that the most economical portions of a resource are used first, to be followed by marginally less attractive, in economic terms. Cost-supply curves of district heating and cooling therefor allow for establishing the costs of supply especially for supply, whose cost highly depends on the potentials used. Because the potentials of district energy highly depend on the location, distribution and distance to sources, it is obvious to use GIS-based cost-supply modelling. The inputs to this are a) the quantification of costs, b) the quantification of supply available at these costs, and c) several other attributes to be used to further specify the cost-supply relations, such as member state, size of system, or the availability of renewable energy sources. All these data can be retrieved from the Heating and Cooling Atlas.

Investment costs have been annualized using a technical lifetime of 30 years and a socio-economic interest rate of 3%.

Figure 5 shows the cost-supply curves for the five countries participating in work package 2 of the Stratego-project as per cent of total urban heat demand. In the UK, the Czech Republic and in Italy about 25% of the total demand in villages, towns and cities can be supplied at less than 1.5 €/GJ annual heat demand. At a threshold of 2 €/GJ the share rises to 50 – 70% in these countries, which is well consistent with Persson and Werner (2011). For Romania the costs are on a higher level because of the low demand densities, while in Croatia the cost-supply curve in Figure 5 is very steep initially and the costs are generally very high, while the economic potential is very small for both countries. Generally, the steeper the cost curves, the higher i the cost sensitivity to geographical factors. It has to be added that the feasibility also depends on the costs of heat supply, and that the specific investment costs are here assumed to be the same for all countries despite different levels of labour costs etc.

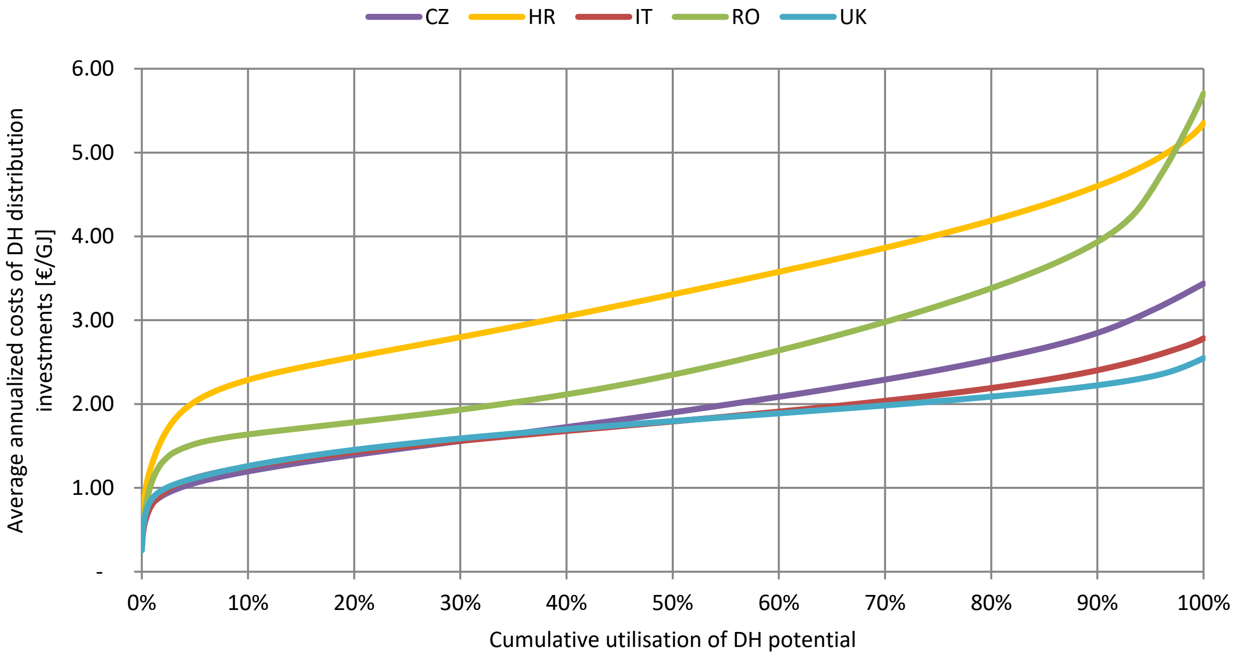


Figure 5: Cost-supply curves for district heat distribution for the 5 STRATEGO countries showing the average, annualized costs of developing district heating distribution infrastructure.

Costs of distributing district cooling are generally higher, partly because the higher specific costs but also because of generally lower cooling demand densities; see Figure 6. At a threshold of 2€/GJ (annualized) the UK may have 22% of its potential cooling demand covered with district cooling, while Croatia may just be at 3% and the other Stratego countries are left with minute potentials at this level. At 2.5 €/GJ, Italy reaches 4%, Croatia 44%, and the UK 56%. Italy reaches 42% at 3€/GJ, while the economic potential remains zero in the Czech Republic and in Romania. However, one great uncertainty is the degree of connectedness of the cooling demand in towns and cities, which along with the fact that all above figures relate to the potential cooling demand, makes any results uncertain and indicative only.

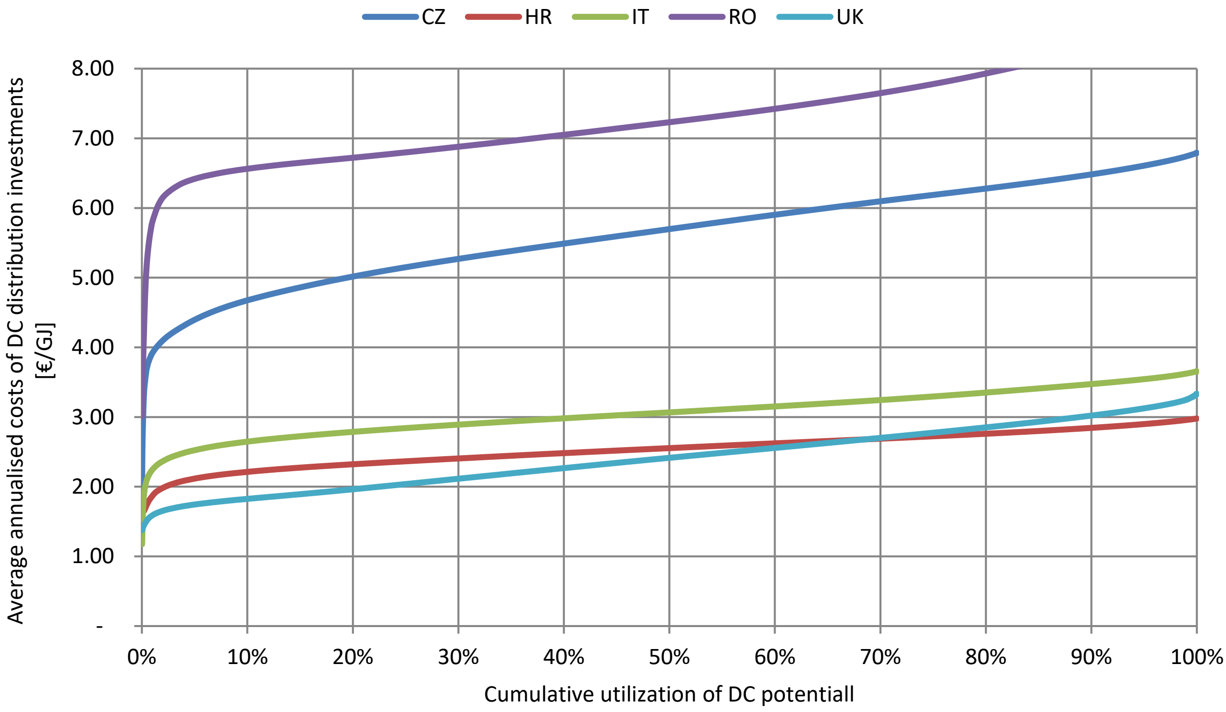


Figure 6: Cost-supply analysis of district cooling grids showing average annualised costs of establishing DC grids in the five Stratego countries.

DH potential by size of system

Using the prospective supply system properties, cost-supply curves can be produced for different system types as well. Accordingly, Figure 7 presents a cost-supply curve for the Czech Republic by prospective district heating system size. Each curve features a more or less distinct turn at which costs increase disproportionally. This indicates a point where the economic (under most optimistic conditions) and the total potential can be separated. Usually the economic potential, it follows from this example, is about half of the total. Depending on the threshold for economic feasibility, which is subject to an overall economic assessment, because other cost factors, such as the production costs of district heat, need to be included, the economic potential for a given location and system size can be derived for systems of different size. It can be seen that larger systems, because they are usually located in denser urban areas of bigger towns and cities, have lower distribution costs than smaller systems. It shows that in the Czech Republic systems > 10PJ/a have a heat supply market of 38PJ/a at an annualized distribution cost of 1.5€/GJ, while another 10PJ/a can be found in systems of 1-3 and 3-10 PJ/a, respectively. For smaller systems the steeper curves furthermore indicate greater uncertainties in the economic potentials.

The economic potentials for district heating in Croatia require generally higher investments in distribution grid infrastructure. Assuming cost thresholds of 2.5 €/GJ, the biggest systems may realize 5PJ/a, while another 3PJ is available in smaller systems, see Figure 8.

Italy shows good economic potentials for the development of district heating systems, see Figure 9. At 2 €/GJ, almost all of the heat demand in the largest cities can be covered, while the share is 50-70% for systems between 0.5 and 10 PJ. Even the smallest systems < 0.3 PJ/a may represent a potential market.

Romania, because it is predominantly rural, has a rather small district heating potential. However, almost all of the heat demand in the biggest city of Bucharest can be covered by district heating, as well as the major part in systems between 1 and 10 PJ annual demand, see Figure 10.

Finally, the heat market of the UK is greatly dominated by large cities, which comprise 80% of the economic potential at 1.5 €/GJ annualized costs, see Figure 11.

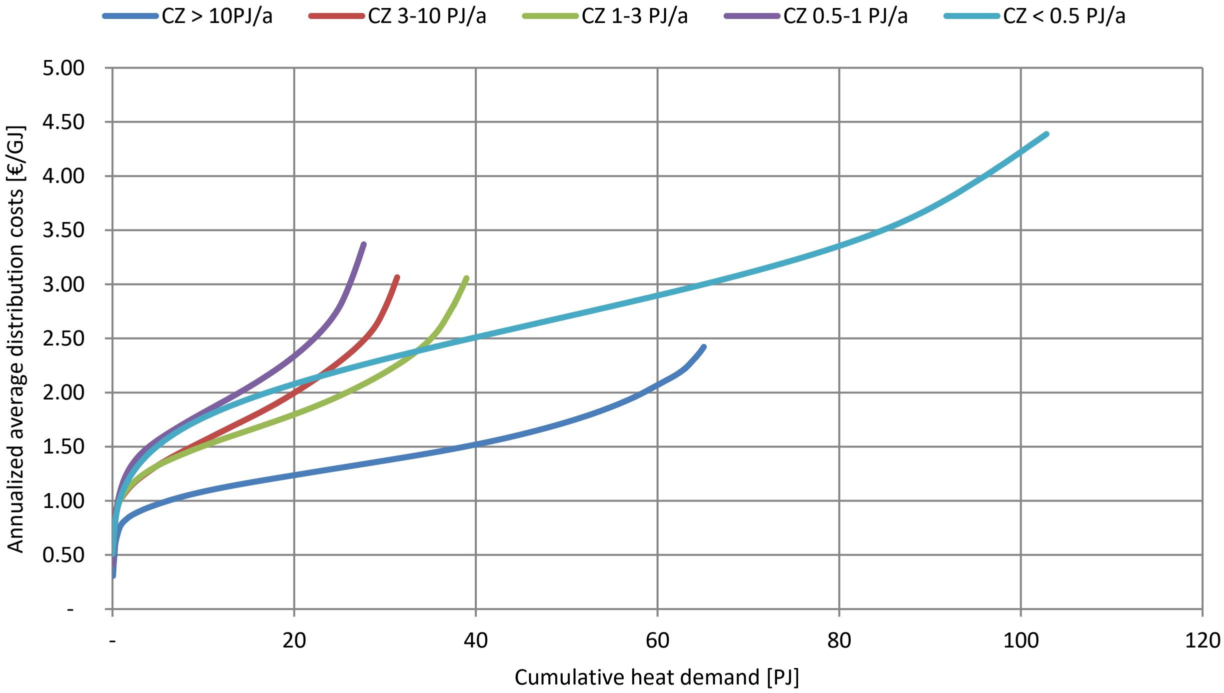


Figure 7: The cost-supply curve for district heating potentials in the Czech Republic by prospective district heating system size.

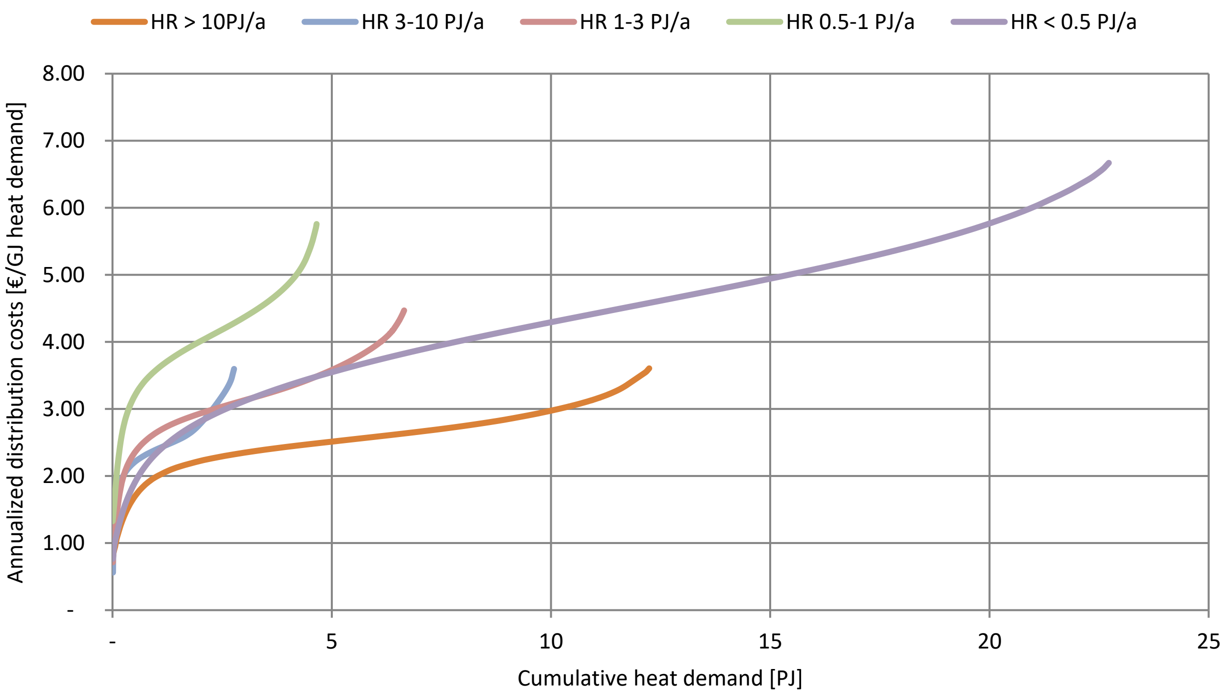


Figure 8: Cost-supply curve for district hearting potentials in Croatia by prospective district heating system size.

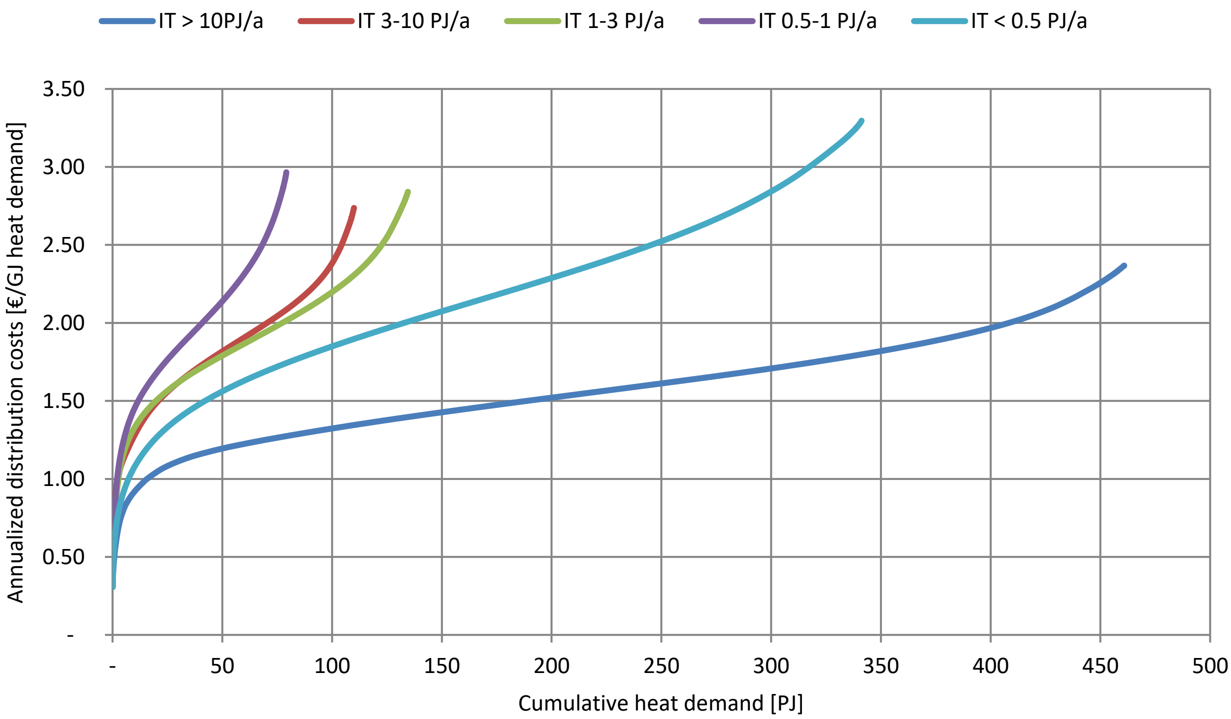


Figure 9: Cost-supply curves for district heating potentials in Italy by prospective district heating system size.

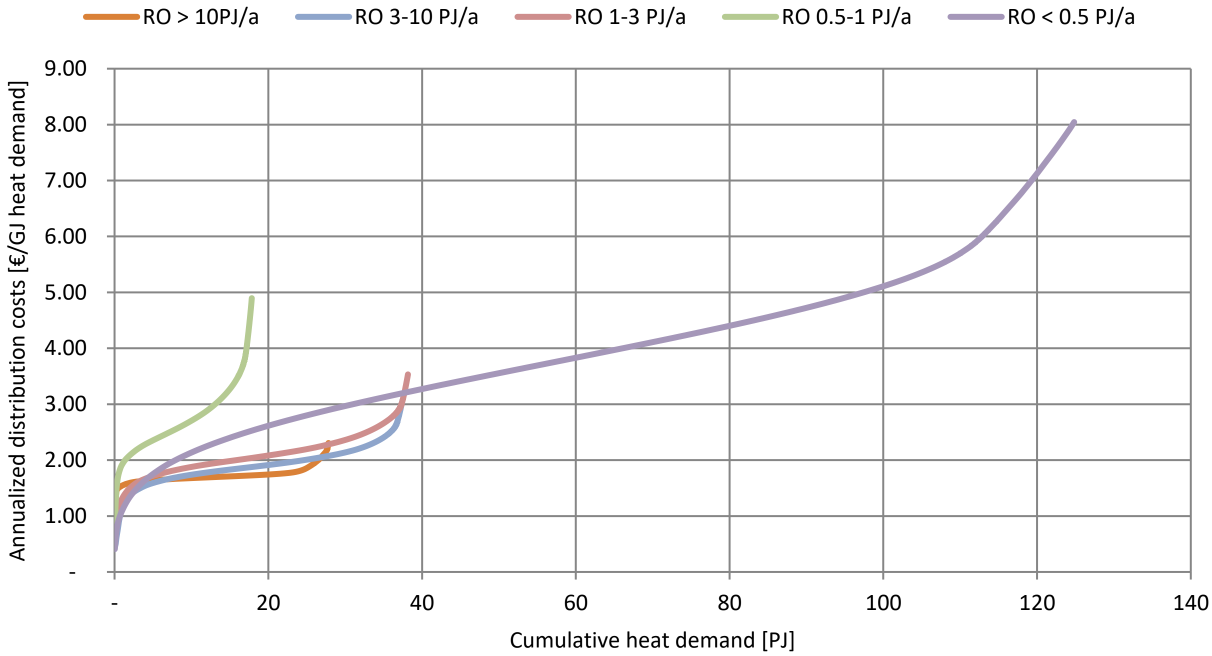


Figure 10: Cost-supply curves for district heating potentials in Romania by prospective district heating system size.

