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Investigating 100% renewable energy supply at regional level using scenario analysis

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ABSTRACT

Energy modelling work to date across the EU has mainly taken place at a Member State level. A regional modelling approach is necessary however to reach the ambitious targets for renewable energy, energy efficiency, and emissions reduction. This paper explores the usefulness of the energy modelling tool EnergyPLAN using Ireland as a case study, specifically investigating the energy system of the South West Region of Ireland. This paper estimates a current 10.5% renewable energy share of energy use, including a 40% renewable share of electricity. We build and assess a reference scenario within EnergyPLAN and three renewable energy scenarios from a technological and resources perspective. The results show that sufficient resources are available for the South West Region energy system to become 100% renewable and quantifies the land-use implications. Moreover, EnergyPLAN can be a useful tool in exploring different technical solutions. However, thorough investigations of as many alternatives as possible, is necessary before major investments are made in a future energy system.

Keywords:

Bioenergy,
energy supply,
energy systems modelling,
energy policy,
regional planning

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1. Introduction

Energy modelling within the European Union (EU) is generally conducted either at EU or at Member State (MS) level, due to the availability of data and where energy policy decision making takes place. Arising from the EU Energy Services Directive, each MS is required to produce National Energy Efficiency Action Plans and the EU Renewable Energy Directive (RES Directive) requires MS to produce National Renewable Energy Action Plans (NREAP).

Due to the variations in renewable energy resource availability and constraints to increased deployment in many MS however, it is necessary to have local and regional plans in order to implement national policies and deliver targets. Studies in the field of regional energy planning have mainly investigated the extent to which regional plans are aligned with national energy plans [1], how using local resources can reduce regional disparity [2], optimizing modelling to exploit and develop renewable energy from a technical and economic perspective [3–5], technology and policy uncertainty [6] and regional energy planning with particular focus on greenhouse gas emissions [7]. A further study [8] has combined a different regional energy system model with regional land use optimisation modelling to investigate the potentials for regional energy autarky in Austria.

The cornerstone for Ireland's renewable energy policy is the NREAP, which specifies how renewable energy will develop to meet Ireland's mandatory target

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to achieve 16% of total energy consumption from renewable sources by 2020. A key deficiency at regional level is the often absent analyses taking a regional full energy systems approach to determine from a techno-economic perspective how in reality renewable energy can be rolled out to the extent to meet targets. Although, a number of local authorities are developing renewable energy strategies for their planning jurisdiction as part of their county development plans [9–12], these strategies are often limited to a county focus and with a certain isolated approach. There are also regional development plans being prepared by Regional Authorities with aspirational targets for renewable energy in individual regions that comprise more than one county [13, 14].

This paper bridges the gap between national and regional energy planning to address the issue of an absent regional full energy system analysis, using the South West Region (SWR) of Ireland as a case study. In Ireland modelling at national level has been investigated using different energy systems modelling tools; the Irish TIMES model has been used to investigate the evolution of Ireland's energy system in response to European climate mitigation targets for 2050 [15], 2030 [16] and 2020 [17]. EnergyPLAN has been used to investigate first steps on how Ireland could reach a 100% renewable energy system [18]. However, regional energy systems modelling is still largely undeveloped, despite the need for local and regional authorities to plan for developments in their area of responsibility. The difficulty in regional modelling in Ireland lies mainly in the lack of publicly available regional data. Currently, only one known study has been conducted at regional level in Ireland with the aim to develop a new regional energy strategy. So far however, only the first part of the study has been published in which a regional energy plan has been initiated to identify how to reduce overall CO_2 emissions by 2020 [19, 20]. Several studies have been conducted using EnergyPLAN modelling energy systems at national level [21–23] of which some have focused on a 100 % renewable energy system [18, 24, 25].

The novelty in this paper is in extending previous modelling work at a national scale using the modelling tool EnergyPLAN to a regional level with a particular focus on bioenergy. This paper will investigate if the South West Region of Ireland can become energy autonomous from a technical perspective and the usefulness of EnergyPLAN in achieving this goal. This initial exploration acts as a useful example for other energy modelling teams who wish to model at a regional level, dealing with boundary issues and the lack of regional data.

The article is structured as follows: in Section 2 the case study and initial analysis thereof is presented, in Section 3 the methodology and scenarios are presented, Section 4 the results from the scenarios are discussed, Section 5 discusses further work needed and in Section 6 final conclusions are drawn.

