A Users Guide to EnergyPLAN

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I would like to thank Prof. Henrik Lund and Assistant Prof. Brain Vad Mathiesen for all their help during my time at Aalborg University. Without their guidance, this document could not be written so soon.

Contents

Section	Title	Page
1	Introduction	4
2	Why EnergyPLAN?	5
3	Collecting the Required Data	7
3.1	Section 1: Data for a Reference-Model with a Technical Optimisation	9
3.1.1	Input Tab	9
3.1.1.1	Electricity Demand	10
3.1.1.2	District Heating	10
3.1.1.3	Renewable Energy	11
3.1.1.4	Storage	13
3.1.1.5	Cooling	14
3.1.1.6	Individual	14
3.1.1.7	Industry	17
3.1.1.8	Transport	18
3.1.1.9	Waste	18
3.2	Section 2: Data for Future-Alternatives with a Technical Optimisation	19
3.2.1	Photovoltaic	19
3.2.2	Tidal	19
3.2.3	Wave Power	20
3.2.4	Future Additions	22
3.3	Section 3: Data for Costs	23
3.3.1	Fuel Tab	23
3.3.1.1	Fuel Price	23
3.3.1.2	Fuel Handling Costs	23
3.3.1.3	Taxes	23
3.3.1.4	CO_2 Content	23
3.3.1.5	CO_2 Price	24
3.3.2	Operation Tab	24
3.3.3	Investment Tab	24
3.3.4	Additional Tab	24

4 Areas of Difficulty 25
4.1 Thermal Energy System 25
4.2 District Heating Groups 26
4.3 Technical Optimisation vs. Market Optimisation 26
4.3.1 Business-economic vs. Socio-economic calculations 26
5 Verifying Reference Model Data 28
6 Common Error Screens 29
6.1 Wrong Number of Data Points 29
6.2 Distribution File Location 30
7 Conclusions 31
8 References 32
9 Appendix A: Ireland's Energy-Balance 2007 34

1 Introduction

This is a brief description of my experience when I learned how to use the energy-system-analysis model *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 or 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, suggestions for new content etc. If you have any further questions or contributions regarding any of the material in this document, please don't hesitate to contact me at david.connolly@ul.ie.

2 Why EnergyPLAN?

Before choosing the energy-systems-analysis model I would use, I had to decide what exactly I wanted to do. After some deliberation, I decided that the model for my investigation must be able

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

This statement, although broad at first, did limit my selection of energy-system-analysis models quite substantially. After a brief review of the energy-system-analysis models available, I narrowed my selection down to six:

1. EnergyPLAN (http://energy.plan.aau.dk/)
2. ENPEP (http://www.dis.anl.gov/projects/Enpepwin.html)
3. HOMER (https://analysis.nrel.gov/homer/)
4. LEAP (http://www.energycommunity.org/)
5. WILMAR (http://www.wilmar.risoe.dk/)
6. TIMES / MARKAL (http://www.etsap.org/)

It is worth mentioning at this point that although I narrowed my selection to these six energy-system-analysis models, there are a lot of others that I may have missed. Prof. Henrik Lund, Assistant Prof. Brian Vad Mathiesen, and I, are currently completing a review paper on the energy-system-analysis models in use today. This paper will provide a much superior overview of the current energy-system-analysis models you can choose from, and a reference will be added here once it is completed.

However, in relation to EnergyPLAN, there were a number of reasons that I chose it for my study:

1. It was simple to use and hence the training period would be short. Also in relation to this point, there is online training available from the EnergyPLAN website so it is easy to experience a typical application of the software [1].
2. The EnergyPLAN software is free to download from its website [1].
3. EnergyPLAN considers the three primary sectors of any national energy system: electricity, heat and transport.
4. EnergyPLAN was used to simulate a 100% renewable energy system for Denmark [2].
5. Prof. Henrik Lund is actively publishing his results using EnergyPLAN within academic journals. A number of energy-model 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 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 [3]
    b. The effectiveness of storage and relocation options in renewable energy systems [4]
    c. Large-scale integration of optimal combinations of PV, wind and wave power into electricity supply [5]
    d. Large-scale integration of wind power into different energy systems [6]

After reading these journal papers and observing the contribution that the results made to the Danish energy system, I felt that I could supply a similar insight into the Irish energy system using EnergyPLAN.

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. I was invited to Aalborg University to learn about EnergyPLAN and complete my first model. My progress has been accelerated beyond expectation due to the support and guidance from both Prof. Henrik Lund and Associate Prof. Brian Vad Mathiesen during my time at Aalborg University. This is an essential aid when embarking on research, especially when deadlines need to be met also.

3 Collecting the Required Data

As mentioned above, once I decided that EnergyPLAN was the most suitable energy-systems-analysis model for my particular study, I moved to Aalborg University for a short period to learn how to use the software correctly. During my time there, I completed a reference model of the existing Irish energy-system. However, I felt that a lot of my questions could have been answered if I simply knew where to begin looking for the answers. Therefore, I decided to complete this document which simply discusses where I found the information I needed to complete my reference model of the 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 **three** primary sections:

1. Data for a Reference-Model with a Technical Optimisation
2. Data for Future-Alternatives with a Technical Optimisation
3. Data for Costs

The order is used as this is the modelling sequence that is recommended when investigating an energy system. Firstly, a reference model must be created to ensure that the model is simulating the energy system correctly, before introducing alternatives. Subsequently, alternatives should be investigated from a technical point of view without including the costs. This ensures that alternative energy-systems can be analysed without the restrictions imposed by existing economic-infrastructures. Finally, the costs are added so the restrictions imposed by economics as well as the actual costs of transforming the energy system can be identified.

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 primary parameters:

1. The total annual production/demand
2. The hourly distribution of the total annual production/demand
    a. There must be 8784 data points, one for each hour
    b. The data points must be between 0 and 1, representing 0-100% of production/demand as shown in Figure 3-1.
    c. The distribution is inputted as a text file

The distribution is simply adjusted to reflect the total annual production/demand. For example, in Figure 3-2, the distributions for three separate demands are shown. In Figure 3-2 the three distributions show how the distribution in Figure 3-1 is manipulated to model the total demand.

