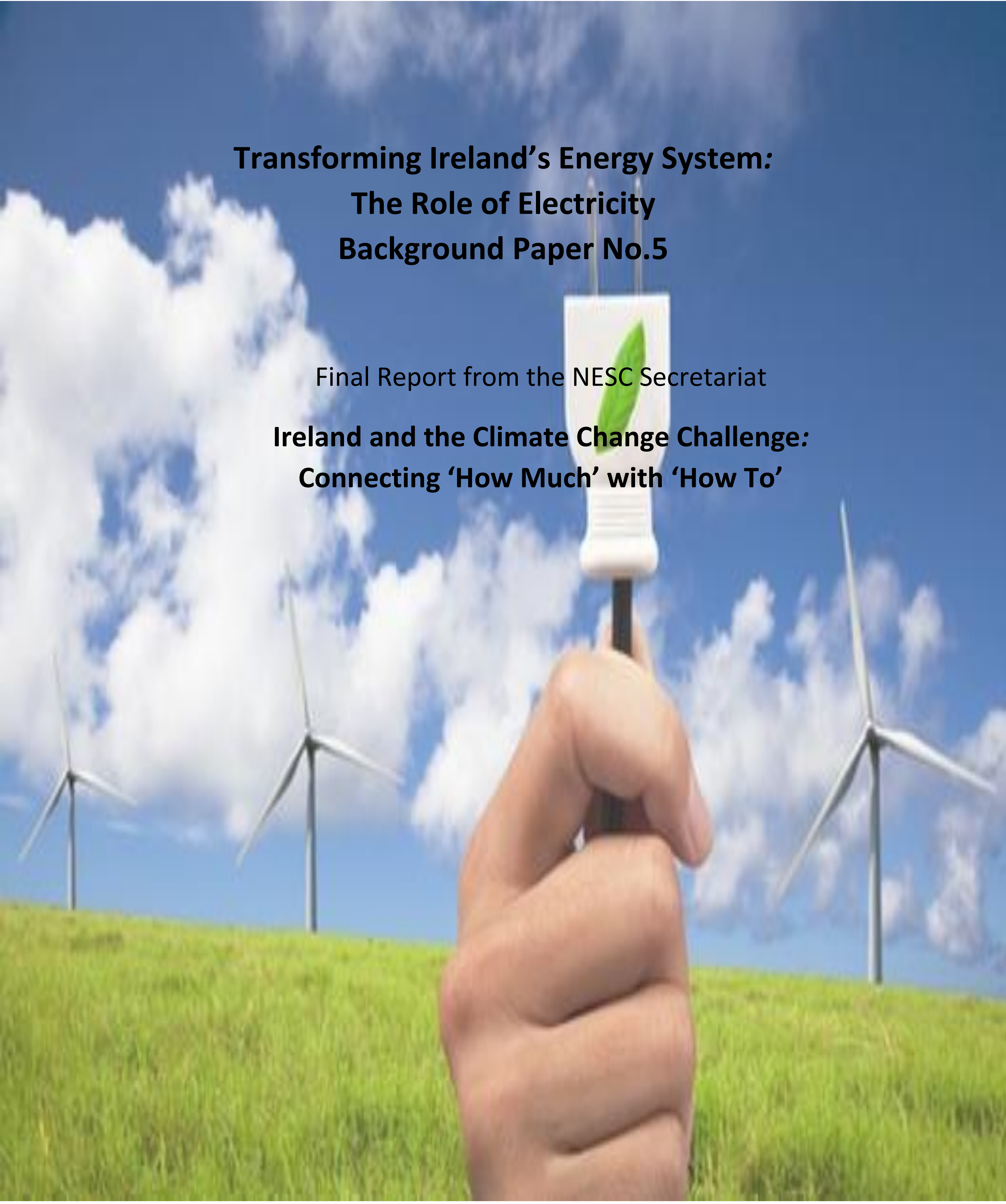


Transforming Ireland's Energy System*:* The Role of Electricity Background Paper No.5

Final Report from the NESC Secretariat

Ireland and the Climate Change Challenge*:* Connecting 'How Much' with 'How To'

An Chomhairle Náisiúnta Eacnamaíoch agus Shóisialta
National Economic & Social Council

Noel Cahill

December 2012

Executive Summary

A transformation of the energy system is required if Ireland is to achieve major reductions in greenhouse gas emissions. The transformation of the energy system also offers security of supply benefits and economic opportunities as well as benefits to air quality and health. The costs of transformation are uncertain and depend on, among other things, the future of fossil fuel and carbon prices.

This paper focuses primarily on the electricity component of energy. Electricity is expected to play a central but not exclusive role in the transition to a carbon-neutral economy. If total emissions are to be reduced by at least 80 per cent by 2050, it will be necessary to move to close to zero-carbon electricity. If electricity can be decarbonised, this will also provide the opportunity to supply low-carbon energy for transport and heating.

Electricity at present represents around one fifth of energy consumption. This share could rise substantially in the transition to a carbon-neutral economy with the widespread electrification of heat and transport. However electricity is not projected to be the only significant energy source so the other dimensions of energy (for example, energy for freight transport) also need to be addressed if low carbon in energy use is to be achieved across the economy. Biofuels are the primary form of renewable energy used in transport at present but some biofuels raise serious social and environmental sustainability concerns.

For Ireland, a decarbonised electricity system could have the following characteristics:

- Electricity is decarbonised with wind playing a central role, supplemented by other renewables (biomass, biogas, wave and tidal energy) and the possible use of carbon capture and storage.
- A substantially higher share of energy needs are met by electricity through the electrification of much heat and transport demand.
- Ireland's electricity system is integrated into a wider European market with a high level of interconnection. The integrated system may include a very large-scale offshore super-grid.
- A smart grid facilitates a high share of variable renewables on the system. There is much greater flexibility in electricity consumption*:* electricity use is linked to variations in supply through a smart grid so that users are

encouraged or enabled to take advantage of electricity when its supply is most abundant and its cost low (through for example the charging of electric vehicles).

Strong progress is being made in moving to a low-carbon electricity system in Ireland. Key policy issues to be addressed to ensure continuing progress include the following: ensuring sufficient progress in expanding the grid; development of the smart grid; achieving sufficient investment in interconnection; the provision of incentives beyond 2020; adapting the regulatory model to the internal EU energy market and to the challenges of the rising share of wind-generated electricity on the grid; sustaining investment in energy research and development; and achieving effective community engagement on renewable energy.

Ireland has abundant renewable energy resources and hence large potential to develop energy exports. In the short term the best opportunities lie in the export of wind-generated electricity. The plans that are being developed for the export of electricity from Ireland to Britain could offer worthwhile benefits but there are also risks that need to be addressed. In the longer term, Ireland has opportunities in the emerging energy technologies of wave, tidal and floating wind.

Acknowledgements

The preparation of this paper benefitted greatly from the assistance of many people. I would like to acknowledge helpful discussions with people from the following organisations: UCC Energy Policy and Modelling Group; Economic and Social Research Institute (ESRI), Department of Communications, Energy and Natural Resources (DCENR), Irish Business and Employers Confederation (IBEC), Sustainable Energy Authority of Ireland (SEAI), Commission for Energy Regulation (CER), Eirgrid, ESB, Glen Dimplex, Smart Grid Ireland and the National Electricity Association of Ireland. Extensive discussions with my NESC colleagues have also helped in writing this paper.

Transforming Ireland's Energy System: The Role of Electricity

1. Introduction

The larger part of Ireland's greenhouse gas (GHG) emissions arise from energy use. A transformation of Ireland's energy system is therefore required if we are to achieve major reductions in GHG emissions. Beyond climate change concerns, there are additional benefits to this transformation; these are explored in Section 2.

It will take a considerable period of time to transform the energy system. However by 2050, there is time for the turnover of the capital stock and its potential replacement by investment that leads to a very low-carbon system.

This paper focuses primarily on the electricity component of energy. The increased significance of electricity in a carbon-neutral economy is discussed in Section 3 along with the possible future composition of the electricity generation portfolio. The potential of offshore energy and energy exports is discussed in Section 4. Wind is likely to play a central role in Ireland's future electricity system. The challenges posed by this and possible responses are discussed in Section 5. A brief discussion of energy issues that arise outside the electricity system itself is provided in Section 6. Section 7 addresses research, development and demonstration.

2. Why Transform the Energy System?

2.1 The Challenge of Climate Change

The Stern Review of the evidence on climate change, prepared for the British government, reached a stark conclusion: 'The scientific evidence is now overwhelming: climate change presents very serious global risks and it demands an urgent global response' (Stern, 2006: i). The report projected that under a 'business as usual' scenario, there was at least a 50 per cent risk of global temperatures increasing by five degrees over the pre-industrial era level. 'This would take humans into unknown territory. An illustration of the scale of such an increase is that we are now only around five degrees warmer than in the ice age' (Stern, 2006: iv). The implications of this are profound. In the words of Stern: 'Temperature increases of this magnitude will disrupt the climate so severely that there will be massive movements of population, global conflict and severe dislocation and hardship' (Stern, 2009: 8).

The rise in global temperatures will continue as long as the stock of greenhouse gases concentrated in the atmospheres is rising. To stabilise the stock of greenhouse gases it is necessary to reduce the annual level of emissions to the level at which greenhouse gases are removed from the atmosphere. This means that annual emissions must first peak and then decline, ultimately to very low levels. The level at which the stock of GHGs in the atmosphere is stabilised depends on the cumulative level of emissions of GHGs less the cumulative level at which they are removed from the atmosphere. The level of stabilisation is related to the expected rise in temperatures (Stern, 2006).

The later the peak in annual emissions occurs, the higher the rate of decline in emissions after the peak or the lower the level of emissions required in the long run in order to achieve any given temperature target with the same probability (Fee *et al.*, 2010). Early peaking matters for the achievement of certain temperature targets because if the year in which emissions peak is delayed for too long, the subsequent decline in emissions required for a given target becomes beyond what is feasible to achieve. As high carbon energy infrastructure becomes locked in, it becomes difficult or impossible to achieve the desired target to limit the rise in temperature.

The international community, in the Copenhagen Accord, adopted the goal of limiting the rise in global temperatures to 2°C. Conditions to ensure a likely (more than 66 per cent) chance of limiting the rise in global temperatures to less than the 2°C were identified by Fee *et al*., as follows:

- A peak in global emissions is required by approximately 2015;
- A decrease in global emissions of 50-70 per cent relative to 1990 levels is necessary by 2050 (Fee *et al.*, 2010).

Larger reductions would be required in developed countries to take account of economic development in other countries. The European Council has adopted the goal of reducing the EU's GHG emissions by 80 to 95 per cent by 2050, relative to 1990 (European Council, 2009); this was reaffirmed in 2011 (European Council, 2011).

2.2 Security of Supply

The achievement of large reductions in energy-related GHG emissions implies a major shift to enhanced energy efficiency and renewable energy. In addition to climate benefits, this would also improve security of energy supply. As the IEA notes, renewable energy and potential for energy efficiency gains exist almost everywhere in contrast to other energy resources which are generally much more geographically concentrated (IEA, 2012a). Ireland has an unusually high reliance on imported fossil fuels and an abundance of renewable energy resources.

There are risks associated with Ireland's high reliance on oil. Oil prices have increased five-fold over the past decade and the IEA (2012b) projects further growth in oil prices in the period to 2035. Its central scenario projects an increase in real prices of 16 per cent in the period from 2011 to 2035 with projected real oil prices of $125/barrel (in 2011 prices) in 2035 or $215/barrel in nominal terms. This projected rise in prices occurs despite substantial projected growth in oil production over the period to 2035 due to increases in unconventional oil and natural gas liquids[1].