2. The case study – south west region of ireland

The Island of Ireland is politically divided into the Republic of Ireland (ROI) and Northern Ireland (NI) which forms part of Great Britain. This paper will only study data from the ROI and hereafter Ireland will be used when referring to the ROI. Ireland has a total population of 4,588,252 (census 2011) [26] living in 26 Counties. County Cork (Co. Cork) and County Kerry (Co. Kerry) forming the South West Region (SWR) of Ireland. Co. Cork is the largest county and Co. Kerry is the fifth largest county in Ireland taking up a combined land area of 18%. In terms of population however, 11% live in Co. Cork and only 3% live in Co. Kerry. In Co. Cork approximately 65% live in towns and cities with more than 1,500 inhabitants and 35 % live in smaller towns or rurally [27]. In Co. Kerry on the other hand the numbers are reversed [28]. It can thus be estimated that 45 % of the population in the SWR live rurally and that 55% live in towns and cities with a population larger than 1,500. The SWR region has several compelling sources of income: tourism, dairy production, meat production, pharmaceutical production, extensive wind resources and wind power generation, thermal power generation and supplier of transport fuel.

2.1. Land use in the SWR

The national average for forestry and agricultural land is 11% and 61% respectively. Agricultural land can be further divided into grassland and tillage, of which the national average is 93 % and 7% respectively. As can be seen in Table 1, land use in Co. Cork in percent is similar in regard to forestry land (12%) and is 10 percent units higher in regard to agricultural land (71%). Of this, 14% is tillage land, which is twice the national average. Co. Kerry on the other hand is similar to the national average, with slightly less agricultural land (59%) overall and slightly more grassland (95%).

Table 1: Percentage of agricultural and forestry land of total land area in Ireland, SWR, Co. Cork and Co. Kerry.

	Ireland	SWR	Co. Cork	Co. Kerry
Total land area [ha][a]	6,889,456	1,216,130	745,988	470,142
Of which				
Agricultural land[b]	61%	66%	71%	59%
Of which grassland[b]	93%	89%	86%	95%
Of which tillage[b]	7%	11%	14%	5%
Forestry land[a]	11%	12%	12%	12%

[a] [29], [b] [30]

2.2. Current energy demand and supply

The only available regional energy balance available at present for the SWR is that of the South West Regional Authority [13] for 2007, generated by distributing the national energy balance [31] on a regional basis according to population share. Other regions have also adopted a *top-down* approach in creating energy balances [32–34]. Using a *bottom-up* approach that associates energy usage to appropriate sectoral indicators is anticipated to provide a more accurate balance but requires much more time and not all necessary data may be available. A top-down approach has been chosen in this paper to update the SWR energy balance using 2011 data. It is appropriate to use an energy per capita approach initially to calculate an estimate of the energy use in the region, as Ireland is relatively small in area and thus has a similar climate across the country. Thus there should be no significant difference in residential need for heat and electricity. Furthermore, it can be assumed that no significant difference exists in transport behaviour as the main mode of transport is private vehicles. There are large industries in Ireland located within certain regions. However, these industries are of national interest and therefore an energy per capita approach should also be appropriate as an estimate. The energy balance for the SWR suggests a total energy consumption (TEC) of 18.8 TWh (final energy rather than primary energy). The electricity sector accounts for 19% of TEC, 3.6 TWh; heating and transport each account for roughly 40% of TEC, 7.7 TWh and 7.5 TWh respectively. The region is heavily dependent on fossil fuels to meet the demand within the electricity, heating and transport sectors. The main sources currently used for electricity production are thermal power plants, wind power and hydropower. For heating the main sources are fossil fuel based (i.e. coal, oil, natural gas, peat) with limited use of bioenergy and solar thermal. The transport sector is dominated by fossil fuel, however there is also a limited use of biofuels. The Irish (and SWR) energy system is still largely segregated in terms of electricity, heating and transport. According to Lund and Mathiesen [35] integration of the energy system is crucial to achieve large scale integration of renewable energy.

2.2.1. Electricity sector

There are a several thermal power plants in both Co. Cork and Co. Kerry. In Co. Cork there are three gas power plants, one combined cycle gas turbine (CCGT) and two open cycle gas turbines (OCGT). Together these have an installed capacity of 1482 MW. In Co. Kerry there is one steam power plant supplying 590 MW installed capacity operating with oil that is due to phase out in the next few years and be replaced by an OCGT and CCGT. These thermal power plants in Co. Cork and Co. Kerry currently only supply electricity. The total installed capacity of thermal power plant in the SWR therefore is 2,072 MW.