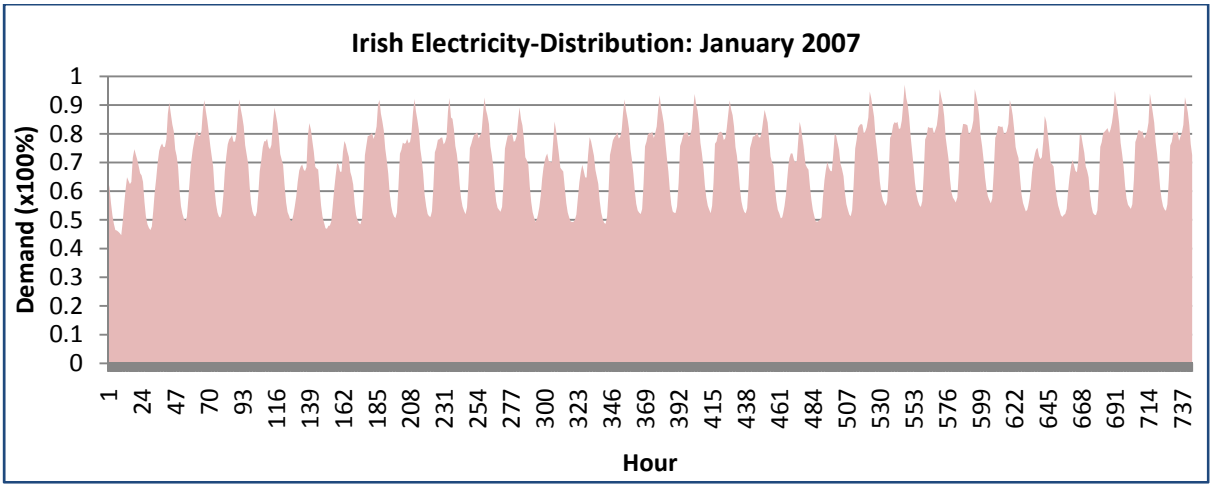

Figure 3-1: Distribution of Irish Electricity-Demand for January 2007

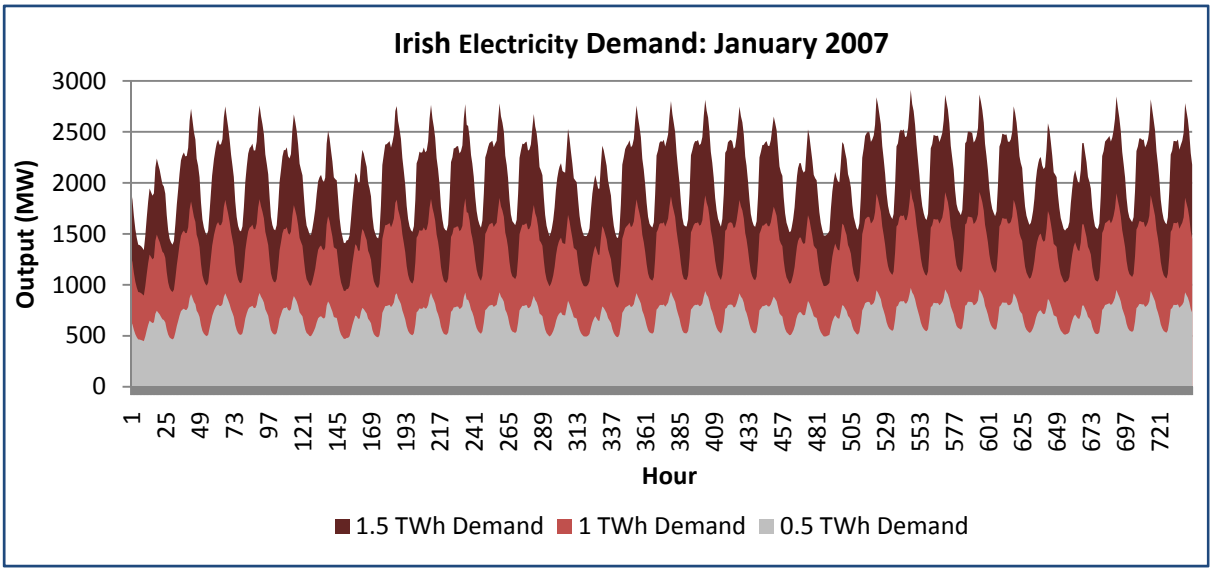

Figure 3-2: Distribution modified by the total demand required

3.1 Section 1: Data for a Reference-Model with a Technical Optimisation

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.

To explain where I got my data, I will discuss each tab within the EnergyPLAN model separately. The 'Frontpage' tab 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 data-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.

3.1.1 Input Tab

For my study, like most, the input tab proved to be a difficult section to complete. As a result, below is a brief description of where I sourced my data for each of the inputs I used in my model[1].

The first piece of information that you should try to source is the 'Energy Balance' for your country. The Irish Energy Balance was completed by Sustainable Energy Ireland [7], the Irish energy agency and they informed me that all OECD countries should have completed a similar document. The Energy Balance indicates the energy consumed within each sector of the energy system, see Figure 3-3 and Appendix A. The International Energy Agency (IEA) completed two reports on energy balances in 2008: one with the Energy Balances for each of the OECD countries [8] and one with the Energy Balances for a number of non-OECD countries [9]. 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.

[1] It is worth noting that the data required for EnergyPLAN is usually generic data that can be obtained in most OECD 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.

Ireland's Provisional Energy Balance 2007 (TWh)

2007 Units :: TWh	Coal	Bituminous Coal	Anthracite + Manufactured Briquettes	Coke	Lignite	Peat	Milled Peat	Sod Peat	Briquettes	Oil	Gas	Refinery Gas	Gasoline	Kerosene	Kerosene	Gasoil	LPG	Gasoil / Diesel Oil	Residual Fuel Oil	Petroleum Coke	Naphtha	Bitumen	White Spirit	Lubricants	Renewable Gas	Renewable	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	6.476	4.711	2.156	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	4.504	4.504	2.311	0.007	0.130	1.166	0.078	0.111	0.176	0.015	0.012	0.000	0.000	30.320
Imports	16.217	16.477	0.264	0.000	0.000	0.000	0.000	0.000	0.000	122.814	48.173	0.000	14.017	0.820	13.816	6.963	1.327	33.161	3.872	0.000	2.766	1.293	0.117	46.421	0.246	0.000	0.000	0.000	0.146	0.000	0.000	0.000	0.140	0.000	0.000	1.413	0.000	185.669
Exports	0.026	0.000	0.026	0.000	0.000	0.693	0.000	0.000	0.000	0.262	16.105	0.000	0.000	0.231	0.302	0.000	13.181	0.176	0.171	0.000	0.132	0.000	0.231	0.070	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	16.315
Net 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	0.709	0.000	0.155	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	1.324
Stock Change	1.020	0.999	0.041	0.000	0.016	1.274	1.313	-0.083	-0.117	2.390	-0.211	0.000	0.044	-0.218	0.268	1.219	0.251	0.480	0.053	0.036	0.000	0.000	0.000	-0.013	-0.178	0.000	0.000	-0.001	0.000	0.000	-0.077	0.000	0.000	0.000	0.000	0.000	0.000	4.853
Primary Energy Supply (Indigenous)	17.243	17.476	0.238	0.000	0.016	6.158	3.398	2.239	-0.145	120.937	31.857	0.000	13.973	0.371	13.546	6.254	1.401	33.486	3.819	0.036	2.634	1.293	0.114	46.348	4.572	4.504	2.311	0.006	0.276	1.166	0.077	0.111	0.316	0.015	0.012	1.413	0.000	197.358
Primary Energy Requirement (excl. non-energ	17.243	17.476	0.238	0.000	0.016	6.158	3.398	2.239	-0.145	120.230	40.262	0.000	13.973	0.371	13.546	5.545	1.401	31.916	2.925	-0.117	0.000	0.000	0.000	40.023	4.572	4.504	2.311	0.006	0.276	1.166	0.077	0.111	0.316	0.015	0.012	1.413	0.000	197.358
Transformation Input	17.243	17.476	0.238	0.000	0.016	6.158	3.398	2.239	-0.145	120.230	40.262	0.000	13.973	0.371	13.546	5.545	1.401	31.916	2.925	-0.117	0.000	0.000	0.000	40.023	4.572	4.504	2.311	0.006	0.276	1.166	0.077	0.111	0.316	0.015	0.012	1.413	0.000	197.358
Public Thermal Power Plants	17.011	17.011	0.000	0.000	0.000	1.490	0.000	0.000	0.000	4.325	0.000	0.000	0.000	0.000	0.000	4.325	0.000	0.000	0.000	0.000	0.000	0.000	0.000	39.000	1.270	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	61.797
Combined Heat and Power Plants	0.000	0.003	0.030	0.000	0.000	0.482	0.042	0.000	0.000	0.496	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	2.798	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.821
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	0.000	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	0.146	0.000	0.146
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	1.092	1.092	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	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.092
Oil Refineries & other energy sector	0.000	0.003	0.030	0.000	0.000	0.000	0.000	0.000	0.000	40.242	40.262	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	0.000	0.000	0.000	0.000	0.182	0.000	40.446
Transformation Output	0.000	0.000	0.000	0.000	0.000	1.582	0.000	0.000	1.108	39.049	0.000	1.065	1.119	2.450	0.000	14.222	0.408	14.490	0.000	0.117	0.000	0.000	0.000	0.000	0.122	0.000	0.000	0.013	0.143	0.013	0.000	0.000	0.000	0.000	0.000	55.206	0.000	82.756
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	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	0.000	0.000	33.139	0.000	33.242
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	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.013	0.000	0.013	0.000	0.000	0.000	0.000	0.000	1.836	0.000	1.865
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	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	0.000	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	0.146	0.000	0.146
Briquetting Plants	0.000	0.000	0.000	0.000	0.000	1.100	0.000	0.000	1.108	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	0.000	0.000	0.000	0.000	0.000	0.000	1.100	0.000	1.100
Oil Refineries	0.000	0.003	0.030	0.000	0.000	0.000	0.000	0.000	0.000	39.049	0.000	1.065	1.119	2.450	0.000	14.222	0.408	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	0.000	0.000	39.049
Exchange and transfers	0.194	-0.124	0.317	0.000	0.000	0.000	0.000	0.000	0.000	-0.006	0.000	0.000	-0.001	2.213	-2.211	0.305	0.000	-0.116	-0.194	0.000	0.000	0.000	0.000	0.000	-0.758	-0.758	-1.264	-0.013	-0.143	-0.013	-0.000	0.000	0.000	0.000	0.000	2.163	0.000	0.199
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	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.758	-0.758	-1.264	-0.013	-0.143	-0.013	-0.000	0.000	0.000	0.000	0.000	2.163	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	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	0.194	-0.124	0.317	0.000	0.000	0.000	0.000	0.000	0.000	-0.006	0.000	0.000	-0.001	2.213	-2.211	0.305	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	0.000	0.000	0.199
Own Use and Distribution Losses	0.000	0.000	0.000	0.000	0.000	0.176	0.176	0.000	0.000	1.241	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	0.000	0.000	0.000	0.000	0.000	2.545	0.000	3.962
Available Final Energy Consumption	17.243	17.351	0.556	0.000	0.016	4.841	2.197	-0.261	0.963	101.403	0.000	0.000	12.644	0.158	11.335	4.461	1.002	16.317	2.375	0.000	2.766	1.293	0.047	17.423	2.417	0.000	1.047	0.000	2.007	0.000	0.000	0.000	0.316	0.015	0.012	26.196	0.000	162.498
Non-Energy Consumption	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.374	0.000	0.000	0.000	1.741	0.182	0.000	0.000	1.561	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	3.484
Final non-Energy Consumption (feedstocks)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.374	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	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.374
Total Final Energy Consumption	17.243	17.351	0.556	0.000	0.016	4.841	2.197	-0.261	0.963	103.776	0.000	0.000	12.644	1.899	11.517	4.461	1.002	16.317	2.375	0.000	2.766	1.293	0.047	17.423	2.417	0.000	1.047	0.000	2.007	0.000	0.000	0.000	0.316	0.015	0.012	26.196	0.000	165.874
Industry*	1.230	1.230	0.000	0.000	0.000	0.003	0.000	0.000	0.000	11.739	0.000	0.000	0.000	1.435	0.000	4.180	0.013	2.014	2.350	0.013	0.000	0.000	0.000	7.416	1.763	0.000	0.000	0.000	1.723	0.000	0.000	0.000	0.000	0.000	0.000	1.471	0.000	21.386
Non-Energy Mining	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.492	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.001	0.016	0.000	0.000	0.000	0.000	0.428	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	1.052
Food, beverages and tobacco	0.160	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.467	0.000	0.000	0.000	0.188	0.000	0.741	0.001	0.488	0.000	0.000	0.000	0.000	0.000	3.028	0.004	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	1.187	0.000	6.316
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	0.000	0.035	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	0.000	0.000	0.000	0.000	0.208
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	0.000	0.068	0.000	0.000	0.000	0.000	0.000	0.246	1.084	0.000	0.000	0.000	1.084	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.000	1.326
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	0.000	0.000	0.033	0.000	0.012	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	0.000	0.000	0.000	0.000	0.723
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	0.254	0.000	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	0.000	0.000	1.180	0.000	3.182
Rubber and plastic products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.470	0.000	0.000	0.000	0.062	0.000	0.008	0.000	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	0.000	0.000	0.175	0.000	0.616
Other non-metallic mineral products	1.391	1.391	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.113	0.000	0.000	0.000	0.022	0.000	0.125	0.007	0.149	0.380	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.574
Basic metals and fabricated metal products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.762	0.000	0.000	0.000	1.027	0.000	2.439	0.008	0.878	0.000	0.000	0.000	0.000	0.000	2.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.690	0.000	6.490
Machinery and equipment n.e.c.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.406	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.330	0.000	0.452
Electrical and optical equipment	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.325	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.198	0.000	2.695
Transport equipment manufacture	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.401	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.012	0.000	0.000	0.000	0.000	0.000	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.000	0.625
Other manufacturing	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.211	0.000	0.000	0.000	0.033	0.000	0.005	0.011	0.074	0.000	0.013	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.640
Transport	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	42.512	0.000	0.000	12.644	0.158	11.335	0.140	0.000	0.012	21.261	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	64.112
Road Freight	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.796	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.768	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	11.768
Road Private Car	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	21.141	0.000	0.000	10.945	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	10.391
Public Passenger Services	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.988	0.000	0.000	0.139	0.000	0.000	0.000	0.000	1.262	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	2.888
Rail	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	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
Domestic Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.019	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	0.000	0.000	0.000	0.000	0.125
International Aviation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.217	0.000	0.000	0.000	0.000	0.000	11.217	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	0.000	11.217
Fuel Tourism	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.364	0.000	0.000	2.131	0.000	0.000	0.000	0.000	0.233	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	4.364	0.000	2.364
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	0.000	0.000	0.000	0.000	0.000	3.848	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	0.921	0.000	4.769
Residential	3.430	3.612	0.000	0.000	0.000	2.102	0.000	0.000	0.767	0.066	12.117	0.000	0.000	0.000	0.182	0.000	0.000	0.000	2.474	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	20.870
Commercial/Public Services	0.203	0.203	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	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	0.203
Commercial Services	0.203	0.203	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	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	0.203
Public Services	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	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
Agricultural	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	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
Statistical Differences	0.210	0.212	-0.001	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	-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