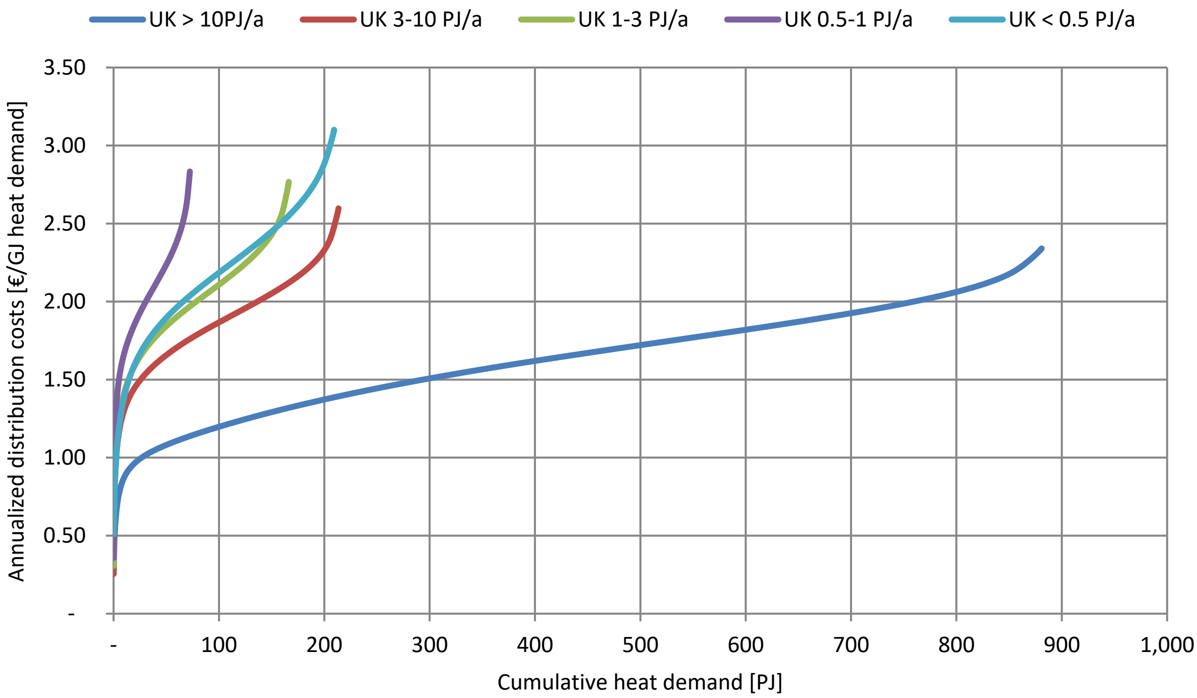


Figure 11: Cost-supply curves for district heating potentials in the United Kingdom by prospective district heating system size.

References

Frederiksen S and Werner S, District Heating and Cooling. Studentlitteratur, 2013.

Persson U, Werner S, Heat distribution and the future competitiveness of district heating. Applied Energy 88 (2011) 568-576.

Project No: IEE/13/650

Quantifying the Excess Heat Available for District Heating in Europe

Work Package 2

Background Report 7

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: Urban Persson

Contact: Halmstad University
S-301 18 Halmstad, Sweden
T: +46 0 3516 7405
E-mail: urban.persson@hh.se
Web: www.hh.se/english

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

1 Background

In terms of quantifying the excess heat available for district heating systems, the approach within the Stratego project is to assess these availabilities on facility level and aggregate found volumes to regional and national levels for planning and modelling purposes. Since explicit information on excess heat from unique thermal power generation plants and fuel transformation processes in industrial activities are principally unavailable in international energy statistics, and very seldom quantified and reported in general, this task poses a methodological challenge for the project. The chosen approach to meet this challenge, which corresponds to that developed and used in the Heat Roadmap Europe project (HRE, 2014), rests on the idea to use publicly available carbon dioxide emission data on facility level in combination with a reversed calculation sequence to establish primary energy inputs and anticipated excess heat volumes from considered activities.

The purpose of quantifying excess heat available for district heating systems in this context is two-fold and aims to illustrate the vast European potential of the long neglected and often disregarded domestic resource of excess heat. First, determining the geographical locations of considered activities is pre-conditional for any regional or national assessments of future heat synergy collaborations, where increased shares of current excess heat available from these plants and activities are to be recovered and distributed in district heating networks. Second, quantification of annual excess heat volumes available from these plants is essential to provide an idea of the magnitude and extent by which these assets may be utilised to replace current heat supply to meet building heat demands.

It should be underlined that anticipated annual excess heat volumes in the following represent maximal levels of rejected secondary heat from the considered activities, levels that due to a multitude of reasons (e.g. thermo-dynamical, geographical, infrastructural, and seasonal) very well may prove difficult to realise fully in unique heat recovery projects. For the local projects within the Stratego project, as well as for any local heat synergy collaboration in future Europe, it is recommended to carry out detailed assessments of available excess heat from any plausible source. Such detailed assessments should ideally be based on actual energy and thermo-dynamical data (temperature levels, state-of-matter etc.), include sensitivity analyses, and as well address organisational aspects such as collaboration agreements with mutually beneficial allocation of synergy benefits to all involved parties.

2 Method

The methodological approach used to quantify excess heat available for district heating systems in this report is mainly based on the use of publicly available carbon dioxide emission data from the European Pollutant Release and Transfer Register (E-PRTR) (EEA, 2013a), energy statistics from the International Energy Agency (IEA, 2012) and a reversed calculation sequence. The approach has previously been partly documented in (Connolly et al., 2014; Connolly et al., 2013; Connolly et al., 2012), as well as in (Persson, 2015), and with full detail in (Persson et al., 2014). The most significant steps in this methodology can be summoned according to the following key bullets:

- Retrieve geographical coordinates and annual carbon dioxide emissions on facility level from the E-PRTR dataset
- Establish characteristic carbon dioxide emission factors, per Member State and per main activity sector, by use of IEA energy statistics on fuel use and standard carbon dioxide emission factors (See Appendix, Table 6 and Table 5, respectively)
- Calculate primary energy supply on facility level based on annual carbon dioxide emissions and characteristic carbon dioxide emission factors
- Apply default recovery efficiencies (see Table 1) to calculated primary energy supplies to assess theoretically available annual excess heat volumes on facility level

The excess heat activities considered in this report includes large scale (> 50 MW) thermal power generation (TP) fuel combustion plants, fuel supply and refineries (FSR), and industrial facilities within six significant energy-intensive industrial sectors; chemical and petrochemical (CPC), iron and steel (IS), non-ferrous metals (N-FM), non-metallic minerals (N-MM), paper, pulp and printing (PPP), and the food and beverage sector (FB). The report also considers Waste-to-Energy (WTE) facilities, although annual excess heat volumes available from European waste incineration plants are calculated by an alternative approach. By performing a separate and dedicated study on the European WTE sector, annual capacity data from 410 facilities was gathered from several complementary sources (CEWEP, 2014; IndustryAbout, 2014; ISWA, 2012). For this sector, annual excess heat volumes are therefore assessed based on found capacities, a default recovery efficiency of 60%, and an anticipated average energy content of waste at 10.3 MJ/kg from European waste incineration (CEWEP, 2013). Considered main activity sectors and corresponding default recovery efficiencies are detailed in Table 1.

Table 1. Main activity sector category labels and corresponding default recovery efficiencies (η_{heat}). Default values set to reflect the maximal excess heat recovery potential from considered main activity sectors at current conditions

Main activity sector category	Abbreviation	η_{heat}
Thermal Power – Main Activity	TP-MA	50%
Thermal Power – Auto-producer	TP-AP	60%
Thermal Power – Waste-to-Energy	TP-WTE	60%
Fuel supply and refineries[a]	FSR	50%
Chemical and petrochemical[b]	CPC	25%
Iron and steel[c]	IS	25%
Non-ferrous metals	N-FM	25%
Non-metallic minerals[d]	N-MM	25%
Paper, pulp and printing	PPP	25%
Food and beverage[e]	FB	10%

[a] *Not including NACE main economic activities: Extraction of crude petroleum, Extraction of natural gas.*

[b] *Not including NACE main economic activities: Extraction of salt, Growing of citrus fruits.*

[c] *Not including NACE main economic activities: Mining of iron ores, Other mining and quarrying n.e.c.*

[d] *Not including Annex I activities: Opencast mining and quarrying, Underground mining and related operations, and NACE main economic activity; Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate.*

[e] *Including NACE main economic activities; Manufacture of oil and fats, Manufacture of starches and starch products, Manufacture of sugar, and Manufacture of other organic basic chemicals.*

Fuel input to thermal power generation in both power-only and cogeneration facilities are compiled with respect to main activity (MA) and autoproducer (AP) facilities. By excluding nuclear energy in the assessment, which is motivated partly since there is a generally weak interest for recovery of nuclear excess heat today, an additional excess heat volume of approximately 6.7 EJ rejected from European nuclear facilities (operating at average total conversion efficiencies of 33%) is neglected here. According to (IEA, 2012), only 5.0 PJ, from a total primary energy supply of 10.0 EJ, was recovered as usable heat during the year 2010, which reflects very low utilisation levels at current. Additionally, several other plausible sources for excess heat recovery, such as sewages, exhaust air ventilation shafts, and server stations, are omitted in this assessment focusing on energy and industry sectors. See for example (Ebrahimi et al., 2014, 2015) for investigations on the use of excess heat from server stations, and (CEC, 1982; McKenna and Norman, 2010; Morandin et al., 2014; Persson and Werner, 2012; Rattner and Garimella, 2011; Swithenbank et al., 2013) for some general references on excess heat recovery from energy and industry sector activities in district heating systems.

The total annual carbon dioxide emission volume from considered excess heat activities amounts to 2.02 billion metric tonnes (see Table 2), which by validation (comparison to corresponding main activity sectors greenhouse gas emissions sent by countries to the UNFCCC (EEA, 2013c) and to verified 2010 EU ETS data reported through the Community Independent Transaction Log (CITL) (EEA, 2013b)), proved reasonable. Although not fully compatible, since UNFCCC main activity sector data includes all sub-sectors and EU ETS data includes combustion installations with rated thermal inputs > 20 MW, both sources indicate European carbon dioxide emission volumes of about 2.2 billion tons from stationary combustion in given sectors for 2010.

All gathered data, carbon dioxide emissions, energy statistics, and geographical coordinates, are assembled in a relational database to allow systematic calculations, where after spatial representation of each considered facility and the creation of continental and national maps are managed and performed within the ArcMap 10.1 GIS interface (ESRI, 2014). In this Background Report, these maps are withheld at a continental scale, while national maps for five Stratego countries are presented in the Country Reports.

3 Data

The E-PRTR dataset includes annual facility reports on land, water, and air emissions, and is publicly available through the European Environmental Agency (EEA). In this data compilation, general, sectorial, and quantitative (emissions) information on European energy and industry sector facilities are stored together with e.g. geographical coordinates, which enables spatial determination of each emitting site. For the purpose in this report, study facilities were retrieved from the dataset by structured query language (SQL) selection on carbon dioxide emissions to air and mainly for the year 2010. Since Croatia, the 28th European Union Member State since July 1, 2013, is not included in the used version of the E-PRTR dataset, corresponding information on carbon dioxide emissions from Croatian energy and industry sector activities were gathered mainly from the European Union Transaction Log (EC, 2014) and from some national reports on fuel use. As detailed in Table 2, the assessments in this report are hereby based on carbon dioxide emissions from 2712 facilities in all.

Table 2. Count of energy and industry sector facilities extracted from the E-EPRTR dataset and additional sources, with reported annual carbon dioxide emissions aggregated to national level, mainly for 2010

Member State	Count of facilities [n]	CO_2 [Mt]	Count of TP facilities	Count of WTE facilities	Count of Industrial facilities
AT	59	33	22	10	27
BE	97	55	28	16	53
BG	34	33	20	-	14
CY	5	5	3	-	2
CZ	76	73	45	3	28
DE	485	497	175	84	226
DK	55	22	17	30	8
EE	9	14	7	-	2
EL	39	61	22	-	17
ES	230	120	99	10	121
FI	89	61	52	3	34
FR	333	119	57	126	150
HR	57	9	10	-	47
HU	42	22	24	2	16
IE	21	16	13	1	7
IT	311	196	130	52	129
LT	8	6	5	-	3
LU	7	2	1	1	5
LV	3	1	1	-	2
MT	2	2	2	-	-
NL	99	90	42	13	44
PL	155	195	94	1	60
PT	40	28	14	2	24
RO	68	48	33	-	35
SE	123	51	41	28	54
SI	8	7	3	1	4
SK	32	21	14	1	17
UK	225	236	106	26	93
EU28 Total	**2712**	**2024**	**1080**	**410**	**1222**

Excess heat activities in industrial sectors dominate the selection and are present in all Member states, with the exception of the Republic of Malta (MT) if considering WTE facilities as a special branch of thermal power generation. Nineteen Member States currently have waste incineration plants in operation, while dedicated thermal power generation plants are present in all Member States.

4 Results

In this section, the results from the performed assessments are presented in a main result map and two tables, considering all main activity sectors for EU28 (in the Appendix, see Figure 2, Figure 3, and Figure 4, divisional maps detailing energy sector, waste incineration, and industrial sectors facilities respectively, are also available). The main result map, Figure 1, depicts the geographical locations of all considered activities from all main activity sectors, as well as anticipated annual excess heat volumes on facility level by use of a scaled legend. A general observation form this map is that excess heat activities are widely distributed over the European continent today, albeit both highly concentrated clusters as well as vacancy areas are visible.

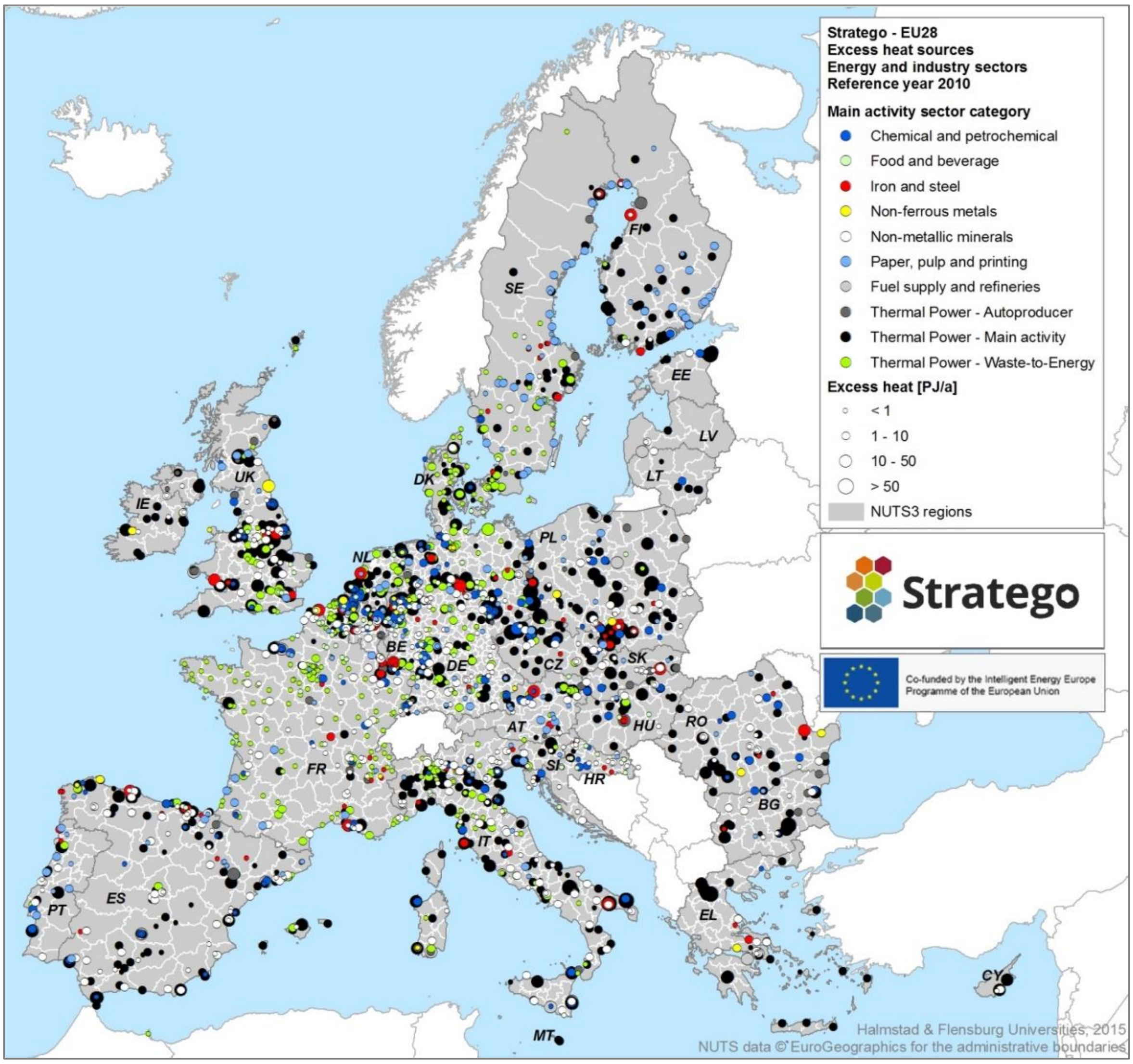


Figure 1. EU28 excess heat facilities by main activity sectors and assessed annual excess heat volumes. Thermal power generation activities > 50 MW. Sources: (CEWEP, 2014; EEA, 2013a; IndustryAbout, 2014; ISWA, 2012).

Persson et. al. (2014) concluded, when performing spatial analysis on regional level to determine the geographical correlation between European excess heat sources (same data source used) and high heat demand density locations (to identify heat synergy regions), that a majority of current excess heat facilities are located inside, or in close vicinity of, large urban zones and major city areas. From a heat recovery and heat distribution perspective, district heating systems being principally local energy infrastructures, this key circumstance suggest general viability of many future heat synergy projects.

As presented in Table 3, a total primary energy supply of 26.2 EJ is anticipated to have been used in the 2712 considered facilities, which, given applied default recovery efficiency values, correspond to a total excess heat volume of approximately 11.3 EJ for the year 2010. Comparison to corresponding main activity sectors primary energy volumes reported by the International Energy Agency (IEA, 2012), amounting to 24.8 EJ in the same year (not including Croatia), indicate a plausible 5% overestimation by the performed reversed calculation sequence. However, given the continental analytical scope withheld and default recovery efficiency values set principally to reflect highest possible recovery levels, this minor deviance is considered negligible. Other possible deviances in the results may be due to inclusion of large-scale thermal activities (> 50 MW) and fuel combustion activities in industrial sectors only. Given the presence of excess heat also from smaller boilers, as well as from industrial exothermic chemical processes, these estimates are considered conservative.

Table 3. Primary energy supply (PES), and excess heat (EH) by EU28 Member State as assessed by the reversed calculation sequence. Excess heat specified by sectors: Thermal power (TP), Waste-to-Energy (WTE), and Industrial (Ind)

Member State	**PES [PJ]**	**EH [PJ]**	***TP [PJ]***	***WTE [PJ]***	***Ind [PJ]***
AT	456	167	*63*	*21*	*84*
BE	805	313	*157*	*17*	*138*
BG	382	180	*161*	-	*19*
CY	66	29	*26*	-	*3*
CZ	812	353	*288*	*5*	*61*
DE	6119	2707	*1980*	*161*	*566*
DK	285	139	*103*	*23*	*12*
EE	153	74	*71*	-	*3*
EL	733	335	*277*	-	*59*
ES	1704	705	*458*	*15*	*233*
FI	685	275	*181*	*2*	*92*
FR	1712	645	*236*	*90*	*319*
HR	125	42	*23*	-	*19*
HU	306	136	*106*	*3*	*27*
IE	227	102	*88*	*1*	*13*
IT	2839	1263	*879*	*43*	*341*
LT	100	42	*21*	-	*21*
LU	35	13	*8*	*1*	*4*
LV	13	4	*2*	-	*2*
MT	25	13	*13*	-	-
NL	1348	583	*366*	*46*	*171*
PL	2171	975	*809*	*0*	*165*
PT	373	147	*76*	*10*	*61*
RO	613	252	*177*	-	*75*
SE	594	217	*82*	*30*	*106*
SI	81	37	*34*	*0*	*3*
SK	258	90	*41*	*1*	*48*
UK	3229	1477	*1140*	*40*	*297*
EU28 Total	**26248**	**11316**	***7865***	***508***	***2943***

As is also visible in Table 3, excess heat from thermal power generation is, at current, by far the richest source to exploit for future heat synergy collaboration, and approximately 70% of all available excess heat originates in main activity and autoproducer power plants. Corresponding relative shares for WTE incineration and industrial excess heat out of total volumes are 4% and 26% respectively. Seven Member States (Germany (23%), Spain (6%), France (7%), Italy (11%), the Netherlands (5%), Poland (8%), and the United Kingdom (12%)) account for a major share of the total primary energy supply (~72%), which is correspondingly reflected in anticipated excess heat availabilities.

From a sectorial perspective, i.e. by main activity sectors, as presented in Table 4, it is clear that main activity thermal power generation plants account for a majority of both total excess heat volumes (68%) as well as thermal power generation main activity sector volumes (91%). Among industrial main activity sectors, fuel supply and refineries (however depicted together with energy sector facilities in Figure 2) represent highest annual excess heat availabilities (9% of the total excess heat volume and 36% of total industrial sectors volumes), while Non-metallic minerals facilities account for 5% of the total excess heat volume and 20% of total industrial sectors volumes.

Table 4. Total count of facilities, annual carbon dioxide emissions, primary energy supply (PES), and excess heat (EH) by main activity sector as assessed by the reversed calculation sequence

Main activity sector	Count of facilities [n]	CO_2 [Mt]	PES [PJ]	EH [PJ]
Chemical and petrochemical	242	123	1868	467
Food and beverage	59	9	145	14
Fuel supply and refineries	116	155	2118	1059
Iron and steel	144	166	2101	525
Non-ferrous metals	35	13	204	51
Non-metallic minerals	454	173	2398	600
Paper, pulp and printing	172	79	908	227
Thermal Power Generation - AP	82	28	354	212
Thermal Power Generation - MA	998	1257	15305	7653
Thermal Power Generation - WTE	410	21	847	508
EU28 Total	**2712**	**2024**	**26248**	**11316**

5 Conclusions

The major conclusions from these Stratego estimations to quantify the excess heat sources available for district heating systems are that:

1. Publicly available carbon dioxide emission data on facility level (e.g. from the European Pollutant Release and Transfer Register (E-PRTR)) may be used in combination with energy statistics and a reversed calculation sequence to assess annual volumes of rejected excess heat from fuel combustion processes in European energy and industry sector facilities

2. Default recovery efficiencies, set here to reveal maximal volumes of rejected secondary heat, may in local heat synergy projects be altered, reduced, and used to characterise viable and realistic excess heat recovery levels

3. For the local projects within Stratego, as well as for local heat synergy collaboration in general, it is recommended to retrieve actual and detailed data on energy and thermo-dynamical properties (temperature levels, state-of-matter etc.) of excess heat to be recovered from considered activities

4. Local heat synergy projects should address also organisational aspects such as collaboration agreements, where mutually beneficial allocation of synergy benefits to all involved parties is a key priority

5. Approximately 26.2 EJ of primary energy was supplied to 2712 considered energy and industry sector facilities in EU28 during the year 2010. A total excess heat volume of 11.3 EJ is anticipated to have been rejected from these activities during this year

6. Excess heat activities in industrial sectors dominate the selection in terms of number of facilities, while main activity thermal power generation plants constitute the major share of annual excess heat volumes. Nineteen EU28 Member States currently have waste incineration plants in operation

7. Seven Member States (Germany, Spain, France, Italy, the Netherlands, Poland, and the United Kingdom) account for 72% of the total primary energy supply, which is correspondingly reflected in anticipated excess heat availabilities.

