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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

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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.

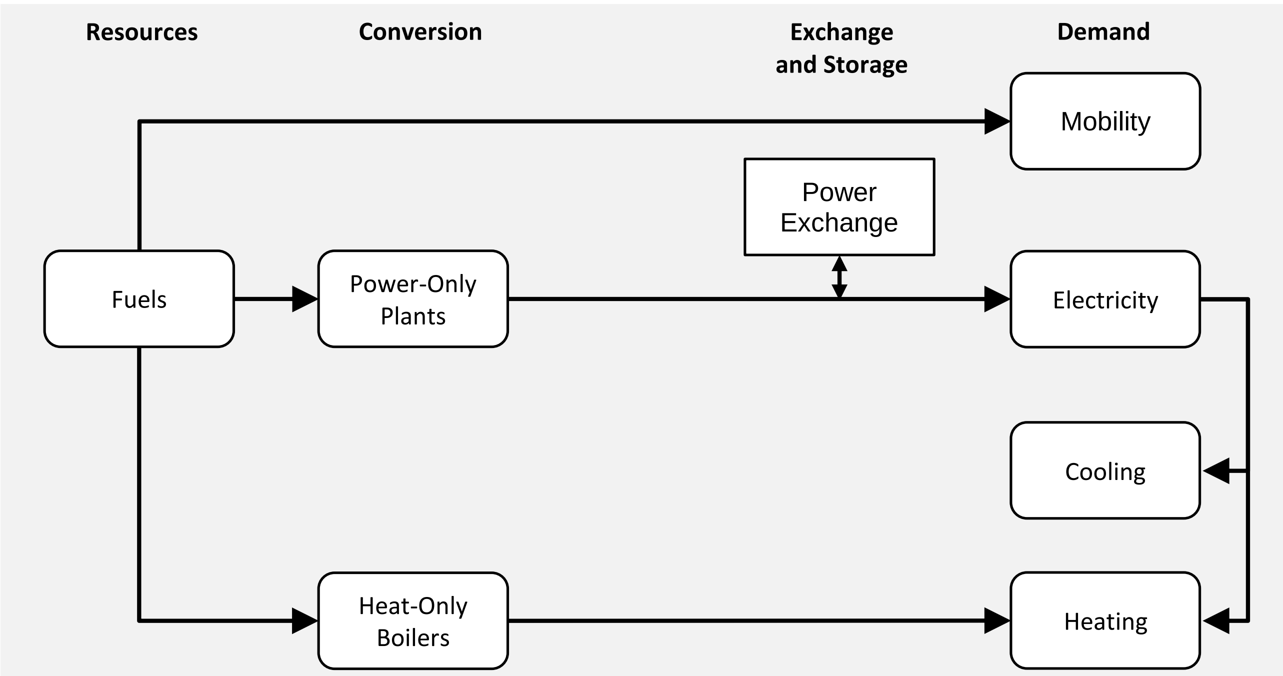

Figure 1: Interaction between sectors and technologies in today's energy system.

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.

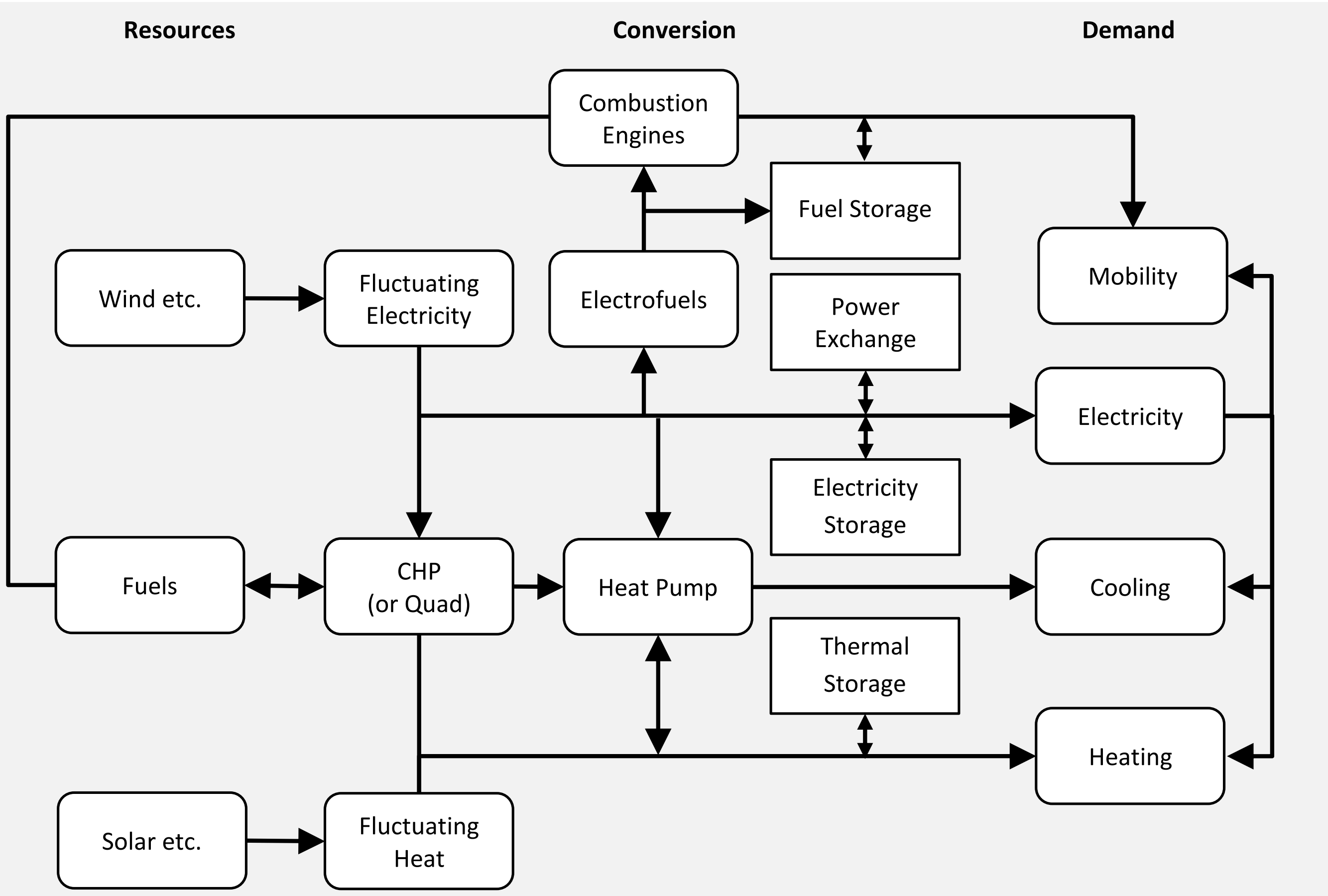

Figure 2: Interaction between sectors and technologies in a future smart energy system (a 100% renewable energy concept [2]**.**

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.

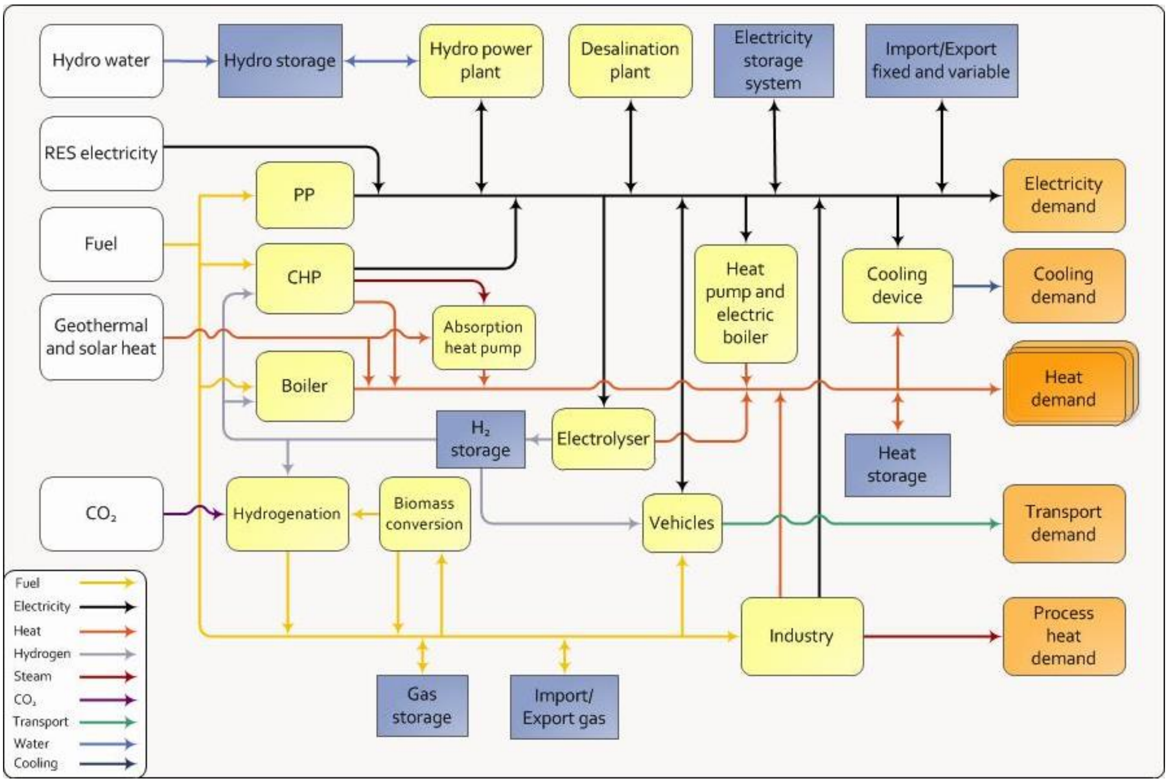

Figure 3: Flow chart of resources, conversion technologies, and demands considered in EnergyPLAN

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.

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

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.

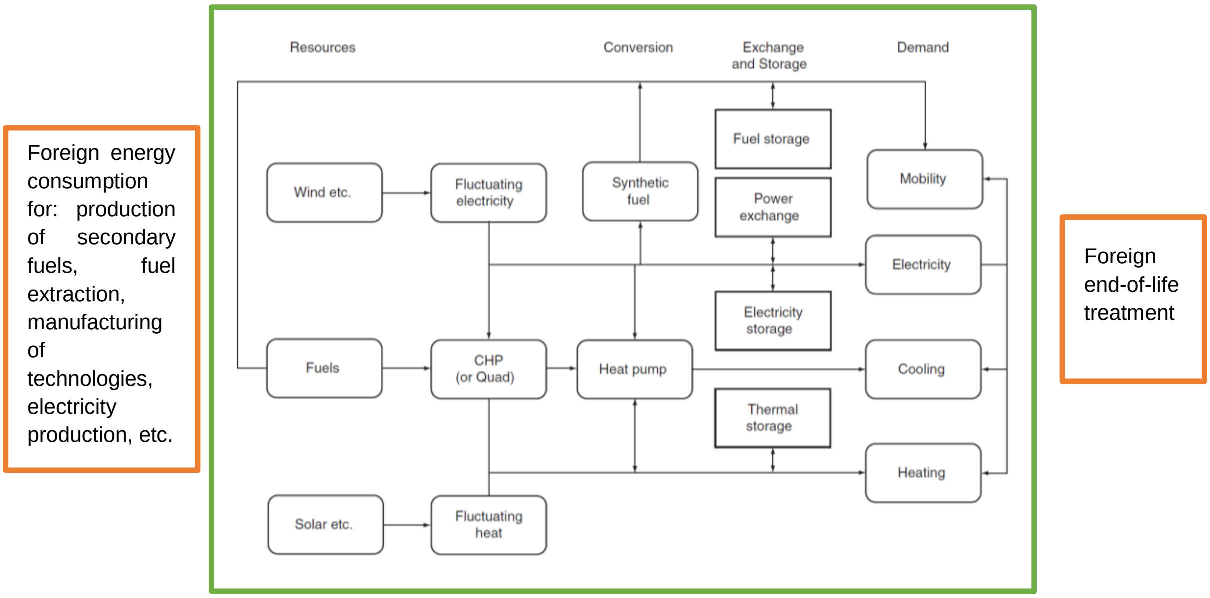

Figure 5: Boundary definition of the national energy system

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]

<table>
<tr><th>Energy source</th><th>Zero equivalent method</th><th>Direct equivalent method (as applied by UN statistics)</th><th>Physical energy content method (as applied by Eurostat and IEA)</th><th>Substitution method (as applied by US EIA)</th><th>Technical conversion efficiencies (as applied in LCA databases, e.g. GaBi 2012)</th></tr>
<tr><td>Hydro</td><td>n.a.</td><td>100%</td><td>100%</td><td>39.7%</td><td>85%</td></tr>
<tr><td>Wind</td><td>n.a.</td><td>100%</td><td>100%</td><td>39.7%</td><td>40%</td></tr>
<tr><td>Solar (photovoltaics)</td><td>n.a.</td><td>100%</td><td>100%</td><td>39.7%</td><td>13.4%</td></tr>
<tr><td>Solar (thermal electric)</td><td>n.a.</td><td>100%</td><td>33%</td><td>39.7%</td><td>12.4%</td></tr>
<tr><td>Geothermal</td><td>n.a.</td><td>100%</td><td>10%</td><td>39.7%</td><td>22.4%</td></tr>
<tr><td>Biomass (solid)</td><td>n.a.</td><td colspan="4">28.6%</td></tr>
<tr><td>Biogas & Bioliquids</td><td>n.a.</td><td colspan="4">26.2%</td></tr>
<tr><td>Waste</td><td>n.a.</td><td colspan="4">17.7%</td></tr>
<tr><td>Nuclear</td><td>n.a.</td><td>100%</td><td>33%</td><td>33%</td><td>33%</td></tr>
<tr><td>Imported electricity</td><td>n.a.</td><td>100%</td><td>100%</td><td>100%</td><td>Source specific, i.e. country specific</td></tr>
</table>

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:

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

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.

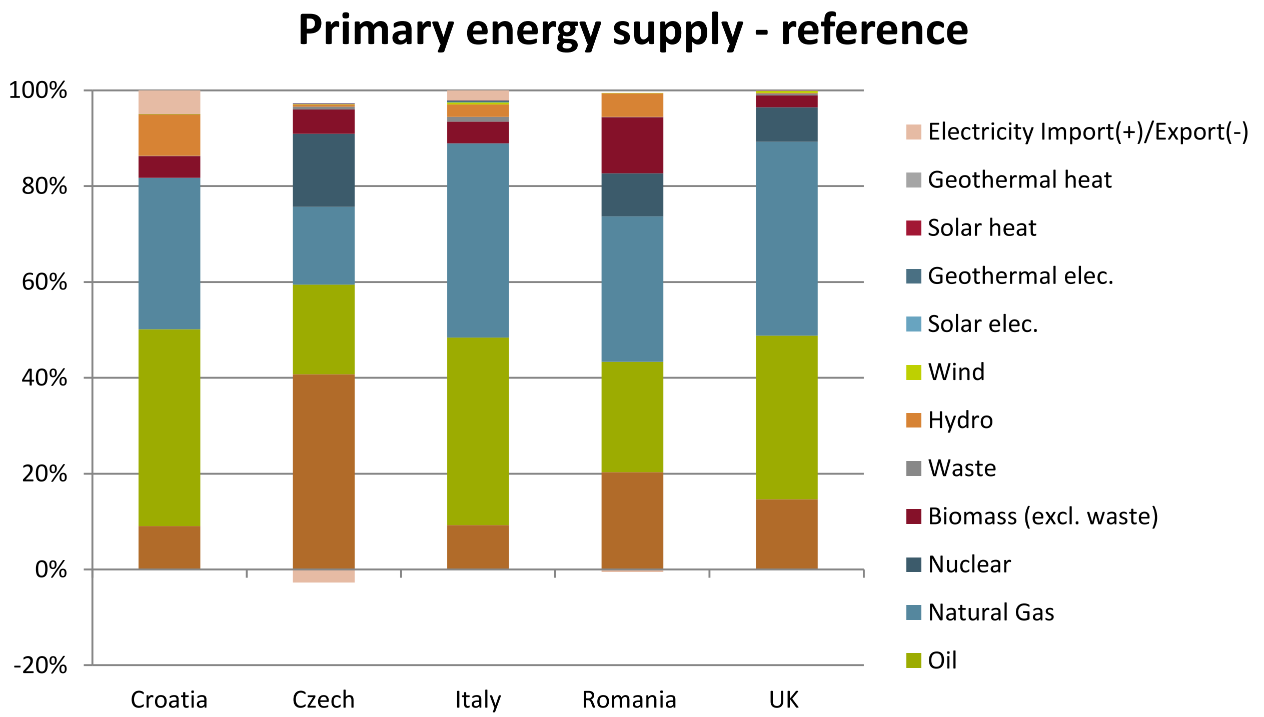

Figure 6: Primary energy supply shares out of the total for each country by fuel types. *A negative value for net import/export electricity indicates export while a positive is import.

