Finding and Inputting Data into EnergyPLAN

(The FIDE Guide)

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26 January 2015
Version 5

Print Double Sided

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1 Introduction

This is a brief description of my experience when I learned how to use the energy tool EnergyPLAN [1]. It is a short description of why I chose EnergyPLAN for my particular study, followed by a brief account of the sources I used to gather the data for the model.

When I was carrying out my work using EnergyPLAN, I did not know where to begin looking for a lot of the data I needed. As a result, the primary aim of this document is to share with others where and how I found the required data for my model. I hope that this brief overview of my experience will enable the reader to use EnergyPLAN quicker and more effectively. Finally, I welcome any contributions that could be made to improve the content of this document, such as new sources of data or suggestions for new content..

Nomenclature

Symbols		GJ	Gigajoule
CF_W	Average capacity factor for an offshore wind farm	GE	The General Electric Company
E_{Annual}	Annual output from a wind farm	HDD	Heat degree days
E_{OUT}	Total electricity produced from a generating facility	IEA	International Energy Agency
E_{IN}	Total electricity consumed by a PHES	kW	Kilowatt
GridStab	Percentage of electricity production from grid stabilising units	kWh	Kilowatt hour
F_{IN}	Total fuel input, Wh	kg	Kilogram
MGSPS	Minimum Grid Stabilisation Production Share	M€	Million Euro
P_W	Installed wind capacity	M2	Data buoy number 2 around the Irish coast
d_{Stab}	Minimum grid stabilisation production share in EnergyPLAN	M4	Data buoy number 4 around the Irish coast
e_{Stab}	Total electricity production from grid stabilising units	MW	Megawatt
stab.-load	Percentage of grid stabilisation criteria which have been met during each hour	OECD	Organisation for Economic Co-Operation and Development
η_{COND}	Efficiency of all the condensing plant	PES	Primary Energy Supply
η_{TH}	Round-trip efficiency of a PHES	PHES	Pumped hydroelectric energy storage
Abbreviations		PP	Power Plant
BEV	Battery Electric Vehicle	SEAI	Sustainable Energy Authority of Ireland
CDD	Cooling degree days	TSO	Transmission System Operator
CEEP	Critical excess electricity production	TWh	Terawatt hour
CHP	Combined Heat and Power	VAT	Value added tax
CSO	Central Statistics Office, Ireland	Wh	Watt-hour
DH	District heating	bbl	Barrel
EEEP	Exportable Excess Electricity Production	m	metre
ENTSO-E	European Network of Transmission System Operators for Electricity	s	second

2 Why EnergyPLAN?

It is difficult to choose a suitable energy tool at the beginning of a study due to the wide range of different energy tools available, which are diverse in terms of the regions they analyse, the technologies they consider, and the objectives they fulfil. In addition, it can be very difficult to define what exactly the primary focus of any research will become. Therefore, the first step which I would advise, is defining an overall objective for any modelling work which you intend to do. For example, the underlying objective in my work was:

"To identify how Ireland could integrate the most renewable energy into its energy system".

After establishing a core objective, it is then possible to rate various different energy tools against one another based on their capabilities of fulfilling this objective. To aid this comparison, an overview of all the energy tools I considered, as well as many others can be found in [2, 3]. Hence, these will not be discussed in detail here, but instead the only reasons I chose EnergyPLAN are outlined below:

1. EnergyPLAN is a user-friendly tool designed in a series of tab sheets and hence the training period required usually varies from a few days up to a month, depending on the level of complexity required. Also in relation to this point, there is online training available from the EnergyPLAN website so it is relatively straight forward to experience a typical application of the software [1].
2. The EnergyPLAN software is free to download [1].
3. EnergyPLAN considers the three primary sectors of any national energy system, which includes that electricity, heat, and transport sectors. As fluctuating renewable energy such as wind power becomes more prominent within energy systems, flexibility will become a vital consideration. One of the most accessible methods of creating flexibility is the integration of the electricity, heat, and transport sectors using technologies such as combined heat and power (CHP) plants, heat pumps, electric vehicles, and hydrogen. Therefore, for certain objectives, this can be an essential issue for a study.
4. EnergyPLAN was previously used to simulate a 100% renewable energy system for Denmark [4-8].
5. The results developed using EnergyPLAN are constantly being published within academic journals. A number of energy tool developers publish their results in private reports for those who fund their investigations. However, in order to obtain my PhD qualification I needed to publish my work in academic journals. Therefore, it was fortunate and important that EnergyPLAN was being used for this purpose.
6. The quality of journal papers being produced using EnergyPLAN was a key attraction. Below are a few examples of the titles I recorded before contacting Prof. Henrik Lund about EnergyPLAN:
   a. Energy system analysis of 100% renewable energy systems – The case of Denmark in years 2030 and 2050 [7].
   b. The effectiveness of storage and relocation options in renewable energy systems [9].
   c. Large-scale integration of optimal combinations of PV, wind and wave power into electricity supply [10].
   d. Large-scale integration of wind power into different energy systems [11].

   After reading these journal papers and observing the contribution that the results made to the Danish energy system, it was evident that similar research would benefit the Irish energy system.
7. Finally and possibly the most important reason for using EnergyPLAN, was Prof. Henrik Lund's supportive attitude when I approached him about using EnergyPLAN. My progress has been accelerated beyond expectation due to the support and guidance from both Prof. Henrik Lund and Associate Prof. Brian Vad Mathiesen. This is an essential aid when embarking on research, especially when learning new skills and meeting deadlines at the same time.

These are only some of reasons for using the EnergyPLAN tool. A more detailed overview of EnergyPLAN can be found in [1], while a more thorough comparison with other energy tools can be found here [2, 3].

3 Collecting the Required Data

After choosing any energy tool for a study, it is crucial that you ensure that the tool is capable of accurately modelling your particular application. Therefore, the first step is to create a reference model of an historical year. In my first study, I chose the 2007 Irish energy system as my reference and hence this report is primarily based on this application. However as I was making the reference model, I felt that a lot of questions could have been answered if I simply knew where to begin looking for the data required. Therefore, this document simply discusses where I found the information I needed to complete my reference model of the 2007 Irish energy system. I hope that this will enable future EnergyPLAN users to collect their data more effectively.

Important: There are important points below that need to be considered when reading the following chapters:

1. I have discussed a number of inputs in great detail and others only briefly. This reflects the effort required and the assumptions made in order to get the data and **not** the importance of the data.
2. When you download the EnergyPLAN model, a number of distributions are included with it. In a lot of studies these distributions will suffice as the results from the EnergyPLAN model may not be greatly improved by a more accurate distribution. Therefore, it is worth analysing the effects of various distributions on your results before allocating large periods of time to creating distributions.

This chapter is divided into **two** primary sections:

1. Technical Data
2. Economic Data

The order is used as this is a typical modelling sequence that can be used when simulating an energy system. Firstly, a reference model is created to ensure that EnergyPLAN can simulate the energy system correctly. The reference model does not require economic inputs, as it is usually only the technical performance that is compared. After creating the reference model using the technical inputs, then the fuel, investment, and O&M costs can be added to carry out a socio-economic analysis of the energy system. Therefore, alternatives can now be created and compared in relation to their technical performance and annual operating costs. Finally, the external electricity market costs can be added so a market simulation can be completed in EnergyPLAN: this enables you to identify the optimum performance of the energy system from a business-economic perspective, rather than a technical perspective. However, typically the aim when creating future alternatives is to identify how the optimum business-economic scenario, can be altered to represent the optimum socio-economic scenario (i.e. by adjusting taxes) as this is the most beneficial for society.

Finally, before discussing the data that was collected, it is important to be aware of the type of data that EnergyPLAN typical requires. Usually, the EnergyPLAN model requires two of the following technical parameters:

1. The total annual production/demand (i.e. TWh/year).
2. The capacity of the unit installed (i.e. MW).
3. The hourly distribution of the total annual production/demand, which have the following criteria:
    a. There must be 8784 data points, one for each hour.
    b. The data points are usually between 0 and 1, representing 0-100% of production/demand as shown in Figure 1[1]. However, if a distribution is entered with values greater than 1, EnergyPLAN will automatically index the distribution: This is done by dividing each entry in the distribution by the maximum value in the distribution. This means that historical hourly data can be directly used in EnergyPLAN for a distribution. An example, displaying how an index is created, and also how an index is used is shown in Table 3-1. One exception is the price distribution under the 'Regulation' tab, which does not normalise the inputs.
    c. The distribution is inputted as a text file and stored in the "Distributions" folder.

[1] This does not apply to the price distributions. For the price distribution, the actual values provided in the distribution are used.

The distribution is simply adjusted to reflect the total annual production/demand. For example, in Figure 2, the distributions for three separate demands are shown, which show how the distribution in Figure 1 is manipulated to model the total demand.

Table 3-1
How a distribution is indexed and subsequently used in EnergyPLAN (Note: 8784 hours in total are required).

Time (h)	Output from a 100 MW Wind Farm (MW)	Index Data		Using Indexed Data to Simulate a 400 MW Wind Farm	
		Fraction	Decimal		
1	20	20/100	0.2	0.2*400	80
2	30	30/100	0.3	0.3*400	120
3	60	60/100	0.6	0.6*400	240
4	100	100/100	1.0	1.0*400	400
5	80	80/100	0.8	0.8*400	320
6	40	40/100	0.4	0.4*400	160

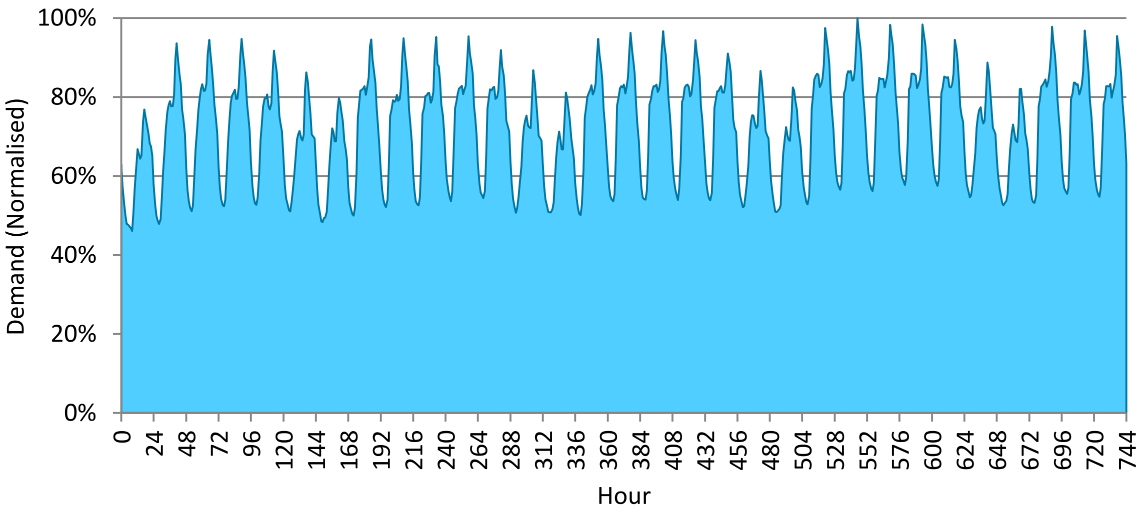


Figure 1: Distribution of Irish electricity demand for January 2007 [12].

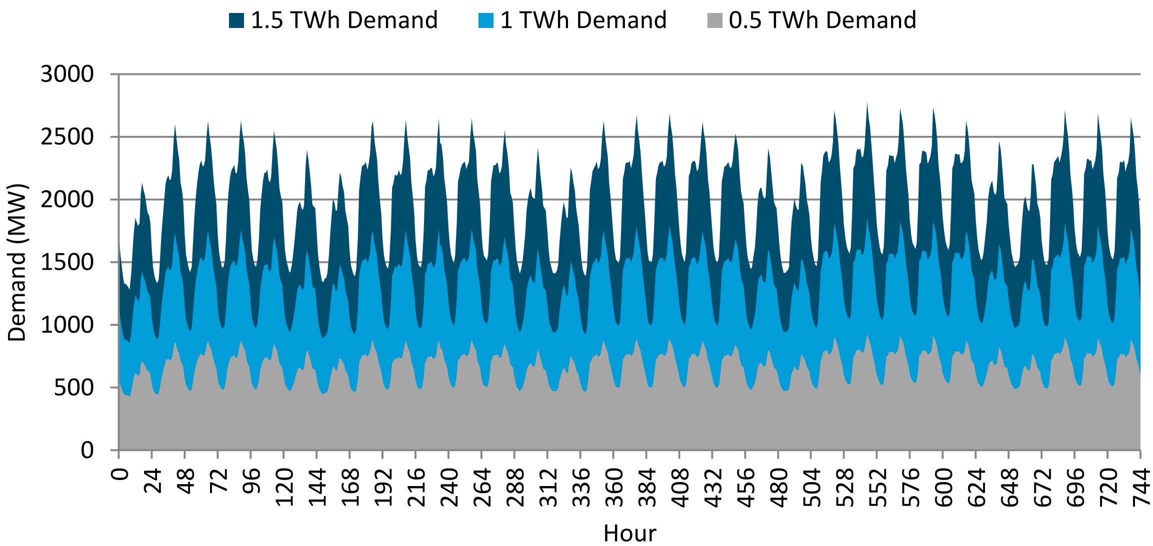


Figure 2: Distribution modified by the total Irish electricity demand required for January 2007 [12].

3.1 Technical Data Required

EnergyPLAN simulates a single year in hourly time-steps. To create an initial model, I picked the year 2007 as it was the most recent when I started gathering my data.

To explain where I got my data, I will discuss each tab within the EnergyPLAN model separately. The 'Frontpage' tab displayed in Figure 3 illustrates a flow diagram of the EnergyPLAN model, indicating how all the various components of the energy system interact with one another. The 'Input' tab is used to describe the parameters of the energy system in question. The 'Cost' tab is used to input the costs associated with the energy system being investigated and the 'Output' tab is used to analyse the results of your investigation. Finally, the 'Settings' tab enables the user to change the scale of the units in the program.

Below I will discuss in detail where I got the information for the 'Input' tab and the 'Cost' tab, as these account for the majority of data required.

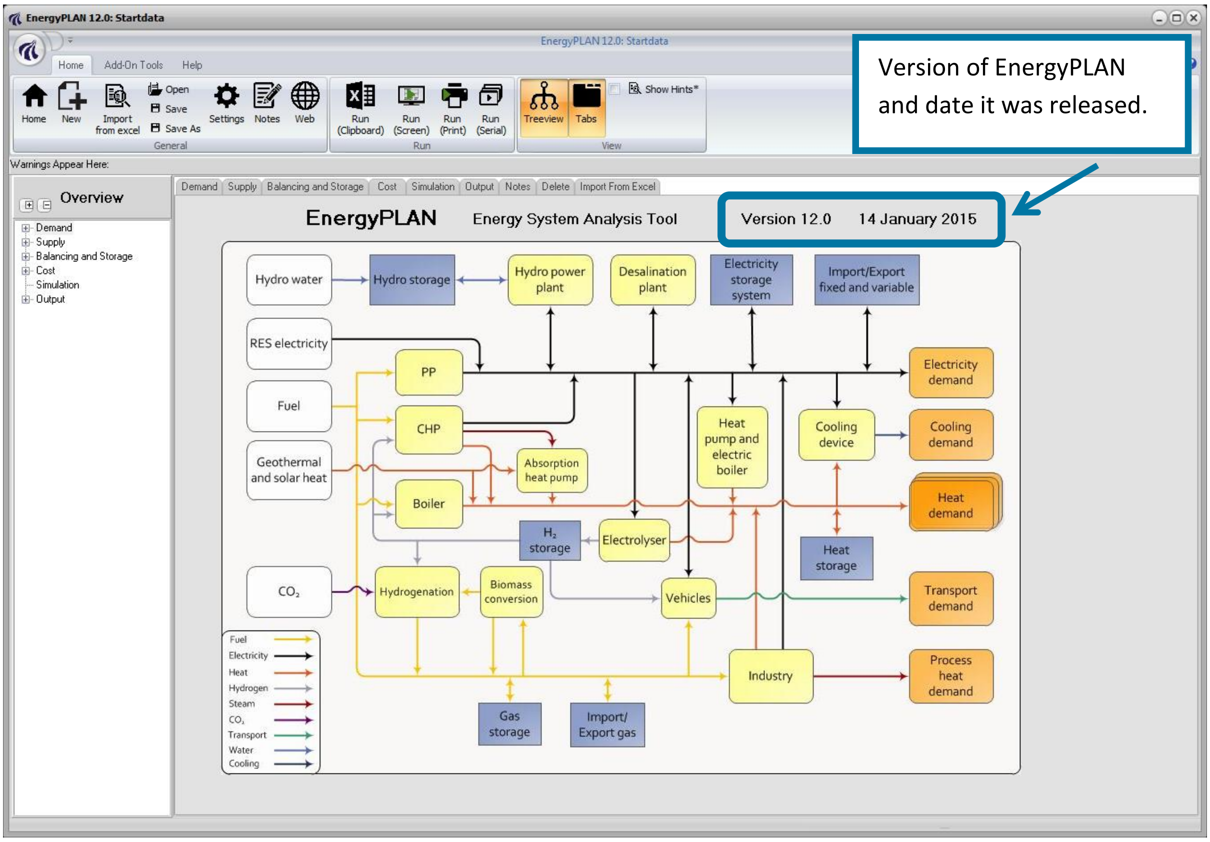


Figure 3: Frontpage of the EnergyPLAN tool.

3.2 Demand Tab

Below is a brief description of the data I used under the 'Input' tab in my model. It is worth noting that the data required for EnergyPLAN is usually generic data that can be obtained in most OECD[2] countries. Therefore, if I was able to obtain the data for the Irish energy system, it is likely to be available in other countries also. Also note that each sub-heading in this section represents data required for a different tab in EnergyPLAN.

The first piece of information that you should try to source is the 'Energy Balance' for your country or region. The Irish Energy Balance was completed by the Irish energy agency called the Sustainable Energy Authority of Ireland (SEAI) [13]. The Energy Balance indicates the energy consumed within each sector of the energy system

[2] Organisation for Economic Co-Operation and Development: http://www.oecd.org.

as displayed Figure 4 and Appendix 7.1. The International Energy Agency (IEA) completed two reports on energy balances in 2008: one with the Energy Balances for each of the OECD countries [14] and one with the Energy Balances for a number of non-OECD countries [15]. These documents must be purchased so I have not obtained a copy. However, this is one possible source for an energy balance of your energy system.

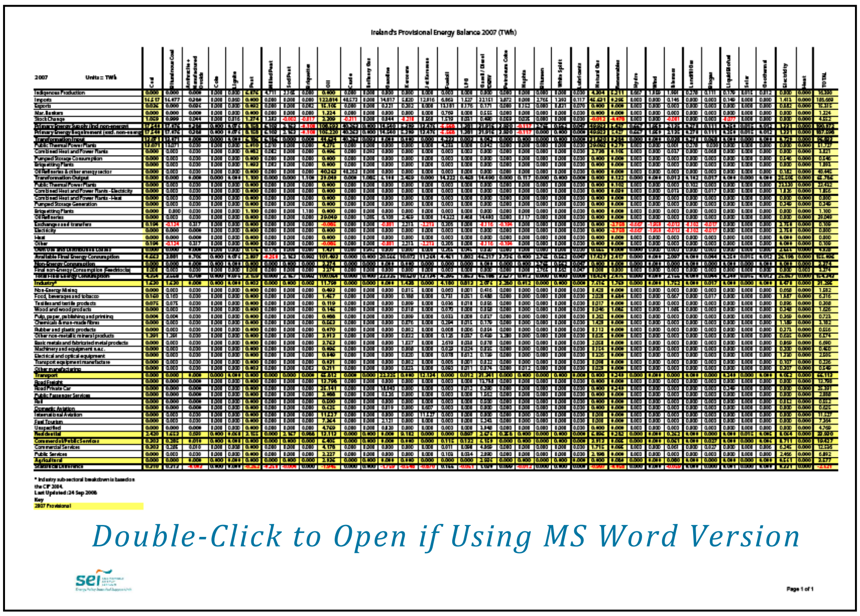


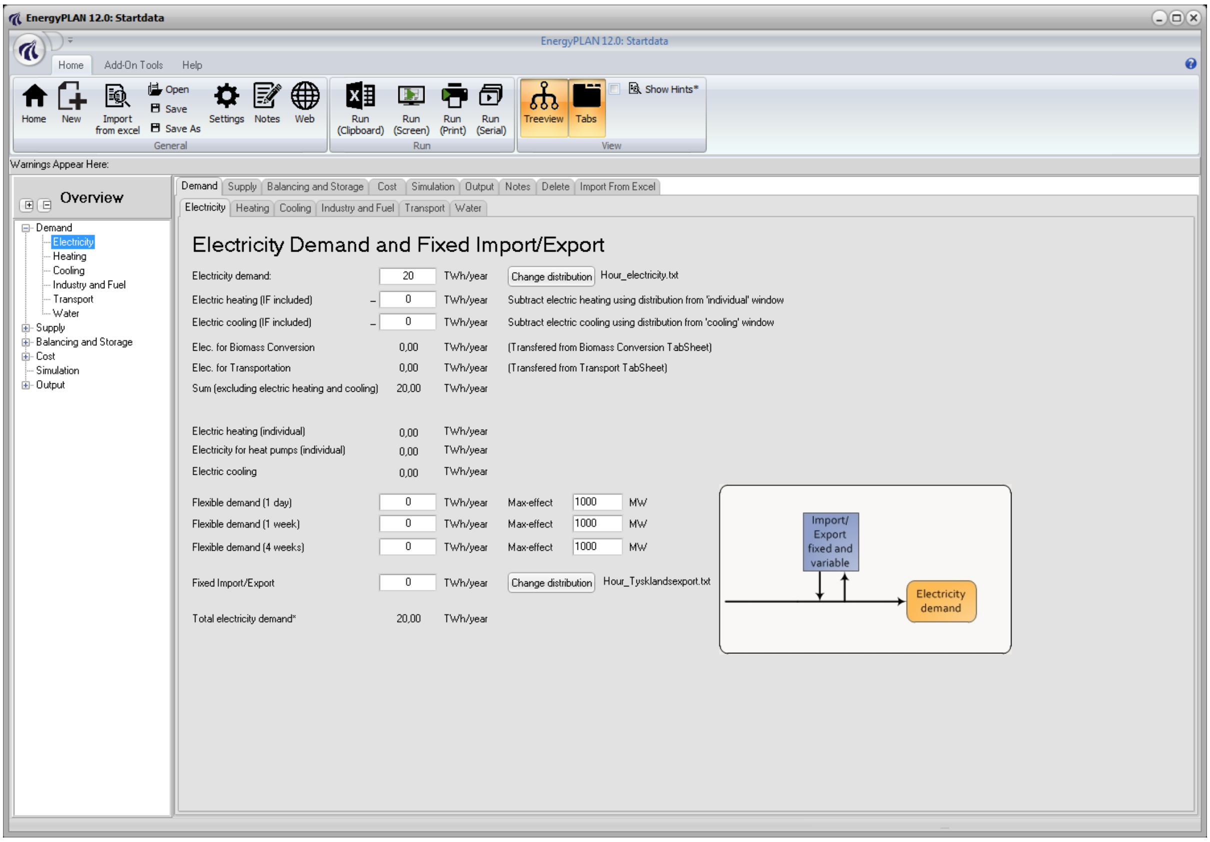
Figure 4: Irish energy balance for 2007: see Appendix 7.1 and reference [16].

The Energy Balance document proved to be the most useful source of information for my investigation. However, it is important to check the accuracy of the data in this document, as the figures can sometimes be based on estimates.

Secondly, meteorological data also proved very important when predicting renewable energy production. Meteorological data can usually be obtained from a national meteorological association. However, another option is to use a program called 'Meteonorm' [17]. This program has gathered data from a number of meteorological stations around the world, which can be accessed using a very intuitive user-interface. However, the program is not free so you will need to decide how important meteorological data will be before purchasing it[3]. Even if you use this program, it could also be useful to compare the data in the software to actual measurements from a weather station to ensure that the program is providing accurate data. There is also some free meteorological data available from this website: www.wunderground.com.

[3] Data from meteorological stations may or may not be free so it is worth enquiring about this also.

3.2.1 Electricity



Total electricity demand was obtained from the Irish transmission system operator (TSO), EirGrid [13], and the Energy Balance document. Imported and Exported electricity was also obtained from the TSO in Ireland.

Twenty-four European countries are involved in the "European Network of Transmission System Operators for Electricity" (ENTSO-E), which provides a lot of detailed data about the production and consumption of electricity. A list of the countries in the ENTSO-E is available from [18], and the data can be obtained from [19]. The data includes the following:

- Statistics
- Production Data
- Consumption Data
- Exchange Data
- Miscellaneous Data
- Country Data Packages

Therefore, this is a useful source of information if you are modelling a European region.

3.2.2 Heating

For my initial energy model I did not have to include any district heating, since there are currently no large-scale installations in Ireland.

3.2.2.1 Heat Distribution

It was very difficult to predict the annual heat distribution for the entire population of Ireland. In order to estimate it, I used 'Degree Day' data from Met Éireann, the Irish meteorological service [25].

There are Heating Degree Days (HDD) and Cooling Degree Days (CDD). As their title suggest, the HDD indicate the level of heating required on a given day, and the CDD indicate the level of cooling required on a given day. In Ireland, cooling is not usually necessary due to the climate and therefore, the HDD was used to estimate the amount of heat required.

Heating Degree Days work as follows: The temperature within a building is usually 2-3°C more than outside, so when the outside temperature is 15.5°C, the inside of a building is usually 17.5°C to 18.5°C. Therefore, once the temperature drops below this 15.5°C outside-temperature setpoint, the inside temperature drops below 17.5/18.5°C and the space heating within a building is usually turned on. Note that this 15.5°C setpoint is specifically for Ireland and it can change depending on a number of factors such as the climate and the typical level of house insulation [36]. A full explanation about the calculation and application of degree data can be obtained from [36, 37].