Other scenarios for oil output and prices are considered in the *World Economic Outlook* of the IMF (2011). This analysis suggests that oil scarcity would not inevitably be a strong constraint on the global economy but that the risks posed should not be underestimated either. The IMF considered a benchmark oil scarcity scenario in which oil production grew by one percentage point less than its historical trend. If this slowdown in the growth of oil production were to occur, it would lead to a cumulative oil price increase of about 200 per cent over 20 years. The longer term output effects would not be very severe with GDP around 3 per cent lower in the euro area compared to an unconstrained oil production scenario. This IMF analysis also considered an alternative scenario whereby oil production declines by 2 per cent annually. This scenario reflects the concerns of peak oil proponents who expect rapid reductions in global oil production. In this scenario, it projected that oil prices would increase by 200 per cent initially and by 800 per cent over 20 years. The economic impacts were projected to be three to four times the size of those in the first scenario considered. However, price changes of this magnitude would be unprecedented so the economic effects are not well captured in existing models.

Ireland is expected to have a continuing need for oil for several decades even if there is a successful transition to a carbon-neutral economy by 2050. In particular there

[1] Natural gas liquids are co-produced with natural gas; they are not generally used for transport purposes.

will a continuing need for oil in transport for an extended period. Some of this demand could be met from oil discovered off Ireland. In October 2012, Providence Resources announced that it estimated that it could recover 280 million barrels of oil from an oil field (Barryroe) off the Cork coast. The company considers that Barryroe represents the first commercial discovery of oil off Ireland's coast. The Department of Communications, Energy and Natural Resources (DCENR) has suggested that there could be a potential 10 billion barrels of oil equivalent (i.e., oil and gas resources) in the Atlantic coastal area off Ireland — as reported by the Joint Oireachtas Committee on Communications, Natural Resources and Agriculture (2012).

In the transition period to a low carbon economy the development of oil resources off Ireland's coast would be desirable as it could improve security of supply and offer economic benefits. However, the development of oil in Ireland's coastal waters would not insulate Ireland from future oil price shocks as oil prices in Ireland would still reflect global markets.

Natural gas provided 30 per cent of Ireland's energy in 2011. The IEA (2012b) estimates that conventional supplies of natural gas are equivalent to more than 120 years of current global consumption while total resources (including unconventional supplies) could be equivalent to 250 years of current consumption. Significant environmental concerns arise from the use of hydraulic fracking in unconventional gas production; serious hazards include the potential for air pollution and the contamination of surface and groundwater. According to the IEA, the know-how exists to address the environmental challenges 'but a continuous drive from governments and industry to improve performance is required if public confidence is to be maintained or earned' (IEA, 2012c: 9).

Natural gas has considerably lower emissions than other fossil fuels, so its increased use could play an important transitional role to a carbon-neutral economy. However, the IEA emphasises that natural gas is not in itself a solution to the climate-change challenge. The IEA points out that the achievement of the 2°C target requires a greater shift to low-carbon energy sources, increased energy efficiency and new technologies including carbon capture and storage (CCS).

In 2010 Ireland's domestic supplies of natural gas represented around 7 per cent of domestic consumption; the bulk of Ireland's natural gas is imported through three pipelines from Britain. There is vulnerability in this situation in that all three pipelines flow through the one onshore pipeline in Scotland. FitzGerald (2011) refers to the loss of supply through this pipeline as 'highly improbable' but the effects would be dramatic. The development of the Corrib gas field would offer an interim solution to this security of supply concern and there is potential for further gas discoveries. The initial annual output from Corrib is forecast to reach around two thirds of 2010 annual gas consumption. It is expected to then decline to around one fifth of 2010 consumption after four years (IEA, 2012d).

Coal represented 9 per cent of Ireland's primary energy supply in 2011. It is in plentiful supply globally. If current policies are maintained, it is estimated by the IEA that coal use would rise 65 per cent by 2035 and coal would overtake oil as the largest fuel in global use. If a scenario consistent with limiting the rise in global temperatures to 2°C were to be achieved, global coal use would need to peak well before 2020 and then decline.

Security of supply issues also arise in relation to renewable energy. Wind is an intermittent source of energy and its ability to contribute to a growing share of electricity generation depends on this being successfully addressed (see Section 6). Biomass supplies are renewable but are subject to resource constraints.

2.3 Economic Benefits

The shift to a low-carbon energy system offers the possibility of economic gains. The IEA (IEA, 2012a) estimates that the shift to the two degrees path would require a doubling of global investment in clean energy by 2020, and additional global energy investment of US$ 36 trillion (35 per cent) from today to 2050, relative to a scenario in which controlling carbon emissions were not a priority. Initially the additional investment cost is projected to exceed the savings in fossil fuels. However, it is projected that the fuel savings for the global economy would outweigh the investment costs by 2025. Furthermore, if a 10 per cent discount factor is used, the discounted present value of global net savings over the period 2010 to 2050 was estimated to be US$ 5 trillion. These estimates of benefits and costs are subject to uncertainty; they depend on assumptions regarding the costs and performance of emerging technologies and future fossil fuel prices

The development of Ireland's renewable energy resources for domestic and export markets could, in certain contexts, boost the level of economic output and employment. The movement to a carbon-neutral economy creates new market opportunities and Ireland may be able to capture some of these; for example, industries related to wave and tidal energy. The transformation of the energy system could lead to other economic gains; for example, the application of ICT to the development of a smart grid could generate new economic opportunities.

It is not inevitable that all renewable energy investments will lead to economic gains. Where renewable energy investments lead to significant cost increases there is the potential for negative effects on competitiveness and the economy. There are uncertainties involved, so not all new energy investments will prove profitable.

2.4 Air Quality and Heath Benefits

The development of clean energy also has the potential to contribute significant air quality benefits. The shift to electricity use in transport and the expansion of public transport could improve urban air quality. It has been estimated that, for the EU, the annual cost of controlling traditional air pollutants could be €10 billion lower in 2030 as a result of policies to reduce GHG emissions. There would be health benefits and reduced damaged to ecosystems (European Commission, 2011a).

2.5 Costs

An important issue is the potential cost of transforming the energy system. There are considerable uncertainties attaching to any cost estimates for 2050; such estimates depend on projections of fuel costs and on technological developments.

Cost estimates for the EU of a number of low-carbon scenarios by 2050 are presented in the European Commission's Energy Roadmap to 2050 (European Commission, 2011b). In this analysis, it is projected that there is either no additional or little additional average annual energy system costs over the period 2011 to 2050 in the low-carbon scenarios *compared to the current policy scenario.* However there are substantial cost increases in all scenarios.

Cost estimates for Ireland are presented by Ó Gallachóir *et al.* (2012) who have modelled possible low-carbon scenarios for the energy system in the period to 2050 using the Irish TIMES model. The Irish TIMES work focussed on two low-carbon scenarios: CO_2-80 in which energy-related emissions are cut by 80 per cent by 2050 relative to 1990 and CO_2-95 in which energy-related emissions are cut by 95 per cent by the same date. If agricultural emissions were cut by 50 per cent by 2050, then a reduction in energy-related emissions of 95 per cent would result in a fall in GHG emissions of 80 per cent by 2050. The low-carbon scenarios are compared to a reference scenario. This is based on the development of the energy system to 2050 in a way that minimises costs but without any constraint on emissions.

It is projected by Ó Gallachóir *et al.* that in the absence of a constraint on emissions (i.e., the reference scenario) the total cost of the energy system in 2050 would be 7.0 per cent of GDP. It was estimated that total costs would be 0.7 per cent of GDP higher in the case of the CO_2-80 scenario while costs are 1.6 per cent of GDP higher in the CO_2-95 scenario. Estimates of marginal costs are also provided. In the case of the CO_2-80 scenario, the marginal cost of reducing emissions is projected to be €273/tonne in 2050 while in the case of the CO_2-95 scenario the projected marginal cost is €1308/tonne. These marginal costs are very high, particularly in the case of the CO_2-95 scenario. However, it is important to note that the marginal cost refers to the cost of achieving the last unit of reduction in emissions. The total cost figures give a better indication of overall costs.

Electricity prices are one dimension of energy costs. Projections of these are not provided in the Irish TIMES analysis. Key influences on electricity prices in low-carbon strategies relative to the alternative are the evolution of gas prices and the carbon price in the emissions trading scheme (ETS) system. With high gas or carbon prices, a high level of wind generation can reduce electricity costs (Diffney *et al.*, 2009). If the EU sustains its commitment to a low-carbon transition then carbon prices can be expected to reach increasingly high levels in the period to 2050. Conversely, if gas or carbon prices are low, then the use of renewable energy in electricity will be more expensive. Electricity prices in different scenarios are explored further in the next section on transforming Ireland's electricity system.

Fuel poverty is a significant problem at present and there is a risk that a transition to a carbon-neutral economy could exacerbate this. However there is considerable potential to reduce fuel poverty while reducing energy-related emissions. In particular targeted assistance for home energy improvements can simultaneously address fuel poverty and save energy. Likewise actions that reduce private car dependence are of particular benefit to people on lower incomes and reduce emissions associated with transport. In moving to a carbon-neutral economy, it is vital to avoid increasing fuel poverty while making full use of the opportunities to reduce it.

2.6 Conclusion

A transformation of the energy system is required to reduce energy-related emissions to address the challenge of climate change. The transformation of the energy system also offers security of supply benefits and economic opportunities as well as benefits to air quality and health. The costs of transformation are uncertain and depend on, among other things, the future of fossil fuel and carbon prices.

3. Transforming Ireland's Electricity System

3.1 Central Role of Electricity in a Carbon-Neutral Economy

Electricity is expected to play a central but not exclusive role in the transition to a carbon-neutral economy. If total emissions are to be reduced by at least 80 per cent by 2050, it will be necessary to move to close to zero-carbon electricity. The European Commission's Low-Carbon Roadmap to 2050 projects a fall in emissions from electricity generation of 93 to 99 per cent for the EU (European Commission, 2011a). If electricity can be decarbonised, this will also provide the opportunity to supply low-carbon energy for transport and heating.

In 2011 electricity represented around one fifth of final energy consumption. In the Irish TIMES modelling it is projected that this share will increase to between 31 per cent and 47 per cent by 2050 if energy-related emissions are cut by 80 to 95 per cent (Chiodi *et al.*, 2013). This however may understate the effective potential contribution of electricity to meeting energy needs. Electric vehicles are a very efficient means of using energy. It is projected by Chiodi *et al*. that the use of electric vehicles could cut the energy used for private transport by 80 per cent by 2050 relative to where it would otherwise be. If account is taken of this effect, the effective contribution of electricity to meeting energy needs in 2050 could exceed 50 per cent. Key areas that are expected to require energy beyond that provided by electricity in 2050 are freight transport, industrial processing and some share of heat in buildings.

The continuation of normal growth in demand for electricity in conjunction with increased use of electricity in transport and heating would lead to a major increase in demand for electricity. A successful transition to a carbon-neutral economy will require major energy savings from improved energy efficiency. Improvements in energy efficiency can be achieved in buildings, heating systems appliances, vehicles and the electrification of transport. Energy efficiency is explored in Background Paper No. 6. Energy savings can moderate the growth in electricity demand although demand would still increase substantially. The SEAI Smart Grids Roadmap envisages an increase in demand for electricity of almost 80 per cent by 2050 relative to 2011 (SEAI, 2011a).