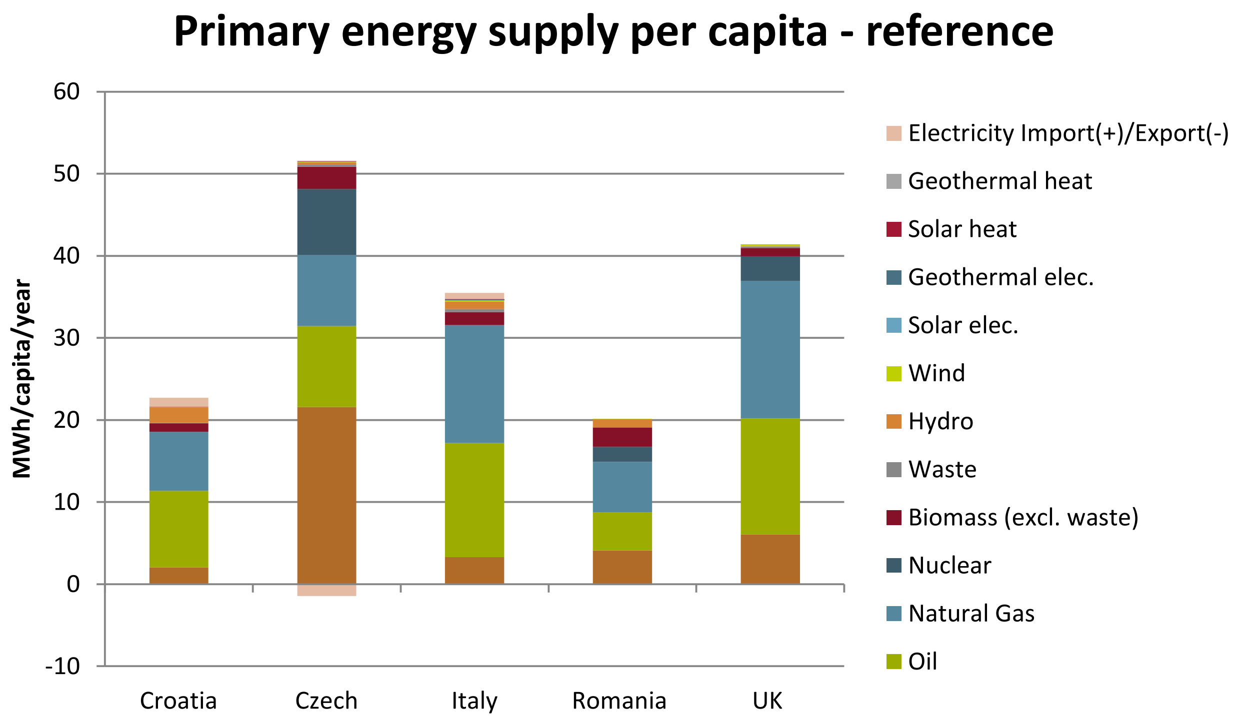

Figure 7: Primary energy supply per capita by fuel type for the STRATEGO countries

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.

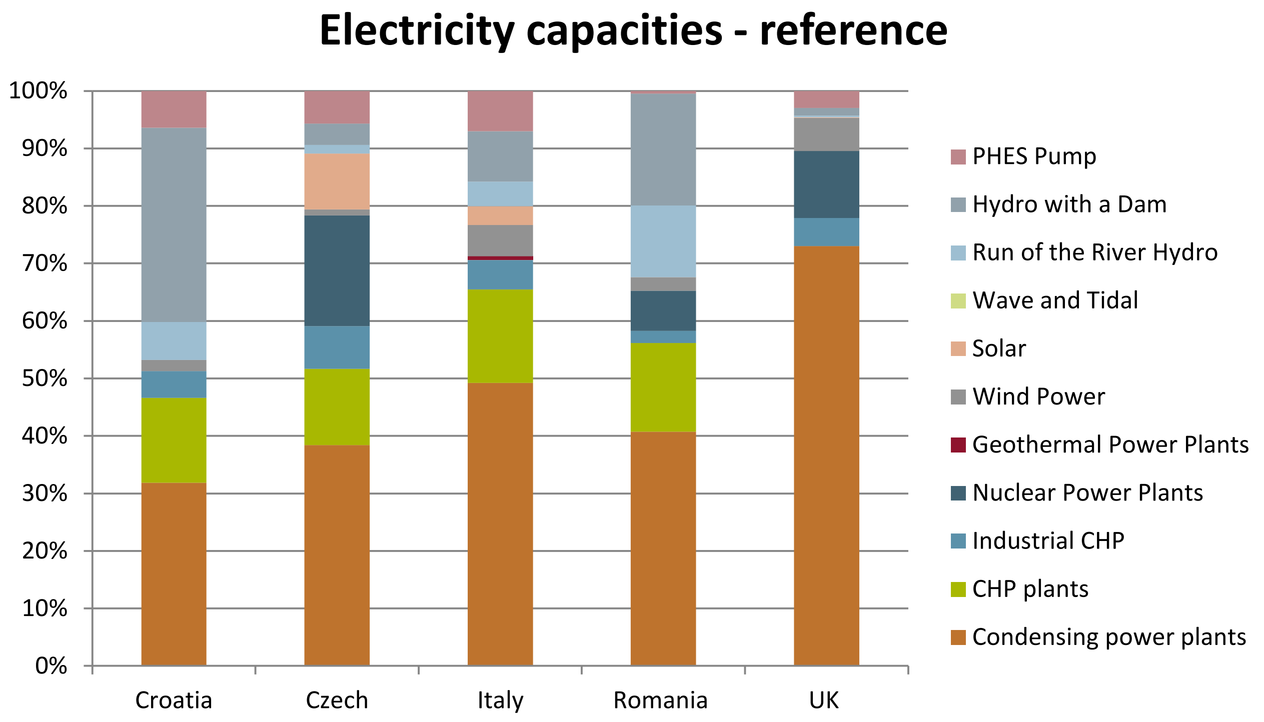

Figure 8: Electricity capacity shares out of the total capacity divided by technology type for the STRATEGO countries

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.

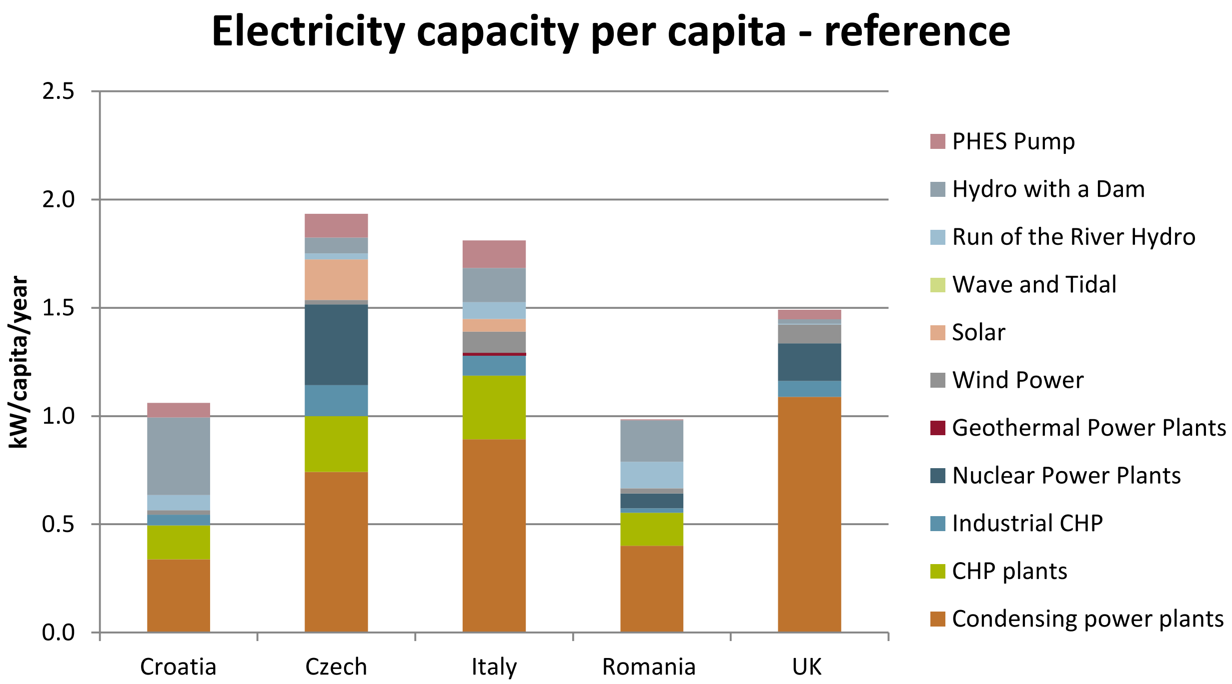

Figure 9: Electricity capacity per capita by technology type for the STRATEGO countries

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

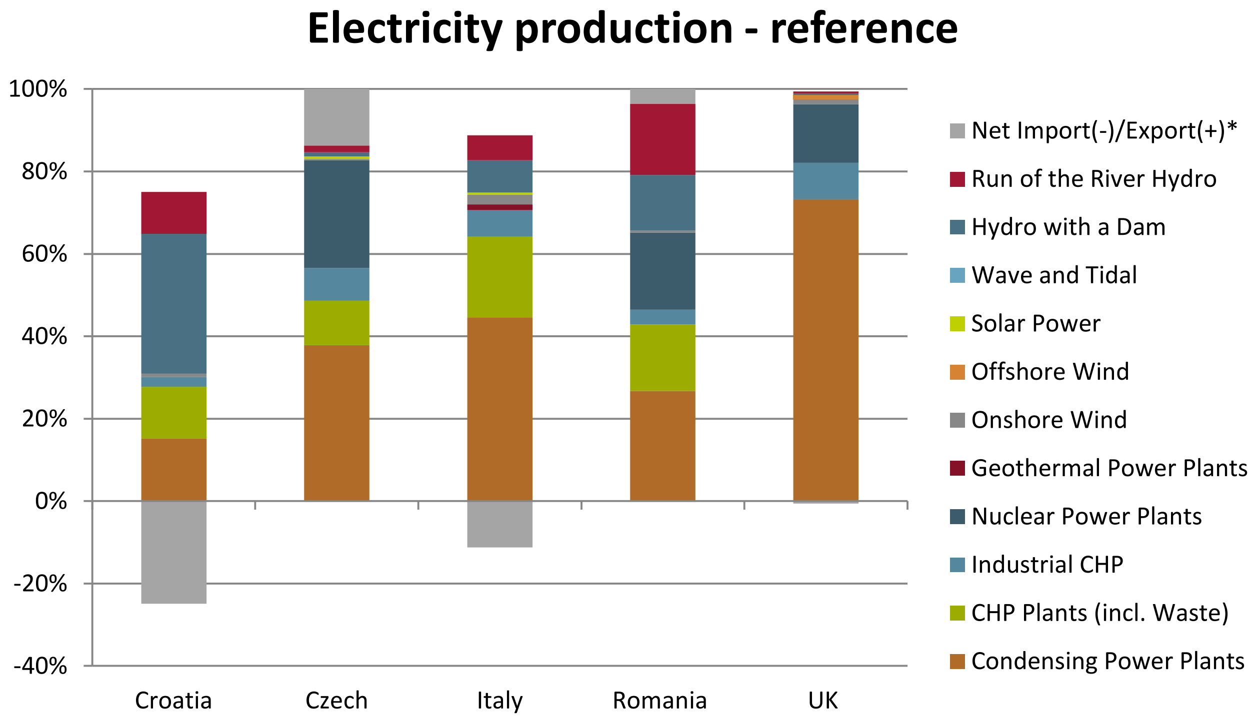

Figure 10: Electricity production shares out of the total production divided by technology type for the STRATEGO countries. *A negative value for net import/export indicates import while a positive is export. It is hence possible to see how large a share of the total electricity demand is covered from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

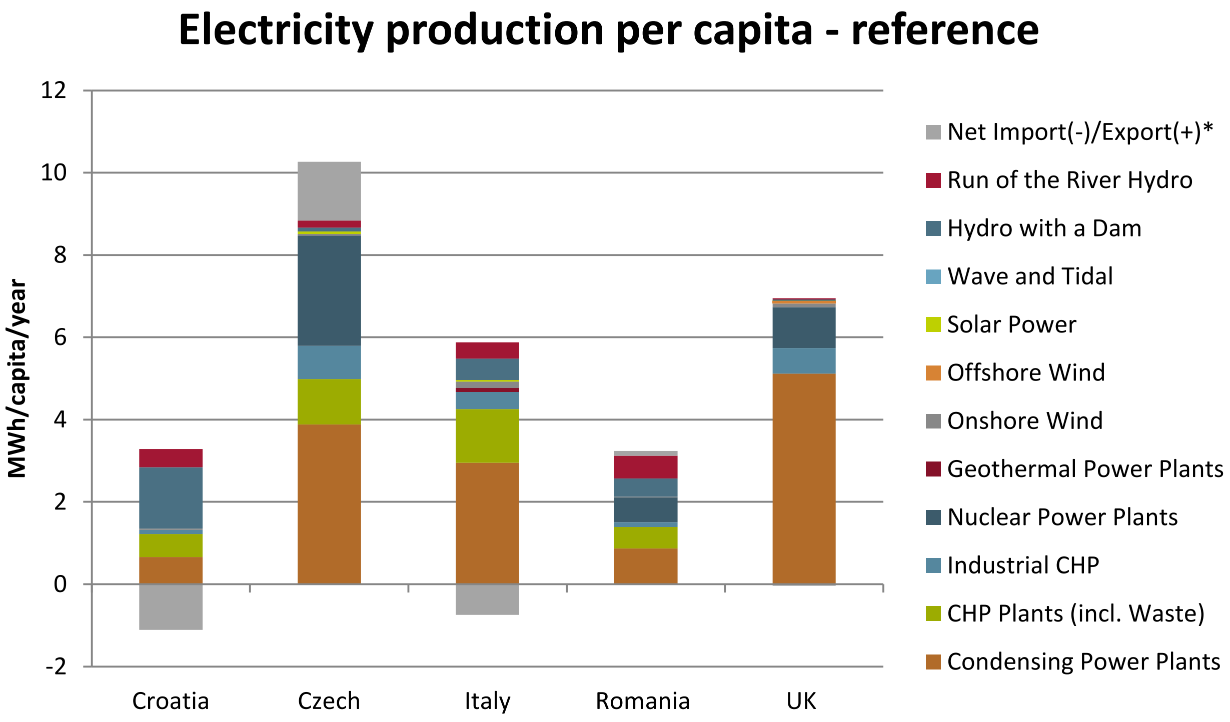

Figure 11: Electricity production per capita by technology type for the STRATEGO countries. *A negative value for net import/export indicates import while a positive is export. It is hence also possible to see how large a share of the total electricity demand is covered from import of electricity or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