For the heat demand, an annual distribution with a resolution of 1 hour is required, but the Degree Day data obtained from various weather stations around Ireland is only recorded on a daily basis, as seen in Figure 5. Therefore, this 1 day data had to be converted into hourly readings. To do this, I took a daily cycle from a similar study completed on Denmark in [7] and applied it to the Irish distribution with a program I developed in MATLAB [31], which is displayed in Figure 6. As district heating is common in Denmark, hourly data could be easily obtained over a 24 hour period and it was assumed that Ireland would have a similar daily distribution in its heat demands as Denmark.

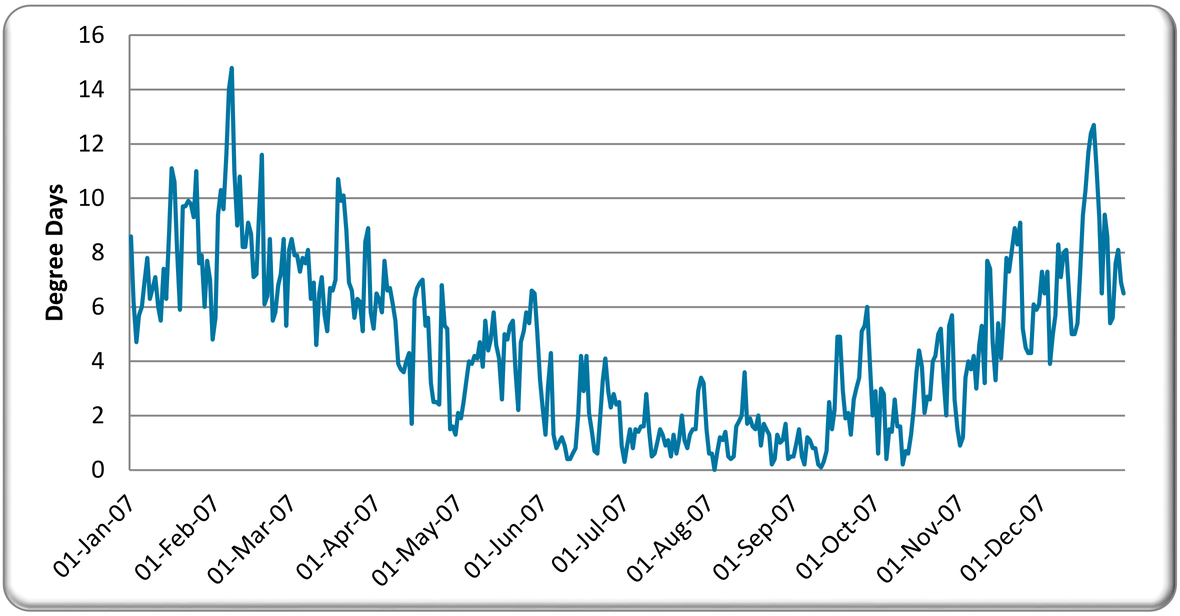


Figure 5: Degree Day data from Belmullet meteorological station in Mayo, Ireland [25].

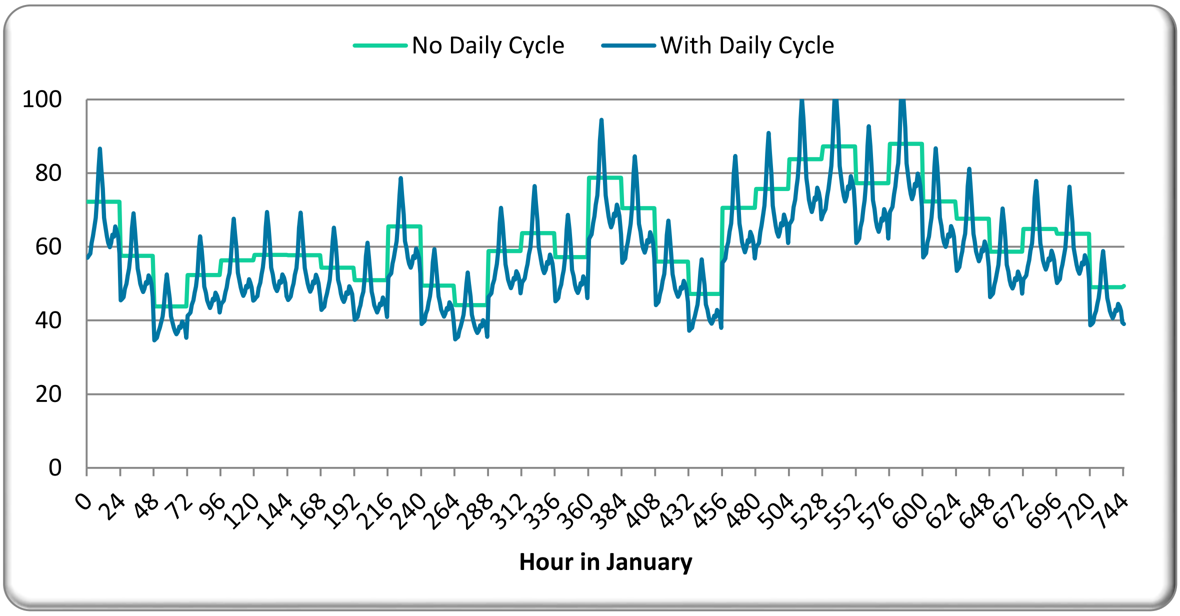


Figure 6: Individual heat distribution for January 2007 in Ireland (Hourly).

Finally, by obtaining the HDD data, the level of heat required each day within a building can be estimated. However, this only considered the space heating distribution and not the hot water distribution. Therefore, a heat distribution which accounted for both space heating and hot water demand had to be constructed. For the summer months, it was assumed that space heating would not be required: it was assumed that the heat absorbed by the building during warm temperatures, and also the building's occupants, would keep the building warm during colder temperatures. Therefore, during the summer hot water is the only heating demand. It was also assumed that hot water is a constant demand each day for the entire year, as people tend to use a consistent amount of water regardless of temperature or time of year. The BERR in the UK completed a report in relation to domestic hot water and space heating, which indicated that the ratio of space heating to hot water heating in the home is 7:3 [38]. Therefore, as seen in Figure 7, for the heat distribution a 30%

constant bandwidth was placed at the base representing hot water demand, and a 70% demand was placed on top (based on Degree Day data) representing the space heating requirements. Figure 7 represents the heat distribution constructed for modelling the heat demand within the Irish energy system.

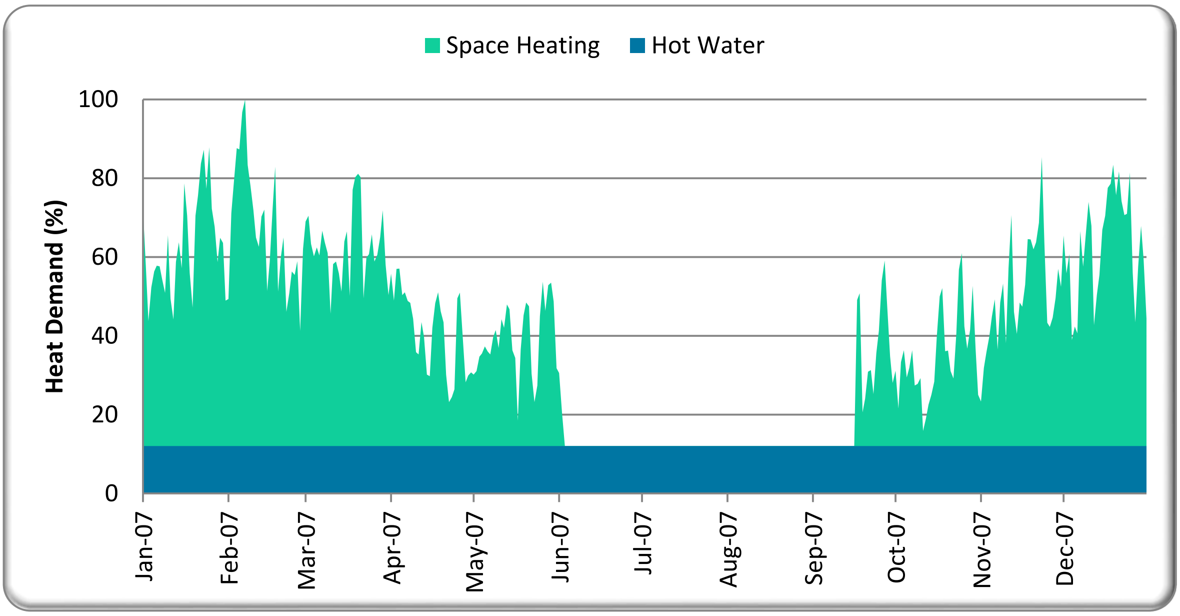


Figure 7: Individual heat distribution for Ireland.

3.2.2.2 Fuel Consumption and Efficiency of Boilers

The fuel consumed for residential heating can be obtained from the Energy Balance. For the boiler efficiencies, I consulted the Building Energy Rating documentation provided by the Irish energy agency, SEAI [39]. This documentation is used by assessors to complete energy ratings for homes in Ireland. Therefore, the documentation gave the typical type and efficiency of different domestic boilers used in Ireland. This could be available in other countries also, or if not, the efficiencies within this documentation could be applied to other applications.

3.2.2.3 Electric Heating

Electric heating demand can also be difficult to quantify as it is usually documented in conjunction with the heating demand and not as a separate entity. From a report completed by the Irish energy agency, SEAI, it was found that 14% of all domestic electricity is used for space heating and 23% for hot water [40]. In a separate report by SEAI, it was found that 12% of commercial electricity was used for heating purposes [41]. Therefore, I used these figures to calculate the electric heating demand in Ireland i.e. (37% of domestic electricity plus 12% of commercial electricity).

3.2.2.4 Solar Distribution

There are two types of solar thermal in the EnergyPLAN model: solar thermal that contributes to district heating and solar thermal for individual households. At present, only individual solar thermal energy is used in Ireland and hence it is discussed here under the individual's heating demands. The inputs required for the EnergyPLAN model are the:

1. The total annual solar thermal production.
2. Hourly distribution of the solar thermal production over the year.
3. Solar thermal share.

The total solar production in Ireland for 2007 was got from the 2007 Energy Balance [16]. For the distribution, an attempt was made to obtain the hourly power output from a solar panel for an existing installation[4] in Ireland, but this could not be obtained. As discussed previously, the solar radiation available in Ireland and Denmark is very similar (see Table 3-3) and hence, a solar thermal output curve which was constructed for Denmark was used. This solar thermal distribution was created by a Danish energy consultancy firm, PlanEnergi [42], for the 2030 Danish Energy Plan [7, 8]. The distribution gives the production from an individual solar thermal installation of 4.4 m^2 during a typical Danish year. The energy produced from the solar panel is based on a daily consumption demand of 150 litres, which needs to be heated from 10°C to 55°C in combination with a 200 litre storage tank. The 4.4 m^2 represents a solar thermal installation designed for hot water and some contribution to space heating.

3.2.2.5 Solar Share

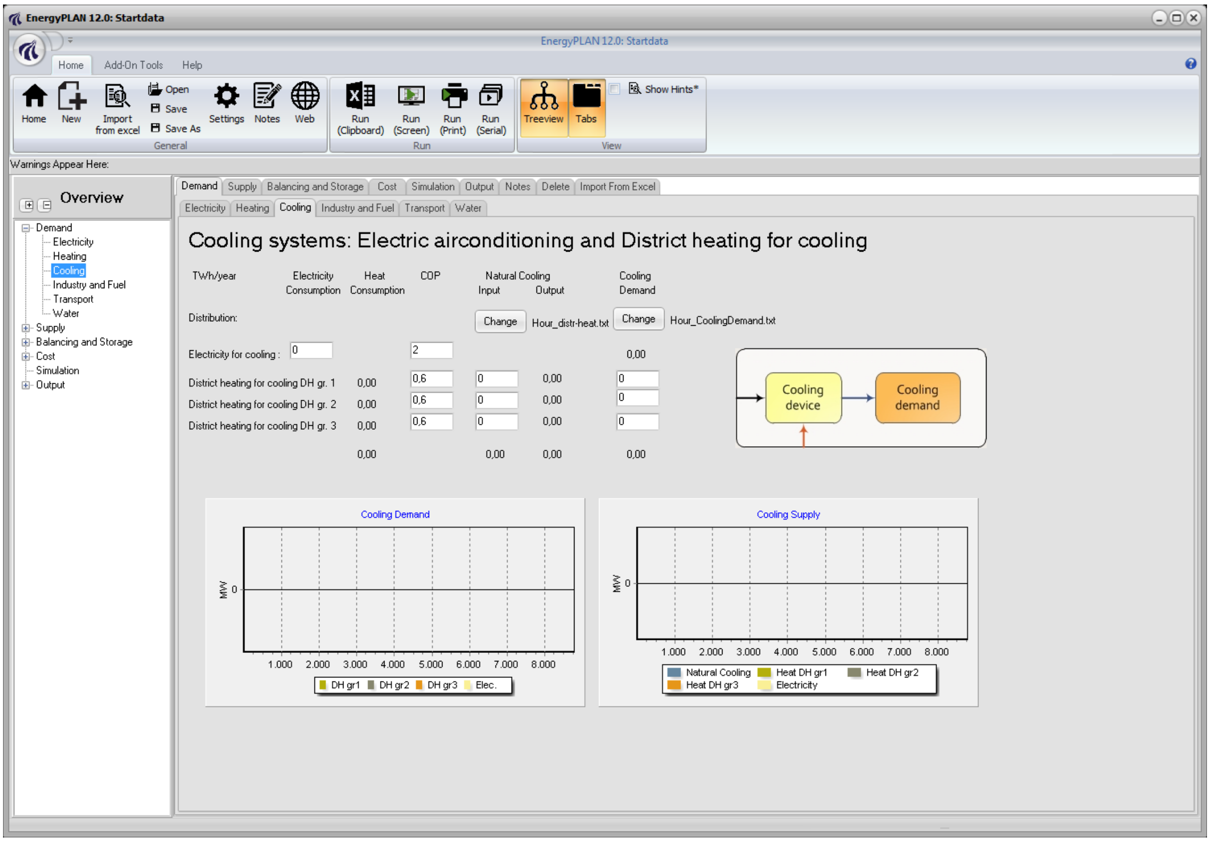
The solar share is the percentage of houses that have a solar panel installed: To estimate this in Ireland, I contacted the Irish energy agency, SEAI [13], who told me that there was 33,600 m^2 of solar thermal panels installed in Ireland. A typical solar installation in Ireland uses 5 m^2, therefore it was assumed that there are approximately 6,720 solar installations in Ireland. From the 2006 census in Ireland, it was stated that there are 1,469,521 homes in Ireland [43]. Therefore, it was concluded that there is a solar thermal installation in 0.45% (6720/1469521) of Irish houses.

3.2.2.6 Solar Input

As stated above, I found the total solar energy utilised from the Irish Energy Balance [16]. The solar input and solar share can be adjusted if necessary to match the solar production with the value stated in the Energy Balance.

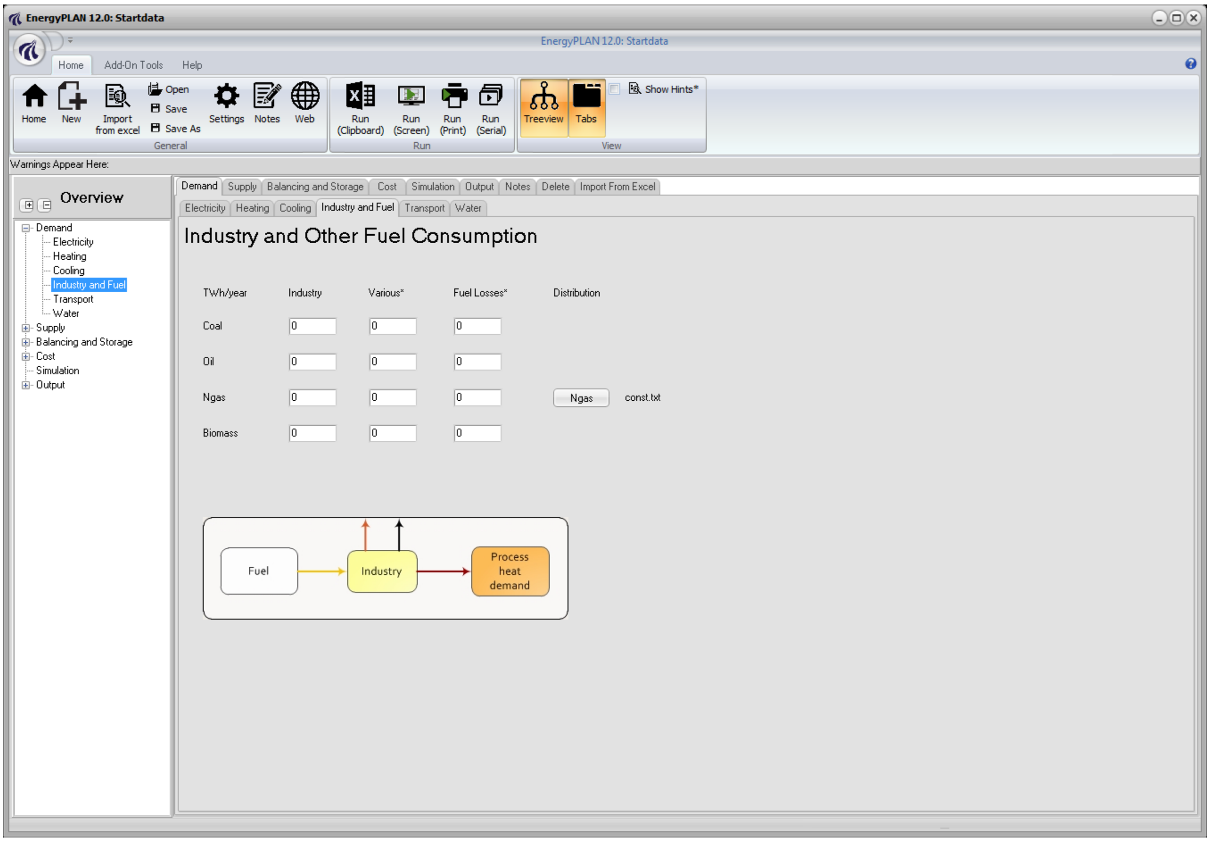
[4] Solar-thermal output can be found by measuring the inlet and outlet temperatures of the collector, and also the flow rate.

3.2.3 Cooling



There is currently no cooling load in Ireland so no data was required for the Irish reference model. Note that the heat demand under the cooling tab is for absorption cooling.

3.2.4 Industry



The quantity of each fuel-type consumed within industry can be found in the Energy Balance [16]. The 'Various' input is only used when a consumption cannot be specified anywhere else or may need to be analysed on its own i.e. gas consumption for offshore drilling.

3.2.5 Transport

The amount of fuel used for transport is available by fuel type, including electricity, from the Energy Balance [16].

3.3 Supply Tab

3.3.1 Heat and Electricity

There is currently no large-scale CHP plants for public district heating systems in Ireland, so only industrial CHP was required for the heat and electricity tabsheet.

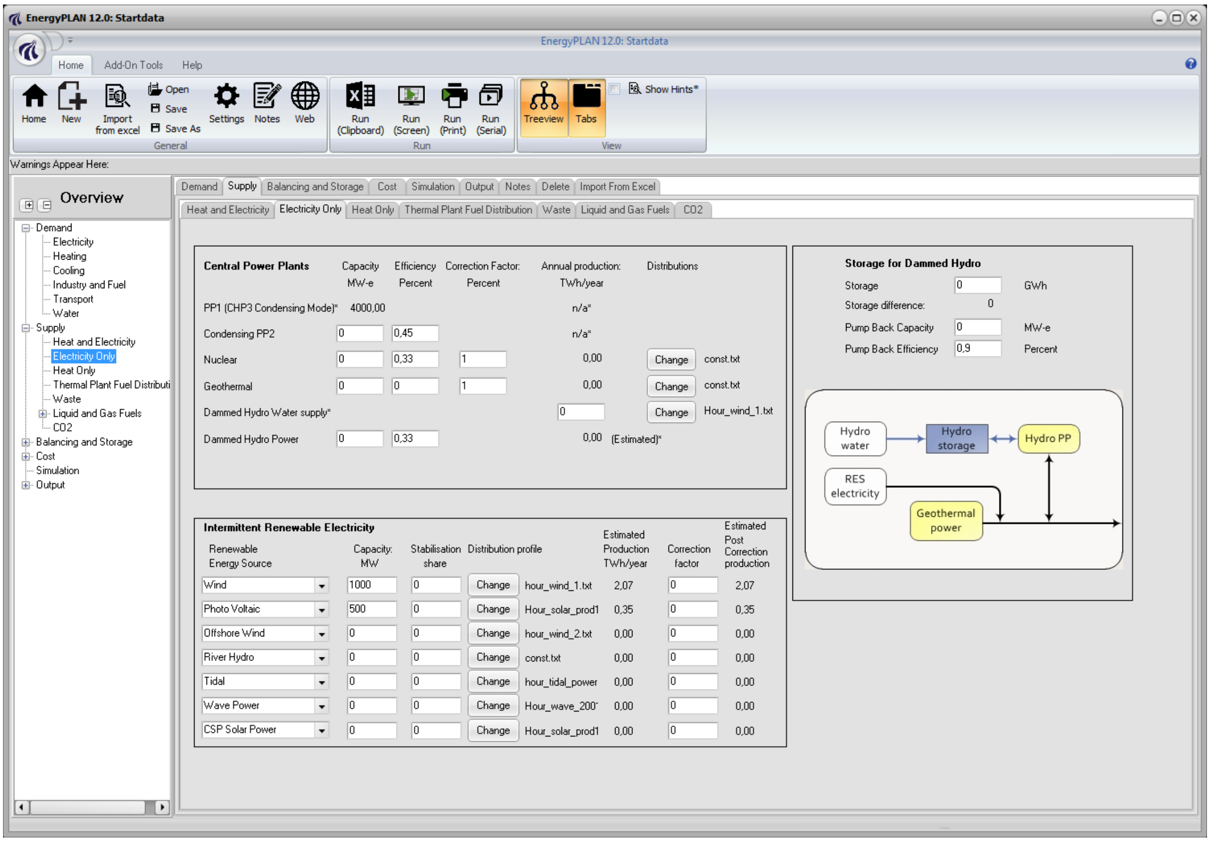
3.3.1.1 Industrial CHP: Energy Production

In order to quantify the capacity of industrial CHP, I had to contact the statistics department within the Irish energy agency, SEAI, who had the breakdown of CHP plants at their disposal. They could identify from their records how much CHP in Ireland was industrial and how much was dispatchable. From this they could also provide the amount of electricity and heat that was produced from both industrial and dispatchable CHP.

3.3.1.2 Industrial CHP: Distribution

Since the industrial CHP in Ireland was not controlled by the TSO, I used the ‘const.txt’ distribution for Industrial CHP, which means the output was simply constant. It is considered the best proxy for modelling a production that cannot be controlled.

3.3.2 *Electricity Only*



3.3.2.1 Power Plants

For power plants, the first parameter required is the total capacity installed, which I got from the Irish TSO [13]. If necessary, it is possible to divide the power plants into two categories: condensing and PP2. The PP2 category is usually used if there is a highly contrasting plant mix on the system i.e. if there is one group of plants with a low efficiency and are expensive, but another group of plants which have a high efficiency and are cheap. Therefore, the PP2 can be suitable for some energy systems.

In addition to the PP capacity, you also need to find the total fuel consumed by the power plants, which is usually available in the energy balance. For example, in the Irish energy balance, you can see that there is a category titled "Public thermal power plants", which can be broken down by coal, oil, gas, and biomass. These values are entered into the "Distribution of Fuel" grid. If you put all of the PP capacity into the "condensing" section, then all of the fuel consumption needs to be in the PP row of the grid. However, if you put some plants in PP and some other plants in PP2, then the fuel will need to be split across these rows, in a way that reflects this divide.

Finally, you will also need the efficiency of the power plants. As mentioned, the total fuel consumption for each type of power plant can be obtained from the energy balance. Using the energy balance document I could calculate the efficiency of all the condensing plant, η_{COND}, using the total fuel input, F_{IN} (Wh), and total electricity generated, E_{OUT} (Wh),

$$\eta_{COND} = \frac{E_{OUT}}{F_{IN}} \tag{1}$$

It was difficult to obtain the efficiencies of the individual condensing plant as it was "commercially sensitive information". However, I obtained a breakdown of fuel inputted into the Irish condensing plants, see Figure 8, once again from the Irish energy agency SEAI, and used this to calculate the efficiencies for the condensing plant of different fuel type (using formula 1). For the reference model you will not need to know this: instead all you need to find out is the total fuel consumed by all the power plants, and the total electricity generated by all the power plants (then you can calculate the condensing efficiency). However, the efficiency of the power plants under each fuel type will be necessary when simulating future alternatives: for example, if you wanted to simulate coal power plants being replaced by natural gas power plants as illustrated in Table 3-2.

Table 3-2
How individual power plant efficiencies alter the overall "Condensing" power plant efficiency.