References

CEC, 1982. Energy - Waste heat from industry for district heating, EUR 8116, Directorate-General Energy, Commission of the European Communities. Luxembourg.

CEWEP, 2013. CEWEP Energy Report III (Status 2007-2010): Results of Specific Data for Energy, R1 Plant Efficiency Factor and NCV of 314 European Waste-to-Energy (WtE) Plants. December 2012, Confederation of European Waste-to-Energy Plants. Würzburg/Brussels.

CEWEP, 2014. Country Reports: 2010 Country Report on Waste Management, Confederation of European Waste-to-Energy Plants. Available at: (http://www.cewep.eu/information/data/subdir/442._Country_Report_on_Waste_Management.html).

Connolly, D., Lund, H., Mathiesen, B.V., Werner, S., Möller, B., Persson, U., Boermans, T., Trier, D., Østergaard, P.A., Nielsen, S., 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. Energy Policy 65, 475-489.

Connolly, D., Vad Mathiesen, B., Alberg Östergaard, P., Möller, B., Nielsen, S., Lund, H., Persson, U., Werner, S., Grözinger, J., Boermans, T., Bosquet, M., Trier, D., 2013. Heat Roadmap Europe 2050 - Second pre-study for EU27. Euroheat & Power, Brussels. Available at: (http://www.euroheat.org/Heat-Roadmap-Europe-165.aspx).

Connolly, D., Vad Mathiesen, B., Alberg Östergaard, P., Möller, B., Nielsen, S., Lund, H., Persson, U., Werner, S., Nilsson, D., Trier, D., 2012. Heat Roadmap Europe 2050 - First pre-study for EU27. Euroheat & Power, Brussels. Available at: (http://www.euroheat.org/Heat-Roadmap-Europe-165.aspx).

Ebrahimi, K., Jones, G.F., Fleischer, A.S., 2014. A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities. Renewable and Sustainable Energy Reviews 31, 622-638.

Ebrahimi, K., Jones, G.F., Fleischer, A.S., 2015. Thermo-economic analysis of steady state waste heat recovery in data centers using absorption refrigeration. Applied Energy 139, 384-397.

EC, 2014. Climate Action: European Union Transaction Log. Overall ETS Period information. Second Commitment Period 2013, Croatia. European Commission, Brussels. Available at (2015-01-15): (http://ec.europa.eu/environment/ets/welcome.do?languageCode=en).

EEA, 2013a. The European Pollutant Release and Transfer Register (E-PRTR). Downloaded data category (2013-07-08): eprtr_v4.2_mdb.zip. European Environment Agency. Available at: (http://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-5).

EEA, 2013b. European Union Emissions Trading System (EU ETS) data from CITL. Downloaded data category (2013-02-27): CITL_v11_csv.zip. European Environment Agency. Available at: (http://www.eea.europa.eu/data-and-maps/data/european-union-emissions-trading-scheme-eu-ets-data-from-citl-5).

EEA, 2013c. National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Downloaded data category (2013-07-08): UNFCCC_v14_mdb.zip. European Environment Agency. Available at: (http://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-7).

ESRI, 2014. Understanding our world, Environmental Systems Research Institute Inc. Available at: (http://www.esri.com/).

HRE, 2014. Heat Roadmap Europe - A low-carbon heating and cooling strategy for Europe, Web page available at (2014-10-29): (http://www.heatroadmap.eu/).

IEA, 2012. Energy Balances of OECD and Non-OECD Countries for 2010 (2012 Edition). Summary Energy Balances. International Energy Agency, Paris.

IndustryAbout, 2014. IndustryAbout: World industrial information, Available at: (http://industryabout.com/).

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. Published: IGES, Japan.

ISWA, 2012. Waste-to-Energy: State-of-the-Art-Report, Statistics, 6th Edition, August 2012., International Solid Waste Association.

McKenna, R.C., Norman, J.B., 2010. Spatial modelling of industrial heat loads and recovery potentials in the UK. Energy Policy 38, 5878-5891.

Morandin, M., Hackl, R., Harvey, S., 2014. Economic feasibility of district heating delivery from industrial excess heat: A case study of a Swedish petrochemical cluster. Energy 65, 209-220.

Persson, U., 2015. District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions, Dissertation Thesis. Series Nr: 3769. Energy and Environment. Chalmers University of Technology, Göteborg.

Persson, U., Möller, B., Werner, S., 2014. Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74, 663-681.

Persson, U., Werner, S., 2012. District heating in sequential energy supply. Applied Energy 95, 123-131.

Rattner, A.S., Garimella, S., 2011. Energy harvesting, reuse and upgrade to reduce primary energy usage in the USA. Energy 36, 6172-6183.

Swithenbank, J., Finney, K.N., Chen, Q., Yang, Y.B., Nolan, A., Sharifi, V.N., 2013. Waste heat usage. Appl. Therm. Eng. 60, 430-440.

Appendix

Table 5. Standard carbon dioxide emission factors from stationary combustion, by fuel type. Source: (IPCC, 2006)

Fuel type	Standard carbon dioxide emission factors (sf_{CO2}) [g,CO_2/MJ]
Coal and coal products	94.6
Peat	106.0
Crude, NGL and feedstock	73.3
Oil products	74.1
Natural gas	56.1
Biofuels	101.2[a]

[a] Average value of standard carbon dioxide emission factors for fuel categories "Municipal wastes (non-biomass fraction)": 91.7, "Municipal wastes (biomass fraction)": 100.0, and "Wood - wood wastes": 112.0.

Table 6. Characteristic EU28 Member State carbon dioxide emission factors by main activity sector. Weighted mean average values based on standard carbon dioxide emission factors and national compositions of fuel use. Sources: (IEA, 2012; IPCC, 2006)

	Characteristic carbon dioxide emission factors (f_{CO2}) [g,CO_2/MJ]									
Member State	**TP-MA**	**TP-AP**	**TP-WTE[a]**	**FSR**	**CPC**	**IS**	**N-FM**	**N-MM**	**PPP**	**FB**
AT	77.3	82.8	-	73.3	72.2	73.0	58.2	79.6	80.6	60.9
BE	71.2	77.1	-	73.3	56.4	70.5	57.6	82.9	90.5	60.9
BG	90.5	61.9	-	73.3	70.4	68.1	77.6	72.9	90.4	63.8
CZ	93.8	93.0	-	73.3	85.3	84.8	59.6	70.6	89.4	61.0
CY	74.1	76.1	-	na[b]	na	na	na	79.2	na	na
DK	85.9	91.1	-	73.3	58.7	58.0	56.1	75.3	82.0	65.1
EE	94.1	84.9	-	na	61.3	56.1	68.9	86.3	65.0	63.1
FI	90.2	90.3	-	73.3	73.7	84.7	79.3	80.4	94.1	77.8
FR	73.7	86.7	-	73.3	71.6	83.4	64.2	67.3	75.4	67.0
DE	89.3	79.1	-	73.3	65.5	77.8	59.9	75.4	72.6	63.0
EL	85.5	69.8	-	73.3	68.7	57.2	78.6	77.1	65.7	85.3
HR	75.0	64.4	-	73.3	56.7	61.5	73.6	76.6	63.9	63.2
HU	76.1	72.5	-	73.3	56.5	88.5	56.1	73.9	61.6	62.4
IE	70.7	61.2	-	73.3	67.5	74.1	65.7	83.6	69.2	74.0
IT	71.0	64.9	-	73.3	58.2	77.1	58.3	66.7	57.3	58.8
LT	59.7	68.2	-	73.3	57.8	73.4	na	87.1	60.5	59.7
LU	59.2	101.2	-	na	62.3	59.2	na	75.3	56.1	64.6
LV	58.1	71.1	-	na	67.9	60.5	56.1	84.5	83.5	65.8
MT	74.1	na	-	na	na	na	na	na	na	na
NL	70.0	77.1	-	73.3	65.5	80.0	56.1	59.1	56.6	57.5
PL	93.8	89.7	-	73.3	85.4	79.6	76.8	77.3	91.6	77.3
PT	76.0	70.3	-	73.3	70.6	61.6	78.6	76.7	96.7	78.2
RO	83.5	85.0	-	73.3	62.9	76.1	na	68.6	58.4	62.8
SK	81.9	94.3	-	73.3	64.9	87.4	59.1	72.8	90.9	56.5
SI	92.3	85.1	-	na	65.8	59.6	62.7	67.6	66.8	61.9
ES	71.3	65.6	-	73.3	62.5	77.7	64.3	68.6	77.0	73.1
SE	92.9	99.1	-	73.3	66.0	86.4	82.2	81.7	99.2	68.9
UK	75.3	79.1	-	73.3	57.9	81.1	60.7	70.0	59.0	58.6
EU28 Total	**81.8**	**77.7**	**-**	**73.3[c]**	**66.5**	**79.0**	**64.6**	**72.2**	**83.3**	**65.2**

[a] Characteristic carbon dioxide emission factors not established for TP-WTE. Separate analysis and data used for this main activity sector.
[b] Notation "na" for "no activity", indicating zero reported volumes of fuel use in respective main activity sector in (IEA, 2012).
[c] Standard carbon dioxide emission factor of 73.3 g,CO_2/MJ for crude, NGL, and feedstock used for main activity sector FSR in all Member States where activity is present, according to (IEA, 2012).

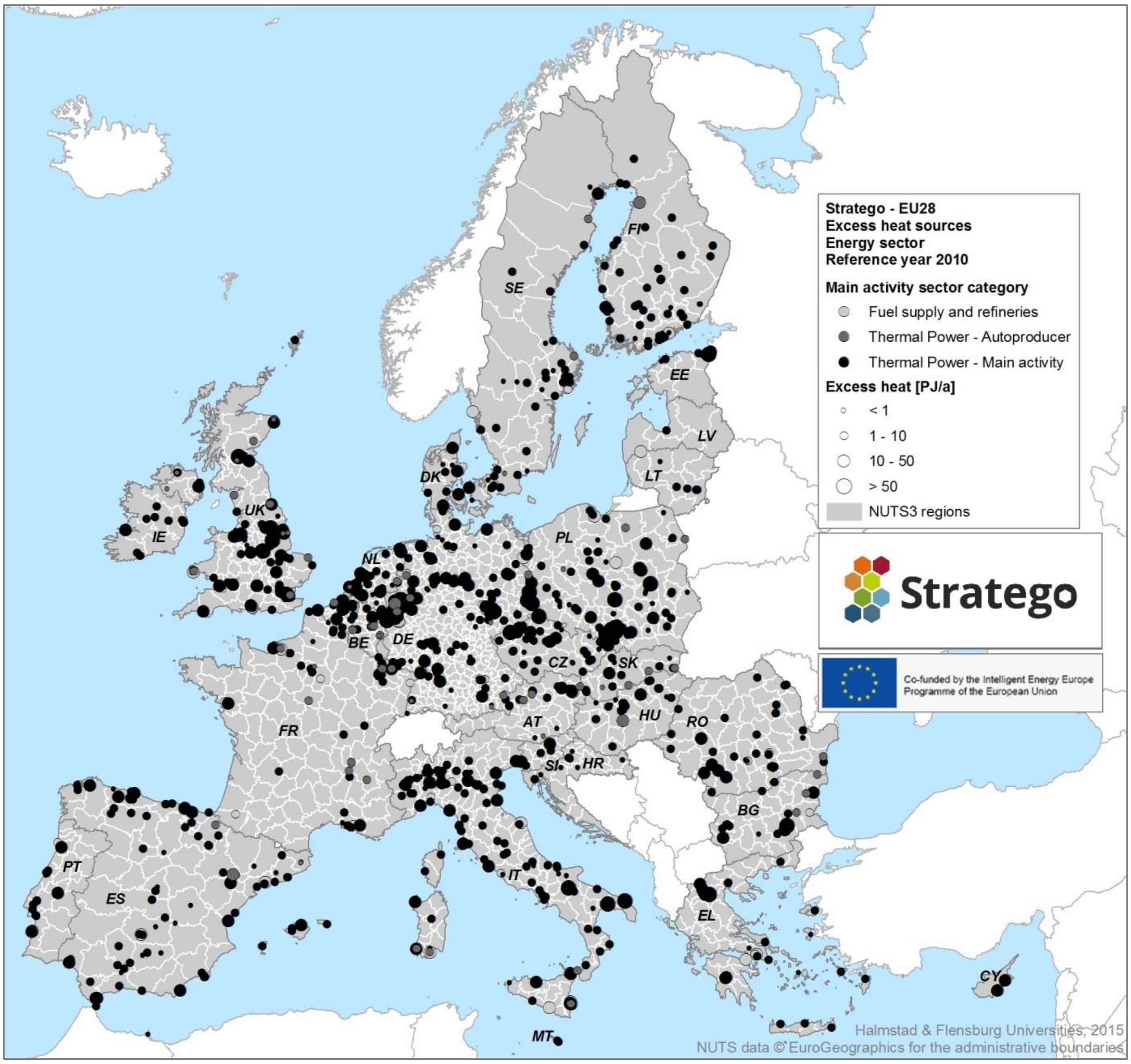


Figure 2. EU28 energy sector excess heat facilities by main activity sectors and assessed annual excess heat volumes. Thermal power generation activities > 50 MW.

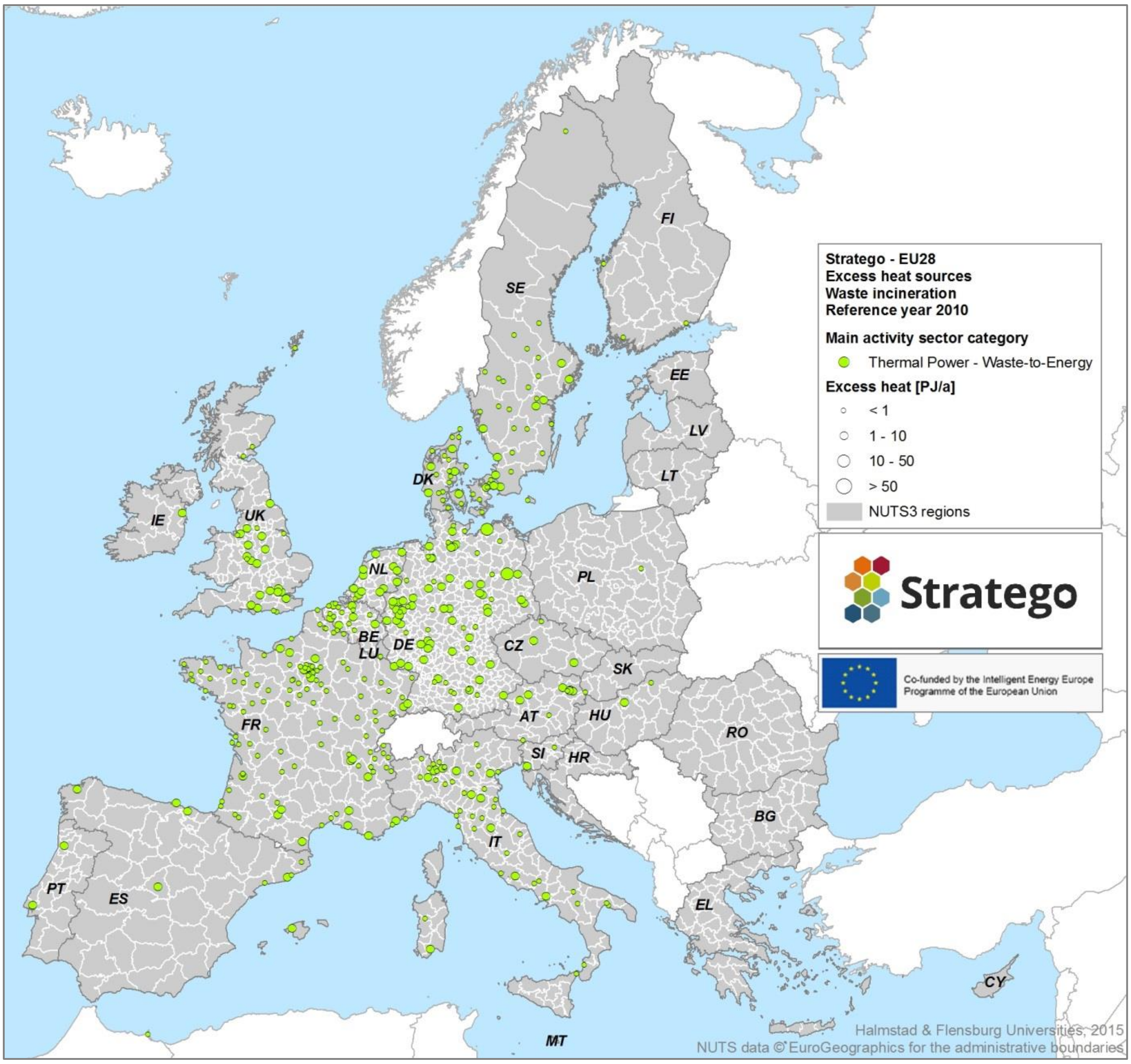


Figure 3. EU28 waste incineration excess heat facilities by main activity sector and assessed annual excess heat volumes.

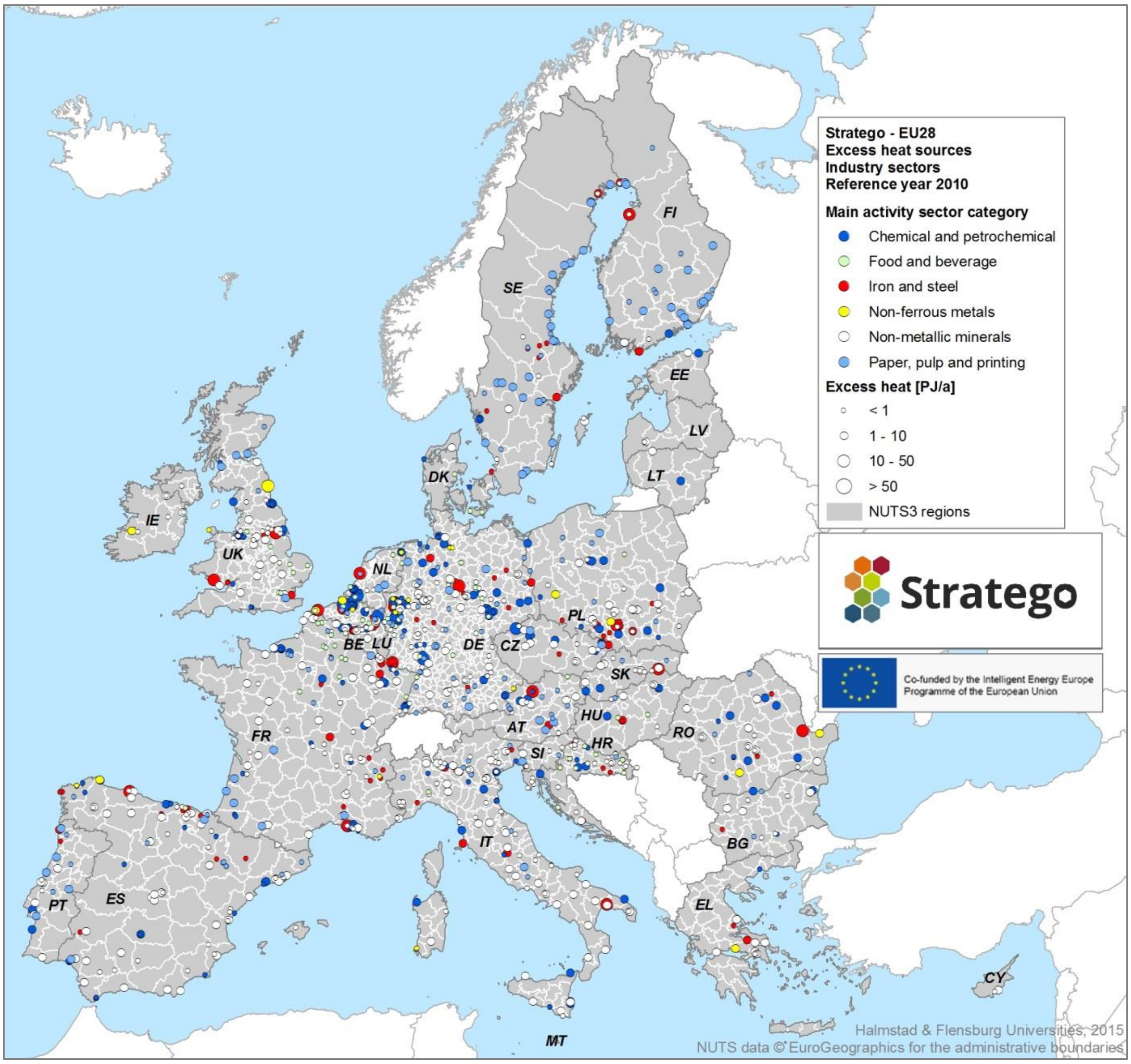


Figure 4. EU28 industry sectors excess heat facilities by main activity sectors and assessed annual excess heat volumes.