3.2 Changing Structure of Energy Supply

Strong progress has been made over the past 20 years on the decarbonisation of Ireland's electricity supply. The carbon intensity of Ireland's electricity has fallen from almost 900g/kilowatt hour (kWh) in 1991 to 490g/kWh in 2011. This sharp fall in carbon intensity is due to the rise in the renewable element of electricity and the shift to gas from more carbon intensive fuels (coal, peat and oil). The share of renewable electricity for electricity generation has increased from 5.0 per cent in 2000 to 19.4 per cent in 2011; when adjusted for weather conditions (the definition used in measuring progress towards EU targets) the renewables share was 17.6 per cent in 2011. The growth of renewable electricity in Ireland over the past decade has been driven by the exceptionally strong growth of wind generation. Wind generation contributed 13.7 per cent of electricity in 2011 while hydro was responsible for another 2.7 per cent; there were further contributions from biomass (0.5 per cent) and landfill gas (0.6 per cent). All wind-generated electricity in Ireland is onshore wind with the exception of one offshore wind farm (the Arklow banks).

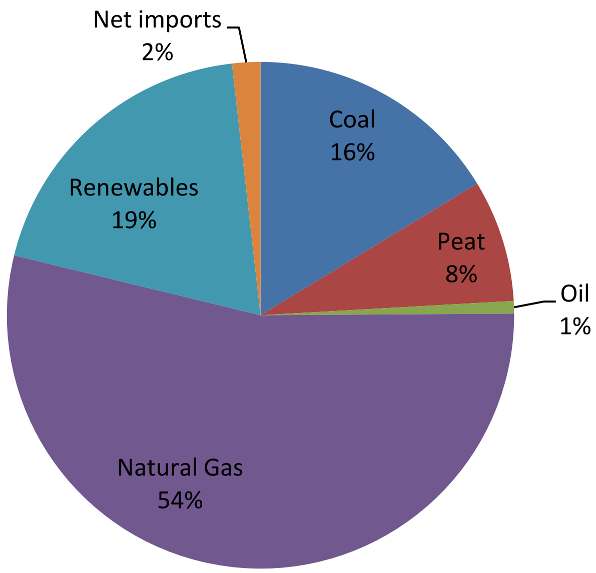
The share of natural gas in electricity generation has risen sharply from 27.7 per cent in 1990 to 53.9 per cent in 2011. Renewable energy sources together have become the second most significant contributor to electricity generation. Coal's share of electricity consumption has fallen substantially, from 41.6 per cent in 1990 to 16.3 per cent in 2011. Peat contributed 7.8 per cent of electricity generation in 2011 while oil represented less than 1.0 per cent.

However, while oil is now a marginal contributor to Ireland's electricity generation it still represented almost half of total energy used in Ireland in 2011[2]. Natural gas contributed 29.8 per cent of Ireland's energy needs in 2011 while coal contributed 9.1 per cent. Renewable energy provided 6.0 per cent of Ireland's primary energy in 2011. The largest components of renewable energy in 2011 were wind (2.7 per cent of total energy) and biomass (1.5 per cent).

---

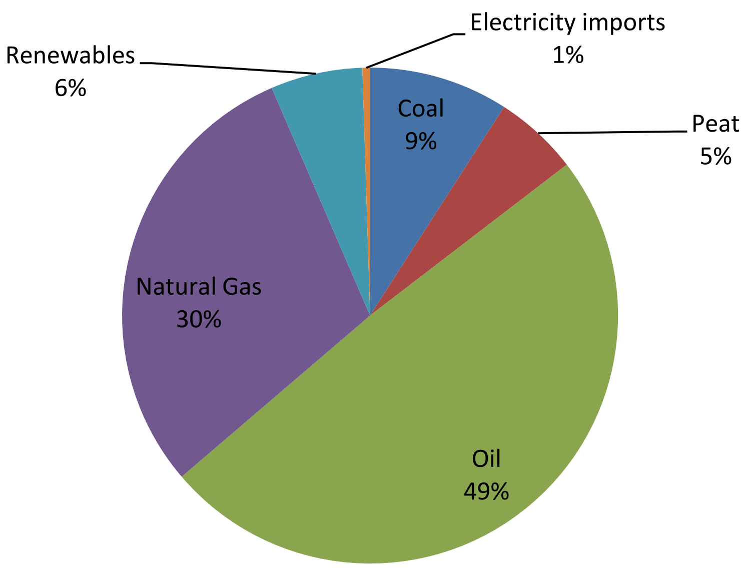
2 Total energy used includes the energy required to transform primary energy such as oil, gas or wind into forms useful for consumers such as electricity and refined oil.

Figure 1: Gross Electricity Consumption by Fuel Source, 2011



Source*:* (SEAI, 2012a).

Figure 2: Total Primary Energy by Fuel Source, 2011



Source*:* (SEAI, 2012b).

3.3 The Renewables Directive

The Renewables Directive (2009/28/EC) sets a target that 20 per cent of energy for the EU as a whole is to be from renewable sources by 2020. Ireland's legal commitment is that 16 per cent of energy consumed in Ireland will be from renewable sources by 2020.

There is also an EU requirement that 10 per cent of energy in transport in each member state is to be renewable by 2020. Biofuels are the primary means of using renewable energy in transport at present. The EU and Ireland rely heavily on imports of biofuels. The policy of the EU and other advanced countries on biofuels has been subject to widespread criticism because of environmental and social sustainability concerns. Biofuels produced from food crops raise social sustainability concerns on account of the impact on global food prices and the increased pressure on land in developing countries that threatens the land rights and livelihoods of rural communities (Anseeuw *et al.*, 2012; Cotula *et al.*, 2008 and Schoneveld *et al.*, 2011). A report by ten international organisations including the IMF and the World Bank to G20 leaders recommended the removal of biofuel subsidies and mandates[3] (FAO *et al.*, 2011). This recommendation was based on analysis that indicated that biofuels resulted in substantially higher prices for some food commodities and a significant increase in food price volatility. An increase in food price volatility is a critical issue as sharp increases in food prices have disastrous consequences for poor people in developing countries. In October 2012 the European Commission proposed that the use of food-based biofuels to meet the 10 per cent renewable transport target would be limited to 5 per cent. If adopted this would have consequences for how Ireland meets its renewable transport target. In any event the serious concerns raised by many international organisations about biofuels call for further reconsideration of both Irish and European policy in this area.

Apart from the transport requirement, there is national discretion on the composition of the 16 per cent renewable energy. Ireland's plans are set out in the *National Renewable Energy Action Plan* (NREAP) (Department of Communications, Energy and Natural Resources, 2009). In Ireland's case, it is intended that the largest contribution will come from electricity with a target that 40 per cent of electricity should be from renewable sources (primarily wind) by 2020 while 12 per cent of heat energy is to be renewable by that date. The IEA (2012d) notes that this would make Ireland a world leader in terms of the share of wind in its generation mix. The

---

[3] Biofuel mandates require oil companies to include some percentage of biofuels in fuel. Ireland and many other countries have such mandates.

challenges now being addressed by Ireland in accommodating a high share of wind within a single power system will be faced later in other systems. Therefore the capabilities being developed in Ireland now are of international significance.

Rapid progress is being made towards the achievement of the 40 per cent renewable electricity target. Progress is slower on the expansion of renewable heating (although its share has doubled to 4.8 per cent of consumption in 2011 since 1990) and renewable transport (a 2.6 per cent share in 2011). Renewable energy represented 6.4 of Ireland's gross energy consumption in 2011.

Table 1: Renewable Energy as Percentage of Gross Energy Consumption by Sector, 1990-2011

	1990	2005	2010	2011	Targets for 2020
Renewable electricity (normalised)	5.3	7.2	14.8	17.6	40
Renewable Transport	0.0	0.0	2.4	2.6	10
Renewable Heating	2.6	3.4	4.3	4.8	12
Total Renewables	2.3	2.8	5.5	6.4	16

Source: (SEAI, 2012b).

3.4 Carbon Price and Incentives

The ETS puts a price on emissions from electricity generation and energy intensive activities. However to date the carbon price in the ETS has been too low to have a significant incentive effect. At present the low prices of carbon and coal have the unfortunate effect that coal-generated electricity is more cost competitive than gas, despite the high emissions from coal. The strong growth in renewable electricity that has occurred has been driven by the price incentives provided for renewable electricity through the renewable energy feed-in tariff (REFIT).

The growth of renewable energy beyond 2020 will be strongly influenced by the EU policy framework. A 2012 discussion paper on renewable energy by the European Commission considers possible options for the period after 2020 (European Commission, 2012). It is vital that an EU policy framework is put in place for the post-2020 period that incentivises low-carbon electricity generation.

3.5 Future Generation Mix

3.5.1 Central Role of Wind

A range of analyses indicate that wind is expected to play a central role in Ireland's future electricity generation mix. Ó Gallachóir *et al.* (2012) used the Irish TIMES model to consider what generation portfolio would minimise electricity generation costs subject to reducing carbon dioxide emissions by 80 to 95 per cent by 2050. In both the 80 and 95 per cent scenarios, it was projected that a major share of onshore and offshore wind (around two thirds) emerged as the lowest cost solution. This result depends on assumptions made regarding the evolution of technology and costs. The generation mix presented in the SEAI Smart Grid Roadmap also involved around two thirds of electricity coming from wind in 2050.

Ireland has among the best quality wind resources in Europe. When account is taken of offshore wind resources, the available resources are a multiple of Ireland's prospective demand for electricity.

The experience to date has shown that wind can be a reasonably low cost way of providing renewable electricity. Analysis by Clifford and Clancy (2011) estimated that there was no additional net cost due to wind generation in 2011. There were extra costs associated with wind in that year arising from the use of the public service obligation (PSO) to provide price guarantees to wind and costs associated with running a stable electricity system arising from the presence of wind. However these extra costs were offset by the impact on wholesale electricity prices: wind replaces fuel with a higher marginal cost and thus reduces electricity prices. The impact of wind on infrastructure costs was not included in this analysis. It was based on the perspective that the level of wind generation in 2011 had not required additional infrastructure investment beyond what would otherwise have been necessary. The ongoing expansion of wind will require grid investment so this is an additional cost that will need to be considered.

Analysis by Diffney *et al.* (2009) examined the impact of varying levels of wind capacity on electricity costs for the island of Ireland in 2020. This analysis included the impact of grid investment costs and interconnection costs as well as direct electricity costs. The analysis considered electricity costs for a range of possible fuels costs and carbon prices and also for different levels of interconnection to Britain. It was assumed that all wind would be onshore wind.

This analysis estimated that in the case of high or medium prices for fuel or carbon, a high level of wind generation—up to 6000 megawatts (MW) on the island—would reduce electricity costs. On the other hand, if gas or carbon prices are low, then a high level of wind would result in higher costs to consumers compared to a low level of wind (2000 MW on the island). The increased costs that result from having too much wind in the presence of low gas or carbon prices are less than the cost of having too little wind should fuel or carbon prices turn out to be high. FitzGerald (2011) infers from this that investment in onshore wind therefore appears to be a hedge against possible future high carbon or fuel prices.

A very high level of wind generation would pose major challenges for the grid. This is partly taken into account in the Irish TIMES results by imposing a 70 per cent limit on the share of variable generation on the grid; further research is being undertaken on this issue. The variability of wind means that the system cannot rely solely on wind. The remainder of this sub-section explores other possible forms of domestic generation. Possible ways of accommodating a growing share of wind on the grid are explored in Section 6.

3.5.2 Projections of Other Sources of Electricity Generation to 2050

The SEAI Smart Grid Roadmap to 2050 sets out a mix of fuels along with wind that could be used to achieve an overall low level of emissions. The largest projected element other than wind in the 2050 power generation mix is biomass/biogas. Wind and biomass, together with other renewables (ocean and hydro) provide 88 per cent of electricity in this scenario in 2050. The other elements of the mix are: gas, gas with CCS and a small amount of coal.

In the Irish TIMES CO_2-80 scenario, the larger part of the additional energy for electricity in 2050 would come from gas with CCS. In the CO_2-95 scenario, the largest complement to wind would be biomass. However, in subsequent work (informed by Teagasc) the projected volume of available wood was revised downwards and, in a revised Irish TIMES CO_2-95 scenario, the largest complement to wind in the generation mix is ocean energy (wave and tidal) with biogas and waste also contributing (Chiodi, 2012)[4].