The main renewable resource exploited in 2011 in Co. Cork and Kerry is wind power with a total installed capacity of 514 MW producing approximately 1.4 TWh annually.

Due to the topography of Ireland there are not many suitable large scale hydropower sites. The largest hydropower station in Ireland is Ardnacrusha with an installed capacity of 87 MW. The largest hydropower station in the SWR is the Inniscarra and the Carrigadrohid on the River Lee with 19 MW and 8 MW installed capacity respectively. The remaining hydropower stations are characterised as micro hydropower and are mainly below 1MW. Hydropower accounts for approximately 31 MW in the SWR.

Currently, the use of photovoltaic systems is not prevalent in the SWR.

2.2.2. Heating sector

The main form of heating in 2011 is coal (0.6 TWh), oil (3.7 TWh), peat (0.4 TWh), or natural gas (2.6 TWh). These numbers are derived from a regional allocation of national energy balance data based on population share. It is worth noting that natural gas is mainly used in Co. Cork as the gas grid does not extend to Co. Kerry.

Biomass use is still limited with 0.06 TWh used in residential and commercial boilers and 0.2 TWh used in industrial boilers. Biogas use is less than 0.01 TWh.

There is also limited use of solar thermal and geothermal (0.01 TWh), which are mainly installed for domestic purposes.

These numbers are derived from a regional allocation of national energy balance data based on population share.

2.2.3. Transport sector

The transport sector uses 66% of all oil consumption in the SWR, which covers both commercial and private vehicles. This number is derived from a regional allocation of national energy balance data based on population share. According to Census 2011 [36-38] the most popular mode of transportation to work is by car (64 %) and only 1 % commute by means of public transportation. Furthermore, 46 % of all households in SWR have two cars or more. There are a further two airports in the SWR and a train system that connects the two catchment areas with each other and also with the main train route to Dublin.

2.2.4. Renewable energy

Table 2 compares the RES percentage of TEC in Ireland, SWR, Co. Cork and Co. Kerry. As can be seen, the total RES percentage of TEC currently depends on the RES-electricity. The high figure for RES-E in Kerry (78%) is mainly due to large amounts of installed wind capacity and low levels of electricity demand.

Table 2: Renewable energy production in the SWR by sector and by share of TEC.

Share of TEC		Ireland	SWR	Co. Cork	Co. Kerry
Electricity	Wind[a]	17.6%	40.3%	29.5%	78.0%
	Hydro[b]				
Heating[c]	Domestic				
	Firewood	5.0%	4.7%	4.8%	4.8%
	Sawmill				
	Bioenergy				
	Biogas				
	Solar/ Geothermal				
Transport[c]	Biofuel	3.6%	2.2%	2.2%	2.1%
TOTAL		6.5%	10.5%	8.5%	17.8%

[a] [39], [b] [40] and [c] scaled using per capita from [31]

2.3. Blue skies – what is possible?

To investigate whether the SWR can become autonomous in terms of RES energy, an initial step is to compare the amount of land available, in hectares (ha), and the amount of energy that can be generated per ha. In reality a combination of different resources will need to be utilised to fully cover the needs of the SWR.

2.3.1. Electricity sector

The main renewable resources investigated for electricity production is wind power and hydropower. A standard wind turbine is assumed to be 3 MW, with a hub height of 80 m above ground. Due to the elliptic nature of the air space around the turbine it is estimated that 13.5 MW can be installed per km^2 [41]. However, the needed energy space per turbine is for the turbine blades to be able to produce the maximum power from wind. In terms of space on the ground, the required area per turbine is roughly 0.01 km^2 per turbine including the turbine foundation, access roads, and any ancillary services necessary for turbine operation [42]. The rest of the space can therefore be used for other purposes such as growing energy crop or pasture land for agriculture.

The energy produced from hydropower is determined by the catchment area and the head difference between upper and lower reservoirs. It is therefore difficult to determine the energy produced per hectares land. However, as the medium sized rivers have already been dammed, the main potential in Co. Cork and Co. Kerry is small-scale hydropower facilities. A study conducted by the Department of Energy in 1985 [43] shows that there are at least 114 potential sites with a potential to install a total capacity of 10.1 MW, which could potentially generate 33.6 GWh. There is therefore a natural limit to the amount of energy available from hydropower.

