Modelling the Irish Energy-System

Data Required for the EnergyPLAN Tool

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1. Introduction

This document describes the assumptions, data and sources used to create a model of the Irish energy-system using the EnergyPLAN energy tool [1]. Firstly, the technical data is provided, followed by the cost data and finally, the regulation constraints are discussed. For clarity purposes, the headings used throughout this report follow a very similar structure to the tabs used within EnergyPLAN.

2. Technical Data Used

This document provides the details of the data gathered to create a model of the Irish energy-system using EnergyPLAN. In order to create the model of the Irish energy-system, a number of inputs were necessary including electricity demands, power-plant capacities, renewable-energy production, individual demands, industrial demand, transport demand and more. Below is a brief description about how this data was gathered. The year 2007 was chosen to build a reference model of Ireland as it was the most recent complete year at the time the model was developed.

2.1. Typical Inputs

EnergyPLAN is used to simulate an energy-system over a one-year time-period using one-hour time-steps. There are two primary types of data used by EnergyPLAN: The first input is the *Annual Energy* (demand or production), and the second input is the *Annual Hourly-Distribution*. The Annual Energy is inputted into the model to indicate what the total energy produced or required over the entire year being simulated was i.e. an electricity demand of 25 TWh. The Annual Hourly-Distribution is inputted into the model to identify how much of the Annual Energy was required for each specific hour over the year being simulated. The following conditions must be met for an Annual Hourly-Distribution:

a. There must be 8,784 data points in the distribution, one for each hour
b. The data points are usually between 0 and 1, representing 0-100% of production/demand[1]. However, if a distribution is entered with values greater than 1, the program will 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 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 1.
c. The distribution is inputted into EnergyPLAN as a text file

This type of data was gathered for numerous sectors of the Irish energy-system, how and where is discussed thoroughly in the following sections.

Table 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

2.2. Electricity Demand

To simulate the electricity demand, EnergyPLAN needs the total annual-electricity-demand and also the hourly distribution for this demand. The hourly electricity-demand for 2007 was obtained from the Irish transmission

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

system operator (TSO), EirGrid [2], and subsequently, the total annual-electricity-demand was derived from this data as 28.5 TWh.

2.3. Conventional Power-Plants

Combined Heat and Power (CHP) and District Heating (DH) are two key elements within EnergyPLAN. However, at present there is no district heating on the Irish energy-system. Therefore, to simulate the power plants in the Irish energy-system, only conventional power-plants needed to be considered. The inputs necessary were:

1. Cumulative power-plant capacity on the Irish electricity network
2. Cumulative power-plant efficiency on the Irish electricity network
3. Cumulative efficiency of the power-plants in each fuel-type
4. Energy generated from power-plants of different fuel-type

The capacity of power-plants was obtained from the Irish TSO, EirGrid [2], as 6,445 MW. The efficiency of the entire power-plant system was identified using the Irish Energy Balance [3]. The Energy Balance indicated that the total fuel input for power plants, F_{IN} (Wh), was 51.727 TWh and the total electricity generated, $Elec_{TOT}$ (Wh) from power plants was 23.43. Therefore, using the energy balance document the cumulative efficiency for power-plants, η_{COND}, was calculated as 45.3% using

$$\eta_{COND} = \frac{Elec_{TOT}}{F_{IN}} \tag{1}$$

As EnergyPLAN does not model individual plants, but instead models plants of similar fuel type as a single unit, the power-plant efficiencies were also obtained for each fuel-type. These efficiencies, which are displayed in Table 2, were found using the 2007 Irish Energy-Balance, the diagram displayed in Figure 1, and Equation 1. These efficiencies are necessary within the model if changes are made to the capacity of power plants on the system, as this will alter the overall efficiency of the system.

Table 2
Power-plant efficiencies calculated for power plants of different fuel-type

Fuel Type	From Energy Balance [3]	From Figure 1		
	Fuel Consumption (TWh)	Fuel Consumption (TWh)	Electricity Generated (TWh)	Efficiency (%)
Electricity Generation [3]	58.052	58.052*	28.736	49.50
Natural Gas [4]	29.092	28.722*	13.375*	46.57
Coal [4]	13.071	12.950	5.353	41.33
Peat [4]	5.010	5.050	2.107	41.72
Oil [4]	4.275	4.180	1.936	46.32
Biomass [4]	0.279	0.406	0.142	35.00

***This was used as the starting point, while all other values were obtained using the percentages in Figure 1.**
****The natural gas used for CHP is subtracted from these values. The CHP data was obtained from [3].**

The fuel consumption for the plants of different fuel type was also found from the Irish Energy-Balance as displayed in Table 2. These were considered more accurate than the values calculated from the percentages contained in Figure 1, although it is clear that both are very similar. Therefore, the efficiencies obtained from Figure 1 and the fuel consumptions obtained from the Irish Energy Balance were used in the final model. Finally, it should be stated that for this model peat and coal were modelled as a single fuel. This is a method that has been carried out in previous models of the Irish Energy-System [5] due to the similar power-plant efficiencies and CO_2 emissions of the two fuels.