* Industry sub-sectoral breakdown is based on the CIP 2004.
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2007 Provisional

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Page 1 of 1

Figure 3-3: Irish Energy Balance for 2007

The Energy Balance document proved to 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.

3.1.1.1 Electricity Demand

Total electricity demand was obtained from the Irish Transmission System Operator (TSO), EirGrid [7], and the Energy Balance document

3.1.1.2 District Heating

For my initial energy model I did not have to include any district heating or CHP as there are currently no large-scale installations in Ireland. However, for the condensing plant data, I got a list of the power plants currently in operation in Ireland from the TSO [7]. 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, $Elec_{TOT}$ (Wh),

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

It was difficult to obtain the efficiencies fuel types 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 3-4, once again from the Irish energy agency SEI, and used this to calculate the efficiencies for the different fuel-type condensing plant (using formula 1).

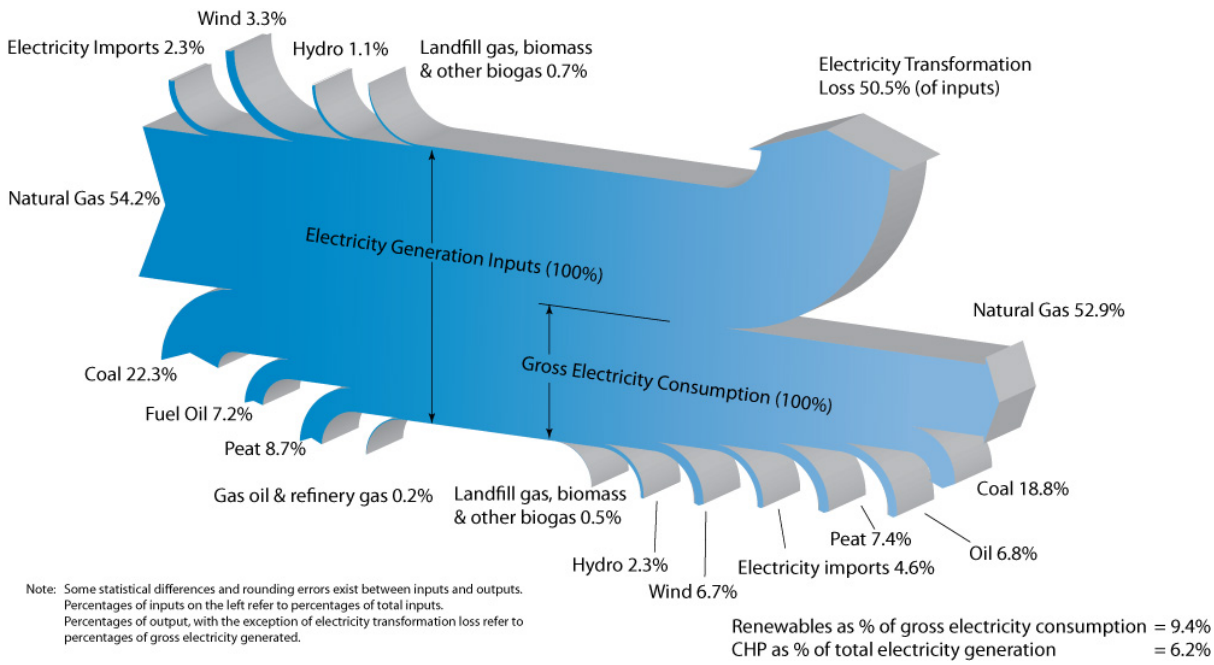


Figure 3-4: Breakdown of fuel consumption and electricity generated in Irish electricity system [10]

There is a second entry available for the Condensing section called PP2. This is used for the economic analysis if there is highly contrasting plant on the system such as one plant with a high efficiency but it is expensive, and another plant which has a low efficiency but it is cheap. These may need to be analysed separately by the model.