[4] While the projected wood energy available was revised downwards the total projected bioenergy supply is higher in the revised projections due to a higher projected contribution of biogas from grass.

3.5.3 All-Island Generation Portfolio Options for 2035

A report commissioned by Eirgrid from consultants (Pöyry Energy Consulting, 2010) considered possible low-carbon generation portfolios that would achieve emissions from electricity generation of below 100g/kWh by 2035. All of the portfolios build on the existing 40 per cent renewable electricity target by 2020. Wind is the single largest share of generation capacity by 2035 in all of the portfolios considered (its share varies from 46 to 57 per cent). Pöyry's analysis also recognised the need to replace existing coal, oil and peat fired generation in the period to 2035 with alternatives. The portfolios considered were as follows:

- gas-focused portfolio;
- CCS-dominated portfolio;
- nuclear-focused portfolio; and,
- high renewables portfolio.

Pöyry compared the final retail prices associated with these generation portfolios; this included estimated wholesale prices, capacity payments and likely subsidies but excluded network charges (for transmission and distribution infrastructure). The gas-focussed portfolio is projected in this analysis to have the lowest prices of the options considered and is viewed by Pöyry as a continuation of current policy and the most likely option. Gas is projected to represent 38 per cent of generation capacity in this portfolio while wind represents 46 per cent of capacity in 2035. In the Irish TIMES analysis an even higher share of gas generation is projected for 2040 in the absence of emissions constraints (i.e., the reference scenario). This approach has the disadvantage of further increasing Ireland's high reliance on imported gas. This would be less of a concern in the event of further domestic gas discoveries or if shale gas led to low European gas prices. However, a further disadvantage of this portfolio is that it fails to achieve a sufficiently low level of emissions: emissions do not fall to the target 100g/kWh target used by Pöyry.

The CCS portfolio achieves the lowest level of emissions of all the portfolio options considered by Pöyry with projected retail prices marginally (1.0 per cent) higher than the gas-focussed option. However there are considerable uncertainties relating to this technology. It has not yet been deployed on a commercial basis and the IEA (2012a) expresses concern at the limited level of investment in CCS.

The nuclear portfolio is also projected by Pöyry to achieve a low level of emissions and the same projected retail price as the gas-focussed portfolio. However it has a number of significant disadvantages. First, Pöyry note that there are high project risks due to the social acceptability and the complexity of this option. The commercially available nuclear plants are large relative to the size of the Irish market and this increases the complexity and risks. It is suggested by Pöyry that nuclear feasibility could be re-examined in future if smaller nuclear plants become commercially available. Second, it is argued by FitzGerald (2011) that, given the success to date of onshore wind in Ireland, a nuclear plant would not be economic. By 2020 Ireland will have a high share of wind. Because wind has a zero marginal cost it depresses the wholesale electricity prices so FitzGerald argues that a nuclear plant would not be able to earn a sufficient return on its investment in this situation.

The high renewables option is based on achieving 80 per cent renewable generation by 2035. The wind share is limited to 60 per cent as it is assumed that above this level the requirement for back-up generation becomes onerous. The balance of renewable electricity is assumed to be supplied by wave and tidal energy and biomass. These other renewable options have higher costs than wind. Variants of the high renewable options were considered. A 'high renewables plus interconnection' option was considered with additional interconnection to Britain and France. A 'high renewables plus storage' option was also considered; this option involves the addition of sea-water based pumped storage in conjunction with wind. The Pöyry analysis projected that the high renewables options would have low emissions[5] but costs were projected to be somewhat higher than the gas-focussed portfolio.

All of the options considered in Pöyry's analysis either come close to or achieve their target of reducing emissions below 100g/kWh by 2035. The gas-dominated portfolio is regarded by Pöyry as the most likely outcome by 2035. A portfolio with a large share of unabated gas generation in 2050 would not be consistent with achieving a low carbon economy by that date. Pöyry acknowledge that this portfolio would not be a sustainable solution in itself, but 'any trajectory towards this portfolio could be considered as a transitional step towards other lower emission options and carbon neutrality by 2050' (Pöyry Energy Consulting, 2010: 1). While gas has a significant role to play as a transitional fuel there is a danger that an excessive level of

[5] Emissions on a standalone basis are well below the 100g/kWh target used by Pöyry for all of the high renewables options but when interconnector volumes are included only the high storage renewables option is below this threshold. This arises because it is assumed that the marginal plant that supplies the imported electricity uses gas. Of the other portfolios considered by Pöyry only the CCS portfolio meets the 100g/kWh target.

investment in gas generation would prevent the achievement of really low emissions by 2050.

3.5.4 Moneypoint

Ireland's Moneypoint power station is a large coal-based plant and will reach the end of its expected lifespan around 2025. Decisions need to be taken in the next few years on its replacement. Coal with CCS is one possibility, although the uncertainty about CCS will probably not be clarified within the time period that a decision would be required. Coal with CCS does not feature in any of the Irish TIMES decarbonisation scenarios. This is because it does not reduce emissions sufficiently to achieve the targets for emissions reductions. Another possibility is gas. Ireland already has a high reliance on gas so further reliance on gas would raise security of supply concerns as discussed above. A large gas plant would not be consistent with radical decarbonisation of electricity generation by 2050, unless it could be subsequently retrofitted with CCS. Another option mentioned by FitzGerald (2011) is enhanced interconnection rather than directly replacing Moneypoint in Ireland.

3.5.5 Biomass

Biomass is a potential complement to wind in a decarbonised electricity system. Its modest role relative to wind in providing renewable electricity to date is a reflection of its higher costs. However, biomass has the advantage of being a low carbon, renewable energy source that can be used to provide a non-varying supply of electricity. Biomass use in Ireland has grown more in heating than in electricity. The use of biomass in heating and industry provides a considerably higher energy return than in electricity for a given input of biomass.

The co-firing of biomass with peat is identified in SEAI's marginal cost of carbon analysis (Motherway & Walker, 2009) as a reasonably low-cost carbon abatement option. This arises because it is being used in existing plants and partially replaces peat, which itself is a fairly high cost fuel. A target of 30 per cent for biomass co-firing by 2015 in the three state-owned peat stations was set in the 2007 White Paper, *Delivering a Sustainable Energy Future for Ireland*. Rapid progress has been made on this in the Edenderry power station. Some imported biomass is used, but there has also been considerable success in mobilising domestic supplies (pulp wood and thinnings). The introduction of the most recent REFIT scheme (REFIT 3) provides support for biomass use in electricity including co-firing. Peat use will eventually be phased out in the generation of electricity. Co-firing is helping to build a supply chain for biomass and increase confidence in this market. The supply chain created could, in time, supply other markets in heating.

There are also environmental impacts associated with the production of biomass that need to be considered.. An assessment by Finnan *et al*. (2012) of plans for peat co-firing with biomass found that the net environmental impact of replacing peat with domestically-produced biomass was considerably more favourable than that of using imported biomass.

Key factors that will affect the future role of biomass in electricity generation are the evolution of costs and availability of supplies and the extent to which other solutions to wind's variability are developed (see below).

3.5.6 Micro-generation

Micro-generation refers to the small-scale generation of electricity. It includes the following: small scale wind turbines; solar photovoltaic (PV) cells (i.e. solar electric panels); micro-hydro; and micro-CHP. The Energy Performance of Buildings Directive is expected to drive the expansion of micro-generation in the EU while the development of the smart grid will facilitate the integration of power from micro-generation.

3.6 Community Engagement

The expansion of renewable electricity and other forms of renewable energy raises issues of community engagement.[6] Grid investment is an essential pre-condition for the expansion of renewable energy and this often encounters community opposition (see Section 5). Community concerns also sometimes arises in relation to wind farms. Ellis *et al.* argue that where opposition to wind farms occurs that it is often fuelled by insensitive handling of proposals (Ellis *et al.*, 2009). International experience suggests that a greater level of local ownership of wind energy projects is an important option for maximising local benefits (Ellis, 2012).

Beyond issues of community acceptance there is scope for communities to develop renewable energy projects. Community involvement in renewable energy, whether with private developers or in community led projects, is a complex and demanding process. The Western Development Commission (2007), based on their experience of facilitating a community wind farm, concluded that a support structure is required

[6] This sub-section draws on Background Paper No. 3.

if community involvement and investment is to occur on a widespread basis in Ireland. These issues are further examined in Background Paper No. 3.

Box 1: Milestones in the Transformation of the Energy Sector

2013: New Energy Policy Framework to be published.

Intergovernmental memorandum signed on renewable electricity exports to the UK while work continues on reaching an intergovernmental agreement.

Final Offshore Renewable Energy Energy Development Plan to be published.

Foreshore legislation for new offshore licensing and permitting regime to be published.

National Bioenergy Strategy to be published.

Final decision on regulatory treatment of curtailment of wind farms.

Rollout of smart meters to commence and to be completed 2017-2019.

2016: Ireland is required to meet requirements of the completion of the EU internal electricity market by the end of 2016.

2020: 40 per cent renewable electricity target to be achieved.

2025: Grid 25 investment programme to be completed.

Moneypoint due to end normal expected lifespan.

4. Potential of Offshore Energy and Energy Exports

4.1 Offshore Resource Potential

According to the IEA, Ireland's location at the edge of the Atlantic Ocean provides one of the best wind and wave resource potentials in Europe (IEA, 2012d). The scale of the potential resource was estimated in the *Draft Offshore Renewable Energy Development Plan* (2010).

Table 2: Ireland's Offshore Renewable Energy Potential

Technology	Potential Energy Resource (MW)
Fixed Offshore Wind	9,800 to 12,500
Wave (0 to 100 meter depth)	12,500 to 13,600
Wave (100 to 200 meter depth)	15,000 to 17,500
Tidal	1,500 to 3,000
Floating Wind	25,000 to 27,000
Total	**63,800 to 73,600**

Source*:* (Department of Communications, Energy and Natural Resources, 2010)

The estimated total potential resource is enormous at 63,800 to 73,600 MW. This can be compared to peak Irish electricity demand at present of around 5000 MW. Hence the estimated total potential resource is over 12 times Ireland's current domestic needs, so this is a major potential export resource.

These estimates of resource potential do not take account of commercial constraints. The extent to which this resource potential can be developed commercially will depend on many factors including technological developments and the extent to which it is supported by policy.

Fixed offshore wind is an established technology that is being already being deployed on a large-scale basis off Britain; it is considered that there is substantial scope to achieve reductions in the cost of offshore wind. Wave, tidal and floating wind are emerging technologies. They are not commercially viable at present but could become so in future years.

4.2 Wind

In the original NREAP, it was indicated that both onshore and offshore wind would be used to meet the 40 per cent renewable electricity target for 2020. However, in the light of changed economic circumstances and policy advice, it has now been decided to seek to achieve the 2020 target through onshore rather than offshore wind in the first instance (Department of Communications, Energy and Natural Resources, 2012a). Offshore wind will be developed if suitable arrangements for export are put in place. Initially the most likely prospect for the export of energy from Ireland is the export to Britain of both onshore wind from the Midlands and offshore wind close to the east coast of Ireland. There are pressures on Britain's electricity supply. A considerable volume of its generation plant is due to close in the coming years. The UK is also having difficulty in meeting its renewable electricity target.