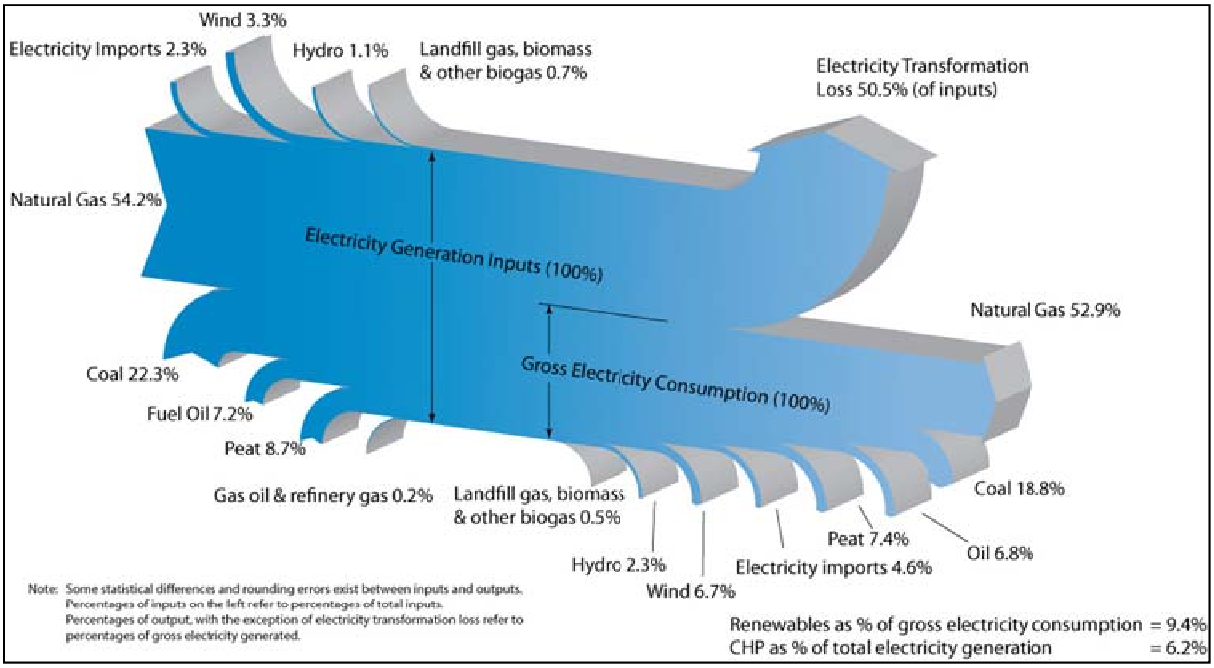

Figure 1: Breakdown of fuel consumption and electricity generated in Irish electricity system [4]

2.4. Renewable Energy

The renewable-energy parameters required for EnergyPLAN are:

1. The type of renewable energy in question
2. The installed capacity of the renewable resource
3. The distribution profile (hourly for one year)

The various forms of renewable energy that need to be considered for the Irish reference model are onshore wind, offshore wind, hydro power, and solar thermal. Solar thermal will be discussed later as it is part of the individual's energy requirements (see section 2.6), and does not contribute to a common grid like onshore wind, offshore wind, and hydro.

2.4.1. Onshore Wind

For onshore wind, the installed wind-capacity and the hourly wind-output for 2007 were obtained from the Irish TSO, EirGrid [2]. The installed wind capacity in Ireland was 723.8 MW at the beginning of 2007 and 785.2 MW at the end of 2007, while the total wind-energy produced in 2007 was 1.88 TWh. However, the amount of this 1.88 TWh that was offshore wind and the distribution for offshore wind could not be obtained.

2.4.2. Offshore Wind

There is currently only one offshore wind farm constructed in Ireland, which is located at Arklow Banks, off the coast of Co. Wicklow. This wind farm was constructed using a new wind turbine developed by GE Energy, and hence no information is being released in relation to the power generated from the turbines. The only information available is that the installed capacity of the wind turbines is 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 to simulate the offshore wind. 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 primary difference between onshore and offshore wind-distributions is the higher capacity-factor for offshore. This is accounted for by the correction factor in EnergyPLAN which is explained in detail within the EnergyPLAN user-manual [6]. For Ireland, the average capacity factor for an offshore wind farm is 40% [7], which corresponds to 88 GWh from a 25.2 MW wind farm. Therefore, the installed capacity was entered as 25.2 MW, the 2007 wind production was used for the hourly distribution, and the EnergyPLAN correction factor was adjusted until the annual energy generated from the wind farm was 88 GWh (final correction factor value was

0.36). This does not provide a very good illustration of the exact output from offshore wind in Ireland in 2007. However, this is not important as offshore wind is only 25.2 MW of a total installed wind capacity of 723.8 MW. This does provide a good illustration of the average expected output form an offshore wind farm. This is much more important in the model, as large-scale offshore wind capacities will be added to the model in the future.