The average number of sunshine hours in Ireland is between 1100 and 1600, with the sunshine hours in the SWR tending towards to the lower end of the scale. The SWR typically receives 1000 kWh/m^2/year with collectors at a tilt of 45° [44]. However, photovoltaic (PV) work well even on days with slight cloud coverage. The ideal positioning for PV is south facing. As part of this project it has been estimated that approximately 50% of the houses in Co. Cork and Co. Kerry are south facing. A typical PV panel (1.3 m^2) may have a rating of 170 Wp. If directly south facing and no overshadowing, one panel (1.3 m^2) should roughly produce 136 kWh per annum.

2.3.2. Heating sector

The main renewable resources available for the heating sector are solar thermal/geothermal and bioenergy. Bioenergy for the heating sector can be further divided into combustion and biogas where resources for combustion are energy crop such as willow and miscanthus, forestry (including thinning), the biodegradable fraction in municipal solid waste (BMW) and wood recovered from construction and demolition (C&D) waste. Resources available for biogas production are manure, agricultural waste from cattle, pig, sheep and poultry, slaughter waste, barley, sugar beet, wheat, maize, grass/silage, and garden and food waste collected. Biogas can be used directly for heating or produce electricity, however, [45–49] show that upgrading biogas to bio-methane is a better utilisation of biogas resources within Ireland. Bio-methane contains more than 97% methane (CH_4) and is almost indistinguishable from natural gas (NG) which means it can be injected into the NG grid and used for electricity production, heating and transport. For the purpose of energy per hectares only biogas potentials will be investigated.

Table 3 summarises the investigated resources by end use category, the energy generation associated with each hectares land used per year and the required land area needed in percent. Required land here means the land required to meet SWR's current heating requirements. The term "productive land" refers to the currently available forestry and agricultural land. BMW, Waste recovered from C&D, and garden and food waste have not been listed in the table because these are generated by human consumption and are assumed to stay constant at 2011 data and that the appropriate energy conversion facilities are in place. Slaughter waste, i.e. stomach contents has also not been listed as this is dependent on animals slaughtered rather than animals per hectares.

2.3.3. Transport sector

The main sources of bioenergy resources that potentially may be available for biodiesel production are oil seed rape (OSR), used cooking oil (UCO), tallow and meat and bone marrow (MBM). However, biogas, as discussed in the previous section, can be upgraded to bio-methane which can be used in transportation. Table 4 summarises the land use associated with biodiesel production. UCO is not listed since it is associated with population size, which is assumed to be constant. Here required land means the land required to deliver SWR's current transport energy requirements

3. Methodology and data

The methodology in short comprises four key elements:

1. Compile data required for EnergyPLAN to model bioenergy supply and demand for the south-west region in Ireland.

Table 3: Available resources for the heating sector by generation per hectare and the required land.

End-use Category	Resource	Biogas yield m^3/ton @65% CH4[a]	GJ/(ha year)	Required % of current productive land
Combustion	Miscanthus	–	140[a]	20%
	Willow	–	140[a]	20%
	Forestry thinning @ 60% MC	–	68	42%
	Forestry roundwood @ 40% MC	–	178	16%
	Wood Chip @ 30% MC		107	26%
Biogas	Manure – Cattle	19.69	4	1338%
	Manure – Pig	14.28	872	7%
	Manure – Sheep	54.4[b]	3	2143%
	Manure – Poultry	71.83	57	99%
	Barley	–	45.4[c]	187%
	Sugarbeet	55	52	327%
	Wheat	348	61	139%
	Maize	160	28	201%
	Grass (fresh)	98	123	46%
	Grass (silage)	189	238	24%

[a][50], [b][46], [c] [51]

Table 4: Available resources for the transport sector by generation per hectares and the required land.

End-use Category	Resource	Biogas yield m^3/ton @65% CH4[a]	Energy value of biodiesel GJ/ton	GJ/(ha year)	Required % of current productive land
Biofuel	Oil seed rape	340[b]	39[c]	46.5	122%
	Tallow: Cattle	298	39.8[d]	6	982%
	Pig			122	1457%
	Sheep			7	805%
	Poultry			8	1181%
	MBM: Cattle	298	15.7[d]	3.8	46%
	Pig			102	56%
	Sheep			4.8	707%
	Poultry			5.3	1062%

[a] [50], [b] [52], [c] [53] and [d] [54]

2. Build and calibrate the EnergyPLAN model for the SWR in Ireland.
3. Use the model to investigate different bioenergy scenarios for the south-west region in Ireland.
4. Investigate the different impacts and constraints associated with each level of deployment.