Discussions are well advanced on reaching an intergovernmental agreement with the UK that would make the export of electricity from Ireland possible. The proposals for energy exports are based on direct one-way connections from Ireland to the British grid. They would not be interconnectors between the Irish and British grids; in fact there would not be any connection to the Irish grid. The connections would not be used to import electricity to Ireland or to export surplus electricity from the Irish system (other than from the dedicated wind farms). The lack of connection to the Irish grid has the advantage that there would not be any contribution to congestion on the Irish system. However, this also means that Ireland's system does not become more interconnected to Britain although it may be possible to subsequently upgrade these links to genuine interconnectors. A disadvantage of the proposed connections functioning as interconnectors with Ireland is that because the capacity in the individual cables is very large, it would not be possible for the Irish grid to cope with these large capacities being turned on or off. This suggests that only a proportion of the capacity of the proposed cables could be used as interconnectors interacting with the Irish grid.

The export of electricity has the potential to provide significant economic benefits to Ireland. The terms under which such exports would take place would be covered by an intergovernmental agreement. An intergovernmental memorandum was signed in January 2013 while work is continuing on developing a full intergovernmental agreement. The Minister for Communications, Energy and Natural Resources (2012) has indicated that the State would have to ensure adequate return from energy exports and that this would likely include either a share of the renewable value or the imposition of a royalty of some kind. There would be income generated for landowners and local authorities (rates) and also employment benefits from the construction of wind farms. In addition it is possible that an increase in scale of activity would stimulate the development of the supply chain in Ireland.

There are also risks arising from the development of wind energy exports. This enterprise opportunity involves a high level of investment and depends on the availability of UK subsidies for renewable electricity. Long term assurance on the availability of UK support is an essential condition for this investment to be worthwhile. The envisaged development of wind farms is on a very extensive scale. In relation to onshore wind farms there is a risk that large-scale development of wind turbines could encounter public opposition. These risks are not insurmountable but need to be taken into account in the development of energy exports.

At present, Ireland's ability to absorb wind is limited by the capacity of the grid. The question arises as to whether at some stage in the future Ireland's own demand for wind-generated electricity could exceed the potential onshore wind capacity. This depends on a number of variables: (i) the extent of Ireland's onshore wind resources—this is influenced by both the natural availability of wind and the social acceptability of wind farms; (ii) the ability to expand the grid's capacity to absorb wind; and (iii) the growth of demand for electricity including that due to electrification of heat and transport. In the case of a large increase in the demand for electricity due to a major shift to the use of electricity use for heat and transport then it is possible that the Irish demand for wind-generated electricity could exceed the available onshore wind resource. In the Irish TIMES modelling work, Ireland's demand for wind generated-electricity in the low carbon scenarios in 2050 is projected to exceed the projected onshore wind resource so that offshore wind is projected to be also used to meet demand (Chiodi *et al.*, 2013).

The further offshore one goes, the greater the costs and challenges in constructing offshore wind farms. The development of floating offshore wind farms could be a way of addressing this and thereby enabling the exploitation of the massive wind resource in far offshore and deep water areas (Henderson *et al.*, 2000). This technology could potentially unlock vast energy resources off the west coast of Ireland in the future.

4.3 Wave and Tidal Energy

The development of wave and tidal energy could provide a major economic opportunity for Ireland. These technologies are at an early stage of development so that these industries have not as yet been established in any location. Hence, in addition to the potential energy value, there is scope for the creation of new industry clusters. Ireland has particularly favourable natural wave energy conditions and there are significant research strengths in wave and tidal technology in Ireland.

Tidal energy has the advantage of being a predictable energy source and thus could be a good complement to wind energy. However, the locations that are suited to tidal energy are more limited than that of wave both in Ireland and globally. A study for SEI (now the SEAI) estimated that taking account of technical, physical, practical (for example, shipping lanes), and commercial constraints, the viable tidal resource that could be available in Irish waters (island of Ireland) in 2010 at 915 GWh (gigawatt hours) per year. This is the equivalent of around 3 per cent of 2011 electricity demand. It was estimated that this could rise to over 6 per cent by 2015 (SEI, 2004).

In 2008, a tidal energy device ('Sea-Gen') was installed in Strangford Lough (in Northern Ireland); its capacity is 1.2 MW. This was first time in the world for a commercial (albeit subsidised) tidal stream energy devise to be connected to an electricity grid. An Irish technology company, Open Hydro, was the first company in the world to deploy a tidal device at the European Marine Energy Centre (EMEC) in the Orkney Islands. Tidal Ventures Limited, a partnership between Open Hydro and Bord Gáis, was awarded a lease in October 2012 by the Crown Estate to develop a 100 MW tidal energy farm off the north Antrim coast. This project is to be completed by 2020. Another partnership between DEME Blue Energy (a Belgian company) and DP Marine Energy (an Irish company) was also awarded a license to develop a 100 MW tidal energy farm off the Antrim Coast.

A 2005 study estimated that the theoretical wave energy resources off Ireland could be up to 525,000 GWh per year (over 18 times annual electricity demand) (SEI & Marine Institute, 2005). Taking account of technical and practical constraints, the accessible resource was estimated at around three quarters of annual electricity demand. Wave energy is variable like wind. Research has found that Irish wave energy has comparable hourly variations to wind, while both wind and wave power outputs peak during winter. The magnitude however of the seasonal variation is greater for wave compared to wind (Kavanagh *et al.*, 2012, forthcoming).

A strategy for the development of ocean energy was published in 2005, *Ocean Energy in Ireland.* The implementation of this policy is co-ordinated by the Ocean Energy Development Unit (OEDU) of SEAI. The OEDU administers a Prototype Development Fund that provides grant aid to industry for the development of ocean energy devices. A quarter-scale test site has been established in Galway. A full-scale test site is planned off Annagh Head in Mayo; a foreshore license was submitted for this in December 2011. There are plans to develop a pre-commercial wave farm off the West coast of Ireland (WestWave); this project is being led by ESB International.

A REFIT tariff to support ocean energy was announced in 2010 although it has not been implemented. A REFIT scheme for ocean energy would be an expensive way of meeting domestic energy needs. However the case for a REFIT incentive is not to meet domestic energy needs but to stimulate investment in this emerging industry. The total cost of such an incentive would be modest if provided for a small energy capacity. It can be argued that ocean energy is better supported through research support rather than a REFIT incentive (FitzGerald, 2011). However this industry is being supported through price incentives elsewhere including the UK (along with other investment support) and failure to provide a REFIT in Ireland could send a negative signal regarding Ireland's interest in encouraging this industry. The progress report on the NREAP of January 2012, set out a scenario where there was 75 MW of wave energy in Ireland by 2020 (Department of Communications, Energy and Natural Resources, 2012a).

The Irish Maritime and Energy Resource Cluster (IMERC) has been formed as a partnership between UCC, Cork Institute of Technology and the Irish Naval Service. This partnership seeks to build on research strengths to establish a cluster of maritime-related industries including ocean energy devices.

While Ireland has significant resources in this area and progress is being made, Scotland appears to be making more rapid progress in supporting this emerging industry. A new offshore renewable energy development plan for Ireland is due to be published soon.

5. Addressing the Challenge of Variable Electricity Generation

The strong growth of variable wind generation poses significant challenges for the operation of the electricity system. These arise in relation to meeting the existing 40 per cent target by 2020 and raise the question as to whether the scenarios discussed above—of even higher levels of wind penetration—are feasible. The All-Island Grid Study of 2008 estimated that it would be feasible to have up to 42 per cent electricity on the island of Ireland from renewable sources by 2020. This was dependent on the required infrastructure investment taking place and was also subject to further investigation into the implications of having such a high proportion of wind from renewable sources (Department of Communications, Energy and Natural Resources & Department of Enterprise, Trade and Investment, 2008). Eirgrid and the System Operator for Northern Ireland (SONI) have developed a work programme, *Delivering a Secure, Sustainable Energy System* (DS3) to ensure that the power system operates securely while the level of variable generation increases.

The scenarios discussed above whereby two thirds of electricity consumption is from wind in 2050 would not be possible today. However, there are promising technological developments that could make this possible in the future. There are a number of dimensions to meeting and exceeding current renewable electricity targets:

- grid investment;
- increasing the share of variable generation that the system can accept at any given time;
- European market integration and interconnection;
- linking the consumption and production of electricity;
- regulation; and
- storage.

Each of these is now discussed.

5.1 Grid Investment

The planned expansion of renewable electricity requires major investment in the grid, both the transmission system managed by Eirgrid (high voltage system) and the distribution system managed by ESB Networks (medium to low voltage). Many of the best opportunities for wind generation are in the more remote areas of the country and their development is dependent on investment in the transmission system. Substantial grid investment would be required even if renewable energy were not expanding. Economic growth in the coming years creates the need for grid investment to ensure continuing security of supply. Investment in the grid also contributes significantly to regional development by expanding the areas of the country where it becomes possible for high-tech industries to locate. Eirgrid has published a plan for upgrading the transmission in the system in the period to 2025, Grid 25. This plan will also facilitate increased interconnection with the UK. The projected cost of this investment is €3.2 billion.

The biggest risk to achieving Ireland's renewable electricity targets arises from potential delays in making the necessary grid investments, due to difficulties with public acceptance of grid investment. The IEA found that 'the planning and consenting regime appears unable to meet Ireland's existing network development targets, particularly regarding grid connections and transmission infrastructure' (IEA, 2012d: 81). Eirgrid has developed a new, structured consultation process that has improved communication between Eirgrid and communities affected and reduced objections.

The Government has issued a policy statement on the strategic importance of transmission and other energy infrastructure. This statement reaffirms 'the imperative need for development and renewable of our energy networks, in order to meet both economic and social policy goals' (Department of Communications, Energy and Natural Resources, 2012b). It acknowledges 'the need for social acceptance and the appropriateness of building community gain considerations into project planning and budgeting' (5). The statement underlines 'the imperative for early and ongoing engagement and consultation with local communities and all stakeholders before entering planning. This is essential for building public confidence ensuring a more balanced public debate and a more timely delivery of projects' (3). This statement provides a mandate for Eirgrid to develop community gain initiatives in its grid development programme.

Those seeking grid connections face significant obstacles and delays. There is a commitment in the Renewable Energy Strategy of June 2012 to work to overcome the existing obstacles and delays in the GATE process (the process for organising applications for grid connections) including environmental, permitting and any regulatory barriers (Department of Communications, Energy and Natural Resources, 2012c).

5.2 Increasing the Share of Variable Generation

At present, Eirgrid and SONI have established a limit of 50 per cent on the share of variable generation (primarily wind) that can be accepted on the system at any one time. This is based on analysis of what is consistent with secure operation of the system given current capabilities. When the level of wind generation rises to this level—this can happen when wind is high and the level of electricity consumption is low—wind farms are curtailed; i.e., the electricity from some wind farms is not accepted onto the system. The issue of how wind farms get paid when curtailment arises is a significant regulatory issue.

Eirgrid is deploying smart grid technologies to manage the rising share of variable electricity on the system. The DS3 programme referred to above is seeking to increase the share of variable electricity on the system at any one time from 50 per cent to 75 per cent. This would significantly reduce the need for curtailment in the coming years and improve the cost effectiveness of wind.

The changes required to realise this 75 per cent target involve technical innovation but they also require behavioural change in the management of electricity plants. The DS3 programme includes the development of financial incentives for better plant performance. Changes in market regulation would be needed to provide appropriate financial incentives.

5.3 Market Integration and Interconnection

The integration of Ireland's electricity system into the UK and European market can facilitate increased wind generation on the Irish system. Interconnection complements wind as it provides the option for the export of surplus wind and thus reduces the need for curtailment. It also makes it possible to import electricity when the wind is low. According to a study by Pöyry: 'Our findings underline the almost critical importance to the Irish market of having interconnection to the British market, although the opposite is not true' (Pöyry Energy Consulting, 2009: 19). Several other authors have emphasised the importance of interconnection to the economics of wind in Ireland (Gorecki, 2011; FitzGerald, 2011 and Diffney *et al.*, 2009).