	Coal PP (MW)	Natural Gas PP (MW)	Coal PP Efficiency	Natural Gas PP Efficiency	Total Capacity (MW)	Overall Efficiency
Reference	1000	2000	0.4	0.5	3000	0.466
Alternative 1	500	2500	0.4	0.5	3000	0.484
Alternative 2	0	3000	0.4	0.5	3000	0.500

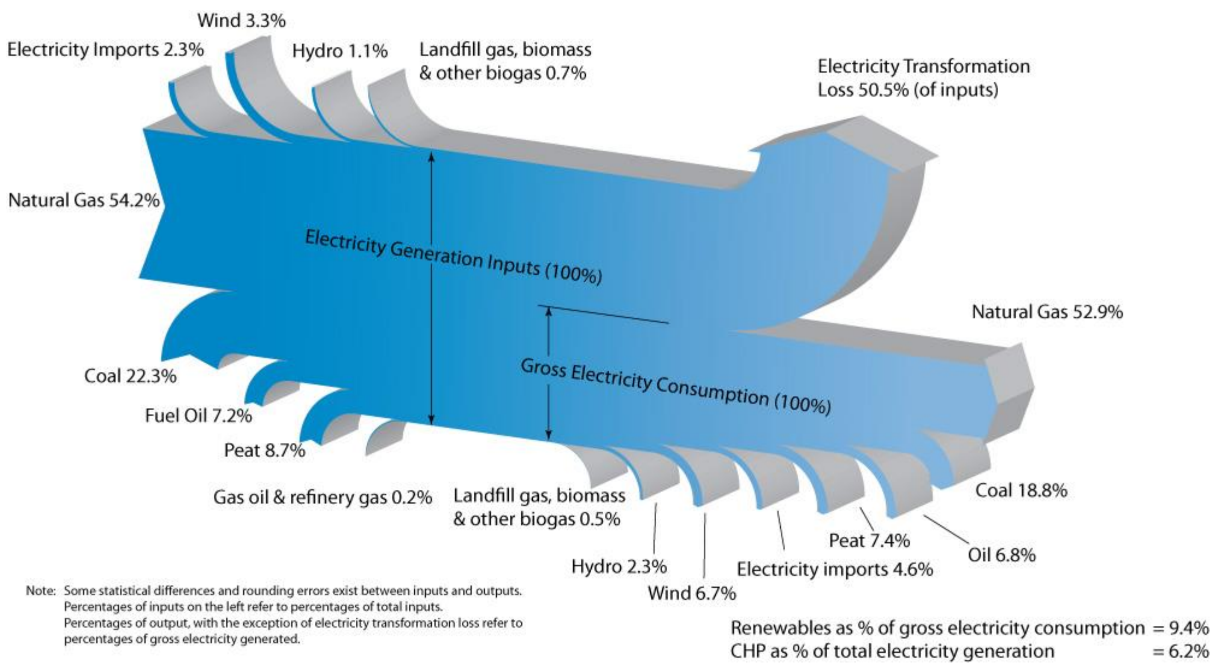


Figure 8: Breakdown of fuel consumption and electricity generated in Irish electricity system [44].

3.3.2.2 Renewable Electricity

In order to define the energy available from a renewable energy resource in your energy system, you need to define five major features:

1. The type of renewable energy in question.
2. The installed capacity of the renewable resource.
3. The distribution profile (hourly for one year).
4. The stabilisation share.
5. The correction factor.

Parameters 1-3 are reasonably intuitive and have been discussed in detail in at the start of section 3. Therefore, I will only recap on the 'stabilisation share' and the 'correction factor' here. So, just to repeat from the EnergyPLAN user manual [1], the stabilisation share is the percentage (between 0 and 1) of the installed capacity of the renewable resource that can contribute to grid stability i.e. provide ancillary services such as voltage and frequency regulation on the electric grid. At present renewable energy technologies, with the exception of hydro plants with storage, cannot help regulate the grid. Therefore, the stabilisation share will be set to 0 unless this changes in the future.

Also from the EnergyPLAN user manual [1], the correction factor adjusts the hourly distribution inputted for the renewable resource. It does not change the power output at full-load hours or hours of zero output. However, it does increase the output at all other times. This can be used for a number of different reasons. For example, future wind turbines may have higher capacity factors, and thus the same installed wind capacity will produce more power.

Onshore Wind

I obtained the installed wind capacity and the hourly wind output for 2007 from the Irish TSO. The stabilisation factor was inputted as 0 because wind power does not contribute to grid stabilisation. Also, the correction factor was inputted as 0 because the installed wind capacity and the distribution used generated the expected annual wind energy. Otherwise, the correction factor would need to be adjusted until the wind production calculated by the model was the same as the actual annual production.

Offshore Wind

There was very little historical data available for offshore wind in Ireland. There is currently only one offshore wind farm constructed, which is located at Arklow Banks near County Wicklow. This wind farm is using a new wind turbine developed by GE Energy (The General Electric Company), hence they will not release any information in relation to the power generated from the turbines. The only information I had was the installed capacity of the wind turbines, which was 25.2 MW (7 x 3.6 MW turbines). As a result I used the onshore wind distribution that I had obtained from the Irish TSO, combined with the correction factor in EnergyPLAN. The reason the onshore wind distribution is a good source of data, is because it accounts for the variations in wind speed over the island of Ireland. The only difference between onshore and offshore wind distributions is the higher capacity factor for offshore. This is accounted for by the correction factor in EnergyPLAN. However, after deciding to use the onshore wind distribution, I then had to identify the annual wind energy produced by the 25.2 MW of offshore wind. I calculated this in two different ways.

For the first method I began by obtaining the average annual wind speed at the location of the offshore wind farm (8.75 m/s), using the Irish wind atlas [20]. Then I got an annual offshore wind distribution from a data buoy located close to the offshore wind farm (data buoy M2 from [21]). This data had an average annual wind speed of 7.82 m/s over the year 2007. Therefore, I scaled up this distribution curve until the average annual wind speed was 8.75 m/s (the same as the average wind speed at the offshore wind farm). Finally, I got the power curve for a Vestas V90 wind turbine as seen in Figure 9, and calculated the expected output for a single year from the offshore wind farm. I did not want to use the power curve for the GE Energy wind turbines which were installed at the offshore wind farm, as these are still at the testing stage. At this point I had calculated an expected offshore wind production of 0.11 TWh: using the power curve and wind speed distribution with average annual wind speed of 8.75 m/s. Using the onshore wind distribution, the annual electricity generated from the 25.2 MW offshore wind farm was 0.07 TWh. However, from my calculations, the total electricity that should have been generated was 0.11 TWh. Consequently, I adjusted the ‘Correction Factor’ (to 0.65) until the total offshore wind output was 0.11 TWh. This accounted for the higher capacity factor of the offshore wind turbines in comparison to the onshore wind turbines. However, if 25.2 MW of wind power produced an annual output of 0.11 TWh, this would give the wind farm a capacity factor of 49.8% which is very high and hence I used a second method also.

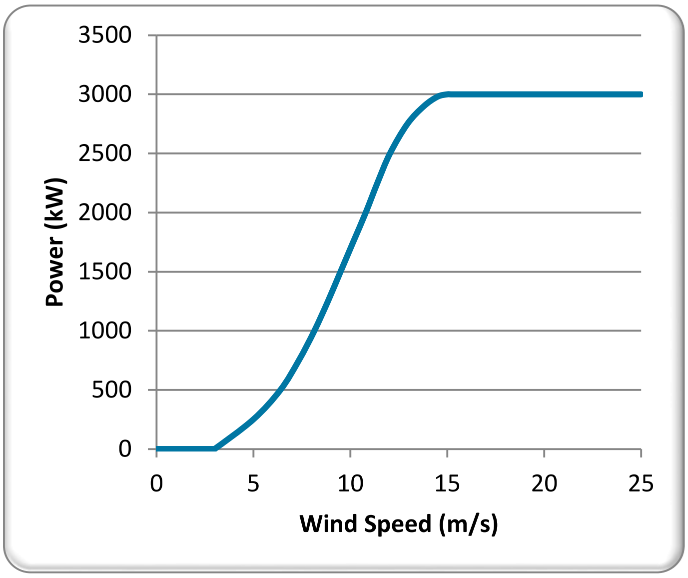


Figure 9: Power curve for a Vestas V90 wind turbine [22].

For the second method, I simply found the average capacity factor for an offshore wind farm in Ireland, which was 40% [23]. I then calculated the annual output from the wind farm, E_{Annual}, using the installed wind capacity, PW, and the average capacity factor for an offshore wind farm, CF_W, as displayed below:

$$E_{Annual} = 8760 P_W CF_W \tag{2}$$

The result was 0.088 TWh from an installed wind capacity of 25.2 MW with a capacity factor of 40%. Therefore, after the offshore wind capacity and onshore wind distribution were inputted into EnergyPLAN, and the correction factor was adjusted (to 0.36) until the annual output was 0.088 GWh. In my opinion, this method is better when simulating alternatives which introduce new large-scale wind capacities, as it uses the average capacity factor. In comparison, the first method is better if you are simulating a specific wind farm as it takes into account the specific wind speeds at that site. As Ireland has very little offshore wind at the moment, but my future alternatives will most likely simulate large-scale offshore wind capacities, I used the second method for my model.

Photovoltaic

As I could not obtain PV output from Ireland, I used the results obtained from a Danish project called Sol300, as the solar radiation in Denmark is very similar to the solar radiation in Ireland, which is displayed in Figure 10. To ensure the Danish solar resource was similar to the Irish solar resource, global solar radiation data was compared between Denmark and Ireland as seen in Table 3-3. It clearly verifies the similarity and therefore it was considered reasonable to assume that the solar thermal output would be very similar for both Denmark and Ireland.

This Sol300 project involved the installation of grid-connected PV panels on 300 homes in Denmark and the corresponding output was recorded. This output is discussed in [10], and is available in the Distributions folder that comes with the EnergyPLAN model. The name of the distribution is hour_PV_eltra2001 and hour_PV_eltra2002, for the years 2001 and 2002 respectively.

Work is currently underway to find a relationship between PV output and global solar radiation (as global solar radiation is the most common form of measuring solar radiation at meteorological stations). This section will be updated when this work is completed.

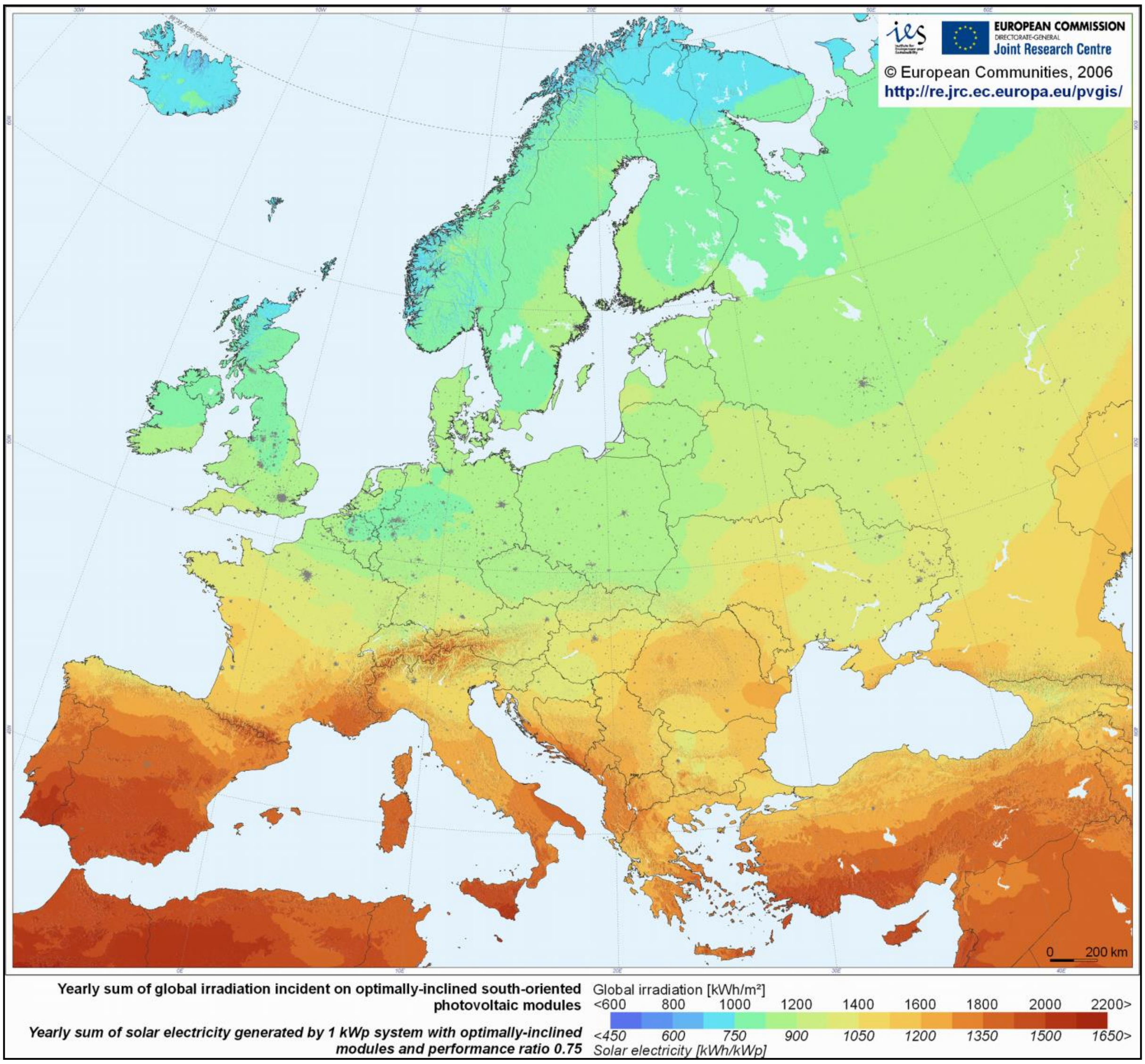


Figure 10: Yearly global irradiation data in Europe [24].

Table 3-3
Global solar radiation in Denmark and Ireland for 2007 [25, 26].

Country	Number of Stations That Provided Data	Average Annual Global Solar Radiation (kWh/m^2)
Denmark	4	976
Ireland	7	989

Tidal

Tidal power is developing rapidly at present. It is very similar to most renewable energy as it must be used at the time of generation. However, the unique characteristic of tidal power is the fact that it can be predicted in on a minute resolution at least three years in advance, if not more. In order to simulate tidal power, I sourced two studies completed in Ireland: one by SEAI (the Irish Energy Authority), titled "Tidal and Current Energy Resources in Ireland" [27], and one by the Department of Communications, Energy and Natural Resources called the "All-Island Grid Study: Renewable Energy Resource Assessment (Workstream 1)" [28]. The first study [27] identified viable tidal energy resource available in Ireland from tidal power (0.92 TWh), and the second study [28] created a power output curve for tidal devices as seen in Figure 11. Using these two inputs it was possible to simulate tidal energy in EnergyPLAN. It is worth noting that these figures were based on 'first-generation tidal devices', so the area investigated came under the following restrictions:

1. Water depth between 20m and 40m.
2. Sites outside major shipping lanes.
3. Sites outside military zones and restricted areas.
4. Sites which do not interfere with existing pipelines and cables.
5. 12 nautical mile limit offshore.
6. Peak tidal velocity greater than 1.5 m/s.

'Second-generation tidal devices' are expected to be developed that can be placed in areas without some of these restrictions (see Figure 12). However, these devices are not expected until 2015 [28].

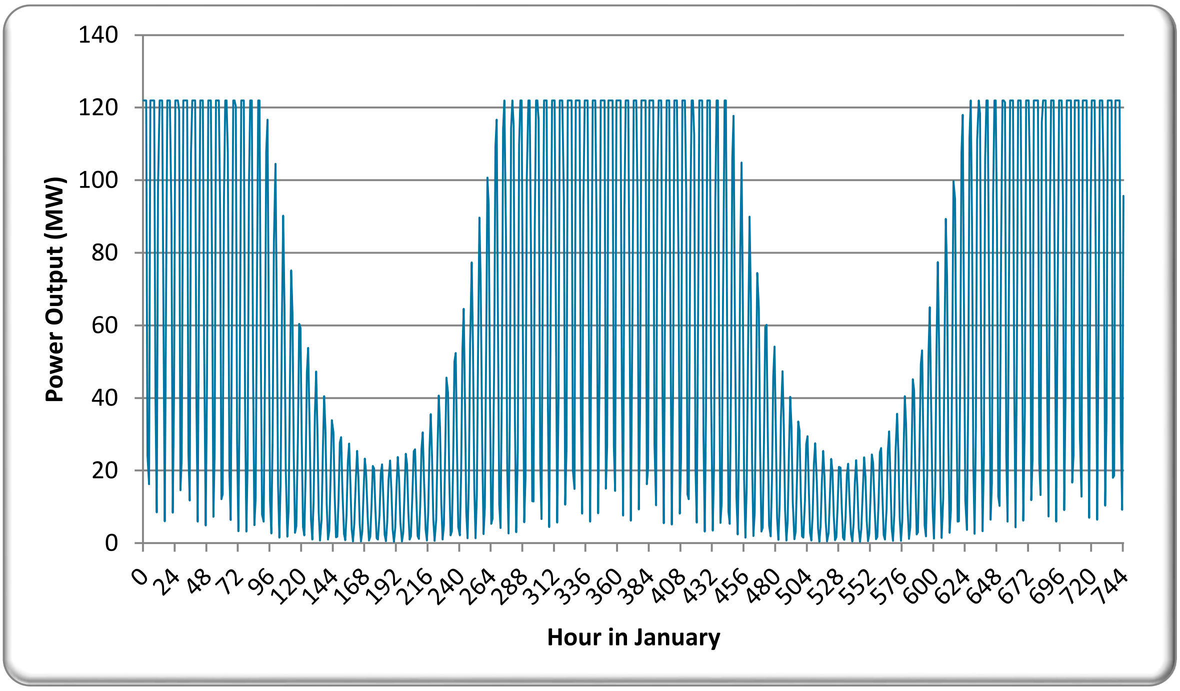


Figure 11: Tidal power output expected in Ireland for the month of January from a 122 MW Tidal Farm [28].

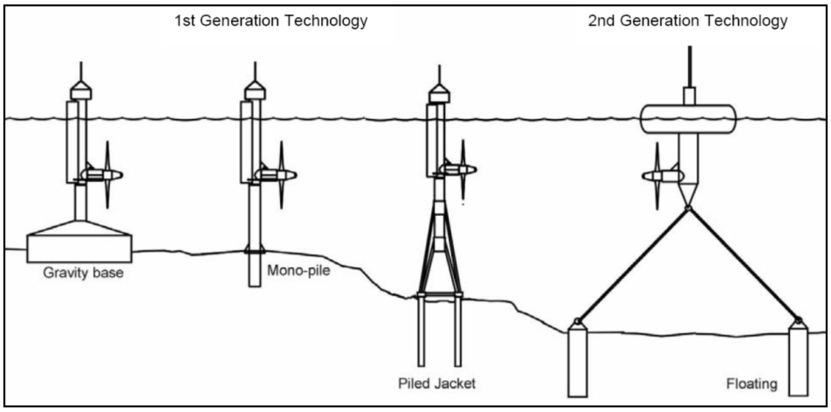


Figure 12: First and Second generation tidal technology [29].

Wave Power

I consulted with Jens Peter Kofoed from Aalborg University in order to generate the expected wave power data for my model. During our discussion, it became apparent that the future of wave power is very unclear.

Unlike wind power where the three-bladed turbine has become the primary technology, there will be no standard design for future wave generators. This is due to the fact that wave power depends on two parameters: wave height and wave period. Different wave generators will be used depending on the specific wave height and period characteristics at a site and hence, it is unlikely that any single wave generator will be the most efficient at all sites.

The most convincing way to predict the wave power contribution for an energy system in the future is to use the output from a wave generator device that is publicly providing a power matrix, such as the Pelamis in Figure 13, the Wave Dragon in Figure 14, and the Archimedes in Figure 15. These power matrices are available to the public and hence can be used in conjunction with wave height and wave period data to predict future wave power.

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

(a) (b)

Figure 13: Pelamis wave generator (a) and power matrix: output in kW (b).

Significant Wave Height - m \ Wave Period – Tz (s)	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	203	276	348	432	516	608	699	798	896	925	953	958	962	941	919	870	820	742	663	555	446
1.5	412	448	485	617	750	899	1049	1212	1375	1433	1491	1509	1527	1502	1477	1404	1332	1209	1086	912	737
2.0	621	621	621	802	983	1191	1398	1626	1853	1941	2029	2061	2092	2063	2034	1939	1844	1677	1509	1269	1028
2.5	1123	1123	1123	1213	1304	1609	1914	2258	2602	2752	2903	2972	3041	3017	2993	2868	2743	2504	2266	1910	1555
3.0	1624	1624	1624	1624	1624	2027	2430	2890	3350	3563	3776	3883	3989	3970	3951	3796	3641	3332	3022	2552	2082
3.5	2581	2581	2581	2581	2581	2783	2984	3588	4191	4494	4796	4870	4945	4935	4926	4845	4765	4374	3983	3372	2761
4.0	3538	3538	3538	3538	3538	3538	3538	4285	5032	5424	5816	5858	5900	5900	5900	5895	5889	5416	4943	4191	3439
4.5	4719	4719	4719	4719	4719	4719	4719	5093	5466	5662	5858	5879	5900	5900	5900	5897	5895	5658	5422	4822	4222
5.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5452	5004
5.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5676	5452
6.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
6.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
7.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
7.5	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900
8.0	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900	5900

Figure 14: Wave Dragon power matrix (optimised for high average wave conditions): output in kW [30].

Significant Wave Height Hsig - m \ Wave Period – Tpow (s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	2	7	13	19	26	34	41	48	58	68	81	93	105	118	131	144	153	163	183	203	213	223	223	223	223	225	227
1.5	4	15	28	41	56	72	85	99	121	143	173	203	226	248	266	285	309	334	357	380	389	398	398	398	398	403	409
2.0	8	26	49	73	100	127	150	172	210	247	292	337	366	395	418	442	482	523	543	563	579	596	596	596	596	597	598
2.5	15	43	78	113	159	205	234	263	320	376	438	499	531	563	603	643	675	708	741	774	785	797	797	797	797	800	804
3.0	25	61	111	161	227	293	339	386	453	521	600	680	722	765	827	888	897	906	945	984	996	1009	1009	1009	1009	1003	998
3.5	35	92	155	218	305	391	454	517	605	694	772	851	913	975	1036	1096	1119	1141	1163	1185	1198	1211	1211	1211	1211	1208	1206
4.0	35	114	194	273	380	486	572	659	776	894	961	1027	1103	1179	1227	1275	1316	1357	1365	1374	1394	1414	1414	1414	1414	1415	1416
4.5	0	0	235	332	479	626	722	819	957	1096	1168	1240	1320	1401	1449	1497	1547	1598	1590	1583	1610	1637	1637	1637	1637	1616	1595
5.0	0	0	280	400	592	784	899	1014	1144	1274	1380	1487	1569	1651	1691	1731	1785	1838	1807	1777	1806	1836	1836	1836	1836	1806	1777
5.5	0	0	320	432	641	849	1033	1216	1331	1446	1568	1690	1778	1867	1919	1970	1977	1984	1994	2005	2017	2030	2030	2030	2030	1990	1951
6.0	0	0	0	0	680	944	1155	1367	1495	1623	1759	1895	1983	2072	2137	2202	2205	2207	2226	2246	2240	2234	2234	2234	2234	2194	2154
6.5	0	0	0	0	720	1123	1335	1547	1678	1809	1963	2116	2200	2284	2332	2380	2425	2470	2452	2434	2403	2373	2373	2373	2373	2354	2336

Figure 15: Archimedes Wave Swing power matrix (unrestricted): output in kW [30].

When multiple power matrices are available, the suitability of the device for a particular site can be evaluated by completing a scatter diagram. The wave height and wave period recorded at the site in question should be plotted against one another as illustrated in Figure 16. If the power matrix and recorded data from the site in question overlap each other significantly on the scatter diagram, then the wave energy generator being investigated is a good choice for that particular location. As seen in Figure 16, the Pelamis is a very good match for the sample site analysed.

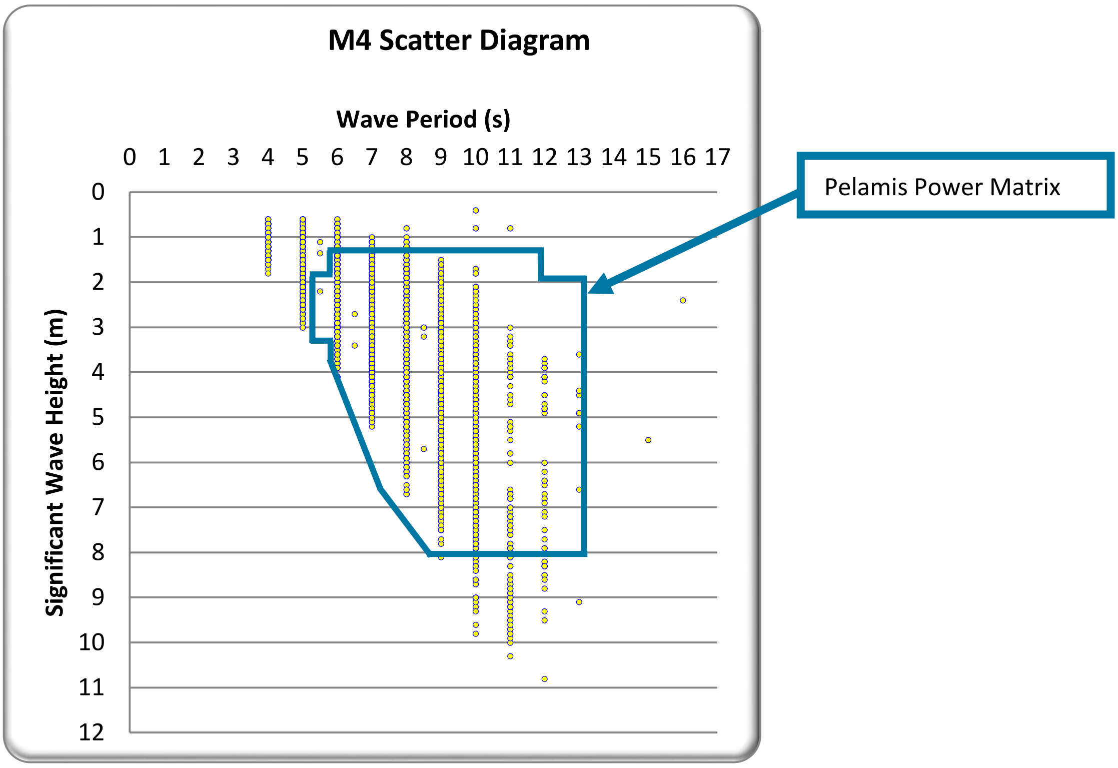


Figure 16: Scatter diagram for M4 data buoy off the coast of Ireland.