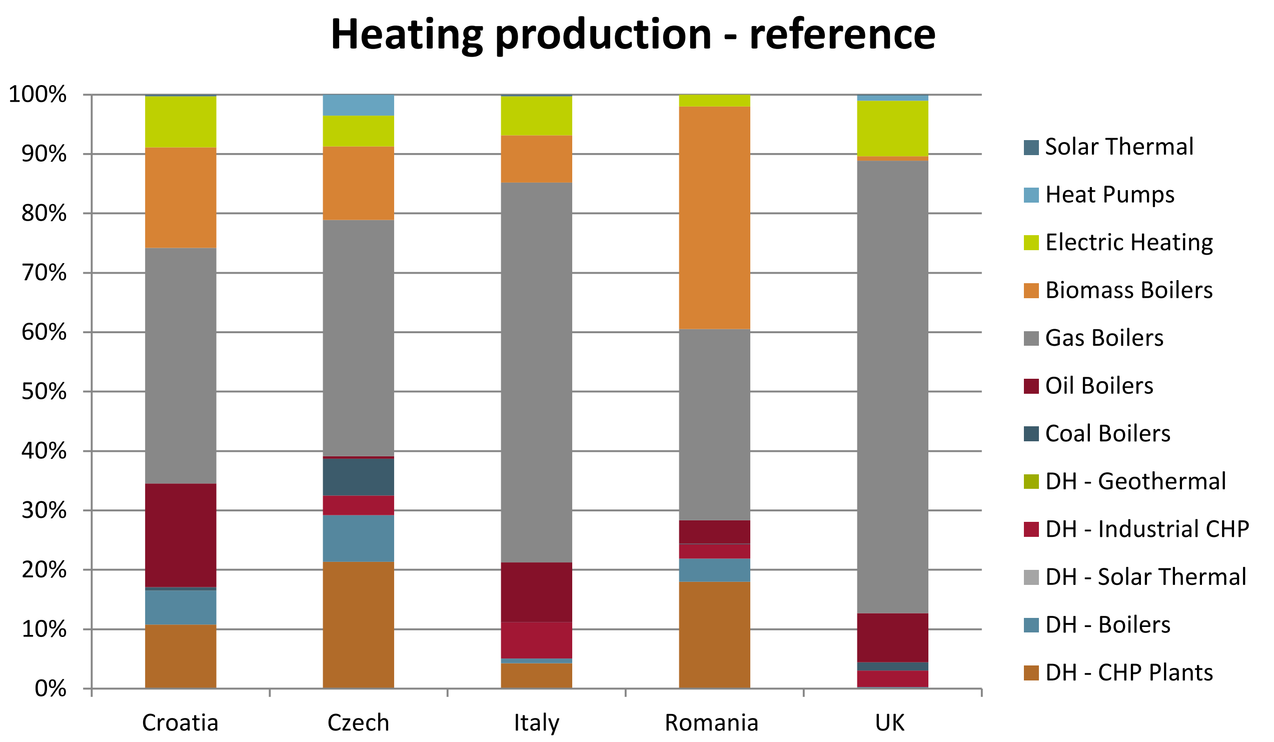

Figure 12: Heating production shares out of the total production divided by technology type for the STRATEGO countries

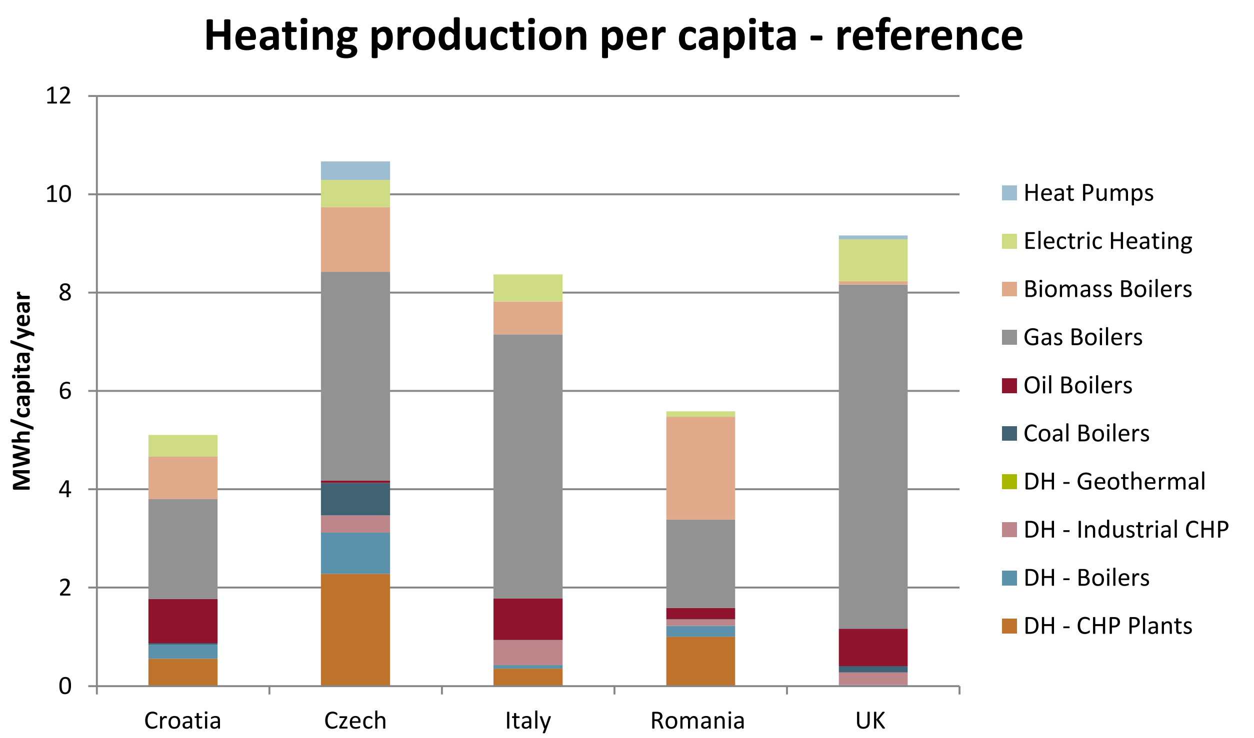

Figure 13: The heating supply per capita for the STRATEGO countries

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

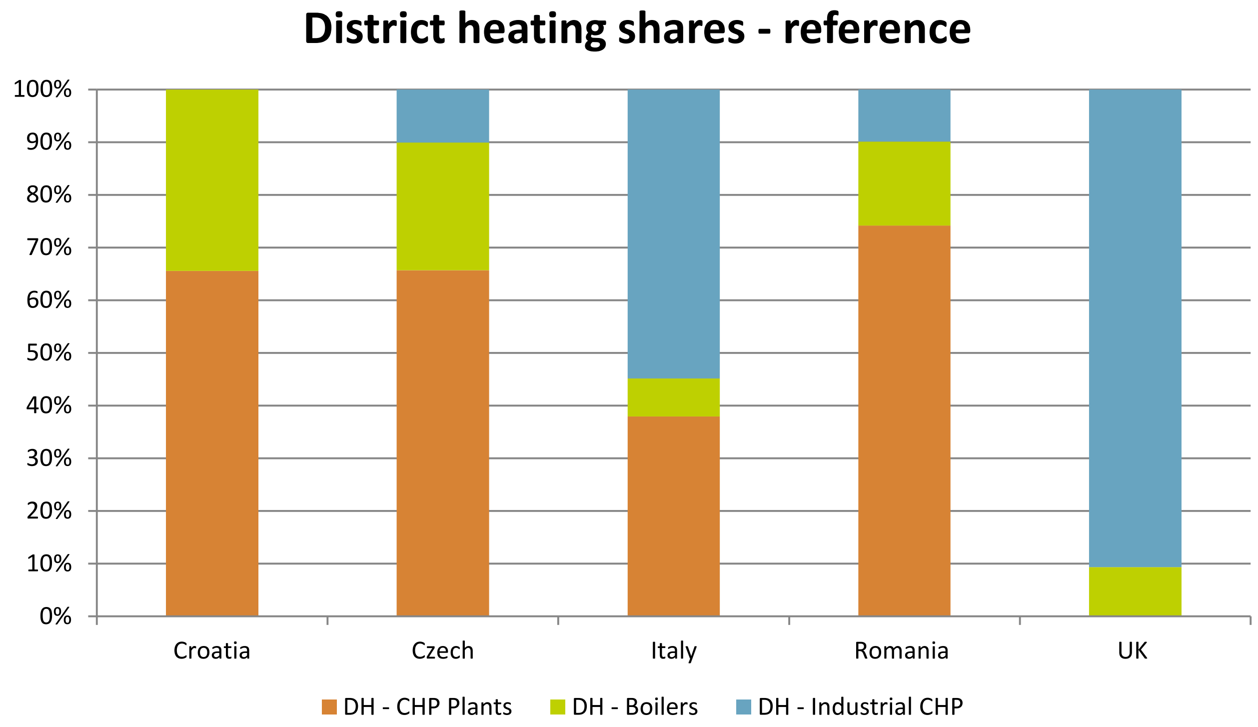

Figure 14: District heating shares out of the total district heating supply. The numbers in the figure represents the annual district heating production in TWh for the different technology types.

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

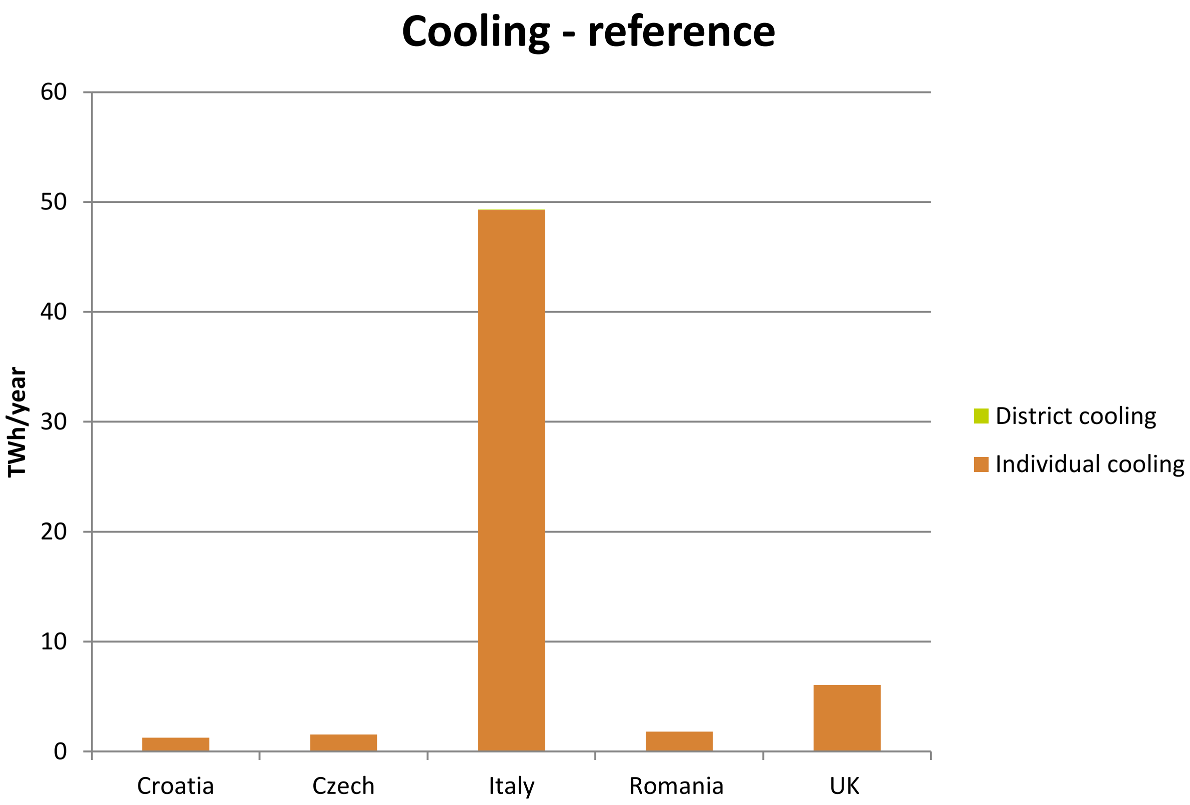

Figure 15: Cooling supply for the STRATEGO countries

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.

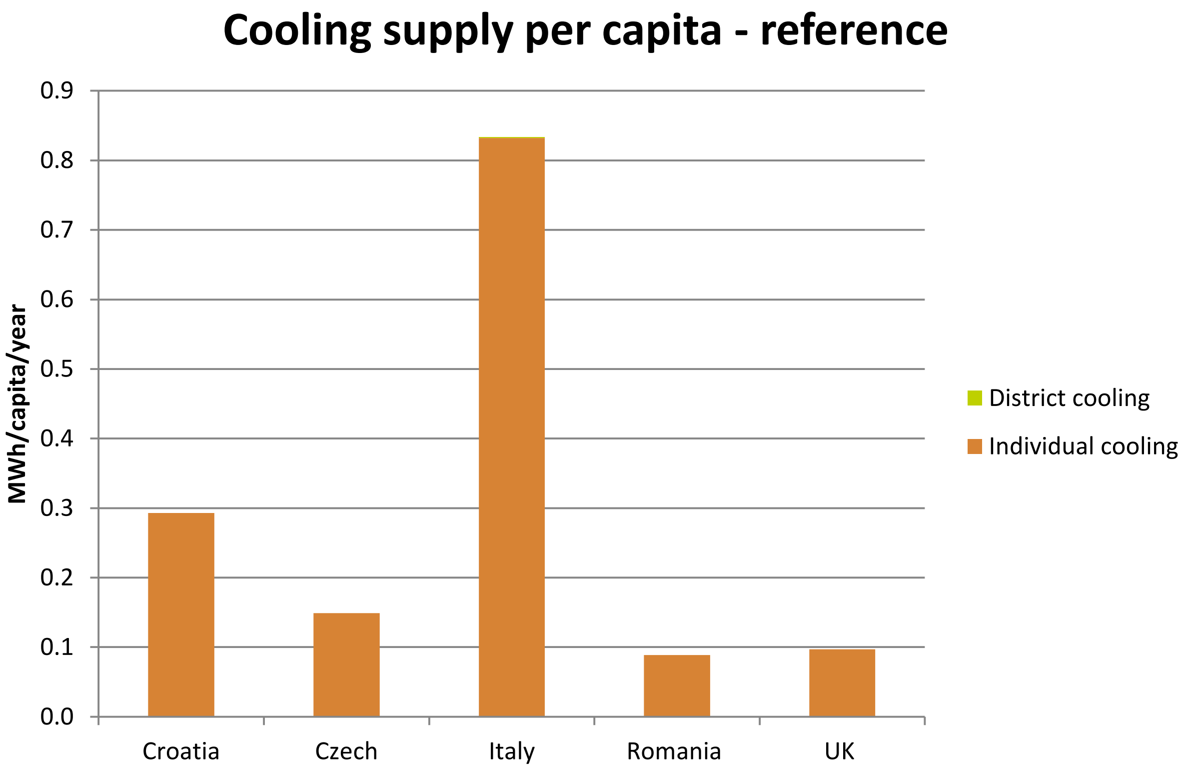

Figure 16: Cooling supply per capita for each of the countries

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

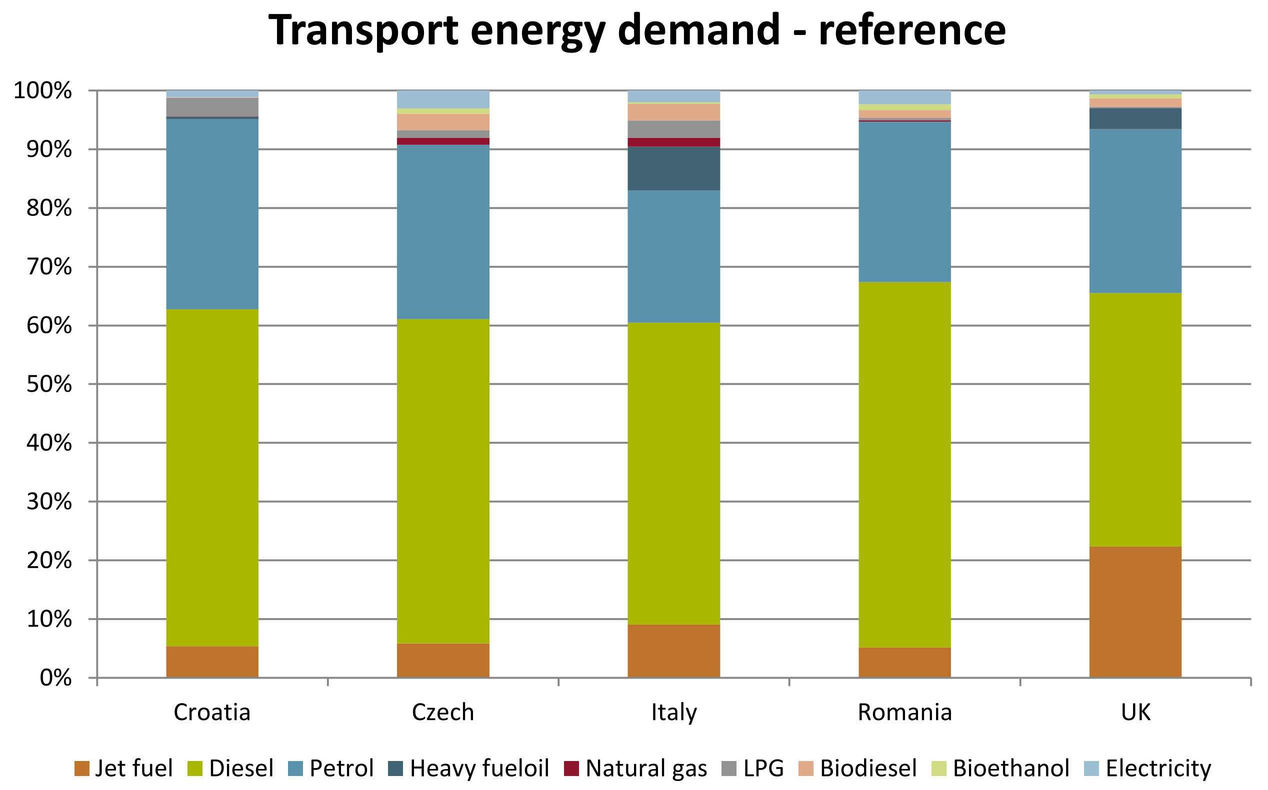

Figure 17: Transport energy demand shares out of the total demand by fuel types for the STRATEGO countries