2.4.3. Hydro

Next the hydro power within the Irish energy-system had to be simulated. Two types of hydro power can be simulated in EnergyPLAN: 'River Hydro', which is hydro power that needs to be used as water is supplied, and 'Hydro Power' that can store water in reservoirs and hence be used when most suitable. The River Hydro option was used in the reference model as it provided a more accurate simulation of the historical operation (see Appendix). However, in future studies, hydro in Ireland will be modelled as 'Hydro Power' in EnergyPLAN so that the model can optimise the dispatch of hydro in Ireland. The data required to create the 'River Hydro' simulation was:

1. The hydro power capacities which were obtained from the Irish TSO, EirGrid [2], are shown in Table 3
2. The total annual-electricity generated from Irish hydro-power in 2007, which was obtained from the Irish Energy-Balance, was 0.66 TWh [3]
3. The hourly distribution of the hydro power generated in 2007, which was created using the hourly power-output from the hydro stations for 2007, was obtained from the Irish TSO's[2] [2, 8].

Table 3
Power capacity and annual production for hydro stations in the Republic of Ireland in 2007

Facility	Power Capacity (MW)	Annual Power Generation (TWh)
Ardnacrusha	86	-.-
Erne	65	-.-
Lee	27	-.-
Liffey	38	-.-
Total	216	0.66

2.5. Storage

Pumped-Hydroelectric Energy Storage (PHES) is the only large-scale energy storage in use in Ireland at Turlough Hill [9]. To model PHES in EnergyPLAN, the following parameters are necessary:

1. Pump Efficiency
2. Turbine Efficiency
3. Pump Capacity
4. Turbine Capacity
5. Storage Capacity

From the 2007 Irish Energy-Balance [3], the round-trip efficiency of Turlough Hill, η_{TH}, was calculated using,

$$\eta_{TH} = \frac{E_{OUT}}{E_{IN}} \tag{2}$$

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 was 63.9%. However, no details could be obtained for the pump and turbine individually. Therefore, the pump efficiency was inputted as 79.9% and the turbine efficiency as 79.9%, resulting in a round-trip efficiency of 63.9% (0.799*0.799) which was the value calculated using Equation 2. The same efficiency was used for the pump and turbine as this is typically the situation within a pumped-hydroelectric energy storage facility [10].

[2] EirGrid provided the data for January to October of 2007, and SEMO provided the data for November and December of 2007

The Turlough Hill storage facility was contacted directly to obtain the pump/turbine power capacities as well as the storage capacity of the facility. The pump capacity is 272.8 MW, the turbine capacity is 292 MW, the head was 285.75 m and the volume of water that can be stored in the upper reservoir is 2.3 million m^3. Using these details the storage capacity (Wh) was calculated using

$$S = \frac{\rho g H V \eta}{3600} \tag{3}$$

where ρ is the density of water, 1000 kg/m^3, g is acceleration due to gravity, 9.81 m/s^2, H is the head, V is the volume of water, and η is the efficiency of the turbine (which is 79.9%). The resulting storage capacity was calculated at 1.431 GWh[3].

2.6. Individual (Domestic) Heating

Below is a description of the energy consumption defined for the residential and commercial sectors within Ireland. Only heat consumed by individuals needs to be accounted for here as the electricity and transport requirements are specified elsewhere. Therefore, the three inputs needed in the EnergyPLAN are:

1. The total annual consumption of each fuel for heating individual (i.e. domestic) homes (fuels are oil, natural gas, peat/coal and electricity)
2. The boiler efficiencies for each fuel
3. An hourly heat-distribution for the year 2007

The fuel consumed by the residential and commercial sectors for heating was obtained in the Irish Energy Balance [3] and are outlined in Table 4. For the boiler efficiencies, the Building Energy Rating documentation provided by the Irish energy agency, SEI [11] was consulted. 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 which is also displayed in Table 4.

Table 4
Energy consumed by individuals and boiler efficiencies [3, 11]

Fuel	Residential Consumption (TWh)	Commercial Consumption (TWh)	Total Individual Consumption (TWh)	Boiler Efficiency (%)
Oil	13.113	6.405	19.518	75
Natural Gas	6.896	3.913	10.809	84
Coal / Peat	5.575	0.303	5.878	60
Biomass	0.262	0.088	0.35	65

Electricity used for heating was not available from the Irish Energy-Balance. However, within a report completed by the Irish energy agency, SEI, it was found that 14% of all domestic electricity is used for space heating and 23% of domestic electricity for hot water [12]. In a separate report by SEI, it was found that 12% of commercial electricity was used for heating [13]. From the 2007 Irish Energy-Balance, the electricity consumed in the residential and commercial sectors were identified as 8.064 TWh and 8.711 TWh respectively. Therefore, using these figures it was concluded that 4.029 TWh (0.37*8.064 + 0.12*8.711) of electricity was used for individual heating in Ireland.