3.1.1.3 Renewable Energy

Before explaining how I obtained the data, I would like to recall what parameters are required. 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. Correction factor

Parameters 1-3 are reasonably intuitive. Therefore, I will only recap on the 'stabilisation share' and the 'correction factor' here. So, just to repeat from the EnergyPLAN user manual [11], 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 [11], 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. This wind farm is using a new wind turbine developed by GE Energy, 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: 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.

Firstly, I found out the average-annual wind-speed for Arklow Banks (8.75 m/s). Then I got an annual offshore wind distribution from a data buoy located close to Arklow Banks (data buoy M2 from [12]). This data had an average-annual wind-speed of 7.82 m/s. Therefore, I scaled-up this distribution curve until the average-annual wind-speed was 8.75 m/s (the same as the average-annual wind-speed at Arklow Banks). Finally, I got the power curve for a Vestas V90 wind turbine as seen in Figure 3-5, and calculated the expected output for a single year from the wind farm at Arklow Banks. I did not want to use the power curve for the GE Energy wind turbines 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.

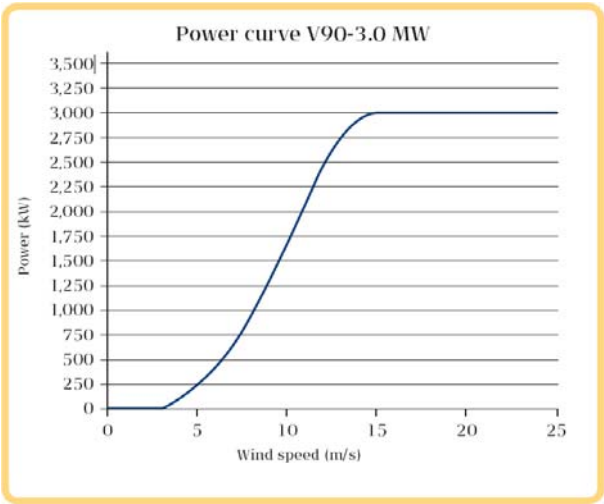


Figure 3-5: Vestas V90 Power Curve [13]

Photovoltaic

There is currently no PV power installed in Ireland so no data was required for the reference model.

River Hydro

River hydro refers to hydroelectric dams with no storage facility i.e. they must operate as water passes through them. There is no river hydro in Ireland, however, if required the TSO would record hourly outputs from it, and could provide you with this data. Note that it took four months to obtain similar data from the Irish TSO, so long waiting-periods may need to be considered.

Tidal

There is currently no tidal power installed in Ireland so no data was required for the reference model.

Wave Power

There is currently no wave power installed in Ireland so no data was required for the reference model.

Hydro Power

I found that hydro data was quite difficult to gather i.e. power capacity and storage capacity. As indicated in Figure 3-4, 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 dams in Ireland. 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 [14] /SEMO [15].

Geothermal / Nuclear

There is currently no geothermal or nuclear power-stations installed in Ireland so no data was required.

3.1.1.4 Storage

Initially, my primary objective was to analyse the effects of additional energy storage on the Irish energy-system. Therefore, the inclusion of energy storage technologies in EnergyPLAN was crucial at the outset. However, to date, only Pumped-Hydroelectric Energy Storage (PHES) is in use in Ireland

so I did not have to gather any data on Electrolysers of 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 (power generated from PHES facilities divided by power used by PHES facilities). I then inserted the pump and turbine efficiencies so that the round-trip-efficiency was the same as that calculated from the Energy Balance. For example, from the Energy Balance, PHES facilities in Ireland had an efficiency of 63.9%. Therefore, I gave the pump an efficiency of 75% and the turbine an efficiency of 85.2%, therefore the round-trip-efficiency was 0.75*0.852 = 0.639.

3.1.1.5 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.

3.1.1.6 Individual

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 Eireann, the Irish meteorological service [16].

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.

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 [16]. A full explanation about the calculation and application of degree data can be obtained from [16, 17].

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 3-6. For the EnergyPLAN model, hourly data is required so this 1 day data was converted into hourly readings using a computer program written in MATLAB: if you follow the same approach you can contact me to use the model at david.connolly@ul.ie. 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.

Remember though, for EnergyPLAN hourly data is required so this 1 day data must be converted into hourly readings.

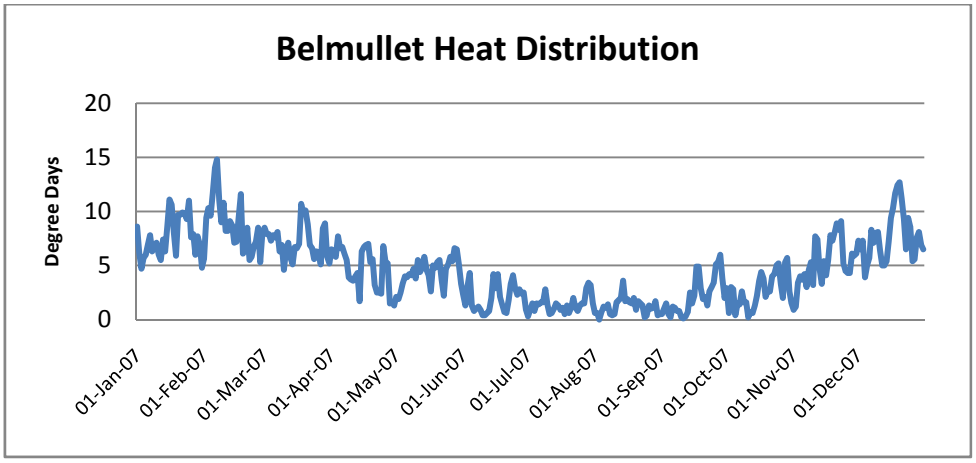


Figure 3-6: Degree Day data from Belmullet meteorological station in Mayo, Ireland

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 [18]. Therefore, as seen in Figure 3-7, 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 3-7**Error! Reference source not found.** represents the heat distribution constructed for modelling the heat demand within the Irish Energy System.

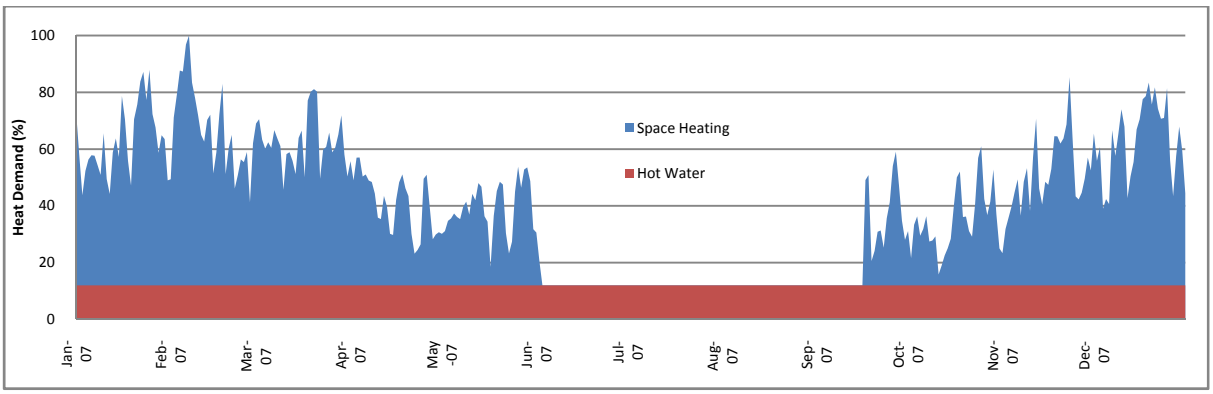


Figure 3-7: Individual heat distribution for Ireland

Finally, the daily distribution created using the degree-day data had to be converted into hourly data for the EnergyPLAN model. To do this a daily cycle was applied to the distribution which is displayed in Figure 3-8. The daily cycle used was taken from a similar study completed on Denmark in [3]. It was assumed that Ireland would have a similar daily distribution for heat as Denmark.