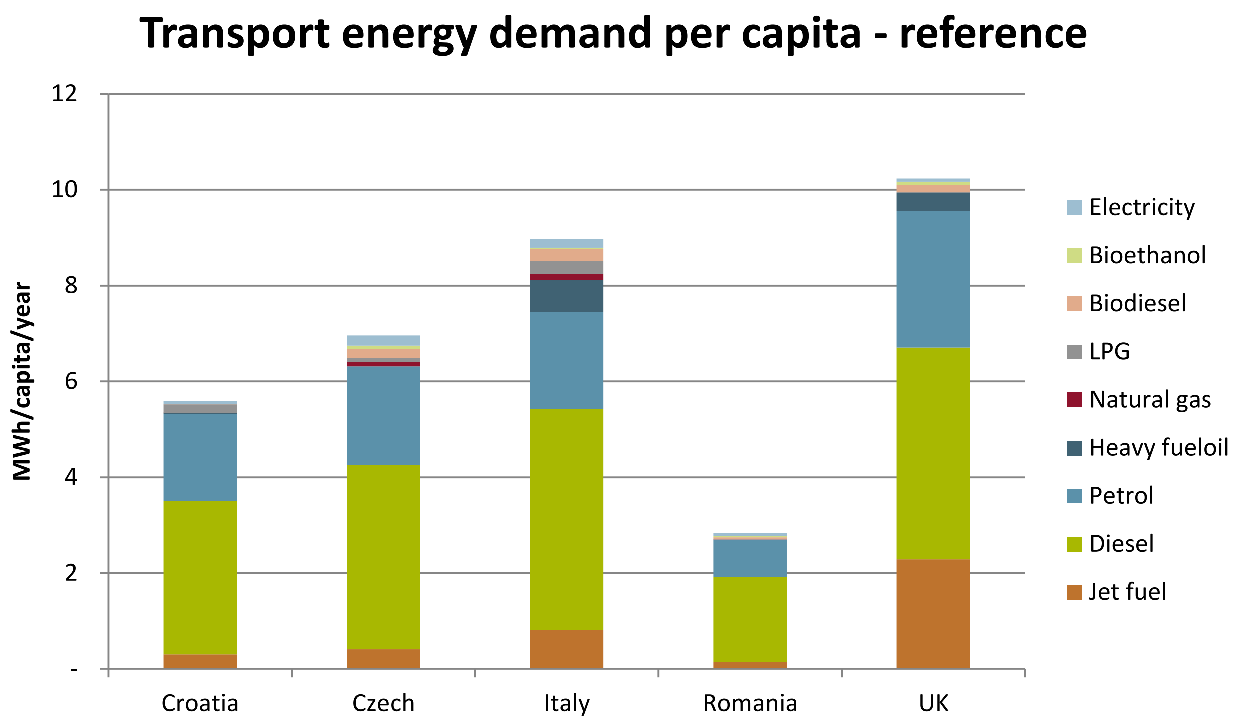

Figure 18: Transport energy demand per capita for the different STRATEGO countries

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

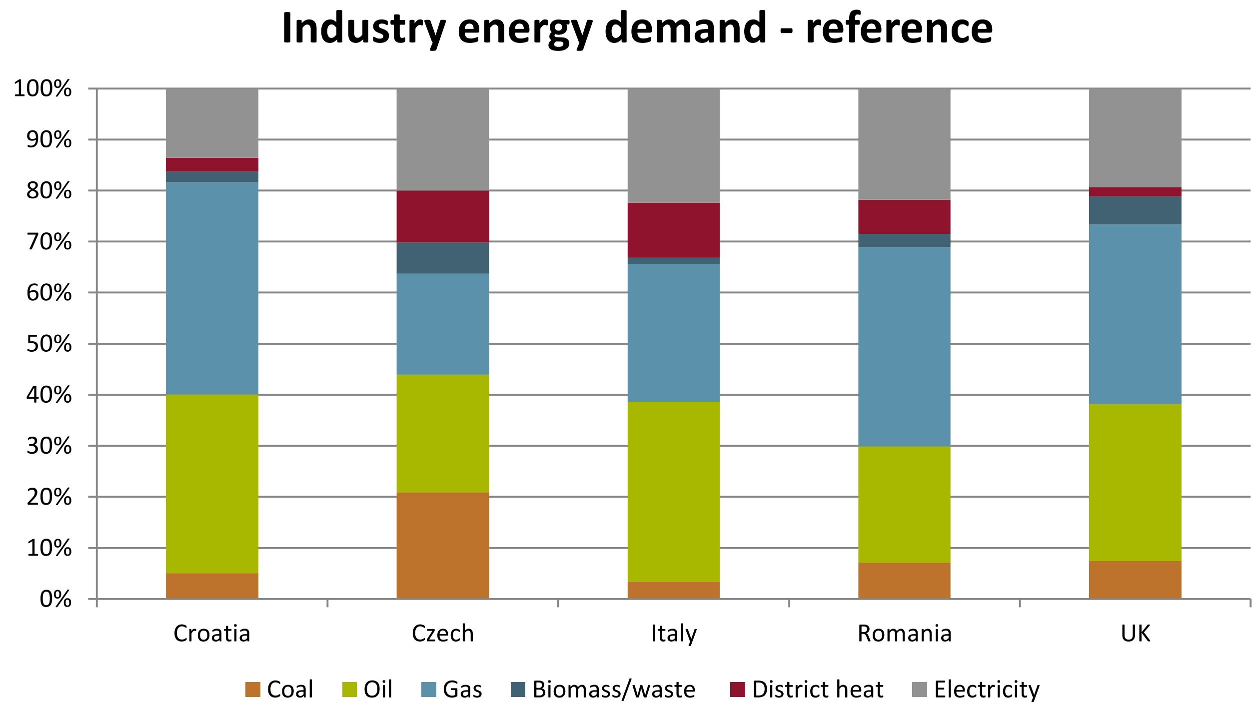

Figure 19: Industrial energy demand out of the total industrial energy demand by fuel types for the STRATEGO countries

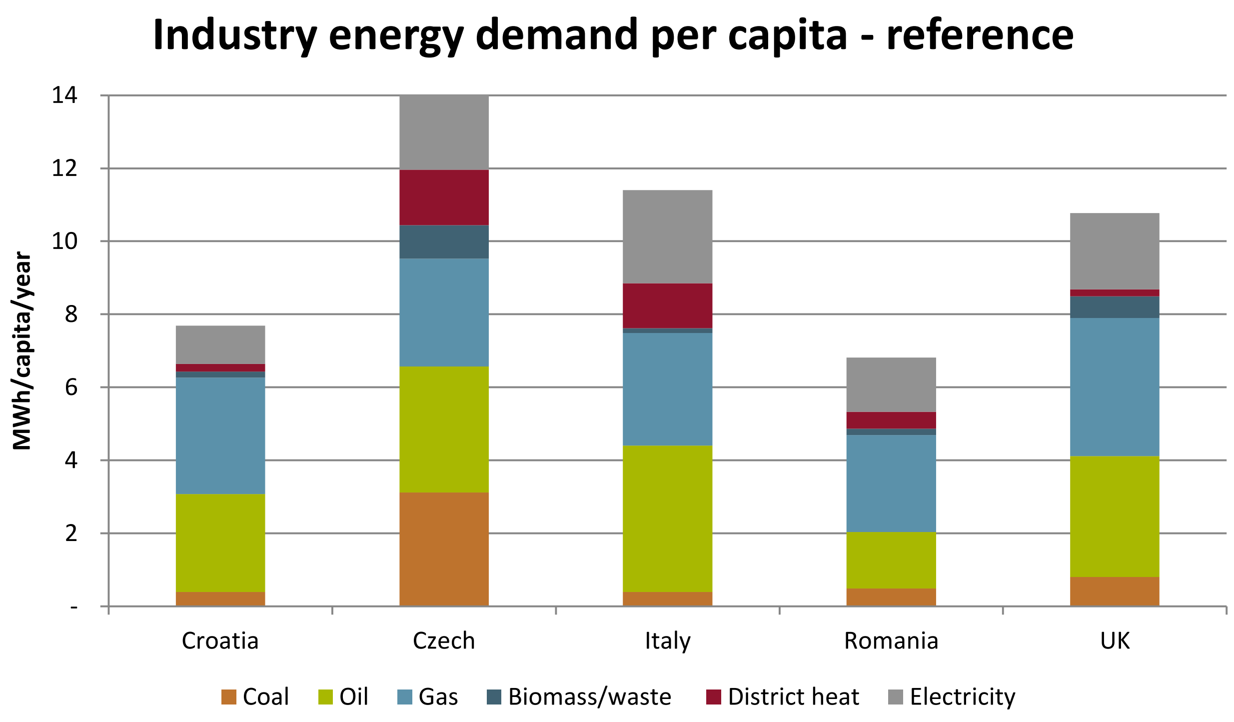

Figure 20: The industrial energy demand per capita in the reference models

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

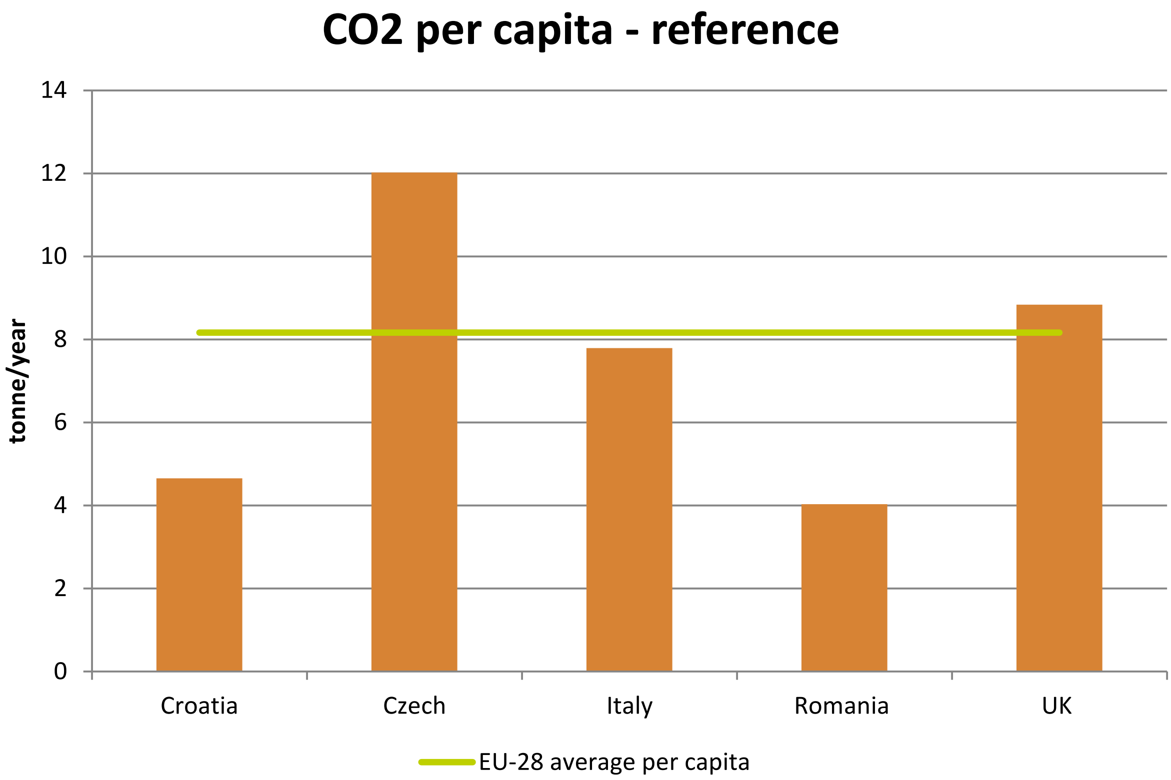

Figure 21: Average CO2-emissions per capita for the STRATEGO countries

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

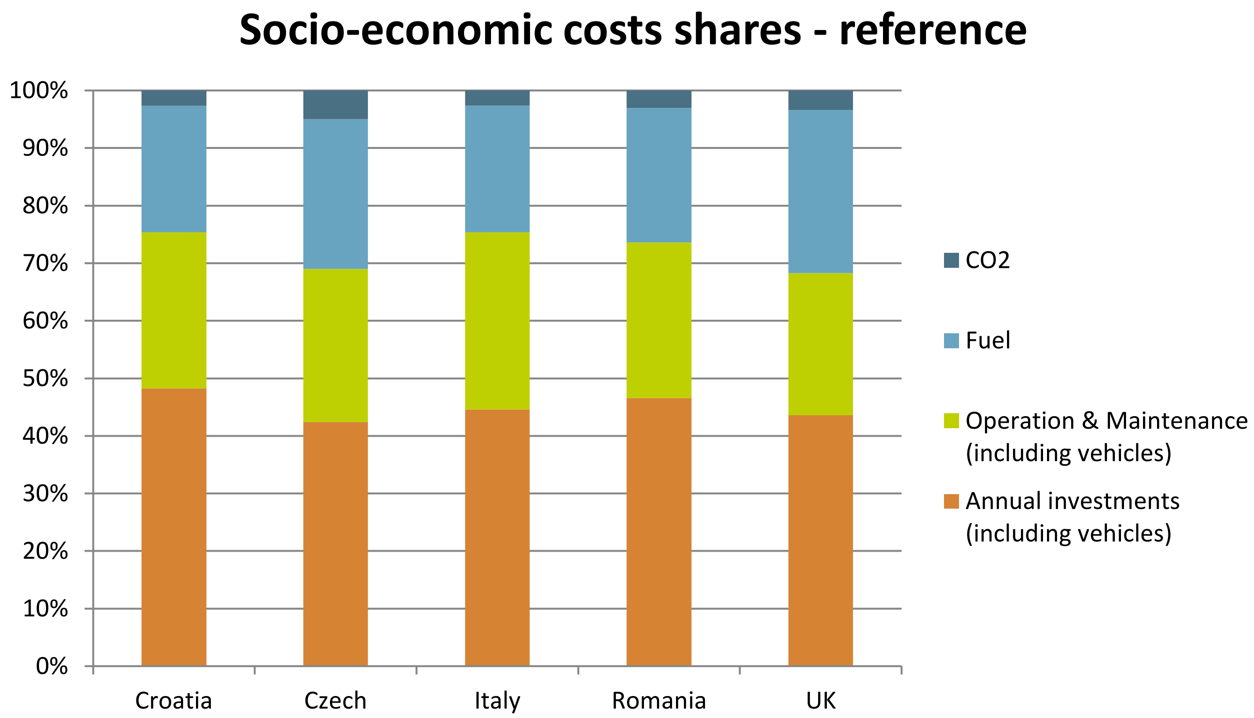

Figure 22: Annual socio-economic cost shares out of the total costs by cost type

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.