With the annual fuel-consumption obtained for individual heating, the hourly distribution of heat was investigated, which is the second parameter required by EnergyPLAN. In order to estimate the heat distribution, 'Degree Day' data was acquired from Met Eireann, the Irish meteorological service [14]. 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 required due to the climate, therefore, using the Heating Degree-Days indicate the amount of heat required could be estimated.

[3] The input for EnergyPLAN is 1,791 MWh as this is the value calculated when the turbine efficiency is 100%.

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 climate, house insulation etc [14]. A full explanation about the calculation and application of degree data can be obtained from [14, 15].

By obtaining the Heating Degree-Day data, the level of heat required each day within a building can be estimated. Consequently, an annual distribution of space-heating demand can be created with a resolution of 1 day (as Degree Day data is only recorded on a daily basis) as seen in Figure 2. However, hourly data is required for EnergyPLAN so this 1 day data was converted into hourly readings using a computer program written in MATLAB. However, this only considered the space-heating distribution and not the hot-water distribution. Therefore, the heat distribution accounting for both space heating and hot-water demand had to be constructed.

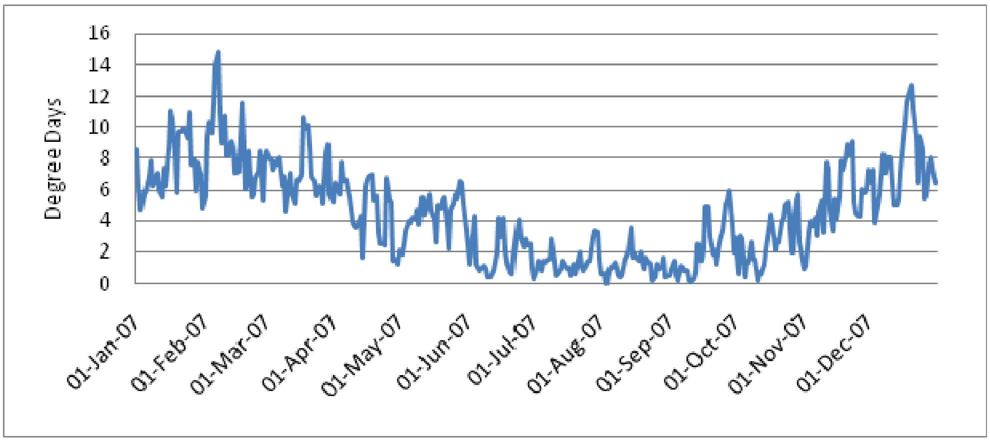

Figure 2: Degree Day data from Belmullet meteorological station in Mayo, Ireland

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 [16]. Therefore, as seen in Figure 3, 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 3 represents the heat distribution constructed for modelling the heat demand within the Irish energy-system.

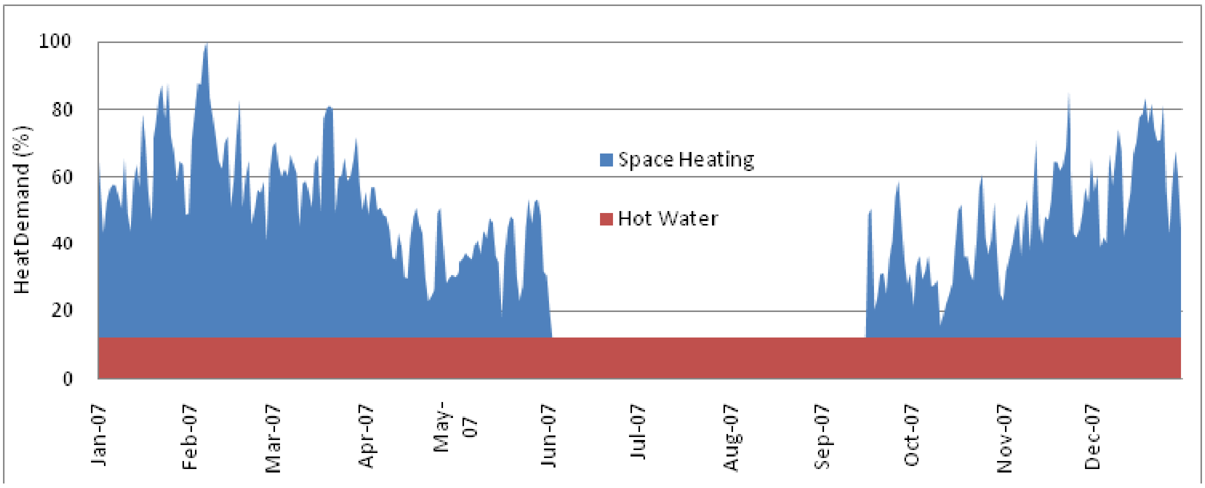

Figure 3: Individual heat-distribution for the year 2007 in Ireland (Daily)

Finally, the daily distribution created using the degree-day data had to be converted into hourly data for EnergyPLAN. To do this a daily cycle was applied to the distribution which is displayed in Figure 4. The daily cycle used was taken from a similar study completed on Denmark in [17]. It was assumed that Ireland would have a similar daily distribution for heat as Denmark.