Once the most suitable wave power device has been chosen, and the power matrix obtained, the wave height and wave period data recorded at the site must be converted into power output. To do this, I created a program in MATLAB [31] and I used wave height and wave period data from four different sites around the coast of Ireland. The data was gathered by the Marine Institute in Ireland using data buoys (see Figure 17) distributed around the Irish coast [32]. Obtaining data from four different locations spread around the island ensured that wave energy fluctuations were minimised. A list of data buoys can be seen at [33].

Figure 17: A Data Buoy.

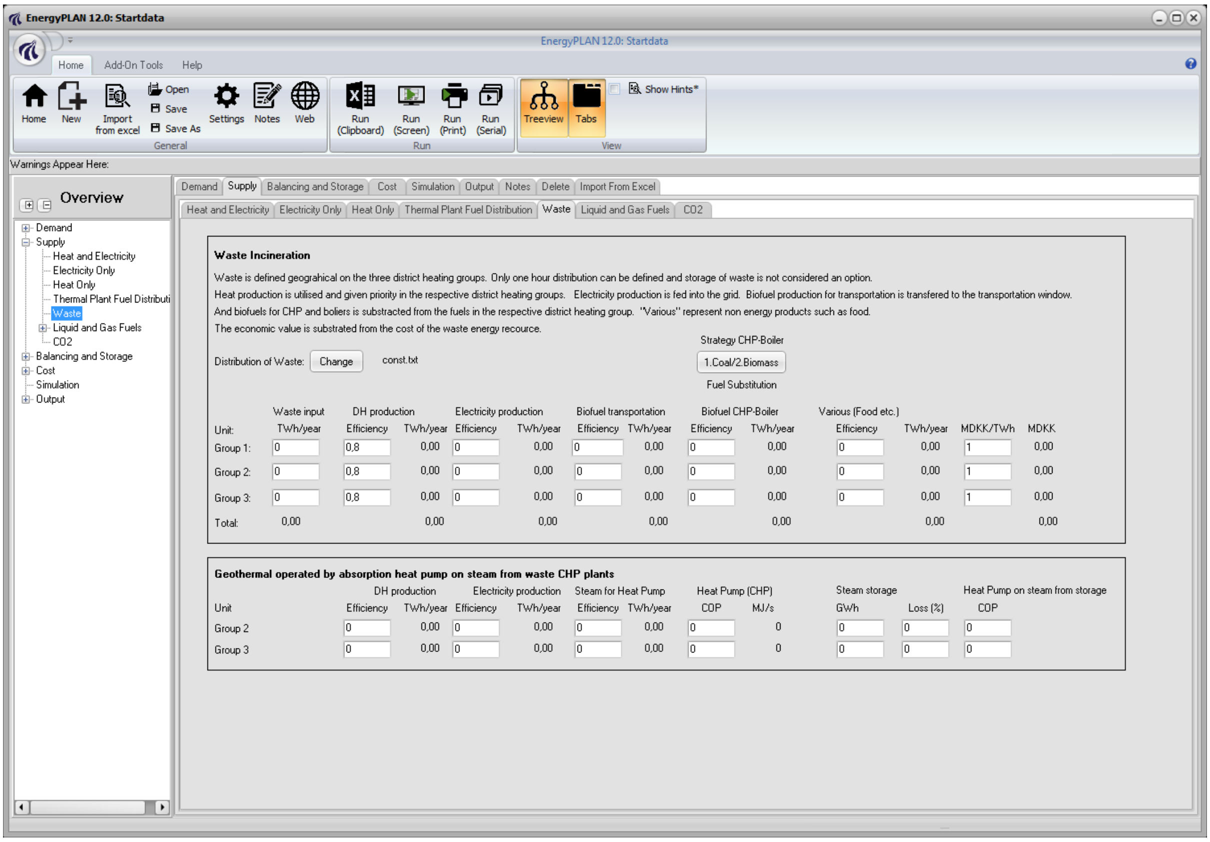
River Hydro

River hydro refers to hydroelectric dams with no storage facility i.e. they must operate as water passes through them. Although there is no river hydro in Ireland at the moment, it was used to simulate the Irish reference model. I found that if hydro power was simulated under the “Hydro” option, which is discussed after this section, EnergyPLAN would simulate the dispatch of hydro itself. However, the optimal dispatch of hydro according to EnergyPLAN was different to the actual dispatch of hydro power in Ireland in the year 2007. In contrast, the river hydro power did not simulate the dispatch of hydro, but instead it replicated the historical hourly values that were inputted as the distribution. These hourly outputs were obtained from the Irish TSO, but note that it took four months to obtain this data so long waiting periods may need to be accounted for. When modelling future alternatives for Ireland, I will use the Hydro Power option in EnergyPLAN, as this will enable EnergyPLAN to simulate the dispatch of hydro itself, which is desirable in the future.

Hydro Power

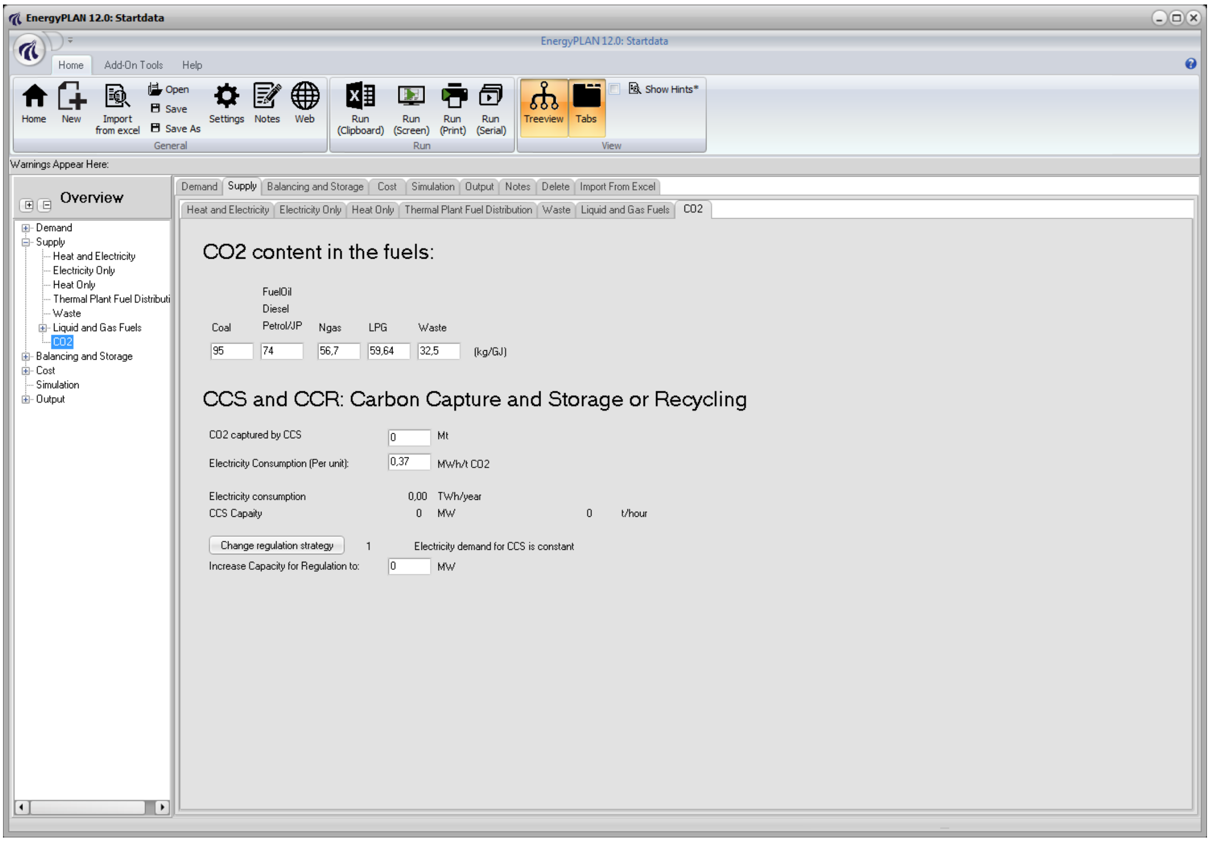
I found that hydro data was quite difficult to gather i.e. power capacity and storage capacity. As indicated in Figure 8, hydro only provides 2.3% of Ireland's electricity demands, and therefore there is not a lot of detailed information which is easily accessible for the hydro plants. As a result, I found that the most productive approach was to contact the hydro plants directly, and request the data required from the operator in the control room. For the distribution of the hydro production, I used annual output data for the hydro plants which was recorded by the Irish TSO's, EirGrid [12] and SEMO [34]. As stated previously, hydro power was only simulated using this option when modelling future alternatives for Ireland, and not when modelling the reference model in 2007.

3.3.3 Waste



There is currently no waste used for energy production in Ireland so no data was required for the Irish reference model. However, Münster carried out a detailed energy system analysis of waste-to-energy options in [45], which could be useful if data is required.

3.3.4 CO2



3.3.4.1 Emission Factors

In the EnergyPLAN model, three CO_2 emission factors are required: one for coal, oil, and natural gas. However, in this study coal and oil do not just account for a single fuel but instead, they account for a group of fuels. The coal category represents peat and coal as these were modelled as a single fuel: this is a method which has been carried out in previous models of the Irish energy system [49] due to the similar power plant efficiencies and CO_2 emissions of the two fuels. The oil category represents a number of different types of oil including kerosene, diesel, and coke. Therefore, the CO_2 emission factors for coal and oil were calculated based on fuel consumptions from the Irish Energy Balance [16], and CO_2 emission factors recommended by SEAI [44] for the various fuels they represent. In conclusion, the CO_2 emission factor used for coal/peat was 100.63 kg/GJ (see Table 3-4), for oil was 73.19 kg/GJ (see Table 3-5) and for natural gas was 57.1 kg/GJ [44].

Table 3-4
CO_2 emission factors for coal and peat.

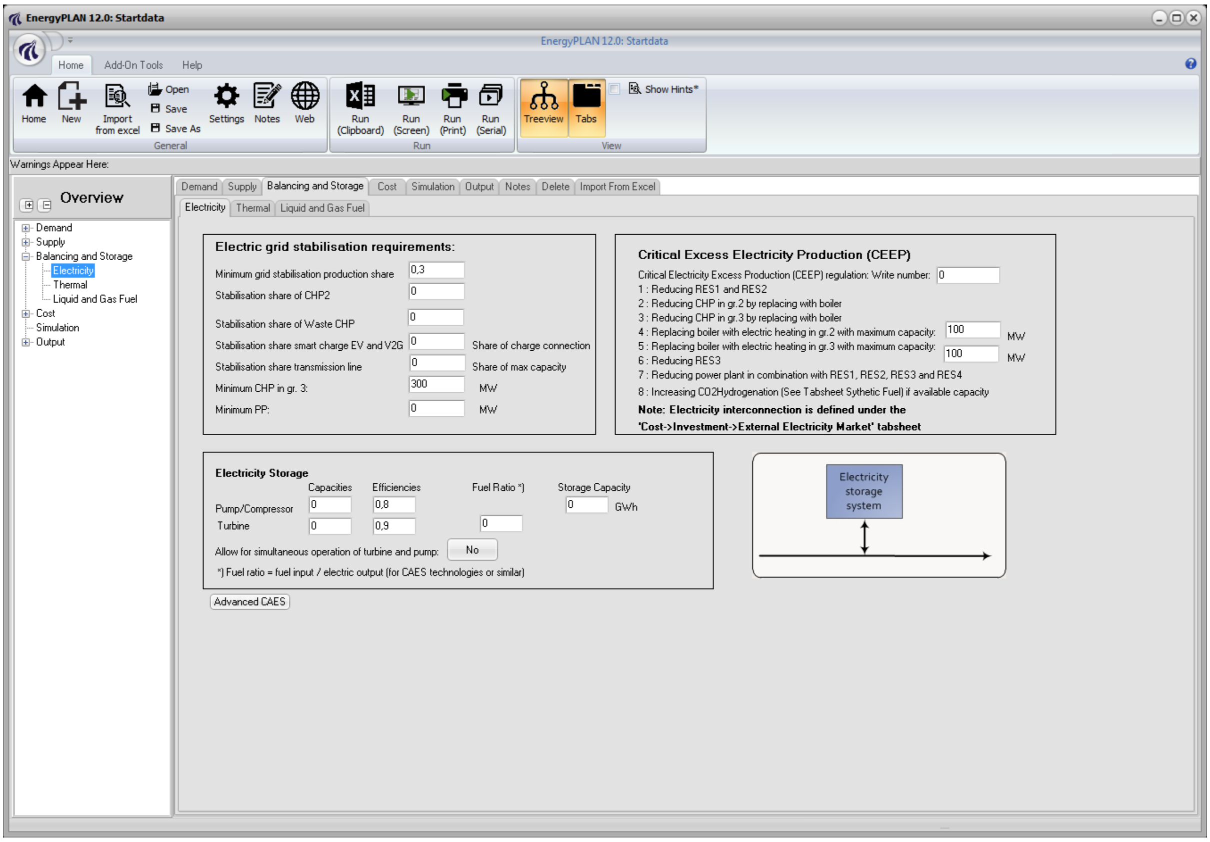
Fuel	Consumption (TWh) [16]	Consumption (% of Total)	CO_2 Emission Factor (kg/GJ) [44]
Coal	17.425	65.09	94.60
Milled Peat	6.186	23.11	116.70
Sod Peat	2.167	8.09	104.00
Briquetted Peat	0.992	3.71	98.90
Total	**26.770**	**100.00**	**100.63**

Table 3-5
CO_2 emission factor for oil.

Fuel	Consumption (TWh) [16]	Consumption (% of Total)	CO_2 Emission Factor (kg/GJ) [44]
Gasoil	45.230	43.35	73.3
Gasoline	17.425	21.40	70.0
Jet Kerosene	12.134	11.63	71.4
Kerosene	10.620	10.18	71.4
Fuel Oil (Residual Oil)	8.528	8.17	76.0
Coke	3.637	3.49	100.8
LPG	1.856	1.78	63.7
Naphtha	0.012	0.01	73.3
Total	**104.342**	**100.00**	**73.2**

3.4 Balancing and Storage

3.4.1 *Electricity Storage*



Only pumped hydroelectric energy storage (PHES) is in use in Ireland so I did not have to gather any data on electrolysers or compressed air energy storage (CAES). For the PHES parameters I simply contacted the plant control rooms and they provided information of pump/turbine and storage capacities. However, plant efficiencies could not be revealed as it was “commercially sensitive”. Therefore, from the Energy Balance, I calculated the overall PHES efficiency using

$$\eta_{TH} = \frac{E_{OUT}}{E_{IN}} \tag{3}$$

where E_{OUT} was the total electricity produced from Turlough Hill in 2007 (0.349 TWh) and E_{IN} is the total electricity consumed by Turlough Hill in 2007 (0.546 TWh). The resulting round-trip efficiency, η_{TH}, was 63.9%. Therefore, I inserted the a pump efficiency of 79.9% and a turbine efficiency of 79.9%, so that the round-trip efficiency was 0.799*0.799 = 0.639. Note that the same efficiency was used for the pump and turbine as this is typically the situation within a PHES facility [35].

3.5 Economic Data Required

EnergyPLAN simulates the costs of an energy system in four primary categories:

1. Investment costs: capital required, the lifetime of each unit, and the interest rate on repayments.
2. Fuel costs: purchasing, handling, and taxes in relation to each fuel as well as their CO_2 costs.
3. Operation costs: the variable and fixed operation and maintenance costs for each production unit.
4. External electricity market (see section 4.5)

3.5.1 General

When downloading the EnergyPLAN tool, you also receive a number of costs databases for different years. These are primarily based on price forecasts from the Danish Energy Agency (DEA), so they can be used as a proxy when completing your studies. For example, the 2020DEACosts.txt file highlighted in Figure 18 provides the costs required for the year 2020 based on data from the DEA. However, costs may vary from country to country so you should consider this when interpreting your results. The most recent version of the EnergyPLAN cost files are available online: www.EnergyPLAN.eu/costdatabase. These can be loaded into the EnergyPLAN tool under the Cost->General tabsheet.

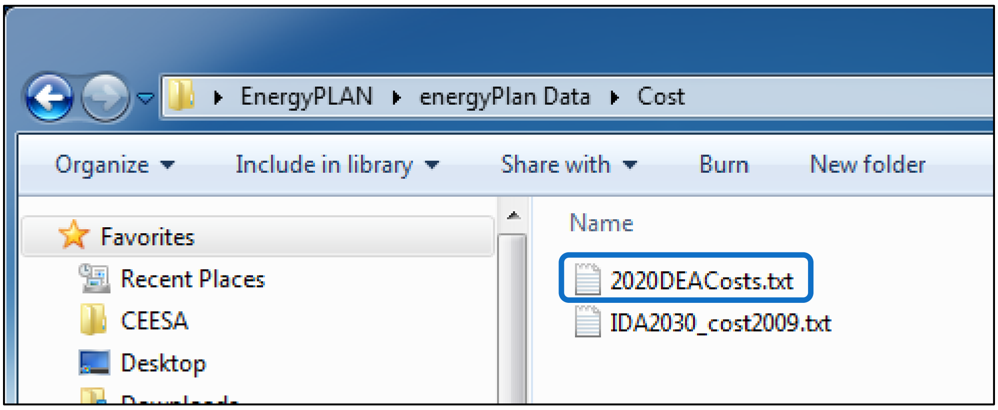


Figure 18: Cost database provided with the EnergyPLAN tool.

The costs can be used by EnergyPLAN to perform socio-economic and business-economic studies, as well as a market simulation for the energy system.

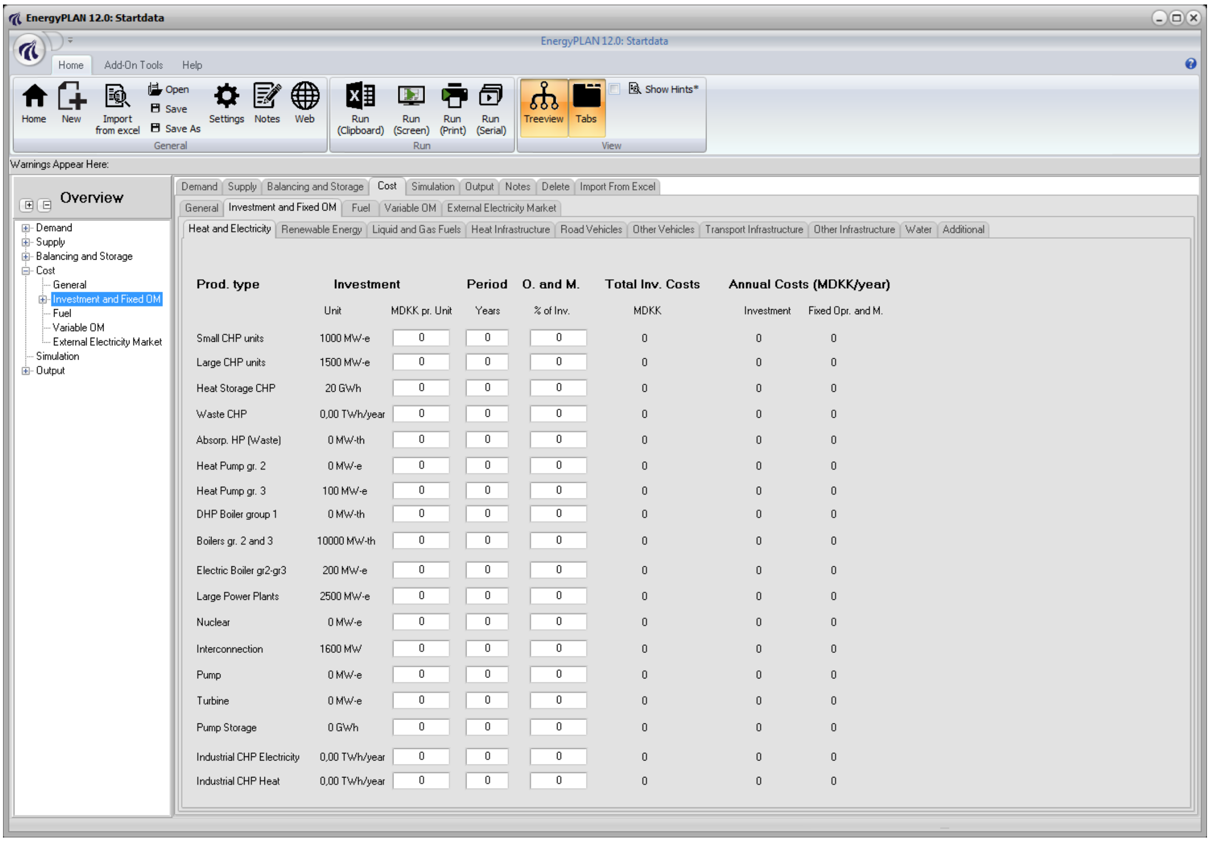
3.5.1.1 Interest Rate

Typically an interest rate of 3% is assumed when preforming an analysis in EnergyPLAN, along with a sensitivity analysis using 6%.

3.5.1.2 CO_2 Price

There is no carbon tax in Ireland at the moment. However, Ireland participates in the European carbon trading scheme and therefore there is a cost associated with carbon, even though it is not an internal government tax. For information on carbon costs, visit http://www.pointcarbon.com.

3.5.2 Investment Tab



Under this tab you must enter the investment, lifetime, and fixed operation and maintenance costs. These costs are used for to calculate the annual costs of each component based on a fixed rate repayment loan: the governing equations for these calculations are discussed in detail in the EnergyPLAN user manual [1]. The investment and operation costs for condensing power plants were obtained from [50], and are displayed in Table 3-6.

Table 3-6
Investment, fixed O&M, and variable O&M costs for Irish condensing power plants [50].

Plant Type	Investment Costs (M€/MW)	Fixed O&M Costs (€/MW/year)	Variable O&M Costs (€/MWh)	2007 Irish Capacity / Fuel Type
Steam turbine, coal fired, advanced steam process, 2004	1.100	16000	1.800	852.5 MW / Coal 806 MW / Oil
Steam turbine, coal fired advanced steam process, 20% co-firing of biomass, 2004	1.200	22000	3.000	345.6 MW / Peat
Gas turbine single cycle, (40 - 125 MW), 2004	0.485	7350	2.500	719 MW / Gas
Gas turbine combined cycle (100 - 400 MW), 2004	0.525	14000	1.500	2806 MW / Gas
Gas turbine combined cycle (10 – 100 MW), 2004	0.700	10000	2.750	208 MW / Gas

The onshore wind and offshore wind costs were obtained from [52]: investment costs for onshore wind are 1.2 M€/MW and offshore wind is €1.6 M€/MW, while the fixed O&M costs are 6 €/MWh for onshore wind and

8.70 €/MWh for offshore wind[5]. The investment costs for hydro power in Ireland were obtained from the British Hydropower Association [53]: the investment cost for hydro stations below 100 MW is 1.765 M€/MW, the fixed O&M costs are approximately 2.7% of the investment and the variable O&M costs are approximately 1.3% of the investment. The costs for PHES in Ireland were found from Gonzalez *et al.* [51] as 0.476 M€/MW and 7.89 M€/GWh for the initial investment, 0.6% of the investment for the fixed O&M cost, and 3 €/MWh for the variable O&M cost.

For the individual heating units (such as boilers, electric heaters, solar) I found the investment and fixed O&M costs by contacting the suppliers as displayed in Table 3-7. Remember to include the installation costs for boilers and solar systems such as the installation of the central heating system, which can be obtained from [54]. The type of individual heating systems in Ireland (by fuel type) was got from a report carried out by the Irish Central Statistics Office (CSO) [55]. Finally, just to note that taxes should not be included in the costs inputted here. Therefore, if a supplier is contacted to obtain the costs, ensure the price quoted is without tax.

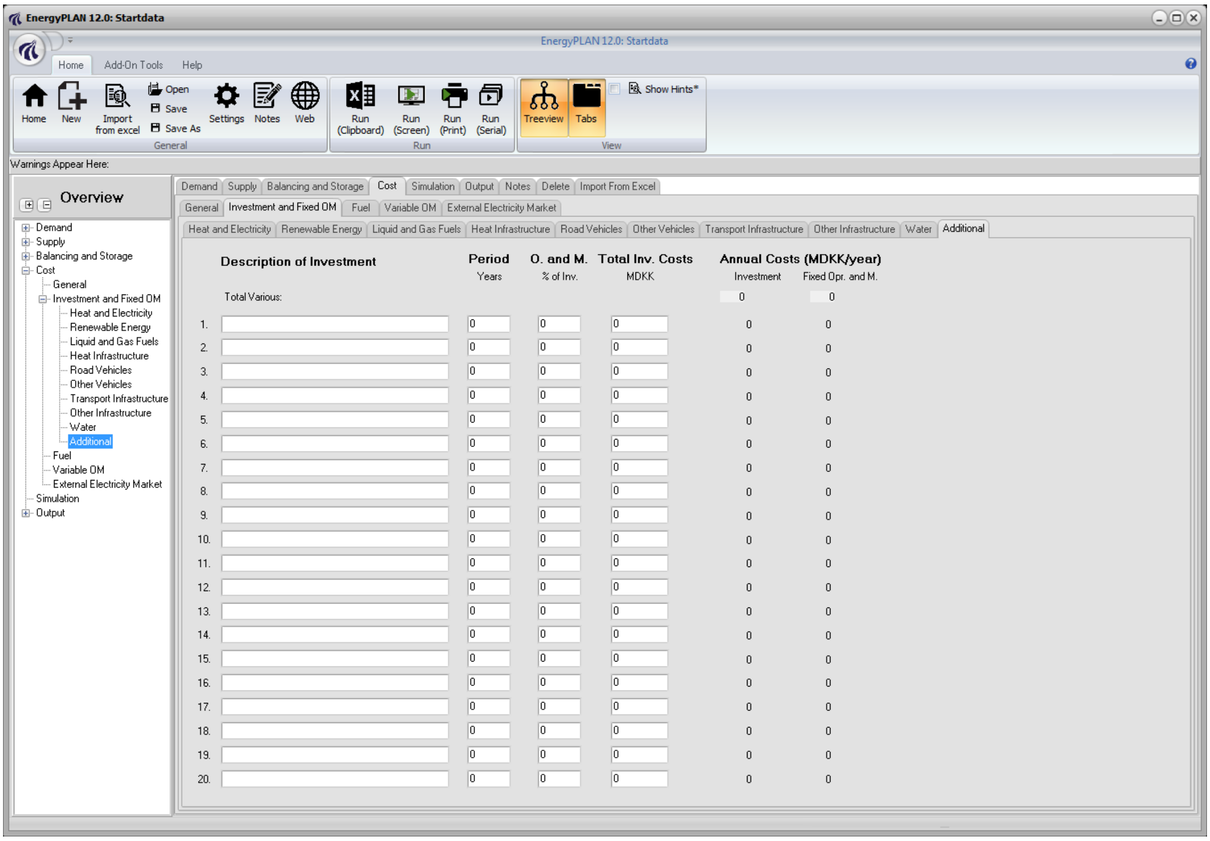
Table 3-7
Costs (excluding taxes) of individual heating systems for the reference model of the Irish energy system.