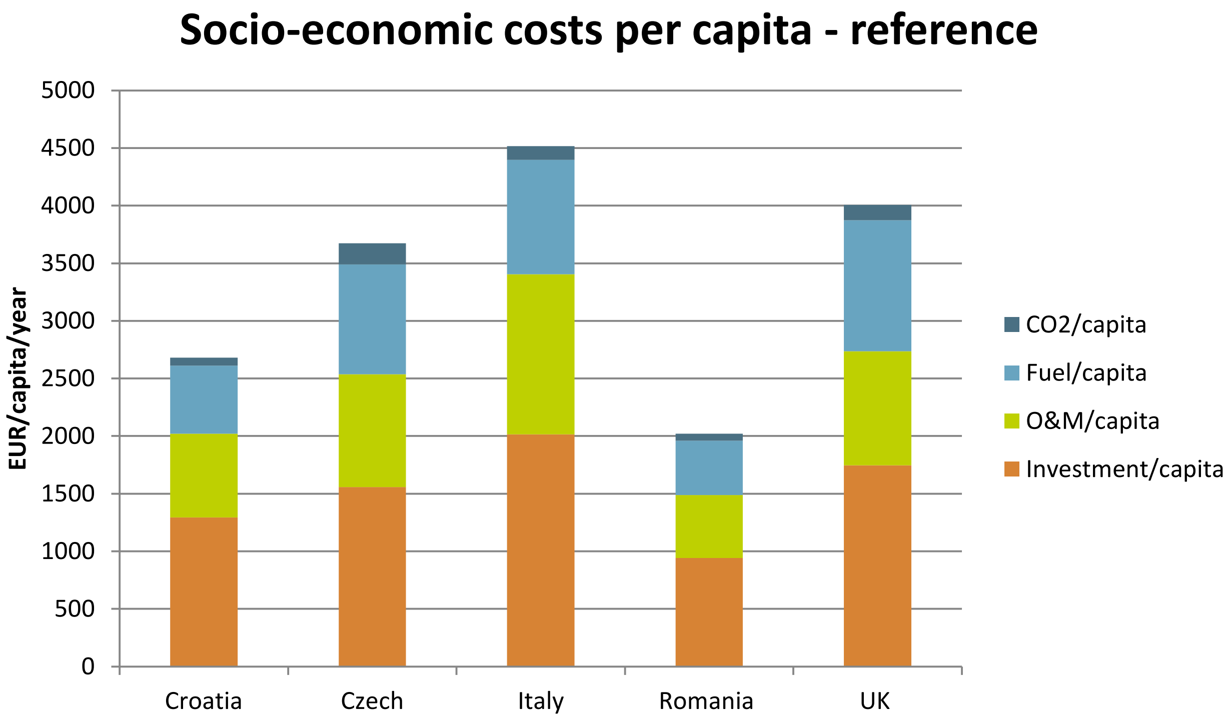

Figure 23: Socio-economic costs per capita by cost type for the STRATEGO countries

3.1.8 Comparison between the STRATEGO models and the 2010 statistics

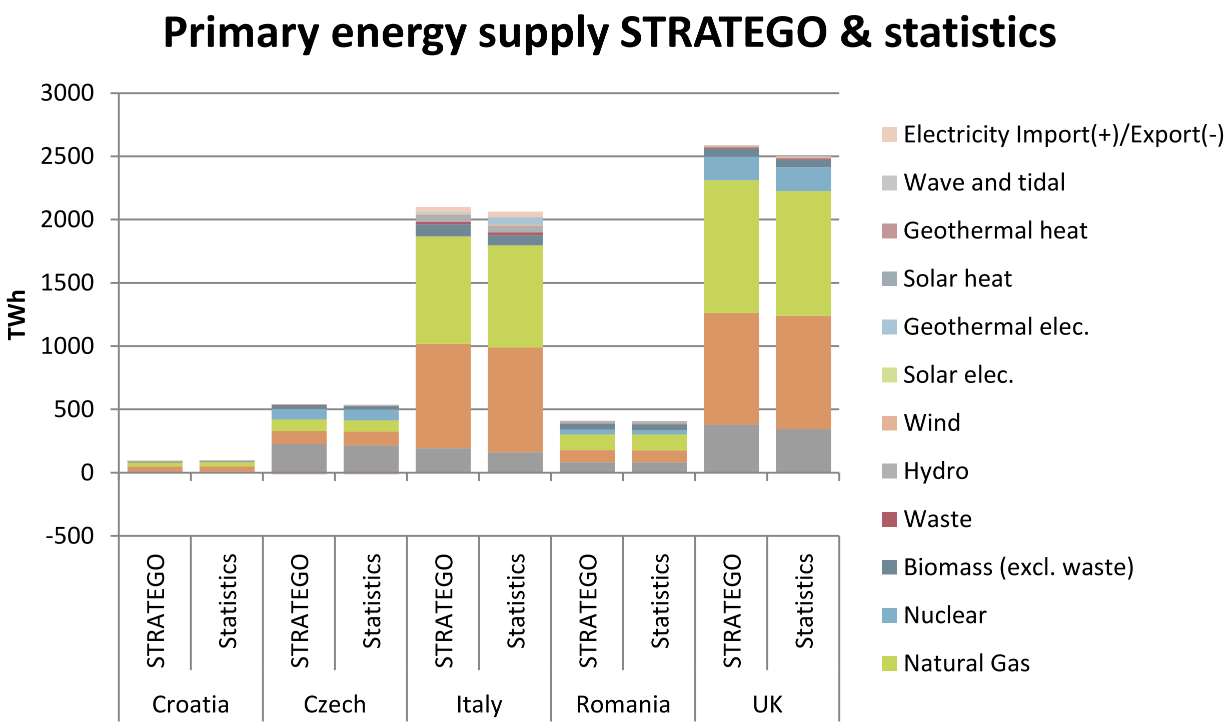

Figure 24: Primary energy supply for all STRATEGO countries based on statistical data and STRATEGO scenarios

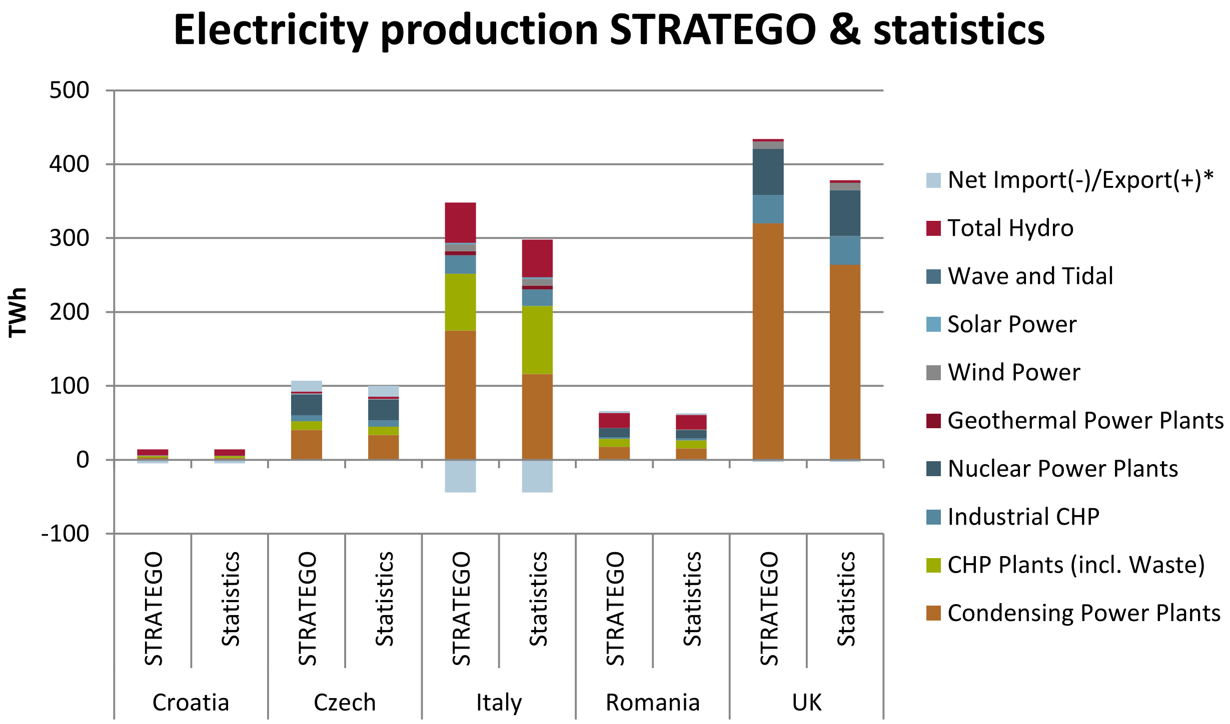

Figure 25: Electricity production for all STRATEGO countries based on statistical data and STRATEGO scenarios

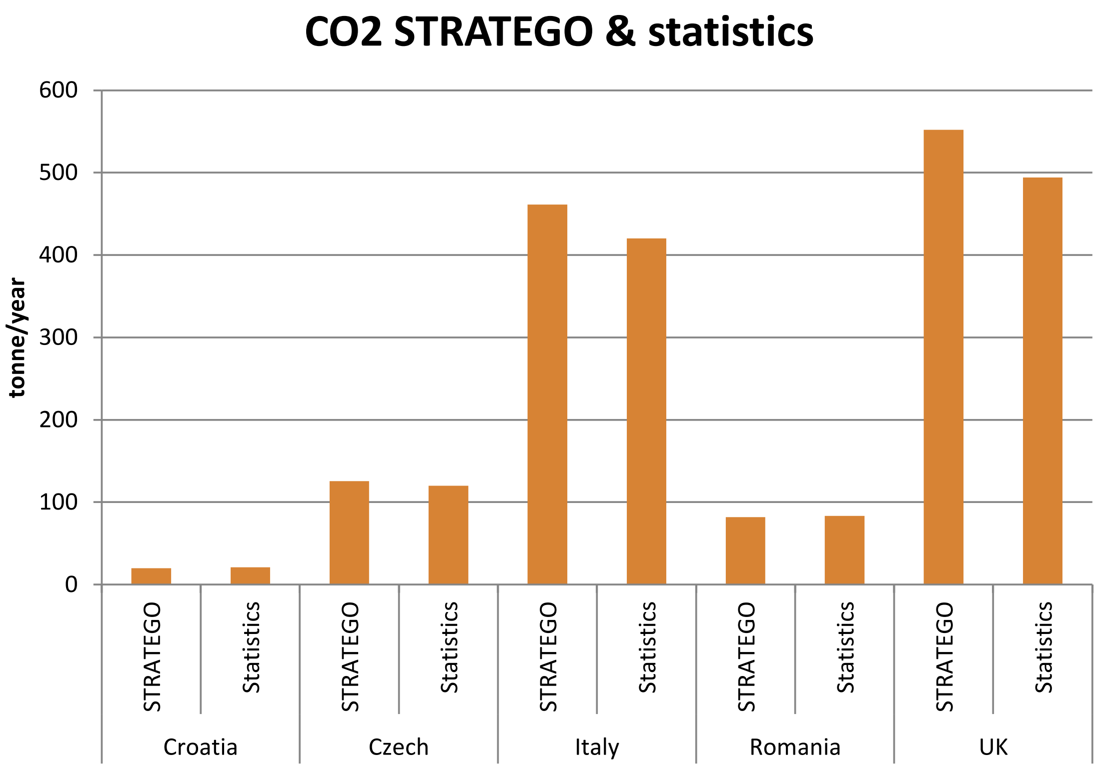

Figure 26: CO_2 emissions for STRATEGO models and statistical data for the reference models for the five STRATEGO countries

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.

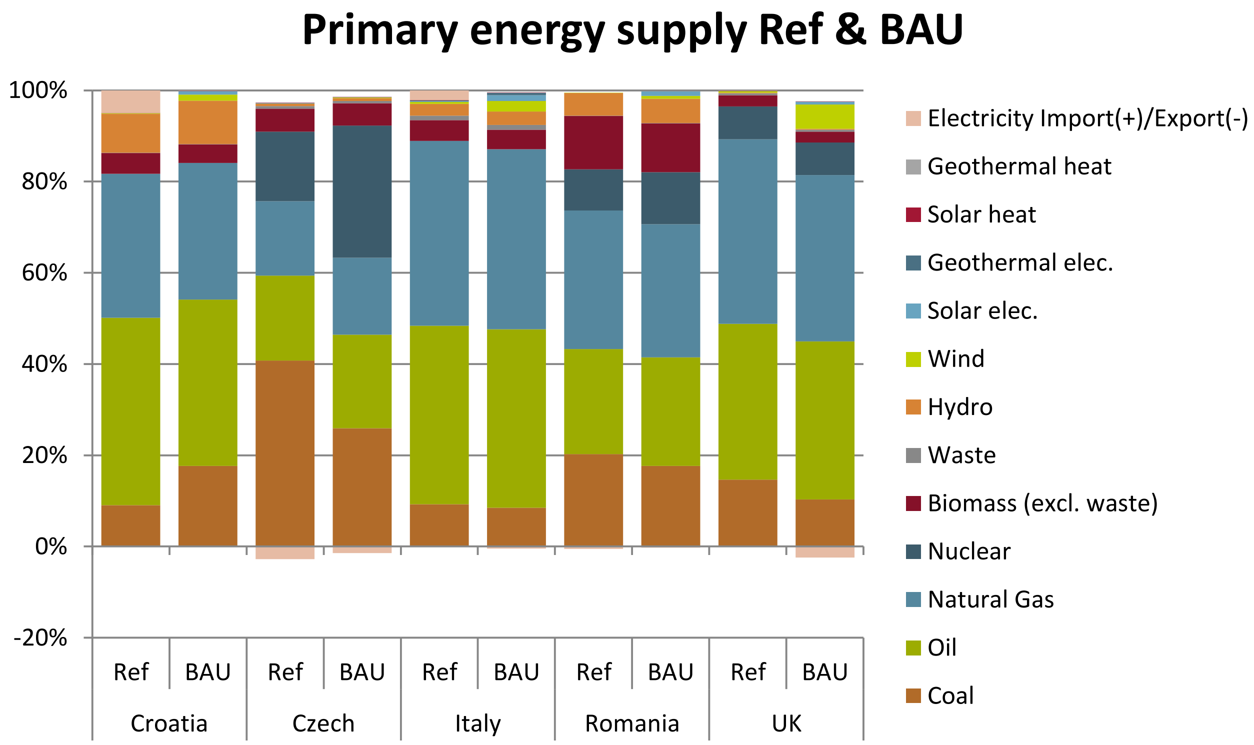

Figure 27: Mix of fuels in the primary energy supply for the 2010 reference and 2050 BAU models for each country