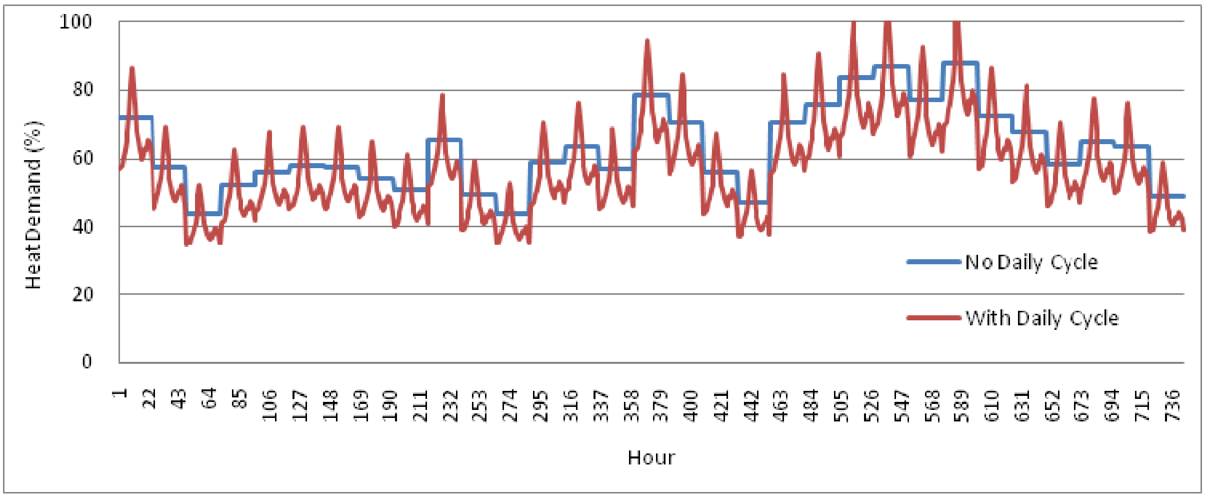

Figure 4: Individual heat-distribution for January 2007 in Ireland (Hourly)

2.7. Solar Thermal

There are two types of solar thermal in EnergyPLAN: 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 in this section under the individual's heating-demands. The inputs required for EnergyPLAN are:

1. The total solar-thermal-production for 2007
2. Hourly distribution of the solar-thermal production in 2007
3. Solar-thermal share

The total-solar-production in Ireland for 2007 was got from the 2007 Irish Energy-Balance [3] as 0.015 TWh. 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 a result, the solar thermal-output curve that was constructed for Denmark [17] was used, as the solar radiation in Denmark is very similar to the solar radiation

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

in Ireland as seen in Table 5. Therefore, it was considered reasonable to assume that the solar-thermal output would be very similar for both Denmark and Ireland. This solar-thermal distribution was created by a Danish energy consultancy, PlanEnergi [18] for the 2030 Danish Energy-Plan [19]. The distribution gives the production of an individual-solar-thermal installation of 4.4 m^2 during a typical Danish year. The production is calculated on the basis of a consumption of 150 litres per day, 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.

Table 5
Global solar-radiation in Denmark and Ireland

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

The final input required for EnergyPLAN was the solar share. This is the percentage of homes in Ireland that have a solar-thermal system installed. To estimate this in Ireland, the first parameter used was obtained from the Irish energy agency, SEI [20]: SEI stated that there was 33,600 m^2 of domestic-solar-thermal panels installed in Ireland by the end of 2007. SEI also stated that a typical solar-thermal installation for individuals in Ireland uses 5 m^2 of solar-thermal panels. Therefore it was calculated that there are approximately 6,720 homes in Ireland with a solar installation. From the 2006 census in Ireland, it was stated that there are 1,469,521 homes in Ireland [21]. Consequently, it was concluded that there is a solar-thermal system in 0.45% of Irish homes.