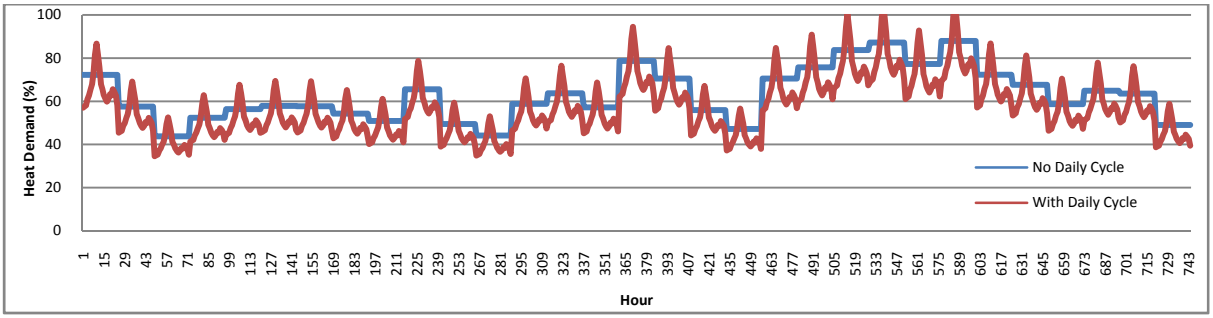


Figure 3-8: Individual heat-distribution for January 2007 in Ireland (Hourly)

Heat Fuel Consumption and Efficiency

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, SEI [19]. 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 documentation is possibly available in other countries also, or if not, the efficiencies within this documentation could be applied to other applications.

Electric Heating

Electric heating demand can also be difficult to quantify as it is usually discussed in conjunction with the heating demand not as a separate entity. From 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% for hot water [20]. In a separate report by SEI, it was found that 12% of commercial electricity was used for heating purposes [21]. Therefore, I used these figures to calculate the electric heating demand in Ireland.

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 in this section under the individual's heating-demands. The inputs required for the EnergyPLAN model are the:

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 Energy Balance [22]. For the distribution, an attempt was made to obtain the hourly power-output from a solar panel for an existing installation[2] in Ireland, but this could not be obtained. As a result, the solar-thermal-output curve that was constructed for Denmark [3] was used, as the solar radiation in Denmark is very similar to the solar radiation in Ireland, as displayed in Figure 3-9. To analyse this further, global-solar-radiation data was compared between Denmark and Ireland as seen in Figure 3-9, which clearly verifies the similarity. Therefore, it was considered reasonable to assume that the solar-thermal output would be very similar for both Denmark and Ireland.

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

This solar-thermal distribution was created by a Danish energy consultancy, PlanEnergi [23] for the 2030 Danish Energy-Plan [2]. 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 3-1: Global solar-radiation in Denmark and Ireland

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

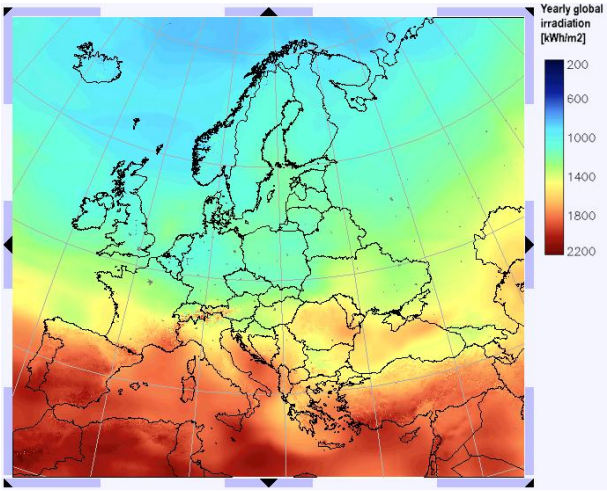


Figure 3-9: Solar radiation

Solar Share

The solar share is the percentage of houses that have a solar panel installed: This is currently being sourced for Ireland.

Solar Input

As stated above, I found the total solar energy utilised from the Irish Energy-Balance [22]. The solar input and solar share can be adjusted until the solar production matches the value stated in the Energy Balance.

3.1.1.7 Industry

Fuel Consumption

The quantity of each fuel-type consumed within industry can be found in the Energy Balance [22]. 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.

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, SEI, 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.

Industrial CHP: Distribution

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

3.1.1.8 Transport

The amount of fuel used for transport is also available from the Energy Balance [22].

3.1.1.9 Waste

There is currently no waste used for energy production in Ireland so no data was required for the Irish reference-model.

3.2 Section 2: Data for Future-Alternatives with a Technical Optimisation

Once the reference model is completed, a number of new technologies can be introduced. Below is a description of the inputs used in the first alternatives analysed for the Irish energy-system.

3.2.1 Photovoltaic

As I could not obtain PV output from Ireland, I used the results obtained from a Danish project called Sol300. This 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 [5], 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.

3.2.2 Tidal

Tidal power is developing rapidly at present. It is very similar to most renewable-energy as you must use it when it is being generated. However, the unique characteristic of tidal power is the fact that it can be predicted in advance: 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 SEI (the Irish Energy Authority), titled "Tidal and Current Energy Resources in Ireland" [24], and one by the Department of Communications, Energy and Natural Resources called "All-Island Grid-Study: Renewable Energy Resource Assessment (Workstream 1)" [25]. The first study [24] identified viable tidal-energy resource available in Ireland from tidal power (0.92 TWh), and the second study [25] created a power-output curve for tidal devices as seen in Figure 3-10. 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 1.5m/s

'Second-generation tidal-devices' are expected to be developed that can be placed in areas without some of these restrictions (see Figure 3-11). However, these devices are not expected until 2015 [25].

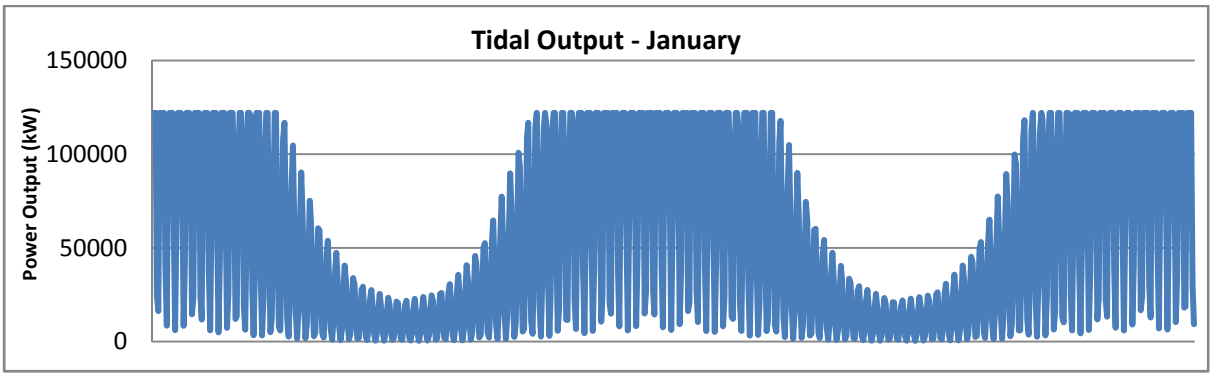


Figure 3-10: Tidal Output from a 122 MW Tidal-Farm [25]

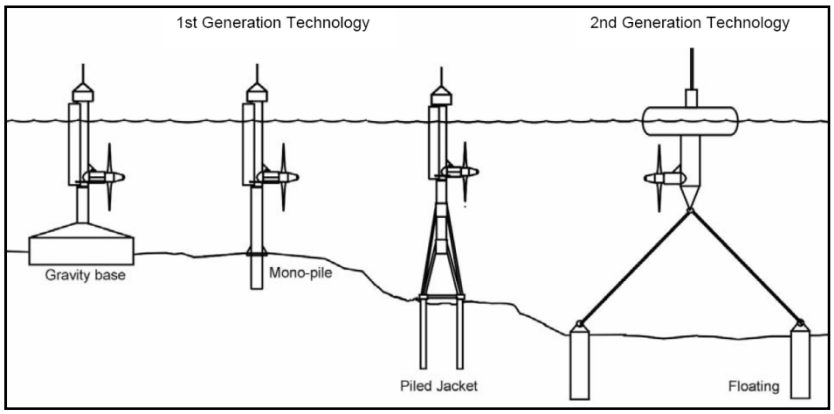


Figure 3-11: First and Second generation tidal technology [26]

3.2.3 Wave Power

I consulted with Jens Peter Kofoed (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 design has become the primary turbine, 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 the sites. 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, particularly the Pelamis, see Figure 3-12a. The Pelamis power matrix (as illustrated in Figure 3-12b) is available to the public and hence can be used in conjunction with wave-height and wave-period data to predict future wave power. Since I created the wave-power output I have also found two other wave-power matrices: one for the Wave Dragon (see Figure 3-13) and the other for the Archimedes (see Figure 3-14).