Fuel Type	Size	Cost Including Installation (€)	Lifetime (years)	O&M Costs (€/year)
Oil	26 kW	14750	15	110
Biomass	19 kW	19500	15	110
Natural Gas	26 kW	14750	15	110
Solid Fuel	21 kW	15300	15	110
Electric Boiler	12 kW	15500	15	0
Electric Heaters	20 kW	6000*	20	0
Solar Thermal	2400 kWh/year	5900	35	55

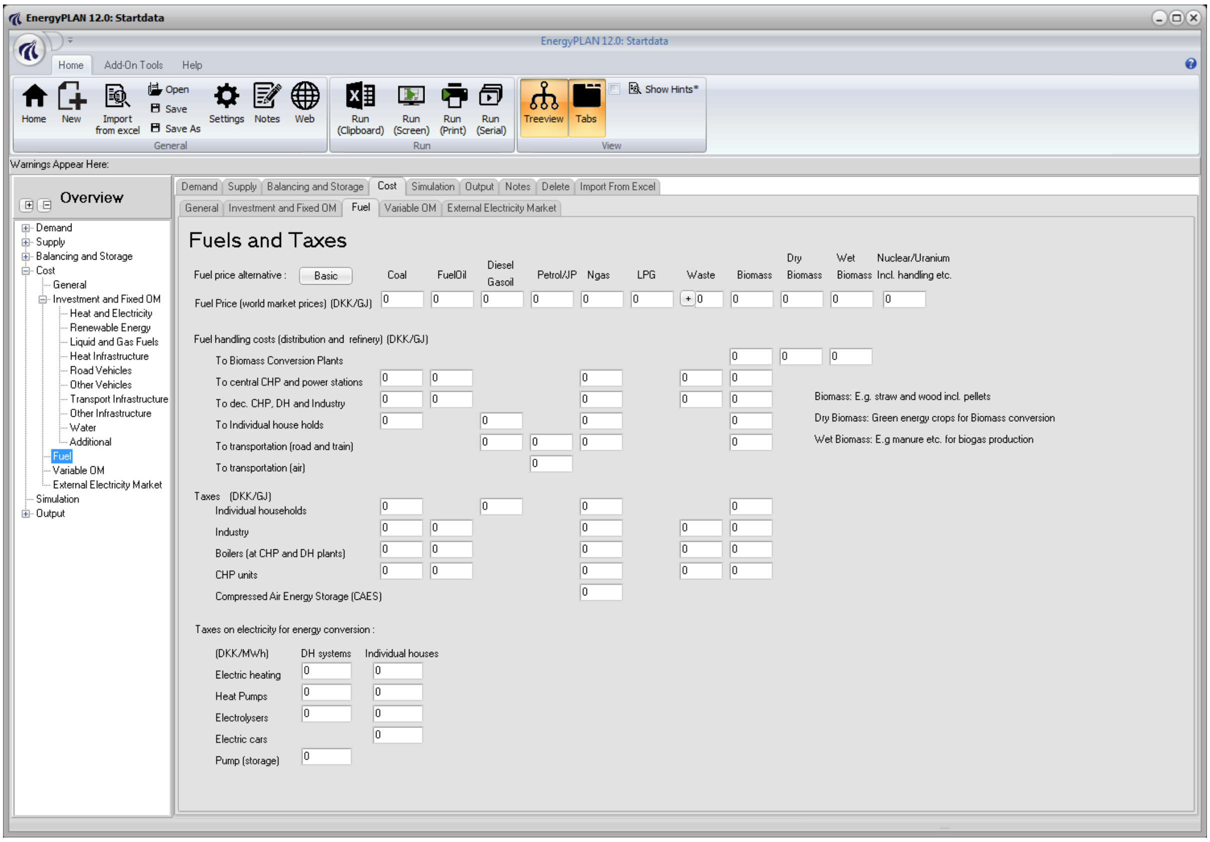
***Does not account for electric transmission upgrades that may be necessary for widespread installations.**

The 'Additional' tab can be used if there are any additional costs which have not been accounted for. For example, the cost of insulating houses to reduce energy demands may be accounted for here.

[5] This does not include the balancing costs associated with wind power.


EnergyPLAN 12.0: Startdata
Overview
Description of Investment
Period
Years
O. and M.
% of Inv.
Total Inv. Costs
MDKK
Annual Costs (MDKK/year)
Investment
Fixed Opr. and M.
Total Various:

3.5.3 Fuel Tab


EnergyPLAN 12.0: Startdata
Overview
Fuels and Taxes
Fuel price alternative :
Basic
Coal
FuelOil
Diesel Gasoil
Petrol/JP
Ngas
LPG
Waste
Biomass
Dry Biomass
Wet Biomass
Nuclear/Uranium Incl. handling etc.
Fuel Price (world market prices) (DKK/GJ)
Fuel handling costs (distribution and refinery) (DKK/GJ)
To Biomass Conversion Plants
To central CHP and power stations
To dec. CHP, DH and Industry
To Individual house holds
To transportation (road and train)
To transportation (air)
Biomass: E.g. straw and wood incl. pellets
Dry Biomass: Green energy crops for Biomass conversion
Wet Biomass: E.g manure etc. for biogas production
Taxes (DKK/GJ)
Individual households
Industry
Boilers (at CHP and DH plants)
CHP units
Compressed Air Energy Storage (CAES)
Taxes on electricity for energy conversion :
(DKK/MWh)
DH systems
Individual houses
Electric heating
Heat Pumps
Electrolysers
Electric cars
Pump (storage)

3.5.3.1 Fuel and CO_2 Costs

The purchasing costs for each fuel were obtained for the year 2007, 2010/2015, and 2020, which were recommended by the International Energy Agency [46] and the Danish Energy Authority [47] and are displayed in Table 3-8. Also, if required the current market price for different fuels can be obtained from the links below:

- Crude Oil: http://www.oil-price.net/
- Coal: http://www.eia.doe.gov/cneaf/coal/page/coalnews/coalmar.html
- Natural Gas: http://www.bloomberg.com/markets/commodities/energyprices.html

Table 3-8
Fuel prices used for 2007, 2010/2015 and 2020 [46, 47].

(€/GJ)	Crude Oil ($/bbl)	Crude Oil	Fuel Oil	Gas Oil/ Diesel	Petrol/JP	Coal	Natural Gas	Biomass
2007	69.33	9.43	6.66	11.79	12.48	1.94	5.07	6.30
2010/2015	100	13.60	9.60	17.00	18.00	3.19	8.16	7.01
2020	110	14.96	10.56	18.70	19.80	3.11	9.16	7.45

The crude oil price was used to identify the cost of Fuel Oil, Diesel, and Petrol/Jet Fuel. As these fuels are refined from crude oil their prices are proportional to the crude oil price and hence, the price ratio between each of these and crude oil typically remains constant. Therefore, the following ratios recommended by the Danish Energy Authority was used to calculate these prices [47]: ratio of crude oil to fuel oil was 1 to 0.70, crude oil to diesel was 1 to 1.25, and crude oil to petrol/jet fuel was 1 to 1.33. Also, the fuel handling costs were obtained from the Danish Energy Agency [47] and are displayed in Table 3-9.

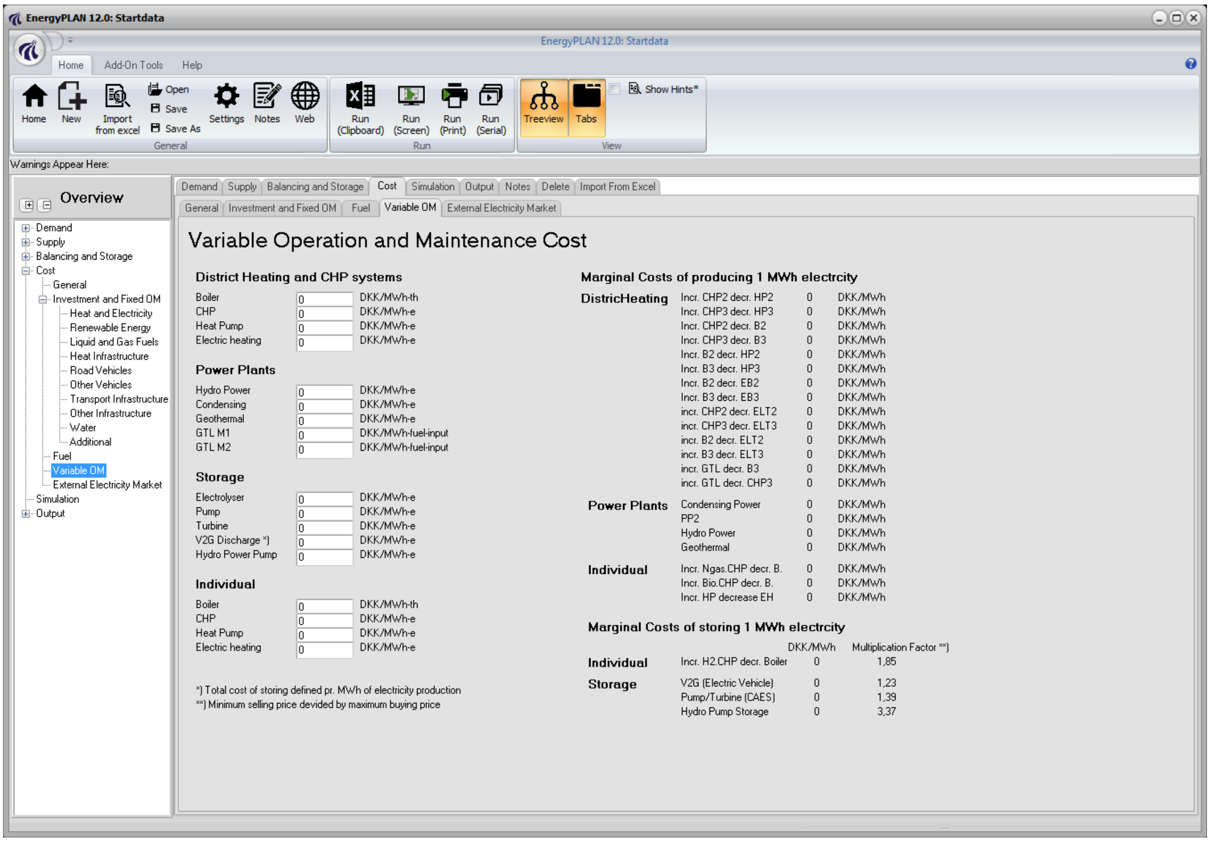
Table 3-9
Fuel handling costs [47].

€/GJ	Fuel Oil	Gas oil/Diesel	Petrol/JP	Coal	Natural Gas	Biomass
Power Stations (central)	0.228	0.228	-.-	0.067	0.428	1.160
Distributed CHP, district heating & industry	1.914	1.807	-.-	-.-	1.165	1.120
Individual households	-.-	2.905	-.-	-.-	2.945	6.118
Road transport	-.-	3.159	4.257	-.-	-.-	11.500 [48]
Airplanes	-.-	-.-	0.696	-.-	-.-	-.-

3.5.3.2 Taxes

I rang the Irish revenue office to find out if there were any taxes on specific fuels or technologies and found that there was none. Note that Value Added Tax (VAT) is not included here.

3.5.4 Variable OM



Under this tab you must enter the variable operation and maintenance costs. These are the costs that occur if the technology in question is used. For example, an annual service has to be done every year regardless of how often the generating plant operates. Therefore, this is a fixed operation and maintenance charge. However, if the generating plant generates 1 GWh it must get a second service costing €1500. Therefore, the generating plant has a variable operation and maintenance cost of €1500/GWh or €1.50/MWh, as this second service will only be necessary if the plant actually operates.

For the condensing plant, I found the variable operation and maintenance costs for each type of power plants from [50], and calculated an overall variable O&M cost of 1.84 €/MWh as displayed in Table 3-6. For the PHES facilities, I obtained the variable operation and maintenance costs from [51], and to date I have not found the variable operation and maintenance cost for the individual units.

4 Areas of Difficulty

Although a large degree of EnergyPLAN is intuitive, there were some areas which I found difficult to understand at first. Therefore, a few aspects of the model are discussed in more detail here.

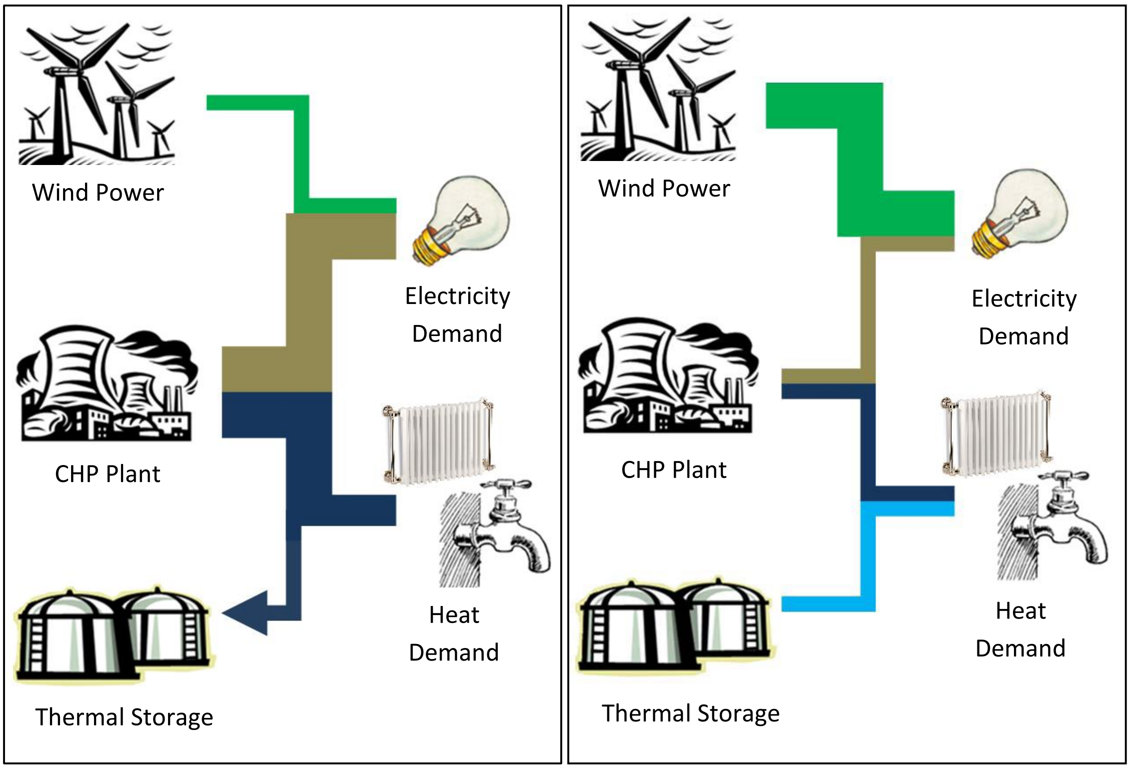
4.1 Thermal Energy System

As there are very little CHP plants or no significant district heating networks in Ireland, heat is usually generated at the point of demand, so I did not fully understand how a thermal energy system worked. As EnergyPLAN can model this type of energy system, a brief outline is provided. To illustrate the flexibility induced by thermal energy storage on such a system, a snapshot of the power production during different scenarios is presented below. The system in question contains a CHP plant, wind turbines, a thermal storage, a hot water demand, and an electrical demand as illustrated in Figure 19.

During times of low wind power, a lot of electricity must be generated by the CHP plants to accommodate for the shortfall in power production. As a result, a lot of heat is also being produced from the CHP plant as seen in Figure 19a. The high production of heat means that production is now greater than demand, and consequently, heat is sent to the thermal storage.

Conversely, at times of high wind power, the CHP plants produce very little electricity and heat. Therefore, there is now a shortage of heat so the thermal storage is used to ensure that demand is met, as seen in Figure 19b.

Note: This system can be simulated by choosing the Technical Simulation 2: Balancing Heat and Electricity Demands under the Regulation tab in EnergyPLAN.



(a) (b)

Figure 19: Energy system with district heating and thermal energy storage during (a) a low wind scenario and (b) a high wind scenario.

This system has been put into practice in Denmark which has the highest wind penetration in the world. Also, Lund and Mathiesen have created a roadmap for Denmark towards achieving a 100% renewable energy system using a thermal energy system [4-8].

4.2 District Heating Groups

After learning about the operation of the thermal storage energy system, the next question that comes to mind relates to the CHP inputs under the 'Input -> DistrictHeating' tab. Under this tab there are three district heating (DH) categories:

1. DH without CHP: These are systems that use boilers, waste heat or some other form of heat supply but do not use CHP.
2. DH with small CHP plants: This category represents CHP plants, which cannot operate without a heat load.
3. DH with large CHP plants: This category specifies the amount of centralised CHP capacity. The primary difference between these and group 2, is the fact that these plants do not need to create heat during the production of electricity. They can remove the heat from their system using water (usually from a river or the sea).

4.3 Technical Simulation vs. Market Simulation

There are two kinds of studies that can be carried out in EnergyPLAN:

1. Technical Simulation (tries to minimise fossil fuel consumption and can be carried out without any cost inputs).
2. Market Simulation (tries to minimise the operation costs of the system).

The technical simulation is based on the technical abilities of the components within the energy system. The difference between demand and supply is met as long as the power producing units are capable of completing the task. Only in situations where the power producing units are not able to meet demand is power imported from the external market, and where excess energy is produced (i.e. during high wind speeds) energy is exported to the external market. There are four types of technical simulation:

1. Balancing Heat Demands: This option performs a technical simulation where heat producing plants must operate according to the heat demand. The units chosen to supply the heat demand are chosen in the following order:
   i. Solar Thermal.
   ii. Industrial CHP.
   iii. Heat Production from Waste.
   iv. CHP Heat.
   v. Heat Pumps.
   vi. Peak Load Boilers.

   This also affects electricity production: Under this regulation, the amount of heat that CHP units produce, and hence the amount of electricity they produce is dependent on the heat demand at that time.
2. Balancing Both Heat and Electricity Demands: This option performs a technical simulation where the export of electricity is minimised, primarily by replacing CHP production with boilers or heat pumps[6] when there is excess electricity. By doing this the electricity consumption is increased (i.e. more electric boilers or heat pumps) and the electricity produced is decreased (i.e. less CHP production). Also for this operating strategy, if there is condensing power plant production on the grid and there is CHP capacity available, then the CHP replaces it and the excess heat produced is sent to a thermal storage. A graphical illustration of this option is displayed in Figure 19. This ensures that the energy system operates with the largest efficiency possible.

[6] Heat pumps are powered by electricity to transfer heat from one heat source (i.e. ground or water) into another heat source (i.e. a district-heating network).

3. Option 2 but "Reducing CHP also when partly needed for grid stabilisation": As stated this is largely the same as option 2. In option 2, CHP is reduced when there is a large output from renewable energy sources. However, in option 3, CHP is also reduced if it is required for grid stabilisation[7].
4. Option 1 using the Triple Tariff: As stated this is largely the same as option 1. However, in this option, CHP plants do not operate according to the heat demand, but instead they operate according to the 'Triple Tariff'. The Triple Tariff was introduced in Denmark to encourage CHP units to produce electricity during peak hours. Therefore, CHP plants got paid 3 times more for producing electricity during peak hours (times) than any other time of the day. As a result, thermal storage became very common with CHP plants, so they could store the excess heat created while output was high during peak electricity hours. This regulation option is used to simulate the Triple Tariff.

The market simulation is designed to match supply and demand at the least cost, rather than on the minimum fuel consumption. For this simulation two primary steps are completed:

1. The short-term marginal cost[8] of producing electricity and/or heat is calculated for each power producing unit.
2. The least-cost combination of production units is chosen to supply the demand.

For a detailed explanation of the calculations completed in both the technical simulation and the market simulation, read chapter 6 and 7 respectively in the EnergyPLAN user manual [1].

4.3.1 Business-economic vs. Socio-economic calculations

Economic results from EnergyPLAN can be divided into two types of studies:

1. Socio-economic costs: Taxes are not included.
2. Business-economic costs: Taxes are included.

The socio-economic studies are designed to minimise the costs to society i.e. the cost for the region/country to provide the energy necessary. In a socio-economic study the aim is to identify the costs associated with the Technical Simulation. This way you can simulate the performance of the energy system without the restrictions imposed by economic infrastructures. Therefore, the following steps can be followed:

1. Complete a Technical Simulation identifying the optimum technical operation of the energy system, for example the system with minimum Critical Excess Electricity Production (CEEP) or minimum CO_2.
2. Complete a socio-economic study to identify the costs associated with the technical simulation.

The business-economic studies show what can be done while being profitable for a business or person. Once the socio-economic study is completed, the market-economic study should be done to identify how the existing market infrastructure obstructs the optimal technical solution. Therefore, after completing steps 1 and 2 above:

3. Carry out a business-economic market simulation to identify how the existing system prevents the introduction of the optimal technical solution.
4. Make changes to the existing tax system to outline how the existing market could be adjusted to promote the optimal technical solution.

Sometimes, socio-economic costs can include the following aspects also:

1. Job Creation.
2. Balance of Payment[9].
3. Public Finances.

---

[7] The electric grid needs to be maintained at a certain frequency and voltage. Power plants usually provide ancillary services that ensure this frequency and voltage are maintained. If the frequency or voltage is not maintained, the electric grid will stop working.
[8] Marginal Cost: Is the cost at which there is enough supply to meet demand.
[9] http://en.wikipedia.org/wiki/Balance_of_payments.

4. Environmental Costs.

However, these calculations are not made by the EnergyPLAN model. Instead, these benefits must be calculated externally by the user based on the investments made in the different energy system sectors. These calculations are discussed further in [56].

4.4 Comparing Energy Systems

It is very important to know how EnergyPLAN identifies that one energy system is better than an alternative energy system. There five primary variables that are recorded when doing this are:

1. PES (Primary Energy Supply): This is the total energy required within the energy system.
2. CO_2: This is the amount of CO_2 produced within the energy system.
3. Annual costs: The annual costs required to supply the required energy demand.
4. EEEP (Exportable Excess Electricity Production): This is the amount of electricity that had to be exported from the energy system, AND it was possible to export because the required transmission out of the energy system was available.
5. CEEP (Critical Excess Electricity Production): This is the amount of electricity that had to be exported from the energy system, BUT COULD NOT be exported because the required transmission was not available.

How important each of these parameters is depends on the objective of your study. Exercise four in the EnergyPLAN training (which is available from the EnergyPLAN website [1]) provides a good example of how these parameters are used to compare alternative energy systems. Finally, other parameters may also be used to compare energy systems, but these are the most common.

4.5 External Electricity Market Price

Under the regulation tab, an external electricity market price can be defined. The distribution is NOT indexed like other distributions in EnergyPLAN: instead the actual values in the distribution are used. The distribution can be manipulated by an 'Addition Factor' and a 'Multiplication Factor'. The addition factor is used to represent the cost of CO_2, because when a CO_2 cost is increased or introduced, it usually increases the cost of electricity by a constant amount for each hour. The multiplication factor is usually used to model an increase in fuel prices, as these usually increase the cost of electricity proportionally during each hour.

4.6 Operation Strategy for Electricity Storage

In EnergyPLAN, electricity storage is described in the form of pumped hydroelectric energy storage (PHES) as this is the largest and most common form of electricity storage in use today [57]. However, this can be used to define any type of electricity storage which has a charging capacity (i.e. pump/compressor), discharge capacity (i.e. turbine), and a storage capacity. When defining the electricity storage capacities available, it is also possible to define an electricity storage operation strategy. Once again, as EnergyPLAN uses PHES as a reference, the question asked in EnergyPLAN when defining an operation strategy is "Allow for simultaneous operation of turbine and pump: YES/NO", which is displayed in Figure 20.

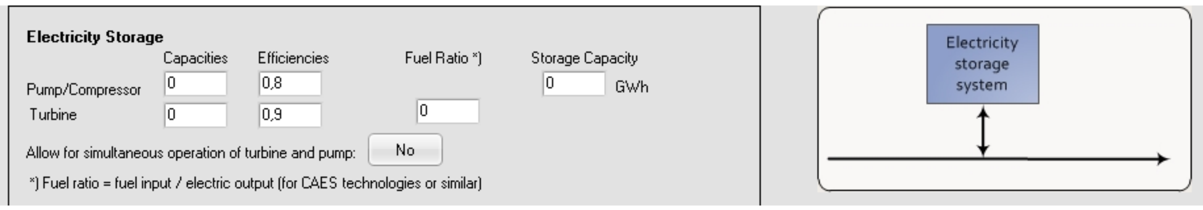


Figure 20: Electricity storage parameters and operation strategy in EnergyPLAN.

Historically, PHES (and other large-scale electricity storage) facilities have typically been constructed with a single penstock system as they were designed to maximise electricity generation from baseload power plants i.e. by charging during the night when electricity prices were low (due to a high percentage of baseload power) and discharging during the day when electricity prices were high (due to a high demand). Therefore, they could not, or never needed to, charge and discharge at the same time. To simulate this scenario in EnergyPLAN, select NO for “Allow for simultaneous operation of turbine and pump”. However, if energy storage devices are designed especially to integrate fluctuating renewable energy, there may be additional benefits when using PHES that can charge and discharge at the same time. This can be achieved in a single PHES facility by installing two penstocks, as displayed in Figure 21, or also by installing multiple single penstock system PHES facilities on the same energy system i.e. one can charge while the other is discharging at the same time. By using a double penstock system, the PHES introduces more flexibility onto the energy system and hence it can aid the integration of more renewable energy. As a result, this operating strategy is also possible in EnergyPLAN by selecting YES when asked “Allow for simultaneous operation of turbine and pump”.

