EPA Climate Change Research Programme 2007-2013

Irish TIMES Energy Systems Model

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by

Environment Research Institute, University College Cork

Authors:

Brian P. Ó Gallachóir, Alessandro Chiodi, Maurizio Gargiulo, Paul Deane, Denis Lavigne and Ullash Kumar Rout

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co.Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

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Details of Project Partners

University College Cork
Environmental Research Institute
Lee Road
Cork
Ireland
Tel.: +353 21 490 3037
E-mail: b.ogallachoir@ucc.ie

Economic and Social Research Institute
Whitaker Square
Sir John Rogerson's Quay
Dublin 2
Ireland
Tel.: +353 1 863 2000
E-mail: r.tol@esri.ie

E4SMA
Via Livorno, 60
Environment Park
I–10144 Turin
Italy
Tel.: +39 011 225 7351
Email: maurizio.gargiulo@e4sma.com

KanORS
Office 4
First Floor
DDA Market
Vasundhara Enclave
Delhi 10096
India
Tel.: +91 11 2261 6656
Email: amit@kanors.com

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Executive Summary

Ireland faces very challenging short-term targets in the period to 2020 arising from EU obligations that are specified in EU Directives and Decisions. In addition to these short-term targets, the EU has committed to a long-term greenhouse gas (GHG) emissions reduction of 80–95% below 1990 levels by 2050, and will require Member States to participate in effort-sharing to deliver deep emissions cuts. Policy-makers require comprehensive, robust, knowledge-based information to inform their decisions on how to meet these targets in a manner that will most benefit the Irish economy.

This project draws on and contributes to the wealth of international energy-systems modelling research activity. It involved building, developing, calibrating, testing and running a (partial equilibrium) energy-systems optimisation model for Ireland – the Irish TIMES model. The model was developed by University College Cork in collaboration with the Economic and Social Research Institute, E4SMA and KanORS over the period March 2009–November 2011.

The real value of the Irish TIMES model is in the new insights it gives into some of the key challenges and decisions facing Ireland in energy and climate policy. The Irish TIMES model provides a means of assessing the implications of alternative future energy system pathways for: (i) the Irish economy (technology choices, prices, output, etc.), (ii) Ireland's energy mix and energy dependence, and (iii) the environment. It is used in this project to assess the implications of emerging technologies and of mobilising alternative policy choices, such as meeting renewable energy targets and carbon-mitigation strategies. The two key new perspectives this research project gives are: (i) a full energy-systems modelling approach and (ii) a focus on the medium term (to 2050) as well as the short term (to 2020).

The scenario results respond directly to a number of key policy questions that could not be readily addressed before this model was developed. These relate to Ireland's targets for: (i) renewable energy to 2020, (ii) GHG reduction to 2020 and (iii) long-term GHG emissions reduction to 2050. The results point to:

1 Alternative pathways for renewable energy to that currently being followed under Ireland's National Renewable Energy Action Plan (NREAP);

2 The need to urgently reassess Ireland's renewable energy policies in light of the non-ETS emissions reduction target;

3 A particular focus on renewable heat, renewable transport and electrification of heat, in contrast to the current dominant focus on wind-generated electricity;

4 The impacts of imposing a higher emissions reduction target on Ireland's energy system to compensate for limited mitigation options in agriculture;

5 The significant challenges in moving to a low-carbon economy in 2050 with renewable energy accounting for 65–85% of energy supply (compared with 6.5% in 2011);

6 Electrification of heat in particular but also of transport, resulting in the share of energy use delivered by electricity increasing from 18% currently to 31–47% of energy use in 2050.

1 Introduction

Ireland faces very challenging short-term targets in the period to 2020 arising from EU obligations that are specified in EU Directives and EU Decisions. These include improving Ireland's energy efficiency by 9% by 2016 and by 20% by 2020, increasing renewable energy deployment (from 6.5% in 2011) to 16% of gross final energy consumption (GFC) by 2020 and achieving at least a 10% renewable share of road and rail transport energy and (most challengingly) reducing GHG emissions in non-emissions trading sectors (non-ETS) by 20% relative to 2005 levels. It is important to note that energy-related GHG emissions account for more than half of non-ETS GHG emissions.

In addition to these short-term targets, the EU has committed to a long-term GHG emissions reduction of 80–95% below 1990 levels by 2050 and will require Member States to participate in effort-sharing to deliver deep emissions cuts.