Power period (T_{pow}, s)

Significant wave height (H_{m_0}, m)	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 3-12: Pelamis wave-generator (a) and power-matrix: output in kW (b)

Wave Period – Tz (s)

Significant Wave Height - m	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 3-13: Wave Dragon Power Matrix (optimised for high average wave conditions): output in kW [27]

Wave Period – Tpow (s)

Significant Wave Height Hsig - m	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 3-14: Archimedes-Wave-Swing Power-Matrix (unrestricted): output in kW [27]

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 3-15. 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 3-15, the Pelamis is a very good match for the sample site analysed.

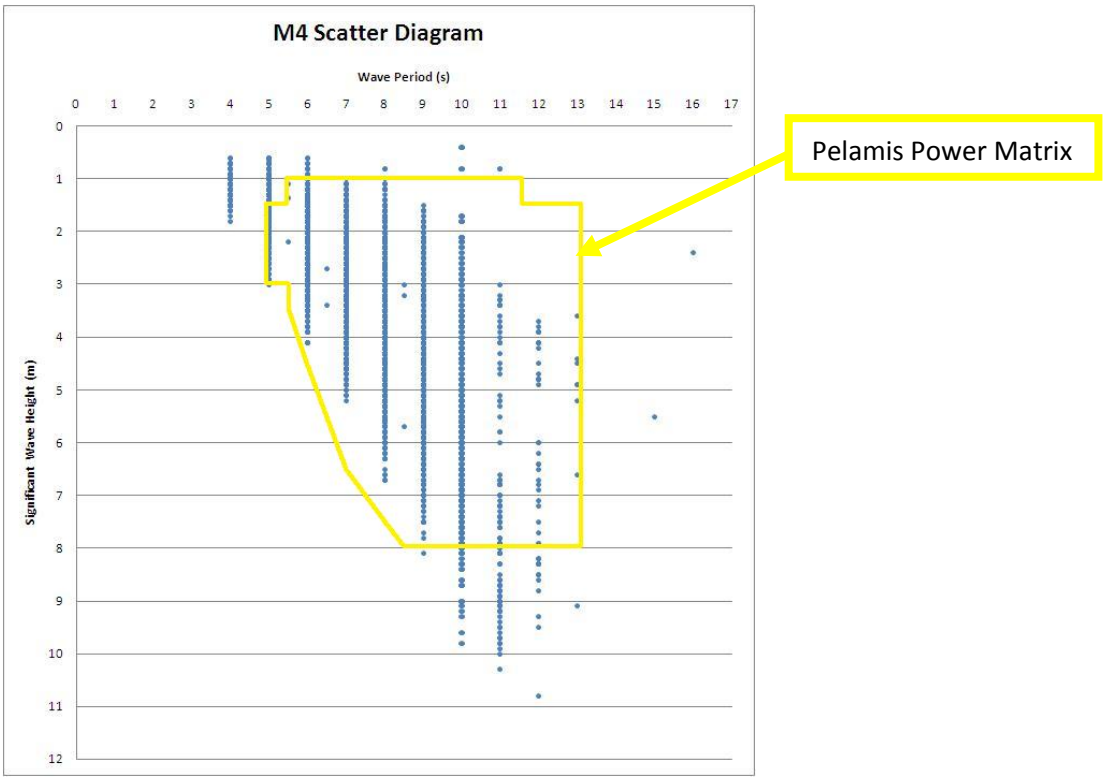


Figure 3-15: Scatter diagram for M4 data buoy off the coast of Ireland

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 have created a program using MATLAB which can be obtained by contacting me at david.connolly@ul.ie.

For my particular study, 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 distributed around the coast [28]. Obtaining data from four different locations spread over each corner of the island, ensured that wave energy fluctuations were minimised. A list of data buoys can be seen at [29].

3.2.4 Future Additions

A number of other technologies will be analysed in upcoming alternatives for the Irish energy-system so the input details will be added in due course.

3.3 Section 3: Data for Costs

3.3.1 Fuel Tab

3.3.1.1 Fuel Price

I found the cost of the individual fuels at the following websites:

- Crude Oil: http://www.oil-price.net/?gclid=COnOoJeI65YCFQpUtAodCUf9PQ
- Coal: http://www.eia.doe.gov/cneaf/coal/page/coalnews/coalmar.html
- Natural Gas: http://www.bloomberg.com/markets/commodities/energyprices.html
- Wood Pellets: http://www.techstore.ie/Renewable-Energy/Wood-Pellet/Wood-Pellet-Supply.htm

Fuel Oil, Diesel and Petrol prices can be found by contacting an oil refinery. For my study, I simply used the ratio of costs recommended by the Danish Energy Authority [30]:

- Crude Oil to Fuel Oil – 1 : 0.70
- Crude Oil to Diesel – 1 : 1.25
- Crude Oil to Petrol – 1 : 1.33

It was presumed that although the price of oil may fluctuate, the costs of processing the oil should remain constant.

3.3.1.2 Fuel Handling Costs

I got the fuel-handling costs from Brian Vad Mathiesen's doctoral thesis also, as seen in Table 3-2 [31]. These are the costs associated with handling the fuel within the energy system i.e. transporting the fuel to the power plant.

Table 3-2: Fuel handling costs [32]

€/GJ	Coal	Natural Gas	Fuel Oil	Gas oil Diesel	Petrol JP	Straw	Wood pellets
Power Stations (central)	0.07	0.43	0.23			1.61	
Distributed CHP, district heating & Industry		1.04	1.87			1.08	
Individual households		2.61		2.84			5.95
Road transport				3.08	4.16		
Airplanes					0.68		

3.3.1.3 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.

3.3.1.4 CO_2 Content

I found the CO_2 content for different fuels from a report completed by the Irish energy agency [33]. They were as follows:

1. Coal/Peat[3]: 88 kg/GJ
2. Fuel Oil: 69 kg/GJ
3. Gas: 51 kg/GJ

[3] Coal and Peat were modelled as a single entity as they have very similar costs and CO_2 emissions. This value should not be used when modelling coal on its own as it is a specific value for the Irish energy system.

3.3.1.5 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/.

3.3.2 Operation Tab

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 from the Danish Energy Authority [34]. For the Pumped-Hydroelectric Energy Storage (PHES) facilities, I obtained the variable operation and maintenance costs from [35]. I could not find the variable operation and maintenance cost for the individual units.

3.3.3 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.

Once again, I got the information for the Condensing Plant from the Danish Energy Authority [34], and from [35] for the energy-storage facilities. For onshore and offshore wind-turbines, the investment and fixed O&M costs in [34] have been updated in [36].

For the individual heating-units (such as boilers, electric heaters, solar) I found the costs by contacting the suppliers. Remember to include the installation costs for boiler and solar systems (i.e. plumbing and storage). The breakdown of the heating systems in Ireland (by fuel type) was got from a report carried out by the Irish Central Statistics Office (CSO) [37]. However, even with this information it is difficult to identify what size boiler was installed in each home. Therefore, a more detailed investigation is necessary in the future for quantifying these costs, and when completed the details will be provided here. 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.

3.3.4 Additional Tab

This can be used if there is any additional costs which have not been accounted for.

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.