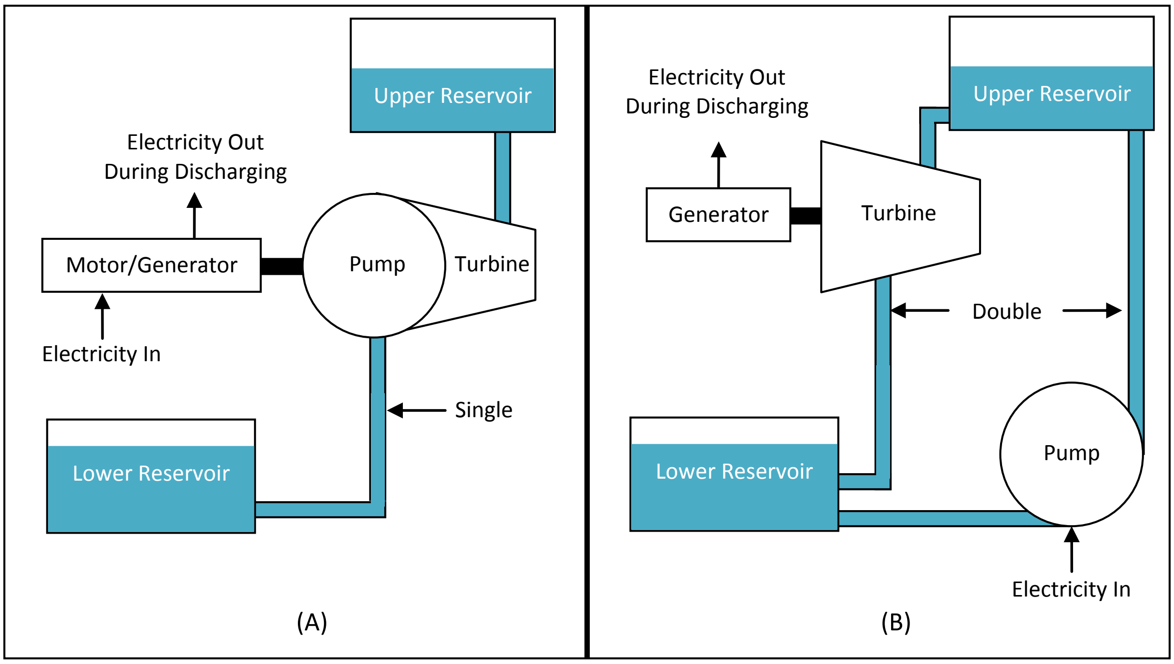


Figure 21: One PHES facility with (A) a single penstock system and (B) a double penstock system.

So how do these operating strategies affect the hourly operation of the system in EnergyPLAN? To illustrate this, an example is presented in Table 4-1 using the parameters defined in Table 4-2. As seen in Table 4-1, the primary advantage of a double penstock PHES facility relates to grid stabilisation: to see how the grid stabilisation percentage is calculated, see section 8.3 of the EnergyPLAN user manual. As the pump and turbine can operate together, a double penstock system can store excess wind production using the pump, while also producing grid stabilising power using the turbine. In contrast, the single penstock system has to prioritise one of these as the pump and turbine cannot operate together. From Table 4-1 it is clear that the single penstock system prioritises the pump and therefore, the excess electricity is sent to the PHES while the power plants (PP) must now provide the grid stabilising power. As a result, a system with single penstock PHES facility typically requires more fuel (i.e. more PP production) than a system with a double penstock PHES. Also, as a double penstock can charge and discharge at the same time, the storage capacity does not fill up as quickly as a single penstock system. Therefore, double penstock system can achieve higher fluctuating renewable energy penetrations at lower storage capacities than a single penstock system.

Table 4-1
Results for hours 1-10 when using a single and a double penstock PHES operation strategy in EnergyPLAN.

hour	elec. demand	wind power	pp	pump	turbine	storage	stab. -load	import	CEEP	EEEP
					Double Penstock System: YES					
1*	397	194	0	0	203	136	170	0	0	0
2	374	266	1	6	113	0	100	0	0	0
3*	362	400	38	209	134	0	100	0	0	0
4	346	522	0	400	224	40	100	0	0	0
5	**331**	**750**	**0**	**740**	**321**	**230**	**100**	**0**	**0**	**0**
6	323	616	0	557	264	346	100	0	0	0
7	326	618	0	557	265	460	100	0	0	0
8	335	860	0	893	369	714	100	0	0	0
9	346	772	0	757	331	906	100	0	0	0
10	354	672	0	606	288	1031	100	0	0	0
					Single Penstock System: NO					
1	397	194	0	0	203	4747	170	0	0	0
2	374	266	114	6	0	4752	100	0	0	0
3	362	400	171	209	0	4919	100	0	0	0
4	346	522	224	101	0	5000	100	0	298	0
5	**331**	**750**	**0**	**0**	**321**	**4598**	**100**	**0**	**740**	**0**
6	323	616	264	502	0	5000	100	0	55	0
7	326	618	0	0	265	4669	100	0	557	0
8	335	860	369	414	0	5000	100	0	479	0
9	346	772	0	0	331	4586	100	0	757	0
10	354	672	288	517	0	5000	100	0	89	0

***Values highlighted in red and green relate to section 4.7 of this report.**

Table 4-2
Parameters used in EnergyPLAN for the sample calculations on the two PHES operation strategies.

Parameter	Capacity*
Electricity demand	4 TWh
Condensing power plants	500 MW
Wind energy	2000 MW
Pump capacity	1000 MW
Turbine capacity	1000 MW
Pump efficiency	0.8
Turbine efficiency	0.8
Storage capacity	5 GWh
Regulation: Minimum grid stabilisation share	0.3 (i.e. 30%)

***All values were entered using the default distributions provided when opening EnergyPLAN.**

4.6.1 Storage capacity for the double penstock system strategy

It should be noted that when using a double penstock system, the storage capacity may never be recorded as full during the hourly values. This is due to the calculation procedure in EnergyPLAN. As stated previously, a double penstock system can charge using excess electricity, while also discharging to provide grid stabilisation. Therefore, at the beginning of each hour EnergyPLAN must decide how much energy will be stored due to excess electricity and how much will be discharged to provide grid stabilisation. To do this the following sequence is used by EnergyPLAN:

1. The amount of excess wind power can be stored is calculated i.e. is there enough pump capacity and storage capacity available to send the excess electricity.
2. It calculates the electricity that needs to be discharged to meet the grid stabilisation requirements.
3. Based on these figures, the electricity that must be imported or exported is evaluated.

Once again, by looking at an example this should become clear. Let's take the values from hour 887 in Table 4-3. At the beginning of this hour there was a demand of 442 MW and a wind production of 1200 MW. Therefore, by following the steps outlined above, EnergyPLAN did the following:

1. The storage capacity from the hour before was 4351 MWh, while the total capacity was 5000 MWh. Therefore, the total capacity available for the next hour was 649 MWh, which equates to a pump demand of 812 MW (i.e. **649**/0.8). Hence there is only room for 812 MW of excess electricity production in the storage during this hour.
2. As the total production during this hour is now 1200 MW of wind, there is no grid stabilising power operating. The regulation used states that 30% of all production must be grid stabilising. However, if the turbine starts producing power, it too will be adding to the production and hence the amount of grid stabilisation required will increase. For example, if the turbine provides 30% of the wind production, which is 360 MW (i.e. 0.3*1200), then the total production is now 1560 MW, but 360/1560 is only 23%, which is less than 30%. Therefore, the total power that must come from the turbine must account for its own production also and is calculated from (see section 8.3 of the EnergyPLAN user manual for full details on grid stabilisation calculations [1]):

   Turbine = 0.3*(Wind+Turbine) = 0.3*(1200+Turbine) => 0.7Turbine = 360 => Turbine = 514 MW

   As the turbine needs to produce 514 MW, it means that **643** MWh (514/0.8) must be removed from the storage facility, so the balance in the storage facility during this hour is **4351** + **649** – **643** = **4357** MWh.
3. Now that EnergyPLAN has evaluated that the maximum electricity it can store is 812 MW and the total electricity it needs for stabilisation is 514 MW, it can equate how much electricity is left for export, which is 1200 + 514 - 812 - 442 = 460 MW. Note that this has a tolerance of ±1 MW as the decimal place may be greater or less than 0.5.

An important issue to notice here is the value recorded for the storage facility at the end of the hour. Even though the value recorded was 4357 MWh, the storage capacity was full during the calculations i.e. after the pump demand was added: **4351** + **649** = 5000 MWh. Therefore, when analysing the results for a double penstock, the 'Maximum Storage' for the PHES facility may not register as the storage capacity, even though it has been full during the analysis.

For clarity purposes, let's look at another example: hour 5 from Table 4-1:

1. There is 1000 MW and 5000 MWh of pump and storage capacity available respectively.
2. There is 750 MW of wind and 0 MW of grid stabilising power. Therefore, the turbine capacity required is: Turbine = 0.3*(Wind+Turbine) => Turbine = 321 MW.
3. Now that the total production is 1071 MW (750+321), but the demand is only 331 MW, 740 MW is sent to the storage as there is sufficient pump and storage capacity available. Therefore, the balance for the storage is 592 MWh (740*0.8) in and 401 MWh out (321/0.8), which means the value at the end of the hour is 40 + 592 - 401 = 231 MWh.
4. Finally, all the excess power was sent to the storage and all of the grid stabilising power was provided by the turbine, so no export or import occurred.

Finally, the single penstock is evaluated in the same way, except if excess power and grid stabilisation must be provided at the same time, the excess power is prioritised (i.e. pump operates) and the power plants (PP) provide the grid stabilisation (i.e. as the turbine cannot operate when the pump is operating).

Table 4-3
Calculating the hour pump and turbine demand for a double penstock PHES.

Hour	Elec. Demand	Wind Power	PP	Pump	Turbine	Storage	stab. load	Import	CEEP	EEEP
885	500	1230	0	1000	527	4220	100	0	257	0
886	472	1212	0	975	519	4351	100	0	284	0
887	**442**	**1200**	**0**	**812**	**514**	**4357**	**100**	**0**	**461**	**0**
888	403	1008	0	804	432	4460	100	0	233	0
889	383	982	0	675	421	4474	100	0	345	0
890	363	1116	0	658	478	4402	100	0	574	0

4.7 Description of ‘stab.-load’ from EnergyPLAN results window

As displayed in Figure 22, there are a number of grid stabilisation regulations that can be specified under the Regulation tab. These are the requirements that must be met to ensure the reliable operation of the electric grid when intermittent renewable energy such as wind power is added to it: a description of the grid issues that occur when wind power is added is available in [58]. The regulation constraints in EnergyPLAN include the “Minimum grid stabilisation production share” (MGSPS), which specifies the percentage of production that must be from grid stabilising units (i.e. power plants, hydro, etc). It is important to remember that this is a percentage of total production and not total demand, which is outlined in detail in section 8.3 of the EnergyPLAN user manual [1].

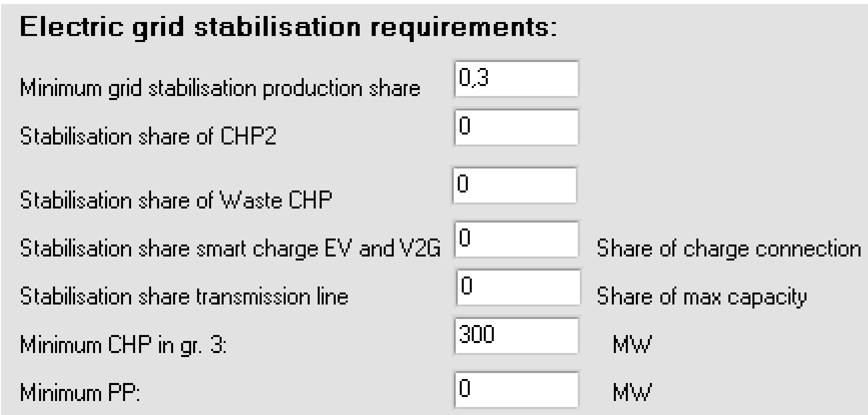
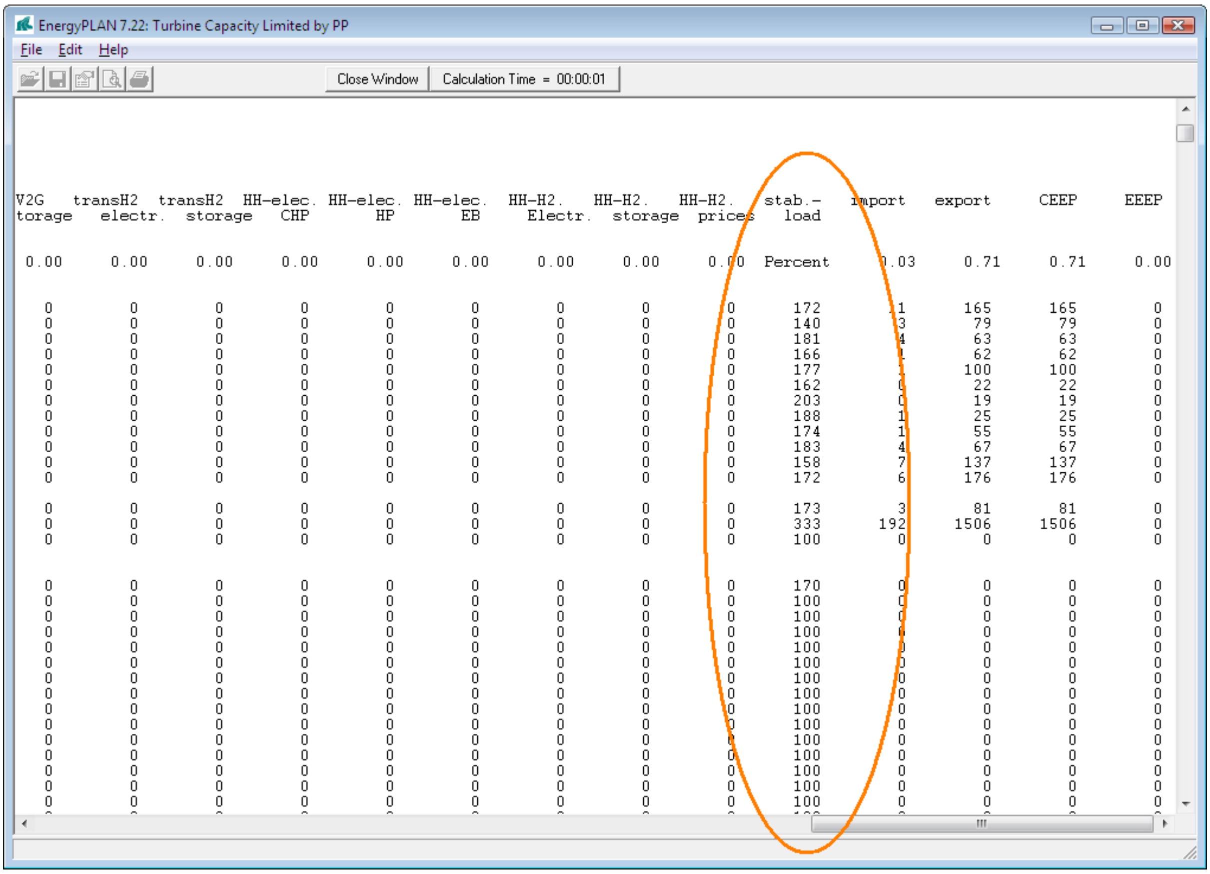


Figure 22: Grid stabilisation criteria in the EnergyPLAN model.

To measure if the system provided the MGSPS during each hour of the simulation, EnergyPLAN calculates the “stab.-load", as shown in Figure 23. This illustrates the percentage of the MGSPS that was satisfied during each hour. This section illustrates how the stab.-load is calculated.



V2G torage	transH2 electr.	transH2 storage	HH-elec. CHP	HH-elec. HP	HH-elec. EB	HH-H2. Electr.	HH-H2. storage	HH-H2. prices	stab.- load	import	export	CEEP	EEEP
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Percent	0.03	0.71	0.71	0.00
0	0	0	0	0	0	0	0	0	172	1	165	165	0
0	0	0	0	0	0	0	0	0	140	3	79	79	0
0	0	0	0	0	0	0	0	0	181	4	63	63	0
0	0	0	0	0	0	0	0	0	166	1	62	62	0
0	0	0	0	0	0	0	0	0	177	1	100	100	0
0	0	0	0	0	0	0	0	0	162	0	22	22	0
0	0	0	0	0	0	0	0	0	203	0	19	19	0
0	0	0	0	0	0	0	0	0	188	1	25	25	0
0	0	0	0	0	0	0	0	0	174	1	55	55	0
0	0	0	0	0	0	0	0	0	183	4	67	67	0
0	0	0	0	0	0	0	0	0	158	7	137	137	0
0	0	0	0	0	0	0	0	0	172	6	176	176	0
0	0	0	0	0	0	0	0	0	173	3	81	81	0
0	0	0	0	0	0	0	0	0	333	192	1506	1506	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	170	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0
0	0	0	0	0	0	0	0	0	100	0	0	0	0

Figure 23: Stab. Load results displayed in EnergyPLAN.

In section 8.3 of the EnergyPLAN user manual, it states that the percentage of electricity production from grid stabilising units, GridStab, is found from:

$$GridStab = \frac{e_{Stab}}{d_{Stab}} * 100 \tag{4}$$

Where e_{Stab} is the total electricity production from grid stabilising units and d_{Stab} is the minimum grid stabilisation production share that was specified in EnergyPLAN (as shown in Figure 22). Using this value the stab.-load is then calculated from:

$$stab.-load = \frac{GridStab}{MGSPS} \tag{5}$$

To make this clear, let's look at hour 1 for a double penstock system in Table 4-1. In hour 1 of Table 4-1, all of the production units are highlighted in red and all of the demand units are highlighted in green. Therefore, for hour 1 the total production is 397 MW, with 203 MW produced by the turbine and 194 MW produced by wind power. However, only the PHES turbine provides grid stabilising power and as a result, the GridStab value for this hour is (203/397)*100 = 51%. However, the MGSPS required is 30%, see Table 4-2 and Figure 22. Therefore, the stab.-load is 51%/30% = 170%, as displayed in Table 4-1.

Let's calculate the stab.-load for hour 3 of the double penstock system in Table 4-1 also. It is clear from Table 4-1 that during this hour the total production is 572 MW, with 400 MW from wind power, 38 MW from power plants, and 134 MW from the PHES turbine. As specified in the EnergyPLAN user manual, both power plants and the PHES turbine can provide grid stabilising power. Therefore, the total grid stabilising power production for hour 3 is 172 MW (38+134). This means that GridStab = (172/572)*100 = 30% and stab.load=30%/30% = 100%.

4.8 Abbreviations for the Results window

In the results window, there are a number of columns which represent various technologies within the EnergyPLAN simulation.

Table 4-4: Abbreviations displayed in the results window of the EnergyPLAN model.

Abbreviation	Input
elec.demand	"Sum(Demand excl. elec. Heating)" under the Input->ElectricityDemand tab.
elec.dem cooling	"Electricity Consumption" under the Input->Cooling tab.
Fixed Exp/Imp	"Fixed Import/Export" under the Input->ElectricityDemand tab
district heating	Sum of "Demand" under Groups I, II, and 3 of Input->DistrictHeating tab.
wind power	"Estimated Post Correction Production" for the renewable energy selected on the first row of "Renewable Energy Source" under the Input->RenewableEnergy tab.
PV	"Estimated Post Correction Production" for the renewable energy selected on the second row of "Renewable Energy Source" under the Input->RenewableEnergy tab.
Wave power	"Estimated Post Correction Production" for the renewable energy selected on the third row of "Renewable Energy Source" under the Input->RenewableEnergy tab.
River hydro	"Estimated Post Correction Production" for the renewable energy selected on the fourth row of "Renewable Energy Source" under the Input->RenewableEnergy tab.
Hydro power	"Estimated annual production" in the "Hydro Power" section under the Input->RenewableEnergy tab.
Hydro pump	Operation of the hydro pump. The capacity is defined in "Pump Capacity" in the "Hydro Power" section under the Input->RenewableEnergy tab.
Hydro storage	Energy in the hydro storage. The capacity is defined in "Storage" in the "Hydro Power" section under the Input-RenewableEnergy tab.
Hydro Wat-Sup	Incoming water to the hydro storage. It is defined in "Annual Water supply" in the "Hydro Power" section under the Input->RenewableEnergy tab.
Hydro Wat-Loss	Sometimes the water flowing into the hydro plant exceeds the demand required and hence, water has to go through the spillway and it is lost.
solar thermal	Sum of all the "Result TWh/year" at the end of all the "Solar thermal" inputs under Groups I, II, and 3 of Input->DistrictHeating tab.
cshp1 heat	"DH prod" for the "DH Gr.1" row under the Input->Industry tab.
waste1 heat	"DH production" in the first "DH Gr. 1" row under the Input->Waste tab.
DHP heat	Demand from district heating units under the input "Demand" of the "Group 1" section in the Input->DistrictHeating tab.
cshp2 heat	"DH prod" for the "DH Gr.2" row under the Input->Industry tab.
waste2 heat	"DH production" in the first "DH Gr. 2" row under the Input->Waste tab.
Geoth2 heat	This is the "DH production" produced by the "Geothermal operated by absorption hear pump on steam from waste CHP plants" for the "DH Gr.2" under the Input->Waste tab.
Geoth2 steam	This is the "Steam for Heat Pump" produced by the "Geothermal operated by absorption hear pump on steam from waste CHP plants" for the "DH Gr.2" under the Input->Waste tab.
Geoth2 storage	This is the "Steam Storage" produced by the "Geothermal operated by absorption hear pump on steam from waste CHP plants" for the "DH Gr.2" under the Input->Waste tab.
chp2 heat	The amount of heat produced from the CHP units in "Group 2" of the Input->DistrictHeating tab. The capacity and thermal efficiency of CHP units available to produce this heat are defined in the "CHP" & "Therm." inputs respectively, which are also under the "Group 2" section.

Abbreviation	Input
hp2 heat	The amount of heat produced from the Heat Pump units in “Group 2” of the Input->DistrictHeating tab. The capacity and coefficient of performance for the heat pump units available to produce this heat are defined in the “Heat Pump” & “COP” inputs respectively, which are also under the “Group 2” section.
boiler heat	The amount of heat produced from the boiler units in “Group 2” of the Input->DistrictHeating tab. The capacity and efficiency for the boiler units available to produce this heat are defined in the “Boiler” & “Therm.” inputs respectively, which are also under the “Group 2” section.
EH2 heat	Heat produced from the electric boiler in group 2 of district heating. This occurs if CEEP regulation number 4 is used under the Regulation tab.
ELT2 heat	Heat produced from the Electrolyser in “Group 2” under the Input->ElecStorage tab.
storage CHP gr2	Energy available in “Heat storage gr.2” for CHP under the Input->DistrictHeating tab.
heat2-balance	The balance between the heat produced (i.e. from Industrial CHP, Waste, Geothermal, CHP, HP, Boilers, Electric Boilers, and Electrolysers), and the heat demand (i.e. “Demand input) under “Group 2” in the Input->DistrictHeating tab.
cshp3 heat	“DH prod” for the “DH Gr.3” row under the Input->Industry tab.
waste3 heat	“DH production” in the first “DH Gr. 3” row under the Input->Waste tab.
Geoth3 heat	This is the “DH production” produced by the “Geothermal operated by absorption hear pump on steam from waste CHP plants” for the “DH Gr.3” under the Input->Waste tab.
Geoth3 steam	This is the “Steam for Heat Pump” produced by the “Geothermal operated by absorption hear pump on steam from waste CHP plants” for the “DH Gr.3” under the Input->Waste tab.
Geoth3 storage	This is the “Steam Storage” produced by the “Geothermal operated by absorption hear pump on steam from waste CHP plants” for the “DH Gr.3” under the Input->Waste tab.
chp3 heat	The amount of heat produced from the CHP units in “Group 3” of the Input->DistrictHeating tab. The capacity of CHP units available to produce this heat is defined in the “CHP” input, which is also under the “Group 3” section.
hp3 heat	The amount of heat produced from the Heat Pump units in “Group 3” of the Input->DistrictHeating tab. The capacity and coefficient of performance for the heat pump units available to produce this heat are defined in the “Heat Pump” & “COP” inputs respectively, which are also under the “Group 3” section.
boiler heat r	The amount of heat produced from the boiler units in “Group 3” of the Input->DistrictHeating tab. The capacity and efficiency for the boiler units available to produce this heat are defined in the “Boiler” & “Therm.” inputs respectively, which are also under the “Group 3” section.
EH3 heat	Heat produced from the electric boiler in “Group 3” of district heating. This occurs if CEEP regulation number 5 is used under the Regulation tab.
ELT3 heat	Heat produced from the Electrolyser in “Group 3” under the Input->ElecStorage tab.
storage CHP gr3	Energy available in “Heat storage gr.2” for CHP under the Input->DistrictHeating tab.
heat3-balance	The balance between the heat produced (i.e. from Industrial CHP, Waste, Geothermal, CHP, HP, Boilers, Electric Boilers, and Electrolysers), and the heat demand (i.e. “Demand input) under “Group 3” in the Input->DistrictHeating tab.
flexible eldemand	Sum of “Flexible demand (1 day)”, “Flexible demand (1 week)”, and “Flexible demand (4 weeks)” inputs under the Input->ElectricityDemand tab PLUS the electricity demand for “Electricity (Dump Charge)” under the Input->Transport tab.
hp elec.	The electricity required to power the heat pumps in “Group 2” and “Group 3” under the Input->DistrictHeating tab.