Stratego | ENHANCED HEATING & COOLING PLANS

PlanEnergi

Subcontract report for the STRATEGO-project

Estimating the Renewable Energy Resources Available in EU Member States

December 2014

NORTH JUTLAND
Jyllandsgade 1
DK–9520 Skørping
Tel. +45 9682 0400
Fax +45 9839 2498

CENTRAL JUTLAND
Vestergade 48 H, 2nd floor
DK–8000 Aarhus C
Tel. +45 9682 0400
Fax +45 8613 6306

ZEALAND
Postal address:
A.C. Meyers Vaenge 15
DK - 2450 København SV
Visitors address:
Frederikskaj 10 A, 1st fl, 1.143
DK -2450 Copenhagen SV
Tel.: +45 2224 2562

www.planenergi.dk
planenergi@planenergi.dk
VAT no.: DK7403 8212

Table of contents

Contact person at PlanEnergi:
Daniel Trier
Tel.: +45 9682 0400
e-mail: dt@planenergi.dk

Quality assurance
LLJ/DMS

1 Introduction

The purpose of the project "Multi level actions for enhanced Heating and Cooling plans – STRATEGO" is to bridge the gap between EU policy, national objectives and effective actions taken at regional and local levels. The STRATEGO project is a European co-funding project developed in the framework of the Intelligent Energy Europe Programme, having the contract no. IEE/13/650/SI2.675851. This report is the outcome of the subcontract under the second work package (WP2) in STRATEGO, "Supporting the development of enhanced NHCPs" in which PlanEnergi has been appointed to estimate the renewable heat and electricity potentials in 5 targeted EU member states.

WP2 in the STRATEGO-project specifies a need for identifying national energy data on the potentials of renewable energy, within Croatia, Czech Republic, Italy, Romania, and the UK. This information is compiled in the present report, *Renewable Electricity and Heat Potentials*.

The authors wish to thank those national contact-points, who have been kind enough to supply data during the process of estimating the potentials for renewable energy in the five target countries.

2 Methodology

No other comprehensive dataset on the potentials for RE heat and electricity has been identified for the countries in this study; hence, the compiled information is based on data from many different references. Consequently, discrepancies have been identified among the different references, when there have been mismatches between numbers. In these cases, the most probable number has been selected, while alternative numbers have been kept as secondary options. This methodology has been chosen, in order to accommodate for the sometimes very large differences between numbers. In the tables under each country is a version with the given energy-data – numbers in capacity [MW] and production [TWh]. A similar table describes the references in [square brackets], including the alternative numbers found. Where there has only been identified a single reference, this is indicated by a single bracketed number in the corresponding cell in the reference-table.

Some national partners in the STRATEGO-project have provided input to the data upon request. These data have been useful, since documentation on the national languages has often proven to be more detailed and plentiful than the more readily available English-language reports used in the screening.

2.1 Numbers and decimals

It is the intention to provide detailed and specific data with this report. Nonetheless, it has not always been possible to obtain precise numbers on all data points. Consequently, numbers without decimals in this report should be interpreted as approximate, while numbers with decimals can be considered more precise. While two decimals have been applied as a standard, it has been chosen to deviate from this rule, in cases where the original reference has only one decimal.

2.2 A note on a particular reference: Atlas of EU biomass potentials

A significant reference used as a supplement to the national sources when finding the future biomass potentials is "Atlas of EU biomass potentials - Spatially detailed and quantified overview of EU biomass potential taking into account the main criteria determining biomass availability from different sources". Will hereafter be referred to as *Biomass Atlas*. It has been deemed relevant to describe this resource in further detail below, since its numbers and assumptions in some occasions is found to vary significantly from other sources. The information in this section is largely based on contents of the Biomass Atlas.

One purpose of the Biomass Atlas is to identify different biomass feedstocks and make an inventory of data to quantify and map the technically constrained biomass potentials. This also includes estimates of alternative uses of by-products and waste in order to estimate the share that is available for bioenergy purposes and the share that competes with other uses. From this, the 2020 and 2030 potentials are quantified in the report according to different scenarios.

The Biomass Atlas uses three main categories for biomass; Biomass from agriculture, Biomass from forestry and Biomass from waste. Under each of these categories, there is a range of subcategories of dedicated biomass production such as biofuel crops, woody and grassy crops, stem wood production and by-products and waste categorized in primary, secondary and tertiary levels. In the data for the STRATEGO project the following categories for biomass is used: Energy crops (residual), Energy crops (dedicated land), Wood, Waste (renewable and fossil) and Biogas. From the national sources used under each country, it has been difficult to find these exact categories, and many numbers are therefore sums from other categories found in the used sources. The numbers from the Biomass Atlas are therefore presented as a separate table in order to compare the found numbers from the national sources (when available) and in order to have a uniform approach to find the numbers under each category.

When estimating the future potential it should at first be realised that the EU policy ambitions go far beyond current consumption of renewable energy. From the report it is stated that the European Commission (2008) calculated that 17.5 million hectares of land would be required to reach the 10 % biofuels target, which would amount to about 10 % of the total Utilised Agricultural Area (UAA) in EU27[*]. The report further states,

"It is clear that the pressure on land will increase strongly under a growing biomass demand. This may cause adverse effects on biodiversity as it may lead to the further intensification of existing land uses, both in agricultural and forest lands, but also the conversion of non-cropped biodiversity-rich land into cropped or forest area. The conversion of biodiversity rich grasslands for example is meant to be prevented with the sustainability scheme for biofuels to be introduced together with the approval of the biofuels target of 10 %. The RES directive states that biofuels shall not be made from raw material obtained from land with recognized high biodiversity value, such as undisturbed forest, areas designated for nature protection purposes or highly biodiverse grasslands. However, the big question is how this land resource is exactly defined and identified (e.g. mapped) and whether not being accountable to the renewable energy target provides enough protection to valuable ecosystems in markets offering very high prices to biomass feedstock.

In addition, there is also an increasing resistance against using existing arable land for the production of biomass at the expense of food and feed production. There are indications that this will endanger the food security situation, especially in third world countries, and that indirect land use changes may take place by bioenergy production pushing food and feed production into uncultivated areas causing loss of valuable natural habitats (e.g. tropical rain forest and savannah) and tremendous releases of greenhouse gas (GHG) stocks in the soil."

---

[*] Their starting point was that 50 % of the production would come from cultivation of rotational biomass crops for 1st generation technology biofuels. The other 50 % would come from ligno-cellulosic by-products and perennial biomass crops or imports from outside the EU. For conversion of this ligno-biomass feedstock they assumed 2nd generation biofuel technology to become commercially available before 2020.

The estimations of biomass potential in the Biomass Atlas are made for different scenario situations taking into account different sustainability criteria. Two scenarios are applied for 2020 and 2030:

1. Reference scenario
2. Sustainable scenario

The sustainability criteria are applied in the reference storyline following the 'Directive on the promotion of energies from renewable sources'[†] and therefore only apply to biofuels and bioliquids. The potentials used in the datasheet are from the sustainable scenario from 2020. The potential is in both scenarios based on three main themes:

1. **Estimating the land potential for bioenergy cropping and for agro-waste potentials**
   The results are based on the CAPRI[‡] model, which predicts future land use changes in the EU-27 related to agricultural production including those for domestic biofuels. The CAPRI model's 2020 baseline runs with the EC report 'Prospects for Agricultural Markets and Income in the EU 2010-2020. This outlook takes into account the most recent Health Check reform, the 2020 RES targets and the most recent OECD-FAO projections on agricultural prices, population and development.

   In order to reach the EU 2020 targets, the mix of biofuel feedstock will change. A priority is given to the most sustainable crop mix per region, taking into account the mitigation requirements set in both the reference and sustainability scenario. The estimation of the mitigation requirement is described in the next step.

2. **Estimating the minimum GHG mitigation requirement per scenario for bioenergy cropping potential**
   First, in the reference scenario a minimal GHG mitigation requirement for biofuel of 50 % is assumed. A much stricter mitigation is assumed in the sustainable scenario as it should include the indirect land use change impacts of biofuels (iLUC) related emissions. The GHG mitigation is assumed to reach 70 % in 2020 and 80 % in 2030, which both applies on biofuels and on cropped biomass for heat and electricity production.

   The estimation of the minimal GHG requirement is built on the approach developed by EEA/ETC-SIA[§] study. An estimate of GHG payback and mitigation ability is made for all crops, including the iLUC effect and taking into account the type of feedstock and related bioenergy delivery pathway.

3. **Excluding high biodiverse land and land with high carbon stock**
   In the reference scenario biofuel crops cannot be cropped on highly biodiverse areas or area with high carbon stock. In the sustainable scenario this applies to all cropped biomass. The land available for biomass cropping is therefore reduced compared to the reference scenario. Both the Natura

---

[†] Directive 2009/28/EC - RES Directive

[‡] The CAPRI (Common Agricultural Policy Regionalised Impact) model is a tool for ex-ante impact assessment of agricultural and international trade policies with a focus on the European Union. It is an economic partial comparative static equilibrium model for agriculture. The core of the model consists of two interlinked modules: about 250 regional aggregate programming models covering the EU27, Norway and Western Balkans at the NUTS 2 level and a global spatial multi-commodity model for agricultural commodities. These together allow calculation of a wide range of economic and environmental indicators.

[§] EEA: European Environment Agency
ETC/SIA: The European Topic Centre for Spatial information and Analysis. ETC/SIA is supporting the European Environment Agency (EEA) in developing seamless European wide spatial reference data. ETC/SIA's main working area is the analysis of Land use and land cover.

2000** (farmland) and the HNV farmlands†† were regarded as highly biodiverse areas and agricultural areas with high carbon stock. These areas were therefore not taken into account in biomass cropping areas in the sustainable scenario.

In short, the stricter sustainability criteria in the Biomass Atlas lead to a lower cropping potential in 2020 and 2030.

3 Countries

3.1 Croatia

On the 1st of July 2013, Croatia became the 28th member of the EU after a decade of carrying out all the reforms needed to bring it into line with EU laws and standards.

The energy statistics carried out within EU are mostly focused on EU27, while Croatia is not included. This can explain the difficulties finding Croatian energy data, which were encountered during this study.

The energy plans made for Croatia is limited to forecasts for 2020 or 2030, so the available numbers for these years have been used, where available. Elsewhere data from The European Commission report 'EU Energy, Transport and GHG Emissions - Trends to 2050 - Reference Scenario 2013' has been used.

It was not possible to collect any data for the biomass potential in the future. It is therefore agreed that AAU will collect remaining data through local contacts in Croatia.

Full-load hours (FLH) and solar performance are presented in the tables below.

	Full-load hours			
Type	2,010.00	2,050.00	Difference	Difference [>100 % means larger than 2010]
Onshore Wind	1,564.67	3,666.67	2,101.99	234%
Offshore Wind	1,544.12	3,666.67	2,122.55	237%
Photovoltaic	840.91	1,523.10	682.19	181%
Concentrated Solar Power				
Direct Geothermal				
Wave				
Tidal				
Hydro				
River Hydro				
Hydro	4,439.47	5,306.91	867.43	120%
Hydro Pump Back (if applicable)				
Type				
Individual Solar Thermal				
Solar Thermal	728.79			
Geothermal	535.38			

Solar-check						
Given information			Calculated	ESTIF 2012 numbers		
Capacity MW	Production TWh	Area m2	Performance kWh/m2	Capacity	Area	Solar Radiation MWh/m2
83.70	0.06	119,600	510.03	84.00	120,000	1.15 to 1.65

Assumptions and crosscheck results are described in the following.

** Natura 2000 is a network of nature protection areas in the territory of the European Union. It comprises various types of protected areas, mainly Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), but it also includes Marine Protected Areas (MPAs) and some special forms defined on a national basis.

†† High Nature Value Farmland. By definition, in HNV farmland agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both.

Onshore/Offshore wind:
The accumulated wind capacity in [1] and [3] is 89 MW. From [4], the onshore/offshore distribution is given to be 3 % offshore, 97 % onshore, hence the results of 86 MW onshore and 3 MW offshore. Croatia has installed more wind capacity since 2010. According to [9], (from 2012), onshore wind power was 179.60 MW.

According to [1], the accumulated wind capacity in Croatia will be 1,079 MW in 2050. This is lower, than what is stated in the national plan for 2020 by [2] and in [HR5]: 1,200 MW in 2020 in total.

In [4], the onshore/offshore distribution is estimated to 71 % offshore, 29 % onshore. Therefore the results of 348 MW onshore and 852 MW offshore. The same method has been applied for the annual production shown in TWh.

From 2010 to 2050 there is seen an increase in FLH by more than 200 % for both onshore and offshore wind. The numbers are the same in the used references, so this can be explained due to technical development and higher share of offshore wind.

Photovoltaic:
The 2010 number from [1] states a capacity of 0 MW. Therefore, 2012 data from [7] has been used, which gives the following data: PV on grid = 3.9 MW and PV off grid = 0.5 MW, hence total = 4.4 MW. [7] has also been used for the production in 2010 with 2012 data.

For the capacity and generation from photovoltaics in 2050 [1] has been used for both numbers. For comparison, [HR4] states a number of 250 MW in year 2030. [HR1] states the technical potential to electricity generation from photovoltaics and solar thermal power plants to be around 33 TWh/year. The economic potential to produce solar electricity would amount to around 0.3 TWh/annum, which is the equivalent of around 200 MW of generating capacity.

The increase by 181 % in FLH may be due to technical development, since all used numbers are from [1].

Hydro:
The capacity in 2010 is from [1], whereas the production is from [HR2] and [2], given to be 8,309 GWh.

The capacity potential in 2050 is from [1]. In [1] the production potential is 8.74 TWh, but in [HR1] the technically exploitable water potential resources in Croatia are estimated at 12.45 TWh/year with a forecast for 2030 of 7.03 TWh (25.31 PJ).

An increase of 120 % in FLH can be explained by difference in use of source for 2010 and by technical development.

Individual solar thermal:
The numbers for individual solar thermal are in both 2010 and 2050 from [HR3]. For 2010, 2012 numbers are available with 0.5 PJ. In 2050 the potential in [HR3] is 12.21 PJ in 2030-numbers.

Solar thermal:
The capacity for 2010 is from [8] with 2012-data: 119,600 m^2 and 83.70 MW. The production in 2010 is taken from [HR2].

The potential for 2050 is from [HR1]. The technical potential to produce heat from solar collectors and the use of passive solar energy (solar architecture) amounts to 175 TWh/annum (630 PJ/year). The economic potential is stated to be 7 % of technical potential.

In the solar check, the performance is calculated to 510 kWh/m^2, which seems to be a reasonable number for the region, where the solar radiation is 1.15 to 1.65 MWh/m^2.

Geothermal:
The capacity is from [HR1] with 2007-data: Total installed heat capacity from supply of geothermal energy 2007 from space heating = 33.66 MW, from space heating and hot water preparation = 113.90 MW. From [HR1] the production in 2007 corresponded to 702.31 TJ = 0.2 TWh. In [HR2] the number is 0.08 TWh.

For the potential in 2050 [HR1] is used with 2030 forecast of 8.54 PJ.

Energy crops, residual:
In [HR1], the agricultural residue is given to be 22.93 PJ. AAU will find 2050-data through local contacts.

Energy crops, dedicated land:
In [HR4] and [HR2] a number for energy forests was given and used as 2010 data of 12.88 PJ. AAU will find 2050-data through local contacts.

Wood:
The number of 16 TWh in 2010 is given in [HR2]. From [HR1] the following numbers are listed, supporting the data:

- Cord wood = 24.33 PJ
- Wood residue = 8.65 PJ
- Abbaino = 2.01 PJ
- Wood industry residue = 17.89 PJ
- Roads, water management, etc. = 4.80 PJ
- Total = 57.68 PJ = 16.02 TWh

AAU will find 2050-data through local contacts.

Waste:
From [HR2] a production of 319 TJ is given. AAU will find 2050-data through local contacts.

Biogas:
The production of biogas in 2010 is in [HR2] = 298 TJ.

For the potential in 2050 data from [HR5] is used: Croatia sets up a goal by this Strategy of 20 % of total conditional cattle heads for energy purposes from agricultural production in 2020 and to produce around 2.6 PJ of energy from biogas, i.e. 100 million m^3 of biogas.

Total biomass:
The total biomass is the sum of the shown numbers. It is stated in [HR5] that Croatia defines a goal to use around 15 PJ of biomass for energy purposes in 2010, and 26 PJ in 2020. Part of this biomass shall be used in biomass-fired, preferably cogeneration, power plants with a collective electricity capacity of 85 MW in 2020.

3.1.1 Data on renewable electricity and heat potentials

Croatia: Renewable Energy Resources	

Renewable Energy Resources - HR						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	86.28	0.14		348.00	1.28	
Offshore Wind	2.72	0.00		852.00	3.12	
Photovoltaic	4.40	0.00		606.00	0.92	
Concentrated Solar Power	-	-		-	-	
Direct Geothermal	-	-		-	-	
Wave	-	-		-	-	
Tidal	-	-		-	-	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						
Hydro	1,900.00	8.44		2,346.00	12.45	
Hydro Pump Back (if applicable)						
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	n/a	0.14		n/a	3.39	
Solar Thermal	83.70	0.06		n/a	12.25	
Geothermal	147.56	0.08		n/a	2.37	

Bienergy (All High Priority)			
	2010	Potential (2050)	
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*	
Energy Crops: Residual	6.37		AAU collects through contact in Croatia
Energy Crops: Dedicated Land	3.58		AAU collects through contact in Croatia
Wood	16.02		AAU collects through contact in Croatia
Waste: Renewable & fossil	0.09		AAU collects through contact in Croatia
Biogas	0.08	0.72	
Total	26.14		

3.1.2 References

Croatia: Renewable Energy Resources	

Renewable Energy Resources - HR						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	[1]+[3] [4]: Onshore/off shore distribution 3% off shore, 97% onshore [9]: (2012-data) Wind power (On shore): 179,6 MW	[1]+[2] + [3]: 139 GWh in total [4]: Onshore/off shore distribution 3% off shore, 97% onshore [9]: (2012-data) Wind power: 0,329 TWh (total) [HR1]: Total wind production 2007 = 125,67 TJ		[1]: 1079 MW cumulated [2]: National plan 2020: 1200 MW in 2020 in total [4] Onshore/off shore distribution: Estimated 71% off shore, 29% onshore [HR5]: 2020: 1,200 MW	[1]: 2291 GWh in total [4] Onshore/off shore distribution: Estimated 71% off shore, 29% onshore [HR1]: Forecast 2030 = 15,84 PJ wind energy -> 4,4 TWh in total	
Offshore Wind	[1]+[3] [4]: Onshore/off shore distribution 3% off shore, 97% onshore [9]: (2012-data) Wind power (On shore): 179,6 MW [9]: (2012-data) Wind power (Off shore): Not on the list.	[1]+[3] [4]: Onshore/off shore distribution 3% off shore, 97% onshore		[1] [4] Onshore/off shore distribution: Estimated 71% off shore, 29% onshoreshore, 29% onshore [HR5]: It is expected that the installed capacity of the wind power in the Republic of Croatia in 2020 amount 1,200 MW	[1] [4] Onshore/off shore distribution: Estimated 71% off shore, 29% onshore	

Photovoltaic	[1]: 0 MW [7]: (2012-data) PV on grid: 3,9 MW PV off grid: 0,5 MW Total: 4,4 MW	[1]: 0 TWh [7]: PV (2012-data) 3,7 GWh		[1] [HR4]: 250 MW till year 2030	[1] [HR1]: The technical potential to electricity generation from photovoltaic (PV) systems and solar thermal power plants amounts to around 33 TWh/annum. The economic potential to produce solar electricity would amount to around 0.3 TWh/annum, which is the equivalent of around 200 MW of electricity-generating capacity	
Concentrated Solar Power	[8]: Not on the list	[8]: Not on the list		[10]: Solar radiation in Croatia is between 1,200 and 1,600 kWh/m2 Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Croatia is therefore unsuitable for CSP	[10]: Solar radiation in Croatia is between 1,200 and 1,600 kWh/m2 Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Croatia is therefore unsuitable for CSP	
Direct Geothermal	[1]	[1]		[1]	[1]	
Wave	[1]	[1]		[1]	[1]	
Tidal	[1]	[1]		[1]	[1]	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						
Hydro	[1]	[HR2] [2] 8309 GWh		[1]	[1]: 8,744 TWh [HR1]: Technically exploitable water potential resources in Croatia are estimated at 12.45 TWh/annum Forecast 2030: 7,03 TWh (25,31 PJ)	
Hydro Pump Back (if applicable)						

Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal*	n/a	[HR3]: 2012 0,5 PJ		n/a	[HR3]: 12,21 PJ in 2030	
Solar Thermal	[8]: (2012-data) Solar Thermal: 119600 m2 83,7 MWth	[HR2]		n/a	[HR1]: The technical potential to produce heat from solar collectors and the use of passive solar energy (solar architecture) amounts to 175 TWh/annum. (630 PJ/annum) Economic potential = 7% of technical potential	
Geothermal	[HR1]: Total installed heat capacity from supåply of geothermal energy 2007: Space heating = 33,66 MW Space heating and hot water preparation = 113,9 MW	[HR2]: 0,079 TWh [HR1]: 702,31TJ = 0,195 TWh (2007)		n/a	[HR1]: Forecast 2030: 8,54 PJ	
Large-scale heat pumps						

Bioenergy			
	2010	Potential (2050)	
*Type**	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*	
Energy Crops: Residual	[HR1]: Agro residue = 22,93 PJ		AAU collects through contact in Croatia
Energy Crops: Dedicated Land	[HR4]+[HR2]: Energy forests = 12,88 PJ		AAU collects through contact in Croatia
Wood	[HR2] [HR1]: Cord wood = 24,33 PJ Wood residue = 8,65 PJ Abbaino = 2,01 PJ Wood industry residue = 17,89 PJ Roads, water management, etc. = 4,80 Total = 16,022 TWh		AAU collects through contact in Croatia
Waste: Renewable & fossil	[HR2] 319 TJ Production		AAU collects through contact in Croatia

Biogas	[HR2]: 298 TJ Production	[HR5]: Croatia sets up a goal by this Strategy of 20% of total conditional cattle heads for energy purposes from agricultural production in 2020 and to produce around 2.6 PJ of energy from biogas, i.e. 100 millions m3 of biogas.
Total	[HR5]: Croatia defines a goal to, along with the existing incentive measures and removing the existing administrative barriers, use around 15 PJ of biomass in energy purposes in 2010, while in 2020 double, around 26 PJ. Part of this biomass shall be used in many biomass fired power plants of total power of 85 MW in 2020, preferably cogeneration plants.	