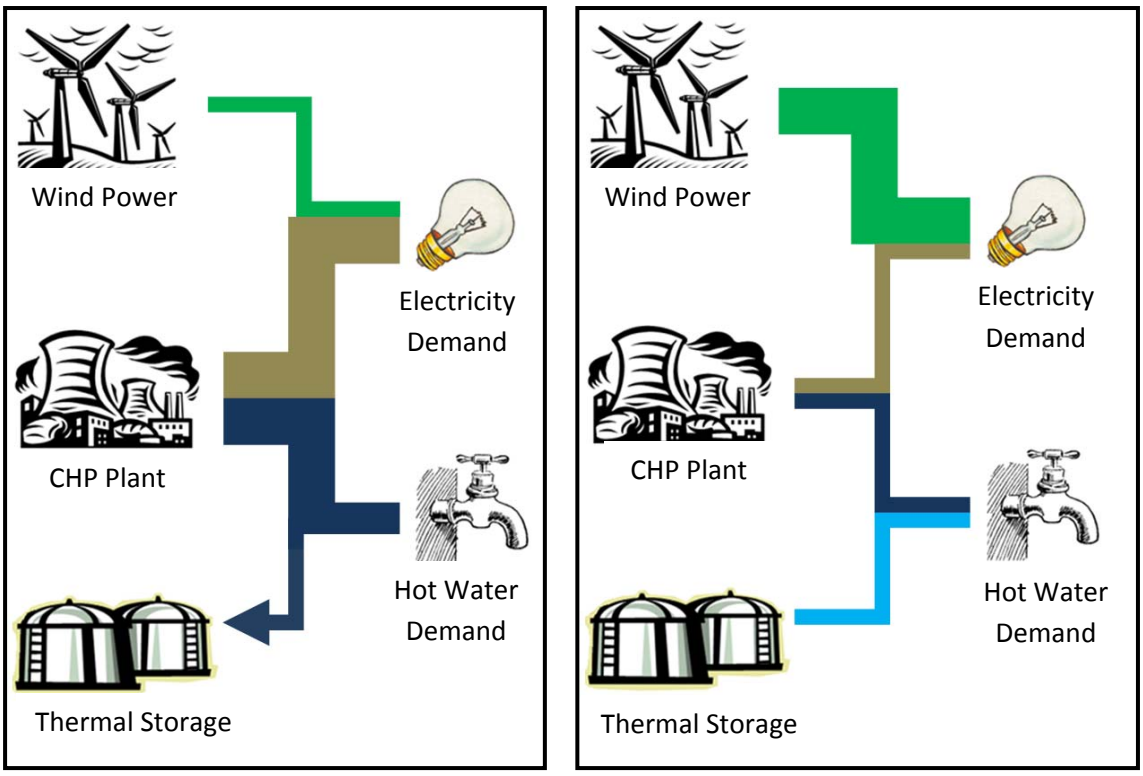
4.1 Thermal Energy System

Coming from a country very little CHP plants or district heating exist, and the fact that heat is usually generated at the point of demand, 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 4-1.

During times of low wind-power, a lot of electricity must be generated by the CHP plants to accommodate for the shortfall power production. As a result, a lot of hot water is also being produced from the CHP plant as seen in Figure 4-1a. The high production of hot water means that production is now greater than demand, and consequently, hot water is sent to the thermal storage.

Conversely, at times of high wind-power, the CHP plants produce very little electricity and hot water. Therefore, there is now a shortage in of hot water so the thermal storage is used to supply the shortfall, as seen in Figure 4-1b.

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



(a) (b)

Figure 4-1: 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 has outlined a roadmap for Denmark to use this setup in achieving a 100% renewable energy system [3].

4.2 District Heating Groups

After learning about the operation of the thermal-storage energy-system, the next question that comes to mind is in relation 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. It is necessary to have this group in order to specify the heat capacity that is not going to be met by CHP plants.
2. DH with small CHP-plants: This category needs to be specified as they 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 Optimisation vs. Market Optimisation

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

1. Technical Optimisation
2. Market Optimisation

The technical optimisation 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 when the power-producing units are not able to meet demand is power imported from the external market.

The market optimisation is designed to match supply and demand at the least cost, rather than on the most technically advantageous. For this optimisation two primary steps are completed:

1. The cost of production is calculated for each power-producing unit
2. The production-level required for each unit to meet the marginal cost[4] is calculated
3. 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 optimisation and the market optimisation, read chapter 6 and 7 respectively in the EnergyPLAN user-manual [38].

4.3.1 Business-economic vs. Socio-economic calculations

There are two types of market optimisations:

1. Business Economic: Taxes are included in the market optimisation
2. Socio Economic: Taxes are not included in the market optimisation

The socio-economic studies are designed to show what society can afford to do. In a socio-economic study the aim is to identify the costs associated with the best Technical Optimisation. This way you

[4] Marginal Cost: Is the cost at which there is enough supply to meet demand

can optimise the performance of the energy system without the restrictions imposed by economic infrastructures. Therefore, the following steps can be followed:

1. Complete a Technical Optimisation 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 optimisation

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-optimisation 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[5]
3. Public Finances
4. Environmental Costs

However, these calculations are not made by the EnergyPLAN model. Instead, these benefits must be calculated externally based on the investments made in the different energy-system-sectors. These calculations are discussed further in [39].

Note: There are a number of areas in EnergyPLAN that I still do not understand, primarily because I have not needed to use these technologies or calculations to date. If anyone would like to add to some information to any of these areas, please contact me at david.connolly@ul.ie.

[5] http://en.wikipedia.org/wiki/Balance_of_payments

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 5-1 also):

1. Check that the electricity demand is correct (including demand, heating, cooling and interconnection)
2. Ensure the consumption is also correct at point 2
3. Check that the production 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?

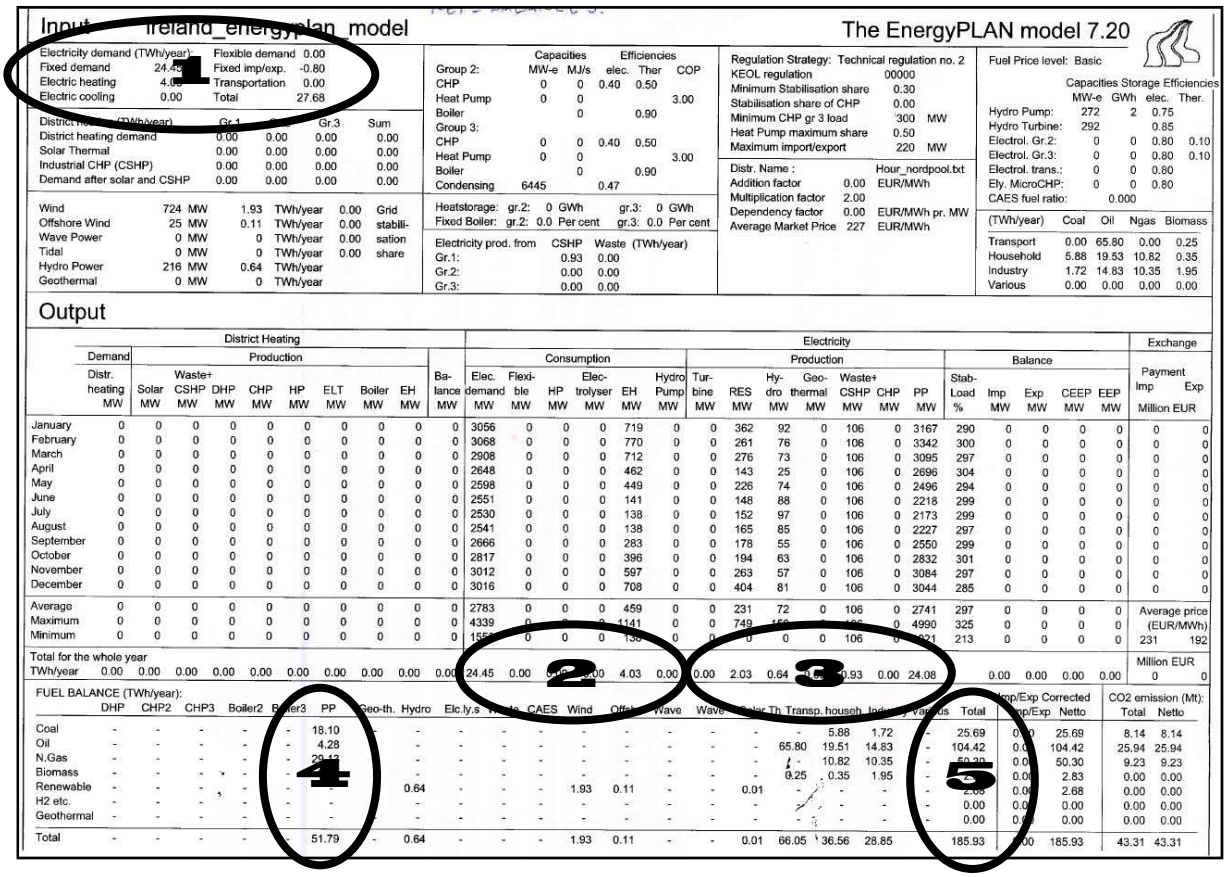


Figure 5-1: Verifying the EnergyPLAN model is functioning accurately

6 Common Error Screens

These are some of the common error screens that I saw during the time that I used EnergyPLAN, with a brief explanation of their cause.

6.1 Wrong Number of Data Points

If you do not have 8784 data points within a distribution in your model, you will get an error that says ***" is not a valid floating point value*** as shown in Figure 6-1. You need to have 8784 data points so that there is a data point for each hour of the year (366 hours * 24 days).