The importance of connecting regional electricity markets is emphasised in a report by the European Climate Foundation (ECF) on a roadmap to a low-carbon electricity system for Europe:

> A large increase in regional integration and interconnection of electricity markets is key to the transition in all pathways and is urgently required even for the level of decarbonisation already mandated for 2020; it is also paradoxically the key to reliable and economic integration of localized energy production, along with investments in smarter control of demand and decentralised supply (ECF, 2010: 16).

The ECF describes the relevance of an expanded European grid in a decarbonisation strategy as follows:

> An expanded European grid can effectively reduce intermittency challenges. … Fluctuations in demand and supply are cancelled out to a large extent and back-up capacity is available at larger scale. The grid investments required are around 10 per cent of generation investments and reduce curtailment to 1 to 5 per cent, making it an effective and economic solution (ECF, 2010: 19).

The ECF points to the potential for increased connection of regional electricity markets to enable the exploitation of counter-cyclicality among renewable power sources. It notes that wind and solar are negatively correlated by season—solar produces more in the summer while wind produces more in winter. There is also counter cyclicality in daily terms between solar and onshore wind.

The importance of grid investment for Europe, including interconnection, is also emphasised in the European Commission's energy roadmap. 'New flexible infrastructure development is a 'no regrets' option and could accommodate various pathways' (European Commission, 2011b: 15). The extent of the need for new grid investment across the EU varies with the decarbonisation pathway followed. It is higher in pathways that have a high level of renewables (as against nuclear or CCS). The European Commission's Energy Roadmap points to the need for additional infrastructure investment to exploit renewable electricity in the North Sea and the Mediterranean.

The ECF (ECF, 2011) estimates that current plans (if implemented) for EU grid investment are generally adequate for the period to 2020 but that a significantly higher level of investment would be required in the decade to 2030. This study projected that the largest additional interconnection facilities in the decade to 2030 would be built between Ireland and Britain (13 GW), North West Germany and West Germany (10 GW), South West France and North West Spain (9 GW) and North UK and South UK (8 GW).

A study by Pöyry Energy Consulting (2011) examined the issue of intermittency across North West European electricity markets. It developed projections of the likely growth of renewables in North West Europe in the period to 2035 and the impact of interconnection in this context. Surprisingly in the light of the ECF analysis, the Pöyry study found that the overall output of renewable electricity across Northern Europe as a whole would be highly variable in 2035 and would not even out across this wide area. A possible reason for the difference with the ECF results is that the ECF study also included Southern Europe.

The island of Ireland has been interconnected to Britain since 2002 via the Moyle interconnector between Northern Ireland and Scotland while the new East West interconnector between the Republic of Ireland and Wales commenced operation in late 2012.

The economics of further interconnection from Ireland have been examined in a study by Eirgrid (Eirgrid, 2009). This study found that a third 500 MW interconnector (i.e., in addition to Moyle and the East West interconnector) is economically attractive by 2020 and more so in 2025, and in some scenarios a fourth interconnector is economically feasible by 2025. Demand projections have been revised downwards since this study was completed.

The EU is seeking to complete the European internal energy market by 2014. Ireland has been given an extension until 2016. Full participation by Ireland in the internal market would require a doubling of the current level of interconnection capacity (Gorecki, 2011).

The other major effect of market integration is to reduce price differentials between electricity markets. Gorecki (2011) argues that this will lead to lower electricity prices in Ireland. It also implies increasing competitive pressure on Irish electricity producers.

While there are clear strategic benefits to Ireland from market integration and enhanced interconnection, there are also potential negative effects, particularly in the short term. Integration of the Irish market will require changes to the single electricity market (SEM) that is in place on the island of Ireland. FitzGerald (2011) points to the risks this poses for Ireland*:* it could force abandonment of what has proved to be an effective market system and result in substantial transaction costs. Another risk posed by enhanced interconnection with Britain is that it increases Ireland's exposure to problems in the British market. If imminent capacity shortages are not addressed in Britain, FitzGerald points out that there could be dramatic price increases there in the second half of the decade. In this case interconnection could mean higher prices for Irish consumers.

The ISLES project was a feasibility study on the development of an offshore transmission network linking potential offshore sites in the waters around Ireland and Scotland. The key conclusions of this study were as follows. First, 'an ISLES cross-jurisdictional offshore integrated network is economically viable and competitive under certain regulatory frameworks and can potentially deliver a range of wider economic, environmental and market related benefits' (RPS *et al.*, 2012: 2). Second, there are no technological barriers to the development of an ISLES network. Third, the network costs would be potentially 15-20 per cent higher than comparable one-off UK offshore wind projects. However the study also found that these higher infrastructure costs could be offset through a variety of benefits. These included the reduced risks for the offshore wind developers from having a integrated network, additional interconnection benefits compared to one-off offshore projects and the possibility of attracting EU/grant funding at a potentially lower cost of capital than alternative schemes.

The North Seas Counties Offshore Grid Initiative (NSCOGI) is 'a framework for regional cooperation to find common solutions to questions related to current and possible future grid infrastructure developments in the North Seas' (European Commission, 2011c: 1). For this initiative, the Irish Sea is one of the North Seas. There are 10 countries involved. Key issues relating to the development and use of a large-scale offshore grid are being examined by three working groups*:* (i) grid development; (ii) regulation and markets; and (iii) planning and permitting. Eirgrid is actively involved in the European modelling work in this project. Ireland co-chairs the regulation and market working group.

The ‘Friends of the Supergrid’ is an alliance of major European energy companies, founded by Mainstream Renewable Energy. It has proposed a new model of an interconnected European power system. Its proposal is to develop a new pan European transmission network to integrate large-scale renewable electricity into the European market and the balancing and transporting of electricity. This would facilitate the integration of very large-scale offshore wind into the gird. This proposal is an alternative to continuing to develop individual point-to-point interconnectors between national systems.

5.4 Linking Electricity Consumption and Production

At present, the pattern of electricity consumption is determined by the users of electricity independently of the costs of generating electricity at different times. The development of a smart grid would make it possible to make demand for electricity more responsive to variations in supply. This would facilitate a larger share of variable electricity to be used effectively to meet energy needs. For example, when the wind is blowing strongly and there is surplus electricity, it would be possible to use this surplus to generate heat in a smart storage heating system, rather than curtailing wind. This would involve automated controls and price incentives. The opportunity cost of electricity varies greatly over the course of 24 hours. A smart grid in conjunction with smart meters would make it possible to reflect these cost differences in consumer prices. The development of the smart grid is discussed in Background Paper No. 6. There is also the possibility of using heat pumps (these are a very efficient way of using electricity for heating) in conjunction with energy storage although there are significant challenges to be addressed to develop this as an attractive option for consumers (Hewitt, 2012).

There is a considerable seasonal variation in the supply of wind generated electricity. Demand response cannot help to manage this variation in supply. It can help to manage supply variability over short time periods. A report by ECF (2010) suggested that for Europe a realistic demand response would be to have up to 10 per cent of the daily load shift in response to the availability of supply in 2030. It was estimated that this would reduce the need for grid capacity by 10 per cent and back-up capacity by 35 per cent.

The electrification of heat and transport would increase the volume of potentially flexible electricity consumption and hence facilitate the expansion of wind. As the share of renewable energy in electricity rises, the electrification of these uses also involves a shift from meeting energy needs through imported fossil fuels to domestic renewable energy. There is also potential for enhanced flexibility in electricity use in industry and other areas of domestic consumption.

While it will take many years for the electrification of transport to become of significance, the prospects in the short term are more promising for heating. Electric heating already exists but is not generally an attractive proposition at present. Much of what is required is close to being in place for the development of electric heating in a way that could make effective use of Ireland's wind generated electricity. A new smart storage heating system has been developed by Glen Dimplex and is being deployed in a pilot initiative.

The SEAI Smart Grid Roadmap considered an ambitious scenario for the electrification of heat and transport as follows*:* if 50 per cent of transport and 80 per cent of heat were electrified, annual electricity demand could rise to 80,000 GWh by 2050*.* In this scenario, 50,000 GWh of wind electricity could be accommodated on the grid; this would be almost double the current total demand for electricity (27,000 GWh)*.* This illustrates that the combination of continuing expansion of wind, electrification of heat and transport and the development of the smart grid could dramatically change how Ireland meets its energy needs and thereby achieve major reductions in emissions*.*

5.5 Regulation

The need for changes to the SEM regulatory structure to meet the requirements of internal EU market integration has been discussed above. In addition, the expansion of renewables also poses challenges for the regulatory model. Ireland's SEM includes provision for 'capacity payments'. These are payments that are made to compensate the provision of capacity; these payments are designed to ensure that there is sufficient capacity to meet peak demand. This is a positive feature of Ireland's SEM and contrasts to some other markets where there is only payment for energy supplied. However, as the level of variable generation (wind in the case of Ireland) rises, flexibility of resources rather than physical capacity becomes of increasing significance. The value of flexibility in the context of the rising share of renewables is generally not adequately recognised by current market structures (Hogan, 2012). There is a need for market regulation to recognise the value of flexibility.

5.6 Storage

Electricity storage is possible but its high cost means that there is very limited use made of electricity storage at present, except where there are favourable natural conditions for pumped storage. Turlough Hill is a longstanding Irish example of the use of pumped storage technology. There is a proposal (Spirit of Ireland) for large-scale development of pumped hydro storage using sea-water in locations along the Atlantic coast. This would offer large scale storage in conjunction with wind-generated electricity. The discussion of the smart grid and flexible electricity consumption, discussed above, is another type of storage.

6. Transforming Energy Use Across the Economy

The decarbonisation of electricity is a central part of the movement to a carbon-neutral economy but it is not sufficient in itself to achieve low carbon emissions from energy use across the economy. While strong progress is being made in expanding low carbon electricity, the development of low carbon energy outside the electricity sector has been considerably slower. Other dimensions of achieving a transition to low carbon energy use are discussed in Background Paper No. 6 and in the final report from the NESC Secretariat on climate change policy (NESC Secretariat, 2013). This section provides a concise overview of these other dimensions.

There is considerable scope for energy savings to be achieved through energy efficiency and this can make a major contribution to achieving a carbon-neutral economy. Opportunities for improvements in energy efficiency arise in buildings (residential and non-residential), transport and industry.

6.1 Heating

Improvements in energy efficiency can substantially reduce the demand for energy for heating purposes in the coming decades. In addition to improving efficiency there is also a need to change Ireland's model of heating toward low carbon energy sources. Electricity could become the major source of low carbon energy for heating in Ireland. In the Irish TIMES modelling work it is projected that from 39 per cent to 76 per cent of residential energy demand (mainly for heating but also including demand for lighting etc.) could come from electricity in 2050. The high electrification scenario arises in the very low carbon CO_2-95 scenario (Chiodi *et al.*, 2013).

Significant challenges arise in the electrification of heating. Standard electric heating is relatively expensive. Heat pumps are a very efficient way of using electricity but there are high capital costs at present. Smart storage heating that interacts with the electricity system to make optimum use of Ireland's wind generated electricity could be attractive for Ireland as discussed above. The NESC Secretariat report proposes a network on the electrification of heating.

The Irish TIMES modelling work also projects a role for the direct use of renewable energy (mainly biomass and biogas) in heating in 2050 (15 to 25 per cent of residential energy consumption). Natural gas has a continuing role in heating in the CO_2-80 scenario in 2050 but only contributes marginally in the really low carbon CO_2-95 scenario. Oil based heating does not feature in any of the low carbon scenarios in 2050. Projections are similar for energy demand in services.

6.2 Transport

Transport is probably the most challenging part of the movement to a low carbon energy system. The key technologies for low carbon transport are less well developed compared to those in electricity and heating so decarbonisation will take longer to achieve in this area. There is scope for investment in public transport and improved planning to reduce emissions and to improve the quality of life. However, even with improved public transport and better planning, transport will still be a major source of energy demand in the coming decades.