2.8. Industry

Industrial energy requirements are also considered separately in EnergyPLAN. The inputs required for this area are:

1. Consumption of each fuel: coal/peat, oil, natural gas and biomass
2. Electricity produced from industrial CHP
3. Heat produced from industrial CHP
4. Distribution of electricity/heat from industrial CHP

The quantity of each fuel consumed within industry was found in the 2007 Energy Balance [3] and is displayed in Table 6. For electricity production from industrial CHP, the statistics department within the Irish energy agency, SEI, provided a breakdown of existing CHP plants as well as the energy they produced. A total of 0.93 TWh was exported from CHP installations to the grid in Ireland in 2007. There is currently no heat provided by industrial CHP to a district-heating network so no data was gathered for this area.

Since the industrial CHP in Ireland was not controlled by the TSO, the distribution used for Industrial CHP was inputted as a constant. This means that the output from Industrial CHP was simply constant during the entire simulation. This is a good proxy for modelling a production that cannot be controlled.

Table 6
Fuel consumed within the industrial sector in Ireland for 2007 [3]

Fuel	Industrial Consumption (TWh)
Oil	14.831
Natural Gas	10.354
Biomass	1.954
Coal / Peat	1.715

2.9. Transport

To model the Irish transport-sector in EnergyPLAN, the only input required was the consumption of the various fuels in this sector: they are jet fuel, diesel, petrol and biomass. This data was also available from the 2007 Energy Balance [3].

Table 7
Fuel consumed within the transport sector in Ireland for 2007 [3]

Fuel	Industrial Consumption (TWh)
Diesel	31.341
Petrol	22.325
Jet Fuel	12.134
Biomass	0.249

2.10. Import/Export of Electricity
The model can simulate the import and export of electricity based on the optimal technical performance of the energy-system. However, for the reference system, a forced import/export has to be included to represent the actual performance of the energy-system in the reference year, in this case 2007. To do this, the following inputs are required:

1. The net transfer of electricity in/out of the energy-system (exports are positive and imports are negative)
2. The hourly distribution of the imported/exported electricity

The Republic of Ireland is only interconnected to Northern Ireland. Therefore, to simulate the imported/exported electricity in 2007, the hourly distribution of imported/exported electricity from/to Northern Ireland was obtained from the Irish TSO, EirGrid [2]. This data showed that 1.31 TWh more electricity was imported than exported in 2007, with a total of 1.39 TWh imported and 0.08 TWh exported [2, 8].

2.11. Interconnection Capacity
As stated previously, EnergyPLAN can import and export electricity based on the optimal technical performance of the energy-system. The only input required for a technical analysis is the interconnection capacity available. Currently, the interconnection capacity from the Republic of Ireland to Northern Ireland is 1440 MW as displayed in Figure 5. However, after analysing the hourly import/export of electricity from/to Northern Ireland to Republic of Ireland obtained from EirGrid, it was found that the import/export capacity never exceeded 220 MW in 2006 or 2007. As a result in the model, the interconnection capacity was inputted as 220 MW.

It is worth noting that a new interconnector is being built from Cavan in the Republic of Ireland to Tyrone in Northern Ireland [22] with a capacity of 1,500 MW. Once this is completed, it is believed that a much larger proportion of the current 1,440 MW interconnection will be utilised.

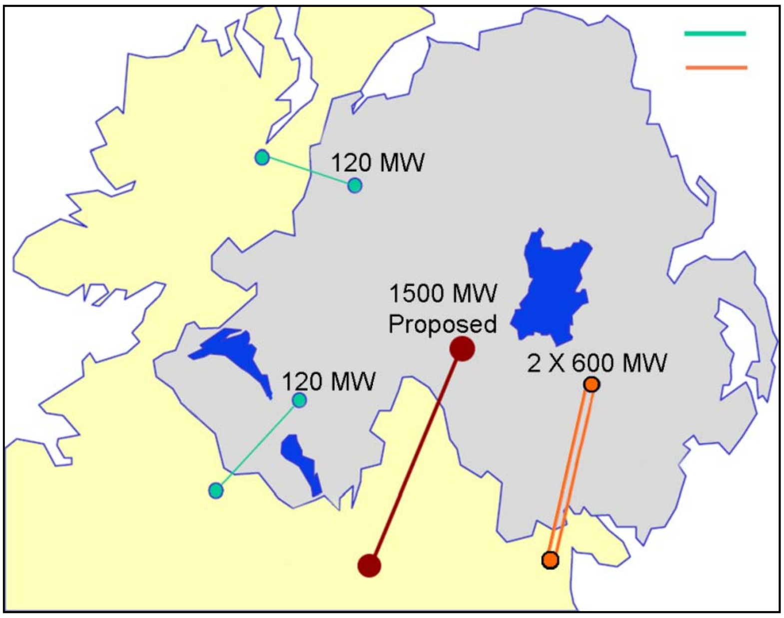

Figure 5: Current and proposed interconnection between Republic of Ireland and Northern Ireland

2.12. CO_2 Emission Factors

In EnergyPLAN 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 were modelled as a single fuel: this is a method which has been carried out in previous models of the Irish energy-system [5] 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, coke etc. Therefore, the CO_2 emission factors for coal and oil were calculated based on fuel consumptions from the Irish energy-balance [3], and CO_2 emission factors recommended by SEI [4] for the various fuel they represent. In conclusion, the CO_2 emission factor used for coal/peat was 100.63 kg/GJ (see Table 8), for oil was 73.19 kg/GJ (see Table 9) and for natural gas was 57.1 kg/GJ [4].