3.2 Czech Republic

For Czech Republic, several references were necessary to use to find the needed data. Both national and EU references have been used. It was necessary to use three national references on biomass data in order to get an overview of the data available.

FLH and solar performance are presented in the tables below.

Type	Full-load hours 2010	2050	Difference	Difference [>100 % means larger than 2010]
Onshore Wind	1,562.79	1,502.14	-60.65	96%
Offshore Wind				
Photovoltaic	314.49	1,069.27	754.77	340%
Concentrated Solar Power				
Direct Geothermal				
Wave				
Tidal				
Hydro				
River Hydro				
Hydro	2,590.53	3,111.28	520.75	120%
Hydro Pump Back (if applicable)				
Type				
Individual Solar Thermal*				
Solar Thermal	220.11	1,859.44	1,639.33	845%
Geothermal	5,427.33	13,880.00	8,452.67	256%
Large-scale heat pumps	1,232.50			

Solar-check						
Given information			Calculated	ESTIF 2012 numbers		
Capacity MW	Production TWh	Area m^2	Performance kWh/m^2	Capacity	Area	Solar Radiation MWh/m^2
463.40	0.10	661,969	154.09	299.13	427,327	

Assumptions and crosscheck results are described in the following.

Onshore wind:

Czech Republic does not have a shoreline; therefore all wind capacity is onshore. In [1] and [2], the wind capacity in 2010 is 215 MW. In [5] the wind capacity is 218 MW. The production in 2010 was 0.34 TWh, according to [1], [2] and [5].

The potential for wind capacity and production in 2050 is both from [1].

There is no positive development in FLH, which might be explained by the lack of shoreline in Czech Republic. Hence, it might be difficult to utilize the wind technology more than it is today. The FLH in 2010 are relatively low, but the used references have more or less the same numbers. Local wind conditions might be the reason for this, but an exact explanation has not been identified.

Photovoltaic:

In [1] the 2010 capacity is 1,959 MW. From [5] there is in (2010):

- PV on grid: 1,958.7 MW
- PV off grid: 0.4 MW
- Total: 1,959.1 MW

The potential for 2050 is from [1].

The used numbers are from the same reference, [1]. Therefore, an assumption on technical development might be the explanation for the increase in FLH by 340 %.

Hydro:
The 2010 data from [1] gives a number for the capacity of 1,077 MW. From [CZ1] the number is 1,048 MW from 2009.

The production in 2010 from [1] is 2.79 TWh. In accordance with this, 2.79 TWh is also given by 'Ministry of Industry and Trade and Energy Regulatory Office Data 2013 preliminary for 2007 to 2013'. In [CZ1] the number is 2.17 TWh in 2009/28/EC.

The potential for 2050 is in [1] equal to 1,330 MW. To support this, the 2020 target in [CZ2] is 1,097 MW. It should be noted that this target does not raise capacity significantly, compared to the installed capacity in 2010. The production potential in 2050 is also given by [1] to 4.14 TWh/year. To compare, the following targets are given in [CZ2] to be:

- 2.53 TWh/year in 2040
- 2.53 TWh/year in 2030
- 2.61 TWh/year in 2020-target

The FLH for use of hydro increase by 120 %. The numbers used for the calculation are from [1] – the difference is therefore attributed to technical development.

Hydro pump back:
The hydro pump back for 2010 is given in [CZ1]. No sources were available for the potential in 2050.

Solar thermal:
In [5] the thermal solar collector area is given to be 661,969 m^2 with a capacity of 463 MW. In [CZ1] the number is only 216 MW. The production is given from [CZ1] to 273 TJ (0.08 TWh).

For the potential of capacity in 2050 only 2020 data is available from [CZ2], with 747 MW as 2020 target. The production potential for 2050 is also from [CZ2] with the following national targets:

- 1.39 TWh/year 2040
- 0.97 TWh/year in 2030
- 0.38 TWh/year (2020-target)

The number for FLH in 2010 is very low. There has been used two different references, which might explain the rather large increase in FLH of 845 %. The difference in references also explains the very low performance of solar thermal in 2010.

Geothermal:
In [5] the geothermal capacity is 4.50 MW, but in [CZ1] the number is 0 MW in 2010. For the production in 2010 in [1] and [CZ1] the number is 0 TWh. In [5] the geothermal energy is equivalent to 2.10 ktoe (0.02 TWh).

For the 2050 potential, [CZ2] have been used with 50 MW as the 2020-target. For the production the following data is given by [CZ2]:

- 0.69 TWh/year (2040)
- 0.47 TWh/year (2030)
- 0.18 TWh/year (2020-target)

The FLH in 2010 seem reasonable, despite two different sources have been used. The too large number of FLH in 2050 is due to the capacity is 2020-data, while the production is the 2040-target.

Large scale heat pumps:

The capacity and production in 2010 is given by [CZ1]. Again is [CZ2] used for the potential of 2050 with the following data for production:

- 4.36 TWh/year (2040)
- 3.72 TWh/year (2030)
- 1.83 TWh/year (2020 - target)

Energy crops, residual:
The residual energy crops is given from [CZ4], Table 16: 13.50 PJ agricultural residues. The potential for 2050 is from [CZ5] with a residual of 35 PJ. In [11], the residual related biomass is 1,510 ktoe in 2030, which corresponds to 17.56 TWh.

Energy crops, dedicated:
The data for 2010 are taken from [CZ4], Table 17: 161.17 PJ biomass potential from energy crops. In [CZ5], the potential for dedicated land in 2050 is 214 PJ. In [11], related to dedicated land (without forests) = 539 ktoe = 6.27 TWh.

Wood:
In [CZ3] the 2010 data is given:
Wood for electricity and heat 2008: 16.11 PJ or 4.48 TWh (wood for electricity alone in 2010 is 0.64 TWh).

Some additional data for 2010 is given in [5] for solid biomass:
Primary energy production: 2.09 Mtoe (24.31 TWh)
Heat consumption: 1.64 Mtoe (19.07 TWh, whereof 0.06 Mtoe to DH)
Gross electricity production:

- Electricity only plants: 0.6 TWh
- CHP plants: 0.9 TWh
- Total: 1.5 TWh

For the 2050 [CZ5] is used with a potential from wood (forestry) of 50 PJ. In [11], the wood related data is 6.22 Mtoe in 2030, equal to 72.29 TWh.

Waste:
The number for 2010 is from [CZ3], with waste = 0.73 TWh/year of which municipal solid waste (MSW) is 59 GWh and industrial waste is 2 GWh.

In [CZ1] waste = 0.82 TWh/year (2009) and in [5], the Municipal Waste (Renewable share) is from Primary energy production equal to 62.70 ktoe (0.73 TWh) with gross electricity production:

- Electricity only plants: 11 GWh
- CHP plants: 25 GWh
- Total: 36 GWh

In [11] the total MSW in 2030 is 806 ktoe = 9.37 TWh.

For the potential in 2050 data from 2020 – 2040 were available from [CZ2]:

- 6.14 TWh/year (2030+2040)
- 1.45 TWh/year (2020)

In [11] the following data for 2050 potential is available:

- MSW = 220 ktoe in 2030 = 2.56 TWh
- MSW landfill = 360 ktoe in 2030 = 4.19 TWh

- In total 6.75 TWh

Biogas:
In 2010 the data from [CZ3] is used with biogas = 2.06 TWh/year. Biogas solely for electricity production is 266.87 GWh.

In [CZ2], the biogas = 1,329 TWh/year in 2009.

From [5] a more detailed division for biogas is given:
- Landfill gas: 29.5 ktoe (0.34 TWh)
- Sewage sludge: 35.9 ktoe (0.42 TWh)
- Other biogas: 111.3 ktoe (1.29 TWh)

With gross electricity production:
- Electricity only plants: 361 GWh
- CHP plants: 275 GWh
- Total: 636 GWh
- The potential for 2050 is from [CZ2]

Biomass Atlas:
The results from the Biomass Atlas are seen in the table below. The numbers here are higher than the numbers shown from the national references from Czech Republic, describes in the biomass categories above. An explanation to this can be that the numbers in the national references are less detailed than the numbers in the Biomass Atlas.

	Biomass Atlas (TWh/year)			
	REF2020	**SUS2020**	**REF2030**	**SUS2030**
Energy crops, residual	24	24	28	27
Energy crops, dedicated	1	0	1	0
Wood	68	59	66	59
Waste	12	12	11	11
Biogas	27	27	21	21
Total	131	121	127	119

3.2.1 *Data on renewable electricity and heat potentials*

Czech Republic: Renewable Energy Resources	

Renewable Energy Resources - Czech Republic						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	215.00	0.34		468.00	0.70	
Offshore Wind	n/a	n/a		n/a	n/a	
Photovoltaic	1,958.70	0.62		2,180.00	2.33	
Concentrated Solar Power	-	-		-	-	
Direct Geothermal	-	-				
Wave	-	-		-	-	
Tidal	-	-		-	-	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						
Hydro	1,077.00	2.79		1,330.00	4.14	
Hydro Pump Back (if applicable)		0.59				
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	n/a			n/a		
Solar Thermal	463.40	0.10		747.00	1.39	
Geothermal	4.50	0.02	-	50.00	0.69	
Large-scale heat pumps	400.00	0.49			4.36	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	3.75	9.72
Energy Crops: Dedicated Land	44.77	59.44
Wood	4.48	13.89
Waste: Renewable & fossil	0.73	6.14
Biogas	2.06	7.53
Total	55.78	96.72

3.2.2 References

Czech Republic: Renewable Energy Resources

Renewable Energy Resources - Czech Republic						
	2010			Potential (2050)		
			Renewable Electricity			
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	[1] + [2]: 215 MW [5]: Wind power: 218 MW	[1] + [2]: 0.335 TWh [5]: Wind power: 0.336 TWh		[1]	[1]	
Offshore Wind	n/a	n/a		n/a	n/a	
Photovoltaic	[1]: 1,958.7 MW [5]: (2010) PV on grid: 1,958.7 MWp PV off grid: 0.5 MWp Total: 3,483.5 MWp	[1] + [2] + [5]: PV: 615.7 GWh (2010)		[1]	[1]	
Concentrated Solar Power	[8]: Not mentioned	[8]: Not mentioned		[10]: Solar radiation in Czech Republic is around 1000 kWh/m²/y Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Czech Republic is therefore unsuitable for CSP	[10]: Solar radiation in Czech Republic is around 1000 kWh/m²/y Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Czech Republic is therefore unsuitable for CSP	
Direct Geothermal	[5]: Geothermal electricity plants: Capacity installed: 0 MW	[1]: Geothermal (and other renewables): 0 GWh				
Wave	[1]	[1]		[1]	[1]	
Tidal	[1]	[1]		[1]	[1]	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						

Hydro	[1]: 1.077 MW in 2010 [CZ1]: 1.048 MW in 2009	[1]: 2.79 TWh in 2010 2.79 TWh in Ministry of Industry and Trade and Energy Regulatory Office Data 2013 preliminary for 2007 to 2013, production in GWh [CZ1]: 2.17 TWh in 2009/28/EC		[1]: 1,330 MW [CZ2]: 1,097 MW in 2020 target	[1]: 4.138 TWh/year [CZ2]: 2.53 TWh/year in 2040 2.53 TWh/year in 2030 2.61 TWh/year in 2020-target	
Hydro Pump Back (if applicable)		[CZ1]				
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	n/a			n/a		
Solar Thermal	[5]: Thermal solar collectors: 661,969 m2 463.4 MWth [CZ1]: 216 MW	[CZ1]: 273 TJ = 0.1 TWh		[CZ2]: 747 MW 2020 target	[CZ2]: 1.39 TWh/year 2040 0.972 TWh/year 0.375 TWh/year (2020-target)	
Geothermal	[5]: Geothermal Capacity: 4.5 MW [CZ1]: 0 MW	[1]: 0 TWh [5]: Geothermal Energy using: 2.1 ktoe [CZ1]: 0 TWh/year	[1]: 0 GWh [CZ1]: 0 GWh	[CZ2]: 50 MW 2020-target	[CZ2]: 0.694 TWh/year (2040) 0.472 TWh/year (2030) 0.175 TWh/year (2020-target)	
Large-scale heat pumps	[CZ1]	[CZ1]			[CZ2]: 4.361 TWh/year (2040) 3.722 TWh/year (2030) 1.826 TWh/year (2020 - target)	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	[CZ4]: Table 16: 13.5 PJ agricultural residues	[CZ5]: Residual 35 PJ [11]: Residuel related: 1510 ktoe in 2030 = 17.56 TWh

Energy Crops: Dedicated Land	[CZ4]: Table 17: 161.17 PJ biomass potential from energycrops	[CZ5]: Dedicated land 214 PJ [11]: Related to dedicated lan (without forests) = 539 ktoe = 6.27 TWh
Wood	[CZ3]: Wood for elctricity and heat 2008: 16.11 PJ or 4.48 TWh (wood for electricity alone in 2010 is 0.642 TWh) [5]: Solid biomass: Primary energy production: 2.09 Mtoe (~24.4 TWh) Heat consumption: 1.64 Mtoe (0.06 Mtoe to DH) Gross electricity production: Electricity only plants: 0.595 TWh CHP plants: 0.898 TWh Total: 1.493 TWh	[CZ5]: Wood (forestry) 50 PJ [11]: Wood related: 6,216 ktoe in 2030 = 72.29 TWh
Waste: Renewable & fossil	[CZ3]: Waste = 0.73 TWh/year of which: Solid municipal waste 59,000 MWh Industrial waste 2,000 MWh [CZ1]: Waste = 0.82 TWh/year (2009) [5]: Municipal Waste (Renewable share): Primary energy production: 62.7 ktoe (~ 0.7 TWh) Gross electricity production: Electricity only plants: 11 GWh CHP plants: 25 GWh Total: 36 GWh [11]: Total MSW in 2030: 806 ktoe = 9.37 TWh	[CZ2]: 6.14 TWh/year (2030+2040) 1.45 TWh/year (2020) [11]: MSW = 220 ktoe in 2030 = 3 TWh MSW landfill = 360 ktoe in 2030 = 4.19 TWh In total 6.75 TWh (Fall in MSW landfill potential)

Biogas	[CZ3]: Biogas = 2,06 TWh/year Biogas solely for electricity production 266.868,3 MWh [CZ2]: Biogas = 1,329 TWh/year (2009) [5]: Landfill gas: 29,5 ktoe (~0,3 TWh) Sewage sludge: 35,9 ktoe (~0,4 TWh) Other biogas: 111,3 ktoe (~1,3 TWh) Gross electricity production: Electricity only plants: 361 GWh CHP plants: 275 GWh Total: 636 GWh	[CZ2]

3.3 Italy

Data from Italy has been collected from national data, the national STRATEGO partner and EU-28 statistics and projections.

FLH and solar performance are presented in the tables below.

	Full-load hours			
Type	2010	2050	Difference	Difference [>100 % means larger than 2010]
Onshore Wind	1,569.66	1,868.45	298.79	119%
Offshore Wind		3,157.89		
Photovoltaic	549.28	1,774.42	1,225.14	323%
Concentrated Solar Power	1,800.00	2,333.33	533.33	130%
Direct Geothermal	6,963.73	6,000.00	-963.73	86%
Wave				
Tidal				
Hydro				
River Hydro	4,300.16	4,300.16	0.00	100%
Hydro	1,965.17	1,899.18	-65.99	97%
Hydro Pump Back (if applicable)	1,197.99	1,262.14	64.15	105%
Type				
Individual Solar Thermal*				
Solar Thermal	878.14	1,094.26	216.12	125%
Geothermal	3,875.74	2,367.42	-1,508.31	61%
Large-scale heat pumps				

Solar-check						
Given information			Calculated	ESTIF 2012 numbers		
Capacity MW	Production TWh	Area m2	Performance kWh/m2	Capacity	Area	Solar Radiation MWh/m2
1,743.00	1.50	2,503,949	599.05	2,356.01	3,365,730	

Assumptions and crosscheck results are described in the following.

Onshore wind:
Two different references were used between 2010 [5] and 2050 [1]. Despite this, the 19 percentage-points increase in FLH of onshore wind seems plausible.

Offshore wind:
FLH not calculated due to lack of installed offshore wind capacity in 2010.

Photovoltaic:
Differences in the assumptions of the two different references (2010: [5] 2050: [1]), might explain the significant increase in FLH. The 2010-numbers on FLH seem quite low.

Concentrated solar power:
A moderate, but not unrealistic increase in FLH, despite three different references (2010: [5] and [IT4] 2050: [IT6])

Direct Geothermal:
The decrease in FLH could be caused by the deployment of geothermal resources with lower yield and/or different operating pattern than current installed capacity. Since [5] is used for 2010-numbers and [IT3] is used for 2050 (although the projection is limited to 2030), the explanation might simply be the difference in assumptions between the references.

River Hydro:
Since numbers on hydro were limited for 2050, and aggregated in the references, it has been necessary to extract these using a combination of different references. The results are in the same order of magnitude, but different from, the numbers provided by the Italian STRATEGO partner.

Hydro:
An aggregate number for hydro was given in the reference. This is subtracted the numbers found in the category “River Hydro”. The results are in the same order of magnitude, but different from, the numbers provided by the Italian STRATEGO partner.

Hydro pump back:
Minor difference between 2010 [IT5] and 2050-numbers [IT9] and [IT10], despite applying three different references.

Solar thermal:
2020-numbers have been applied for 2050, due to lack of data. Additionally, the solar thermal categories have been merged, since it has not been possible to distinguish between individual and large-scale solar thermal. The performance of 599 kWh/m^2/year appears reasonable, and the difference in FLH can be attributed to the three different references applied, [5], [IT1] and [IT2].

Geothermal:
As with geothermal electricity, the FLH for geothermal heat decreases. The reason can be that two different references are used, but might also be explained as described above: The deployment of geothermal resources with lower yield and/or different operating pattern than current installed capacity.

Large-scale heat pumps:
References are limited to the assumed production in 2050, specifically connected to geothermal heat.

Biomass Atlas:
All biomass categories are aggregated under this description. The Biomass Atlas has been applied as main reference for all biomass-categories. It is worth noticing the significant differences between these numbers, and numbers found in [IT11]. Generally, the focus on sustainable cropping is visible in the numbers from the Biomass Atlas, which tends to be higher than [IT11], when utilising residual and waste-resources, and lower when utilising dedicated land.

	Biomass Atlas (TWh/year)			
	REF2020	SUS2020	REF2030	SUS2030
Energy crops, residual	128	114	126	82
Energy crops, dedicated	42	0	4	0
Wood	74	69	75	69
Waste	19	19	15	15
Biogas	67	67	76	76
Total	329	269	296	242

3.3.1 Data on renewable electricity and heat potentials

Italy: Renewable Energy Resources

Renewable Energy Resources - IT						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	5,814.00	9.13		29,031.00	54.24	
Offshore Wind	0.00	0.00		1,900.00	6.00	
Photovoltaic	3,470.00	1.91		45,505.00	80.75	
Concentrated Solar Power	5.00	0.01		3,000.00	7.00	
Direct Geothermal	772.00	5.38		2,000.00	12.00	
Wave	-	-		-	-	
Tidal	-	-		-	-	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro	4,902.80	21.08		5,593.63	24.05	
Hydro	12,303.70	24.18		14,037.37	26.66	
Hydro Pump Back (if applicable)	7,659.10	9.18	96.00	10,300.00	13.00	125.00
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	1,752.80	1.54		39,551.08	43.28	
Solar Thermal						
Geothermal	418.00	1.62		8,800.00	20.83	
Large-scale heat pumps					4.17	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	185.38	126.16
Energy Crops: Dedicated Land	41.69	3.73
Wood	16.25	75.37
Waste: Renewable & fossil	46.42	15.31
Biogas	96.06	75.68
Total	385.80	296.25

3.3.2 *References*

Italy: Renewable Energy Resources

Renewable Energy Resources - IT						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	[5]: Wind power: 5,814.3 MW	[5]		[1]	[1]	
Offshore Wind	[IT4] [6]: (2010-data) Wind power (Off shore): Not on the list.	[IT4]		[IT6]	[IT6]	
Photovoltaic	[5]: (2010) PV on grid: 3,470 MWp PV off grid: 13.5 MWp Total: 3,483.5 MWp	[5]		[1]	[1]	
Concentrated Solar Power	[5]: 5 MW (Archimede (prototype), commissionning date 2010)	[IT4]		[IT6]	[IT6]	
Direct Geothermal	[5]: Geothermal electricity plants: Capacity installed: 882.5 MW Net capacity: 728.1 MW	[5]		[IT3]: 2030-numbers. In a favorable scenario [1]: 1,353 Mwe	[IT3] 2030-numbers. In a favorable scenario [1]: 12.181 TWh	
Wave	[1]	[1]		[1]	[1]	
Tidal	[1]	[1]		[1]	[1]	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro	[IT5]	[IT5]		Scaled according to 2050 numbers from [1] and 2010 numbers from [IT6] Italian partner: 7,800 MW	Scaled according to 2010-production and 2050 capacity Italian partner: 33 TWh	
Hydro	[IT5]	[IT5]		[1]: Subtracted the calculated river hydro Italian partner: 17,000 MW	[1] subtracted river hydro Italian partner: 31.7 TWh	
Hydro Pump Back (if applicable)	[IT5]	[IT5]	[IT7] [IT8]	[IT9]	[IT10]	[IT10]

Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	[5]: Thermal solar collectors: 2,503,949 m2 1,752.8 MWth	[5] and [IT1] 2,413 MWth in 2012 and 2.12 TWh 1,752.8 MWth in 2010 and unknown TWh Scaled according to 2012-numbers: 1.54 TWh		[IT2] Based on 2020-numbers	[IT2] Local partner. Based on 2020-numbers	
Solar Thermal						
Geothermal	[5]	[5]		[IT3]	[IT3]	
Large-scale heat pumps					[IT3] Number only refers to heat pumps connected to geothermal	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	[11]	[11] Note large difference from [IT11]: 108.2 TWh
Energy Crops: Dedicated Land	[11]	[11] Note large difference from [IT11]: 46.5 TWh
Wood	[11] Note large difference - [5]: 38.9 TWh	[11] Note large difference from [IT11]: 35 TWh
Waste: Renewable & fossil	[11] Note large difference - [5]: 9.1 TWh	[11] Note large difference from [IT11]: 3.5 TWh
Biogas	[11] Note large difference - [5]: 5.2 TWh	[11] Note large difference from [IT11]: 127.9 TWh
Total	Note large difference to [1] 7,033 ktoe - 81.8 TWh production	Note large difference to [1] 2050: 10,050 ktoe - 116.9 TWh

3.4 Romania

Five different references have been used on national basis, but international reports have also been used in order to collect the data.