3.1. The EnergyPLAN model

This section will summarise the main points of the EnergyPLAN model. The detailed documentation can be found in [55], a more condensed user's guide can be found in [56] and further help with finding and inputting data can be found in [57].

The EnergyPLAN model is used to analyse an energy system in hourly steps for one year. The model was developed to assist in the technical and economical design of national energy strategies but can be used for European as well as regional and local level. Its design emphasises the option of examining the entire energy system of electricity, heat and transport.

The model is an input/output model where input are divided into eleven sets of data: electricity demand, district heating, renewable energy, electricity storage, cooling, individual, industry, transport, waste, biomass conversion and synthetic fuels (see Figure 1). The model also uses different regulation strategies with an emphasis on the interaction between combined heat and power (CHP) and fluctuating renewable energy sources. EnergyPLAN uses constant efficiencies i.e. efficiencies that are not load-dependent or dependent on external factors.

The model can be used for 3 main types of energy system analysis:

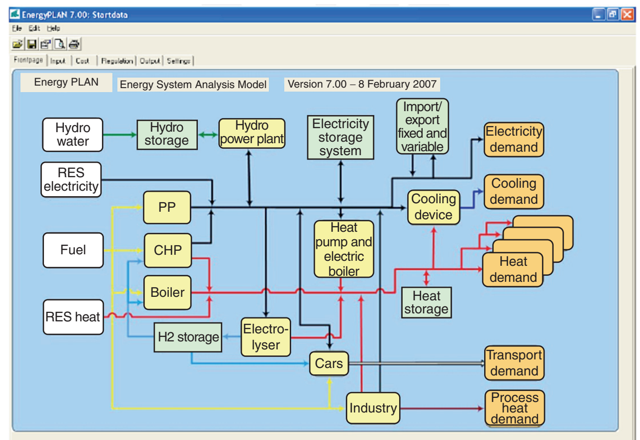

Figure 1: Overall structure of the EnergyPLAN model. Screenshot from the model.

1. Technical Analysis
2. Market Exchange Analysis
3. Feasibility Studies

This paper will initially focus on the technical analysis of the south west region where input is a description of energy demand, production capacities and efficiencies, and energy sources. Output will consist of energy balances, fuel consumptions and CO_2 emissions. An economic analysis has not been carried out for this paper.

3.2. Reference model and scenarios

We generated an initial reference model for the SWR using 2011 data. The reference model is used to confirm that the model is working correctly and to provide a base-case scenario to which the RE scenarios can be compared. In total 3 RE scenarios have been investigated. A model constraint was set so that no electricity import was allowed but that electricity export was. The three scenarios are all based on a 100% renewable energy system using different input and technologies. The assumptions for each scenario are listed below and a summary table can be found in Table 5:

3.2.1. Scenario 1 – maximising energy from waste

This scenario investigates a 100% renewable energy system where the utilisation of each waste stream is maximised. The basic assumptions are:

1. Population, herd numbers and energy demand are kept constant at 2011 data.
2. The energy from the total tonnes of collected MSW and waste wood from C&D is recovered in a Waste-to-Energy plant to produce electricity. Although only 71% [58] of MSW is biodegradable (i.e. renewable), for the purpose of this scenario, it is assumed that the entire amount of MSW is considered renewable.
3. The herd numbers determine the amount of manure, slaughter waste (i.e. stomach content), and tallow and meat and bone marrow available. One caveat is that this paper does not take into account the possible rise in herd numbers due to Harvest 2020.
4. Manure and slaughter waste will be converted to bio-methane (≤ 97% CH_4) for injection into the natural gas grid.
5. Meat and bone marrow will be used for biodiesel production.
6. Used Cooking Oil (UCO) is calculated on a per capita basis, with the assumption that 3.46 tonnes [54] is collectable per capita and year. UCO will be used for biodiesel production.
7. As part of this project it has been estimated that approximately 50% of housing stock is south facing and that 50% of all south facing roof tops will use solar thermal for heating, where the average solar thermal installation covers 6 m^2 producing 2000 kWh/year.
8. Wind generation will cover 50% of the overall electricity demand.
9. The residual demand for heat and transport will be covered by grass, which in turn will be converted to bio-methane of NG quality to be used both in heating and transport.