While electric vehicles (EVs) have a marginal role at present, they may become the primary form of private transport in the decades ahead. EVs could be an effective complement to Ireland's wind generated electricity system by acting as a source of energy storage. While EVs could become the predominant means of private transport it is likely that other technologies will also be required. Biofuels or biogas could be the the energy sources for freight transport. However, some biofuels pose major social and sustainability challenges at present. It is argued by Murphy *et al*. (2011) that there is scope for biogas from grass to be a sustainable fuel source in Ireland although there is still a trade-off with food production. Where waste can be used as a fuel source there is clearly no trade-off.

6.3 Industry

Bioenergy (i.e. biomass and biogas) could become a major energy source for industry in a carbon-neutral economy. The Irish TIMES modelling work projects that bioenergy could represent over two thirds of energy use in industry in 2050. Bioenergy and electricity together would contribute almost all energy for industry in 2050 (Chiodi *et al*., 2013). Bioenergy use is suited to industry on account of the economies of scale arising from its use in industry and the lack of low carbon alternatives at present for many industrial purposes. For some industries CCS could be an important technology.

6.4 Conclusion

The achievement of low carbon energy use in the economy generally requires widespread changes in addition to the decarbonisation of electricity. These include improvements in energy efficiency, more widespread use of electricity in heating and transport and the development of other renewable energy sources.

7. Research, Development and Demonstration

Ireland is making considerable investment in energy research, development and demonstration (RD&D). SEAI data indicate that government spending on RD&D increased almost fourfold between 2005 and 2009 and the increased level of expenditure been sustained during the economic crisis.

SEAI undertook an analysis of the areas of academic-led energy RD&D over the period 2004 to 2010. This covered public and private expenditure on academic research in this area. The two largest areas of expenditure were energy efficiency (21 per cent) and bioenergy (18 per cent). Other significant areas of expenditure were solar (13 per cent), marine energy (10 per cent), energy policy/modelling and analysis (10 per cent) and electrical grid (9 per cent) (SEAI, 2011b).

An energy research strategy for Ireland was published by the Irish Energy Research Council in 2008. This strategy set out the following strategic research priorities:

- energy systems modeling and analysis;
- fundamental frontier and multidisciplinary research (to be funded by Science Foundation Ireland);
- RD&D in priority sectors: ocean energy, grid/infrastructure, energy in buildings, energy in transport and sustainable bioenergy;
- a watching brief to understand and interpret the outcomes of international energy technology development of potential relevance to the island of Ireland and to inform government policy; and
- research support in mapping Ireland's energy resources (Irish Energy Research Council, 2008).

Priorities for publically funded research in Ireland were considered by a Research Priorities Steering Group (Forfás, 2012). This group was requested to identify priorities that would deliver sustainable economic returns through their contribution to enterprise development, employment growth, job retention and tangible improvements in quality of life. The group adopted four high level criteria in its assessment of priority areas for research as follows:

- The priority area is associated with a large global market or markets in which Irish-based enterprises already compete or can realistically compete;
- Publicly performed R&D in Ireland is required to exploit the priority area and will complement private sector research and innovation in Ireland;
- Ireland has built, or is building (objectively measured), strengths in research disciplines relevant to the priority area; and
- The priority area represents an appropriate approach to a recognised national challenge and/or a global challenge to which Ireland should respond (Forfás, 2012: 10).

Based on these criteria, the Group identified 14 priority areas for publicly-funded investment in R&D. These included digital platforms, content and applications; medical devices; and food for health. In the energy area, this group identified two priority areas: marine renewable research (including offshore wind, wave and tidal); and smart grids and smart cities.

Energy R & D includes investment in policy modelling and analysis capabilities. This is important both to inform Ireland's position in international climate negotiations and to provide a knowledge base for Irish energy policy. This paper and the NESC Secretariat reports on climate policy have drawn upon Irish modelling and research work.

The IEA (IEA, 2012d) considers that, on the whole, Ireland's national research priorities are well aligned with the country's energy policy priorities and that there is good co-ordination within the energy RD&D community. However it advocates greater co-ordination across all relevant departments and agencies to encourage greater synergies and impetus for successful projects. In relation to ocean energy, it proposes a concentration of national efforts and continued international collaboration with a view to accelerating the development of this emerging industry. It also recommends further encouragement of research on biogas in the context of Ireland's high reliance on natural gas imports.

The Marine Renewables Industry Association (2012) has published a paper on the views of key stakeholders on R&D in ocean energy. The ocean energy industry had generally positive view of the R&D in third level institutions and work of agencies in developing R&D infrastructure. However, there was criticism of lack of co-ordination of research and the industry considers funding support to be a major problem at present.

8. Conclusions

Electricity is expected to play a central role in the transition to a low-carbon economy. If total emissions are to be reduced by at least 80 per cent by 2050 it will be necessary to move to close to zero-carbon electricity. The European Commission's Low-Carbon Roadmap to 2050 projects a fall in electricity emissions of 93 to 99 per cent for the EU.

The progress made in recent years, in conjunction with current plans, suggests that Ireland is positioned to achieve a radical transformation in its electricity system in the years and decades ahead. The key elements of the ongoing transformation are as follows:

- The carbon intensity of Ireland's electricity has fallen from almost 900g/kWh in 1991 to 490g/kWh in 2011.
- The share of renewable electricity has increased from 5.0 per in 2010 to 17.6 per cent in 2011.
- Considerable upgrading of Ireland's electricity grid has already taken place. Ireland has achieved a leadership position in the deployment of a smart grid (see Background Paper No. 6).
- Eirgrid is seeking to increase the share of variable electricity that can be accommodated on the system at any one time, from 50 per cent to 75 per cent through its DS3 programme.
- Following a successful trial of smart meters, there is a plan for the deployment of smart meters nationally and the introduction of electricity charges that would vary over the time of day or night.
- An advanced smart storage heating system is being piloted.
- The infrastructure for electric vehicles is being developed by the ESB.

For Ireland, a decarbonised electricity system could have the following characteristics:

- Electricity is decarbonised with wind playing a central role, supplemented by other renewables (biomass, biogas, wave and tidal energy) and the possible use of carbon capture and storage.
- A substantially higher share of energy needs is met by electricity through the electrification of much heat and transport demand.
- Ireland's electricity system is integrated into a wider European market with a high level of interconnection. The integrated system may include a very large-scale offshore super-grid.
- A smart grid facilitates a high share of variable renewables on the system. There is much greater flexibility in electricity consumption: electricity use is linked to variations in supply through a smart grid so that users are encouraged or enabled to take advantage of electricity when its supply is most abundant and its cost low (through for example the charging of electric vehicles).

The key incentive driving the transformation of Ireland's electricity system at present is the REFIT scheme. This is designed to achieve the 40 per cent renewable electricity target by 2020. Progress beyond 2020 will be strongly influenced by EU energy and climate policy that is put in place for the period beyond that date. Continuing progress beyond 2020 will depend on, among other things, a sufficiently high carbon price or other incentives. The carbon price to date under the ETS has not provided a significant incentive for decarbonisation.

As electricity becomes a lower carbon source of energy, there is an opportunity to use electricity as a low carbon energy source for heat and electricity. There are major challenges to be addressed in both the electrification of heat and transport. The final NESC report on climate change proposed the establishment of networks to address both electric vehicles and the electrification of heat (NESC Secretariat, 2013).

Electricity represents around one fifth of energy use at present and this share is expected to rise. Even assuming widespread electrification is achieved there is still expected to be substantial demand for energy in forms other than electricity in 2050. Key areas where other energy is likely to be required include freight transport and industrial processing. While strong progress is being made in expanding low carbon electricity, the development of low carbon energy outside the electricity sector has been considerably slower. If all energy-related emissions are to be reduced it is vital to also address these other areas of energy use. Biofuels at present represent the primary renewable energy used for transport. Much of the current biofuels production raises serious concerns about environmental and social sustainability.

The serious concerns raised by several international organisations about biofuels call for further reconsideration of both Irish and European policy on biofuels.

The biggest risk to the achievement of the 40 per cent renewable electricity target by 2020 target is that there will not be sufficient progress in building the grid to accommodate the rise in wind generation. This is due to the social acceptability of grid expansion. Eirgrid has developed an improved process of communication with the communities affected by gird expansion. Sustaining Ireland's renewable electricity progress requires more effective community engagement particularly, but not limited to, grid development (see Background Paper No. 3).

The analysis of Pöyry suggests that the most likely outcome for 2035 based on current policy is one in which gas also plays a prominent role (projected to represent around 38 per cent of generation capacity in 2035 in their gas-dominated portfolio) along with wind (46 per cent of capacity) (Pöyry Energy Consulting, 2010). Gas has a significant role to play in the transition to a low carbon economy; gas generation capacity provides necessary back-up for wind. However, there is a risk that too high a level of investment in gas generation capacity could be an obstacle to the achievement of really low emissions by 2050.

The development of a high level of interconnection to an integrated European market is a central component of how Ireland can become a carbon-neutral economy. Interconnection facilitates a high level of variable generation and would enable Ireland to become an energy exporter. It is European policy to achieve an integrated market and to promote interconnection. The incentive to invest in interconnection is strongly influenced by EU renewable energy policy. An EU policy that sets an EU target for renewables (rather than national targets) encourages the expansion of renewables in those member states with the lowest costs and promotes the highest level of investment in interconnection (Lynch *et al.*, 2012). Ireland needs to actively participate in discussions on the future of European energy policy to promote solutions that make sense for both Ireland and Europe.

A large-scale European offshore grid could be a core way of meeting Europe's future energy needs through offshore wind and would fit well with Ireland's large offshore energy resources. Ireland should continue its active involvement in the North Seas Offshore Grid Initiative

Ireland has abundant renewable energy resources and hence large potential to develop energy exports. In the short term, the best opportunities lie in onshore and offshore wind close to the east coast of Ireland. Work is progressing on an intergovernmental agreement with the UK to facilitate this. This is potentially a valuable export opportunity that is worth pursuing while taking account of the risks involved. Account needs to be taken of the possibility that Ireland's onshore wind resources may be needed in future decades to meet Ireland's own demand for electricity. In the longer term, Ireland has opportunities in the emerging energy technologies of wave, tidal and floating wind. There is an opportunity to benefit from the establishment of industry clusters. Ireland has considerable advantages in wave and tidal power: large scale wave energy resources, research capabilities and a number of pioneering wave and tidal companies. The forthcoming Final Offshore Renewable Energy Development Plan offers an opportunity to clearly set out Ireland's ambitions and policies to realise both the energy and economic opportunities in developing Ireland's offshore energy resources.

Ireland's regulatory model for electricity appears to be relatively successful. However the growing share of variable generation poses challenges for the regulatory model in Ireland and elsewhere. As the level of variable generation (wind in the case of Ireland) rises, flexibility of resources rather than physical capacity becomes of increasing significance. The value of flexibility in the context of the rising share of renewables is generally not adequately recognised by current market structures (Hogan, 2012). Ireland's model also has to address the challenge of integration into the EU internal energy market. It is important not to lose key strengths of the Irish model in this transition.

Ireland is making a significant national investment in energy RD&D. A strong national RD&D energy programme that is of relevance to Ireland's transition to a carbon-neutral economy should be sustained while it is important to maximize the use of knowledge gained from this investment. This should include continued investment in policy analysis and modelling.

Strong progress is being made towards the target that 40 per cent of Ireland's electricity will come from renewable sources by 2020. If current developments are sustained then Ireland will be well positioned by 2020 to move to almost zero-carbon electricity in subsequent decades.