FLH and solar performance are presented in the tables below.

Type	Full-load hours 2010	2050	Difference	Difference [>100 % means larger than 2010]
Onshore Wind	662.44	1,994.04	1,331.60	301%
Offshore Wind	659.11	1,996.65	1,337.55	303%
Photovoltaic	769.23	1,178.96	409.73	153%
Concentrated Solar Power				
Direct Geothermal				
Wave				
Tidal				
Hydro				
River Hydro				
Hydro	3,111.24	3,828.48	717.25	123%
Hydro Pump Back (if applicable)				
Type				
Individual Solar Thermal*	15.01			
Solar Thermal				
Geothermal	2,436.83			

Solar-check						
Given information			Calculated	ESTIF 2012 numbers		
Capacity MW	Production TWh	Area m^2	Performance kWh/m^2	Capacity	Area	Solar Radiation MWh/m^2
73.00	0.00	104,700	9.55	77.49	110,700	

Assumptions and crosscheck results are described in the following.

Onshore/Offshore wind:

From [1] the cumulated wind in 2010 is 462 MW. In [4], the onshore/offshore distribution is 3 % offshore and 97 % onshore. Comparable numbers are found in [2] with 400 MW cumulated and [5] with 388 MW cumulated wind power. The same references are used for the production in 2010 with [1] as main source. From [4] the onshore/offshore distribution is assumed to be 3 % offshore and 97 % onshore. From [5] the production is 0.31 TWh.

The potential for 2050 is from [1]. Where [4] is used for distribution of onshore 20 % and 80 % offshore. The offshore is lower than Croatia due to short shoreline in Romania. Therefore, the numbers in [4] from 2020 have been used.

The FLH in 2010 are rather low. The increase in FLH can be explained with an expectation of better utilization of wind in the potential. The used numbers are from [1] in both 2010 and 2050.

Photovoltaic:

In [5] 2010-data is found for the capacity: PV on grid = 1.3 MW, PV off grid = 0.6 MW, in total = 1.9 MW. The production is also found from [5].

The potential for 2050 is found in [1] with 3,788 GWh. In [RO1] the number is 1.2 TWh electricity from solar energy.

The used reference in 2010 is [5], whereas the used reference for the 2050-data is [1]. This may explain the increase in FLH together with technical development.

Direct geothermal:
From [1] the potential for geothermal (and other renewables) is 18 GWh. In the table, this is not included since the share of geothermal is unclear.

Hydro:
The capacity and production in 2010 is from [1] with [2] supporting the production found in [1].

Reference [1] is also used for the potential in 2050 with 25,169 GWh. In [RO1] the Romanian technically developable hydropower potential is 36,000 GWh/year from which, 30,000 GWh/year (taking into consideration the economic potential) can be exploited.

Individual solar thermal and solar thermal:
It was not possible to find any data on individual solar thermal, therefore the data for the individual solar thermal and solar thermal has been merged. In [5] for 2010 capacity, the thermal solar collector area is 104,700 m^2 with a capacity of 73.3 MW.

The production in [RO2] is 4 TJ from solar thermal. The very low performance seen in the crosscheck table can be explained by use of different sources.

For the 2050 potential [RO1] gives a number for solar energy of 60 PJ/year heat.

The performance of solar thermal is much too low to be realistic. This can only be explained by difference in references, since the capacity is given in [5] and the production in [RO2].

Geothermal:
From [5], the geothermal capacity is 153.2 MW. The production in 2010 is also from [5] with geothermal energy using of 32.1 ktoe, corresponding to 0.37 TWh. In [RO2], the 2010 number is 962 TJ.

In [RO1] the potential for 2050 is found to be for geothermal energy = 7 PJ heat.

Energy crops, residual:
For residual energy crops, reference [11] is used. However, this is only a number for the straw potential from 2004 of 1,351 ktoe = 15.71 TWh. The potential for 2010 might therefore be higher than this number.

In [RO3], the agricultural residues - biomass potential is in 2004 for the future in Romania to be 247.21 PJ. An alternative number is found in [11], where residues related biomass is 3,621 ktoe in 2030, which corresponds to 42.11 TWh.

Energy crops, dedicated:
In [RO5], biomass from agriculture in 2008 used for energy is 65 PJ, equal to 18.06 TWh. For the potential in 2050, the estimated biomass potential from agricultural biomass = 200,935 TJ in [RO3]. In [11] the number is much lower, where dedicated land (without forests) is 666 ktoe in 2030 = 7.75 TWh.

Wood:
The number for solid biomass in [5] is used as reference for wood, where solid biomass contributes to the primary energy production by 3,459 Mtoe (2011-data), which is 40.22 TWh.

The potential of wood in 2050 is found in [RO3], where the potential for biomass wood forestry = 49,241 TJ + wood waste = 20,432 TJ, which corresponds to 19.35 TWh.

In [11] the wood related in 2030 is much higher with 13,420 ktoe = 156.08 TWh.

Waste:
From [RO2] the energy production from waste is 1,284 TJ, which only equals 0.36 TWh. The number from [11] is much higher, where the total MSW in 2010 is 1,792 ktoe = 20.84 TWh.

In [RO3], the urban waste potential amounts to 22,805 TJ = 6.34 TWh. In [RO4], the municipal waste electricity CHP = 17 ktoe, municipal waste heat = 110 ktoe, which is 1.48 TWh/year

In [11] the number is much higher with total MSW = 940 ktoe in 2030, which is 10.93 TWh.

Biogas:
In [5] the following data is found on biogas:

- Landfill gas: 0 ktoe
- Sewage sludge: 0 ktoe
- Other biogas: 3.0 ktoe (0.03 TWh)

Gross electricity production:

- Electricity only plants: 0 GWh
- CHP plants: 1 GWh
- Total: 1 GWh

The future potential is found from [RO3], where the biogas potential = 24,620 TJ or 6.84 TWh

Biomass Atlas:
The data from the Biomass Atlas is seen in the Table below. The found data for the biomass in 2010 and the potential in 2050 deviates from the numbers given in the Biomass Atlas. More sources have been used in order to find data from national sources and these have not been as detailed as the data in the Biomass Atlas, i.e. there have not been the same detail level of categories. It has not been possible to find background data on the used sources in order to find which categories are behind each number.

	Biomass Atlas (TWh/year)			
	REF2020	SUS2020	REF2030	SUS2030
Energy crops, residual	83	77	55	53
Energy crops, dedicated	8	0	6	0
Wood	156	142	93	85
Waste	13	13	12	12
Biogas	6	6	17	17
Total	266	238	184	167

3.4.1 Data on renewable electricity and heat potentials

Romania: Renewable Energy Resources	

Renewable Energy Resources - RO						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	447.89	0.30		3,826.40	7.63	
Offshore Wind	14.11	0.01		956.60	1.91	
Photovoltaic	1.30	0.00		3,213.00	3.79	
Concentrated Solar Power	-	-		-	-	
Direct Geothermal	-	-			0.02	
Wave	-	-		-	-	
Tidal	-	-		-	-	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						
Hydro	6,275.00	19.52		7,836.00	30.00	
Hydro Pump Back (if applicable)						
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	73.30	0.00		n/a	16.67	
Solar Thermal						
Geothermal	153.20	0.37		n/a	1.94	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	15.71	68.67
Energy Crops: Dedicated Land	18.05	55.82
Wood	40.22	19.35
Waste: Renewable & fossil	0.36	6.33
Biogas	0.03	6.84
Total	56.32	157.01

3.4.2 *References*

Romania: Renewable Energy Resources	

Renewable Energy Resources - RO						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	[1]: 462 MW cumulated [4]: Onshore/off shore distribution 3% off shore, 97% onshore [2]: 400 MW cumulated [5]: Wind power: 388 MW	[1] [4]: Onshore/off shore distribution 3% off shore, 97% onshore [5]: Wind power: 0.306 TWh		[1] [4]: Distribution of onshore 20 % and 80 % offshore (lower than Croatia due to short shore line, numbers from 2020)	[1] [4]: Distribution of onshore 20 % and 80 % offshore (lower than Croatia due to short shore line, numbers from 2020)	
Offshore Wind	[1] [4]: Onshore/off shore distribution 3% off shore, 97% onshore [6]: (2010-data) Wind power (Off shore): Not on the list.	[1] [4]: Onshore/off shore distribution 3% off shore, 97% onshore		[1] [4]: Distribution of onshore 20 % and 80 % offshore (lower than Croatia due to short shore line, numbers from 2020)	[1] [4]: Distribution of onshore 20 % and 80 % offshore (lower than Croatia due to short shore line, numbers from 2020)	
Photovoltaic	[5]: (2010) PV on grid: 1.3 MWp PV off grid: 0.6 MWp Total: 1.9 MWp	[5]: PV: 1.0 GWh (2010)		[1]	[1]: 3,788 GWh [RO1]: 1.2 TWh electricity from solar energy	
Concentrated Solar Power	[8]: Not on the list	[8]: Not on the list		[10]: Solar radiation in Romania is between 1000 and 1500 kWh/m²/y Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Romania is therefore unsuitable for CSP	[10]: Solar radiation in Romania is between 1000 and 1500 kWh/m²/y Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. Romania is therefore unsuitable for CSP	
Direct Geothermal	[1]: 0 MW [5]: Geothermal electricity plants: Capacity installed: 0 MW	[1] + [RO2]: 0 GWh [5]: Geothermal electricity plants: 0 GWh		[1]: Geothermal (and other renewables): 18 GWh Not included since it is questionable whether or not it is Geothermal.	[1]:	

Wave	[1]	[1]		[1]	[1]	
Tidal	[1]	[1]		[1]	[1]	
Hydro			*Hydro Storage (GWh)*			*Hydro Storage (GWh)*
River Hydro						
Hydro	[1]	[1] + [2]		[1]	[1]: 25,169 GWh [RO1]: The Romanian hydraulic potential technically developable is 36,000 GWh/year from which, 30,000 GWh/year (taking into consideration the developable economic potential) can be exploited	
Hydro Pump Back (if applicable)						
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWe)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	[5]: Thermal solar collectors: 104,700 m2	[RO2]: 4 TJ solar thermal production		n/a	[RO1]: Solar energy 60 PJ/year heat	
Solar Thermal						
Geothermal	[5]: Geothermal: Capacity: 153.2 MW	[5]: Geothermal: Energy using: 32.1 ktoe [RO2]: 962 TJ		n/a	[RO1]: Geothermal energy = 7 PJ heat	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual	[11]: Straw potential from 2004: 1,351 ktoe = 15.71 TWh	[RO3]: Agricultural residues - biomass potential in 2004 in Romania = 247.21 PJ [11]: Residues related = 3,621 ktoe in 2030 = 42.11 TWh
Energy Crops: Dedicated Land	[RO5]: Biomass from agriculture in 2008 used for energy = 65 PJ = 18.06 TWh	[RO3]: Agricultural biomass = 200,935 TJ [11]: Dedicated land (without forests) 666 ktoe in 2030 = 7.75 TWh

Wood	[5]: Solid biomass: Primary energy production: 3,459Mtoe Heat consumption: 3,942 Mtoe (0,035 Mtoe to DH) Gross electricity production: Electricity only plants: 0,048 TWh CHP plants: 0,062 TWh Total: 0,110 TWh	[RO3]: Biomass wood forestry = 49 241 TJ + Wood wastes = 20 432 TJ [11]: Wood related in 2030: 13420 ktoe = 156.08 TWh
Waste: Renewable & fossil	[5]: Municipal Waste (Renewable share): Primary energy production: ktoe Gross electricity production: Electricity only plants: GWh CHP plants: GWh Total: GWh [RO2]: 1284 TJ = 0,357 TWh [11]: Total MSW in 2010: 1792 ktoe = 20.84 TWh	[RO3]: Urban Wastes potential: 22 805 TJ = 6,335 TWh [RO4]: Municipal waste electricity CHP = 17 ktoe, municipal waste heat = 110 ktoe --> 1,48 TWh/year [11]: Total MSW = 940 ktoe in 2030 = 10.93 TWh
Biogas	[5]: Landfill gas: 0 ktoe Sewage sludge: 0 ktoe Other biogas: 3,0 ktoe (~0,035 TWh) Gross electricity production: Electricity only plants: 0 GWh CHP plants: 1 GWh Total: 1 GWh	[RO3]: Biogas potential = 24 620 TJ = 6,84 TWh
Total	Note large difference to [1] 7033 ktoe - 81.7937 TWh production	

3.5 United Kingdom

In order to find the resource potentials for renewables in United Kingdom, it has been necessary to use several references to find the needed data. Most references have been from government publications, but also references from EU and other references from the United Kingdom have been used.

It was necessary to use two governmental references on biomass data in order to get full overview of the potential.

Most 2010 data for United Kingdom is from the government publication “Digest of United Kingdom energy statistics (DUKES) 2011” [UK4]. These data are deemed highly reliable.

FLH and solar performance are presented in the tables below. For onshore wind production in 2050 only the capacities has been found in the references, so the FLH has been assumed based on 2020 numbers [UK8]. For offshore wind production, the FLH has been estimated based on [1]. For marine energy, the production has been estimated based on [UK8].

	Full-load hours			
Type	2010	2050	Difference	Difference [>100 % means larger than 2010]
Onshore Wind	1,768.03	2,300.00	531.97	130%
Offshore Wind	2,271.10	3,000.00	728.90	132%
Photovoltaic	429.13	1,009.35	580.23	235%
Concentrated Solar Power				
Direct Geothermal				
Marine Energy		3,000.00		
River Hydro				
Hydro	2,185.89	3,046.35	860.47	139%
Hydro Pump Back (if applicable)				
Renewable Heat				
Individual Solar Thermal				
Solar Thermal				
Geothermal	4,652.00	4,652.00	0.00	100%
Large-scale heat pumps				

Solar-check						
Given information			Calculated	ESTIF 2012 numbers		
Capacity MW	Production TWh	Area m2	Performance kWh/m2	Capacity	Area	Solar Radiation MWh/m2
374.00		534,043		496.77	709,673	

Assumptions and crosscheck results are described in the following.

Onshore wind:
The potentials for onshore wind in 2050 have been deduced from the total wind potential of 67,334 MW from [1] where the offshore potential in 2030 of 40,000 MW from [UK8] has been deducted. FLH for 2020 (2,300 hours) have been used to calculate the annual production on 63 TWh/year.

Offshore wind:
The potential for offshore wind of 40,000 MW in 2030 [UK8] have been used for the 2050 potential. FLH from [1] (3,000 hours) have been used to calculate the annual production on 120 TWh/year.

Marine energy:
For United Kingdom is has been difficult to find potentials divided into wave and tidal, since most references aggregate them into marine energy or ocean energy. The potential for marine energy production in 2050 has been estimated based on a capacity potential on 27,000 MW from [UK8] and 3,000 FLH for marine energy in 2020.

Hydro:
For United Kingdom is has been difficult to find present capacities and productions divided into river hydro and hydro (reservoir), so the data has been aggregated into hydro. The potentials for 2050 on 1,769 MW and 5.4 TWh/year are from [1].

Hydro pump-back and hydro storage:
The hydro pump back capacity for 2010 from [UK5] is used for 2050 since no usable references where found for the potential in 2050. The hydro storage for 2010 on 3,139 GWh/year is also used for 2050. For the hydro storage on 3,139 GWh/year there were used 4,212 GWh of electricity. It is assumed that the 2010 numbers will be valid for 2050 since the technical potential for hydro in the United Kingdom seems to be utilised, especially when considering environmental concerns.

Solar thermal:
In [5] the solar thermal collector area is stated to be approximately 534,000 m^2 with a capacity of 374 MW. It has been difficult to find other present capacities and productions as well as potentials for 2050. However, it is assumed that the technical and economic potential for solar thermal is higher for 2050 than 2010. Data on the 2012 capacity from the European Solar Thermal Industry Federation (ESTIF) also suggest that the potential is higher.

Geothermal:
In [5] the geothermal capacity is 2 MW thermal in 2010 and the production is 0.01 TWh/year. The thermal capacity potential in 2050 from [1] is 26 MW, where [UK9] is much higher with 100,000 MW. The potential for 2050 from [1] is deemed the most plausible. This potential and FLH in 2010 [5] on 4,652 hours have been used to calculate the annual production on 0.1 TWh/year.

Large-scale heat pumps:
It has not been possible to find any data on capacity nor production in 2010 from large-scale heat pumps, and it is likely that it is due to the lack of any large-scale heat pumps in the present system. In [UK6] the production potential for 2050 is 12 TWh/year.

Energy crops, residual & dedicated:
The consumption of residual and dedicated energy crops on 5.5 TWh/year in 2010 is from [UK4] and consists of the categories straw, short rotation coppice (SRC), and other plant-based biomass. For 2050 the potential on 18.3 TWh/year is from [UK2] and consists of the category perennial energy crops. The alternative potential on 152.7 TWh/year for 2050 from [UK3] seems very high.

Wood:
The consumption of wood on 6.7 TWh/year in 2010 is from [UK4] and consists of the categories wood and wood waste. For 2050 the potential on 20.7 TWh/year is from [UK2] and consists of the categories forestry and forestry waste. The alternative potential on 6.9 TWh/year for 2050 from [UK3] seems very low.

Waste:
The consumption of renewable and fossil waste on 11.7 TWh/year in 2010 from [UK4] consists of the categories waste (municipal solid waste, general industrial waste and hospital waste) and tyres. The potential on 97.3 TWh/year in 2050 is from [UK3].

Biogas:
The present consumption in 2010 is on 24.4 TWh/year cf. [UK4] if combining the categories landfill gas, sewage gas, and poultry litter, meat and bone, and farm waste. The categories poultry litter, meat and bone, and farm waste is allocated to biogas since it is deemed the best use of the "resource". For 2050 the potential on 38.3 TWh/year is from [UK2] and consists of the category "agricultural residues". The alterna-

tive potential on 20.8 TWh/year for 2050 from [UK3] seems too low compared to the present consumption on 24.4 TWh/year.

Biomass Atlas:

The results from the Biomass Atlas are seen in the Table below. The numbers here are a bit higher compared to the numbers shown from the governmental references for the United Kingdom. The total potential for 2050 from the governmental references is 175 TWh/year, which is relatively close to 198 TWh/year for the sustainable 2030 potential from the Biomass Atlas.

	Biomass Atlas (TWh/year)			
	REF2020	**SUS2020**	**REF2030**	**SUS2030**
Energy crops, residual	69	62	60	42
Energy crops, dedicated	5	0	6	0
Wood	67	63	66	62
Waste	47	47	36	36
Biogas	43	43	58	58
Total	232	215	226	198

3.5.1 *Data on renewable electricity and heat potentials*

Red numbers indicate that 2010-numbers are used, due to lack of available data

United Kingdom: Renewable Energy Resources

Renewable Energy Resources - UK						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	4,036.70	7.14		27,334.00	62.87	
Offshore Wind	1,341.20	3.05		40,000.00	120.00	
Photovoltaic	76.90	0.03		9,193.00	9.28	
Concentrated Solar Power	-	-		-	-	
Direct Geothermal	-	-		9,500.00		
Marine Energy	3.05			27,000.00	81.00	
			Hydro Storage (GWh)			*Hydro Storage (GWh)*
River Hydro						
Hydro	1,648.30	3.60		1,769.00	5.39	
Hydro Pump Back (if applicable)	2,800.00		3,139.44	2,800.00		3,139.44
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal	373.80					
Solar Thermal						
Geothermal	2.00	0.01		26.00	0.12	
Large-scale heat pumps					12.00	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual		
Energy Crops: Dedicated Land	5.51	18.31
Wood	6.73	20.67
Waste: Renewable & fossil	11.65	97.33
Biogas	24.35	38.25
Total	48.25	174.56

3.5.2 *References*

United Kingdom: Renewable Energy Resources

Renewable Energy Resources - UK						
	2010			Potential (2050)		
Renewable Electricity						
Type	*Capacity (MWe)*	*Annual Production (TWh/year)*		*Capacity (MWe)*	*Annual Production (TWh/year)*	
Onshore Wind	[UK4]: Wind Onshore (DUKES): 4,036.7 MW [1]: Wind (On- & Offshore): 5,204 MW [5]: Wind power (On- & Offshore): 5,378 MW. [6]: Wind power (Offshore): 1,341 MW = 4,037 MW.	[UK4]: Wind Onshore (DUKES): 7,137 GWh [1]: Wind (On- & Offshore): 10,183 GWh [5]: Wind power: 10.18 TWh		67,334 MW [1] - 40,000 MW [UK8]= 27,334 MW [1]: Wind (On- & Offshore): 67,334 MW [UK8]: Offshore Wind: >40 GW in 2030. Onshore Wind: 10-19 GW (23-45 TWh) in 2020.	Based on 2300 full load hours per MW in [UK8] for onshore wind in 2020.	
Offshore Wind	[UK4]: Wind Offshore (DUKES): 1,341 MW [6]: (2010-data) Wind power (Off shore): 1,341.2 MW [1]: Wind (On- & Offshore): 5,204 MW	[UK4]: Wind Offshore (DUKES): 3,046 GWh [4]: Wind (On- & Offshore): 10,183 GWh		[UK8]: Offshore Wind: >40 GW in 2030. [1]: Wind (On- & Offshore): 67,334 MW	Based on 3000 full-load hours per MW in [1] for on- and offshore wind in 2050. Wind (On- & Offshore): 204340 GWh (67334 MW)	
Photovoltaic	[UK4]: (DUKES) Solar photovoltaics: 76.9 MW [1]: (2010) Solar: 77 MWp [5]: (2010) PV on grid: 77 MWp PV off grid: 2 MWp Total: 79 MWp	[UK4]: (DUKES) Solar photovoltaics: 33 GWh [4]: Solar: 33 GWh (2010) [5]: PV: 33.2 GWh (2010)		[1]: Solar: 9,193 MW	[1]: Solar: 9,279 GWh	
Concentrated Solar Power	[8]: Not on the list	[8]: Not on the list		[10]: Solar radiation in UK is below 1000 kWh/m2 Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. UK is therefore unsuitable for CSP	[10]: Solar radiation in UK is below 1000 kWh/m2 Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints. UK is therefore unsuitable for CSP	
Direct Geothermal	[5]: Geothermal electricity plants: Capacity installed: 0 MW	[1]: Geothermal (and other renewables): 0 GWh		[UK9]	[1]: Geothermal (and other renewables): 8,898 GWh Not included since it is questionable whether or not it is Geothermal.	