3.2.2. Scenario 2 – 50% energy from waste & CHP

This scenario investigates a 100% renewable energy system where only 50% of all the waste streams available for Scenario 1 is available. This scenario incorporates combined heat and power (CHP) and uses grass as energy crop. The assumptions are the following:

1. Population, herd numbers and energy demand are kept constant at 2011 data.
2. 50% of the waste streams calculated in scenario 1 will be used – the streams will be used in the same way as in scenario 1.
3. The planned gate 2 and 3 wind projects as well as those already in the planning permission pipeline are used. This roughly equates to 75% of the total electricity demand.

Table 5: Summary of the input for Ref 2011 and the three RE scenarios.

	Ref 2011	Scenario 1	Scenario 2	Scenario 3
Electricity	NG	Bio-methane	Wind	Wind
	Oil	Wind	Hydro	Hydro
	Wind	Hydro	CHP	Forestry - PP
	Hydro power			
Heat	NG	Bio-methane	CHP	Bio-methane
	Oil	Solar thermal	Bio-methane	Solar thermal
	Coal		Solar thermal	
	Peat			
	Forestry			
Transport	Oil	Biodiesel	Biodiesel	Biodiesel
	Bio-methane	Bio-methane	Bio-methane	

4. The residual electricity demand will be covered by CHP utilising forestry biomass. The heat from the CHP will be used to cover some of the heat demand.
5. It is estimated that 50% of housing stock is south facing and that 50% of all south facing roof tops will use solar thermal for heating, where the average solar thermal installation covers 6 m^2 producing 2000 kWh/year.
6. Residual heat and transport demand will be filled using grass to bio-methane for injection into the NG grid.

3.2.3. Scenario 3 – 50% energy from waste & No CHP

This scenario investigates a 100% renewable energy system where only 50% of all the waste streams available for Scenario 1 is available. This scenario does not incorporate CHP and uses wheat and rape seed as energy crop. The assumptions are the following:

1. Population, herd numbers and energy demand are kept constant at 2011 data.
2. 50% of the waste streams calculated in scenario 1 will be used – the streams will be used in the same way as in scenario 1.
3. The planned gate 2 and 3 wind projects as well as those already in the planning permission pipeline are used. This roughly equates to 75% of the total electricity demand.
4. The residual electricity demand is covered by power plant using forestry biomass for electricity production only.
5. It is estimated that 50% of housing stock is south facing and that 50% of all south facing roof tops will use solar thermal for heating, where the average solar thermal installation covers 6m^2 producing 2000 kWh/year.
6. Remaining need for heat and transport to be filled by wheat and rape seed.

4. Results and discussion

4.1 Technical results

By using the methodology described above three RE scenarios and a reference model were created. As can be seen in Figure 2 all three scenarios have a lower primary energy supply than the reference. Scenario 3 has the higher primary energy of the three and is roughly similar to the reference model; neither of which

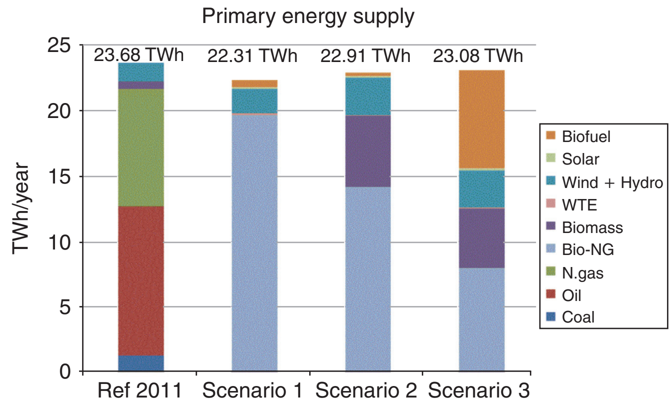

Figure 2: A comparison of fuel mix between the Ref 2011 and the three scenarios.

have any integration of the energy sectors, i.e. no electric heating or electrification of transportation. For Scenario 1 and 2 therefore, the lower primary energy supply may be explained by the partially integrated electricity, heat, and transport sector, making the entire energy system more efficient. The reference model calculates a RES share of 8.3 % of primary energy and 38 % of electricity. This compares favourably with calculations made in the previous section discussing current energy demand and supply (10.5% and 40.3% respectively). Table 6, summarises the percentages of each renewable resource in the reference model and the three RE scenarios.