Bibliography

Anseeuw, W., Alden Wily, L., Cotula, L. & Taylor, M. (2012), *Land Rights and the Rush for Land*, Findings of the Global Commercial Pressures on Land Research Project, Rome: International Land Coalition. http://www.landcoalition.org/cpl/CPL-synthesis-report.

Chiodi, A. (2012), 'Updating Input Data', Presentation to the SEAI, "Irish TIMES Stakeholder Workshop", Dublin, 9 October.

Chiodi, A., Gargiulo, M., Rogan, F., Deane, J. P., Lavigne, D., Rout, U. K. & Ó Gallachóir, B. P. (2013), 'Modelling the Impacts of Challenging 2050 European Climate Mitigation Targets on Ireland's Energy System', *Energy Policy,* 53: 169-89.

Clifford, E. & Clancy, M. (2011), *Impact of Wind Generation on Wholesale Electricity Costs in 2011*, SEAI and Eirgrid. http://www.eirgrid.com/media/ImpactofWind.pdf.

Cotula, L., Dyer, N. & Vermeulen, S. (2008), *Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land*, London: International Institute for Environment and Development and Food and Agriculture Organisation of the United Nations.

Department of Communications, Energy and Natural Resources (2009), *National Renewable Energy Action Plan Ireland*, Dublin: Department of Communications, Energy and Natural Resources.

Department of Communications, Energy and Natural Resources (2010), *Draft Offshore Renewable Energy Development Plan*, Dublin: Department of Communications, Energy and Natural Resources.

Department of Communications, Energy and Natural Resources (2012a), *National Renewable Energy Action Plan Ireland: First Progress Report*, Dublin: Department of Communications, Energy and Natural Resources.

Department of Communications, Energy and Natural Resources (2012b), *Government Policy Statement on the Strategic Importance of Transmission and Other Energy Infrastructure*, Dublin: Department of Communications, Energy and Natural Resources.

Department of Communications, Energy and Natural Resources (2012c), *Strategy for Renewable Energy 2012-2020*, Dublin: Department of Communications, Energy and Natural Resources.

Department of Communications, Energy and Natural Resources & Department of Enterprise, Trade and Investment (2008), *All Island Grid Study: Work Stream 4, Analysis of Impacts and Benefits*. http://www.dcenr.gov.ie/NR/rdonlyres/43CF090D-22AD-40FC-9C7E-02948122D35F/0/AllIslandGridStudyAnalysisofImpactsandBenefitsJan08a.pdf.

Diffney, S., FitzGerald, J., Lyons, S. & Malaguzzi Valeri, L. (2009), 'Investment in Electricity Infrastructure in a Small Isolated Market: the Case of Ireland', *Oxford Review of Economic Policy,* 25(3): 469-87.

ECF (2010), *Roadmap 2050: A Practical Guide to a Prosperous Low Carbon Europe, Technical Analysis*, Executive Summary, Brussels: European Climate Foundation.

ECF (2011), *Power Perspectives 2030: On the Road to a Decarbonised Power Sector,* Brussels: European Climate Foundation.

Eirgrid (2009), *Interconnection: Economic Feasibility Report*, Dublin: Eirgrid.

Ellis, G. (2012), *A Review of the Context for Enhancing Community Acceptance of Wind Energy in Ireland*, Dublin: Sustainable Energy Authority of Ireland.

Ellis, G., Cowell, R., Warren, C., Strachan, P. & Szarka, J. (2009), 'Wind Power: Is there a 'Planning Problem'? Expanding Wind Power: A Problem of Planning or of Perception?', *Journal of Planning Theory and Practice,* 10(4): 521-547.

European Commission (2011a), *A Roadmap for Moving to a Competitive Low-Carbon Economy in 2050*, COM 112, Brussels: European Commission.

European Commission (2011b), *Energy Roadmap 2050*, COM 885/2, Brussels: European Commission.

European Commission (2011c), *NSCOGI Report 2011*. http://ec.europa.eu/energy/infrastructure/tent_e/doc/off_shore_wind/2011_annual_report_annex2_en.pdf.

European Commission (2012), *Impact Assessment Accompanying the Document Renewable Energy: A Major Player in the European Energy Market*, SWD 149 final, Brussels: European Commission.

European Council (2009), *Presidency Conclusions*. http://www.eu-un.europa.eu/articles/en/article_9179_en.htm.

European Council (2011), *Presidency Conclusions*. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/119175.pdf.

FAO, IFAD, IMF, OECD, UNCTAD, WFP, World Bank, WTO, IFPRI & UN HLTF (2011), *Price Volatility in Food and Agricultural Markets: Policy Responses*. http://www.worldbank.org/foodcrisis/pdf/Interagency_Report_to_the_G20_on_Food_Price_Volatility.pdf.

Fee, E., Johansson, D. J. A., Lowe, J., Marbaix, P., Matthews, B. & Meinshausen, M. (2010), *Scientific Perspectives after Copenhagen*, Information Reference Document, EU's Climate Change Science Experts, Copenhagen: The Spanish and Belgian Presidency. http://www.pik-potsdam.de/~mmalte/pubs/ScientificPerspectivesAfterCopenhagen_4October2010_web.pdf.

Finnan, J., Styles, D., Fitzgerald, J., Connolly, J. and Donnelly, A. (2012), 'Using a Strategic Environmental Assessment framework to quantify the environmental impact of bioenergy plans', *GCB Bioenergy*, 4: 311–329.

FitzGerald, J. (2011), *A Review of Irish Energy Policy*, Research Series, No 21, Dublin: Economic and Social Research Institute.

Forfás (2012), *Report of the Research Prioritisation Steering Group,* Dublin: Forfás.

Gorecki, P. K. (2011), *The Internal EU Electricity Market: Implications for Ireland*, Research Series No. 23, Dublin: Economic and Social Research Institute.

Henderson, A. R., Watson, G. M., Patel, M. H. & Halliday, J. A. (2000), *Floating Offshore Wind Farms - An Option? Offshore Wind Energy in Mediterranean and Other European Seas*. http://www.tudelft.nl/live/binaries/0678df0d-722f-4741-acc7-78c36bd3e5f8/doc/owemes00_arh.pdf.

Hewitt, N. (2012), 'Heat Pumps and Energy Storage—The Challenges of Implementation', *Applied Energy,* 89: 37-44.

Hogan, M. (2012), *What Lies Beyond Capacity Markets? Delivering Least-Cost Reliability Under the New Resource Paradigm*, Brussels: Regulatory Assistance Project.

IEA (2012a), *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*, Paris: International Energy Agency.

IEA (2012b), *World Energy Outlook 2012,* Paris: International Energy Agency.

IEA (2012c), *Golden Rules for a Golden Age of Gas*, Paris: International Energy Agency.

IEA (2012d), *Energy Policies of IEA Countries - Ireland 2012 Review*, Paris: International Energy Agency.

IMF (2011), *World Economic Outlook,* Washington DC: International Monetary Fund.

Irish Energy Research Council (2008), *An Energy Research Strategy for Ireland*, Dublin: Department of Communications, Energy and Natural Resources.

Joint Oireachtas Committee on Communications, Natural Resources and Agriculture (2012), *Report: Offshore Oil and Gas Exploration*, Dublin: Houses of the Oireachtas.

Kavanagh, D., Keane, A. & Flynn, D. (2012, forthcoming), *Capacity Value of Wave Power,* IEEE Transactions on Power Systems.

Lynch, M. A., O'Malley, M. & Tol, R. S. J. (2012), 'Optimal Interconnection and Renewable Targets for North-West Europe', *Energy Policy,* 51: 605-17.

Marine Renewables Industry Association (2012), *R and D and Ocean Energy: A Review of Research and Development in Ocean Energy in the Republic of Ireland,* http://www.mria.ie/publications.php.

Minister for Communications, Energy and Natural Resources (2012), *Written Answer to Dail Question No. 148,*, http://oireachtasdebates.oireachtas.ie/debates%20authoring/debateswebpack.nsf/takes/dail2012112900055?opendocument.

Motherway, B. & Walker, N. (2009), *Ireland's Low Carbon Opportunity: An Analysis of the Costs and Benefits of Reducing Greenhouse Gas Emissions,* Dublin: Sustainable Energy Authority of Ireland.

Murphy, J., Korres, N. E., Singh, A., Smyth, B., Nizami, A. S. & Thamsiriroj, T. (2011), *The Potential for Grass Biomethane as a Biofuel: Compressed Biomethane Generated form Grass, Utilised as a Transport Biofuel*, CCRP Report, Wexford: Environmental Protection Agency.

NESC Secretariat (2013), *Ireland and the Climate Change Challenge: Connecting 'How Much' with 'How to'*, Final Report from the NESC Secretariat, to the Department of Environment, Community and Local Government, Dublin: National Economic and Social Council.

Ó Gallachóir, B. P., Chiodi, A., Gargiulo, M., Lavigne, D. & Rout, U. K. (2012), *Irish TIMES Energy Systems Model Final Report*, Wexford: Environmental Protection Agency.

Pöyry Energy Consulting (2009), *Impact of Intermittency: How Wind Variability Could Change the Shape of the British and Irish Electricity Markets*, Summary Report, Oxford: Pöyry Energy Consulting. http://www.poyry.co.uk/sites/www.poyry.uk/files/202_0.pdf.

Pöyry Energy Consulting (2010), *Low Carbon Generation Options for the All-Island Market*, Oxford: Pöyry Energy Consulting. http://www.poyry.co.uk/sites/www.poyry.uk/files/085.pdf.

Pöyry Energy Consulting (2011), *The Challenges in Intermittency in North West European Power Markets*, Oxford: Pöyry Energy Consulting. http://www.smartpowergeneration.com/spg/files/library/Poyry%20The%20challenges%20of%20intermittency%20in%20North%20West%20European%20power%20markets%20March2011.pdf.

RPS, TNEI Enterprise with Energy, PPA Energy, IHC Merwede & IHC Engineering Business Ltd (2012), *Irish-Scottish Links on Energy Study (ISLES): Executive Summary*. http://www.scotland.gov.uk/Resource/0039/00395581.pdf, 21/12/12.

Schoneveld , G. C., German, L. A. & Nutakor, E. (2011), 'Land-based Investments for Rural Development? A Grounded Analysis of the Local Impacts of Biofuel Feedstock Plantations in Ghana', *Ecology and Society,* 16(4): 10.

SEAI (2011a), *Smartgrid Roadmap*. http://www.seai.ie/News_Events/Press_Releases/2011/SEAI_energy_roadmaps_point_the_way_to_a_sustainable_energy_future_for_Ireland.html, 13/11/12.

SEAI (2011b), *Energy Research in Ireland 2004-2010,* Dublin: Sustainable Energy Authority of Ireland.

SEAI (2012a), *Renewable Energy in Ireland 2011,* Dublin: Sustainable Energy Authority of Ireland.

SEAI (2012b), *Energy in Ireland 1990-2011*, Dublin: Sustainable Energy Authority of Ireland.

SEI (2004), *Tidal and Current Energy Resources in Ireland*. http://www.seai.ie/Grants/Renewable_Energy_RD_D/Projects_funded_to_da

te/Ocean/Tidal_and_Marine_Current_Energy_Resource_in_Ireland/Tidal_and _Current_energy_Resources_in_Ireland.pdf.
SEI & Marine Institute (2005), *Accessible Wave Energy Resource Atlas 2005,* Dublin: ESB International.
Stern, N. (2006), *Stern Review: The Economics of Climate Change: Executive Summary*, http://siteresources.worldbank.org/INTINDONESIA/Resources/226271-1170911056314/3428109-1174614780539/SternReviewEng.pdf.
Stern, N. (2009), *A Blueprint for a Safer Planet*, London: The Bodley Head.
Western Development Commission (2007), *Communities and Renewable Energy: A Guide*, Ballaghaderreen: Western Development Commission.

Front Cover Image

Source online at Small Business Trends