Table 8
CO_2 emission factor for coal/peat

Fuel	Consumption (TWh) [3]	Consumption (% of Total)	CO_2 Emission Factor (kg/GJ) [4]
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 9
CO_2 emission factor for oil

Fuel	Consumption (TWh) [3]	Consumption (% of Total)	CO_2 Emission Factor (kg/GJ) [4]
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. Cost Data Used

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

1. Fuel costs: purchasing, handling and taxes in relation to each fuel as well as CO_2 costs
2. Investment costs: capital required, the lifetime of each unit and the interest rate on repayments
3. Operation costs: the variable and fixed operation and maintenance costs for each production unit
4. Additional costs: any extra costs not accounted for in the program by default e.g. the cost of insulating houses for increased energy efficiency. This was not used to create the 2007 Irish energy-system but may be used for future scenarios.

These costs are used by EnergyPLAN to perform socio-economic and business-economic studies, as well as a market optimisation for the energy-system.

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 [23] and the Danish Energy Authority [24] and are displayed in Table 10.

Table 10
Fuel prices used for 2007, 2010/2015 and 2020 [23, 24]

(€/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 [24]: 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 [24] and are displayed in Table 11.

After consulting with the Irish revenue office, it was found that there are currently no taxes (other than value added tax [VAT]) placed on fuels in Ireland. In addition, there is also no carbon tax in Ireland. However, Ireland does participate in the European carbon trading scheme so these costs had to be accounted for. To identify this cost, historical trading prices were obtained from [25] and an average value of €20.63/tCO_2 ($30/t$CO_2$) was found for the year 2007.

Table 11
Fuel handling costs [24]

€/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 [26]
Airplanes	-.-	-.-	0.696	-.-	-.-	-.-

3.2. Investment and Operational Costs

The investment and operation costs for condensing power-plants were obtained from a report completed by the Danish Energy Authority, Ekraft System, and Eltra[5] [27], and are displayed in Table 12. Using these details the cost of condensing plant on the Irish energy-system was calculated as 0.733 M€/MW, with a fixed O&M cost of 14,081 €/MW/year and a variable O&M cost of 1.84 €/MWh.

Table 12
Investment, fixed O&M and variable O&M costs for Irish condensing power-plants [27]

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

[5] Ekraft System and Eltra have been combined to form a single Danish TSO called Energinet.dk

Gas turbine combined cycle (10 - 100 MW), 2004	0.700	10000	2.750	208 MW / Gas

The onshore wind and offshore wind costs were also obtained from the Danish Energy Authority [28]: 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[6]. The investment costs for the hydro power in Ireland were obtained from the British Hydropower Association [29]: 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 pumped-hydroelectric energy-storage in Ireland were found from Gonzalez *et al.* [30] as €0.473.6 M€/MW and €7.89 / GWh for the initial investment, 3,000 €/MW for the fixed O&M cost and 3 €/MWh for the variable O&M cost.

Finally, the investment and O&M costs were obtained for the individual heating systems used in the 2007 Irish energy-system as displayed in Table 13. This ensured that all costs within the heating and electricity sectors were accounted for in the reference model.

Table 13
Cost (excluding taxes) of individual heating-systems for 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**

4. Regulation

For every analysis competed, two primary regulations were placed on the energy-system to ensure it operated in a realistic manner. The first was that 30% of power produced on the electric grid must come from facilities that contribute to grid stabilisation, and the second was that the aggregated output of condensing power-plants could not operate below 500 MW.

5. Conclusions

This report provides details about the data and sources used to create a reference model of the 2007 Irish energy-system. A comparison between the model and actual figures from 2007 was made in [31, 32], while a cost sensitivity analyses, and the 'optimum' technical and economical wind-penetrations were identified for the Irish energy-system using the model in [32]. In addition, the model will be used as a starting point for developing alternative energy-systems for Ireland in the future.

6. Appendix: Simulating Hydro Power

Two types of hydro power can be simulated in EnergyPLAN: 'River Hydro', which is hydro power that needs to be used as water is supplied, and 'Hydro Power' which is hydro that can store water in reservoirs and hence be used when most suitable. Both techniques were investigated to simulate the hydro power in the Irish energy-

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

system, as it was not clear if power is generated at the hydro stations as water is supplied (river hydro) or if water is stored in the reservoirs available (hydro power).