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

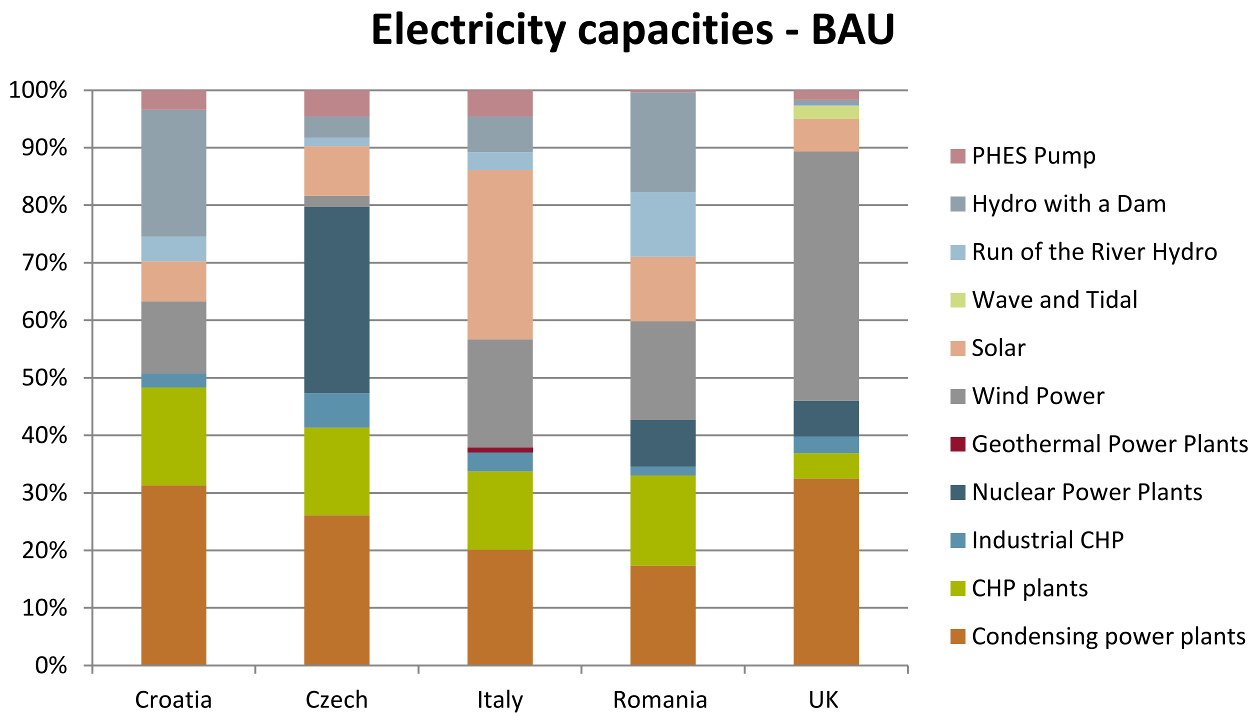

Figure 28: Electricity capacity for the 2050 Business-as-usual models

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**

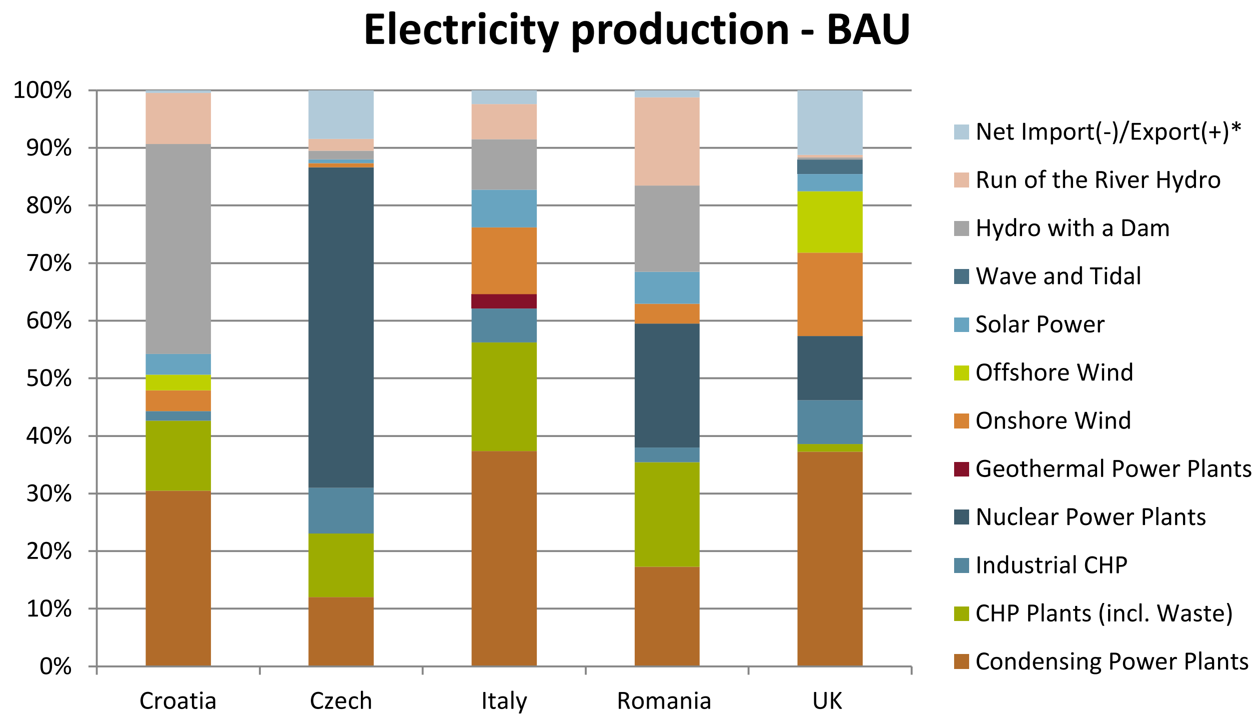

Figure 29: Electricity production in 2050 business-as-usual for the STRATEGO countries

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.

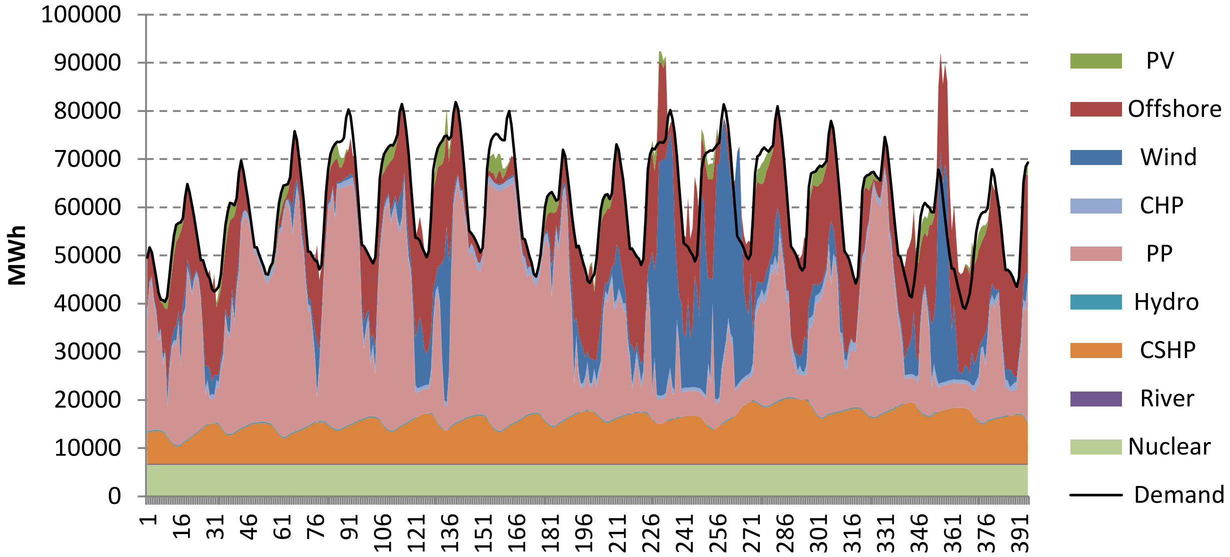

Figure 30: Hourly electricity production by plant type and the total electricity demand for the first 400 hours of the 2050 BAU model of the UK

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

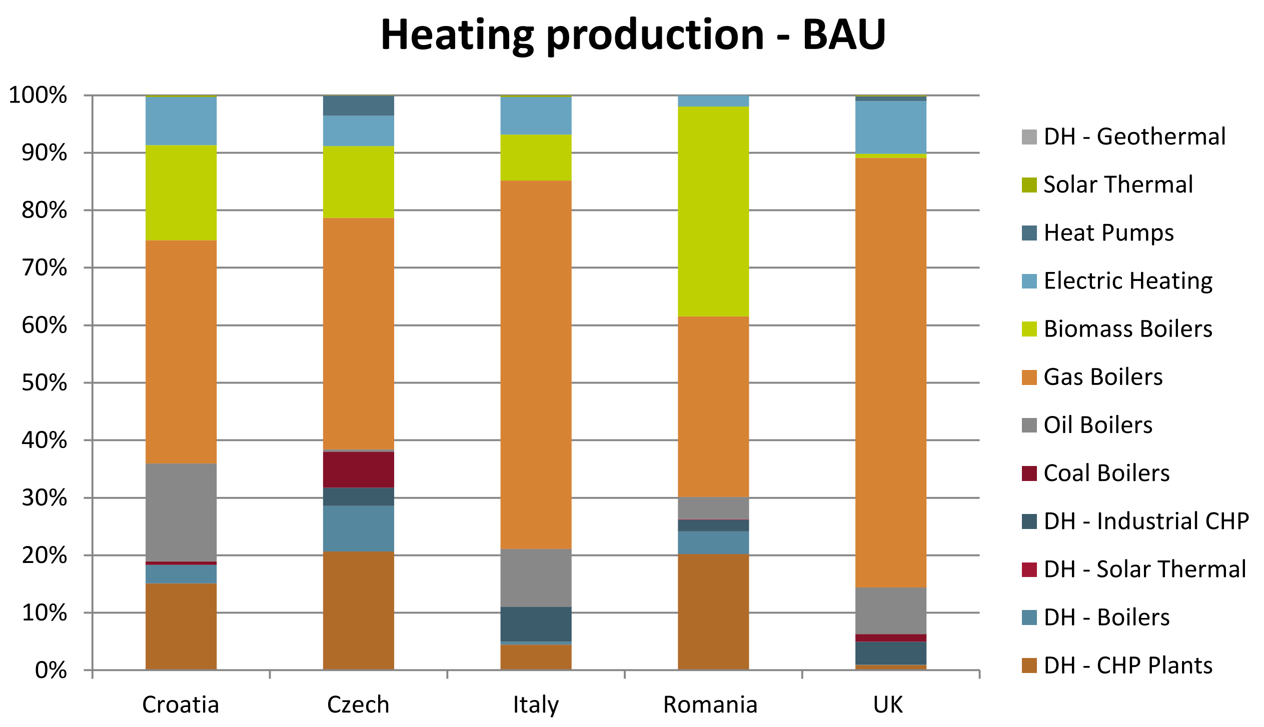

Figure 31: The heating production in the 2050 business-as-usual scenarios

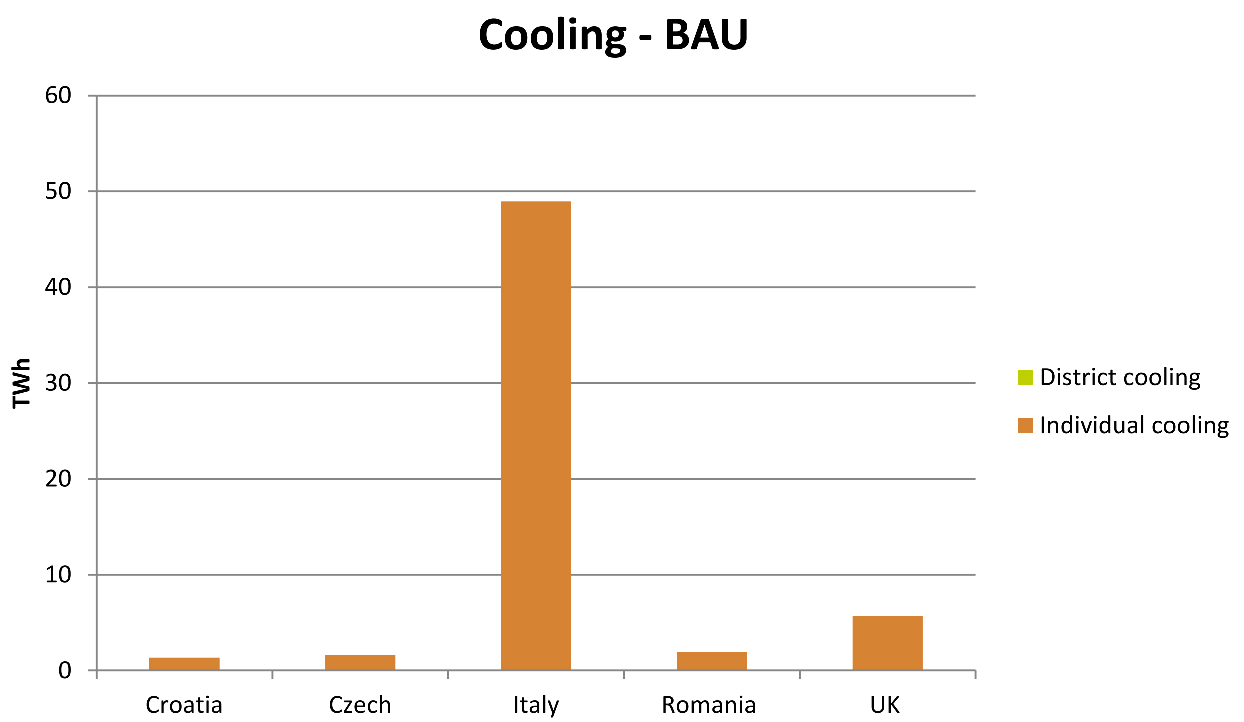

Figure 32: Cooling production in the STRATEGO countries in the business-as-usual models

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.

