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The first step towards a 100% renewable energy-system for Ireland

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ABSTRACT

In 2007 Ireland supplied 96% of the total energy demand with fossil fuels (7% domestic and 89% imported) and 3% with renewable energy, even though there are enough renewable resources to supply all the energy required. As energy prices increase and the effects of global warming worsen, it is essential that Ireland begins to utilise its renewable resources more effectively. Therefore, this study presents the first step towards a 100% renewable energy-system for Ireland. The energy-system analysis tool used was EnergyPLAN, as it accounts for all sectors of the energy-system that need to be considered when integrating large penetrations of renewable energy: the electricity, heat, and transport sectors. Initially, a reference model of the existing Irish energy-system was constructed, and subsequently three different 100% renewable energy-systems were created with each focusing on a different resource: biomass, hydrogen, and electricity. These energy-systems were compared so that the benefits from each could be used to create an 'optimum' scenario called combination. Although the results illustrate a potential 100% renewable energy-system for Ireland, they have been obtained based on numerous assumptions. Therefore, these will need to be improved in the future before a serious roadmap can be defined for Ireland's renewable energy transition.

1. Introduction

On a global scale in recent years the affects of climate have become more apparent, new fossil fuel reserves have become scarce, and energy prices have reached all-time highs. Meanwhile in Ireland,[1] approximately 93% of the energy used for electricity generation in Ireland is fossil-fuel based, with 59% of this energy wasted due to transformation losses [1]. Also, approximately 89% of the total fuel consumed in Ireland is imported, which is an extremely volatile situation in the current economic climate [1]. In contrast to fossil fuels, Ireland has an abundant renewable energy resource [2,3] and hence under European Commission regulations, Ireland must supply 16% of the total energy requirement from renewable resources by 2020 [4]. With this in mind, it is essential that Ireland identifies the most effective transition from a fossil-fuel to a renewable energy-system (RES). Therefore, the aim of this work is to evaluate how Ireland can make this transition to a RES. Also, as the Irish energy-system is very similar to those that exist in most developed countries [5], the results obtained in this investigation reflect the changes necessary in a number of other energy-systems also. In addition, the Irish energy-system is an excellent laboratory for experimenting with new technologies as it is a relatively small country with 4.4 million people, it is an island which makes it specifically attractive for the implementation of alternative transport technologies such electric vehicles, and it has an abundant resource of renewable energy in the form of wind, wave, tidal, solar and biomass [2,3].

To date, a number of analyses have been carried out on the feasibility of integrating renewable energy onto the Irish electric grid. In 2003, Gardner et al. [6] investigated the effects of more wind energy on the electricity grid in Ireland and Northern Ireland, concluding that there is no technical limit on the wind penetration feasible, but instead costs are the limiting factor. Therefore, Garner et al. identified the most costly aspects of increasing the wind penetration as transmission reinforcement, wind curtailment, capital costs and operating costs. In 2004, ESB National Grid [7] also analysed the costs associated with increasing the wind penetration in Ireland, but in addition this report also investigated the effects of large wind-penetrations on conventional generation. The report concluded that increasing the wind penetration in Ireland from 0% to 11.7% would increase the total generation costs by €196 million, and would minimally affect baseload plant. However, peaking and mid-merit power plants would be affected as the wind penetration increases due to their more frequent start-ups, increased ramping, and lower capacity factors. Finally, in 2007, Meibom et al. [8] modelled the Irish electricity grid using the WILMAR energy tool [9]. The objective was to identify the effects of large wind-penetrations on the island of Ireland in relation to overall

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[1] Ireland refers to the Republic of Ireland only unless otherwise specified.

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operation, costs and emissions. Meibom et al. concluded that a wind penetration of 42% was feasible on the island of Ireland by 2020, overall operation costs will be reduced with a wind penetration of 42% compared to the current situation, and also, the CO_2 emissions from electricity generation will be reduced to 15 Mt at a wind penetration of 42%.[2] In summary, a number of studies have been carried out in Ireland on the integration of renewable energy. However, these studies are primarily focused on wind generation in the electricity sector.

Focusing on wind energy in the electricity sector is a common situation throughout energy planning [10–13]. In contrast the aim of this work is to analyse the entire energy-system, which includes the electricity, heat and transport sectors, to identify the possibility of supplying these demands using all forms of renewable energy such as wind, wave, solar, tidal, and biomass. Although not as common as analysing the effects of large wind-penetrations in the electricity sector, a number of studies have also been completed in this area: Krajacic et al. [14] investigated the feasibility of 100% RES on the island of Mljet, Croatia, Lund and Mathiesen [15] identified how Denmark could transfer to a 100% RES, while Lehmann proposed a 100% RES for Japan [16]. In conclusion, as it is clearly necessary for Ireland to integrate more renewable energy onto its energy-system, and the integration of renewable energy into the entire Irish energy-system has never been comprehensively analysed previously, the aim of this work is to identify the feasibility of a 100% RES for Ireland, using the methodology proposed by Lund and Mathiesen [15].