6.1. River Hydro

Two pieces of data are required to simulate Irish hydro-power as River Hydro in EnergyPLAN. Firstly, the total annual electricity generated from Irish hydro-power in 2007 was obtained from the Irish Energy-Balance as 0.66 TWh [3]. Secondly, for the hourly distribution input, the hourly production from the hydro plants in 2007 was obtained from the Republic of Ireland TSO, EirGrid for January to October [2], and from the All-Island TSO, SEMO for November and December of 2007 [8].

6.2. Hydro Power

The data required to simulate the Irish hydro-power as Hydro Power in EnergyPLAN included the hydro power-capacity available, hydro storage-capacity, efficiencies, and the water inflow to the hydro stations. Hydro data was difficult to obtain as it is a very small contributor within the Irish energy-system, as outlined in Figure 1. The most productive approach was to contact the individual hydro plants directly, and request the data required from the operator in the control room. Using this method the hydro data in Table 14 was collected. The storage capacities, S, which were calculated in Wh using Equation 3 are displayed in Table 14. Note that the hydro plant efficiency used to calculate the storage capacities was 90% as this is the typical efficiency of a hydro plant [33].

Finally, the amount of water available to the hydro stations to generate power had to be inputted in TWh/year. This data could not be obtained as the hydro plants in Ireland do not measure the water that is not used (i.e. the water that must pass down the hydro-plant spillway). Therefore, with all other inputs completed, this figure was adjusted to 0.86 TWh: at this point the annual power generated from hydro plants in the model matched the actual 2007 power generated (which was obtained from the Irish Energy Balance as 0.66 TWh [3]).

Table 14
Hydro parameters obtained for EnergyPLAN

Facility	Head (m)	Power Capacity (MW)	Storage Capacity* (x 10^6 m^3)	Storage Capacity (GWh)$^+$
Ardnacrusha	28.5	86	55.0	3.844
Erne	40.0	65	194.0	14.273
Liffey	46.9	38	99.8$^\#$	11.479
Lee	45.0	27	45.4	4.966
Total	-.-	216	-.-	34.558

***Calculated values**
$^+$This is the maximum quantity of water that can be utilised by the hydro plant
$^\#$Only includes Pollaphuca plant (1 of 3 hydro stations on the Liffey) as it accounts for 98.5% of the storage in Liffey hydro schemes

6.3. Comparison

To decide which method was most suitable, the hourly output created by both simulations was compared to the actual hourly hydro-power generated in 2007. A sample of this comparison is displayed in Figure 6. It was concluded from this comparison that the 'River Hydro' simulation provided a more accurate representation of the actual 2007 hydro-output in Ireland. However, the 'Hydro Power' simulation indicated the most advantageous method of operating the Irish hydro power from a technical point of view. Even though it was profitable to operate hydro at certain times, it may not be the most beneficial from a grid perspective. Consequently, when completing the reference model, 'River Hydro' was used. However, when alternatives are carried out in the future to optimise the technical performance of the Irish energy-system, the 'Hydro Power' simulation method will be used.

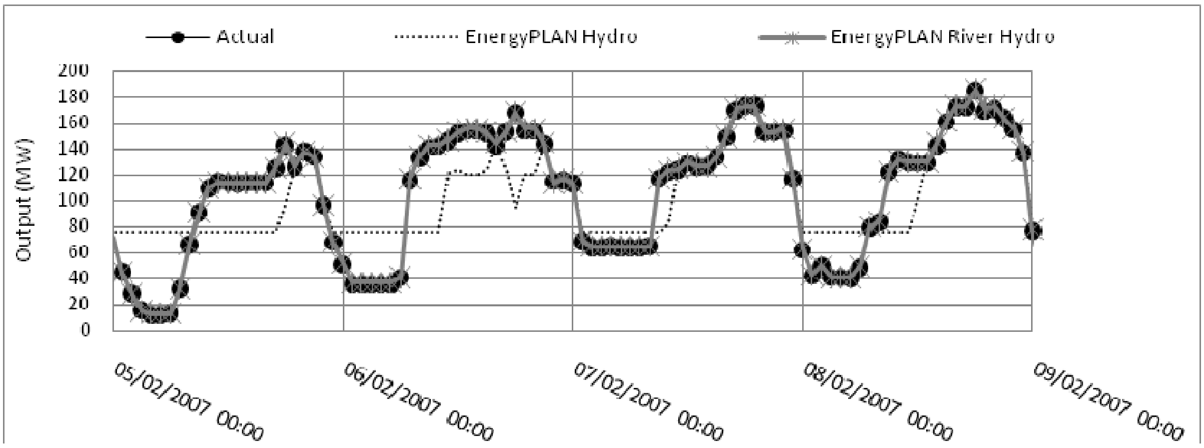

Figure 6: Hourly hydro-power generated in Ireland using River Hydro and Hydro Power simulations in EnergyPLAN, compared to the actual hydro power generated in Ireland

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