Abbreviation	Input
cshp elec.	Sum of "Electricity production" in the first "DH Gr.1", "DH Gr.2", and "DH Gr.3" rows in the Waste section only under the Input->Waste tab PLUS sum of "Electricity prod" for "DH Gr.1", "DH Gr.2", and "DH Gr.3" under the Input->Industry tab.
chp elec.	The electricity produced by the CHP units in "Group 2" and "Group 3" under the Input->DistrictHeating tab.
pp elec.	The electricity produced by the "Condensing" power plant units in "Group 3" under the Input->DistrictHeating tab.
pp2 elec.	The electricity produced by the "PP2" power plant units in "Group 3" under the Input->DistrictHeating tab.
geother. Elec.	The electricity produced by "Geothermal Power" and "Nuclear Power" under the Input->RenewableEnergy tab.
pump elec.	The electricity demand required to power the "Pump/Compressor" in the "Electricity Storage" section under the Input->ElecStorage tab.
turbine elec.	The electricity produced by the "Turbine" in the "Electricity Storage" section under the Input->ElecStorage tab.
pump-storage	The energy contained in the "Storage Capacity", which is in the "Electricity Storage" section under the Input->ElecStorage tab. The total energy put into the storage is equal to the "pump elec." multiplied by the "Pump/Compressor" efficiency and the total energy removed is equal to the "turbine elec." divided by the "Turbine" efficiency.
ELT2 elec.	The electricity consumed by the Electrolyser in "Group 2" under the Input->ElecStorage tab.
H2stor elt. 2	Energy stored in the form of fuel in the "Hydrogen Storage" of "Group 2" under the Input->ElecStorage tab.
ELT3 elec.	The electricity consumed by the Electrolyser in "Group 3" under the Input->ElecStorage tab.
H2stor elt. 3	Energy stored in the form of fuel in the "Hydrogen Storage" of "Group 3" under the Input->ElecStorage tab.
V2G Demand	This is the electricity required by the smart/V2G electric vehicles for transport purposes only (i.e. not the demand used when acting as a grid storage facility) and it is obtained by multiplying the "Electricity (Smart Charge)" input by the "Efficiency (grid to battery)" input under the Input->Transport tab. Note that the "Electricity (Dump Charge)" input is treated separately in the "flexible eldemand" results.
V2G Charge	This is the electricity demand taken from the grid for the smart/V2G electric vehicles and is from the "Electricity (Smart Charge)" input under the Input->Transport tab. Note that this could be higher if the V2G is used as a storage facility for the grid (i.e. energy is passed in and out of the cars). Note also that the "Electricity (Dump Charge)" input is treated separately in the "flexible eldemand" results already discussed.
V2G Discha.	This is the amount of electricity supplied from the smart/V2G cars to the grid. Its maximum value is obtained by multiplying the "Capacity of battery to grid connection" input by the "Share of parked cars grid connected". When comparing this value to other hourly values, the "Efficiency (battery to grid)" will also need to be considered.
V2G Storage	This is the amount of energy in the "Battery storage capacity" under the Input->Transport tab. Energy can be removed at 100% efficiency from this storage for transport (i.e. for the V2G Demand). However, the total energy put into the storage is equal to the "V2G Charge" multiplied by the "Efficiency (grid to battery)" and the total energy removed is equal to the "V2G Discha." divided by the "Efficiency (battery to grid).
transH2 electr.	The electricity consumed by the electrolyser which creates hydrogen for the transport sector. The value depends on the capacity and efficiency defined for "Transport" under the Input->ElecStorage tab, as well as the "H2 (Produced by Electrolysers) under the Input->Transport tab.

Abbreviation	Input
transH2 storage	This is the “Hydrogen Storage” capacity for “Transport” contained in the Input->ElecStorage tab.
HH-elec.CHP	The “Estimated Electricity Production” from the “H2 micro CHP”, “Ngas micro CHP”, and the “Biomass micro CHP” under the Input->Individual tab.
HH-elec. HP	The “Estimated Electricity Production” from the “Heat Pump” under the Input->Individual tab. This will increase as the “Capacity Limit” is reduced, as an electric boiler will supply the shortfall in heat supply at peak times.
HH-elec. EB	The “Estimated Electricity Production” from the “Electric heating” under the Input->Individual tab.
HH-H2. Electr.	The electricity consumed by the “Micro CHP” electrolyser under the Input->ElecStorage tab.
HH-H2 storage	The “Hydrogen Storage” capacity for “Micro CHP” under the Input->ElecStorage tab.
HH-H2 prices	The “H2 micro CHP” will only operate if it is cheaper than using a conventional boiler. Therefore, EnergyPLAN calculates the price of purchasing hydrogen and compares it to the price of operating a conventional boiler.
HH-heat Demand	Sum of “Heat Demand” for the “H2 micro CHP”, “Ngas micro CHP”, “Biomass micro CHP”, “Heat Pump”, and “Electric Heating” under the Input->Individual tab.
HH-heat CHP+HP	Sum of “Heat Demand” for the “H2 micro CHP”, “Ngas micro CHP”, “Biomass micro CHP”, and “Heat Pump” under the Input->Individual tab.
HH-heat Boiler	This is the total amount of heat supplied by the boiler component only in the “H2 micro CHP”, “Ngas micro CHP”, and “Biomass micro CHP”. This is dependent on the “Heat Demand” and the “Capacity Limit” of these technologies, which are defined under the Input->Individual tab.
HH-heat Solar	The sum of the “Solar Thermal Output” which was built in conjunction with the “H2 micro CHP”, “Ngas micro CHP”, “Biomass micro CHP”, “Heat Pump”, and “Electric Heating” under the Input->Individual tab.
HH-heat Storage	The operation of the “Heat Storage” which was built in conjunction with the “H2 micro CHP”, “Ngas micro CHP”, “Biomass micro CHP”, and “Heat Pump” under the Input->Individual tab.
HH-heat Balance	This is the balace between supply and demand for the “H2 micro CHP”, “Ngas micro CHP”, “Biomass micro CHP”, “Heat Pump”, “Electric Heating”, “Heat Storage”, and “Solar Thermal” under the Input->Individual tab. Note, at least one full row needs to be complete for the heat balance to be activated.
stab.-load	This needs to be 100% to ensure that the “Minimum grid stabilisation production share” under the Regulation tab is met. It is explained in detail in the User’s Guide to EnergyPLAN.
import	This is the amount of electricity that needed to be imported due to a shortage in supply or to ensure grid constraints were met. Note that this can exceed the “Maximum imp./exp. Cap:” defined under the Regulation tab.
export	This is the amount of electricity that needed to be exported due to an oversupply or to ensure grid constraints were met. Note that this can exceed the “Maximum imp./exp. Cap:” defined under the Regulation tab.
CEEP	This is the amount of electricity that was exported which did exceed the “Maximum imp./exp. Cap:” defined under the Regulation tab.
EEEP	This is the amount of electricity that was exported without exceeding the “Maximum imp./exp. Cap:” defined under the Regulation tab.
Nordpool prices	This is the “Price Distribution” in the “External Electricity Market Definition” section under the Regulation tab AFTER it has been manipulated by the “Addition factor” and the “Multiplication Factor”.
Nordpool-prod	This is the “Price Distribution” in the “External Electricity Market Definition” section under the Regulation tab AFTER it has been manipulated by the “Addition factor” and the “Multiplication Factor”. Also, for a market simulation, the price elasticity is also considered. It is used to determine the units which can afford to buy electricity (i.e. heat pumps, electrolysers, energy storage, etc).

Abbreviation	Input
System prices	The system price is the resulting price after the NordPool price has been influenced by the import/export of electricity as defined by the price electricity input in the Regulation tab. The system price is lower (than the NordPool price) when there is export and higher when there is import.
DKmarket prices	This is the market price for the energy system being simulated, which is calculated based on the units operating, their capacities, and their corresponding costs from the Cost->Fuel and the Cost->Operation tabs.
Btl-neck prices	This is the price difference between the external market price “System Price” and the market being simulated “DKmarket prices”.
import payments	This is the cost of importing electricity and it is obtained by multiplying the “import” by the “System Price”. The value displayed needs to be multiplied by 1000 to obtain the true figure and it is a monetary value.
export payments	This is the revenue from exporting electricity and it is obtained by multiplying the “export” by the “System Price”. The value displayed needs to be multiplied by 1000 to obtain the true figure and it is a monetary value.
blt-neck payment	These are the costs that occur due to bottlenecks that occur when import/export reaches its maximum capacity. It is calculated by multiplying the “Btl-neck prices” by the import/export capacity. Note that this is then divided by 2, as the revenue from bottlenecks is normally split between the 2 operators on each side of the interconnector.
addexport payment	The is the cost/revenue that occurs due to the “Fixed Import/Export” which was defined under the Input->ElectricityDemand tab. It is the “Fixed Exp/Imp” in the results window multiplied by the “DKmarket prices”.
DHP and Boilers	This is the amount of gas consumed for “DH” systems without CHP, which is “Group 1”, plus the gas consumed by the boilers in “Group 2” and “Group 3”, under the Input->DistrictHeating tab.
CHP2 CHP3	This is the amount of gas consumed for CHP plants in “Group 2” and “Group 3” under the Input->DistrictHeating tab.
PP CAES	This is the amount of gas consumed for the “Condensing” and “PP2” units in “Group 3”, under the Input->DistrictHeating tab, as well as for CAES energy storage facilities under the Input->ElecStorage tab.
Individual	This is the amount of gas consumed for the “Ngas boiler” and the “Ngas micro CHP”, under the Input->Individual tab.
Transp.	This is the amount of “Ngas” consumed under the Input->Transport tab.
Indust. Various	This is the amount of “Ngas” consumed by “Industry” and “Various”, under the Input->Industry tab.
Demand Sum	The is the total gas demand: “DHP and Boilers” + “CHP2 CHP3” + “PP CAES“ + “Individual” + “Transp.” + “Indust. Various”.
Biogas	This is the “Input to Gas Grid” from the “Biogas Plant” under the Input->Biomass Conversion tab.
Syngas	This is the “Input to Gas Grid” from the “Gasification Plant” under the Input->Biomass Conversion tab.
Storage	This is the amount of gas consumed from (positive) or sent to (negative) the gas storage facility during each hour of the simulation.
Storage Content	This is the amount of gas in the gas storage facility.
Sum	This is the difference between demand and supply for gas.
Import	If the “Sum” results indicate that there is a shortage in gas, then it is imported.
Export	If the “Sum” results indicate that there is excess gas, then it is exported.

4.9 Understanding the Print Results

Instead of using the Results window in EnergyPLAN, it is also possible to print a summary of the main results on 2 x A4 pages. An example of this is presented in Figure 24 below.

Input CEESA_2050_Rec_MI_201312_Complete.txt — The EnergyPLAN model 12.0

Electricity demand (TWh/year):			
Fixed demand	21,80	Flexible demand	4,07
Electric heating + HP	1,65	Fixed imp/exp.	0,00
Electric cooling	0,00	Transportation	8,22
		Total	35,74

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	2,96	11,09	24,34	38,39
Solar Thermal	1,25	2,05	0,91	4,20
Industrial CHP (CSHP)	0,00	0,00	2,65	2,65
Demand after solar and CSHP	1,71	9,04	20,78	31,54

Wind	4454 MW	12,63	TWh/year	0,00	Grid
Offshore Wind	10173 MW	41,75	TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,46	TWh/year	0,00	sation
Wave Power	300 MW	0,79	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	1945	1241	0,58	0,37	
Heat Pump	300	1050			3,50
Boiler		3484		0,95	
Group 3:					
CHP	2500	1292	0,60	0,31	
Heat Pump	600	2100			3,50
Boiler		7574		0,95	
Condensing	10333		0,60		

Heatstorage: gr.2: 40 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,39
Gr.3:	0,89	0,72

Regulation Strategy: Technical regulation no. 3
KEOL regulation 23458000
Minimum Stabilisation share 0,00
Stabilisation share of CHP 0,00
Minimum CHP gr 3 load 0 MW
Minimum PP 0 MW
Heat Pump maximum share 0,50
Maximum import/export 0 MW

Distr. Name : Price_DKV_2008.txt
Addition factor 100,00 DKK/MWh
Multiplication factor 1,05
Dependency factor 0,02 DKK/MWh pr. MW
Average Market Price 541 DKK/MWh
Gas Storage 6000 GWh
Syngas capacity 3522 MW
Biogas max to grid 895 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,85	
Hydro Turbine:	0		0,85	
Electrol. Gr.2:	0	0	0,00	0,00
Electrol. Gr.3:	0	0	0,00	0,00
Electrol. trans.:	1909	477	0,73	
Ely. MicroCHP:	0	0	0,00	

CAES fuel ratio: 0,000

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,13
Industry	0,00	0,00	0,00	19,03
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	6657	190	1307	446	1332	2693	0	620	73	-2
February	6790	401	1307	391	873	2856	0	782	175	4
March	5921	454	1307	308	990	2459	0	311	80	11
April	4928	692	1307	170	842	1853	0	74	24	-34
May	4066	758	1306	63	718	1188	0	3	2	28
June	2347	624	1270	17	241	237	0	0	1	-43
July	2347	685	1264	17	270	144	0	0	1	-33
August	2347	644	1266	17	249	204	0	0	0	-35
September	3109	581	1300	23	587	628	0	1	1	-13
October	4179	398	1307	150	501	1779	0	12	19	14
November	5196	216	1307	325	752	2334	0	157	104	1
December	6024	128	1307	416	1399	2284	0	407	74	10
Average	4487	481	1296	195	730	1551	0	196	46	-8
Maximum	10955	3841	1307	836	2532	3150	0	3719	600	1613
Minimum	2170	0	1056	16	0	21	0	0	0	-2308
TWh/year	39,41	4,22	11,38	1,71	6,41	13,62	0,00	1,72	0,40	-0,07

Electricity / Exchange

	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million DKK)	Exchange Payment Exp (Million DKK)
January	2787	1398	1042	3364	73	0	0	5908	0	0	200	2340	385	100	0	15	15	0	0	4
February	2759	1399	1079	4405	175	0	0	8139	0	0	200	1539	207	100	0	96	96	0	0	25
March	2661	1422	944	4179	80	0	0	7306	0	0	200	1745	216	100	0	148	148	0	0	29
April	2361	1382	698	4162	24	0	0	6853	0	0	200	1492	224	100	0	141	141	0	0	33
May	2307	1394	459	4434	2	0	0	7327	0	0	200	1276	192	100	0	399	399	0	0	96
June	2246	1408	109	4113	1	0	0	7446	0	0	204	406	121	100	0	302	302	0	0	77
July	2060	1411	70	2935	1	0	0	5747	0	0	205	463	381	100	0	320	320	0	0	83
August	2349	1389	96	3245	0	0	0	6275	0	0	205	425	411	100	0	236	236	0	0	74
September	2407	1412	256	3730	1	0	0	6412	0	0	201	1028	317	100	0	151	151	0	0	60
October	2492	1408	659	5067	19	0	0	8794	0	0	200	876	154	100	0	380	380	0	0	113
November	2682	1400	881	4637	104	0	0	8178	0	0	200	1325	148	100	0	140	140	0	0	39
December	2683	1378	905	3747	74	0	0	5913	0	0	200	2460	361	100	0	53	53	0	0	12
Average	2482	1400	598	3997	46	0	0	7017	0	0	202	1282	261	100	0	199	199	0	Average price	
Maximum	3754	6906	1184	7659	600	0	0	18479	0	0	228	4445	3287	100	0	6418	6418	0	(DKK/MWh)	
Minimum	1312	-246	6	0	0	0	0	29	0	0	200	0	0	100	0	0	0	0	562	369
TWh/year	21,80	12,30	5,26	35,11	0,40	0,00	0,00	61,63	0,00	0,00	1,77	11,26	2,29		0,00	1,75	1,75	0,00	0	645

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	Wind	Offsh.	PV	Wave	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt): Total	CO2 emission (Mt): Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	8,44	10,61	-	-	3,82	-	-	-	-	-22,85	-0,01	-	-	-	-	-	-	-	-	0,00	-2,92	-2,91	0,00	-0,60
Biomass	1,81	-	-	0,77	1,05	-	-	-	4,16	-	38,87	-	-	-	-	-	-	-	0,92	19,03	66,60	0,00	66,60	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	3,45	-	-	-	12,63	41,75	6,46	0,79	6,39	-	-	-	71,47	0,00	71,47	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-24,77	-10,85	35,62	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-32,15	-	-	-	-	-	32,15	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	1,81	8,44	10,61	0,77	1,05	3,82	-	-	7,61	-24,77	5,17	3,45	12,63	41,75	6,46	0,79	6,39	32,15	0,92	19,03	138,07	-2,92	135,16	0,00	-0,60

26-januar-2015 [13:01]

Output specifications CEESA_2050_Rec_MI_201312_Complete.txt — The EnergyPLAN model 12.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW
January	504	59	0	446
February	515	124	0	391
March	448	140	0	308
April	371	201	0	170
May	305	241	0	63
June	172	155	0	17
July	172	155	0	17
August	172	155	0	17
September	231	208	0	23
October	313	163	0	150
November	392	66	0	325
December	455	39	0	416
Average	337	142	0	195
Maximum	836	707	0	836
Minimum	158	0	0	16
Total for the whole year TWh/year	2,96	1,25	0,00	1,71

	Gr.2 District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	2006	92	146	645	829	0	246	49	15417	0
February	2044	193	146	412	909	0	267	114	16167	2
March	1793	219	146	462	762	0	141	51	12219	12
April	1506	341	146	374	599	0	49	18	11337	-21
May	1257	359	146	310	422	0	1	1	16531	18
June	761	325	146	163	137	0	0	1	15022	-12
July	761	363	146	163	85	0	0	1	14327	2
August	761	341	146	156	124	0	0	0	16037	-8
September	981	259	146	291	293	0	1	1	15200	-11
October	1290	164	146	254	698	0	9	14	14923	5
November	1584	104	146	357	777	0	105	90	15689	5
December	1823	62	146	676	704	0	179	51	17492	6
Average	1379	235	146	356	527	0	83	32	15032	0
Maximum	3247	2175	146	1241	1050	0	1332	400	30491	658
Minimum	709	0	146	0	7	0	0	0	0	-926
TWh/year	12,11	2,07	1,28	3,12	4,63	0,00	0,73	0,28		0,00

	Gr.3 District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	4147	40	1161	687	1863	0	374	24	3117	-2
February	4231	85	1161	461	1946	0	515	61	5730	2
March	3680	96	1161	527	1697	0	170	30	4569	-1
April	3051	149	1161	468	1254	0	25	6	5081	-13
May	2505	157	1160	408	766	0	2	1	8299	9
June	1414	144	1124	77	100	0	0	0	6123	-31
July	1414	167	1118	107	59	0	0	0	6242	-36
August	1414	148	1120	93	80	0	0	0	6242	-27
September	1898	114	1155	296	335	0	0	0	6287	-2
October	2576	71	1161	247	1081	0	3	5	6298	9
November	3221	45	1161	395	1557	0	52	15	4931	-4
December	3746	27	1161	724	1580	0	228	22	2894	4
Average	2771	104	1150	374	1024	0	113	13	5482	-8
Maximum	6872	1275	1161	1292	2100	0	2597	200	10000	1117
Minimum	1302	0	910	0	14	0	0	0	0	-1392
TWh/year	24,34	0,91	10,10	3,29	8,99	0,00	0,99	0,12		-0,07

	RES specification: RES1 Wind MW	RES2 Offshore MW	RES3 Photo MW	RES 4-7 ic MW	Total MW
January	1303	4348	168	88	5908
February	1841	5637	495	166	8139
March	1509	4962	716	119	7306
April	1271	4432	1093	58	6853
May	1270	4372	1631	53	7327
June	1356	4782	1260	48	7446
July	918	3345	1436	48	5747
August	1267	4289	654	65	6275
September	1265	4382	678	87	6412
October	2013	6214	439	128	8794
November	1930	5944	177	128	8178
December	1332	4408	73	99	5913
Average	1437	4753	736	90	7017
Maximum	4454	10173	5000	300	18479
Minimum	0	0	0	1	29
TWh/year	12,63	41,75	6,46	0,79	61,63

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million DKK)		
Total Fuel ex Ngas exchange =		14787
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	3380	
Gas handling =	646	
Biomass =	10761	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		1
Marginal operation costs =		275
Total Electricity exchange =		0
Import =	0	
Export =	-645	
Bottleneck =	645	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		15063
Fixed operation costs =		36484
Annual Investment costs =		96264
TOTAL ANNUAL COSTS =		147810

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	3959	642	0	0	0	4601	895	2254	1545	1814	-3660	1753	0	0	0
February	0	2602	345	0	0	0	2947	895	1616	2015	1814	-3660	267	0	0	0
March	0	2951	361	0	0	0	3311	895	1891	1896	1814	-3660	476	0	0	0
April	0	2521	373	0	0	0	2894	895	1868	1881	1814	-3660	96	0	0	0
May	0	2155	320	0	0	0	2475	895	1790	2045	1814	-3660	-409	0	0	0
June	0	691	202	0	0	0	894	895	991	1935	1814	-3660	-1081	0	0	0
July	0	786	636	0	0	0	1421	895	1497	1427	1814	-3660	-551	0	0	0
August	0	723	685	0	0	0	1407	895	1441	1531	1814	-3660	-613	0	0	0
September	0	1740	528	0	0	0	2268	895	1855	1738	1814	-3660	-375	0	0	0
October	0	1483	257	0	0	0	1740	895	1266	2325	1814	-3660	-900	0	0	0
November	0	2240	247	0	0	0	2487	895	1542	2110	1814	-3660	-214	0	0	0
December	0	4160	602	0	0	0	4762	895	2447	1749	1814	-3660	1517	0	0	0
Average	0	2169	435	0	0	0	2604	895	1707	1848	1814	-3660	0	0	0	0
Maximum	0	7520	5479	0	0	0	11042	895	3522	3703	1814	-3660	8471	0	0	0
Minimum	0	0	0	0	0	0	0	895	120	0	1814	-3660	-2872	0	0	0
Total for the whole year TWh/year	0,00	19,05	3,82	0,00	0,00	0,00	22,87	7,86	14,99	16,23	15,93	-32,15	0,00	0,00	0,00	0,00

RES Share: 100,0 Percent of Primary Energy 243,3 Percent of Electricity 62,5 TWh electricity from RES 26-januar-2015 [13:01]

Figure 24: Two A4 pages with a summary of the main results which can be printed using EnergyPLAN.

In this section, some of the main results from these output sheets are described.

4.9.1 *Page 1: To be completed*

4.9.2 *Page 2: To be completed*

The left top half of pages 2 summarises the district heating production and demands. These are described for the following:

- The average production/demand for each month
- The average, maximum, and minimum hourly demand/production over the year being simulated
- The total demand/production over the year

Output specifications CEESA_2050_Rec_MI.txt The EnergyPLAN

District Heating Production

	Gr.1				Gr.2									
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	504	59	0	446	2006	92	128	838	518	4	426	0	27435	-1
February	515	124	0	391	2044	193	128	532	594	7	591	0	25880	-2
March	448	140	0	308	1793	219	128	579	506	5	346	0	24602	9
April	371	201	0	170	1506	341	128	446	451	3	156	0	21267	-20
May	305	241	0	63	1257	359	128	319	405	4	10	0	27227	31
June	172	155	0	17	761	325	128	160	156	3	5	0	24163	-16
July	172	155	0	17	761	361	128	161	101	3	3	0	23892	3
August	172	155	0	17	761	340	128	156	142	3	4	0	25467	-12
September	231	208	0	23	981	259	128	304	288	4	10	0	24204	-13
October	313	163	0	150	1290	164	128	308	527	8	138	0	23050	16
November	392	66	0	325	1584	104	128	450	545	8	352	0	24369	-4
December	455	39	0	416	1823	62	128	865	455	4	307	0	21717	2
Average	337	142	0	195	1379	235	128	427	390	5	194	0	24442	0
Maximum	836	707	0	836	3247	2154	128	1605	700	19	1851	34	40000	1144
Minimum	158	0	0	16	709	0	128	0	34	0	0	0	0	-1316
Total for the whole year														
TWh/year	2.96	1.25	0.00	1.71	12.11	2.06	1.13	3.75	3.42	0.04	1.71	0.00		0.00

	Gr.3									
	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	4147	44	1110	693	1380	8	912	0	2	0
February	4231	93	1110	454	1386	15	1173	0	18	0
March	3680	105	1110	532	1315	11	607	0	165	0
April	3051	164	1110	490	1045	9	246	0	2188	-13
May	2505	173	1109	428	757	7	18	0	4759	13
June	1414	157	1073	95	128	2	0	0	7372	-40
July	1414	181	1066	130	75	1	0	0	7597	-39
August	1414	161	1069	113	100	1	0	0	7597	-30
September	1898	125	1102	325	345	2	0	0	7586	-3
October	2576	78	1110	279	1021	12	69	0	6932	7
November	3221	50	1110	414	1227	15	405	0	1203	0
December	3746	30	1110	732	1255	8	610	0	2099	1
Average	2771	113	1099	391	835	7	334	0	3975	-9
Maximum	6872	1401	1110	1207	1400	34	3339	2	10000	1003
Minimum	1302	0	859	0	28	0	0	0	0	-1113
Total for the whole year										
TWh/year	24.34	1.00	9.65	3.43	7.33	0.06	2.93	0.00		-0.08

There are two rows of abbreviations on top. The first signifies the type of district heating:

- Gr.1 = Group 1 district heating
- Gr.2 = Group 2 district heating
- Gr.3 = Group 3 district heating

These different groups are described in section 4.2. The next row signifies the type of production or demand with each of the groups:

- District Heating = the district heating demand in that specific group.
- Solar = District heating supplied to the grid by solar district heating systems.
- CSHP = District heating supplied to the grid by waste incineration and industry.
- DHP = District heating supplied to the grid by boilers. This is only applicable to group 1 so in these systems the boilers are the primary conventional source of district heating.
- Boiler = District heating supplied to the grid by boilers. This is applicable to group 2 and group 3, so in these systems the boilers are mostly required for peak heat demands or as backup to CHP plants.
- CHP = District heating supplied to the grid by combined heat and power plants.
- HP = District heating supplied to the grid by solar heat pumps.
- ELT = District heating supplied to the grid by the surplus heat from electrolysers.
- EH = District heating supplied to the grid by electric boilers.
- Storage = This is the amount of energy in the thermal storage system for district heating
- Balance = This outlines if there is a shortfall (+) or excess (-) of heat being produced in the district heating system. If there is a significant imbalance, then this needs to be rectified by adding or removing units from the district heating system **OR** by increasing or decreasing the demand.