2. Methodology

To identify how Ireland can transform from a fossil-fuel based energy-system to a renewable energy-system, the first step is to create a model of the Irish energy-system. Therefore, a study was carried out to identify which tool would be most suitable for this investigation. A detailed report of the various tools considered has been completed [17] and therefore this will not be discussed in detail here. Instead the two primary reasons that EnergyPLAN was chosen are discussed. Firstly, EnergyPLAN considers the three primary sectors of any national energy-system: electricity, heat and transport. To date Ireland has no integration within its energy-system and therefore, the electricity, heat and transport sectors of the Irish energy-system are completely segregated. However, the integration of the three sectors is crucial in order to achieve large-scale penetrations of renewable energy, which has been outlined in [15]. Therefore, in order to meet Ireland's energy targets outlined previously, it will be imperative that Ireland begins to integrate its energy-system more. With this in mind, the EnergyPLAN model had a key advantage over a number of others considered. Secondly, EnergyPLAN has already been used to complete several studies that would be beneficial if applied to Ireland. These include studies analysing the effects of large wind-penetrations [18], the optimum combination of various renewable energy technologies in an energy-system [19], the benefits of energy storage [20] and finally, the pathway towards a 100% renewable energy-system for Denmark [15,21]. These are typical of the studies that will identify how Ireland can work towards its 2020 energy targets and beyond.

EnergyPLAN is a deterministic input/output model. General inputs are the demands, renewable energy sources, energy station capacities, costs, and a number of optional regulation strategies. Outputs are energy balances and the resulting annual productions, fuel consumption, import/export of electricity and the total costs including income from the exchange of electricity. The structure of the EnergyPLAN model is illustrated in Fig. 1 [22]. The main purpose of EnergyPLAN is to assist in the design of national or regional energy-planning strategies on the basis of technical and economic analysis, resulting from the implementation of different energy-systems and investments. It uses an hourly simulation over a period of 1 year as well as aggregated data, i.e. all power plants are modelled as a single power-plant, with a combined efficiency. EnergyPLAN also uses analytical programming rather than iterations so the calculations are completed in a very short period of time. Finally, EnergyPLAN can identify the optimum technical operation of the energy-system as well as the optimal economic-operation, which is one of its key advantages. A lot of energy tools are capable of optimising an energy-system based on costs. However, EnergyPLAN can optimise the energy-system based on the technical operation of its components. This is very useful as it eliminates the constraints imposed by existing financial-infrastructures when analysing future alternatives. Furthermore, EnergyPLAN is able to model the energy-system according to the costs if required. A more detailed description of the EnergyPLAN model and its applications can be found at [23].

In order to ensure the model was simulating the Irish energy-system correctly, a reference model was created representing the year 2007. Details of the inputs used and the assumptions made to create the reference model are discussed in detail in [24] where it was concluded that EnergyPLAN was providing an accurate simulation of the Irish energy-system. Once the reference model was proved accurate, an initial draft of a 100% RES for Ireland could then be created. In total, four 100% renewable energy scenarios were made for Ireland in this study:

1. *Biomass energy-system (BES)*: a 100% renewable energy-system based on biomass.
2. *Hydrogen energy-system (HES)*: a 100% renewable energy-system using hydrogen.
3. *Electricity energy-system (EES)*: a 100% renewable energy-system maximising the use of renewable generated electricity.
4. *A combination of each (COMBO)*: a 100% renewable energy-system based on the results from the BES, HES and EES scenarios.

For each scenario a number of assumptions were made about the future energy demands and production units required. Although these assumptions would have to be validated further before an accurate solution is proposed, they do provide an indication of the trends that can be expected. Listed below are the assumptions used in three of the 100% renewable energy-systems investigated for Ireland:

Assumptions for the biomass energy-system (BES).

1. All electricity, heat and transport demands were maintained at 2007 levels.
2. Energy storage is increased to 3000 MW and 15 GWh.
3. Eliminate existing electric heating.
4. Supply 10% of individual heating with solar thermal.
5. Supply 35% of individual heating with biomass boilers: accounts for all home in rural areas.
6. Supply 55% of individual heating using district heating: accounts for heating demand in all towns and cities with more than 1500 people.
7. Introduce 251 MW (0.92 TWh) of tidal power.
8. The entire fuel demand in industry is supplied using biomass.
9. All transportation fuel is supplied by biofuels, including jet fuel. Biomass is converted to bio-ethanol at a ratio of 1:1.35 (for private cars and jet fuel) and to biodiesel at a ratio of 1:1 (for road freight).

[2] In 2007 Ireland emitted 15.4 Mt of CO_2 due to electricity generation.