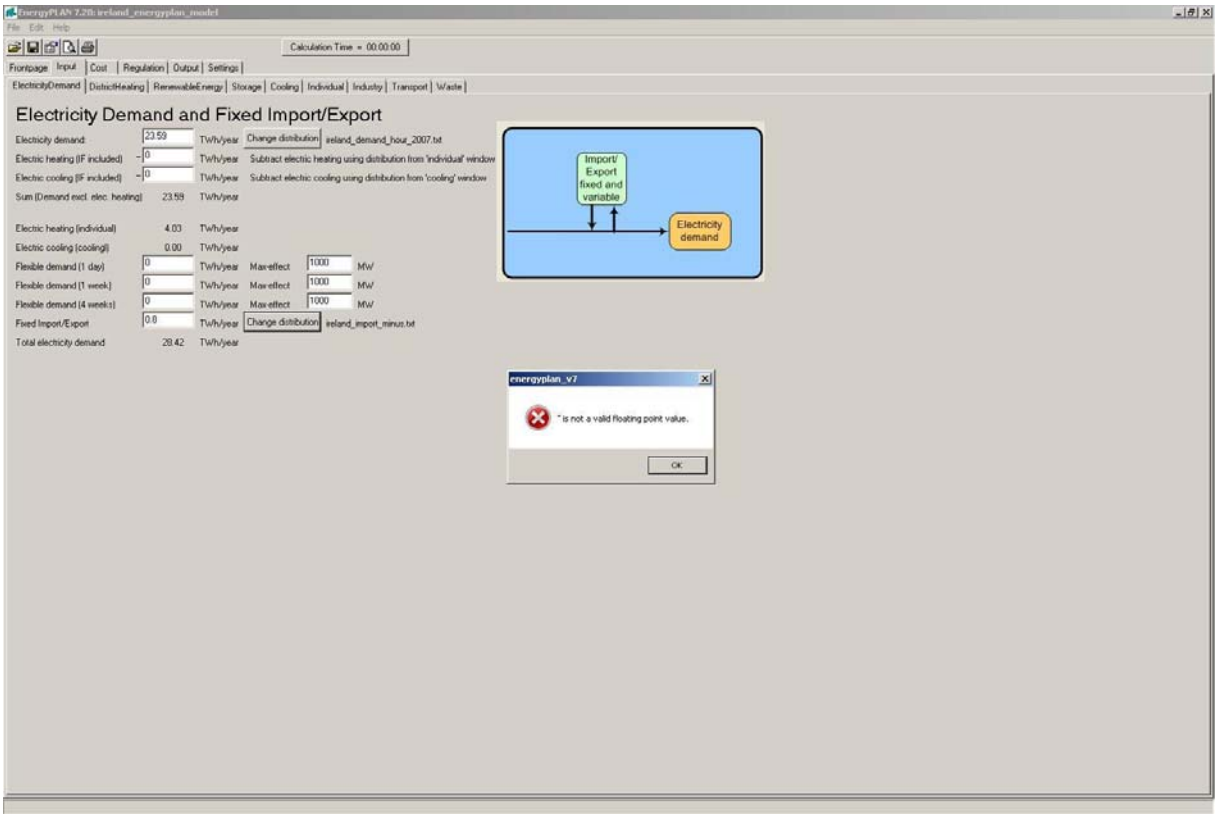


Figure 6-1: Error that occurs with the wrong number of data points in a distribution

6.2 Distribution File Location

If the distribution file that you have used is not located in the Distributions folder that you downloaded with the EnergyPLAN model, you will receive an error that says **File not found: location\distribution_name.txt** as shown in Figure 6-2.

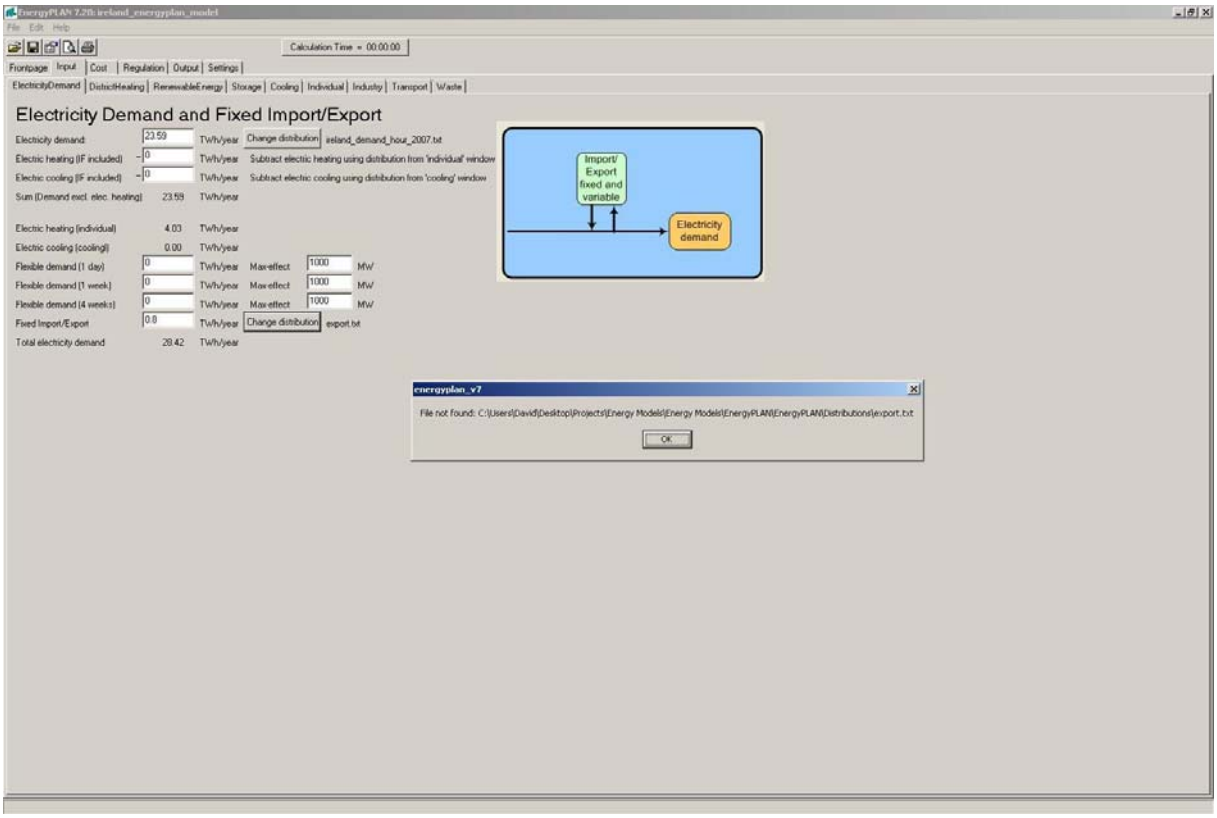


Figure 6-2: Error that occurs when the distribution is placed in the wrong folder

7 Conclusions

The EnergyPLAN model is extremely useful because it is simple. However, this simplicity creates a responsibility on the user to ensure that the data inputted is as accurate and applicable 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, conventional, storage and transport technologies, in a relatively short period of time. Hopefully upon completion of my study, I will be able to expand the benefits of EnergyPLAN even further.

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.

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9 Appendix A: Ireland's Energy-Balance 2007

Ireland's Provisional Energy Balance 2007 (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	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	6.876	4.711	2.165	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	4.304	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	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	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	0.036	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	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	0.000	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	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	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	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)	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	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)	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	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	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	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	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	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	0.000	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	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	0.000	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	1.093	1.093	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	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	40.263	40.263	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	0.000	0.000	0.182	0.000	40.445
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	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	0.000	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	0.102	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	0.000	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	0.030	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	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	0.000	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	1.100	0.000	0.000	1.100	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	0.000	0.000	0.000	0.000	0.000	0.000	1.100
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	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	0.194	-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	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	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	-2.758	-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	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	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	0.000	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	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	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	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	0.000	0.000	0.000	0.000	0.000	3.374	0.000	0.000	0.000	0.000	0.000	0.000	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	0.000	0.000	0.000	0.000	0.000	3.374	0.000	0.000	0.000	0.000	0.000	0.000	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	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	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*	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	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	0.000	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	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	0.160	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	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	0.075	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	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	0.000	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	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	0.004	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	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	0.000	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	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	0.000	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	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	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	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	0.000	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	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.	0.000	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	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	0.000	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	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	0.000	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	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	0.000	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	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	0.000	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	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	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	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	0.000	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	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	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	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	0.000	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	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	0.625	0.000	0.000	0.019	0.000	0.607	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	0.625
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	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	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	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	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	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	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	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	0.303	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	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	0.303	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	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	0.000	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	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	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	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	0.310	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	-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.

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