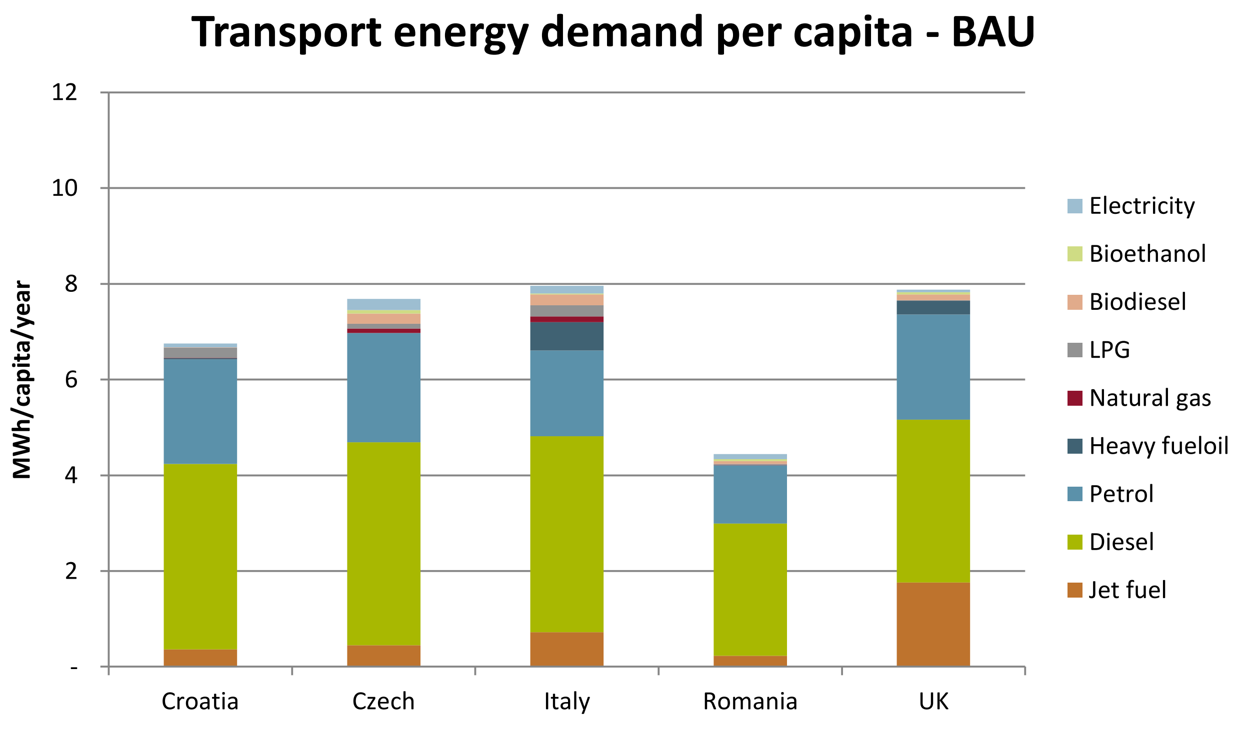

Figure 33: Transport energy demand per capita in the business-as-usual scenarios

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

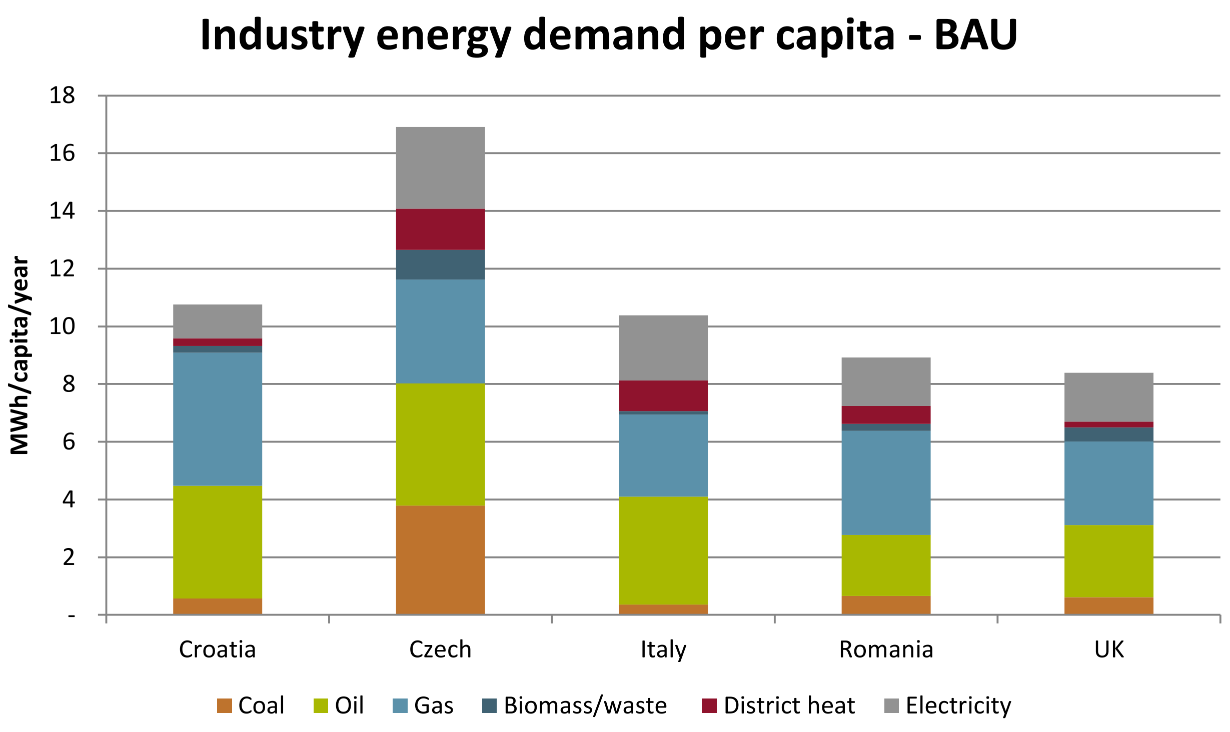

Figure 34: Industry energy demand per capita in the 2050 business-as-usual scenarios

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.

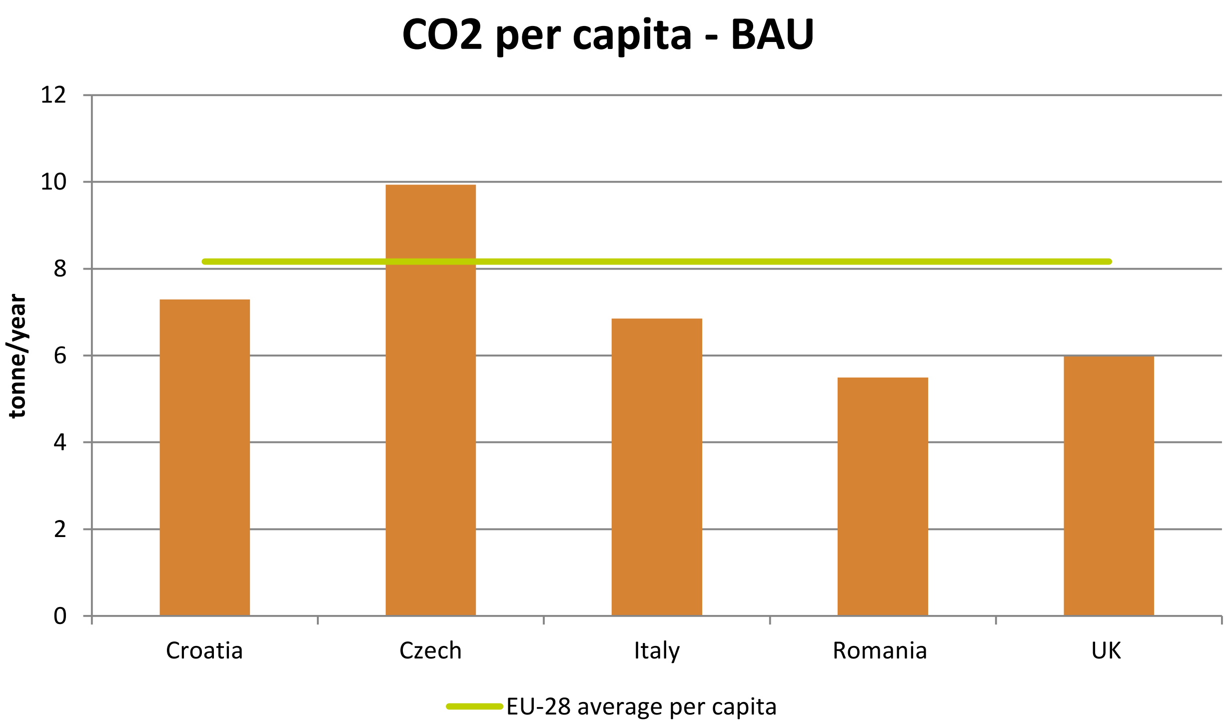

Figure 35: CO_2 emissions per capita in the 2050 business-as-usual scenarios

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.

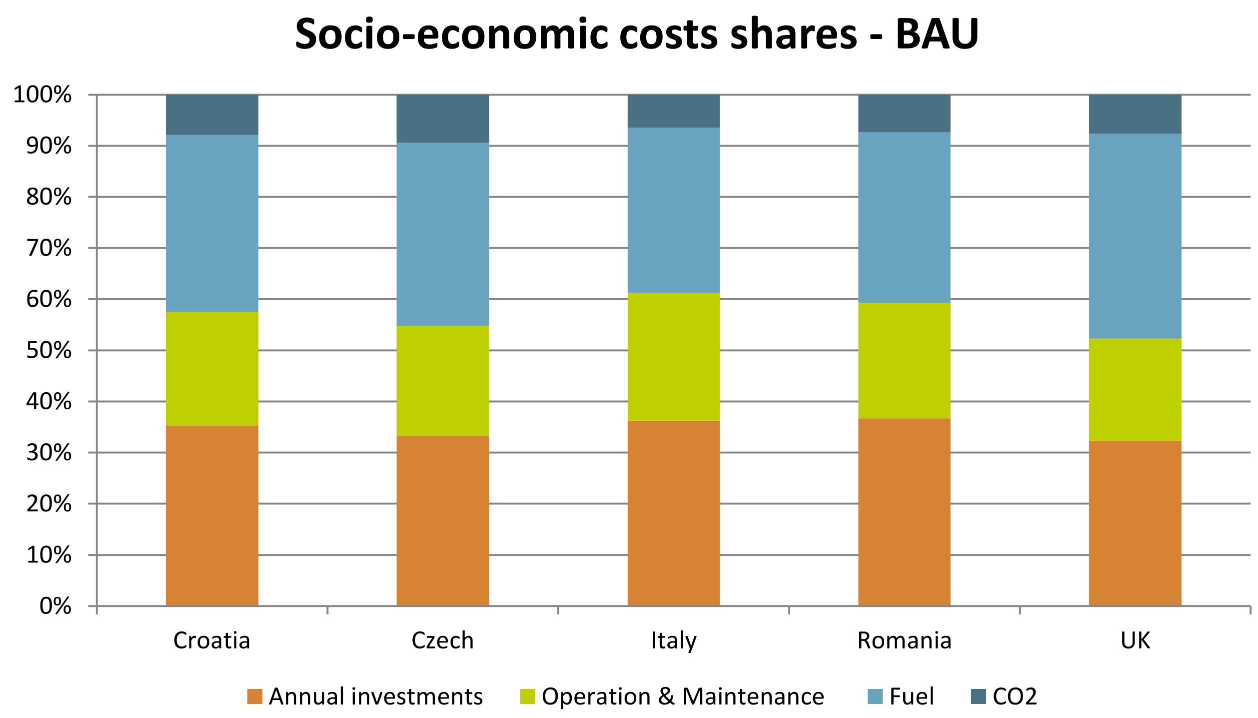

Figure 36: Breakdown of socio-economic cost for each country in the BAU scenario

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.

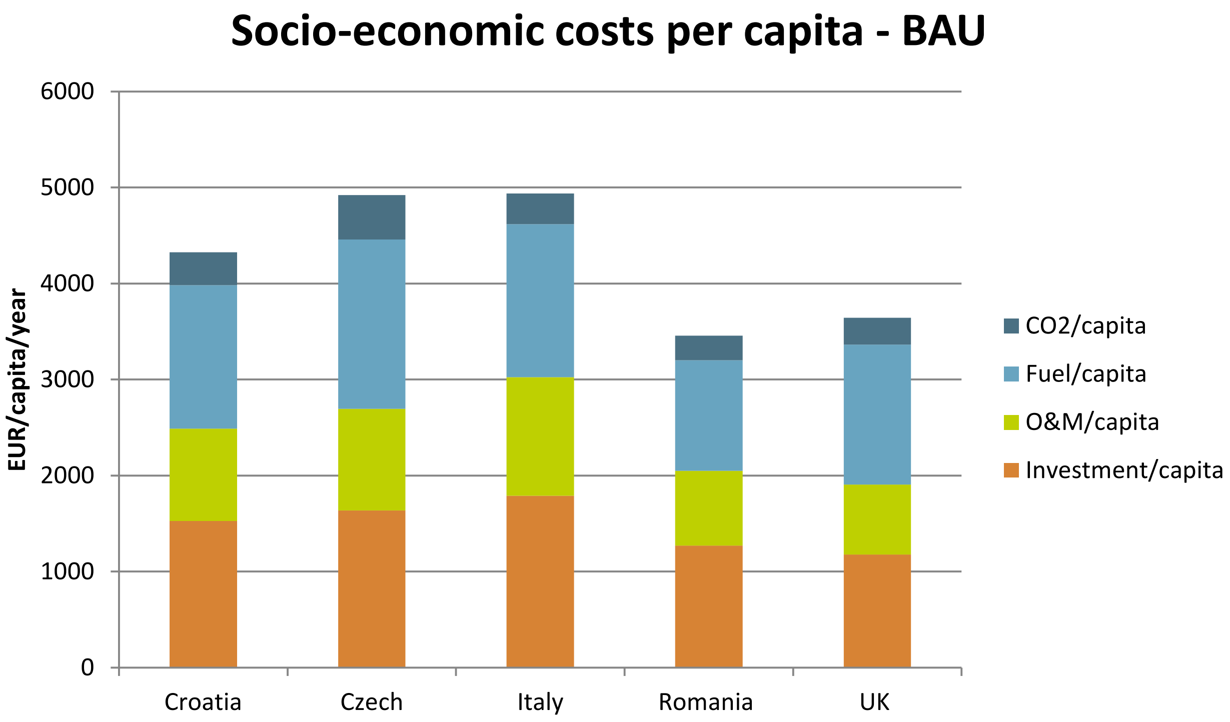

Figure 37: Socio-economic cost per capita for each country in the BAU scenario

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.