The main fuel source in all three scenarios is biomass. In Scenario 1, maximising the waste streams

Table 6: RE mix in the reference model and the three RE scenarios in percent.

	REF 2011	Scenario 1	Scenario 2	Scenario 3
Wind	5.8%	8.1%	12.1%	12%
Hydro	0.3%	0.3%	0.3%	0.3%
WTE	–	0.6%	0.3%	0.3%
Solar	–	0.7%	0.6%	0.7%
Biomethane (waste)	–	6.1%	3.0%	3%
Biomethane (grass)	–	81.9%	58.8%	
Biomethane (wheat)	–	–	–	31.4%
Biodiesel (waste)	–	2.2%	1.1%	1.1%
Biodiesel (oil seed rape)	–	–	–	31.4%
Biomass (forestry)	2.5%	–	23.7%	19.8%
TOTAL	8.6%	100%	100%	100%

provides 0.13 TWh waste-to-energy and 1.37 TWh biomethane from agricultural and food and organic wastes and 0.5 TWh biodiesel from slaughter waste; a total of 2 TWh. The technology of choice in this scenario was to convert grass to bio-methane with NG quality so that it can be injected into the NG grid. The assumption in this case is that the NG grid is extended beyond its current reach. The total required biomethane for this scenario is 19.65 TWh, which means that 18.28 TWh of biomethane needs to come from grass. The grass biomethane is 81.9% of TEC in Scenario 1. Depending on grass silage energy yield the required land area is between 34% and 66% of the currently available agricultural land or between 29% and 56% of the currently available agricultural and forestry land available in the SWR.

In contrast, In Scenario 2 only half of the energy from waste is used, giving a total of 1 TWh from all the waste streams used in electricity, heat and transport. In addition forestry biomass is used to produce electricity (alongside hydropower and wind) and grass is used to produce biomethane for the heat and transport sector (alongside solar). The technology of choice in Scenario 2 is CHP and the natural gas grid. The first priority for the CHP is to produce enough electricity to cover the demand not filled by the other resources also producing electricity, and second to produce and distribute the heat produced in the CHP process. The total need for biomass from forestry amounts to 5.43 TWh. The resource used in the CHP is a mixture of forestry thinning and wood chip. Realistically only 60% of the currently available forestry land in the SWR can be mobilised, which means that forestry thinning can contribute with 1.6 TWh. The remaining 3.8 TWh of woodchip requires a land use of 87% of the currently available forestry land. The need for biomethane from grass amounted to 13.5 TWh in this Scenario. Depending on the achieved biogas yield the required land use is between 25% and 49% of the currently available agricultural land.

Scenario 3 differs from Scenario 1 and 2 in that it uses wood biomass to produce electricity only, alongside wind, waste and hydro power, wheat for the heat demand alongside solar thermal and oil seed rape converted to biodiesel (alongside slaughter waste) for the transport sector. The need for forestry biomass in this scenario is 4.57 TWh. By using the same assumption as in Scenario 2 i.e. that 60 % thinning can be mobilised from current forestry land, the rest of the heat demand requires only 67% of forestry land, or 10% of forestry and agricultural land currently available in the SWR. Wheat was used to produce biomethane with NG quality to inject into the NG grid. However, with an energy yield of 61 GJ/ha this means that 53% of the agricultural land or 45% of the agricultural and forestry land, currently available in the SWR is required. Furthermore, for oil seed rape to produce enough biodiesel to cover the 7.24 TWh demand at 46.5 GJ/ha, 69 % of the agricultural land or 59% of the agricultural and forestry land is required. This means that a total of 114% of the currently available agricultural and forestry land in the SWR.

It is clear that none of the three scenarios provides an optimum solution for a 100% renewable energy system, although Scenario 1 and 2 are more promising than Scenario 3. The use of CHP in scenario 2 also shows a more efficient energy system as the electricity and heat sectors become more integrated, resulting in a more efficient use of resources. Nonetheless, they highlight that the main resources available to the SWR are grass, forestry biomass and wind power and that it is the use of technical solutions that is the main issue that needs to be solved in reaching an optimum solution. Other resources that are worth investigating further are miscanthus and willow as these also have a high energy yield per hectare. In summary, scenario 1 requires between 29% and 56% Scenario 2 requires between 34% and 54% and Scenario 3 requires 114% of the currently available forestry and agricultural land available in the SWR, for the SWR to become autonomous in terms of RES energy. The results are summarised in Table 7.