Marine Energy	[5]: Ocean energy: Wave: 0.5 MW Limpet 0.8 MW Oyster 2 0.75 MW E.ON Pelamis P2 Tidal: 0.25 MW Open Center Turbine 1.2 MW SeaGen 0.1 MW Pulse Stream 100 1 MW Atlantis AK 1000 0.5 MW DeepGen Tidal Generation [1]: Other renewables (tidal etc.): 0 MW	Only test sites		[UK8]: Marine energy: 27 GW in 2050 [1]: Other renewables (tidal etc.): 3,536 MW	Based on 3,000 full load hours per MW in [UK8] for marine energy in 2020.	
			Hydro Storage (GWh)			*Hydro Storage (GWh)*
River Hydro						
Hydro	[UK4]: (DUKES) (Small scale & Large scale excl. pumped storage): 195.4 MW + 1,453 MW = 1,648 MW [1]: Hydro (pumping excl.): 1,595 MW	[UK4]: (Small scale & Large scale excl. pumped storage): 511 GWh + 3,092 GWh = 3,603 GWh [1]: Hydro (pumping excl.): 3,604 GWh 2010 seams to be a dry year in UK, based on the data in DUKES [UK5].		[1]: Hydro (pumping excl.): 1,769 MW	[1]: Hydro (pumping excl.): 5,389 GWh	
Hydro Pump Back (if applicable)	[UK5]		[UK5]: (DUKES) Pumped Storage: 3,139 GWh (Electricity used in pumping at pumped storage stations: 4,212 GWh)	No reference found. 2010-data is used.		No reference found. 2010-data is used.
Renewable Heat						
Type	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*	*Capacity (MWth)*	*Annual Production (TWh/year)*	*Thermal Storage (GWh)*
Individual Solar Thermal						
Solar Thermal	[5]: Thermal solar collectors: 534,043 m2 373.8 MWth					
Geothermal	[5]: Geothermal: Capacity: 2 MW	[5]: Geothermal: Energy using: 0.8 ktoe		[1]: Geothermal: 26 MWth [UK9]: 100 GWth	Same full load hours as in 2010, and capacity based on [1].	
Large-scale heat pumps					[UK6]: Large scale heat pumps (either ground source or marine) in the RESOM model: 12 TWh/yr	

Bioenergy		
	2010	Potential (2050)
Type	*Annual Consumption (TWh/year)*	*Annual Consumption (TWh/year)*
Energy Crops: Residual		
Energy Crops: Dedicated Land	[UK4]: (DUKES) Straw, SRC, and other plant-based biomass: 474 ktoe (~5.51 TWh/yr) [UK1]: Perennial Energy Crops: 2.2 PJ Biodiesel from oilseed rape, tallow and used cooking oil: 2.2 PJ Bio-ethanol from sugar beet: 0.8 PJ Straw: 3.0 PJ	[UK2]: Perennial energy crops: 65.9 PJ/yr (assumed 2030) Alternative: [UK3]: Perennial energy crops: 550 PJ/yr
Wood	[UK4]: (DUKES) Wood waste: 220 ktoe Wood: 359 ktoe Total: 579 ktoe (~6.73 TWh/yr) [UK1]: Wood: 15.0 PJ Wood waste: 4.5 PJ [5]: Solid biomass: Primary energy production: 1.32 Mtoe (~15.35 TWh) Heat consumption: 0.81Mtoe (- Mtoe to DH) Gross electricity production: Electricity only plants: 4.68 TWh CHP plants: 0.58 TWh Total: 5.25 TWh	[UK2]: Forestry and forestry residues: 74.4 PJ/yr (assumed 2030) Alternative: [UK3]: Forestry and forestry residues: 25 PJ/yr

Waste: Renewable & fossil	[UK4]: (DUKES) Waste* and tyres: 1002 ktoe () *Municipal solid waste, general industrial waste and hospital waste. [UK1]: MSW, Tyres and "other" plant based biomass: 54.6 PJ [5]: Municipal Waste (Renewable share): Primary energy production: 557,6 kt Gross electricity production: Electricity only plants: 1157 GWh CHP plants: 441 GWh Total: 1598 GWh	[UK3]: Wastes: 350.4 PJ (assumed 2030)
Biogas	Landfill gas: 1574 ktoe (~18,31 TWh/yr) Sewage gas: 224 ktoe (~2,61 TWh/yr) Poultry litter, meat and bone, and farm waste: 296 ktoe (~3,44 TWh/yr) Total: 24,35 TWh/yr [UK1]: Landfill methane: 65.0 PJ Sewage gas: 10.2 PJ Poultry litter: 5.9 PJ Other Meat, bone & farm waste: 6.5 PJ [5]: Landfill gas: 1492,6 ktoe (~17,4 TWh) Sewage sludge: 258 ktoe (~3,0 TWh) Other biogas: 0 ktoe Gross electricity production: Electricity only plants: 5137 GWh CHP plants: 575 GWh Total: 5712 GWh	[UK2]: Agricultural residues: 137.7 PJ/yr (assumed 2030) Alternative: [UK3]: Agricultural residues: 75 PJ/yr.

4 References

4.1 General

[1] European Commission. 2013. EU Energy, Transport and GHG Emissions - Trends to 2050 - Reference Scenario 2013. http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf.

[2] EWEA European Wind Energy Association. 2013. Eastern winds - Emerging European wind power markets. http://www.ewea.org/fileadmin/files/library/publications/reports/Eastern_Winds_emerging_markets.pdf

[3] EWEA, The European Wind Energy Association. Annual Report 2010. Powering the energy debate.

[4] EWEA, The European Wind Energy Association. 2011. EU Energy Policy to 2050 - Achieving 80-95 % emissions reduction

[5] EurObserv'ER. 2012a. The State of Renewable Energies in Europe 2012 Edition. http://www.eurobserv-er.org/pdf/press/year_2012/bilan/english.pdf.

[6] EurObserv'ER. 2012b. Wind power barometer. http://www.eurobserv-er.org/pdf/press/year_2012/bilan/english.pdf.

[7] EurObserv'ER. 2014a. Photovoltaic Barometer. http://www.eurobserv-er.org/pdf/windpower_2012.pdf

[8] EurObserv'ER. 2014b. Solar thermal and concentrated solar power barometer. http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro221_en.pdf

[9] EurObserv'ER. 2014c. Wind energy barometer. http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro-jde14-gb.pdf

[10] Breyer, Christian & Gerhard Knies. 2009. "Global Energy Supply Potential of Concentrating Solar Power." In Proceedings SolarPACES 2009, Berlin, 2009. http://www.trec-uk.org.uk/reports/Breyer_paper_SolarPACES_GlobalEnergySupplyPotentialCSP_final_090630_proc.pdf

[11] Alterra & IIAS. 2012. Biomass Futures - Atlas of EU biomass potentials.

4.2 Croatia

[HR1] AgriPolicy - Enlargement Network for Agripolicy Analysis. 2009. Analysis of Renewable Energy and its Impact on Rural Development in Croatia

[HR2] IEA. 2014. International Energy Agency Statistics Database. http://www.iea.org/statistics/statisticssearch/report/?country=CROATIA&year=2010&product=RenewablesandWaste

[HR3] Embassy of Belgium in Croatia - Economic and Commercial Office. 2012. Renewable Energy in Croatia.

[HR4] Inteligentna Energija. Biomass EuVET 2012. BIOMASS IN CROATIA Report on the situation of biomass (production, supply, use) as fuel in Croatia, and RES in education as an answer to renewable market demands

[HR5] Croatia. Ministry of Economy, Labour and Entrepreneurship. 2009. Energy Strategy of the Republic of Croatia. http://www.mingo.hr/userdocsimages/White%20Paper%20Energy%20Staregy%20of%20the%20Republic%20of%20Croatia.pdf

4.3 Czech Republic

[CZ1] Czech Republic. Ministry of Industry and Trade. 2010. National Renewable Energy Action Plan for the Czech Republic. http://ec.europa.eu/energy/renewables/transparency_platform/doc/dir_2009_0028_action_plan_czechrepublic.zip

[CZ2] Association for the District Heating of the Czech Republic (ADH CR). 2014. State energy concept data (version September 2013). Data sent 17th of September 2014 via email.

[CZ3] Czech Biomass Association (CZ Biom). 2011. 4Biomass - Study on Biomass Trade in the Czech Republic. http://www.central2013.eu/fileadmin/user_upload/Downloads/outputlib/4Biomass_Trade_study_Czech_Republic_uploaded.pdf

[CZ4] BSREC, BIOMASA, CRES, Innoterm, ISPE & SEVEn. n.d.. Accelerated Penetration of Small-Scale Biomass and Solar Technologies - Maps and databases on the biomass potential in BULGARIA, CZECH REPUBLIC, HUNGARY, ROMANIA, SLOVAKIA + Greece. http://www.fao.org/uploads/media/biomass_maps_databases.pdf

[CZ5] Czech Biomass Association (CZ Biom). 2009. 4Biomass - Country Study on Political Framework and Availability of Biomass. The estimated maximal technical potential will be reached in the year 2050. http://www.central2013.eu/fileadmin/user_upload/Downloads/outputlib/4biomass_country_study_Chech_Republic.pdf

4.4 Italy

[IT1] IEA SHC. 2014. Solar Heat Worldwide. http://www.iea-shc.org/solar-heat-worldwide.

[IT2] CNES. 2008. Rapporto prelimiare sullo stato attuale del solare termico nazionale. http://www.regione.sicilia.it/industria/use/Documenti%20ufficiali%20energia/Nazionali/rapporto_preliminare_cnes_solare_termico.pdf

[IT3] UGI. 2011. Previsioni di crescita della geotermia in Italia fino al 2030. http://www.unionegeotermica.it/pdfiles/stime-sommario.pdf

[IT4] GSE. 2009. Piano di Azione Nazionale per le energie rinnovabili. http://approfondimenti.gse.it/approfondimenti/Simeri/AreaDocumentale/Documenti%20Piano%20di%20Azione%20Nazionale/PAN%20DETTAGLIO.pdf

[IT5] Terna. 2010. Impianti di generazione. http://www.terna.it/LinkClick.aspx?fileticket=%2Bh7uq4IGmE8%3D&tabid=418&mid=2501

[IT6] ENEA. 2010. Le fonti rinnovabili. http://www.fire-italia.it/20_20_20/FontiRinnovabili_enea.pd

[IT7] ENEL. 2014. ENEL website. http://www.enel.it/it-IT/impianti/

[IT8] ProgettoDighe. 2014. ProgettoDighe website. http://www.progettodighe.it/main/le-centrali/

[IT9] RSE. 2011. Valutazione del potenziale dei sistemi di accumulo di energia mediante centrali di pompaggio idroelettrico per il sistema idroelettrico italiano. http://doc.rse-web.it/doc/doc-sfoglia/11000299-314162/11000299-314162.html

[IT10] Italian District Heating Association (AIRU). 2014. Data sent 19th of September 2014 via email.

[IT11] ITABIA. 2008. Goals of bioenergy in Italy. http://www.itabia.it/pdf/rapporto2008eng.pdf

4.5 Romania

[RO1] Harghita Energy Management Public Service & UEM-CARDT. Romania National Report. http://www.southeast-europe.net/document.cmt?id=311

[RO2] IEA. 2014. International Energy Agency Statistics Database. http://www.iea.org/statistics/statisticssearch/report/?country=ROMANIA&product=renewablesandwaste&year=2010

[RO3] BSREC, BIOMASA, CRES, Innoterm, ISPE & SEVEn. n.d.. Accelerated Penetration of Small-Scale Biomass and Solar Technologies - Maps and databases on the biomass potential in BULGARIA, CZECH REPUBLIC, HUNGARY, ROMANIA, SLOVAKIA + Greece. http://www.fao.org/uploads/media/biomass_maps_databases.pdf
[RO4] Romania. Ministry of Economy, Trade and Business Environment. 2010. Biomass Master Plan for Romania. http://www.enero.ro/en/projects/StudiiBiomasa/doc/Biomass%2520Master%2520Plan%2520Romania_EN.pdf
[RO5] ENERO - Center for Promotion of Clean and Efficient Energy in Romania. 2009. Market development biomass Romania survey: Scenarios Study Biomass Romania. http://www.enero.ro/proiecte/StudiiBiomasa/doc/Study%20on%20Scenarios_Biomass_Romania_2009.pdf

4.6 United Kingdom

[UK1] United Kingdom. UK Energy Research Centre. 2010. The UK bio-energy resource base to 2050: estimates, assumptions, and uncertainties. http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=727.
[UK2] United Kingdom. Department for Environment, Food & Rural Affairs. 2007. UK Biomass strategy 2007. Found in [1]. (Scenario: Future High (no date - assumed 2030))
[UK3] United Kingdom. Royal Commission for Environmental Pollution. 2004. Biomass as a renewable resource. Found in [1].
[UK4] United Kingdom. Department of Energy and Climate Change. 2011. Digest of United Kingdom energy statistics (DUKES) 2011. http://webarchive.nationalarchives.gov.uk/20130109092117/http://www.decc.gov.uk/media/viewfile.ashx?filetype=4&filepath=11/stats/publications/dukes/2312-dukes-2011--full-document-excluding-cover-pages.pdf
[UK5] United Kingdom. Department of Energy and Climate Change. 2014. Historical electricity data: 1920 to 2013. https://www.gov.uk/government/statistical-data-sets/historical-electricity-data-1920-to-2011
[UK6] United Kingdom. Department of Energy and Climate Change. 2013. The future of heating: meeting the challenge. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf (Explicit in [UK7])
[UK7] Redpoint. 2013. Modelling to support The future of heating: meeting the challenge - report by Redpoint. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197562/baringa_heat_paper_analytical_support.pdf
[UK8] United Kingdom. Department of Energy and Climate Change. 2011. UK Renewable Energy Roadmap. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-uk-renewable-energy-roadmap.pdf
[UK9] Renewable Energy Association. 2012. Deep geothermal resource has potential to produce up to 20 % of UK electricity and heat for millions. http://www.r-e-a.net/news/deep-geothermal-resource-has-potential-to-produce-up-to-20-of-uk-electricity-and-heat-for-millions

Project No: IEE/13/650

Stratego
ENHANCED HEATING & COOLING PLANS

Mapping the Renewable Heat Resources in Europe

Work Package 2

Background Report 9

Co-funded by the Intelligent Energy Europe Programme of the European Union

Authors: Bernd Möller
Contact: University of Flensburg
Munketoft 3b
Raum MV 014
24937 Flensburg
Tel: +49 (0) 461/805-2506
Fax: +49 (0) 461/805-2505

Deliverable No. D 2.2: Public Document.

Co-funded by the Intelligent Energy Europe Programme of the European Union

The STRATEGO project (Multi-level actions for enhanced Heating & Cooling plans) is supported by the Intelligent Energy Europe Programme. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

4DH
4th Generation District Heating Technologies and Systems

STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Heat Roadmap Europe 2050

Contents

1 Biomass mapping

The availability of sustainable biomass in the EU is difficult to quantify as it depends on many factors. The operation of biomass and other fuel markets; the available economic incentives; and also the pace of technological change in the renewable energy system all influence the type, amount and geographical origin of biomass, which will contribute to achieve the 20% target for renewable energy supply in 2020. The European Commission states that *"The projected contribution of biomass thus hinges heavily on assumptions."* (EC, 2015).

Biomass resource assessments differ greatly for the same area or country, because of the many different methods used, because of heterogeneous data, uncertainties in the empirical data base, as well as different perceptions on the technology implied (BEE, 2015).

This means that it is not possible on none of the three levels: ecology, agro-forest economy, and technology to reach agreement on the absolute amounts of biomass, let alone their geographical distribution in a given country or region. Several reports, however, comprise national and sometimes regional accounts for future available biomass for energy purposes (AEBIOM, 2011; AEBIOM, 2014) and also formulate limits of sustainable biomass use (EEA, 2006).

A regionalized account of all biomass resources for the purpose of quantifications of the amounts of available and economically feasible biomass is therefore discouraging to attempt. A simple way of quantifying biomass for energy would be to map the amounts of biomass from forestry operations as well as agricultural residues on the basis of empirical data on current and past management practices. However, a significant proportion of this potential is already being used for energy and non-energy purposes, often outside a quantifiable supply chain. Also, the use of biomass for energy purposes usually brings along a change of management practices, so empirical yield and waste potential data cannot be used. Then, the present management practices and their resulting biomass extraction ratios do not in general represent a state of equilibrium in either an economic or ecologic sense. Finally, the processes and their variables which describe the proportions of biomass that can be harvested on an economic basis in the regional biomass for energy markets are largely unknown on a European scale. Any attempt to map a regional distribution of sustainable and economically available biomass resources is therefore a major challenge.

1.1 Sustainable biomass resources

Sustainability of biomass for energy implies a long-term maintenance of carbon stock and biodiversity. This can only be achieved in forestry when maintaining forest volumes, forest density (in terms of standing volume per area as well as forest area per land area), and forest area and forest ecosystems. Any shift towards lower carbon stock results in a depletion, which should be avoided. For the agricultural sector, this implies the maintenance of soil texture (amount of organic matter, humus) and hence fertility as well as the land available as arable land. It also includes indirect land use change (ILUC) effects, which result from the shift of crops and their substitutes from one part of the world to another, like it is often seen with the replacement of domestic fodder with imported soy beans e.g. due to an increase in domestic energy crops. Any addition to the biomass resource potential should therefore avoid changing land use, the intensity of land use, as well as the present carbon stock per land use unit, assuming that the present land use is sustainable, which can be argued about.

Wood for biomass is increasingly imported from neighboring regions such as the Baltic area, Russia or even traded globally from North America or elsewhere. The present study only includes domestic wood resources from within the EU28 and focuses on the local availability, which excludes long distance transport.

Biomasses used for the production of biofuels are also excluded from the study, which primarily looks at the fuel demands for the heating and power generation sectors.

1.2 Biomass from agriculture

Emphasis is here on residues from agriculture, which are marginal to agricultural production. Dedicated energy crops are not included, partly because they may be too costly for district heat generation, partly because of increasing issues of sustainability. On a large scale, only the waste products of the main agricultural crops, here mainly straw from cereals, are included here.

Assuming that land use remains unchanged and that the present productivity is not increased for the sake of biomass for energy production, the gross potential of straw can be assessed using the present area of arable land and the present productivity of cereal production, as well as the ratio of straw production to cereals production. In Denmark, where the use of straw for energy purposes is probably at its highest development stage, about 40% of the cereals yield is available as straw in a long-term average (Statistics Denmark, 2014).

Straw production among the 28 member states was assessed using Eurostat agricultural statistics dating from 2009 to 2013 (where available). An average productivity of cereal production was derived using the 5-year averages of annual production divided by the area on which cereals were planted in that period. Then, agricultural areas were mapped by extracting the “Arable land” land use class from the 2006 Corine land cover database (EEA, 2014). The potential production of cereals, to which the possible straw production is proportional, is hence the locally available arable field area times the productivity achieved in each country. It is here assumed that cereals or similar crops, which would produce similar wastes as straw, are planted on all arable lands, which e.g. does not seem to be the case for the UK. This method further assumes that productivity is the same within a given country and that the national productivity is unchanged. It includes those factors, like the intensity, the degree of mechanization, the economic efficiency etc. of cereal production in a given country, but assumes that cereals can be planted on all arable land.

Since the exact location is neither important nor possible to know, the resulting potential of straw is here summarized within a 30km radius around each location on the map. The distance refers to the distance at which straw usually is transported for small scale applications such as district heating plants. The resulting map, see Figure 1, shows the regional maximal availability of straw from agriculture.

A few restraints have to be considered. First, the present method assumes that all available arable land is used for cereals. Although the Corine land use classification distinguishes quite well between land use and types of agriculture, arable land may also be used for other crops. Neither is it possible to include on this scale the fertility of soils, which effectively reduces the potential to grow cereals.