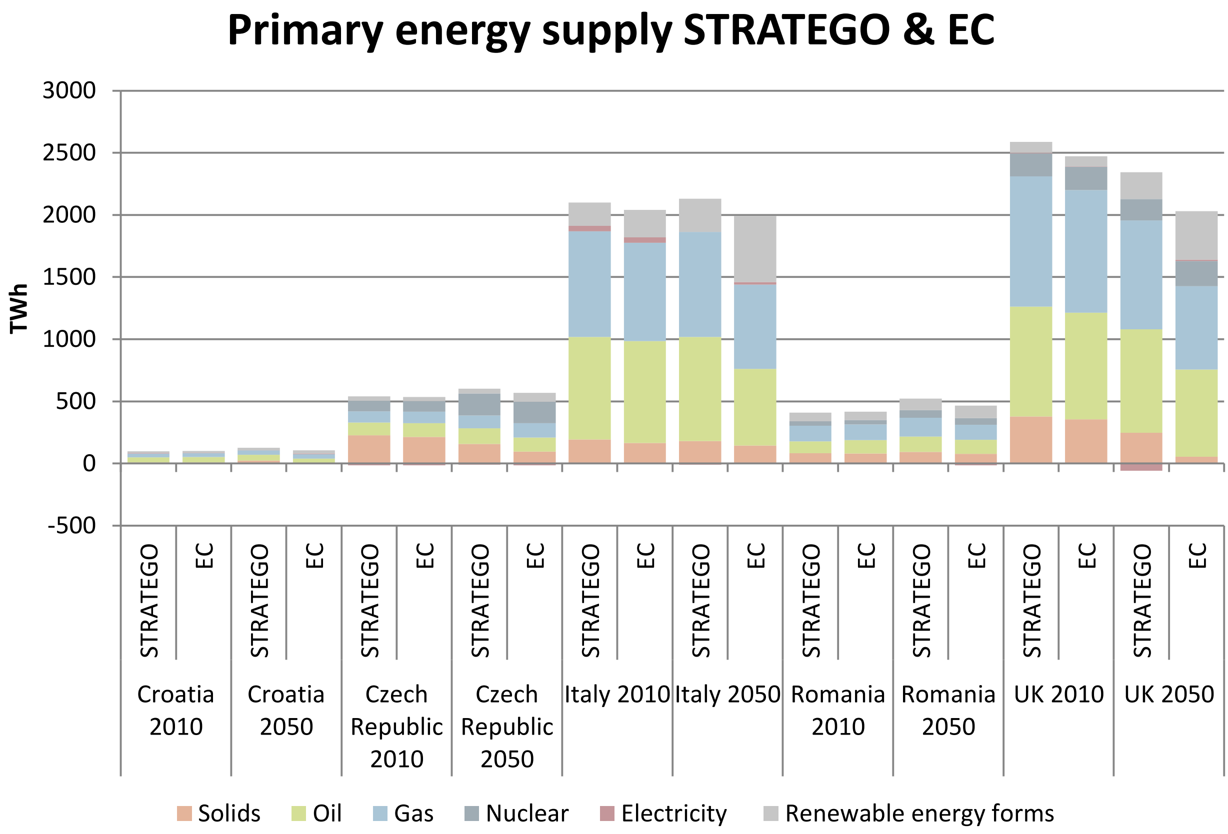

Figure 38: Primary energy for STRATEGO and EC scenarios for 2010 and 2050

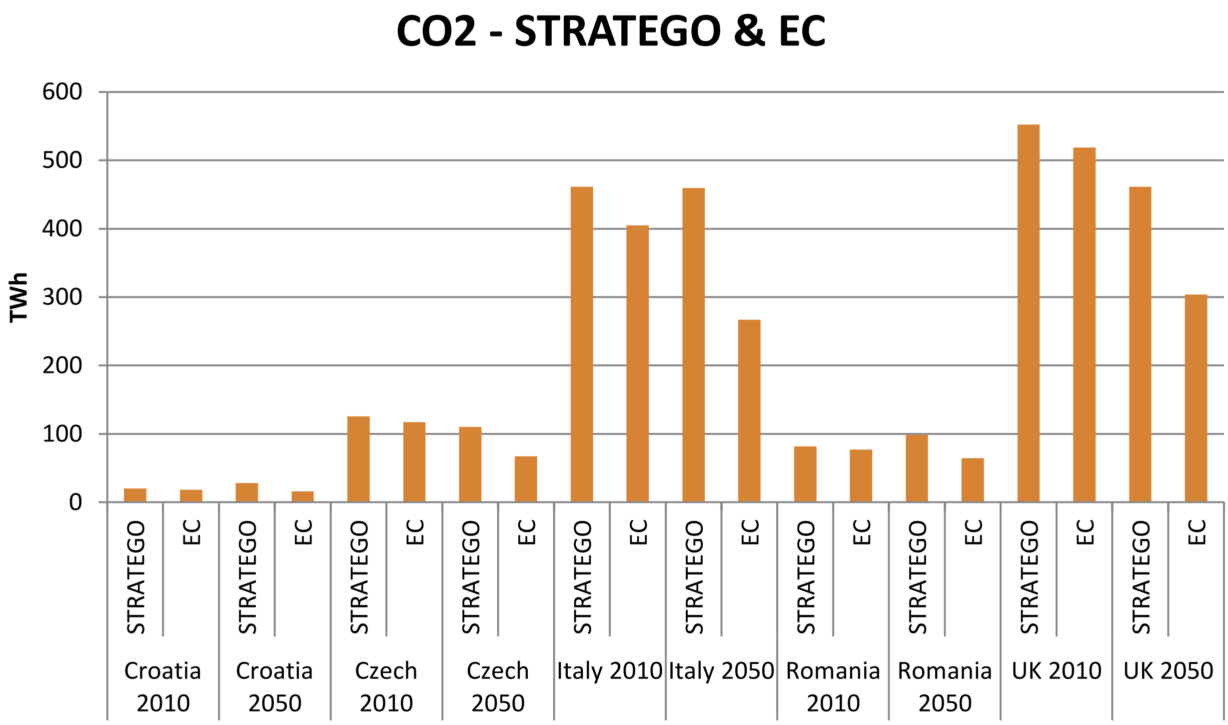

Figure 39: CO_2-emissions for STRATEGO and EC scenarios for 2010 and 2050

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

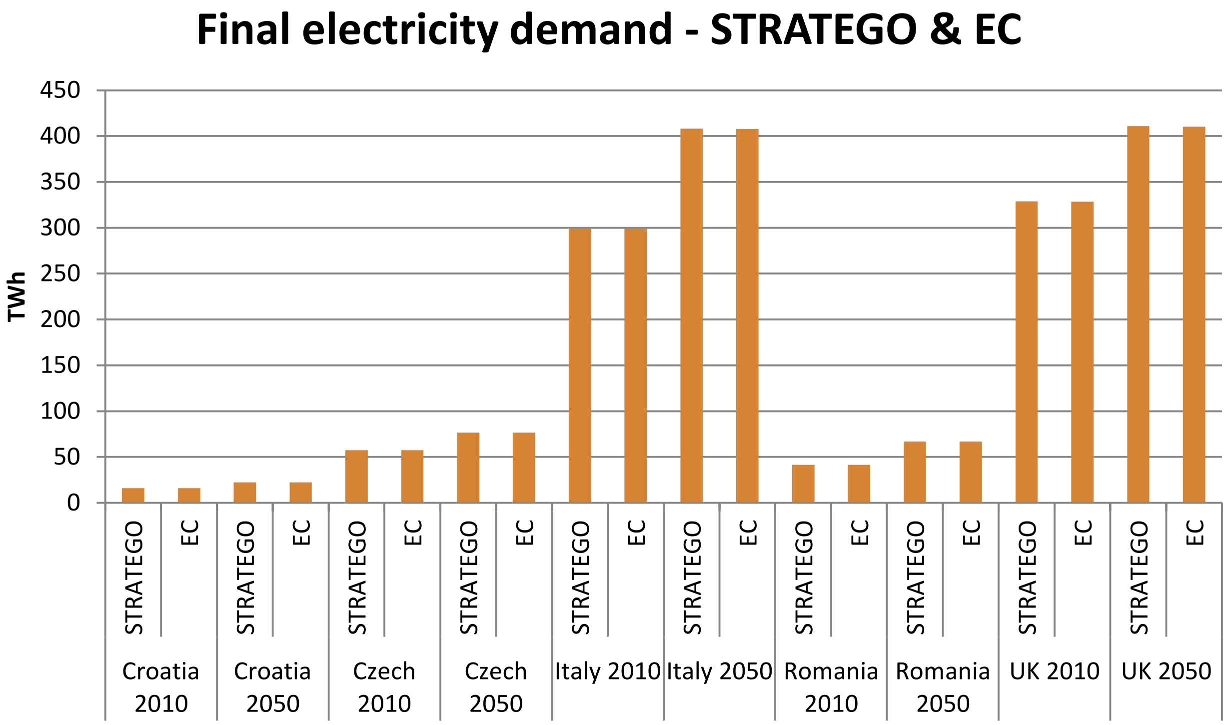

Figure 40: Final electricity demand for STRATEGO and EC scenarios for 2010 and 2050

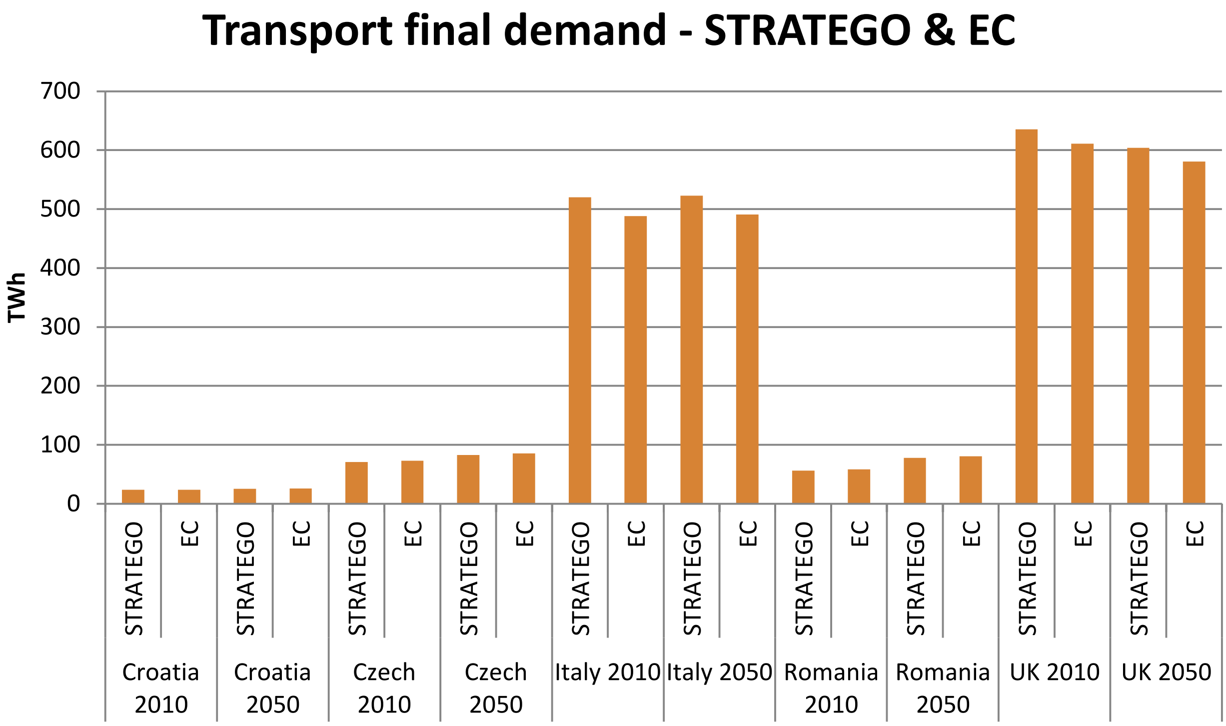

Figure 41: Fuel consumption for transport for the STRATEGO and EC scenarios for 2010 and 2050

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).

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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.

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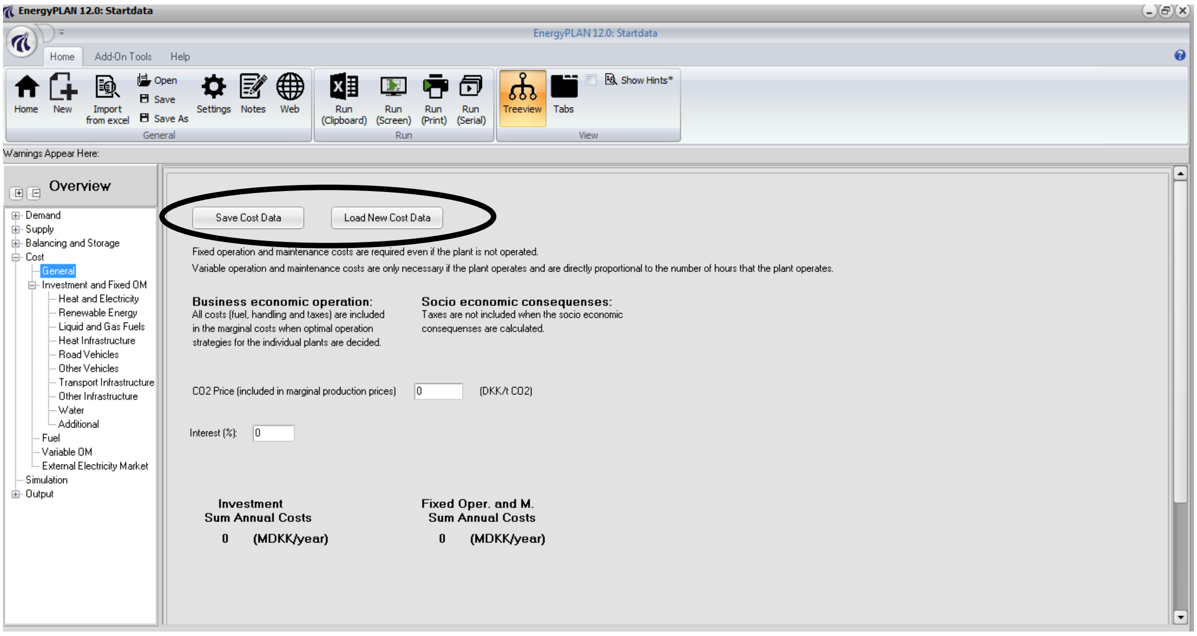
1 Introduction

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

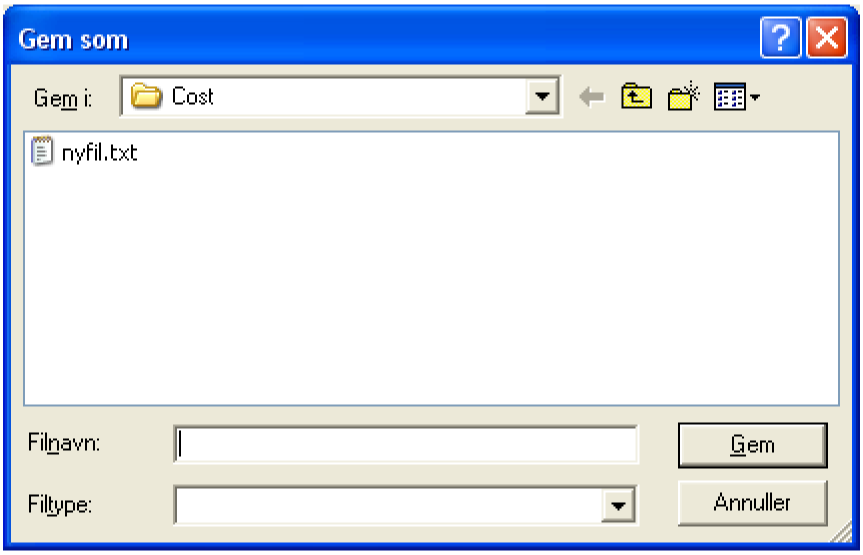
- General
- Investment and Fixed OM
- Fuel
- Variable OM
- External electricity market

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

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.

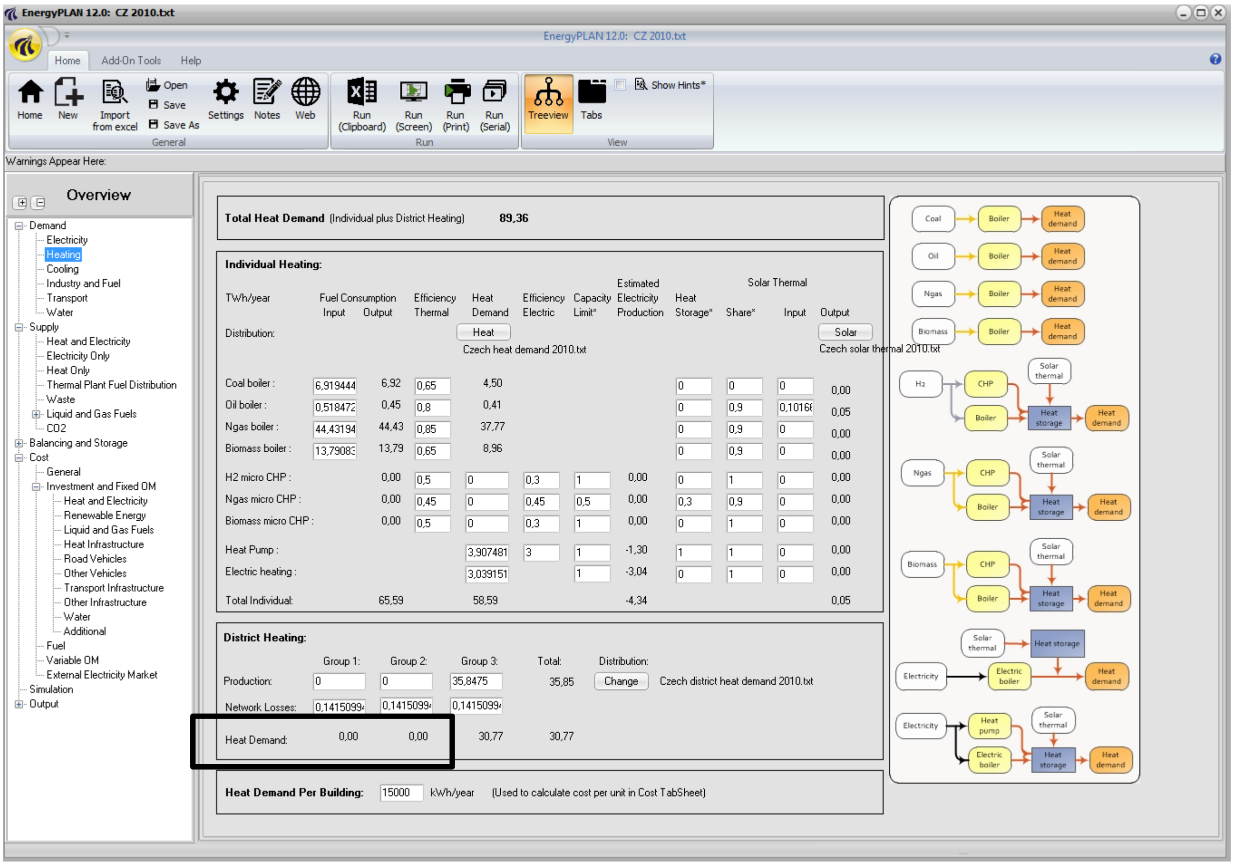


Table 38: Individual heating unit costs for 2020 in the EnergyPLAN Cost Database [5].

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