4.2. Preliminary economic analysis

A preliminary economic analysis has been conducted on the reference model as well as on Sc1 and Sc2 using EnergyPLAN. Simplified assumptions were made based on the technology and fuel cost information readily available within the EnergyPLAN databases [59]. The comparison here is limited to Sc1 and Sc2 as Sc3 was not feasible due to insufficient land availability.

Table 7: Land requirement in each scenario of the available agricultural and forestry land in %.

	Scenario 1	Scenario 2	Scenario 3
Grass	29% – 56%	21% – 41%	
Wood chip		13%	10%
Wheat			45%
Oil seed rape			59%
TOTAL	29% – 56%	34% – 54%	114%

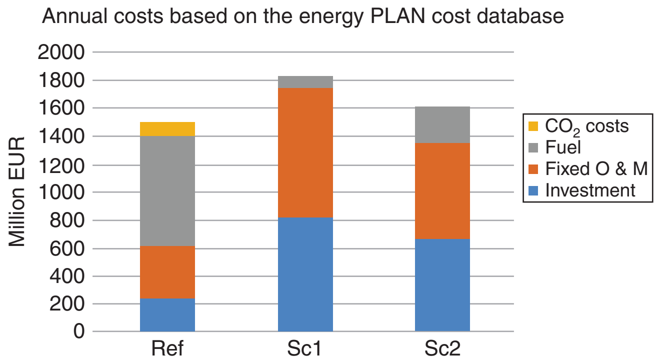

Figure 4: Comparison of annual costs based on the EnergyPLAN cost database.

However, some high level comparisons can still be made that can provide initial insights and point to where further useful analysis can be undertaken. The key results are presented in Figure 4 showing total annual energy system costs distinguishing between investment costs, O&M costs, fuel costs and CO_2 costs (based on a carbon price of 20EUR/t CO_2), as follows:

- The key result is that a 100% renewable energy system is unlikely to be multiples of the cost of the fossil fuel alternative. The scale of energy cost difference between the reference model and Sc1 as calculated in this model suggests a maximum increase of only 20%.
- In the reference model more than half of the annual cost is fuel. In Sc1 and Sc2 the main costs are investments in new biogas and biogas upgrading technologies. There are also no CO_2 costs associated with Sc1 and Sc2.

What is not captured here are the potential positive feedback effects to the local economy. With less dependency on imported fossil fuel more money would be available within the region which would help create more local jobs in among others the biomass and construction industry. A more general sensitivity is the technology used. In the case of Sc1 and Sc2 a lot of biogas was produced and upgraded to natural gas standard for the natural gas grid. Ultimately the choice of technology will determine the cost.

5. Further work

The majority of the data presented in this paper is based on a top-down approach, where national data has been scaled either using population in regards to electricity demand or land area in regards to availability of bioenergy resources. One issue is that most of the available data is only collated at national level. This highlights the difficulty to find and use regional or local data for regional modelling in Ireland. The perhaps crude data collection for this paper has however provided a starting point on which further investigation and modelling can build. Further work includes continuously searching for better data which will help create a more robust technically optimal solution using the readily available resources discussed in this paper. Furthermore, a more robust economic analysis needs to be made to reflect the technically most optimum energy system scenarios. The overall work of all future studies should involve defining a realistic pathway to a 100% renewable energy system in the SWR, which should be of benefit to all future regional and county level planning in Ireland.

6. Conclusion

This paper has explored the possibility of using EnergyPLAN to determine a regional energy plan for moving the SWR towards a 100 % renewable energy system. In summary, this model is a useful tool in exploring different technical solutions. Its simplicity however, places the onus on the user to ensure the input data is as accurate as possible. Furthermore, the model has a natural focus on CHP and district heating; although these functions do not need to be used.

Collecting appropriate data is time consuming and it has in many cases been impossible to find local or regional data. In these cases different weightings have had to be applied to national data. Some of the data at regional or local level is not collected, in other cases it is but is not released due to commercial sensitivity.

This paper clearly shows the possibility of the SWR becoming a 100 % renewable energy system by applying the correct combination of technologies. As a consequence, it is essential that a thorough investigation of as many alternatives as possible is made before major investments are made in a future energy system.

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