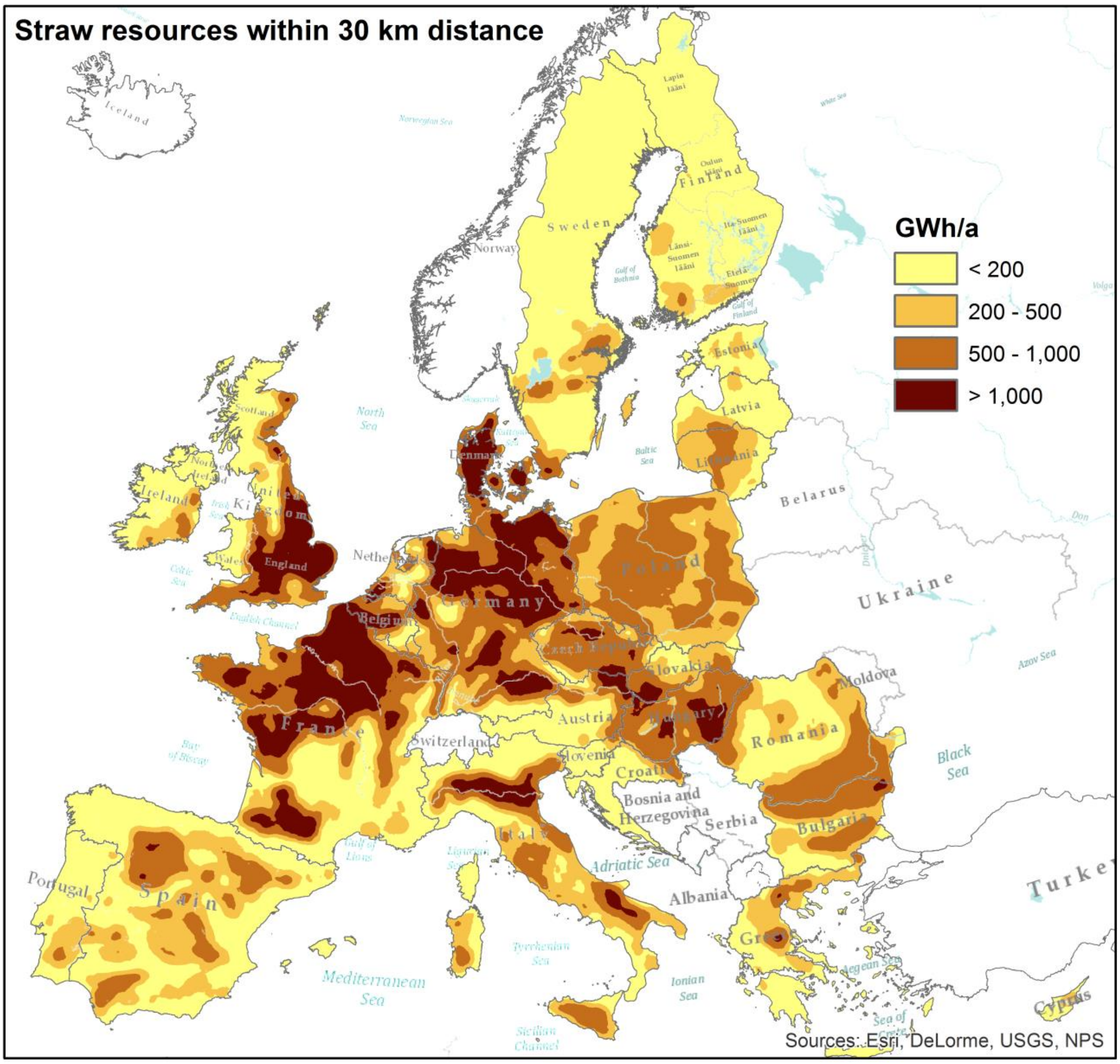


Figure 1: Straw resources from biomass within a distance of 30km of each location. This map shows densities of straw wastes from cereal production from all possible arable lands.

1.3 Biomass from forestry

Similar to the agricultural biomass potential assessment above, the resources of forestry biomass have been based on land use as well as recent productivity. However, forest land use cannot easily be expanded, and forestry management is highly affected by conservation and environmental protection. Therefore the present method of biomass resource assessment from the European forest sector excludes national conservation areas (domestic denominated areas), (EEA, 2015a) as well as areas subject to the Natura2000 directive (EEA, 2015b). Also, although the distribution of forests of different densities and species highly depend on the local and regional geography, a uniform productivity is being applied within each country.

Forest distribution by density is done using the forest density map available at 1km resolution from the European Forest Institute (EFI, 2014). It shows the percentage of forest coverage and density combined for each square kilometre, resulting in a count of dense hectares per km^2. That means if there are patches of forest within a km^2, or heterogeneous forest density within that area unit, the value of the grid is still a count of hectares. Only the total density was used, disregarding the difference between deciduous and coniferous species, for which no distinction is made in the Eurostat table of forest productivity.

From the forest density maps those areas are excluded, which are Natura2000 areas or domestic conservation areas (except IUCN code "V", which comprises many areas of protected landscape character, where forestry operations are not affected by conservation legislation). This is done mainly to reduce the high pressure on remaining natural forests as well as national parks or smaller habitat areas, from which no commercial forest extraction is expected (in fact the Danish Nationalpark Thy is a major source of wood chips from sustainable forest management and the gradual modification of the national park area to near-nature state forest, which may take decades to implement).

The Eurostat tables for forest increment and felling, which contain productivity data since 1990, were used to derive long term averages (20 years) of the increment due to net forest volume and area growth as well as the extraction of timber. This should level out storm events as well as major changes in management practices, which are significant in particular for some member states in the East of Europe under the structural change towards a more commercial timber production.

This study assumes that across Europe, 20% of the annual felling and a further 10% of the net increment can be used for energy purposes. This includes the sustainable use of felling residues, which can be up to 50%, which otherwise would be left in the forest, as well as the extraction of predominantly young, non-commercial timber in thinning operations as part of forest management. A wood resource extraction ratio ($m^3/(ha*a)$ was calculated using the actual forest management statistics in combination with these assumptions. The extraction ratio was multiplied with the forest density map that excludes conservation areas, as well as a heat value of wood residues to derive an energy density map. Finally, a 30km radius was applied for accounting locally available biomass resources, see Figure 2. Although forest residues can be economically transported over larger distances, the emphasis is here on locally available resources. And since no allocation of resources on specific locations is made, a further increase of distances is not necessary. The resulting map shows the regional availability of forest resources under the chosen constraints.

The present method neglects the fact that in some areas the biomass is already used in existing bioenergy schemes or otherwise a commercial commodity that is not available for energy purposes. Further, the productivity rates are calculated as national averages, while the real forest sector is rather heterogenic, with high-intensity areas as well as low-productivity forest. Cross-border flows of timber are not considered across the external EU borders. Finally, not all of the wood in the periphery of Europe is equally accessible for transport to energy plants, e.g. in Northern Scandinavia.

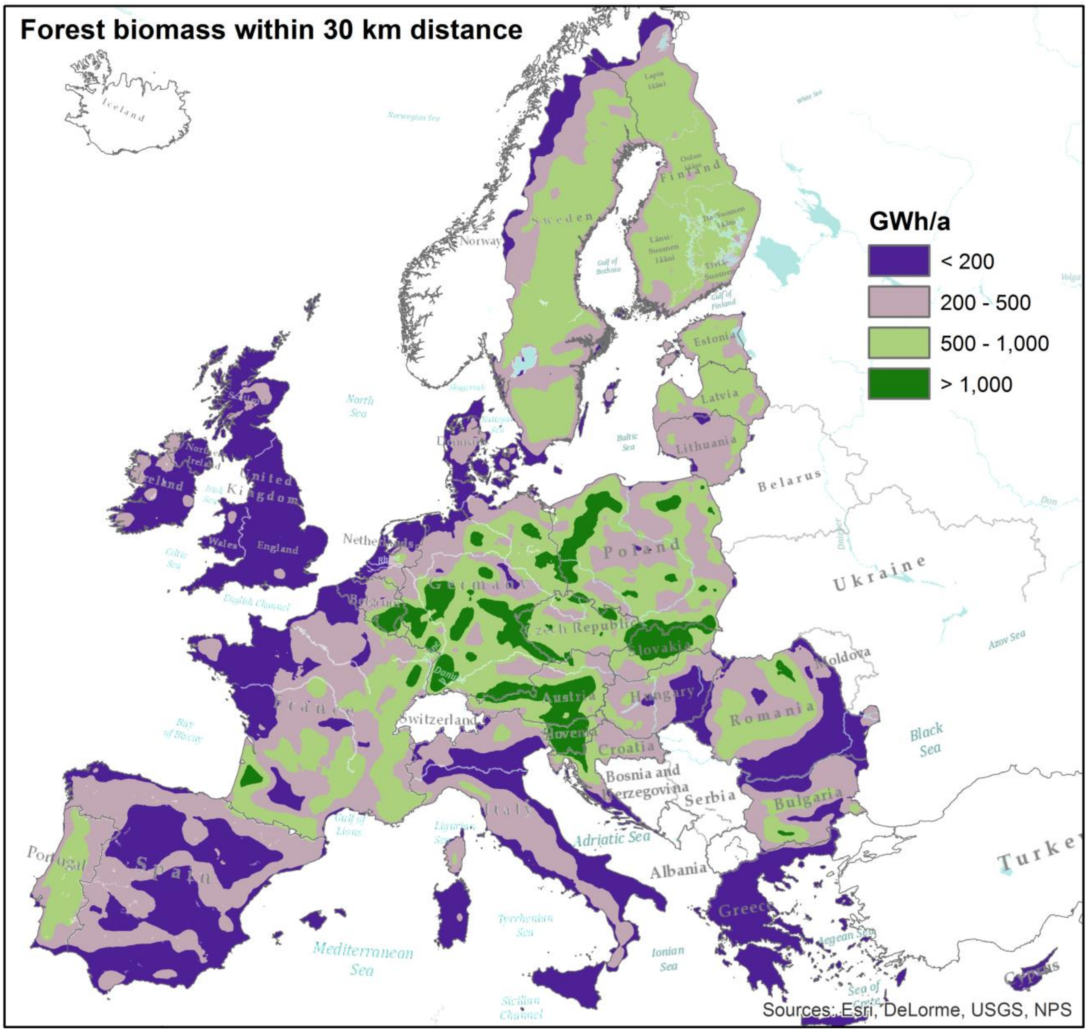


Figure 2: Potential biomass resources from forestry including thinning as fraction of annual increment and logging residues as share of annual felling. The map shows densities by accounting for forest biomass available within a radius of 30km around each location.

The total amounts of straw and wood for energy purposes in the five Stratego countries are given in Table 1. The figures reflect the current productivity of the forest sector and the assumed productivity in the agricultural sector. The rationale is that while changes in forest productivity take decades to implement, the change of crops on available arable land could be accomplished within much shorter times. Of course the emphasis on straw and other waste materials as marginal products implies that there is a market for the crops produced. The same applies for forest products and is linked to forest and agricultural policies, which, as stated before, are not necessarily operating at optimum at present times.

Table 1: Biomass amounts in TWh/a in the target countries.

Member state	Forest biomass	Straw
CZ	22.26	6.08
HR	10.57	0.82
IT	23.64	16.16
RO	30.68	10.74
UK	7.72	18.25

2 Mapping geothermal heat resources relative to district heating potentials

Geothermal heat of sufficient temperature and volume may be found under large parts of Europe. In order to assess the potential for geothermal energy, underground temperature (enthalpy) is only one of several selection criteria. The bedrock permeability and the presence of water influence the heat flow as well. That means that a study of the geothermal heat supply is based on interpreted information on the geological conditions. Still, a great deal of uncertainty remains. The GeoDH project (GeoDH, 2015) has mapped reservoirs and other conditions that indicate favourable conditions for geothermal heat. For the present assessment of geothermal energy sources the GeoDH project kindly made available the geographical data layers that are the basis of geothermal mapping.

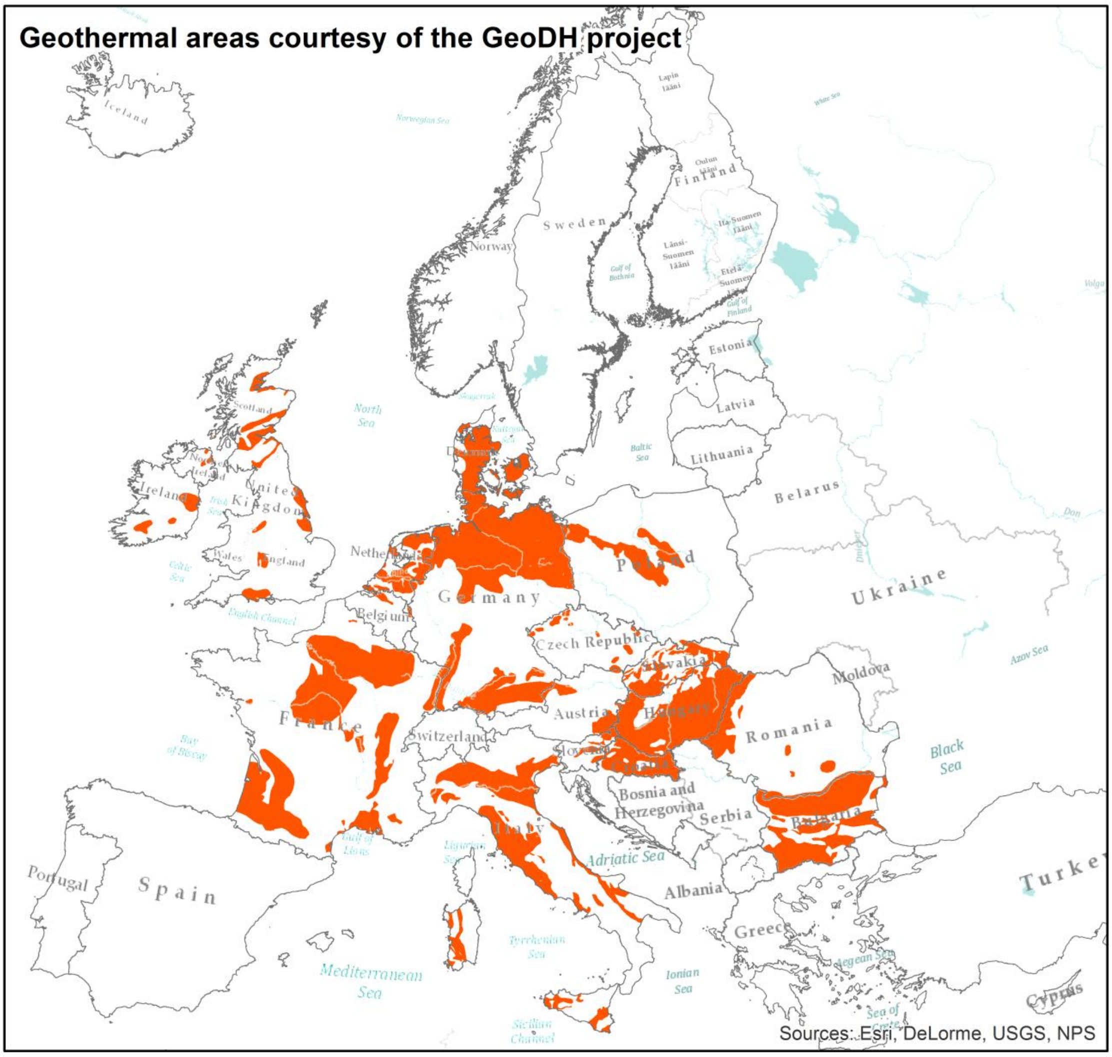


Figure 3: Map of suitable geothermal areas, which are characterised by hot sedimentary aquifers or other potential reservoirs.

From the several layers available in the GeoDH GIS, “hot sedimentary aquifers” and “other potential reservoirs” were chosen, as they are deemed suitable for geothermal district heating and cooling.

Further, the temperature levels at certain depths are relevant to look at, where one would look for temperatures exceeding 60°C and located no deeper than 3km (GeoDH, 2015).

It was found that the map below (Figure 3) is not concise, as e.g. the city of Lund in Sweden has installed a geothermal district heating system, while it is not located within one of the favourable areas. For further development of the model a more advanced method like the one used for the Geoelec project (Geoelec, 2014) could be made available for the present atlas.

To assign the geothermal heat potentials to district heating potentials, the heat demand in prospective district heating areas of different size was summarized by location within geothermal areas, seeTable 2. Also, for each prospective district heating system an attribute of geothermal potential has been assigned if it lies within a geothermal area.

Table 2: Heat demand located in potential geothermal areas by the size of district heating system (in PJ annual heat demand)

	< 0.3 PJ	0.3-1 PJ	1-3 PJ	3-10 PJ	>10 PJ	Total
CZ	6.59	5.80	13.25	3.70	-	29.342
HR	11.48	5.32	2.24	-	12.08	31.119
IT	110.93	53.48	70.09	42.50	319.51	596.506
RO	15.19	2.78	6.03	3.63	27.83	55.449
UK	18.98	13.00	22.96	15.48	33.38	103.812

3 Mapping sources of ambient heat in surface and sewage water bodies

Ambient heat as a source of heat to be used by means of large-scale heat pumps has been mapped using land-use mapping (Corine) of surface water bodies exceeding 1 hectare in size as well as rivers (EEA) and their network hierarchy. The rationale is that surface water, still or running may be used as low-temperature heat reservoirs. The size and vicinity of lakes, the access to coastal waters, as well as the run-off volume of rivers are assumed to be relational to the contribution to heat that is possible to deliver by heat pumps. A series of factors makes an absolute assessment of heat quantities extremely difficult, which is why the accessibility of surface water is here expressed on a scale of 1 (poor) to 5 (excellent). While the total potential of heat recoverable from the environment is related to the net solar radiation, the following factors limit this: environmental considerations, technical feasibility, water rights, alternative uses, as well as temperature levels.

Proximity to surface water has been mapped in a focal statistics function, which summarizes the number of 1ha cells per km^2 within a radius of 5km. Hereby a density surface, which describes the area of lakes and coastal waters within the given radius, is produced. By reclassification to a scale of 1 to 5 a linear relation between the water area within reach of a heat pump and each prospective location of a district heating system has been established, where a value 5 indicates the highest availability of surface water.

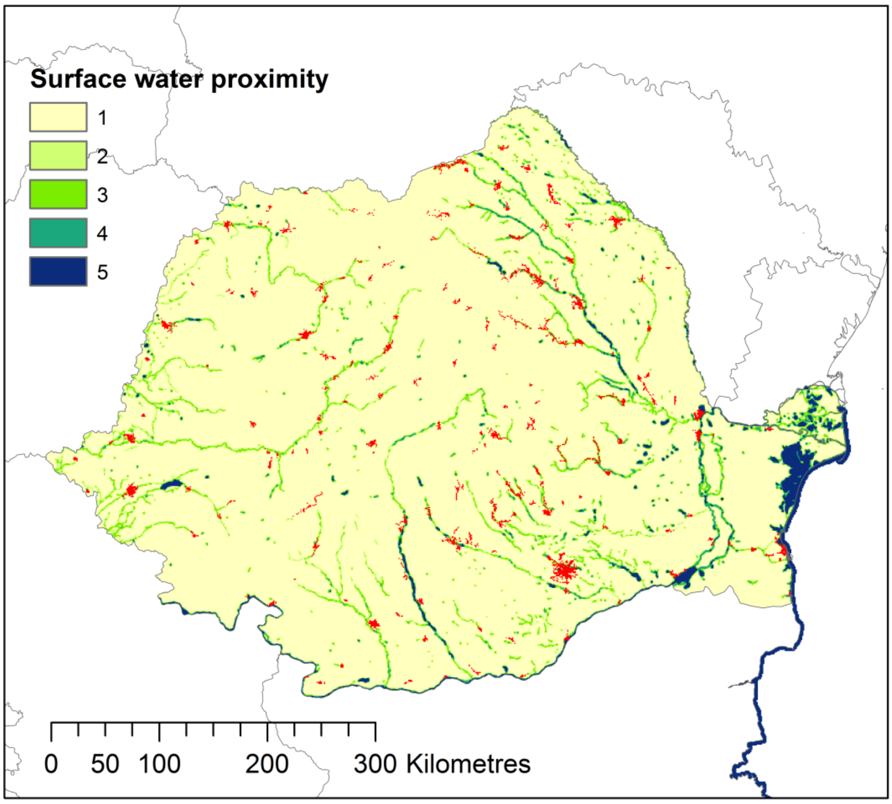


Figure 4: Map of surface water proximity for Romania.

For rivers, the European river network database (EEA) was used, which describes the river network hierarchy by means of the Strahler method, where the rank of rivers is increased from values of 1 onwards every time two rivers of the same order intersect. This results in an approximation of the run-off volumes of all rivers in Europe, which is thought to be proportional to the amount of low-temperature heat that can be extracted from rivers by means of heat pumps.

In order to assign the potential of river- and lake-based heat pumps, the highest potential score available at each prospective district heating system was related to these by means of a spatial statistics operation. Figure 4 shows the surface water proximity assessment in five classes relative to urban areas in Romania.

Heat extracted from sewage water by means of large heat pumps is assumed to be proportional to the population of towns and cities. A report by the heat pump manufacturer Ochnser (2012) assumes that 5% of heat demand can be covered in towns and cities with more than 10.000 people. Table 3 shows the potential of sewage water heat, which has been calculated using the population count (Geostat, see chaper 2.7) and calculated heat demand for each prospective district heating system with more than 10,000 inhabitants within the DH system boundaries.

Table 3: Heat extractable from urban sewage systems by means of heat pumps.

Country	Heat demand covered by sewage water (PJ)
CZ	1.37
HR	0.28
IT	7.61
RO	1.39
UK	13.87

References

AEBIOM (2014): European Biomass Association Statistical Report 14, Brussels.

AEBIOM (2013): European Biomass Association Annual Report 2013, Brussels.

Biomass Energy Europe (2015): Political Framework and User Requirements of Biomass Resource Assessments for Energy. Jyväskylä, 2010 (http://www.eu-bee.eu/_ACC/_components/ATLANTIS-DigiStore/BEE_D35_Political_Framework_and_User_Requirements_Version3_1_07e1b.pdf?item=digistorefile;247972;837&params=open;gallery

European Commission (2015): Agriculture and Rural Development, Biomass Potential. (http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm)

European Environmental Agency (2006): How much bioenergy can Europe produce without harming the environment? European Environmental Agency Report No 7/2006. Copenhagen.

European Environmental Agency (2014): Corine 2006, Coordination on Information on the Environment. Geodata downloaded from www.eea.europa.eu (August 2014)

European Environmental Agency (2015a): Domestic denominated areas. Geodata downloaded from www.eea.europa.eu (November 2014)

European Environmental Agency (2015b): Habitats directive , Article 17 habitats and species conservation status at the European level for the 2007-2012 reporting period. Geodata downloaded from www.eea.europa.eu (November 2014)

European Forest Institute (2014): Forest Map of Europe. Geodata downloaded from www.efi.int (November 2014)

Eurostat (2014): Eurostat agricultural and forestry sector statistics.

GeoDH (2015): The GeoDH Project. Geodata on geothermal potential. www.geodh.eu (October 2014)

Geoelec (2014): The Geoelec Project. www.geoelec.eu (January 2015)

Ochsner (2012): Waste water as heat source of heat pump. REHVA, Federation of European Heating,

Ventilation and Air Conditioning Associations, Brussels.

Statistics Denmark (2014): Agricultural statistics. www.dst.dk (January 2015)