5 Verifying Reference Model Data

Once all the data has been inputted into EnergyPLAN, the final step is to verify that the model created is operating the same as the energy system that you are trying to simulate.

The first step is to ensure that all the capacities and distributions are correct, including interconnection capacity that is placed under the Regulation tab. Afterwards, the energy outputs from the model must be compared with those of the actual energy system. There are five guidelines listed below that may be useful for completing this task (see Figure 25 also):

1. Ensure the electricity demand is correct (including demand, heating, cooling, and interconnection).
2. Confirm the consumption is also correct at point 2.
3. Check that the production units, other than the power plants, are producing the required amount of energy.
4. Are the power plants generating the correct amount of energy for each fuel type? If steps 3 and 4 are correct, but the power plants are not generating the correct amount of energy, then the power plant efficiency under the Input -> DistrictHeating tab needs to be adjusted.
5. Is the total amount of fuel being used within the energy system correct?

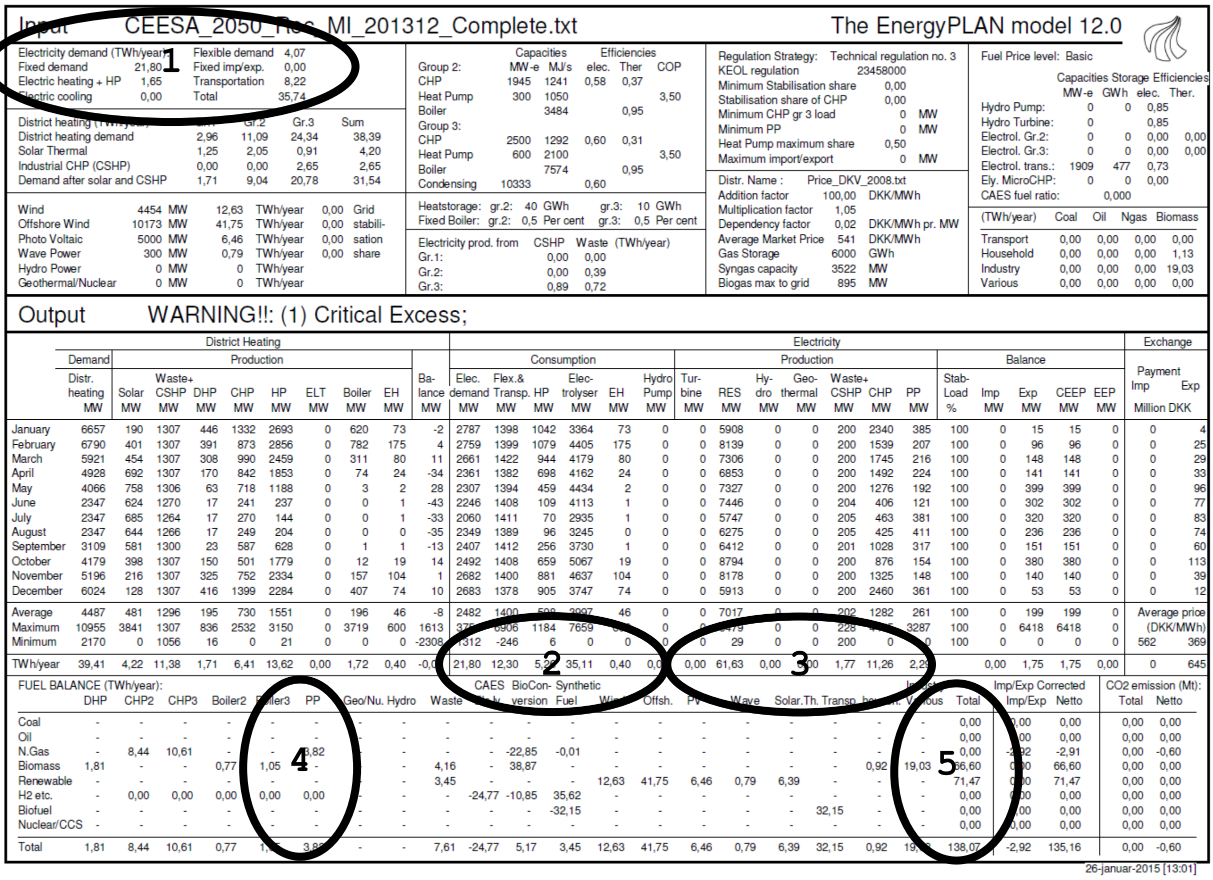


Figure 25: Verifying the EnergyPLAN model is functioning accurately.

Input CEESA_2050_Rec_MI_201312_Complete.txt — The EnergyPLAN model 12.0

Electricity demand (TWh/year):			
Fixed demand	21,80	Flexible demand	4,07
Electric heating + HP	1,65	Fixed imp/exp.	0,00
Electric cooling	0,00	Transportation	8,22
		Total	35,74

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	2,96	11,09	24,34	38,39
Solar Thermal	1,25	2,05	0,91	4,20
Industrial CHP (CSHP)	0,00	0,00	2,65	2,65
Demand after solar and CSHP	1,71	9,04	20,78	31,54

Wind	4454 MW	12,63 TWh/year	0,00	Grid
Offshore Wind	10173 MW	41,75 TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,46 TWh/year	0,00	sation
Wave Power	300 MW	0,79 TWh/year	0,00	share
Hydro Power	0 MW	0 TWh/year		
Geothermal/Nuclear	0 MW	0 TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	1945	1241	0,58	0,37	
Heat Pump	300	1050			3,50
Boiler		3484		0,95	
Group 3:					
CHP	2500	1292	0,60	0,31	
Heat Pump	600	2100			3,50
Boiler		7574		0,95	
Condensing	10333		0,60		

Heatstorage: gr.2: 40 GWh gr.3: 10 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	0,39
Gr.3:	0,89	0,72

Regulation Strategy:	Technical regulation no. 3	
KEOL regulation	23458000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Price_DKV_2008.txt	
Addition factor	100,00	DKK/MWh
Multiplication factor	1,05	
Dependency factor	0,02	DKK/MWh pr. MW
Average Market Price	541	DKK/MWh
Gas Storage	6000	GWh
Syngas capacity	3522	MW
Biogas max to grid	895	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,85	
Hydro Turbine:	0		0,85	
Electrol. Gr.2:	0	0	0,00	0,00
Electrol. Gr.3:	0	0	0,00	0,00
Electrol. trans.:	1909	477	0,73	
Ely. MicroCHP:	0	0	0,00	

CAES fuel ratio: 0,000

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,13
Industry	0,00	0,00	0,00	19,03
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

District Heating / Electricity

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW
January	6657	190	1307	446	1332	2693	0	620	73	-2	2787	1398	1042	3364	73	0
February	6790	401	1307	391	873	2856	0	782	175	4	2759	1399	1079	4405	175	0
March	5921	454	1307	308	990	2459	0	311	80	11	2661	1422	944	4179	80	0
April	4928	692	1307	170	842	1853	0	74	24	-34	2361	1382	698	4162	24	0
May	4066	758	1306	63	718	1188	0	3	2	28	2307	1394	459	4434	2	0
June	2347	624	1270	17	241	237	0	0	1	-43	2246	1408	109	4113	1	0
July	2347	685	1264	17	270	144	0	0	1	-33	2060	1411	70	2935	1	0
August	2347	644	1266	17	249	204	0	0	0	-35	2349	1389	96	3245	0	0
September	3109	581	1300	23	587	628	0	1	1	-13	2407	1412	256	3730	1	0
October	4179	398	1307	150	501	1779	0	12	19	14	2492	1408	659	5067	19	0
November	5196	216	1307	325	752	2334	0	157	104	1	2682	1400	881	4637	104	0
December	6024	128	1307	416	1399	2284	0	407	74	10	2683	1378	905	3747	74	0
Average	4487	481	1296	195	730	1551	0	196	46	-8	2482	1400	598	3997	46	0
Maximum	10955	3841	1307	836	2532	3150	0	3719	600	1613	3754	6906	1184	7659	600	0
Minimum	2170	0	1056	16	0	21	0	0	0	-2308	1312	-246	6	0	0	0
TWh/year	39,41	4,22	11,38	1,71	6,41	13,62	0,00	1,72	0,40	-0,07	21,80	12,30	5,26	35,11	0,40	0,00

	Production: Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp	Exp Million DKK
January	0	5908	0	0	200	2340	385	100	0	15	15	0	0	4
February	0	8139	0	0	200	1539	207	100	0	96	96	0	0	25
March	0	7306	0	0	200	1745	216	100	0	148	148	0	0	29
April	0	6853	0	0	200	1492	224	100	0	141	141	0	0	33
May	0	7327	0	0	200	1276	192	100	0	399	399	0	0	96
June	0	7446	0	0	204	406	121	100	0	302	302	0	0	77
July	0	5747	0	0	205	463	381	100	0	320	320	0	0	83
August	0	6275	0	0	205	425	411	100	0	236	236	0	0	74
September	0	6412	0	0	201	1028	317	100	0	151	151	0	0	60
October	0	8794	0	0	200	876	154	100	0	380	380	0	0	113
November	0	8178	0	0	200	1325	148	100	0	140	140	0	0	39
December	0	5913	0	0	200	2460	361	100	0	53	53	0	0	12
Average	0	7017	0	0	202	1282	261	100	0	199	199	0	Average price	
Maximum	0	18479	0	0	228	4445	3287	100	0	6418	6418	0	(DKK/MWh)	
Minimum	0	29	0	0	200	0	0	100	0	0	0	0	562	369
TWh/year	0,00	61,63	0,00	0,00	1,77	11,26	2,29		0,00	1,75	1,75	0,00	0	645

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Synthetic Fuel	Wind	Offsh.	PV	Wave	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	8,44	10,61	-	-	3,82	-	-	-	-	-22,85	-0,01	-	-	-	-	-	-	-	-	0,00	-2,92	-2,91	0,00	-0,60
Biomass	1,81	-	-	0,77	1,05	-	-	-	4,16	-	38,87	-	-	-	-	-	-	-	0,92	19,03	66,60	0,00	66,60	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	3,45	-	-	-	12,63	41,75	6,46	0,79	6,39	-	-	-	71,47	0,00	71,47	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-24,77	-10,85	35,62	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-32,15	-	-	-	-	-	32,15	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	1,81	8,44	10,61	0,77	1,05	3,82	-	-	7,61	-24,77	5,17	3,45	12,63	41,75	6,46	0,79	6,39	32,15	0,92	19,03	138,07	-2,92	135,16	0,00	-0,60

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Figure 26: Sample of the WARNING for excess electricity production on the results printout of EnergyPLAN.

6 Conclusions

The EnergyPLAN model is extremely useful because it is simple to use. However, this simplicity creates a responsibility on the user to ensure that the data inputted is as accurate and relevant as possible. The time required to build the reference model is cumbersome as there is a lot of false paths along the way. However, the wave of possibilities that present themselves upon completion of the reference model, ensure that the time spent searching for data becomes a worthy experience.

Once the reference model is completed, it is possible to build and analyse energy systems with endless quantities of renewable energy, conventional plant, energy storage, and transport technologies, in a relatively short period of time.

Finally, the level of detail discussed in this report is not necessary for every study completed using EnergyPLAN, especially in relation to the distributions used. Therefore, before spending a large period of time gathering data, ensure that the data is required for the accuracy of the results.

7 Appendix

7.1 Ireland's Energy Balance 2007

Ireland's Provisional Energy Balance 2007 (TWh)

2007 Units = TWh

2007 Units = TWh	Coal	Bituminous Coal	Anthracite + Manufactured Ovoids	Coke	Lignite	Peat	Milled Peat	Sod Peat	Briquettes	Oil	Crude	Refinery Gas	Gasoline	Kerosene	Jet Kerosene	Fueloil
Indigenous Production	0.000	0.000	0.000	0.000	0.000	6.876	4.711	2.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Imports	16.517	16.077	0.380	0.000	0.060	0.000	0.000	0.000	0.000	122.814	40.573	0.000	14.817	5.820	12.916	6.863
Exports	0.036	0.000	0.036	0.000	0.000	0.092	0.000	0.000	0.092	15.105	0.000	0.000	0.321	0.202	0.000	13.181
Mar. Bunkers	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.324	0.000	0.000	0.000	0.000	0.000	0.769
Stock Change	1.059	0.999	0.044	0.000	0.016	1.374	1.393	-0.002	-0.017	2.209	-0.311	0.000	0.044	-0.218	0.560	1.519
Primary Energy Supply (incl non-energy)	17.540	17.076	0.388	0.000	0.076	8.158	6.103	2.163	-0.108	108.593	40.263	0.000	14.540	5.399	13.476	-5.568
Primary Energy Requirement (excl. non-energy)	17.540	17.076	0.388	0.000	0.076	8.158	6.103	2.163	-0.108	105.220	40.263	0.000	14.540	5.399	13.476	-5.568
Transformation Input	13.071	13.071	0.000	0.000	0.000	6.186	6.186	0.000	0.000	44.634	40.263	0.093	0.000	0.000	0.000	4.233
Public Thermal Power Plants	13.071	13.071	0.000	0.000	0.000	5.010	5.010	0.000	0.000	4.275	0.000	0.000	0.000	0.000	0.000	4.233
Combined Heat and Power Plants	0.000	0.000	0.000	0.000	0.000	0.082	0.082	0.000	0.000	0.096	0.000	0.093	0.000	0.000	0.000	0.000
Pumped Storage Consumption	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	1.093	1.093	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oil Refineries & other energy sector	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	40.263	40.263	0.000	0.000	0.000	0.000	0.000
Transformation Output	0.000	0.000	0.000	0.000	0.000	1.100	0.000	0.000	1.100	39.049	0.000	1.085	6.108	2.459	0.000	14.322
Public Thermal Power Plants	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Combined Heat and Power Plants - Electricity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Combined Heat and Power Plants - Heat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pumped Storage Generation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	1.100	0.000	0.000	1.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oil Refineries	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	39.049	0.000	1.085	6.108	2.459	0.000	14.322
Exchanges and transfers	0.194	-0.124	0.317	0.000	0.000	0.000	0.000	0.000	0.000	-0.085	0.000	0.000	-0.081	2.213	-2.213	0.306
Electricity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.194	-0.124	0.317	0.000	0.000	0.000	0.000	0.000	0.000	-0.085	0.000	0.000	-0.081	2.213	-2.213	0.306
Own Use and Distribution Losses	0.000	0.000	0.000	0.000	0.000	0.176	0.176	0.000	0.000	1.431	0.000	0.992	0.000	0.000	0.000	0.365
Available Final Energy Consumption	4.663	3.881	0.706	0.000	0.076	2.897	-0.258	2.163	0.992	101.493	0.000	0.000	20.566	10.072	11.264	4.461
Non-Energy Consumption	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.374	0.000	0.000	0.000	0.000	0.000	0.000
Final non-Energy Consumption (Feedstocks)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.374	0.000	0.000	0.000	0.000	0.000	0.000
Total Final Energy Consumption	4.354	3.568	0.709	0.000	0.076	3.159	0.000	2.167	0.992	100.064	0.000	0.000	22.325	10.620	12.134	4.295
Industry*	1.630	1.630	0.000	0.000	0.000	0.003	0.000	0.000	0.003	11.799	0.000	0.000	0.000	1.438	0.000	4.180
Non-Energy Mining	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.493	0.000	0.000	0.000	0.015	0.000	0.060
Food, beverages and tobacco	0.160	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.457	0.000	0.000	0.000	0.188	0.000	0.731
Textiles and textile products	0.075	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.119	0.000	0.000	0.000	0.009	0.000	0.036
Wood and wood products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.146	0.000	0.000	0.000	0.018	0.000	0.070
Pulp, paper, publishing and printing	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.088	0.000	0.000	0.000	0.009	0.000	0.033
Chemicals & man-made fibres	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.563	0.000	0.000	0.000	0.076	0.000	0.294
Rubber and plastic products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.002	0.000	0.008
Other non-metallic mineral products	1.391	1.391	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.913	0.000	0.000	0.000	0.032	0.000	0.126
Basic metals and fabricated metal products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.763	0.000	0.000	0.000	1.037	0.000	2.619
Machinery and equipment n.e.c.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.000	0.000	0.008	0.000	0.029
Electrical and optical equipment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.849	0.000	0.000	0.000	0.020	0.000	0.078
Transport equipment manufacture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000	0.000	0.000	0.002	0.000	0.006
Other manufacturing	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.003	0.211	0.000	0.000	0.000	0.023	0.000	0.090
Transport	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	65.812	0.000	0.000	22.325	0.000	12.134	0.000
Road Freight	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.798	0.000	0.000	0.000	0.000	0.000	0.000
Road Private Car	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	25.141	0.000	0.000	18.840	0.000	0.000	0.000
Public Passenger Services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.088	0.000	0.000	0.526	0.000	0.000	0.000
Rail	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000
Domestic Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.625	0.000	0.000	0.019	0.000	0.607	0.000
International Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.527	0.000	0.000	0.000	0.000	11.527	0.000
Fuel Tourism	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	7.364	0.000	0.000	2.121	0.000	0.000	0.000
Unspecified	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.769	0.000	0.000	0.820	0.000	0.000	0.000
Residential	2.420	1.653	0.699	0.000	0.068	3.155	0.000	2.167	0.988	13.113	0.000	0.000	0.000	9.182	0.000	0.000
Commercial/Public Services	0.303	0.285	0.010	0.000	0.008	0.000	0.000	0.000	0.000	6.405	0.000	0.000	0.000	0.000	0.000	0.115
Commercial Services	0.303	0.285	0.010	0.000	0.008	0.000	0.000	0.000	0.000	4.178	0.000	0.000	0.000	0.000	0.000	0.011
Public Services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.227	0.000	0.000	0.000	0.000	0.000	0.103
Agricultural	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.936	0.000	0.000	0.000	0.000	0.000	0.000
Statistical Difference	0.310	0.313	-0.003	0.000	0.000	-0.262	-0.258	-0.004	0.000	-1.945	0.000	0.000	-1.759	-0.548	-0.870	0.166

2007 Units = TWh	LPG	Gasoil / Diesel /DERV	Petroleum Coke	Naphta	Bitumen	White Spirit	Lubricants	Natural Gas	Renewables	Hydro	Wind	Biomass	Landfill Gas	Biogas	Liquid Biofuel	Solar	Geothermal	Electricity	Heat	TOTAL
Indigenous Production	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.304	5.211	0.667	1.959	1.991	0.278	0.111	0.179	0.015	0.012	0.000	0.000	16.390
Imports	1.527	32.151	3.872	0.000	2.765	1.393	0.117	45.631	0.295	0.000	0.000	0.146	0.000	0.000	0.149	0.000	0.000	1.413	0.000	186.669
Exports	0.176	0.171	0.000	0.152	0.000	0.831	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.082	0.000	15.315
Mar. Bunkers	0.000	0.555	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.324
Stock Change	0.031	0.490	0.059	0.035	0.000	0.000	0.000	-0.012	-0.078	0.000	0.000	-0.001	0.000	0.000	-0.077	0.000	0.000	0.000	0.000	4.552
Primary Energy Supply (incl non-energy)	1.381	31.916	3.930	-0.117	2.765	0.562	0.047	49.923	5.427	0.667	1.959	2.135	0.278	0.111	0.250	0.015	0.012	1.331	0.000	190.972
Primary Energy Requirement (excl. non-energy)	1.381	31.916	3.930	-0.117	0.000	0.000	0.000	49.923	5.427	0.667	1.959	2.135	0.278	0.111	0.250	0.015	0.012	1.331	0.000	187.598
Transformation Input	0.003	0.042	0.000	0.000	0.000	0.000	0.000	31.830	0.384	0.000	0.000	0.038	0.278	0.068	0.000	0.000	0.000	0.729	0.000	96.833
Public Thermal Power Plants	0.000	0.042	0.000	0.000	0.000	0.000	0.000	29.092	0.279	0.000	0.000	0.001	0.278	0.000	0.000	0.000	0.000	0.000	0.000	51.727
Combined Heat and Power Plants	0.003	0.000	0.000	0.000	0.000	0.000	0.000	2.738	0.105	0.000	0.000	0.037	0.000	0.068	0.000	0.000	0.000	0.000	0.000	3.021
Pumped Storage Consumption	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.546	0.000	0.546
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.093
Oil Refineries & other energy sector	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.182	0.000	40.445
Transformation Output	0.468	14.490	0.000	0.117	0.000	0.000	0.000	0.000	0.132	0.000	0.000	0.013	0.102	0.017	0.000	0.000	0.000	25.505	0.000	65.786
Public Thermal Power Plants	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.102	0.000	0.000	0.000	0.102	0.000	0.000	0.000	0.000	23.330	0.000	23.432
Combined Heat and Power Plants - Electricity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.013	0.000	0.017	0.000	0.000	0.000	1.826	0.000	1.856
Combined Heat and Power Plants - Heat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pumped Storage Generation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.349	0.000	0.349
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.100
Oil Refineries	0.468	14.490	0.000	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	39.049
Exchanges and transfers	0.000	-0.116	-0.194	0.000	0.000	0.000	0.000	0.000	-2.758	-0.667	-1.959	-0.013	-0.102	-0.017	0.000	0.000	0.000	2.758	0.000	0.109
Electricity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-2.758	-0.667	-1.959	-0.013	-0.102	-0.017	0.000	0.000	0.000	2.758	0.000	0.000
Heat	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.000	-0.116	-0.194	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.109
Own Use and Distribution Losses	0.045	0.030	0.000	0.000	0.000	0.000	0.000	0.665	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.666	0.000	4.938
Available Final Energy Consumption	1.802	46.217	3.736	0.000	2.765	0.562	0.047	17.427	2.417	0.000	0.000	2.097	0.000	0.044	0.250	0.015	0.012	26.198	0.000	155.096
Non-Energy Consumption	0.000	0.000	0.000	0.000	2.765	0.562	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.374
Final non-Energy Consumption (Feedstocks)	0.000	0.000	0.000	0.000	2.765	0.562	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.374
Total Final Energy Consumption	1.853	45.188	3.637	0.012	0.000	0.000	0.000	18.424	2.476	0.000	0.000	2.156	0.000	0.044	0.249	0.015	0.012	25.867	0.000	154.343
Industry*	0.813	2.076	3.280	0.012	0.000	0.000	0.000	7.616	1.769	0.000	0.000	1.752	0.000	0.017	0.000	0.000	0.000	8.478	0.000	31.295
Non-Energy Mining	0.001	0.416	0.000	0.000	0.000	0.000	0.000	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.668	0.000	1.582
Food, beverages and tobacco	0.051	0.488	0.000	0.000	0.000	0.000	0.000	2.028	0.684	0.000	0.000	0.667	0.000	0.017	0.000	0.000	0.000	1.987	0.000	6.316
Textiles and textile products	0.018	0.056	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.308
Wood and wood products	0.000	0.058	0.000	0.000	0.000	0.000	0.000	0.046	1.085	0.000	0.000	1.085	0.000	0.000	0.000	0.000	0.000	0.348	0.000	1.626
Pulp, paper, publishing and printing	0.009	0.037	0.000	0.000	0.000	0.000	0.000	0.262	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.369	0.000	0.723
Chemicals & man-made fibres	0.015	0.179	0.000	0.000	0.000	0.000	0.000	1.429	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.189	0.000	3.182
Rubber and plastic products	0.006	0.054	0.000	0.000	0.000	0.000	0.000	0.113	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.373	0.000	0.556
Other non-metallic mineral products	0.037	0.439	3.280	0.000	0.000	0.000	0.000	0.635	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.635	0.000	6.574
Basic metals and fabricated metal products	0.030	0.078	0.000	0.000	0.000	0.000	0.000	2.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.869	0.000	6.690
Machinery and equipment n.e.c.	0.024	0.035	0.000	0.000	0.000	0.000	0.000	0.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.450
Electrical and optical equipment	0.612	0.139	0.000	0.000	0.000	0.000	0.000	0.326	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.330	0.000	2.505
Transport equipment manufacture	0.001	0.022	0.000	0.000	0.000	0.000	0.000	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.000	0.236
Other manufacturing	0.011	0.074	0.000	0.012	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.307	0.000	0.549
Transport	0.012	31.341	0.000	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.052	0.000	66.113
Road Freight	0.000	13.798	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.798
Road Private Car	0.012	6.290	0.000	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.000	0.000	25.391
Public Passenger Services	0.000	1.562	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.088
Rail	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.000	0.552
Domestic Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.625
International Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.527
Fuel Tourism	0.000	5.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	7.364
Unspecified	0.000	3.948	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.769
Residential	0.897	2.676	0.358	0.000	0.000	0.000	0.000	6.896	0.282	0.000	0.000	0.262	0.000	0.000	0.000	0.015	0.005	8.064	0.000	33.930
Commercial/Public Services	0.132	6.159	0.000	0.000	0.000	0.000	0.000	3.913	0.095	0.000	0.000	0.061	0.000	0.027	0.000	0.000	0.006	8.711	0.000	19.427
Commercial Services	0.098	4.069	0.000	0.000	0.000	0.000	0.000	1.715	0.095	0.000	0.000	0.061	0.000	0.027	0.000	0.000	0.006	6.245	0.000	12.536
Public Services	0.034	2.090	0.000	0.000	0.000	0.000	0.000	2.198	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.466	0.000	6.892
Agricultural	0.000	2.936	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.080	0.000	0.000	0.000	0.000	0.000	0.561	0.000	3.577
Statistical Difference	-0.051	1.030	0.099	-0.012	0.000	0.000	0.000	-0.997	-0.058	0.000	0.000	-0.059	0.000	0.000	0.001	0.000	0.000	0.331	0.000	-2.621

* Industry sub-sectoral breakdown is based on the CIP 2004.

Last Updated :24 Sep 2008

Key

2007 Provisional

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