Mitigation strategies for deep cuts in emissions require significant financial investment: therefore, the development of strategies based on poor information and analysis will be expensive and wasteful. Policy-makers need comprehensive, robust, knowledge-based information to inform their decisions on how to meet these targets in a manner that will most benefit the Irish economy. In particular, given Ireland's current economic difficulties, it is vital that modelling capacity is improved as a matter of urgency and that the information base that feeds into policy decisions is improved greatly. This research project – the development of the Irish TIMES Energy Systems Model – makes a considerable contribution to Ireland's need to expand its capability in energy modelling significantly.

The project involved building, developing, calibrating, testing and running a (partial equilibrium) energy-systems optimisation model for Ireland, called Irish TIMES. The Irish TIMES model forms part of the MARKAL/TIMES family of modelling tools currently being used in over 200 institutions in 69 countries. This project draws on and contributes to the wealth of international energy-systems modelling research activity through the International Energy Agency Energy Technology Systems Programme (IEA-ETSAP) Implementing Agreement. The model was developed by University College Cork (UCC), in collaboration with the Economic and Social Research Institute (ESRI), E4SMA and KanORS over the period March 2009–November 2011.

The Irish TIMES model provides a range of future energy system configurations for Ireland that vary according to a range of policy constraints for the period out to 2050, but in each case delivering projected energy service demand requirements optimised to least cost. It provides a means of testing energy policy choices and scenarios, and assessing the implications for: (i) the Irish economy (technology choices, prices, output, etc.), (ii) Ireland's energy mix and energy dependence, and (iii) the environment, focusing mainly on GHG emissions. It is used to both examine baseline projections, and to assess the implications of emerging technologies and of mobilising alternative policy choices, such as meeting renewable energy targets and carbon-mitigation strategies.

The scenarios developed respond directly to a number of key policy questions (that could not be readily addressed before this model was developed) relating to Ireland's targets for: (i) renewable energy to 2020, (ii) GHG reduction to 2020 and (iii) long-term GHG emissions reduction to 2050. It is important to note that TIMES focuses on the contribution that technology choices may make in future scenarios.

There are clear limitations that need to be borne in mind when interpreting the results – most notably, these results are not attempts to forecast the future. The scenarios are based on different policy assumptions, and the results from one scenario are best interpreted by comparing them with the results from other scenarios, rather than as absolute results. Regarding the absolute results, they clearly depend on the robustness of future projections of economic growth and fuel prices that drive the model. In addition, as the focus of this model is on technology choice, the representation of behavioural effects is currently represented in only a limited manner.

Despite the limitations, the real value of the Irish TIMES model is in the new insights it gives into some of the key challenges and decisions facing Ireland in terms of energy and climate policy. The two key new perspectives this research project provides are a full energy-systems modelling approach and a focus that can examine the medium term (to 2050) as well as the short term (to 2020).

2 Methodology

Irish TIMES is a partial equilibrium model of Ireland's energy system, built with TIMES, the techno-economic modelling tool developed by IEA-ETSAP.[1] TIMES (The Integrated MARKAL-EFOM System) is a linear programming model generator, which provides a technology-rich basis for estimating energy dynamics over a long-term, multiple-period time horizon. It is usually applied to the analysis of the entire energy sector of a country or a region, but may also be applied to study single sectors (e.g. the electricity sector) in detail. It maximises the total surplus, equivalent to minimising the total discounted energy system cost, over the entire time horizon while respecting environmental and many technical constraints. There is a considerable body of ongoing international research involving TIMES (and its predecessor MARKAL) models. The recent IEA-ETSAP report (IEA-ETSAP, 2011) covering the period 2008–2010 summarises over 350 publications (including 86 peer-reviewed papers).

Figure 2.1 shows in schematic form how a TIMES model operates. The core model contains a large database of energy supply-side and demand-side technologies (over 1350 in the case of Irish TIMES). The database contains technical data (e.g. thermal efficiency, capacity), environmental data (e.g. emission coefficients) and economic data (e.g. capital costs) that vary over the entire time horizon. The exogenous model inputs are shown in Fig. 2.1 entering from the left-hand side (energy supply) and right-hand side (energy service demands) of the model. On the supply side, these include indigenous energy resource availability, primary energy (mostly fuel) prices and available energy imports. On the demand side, separate energy service demand projections are inputted, derived from macro-economic projections of the economy to 2050.

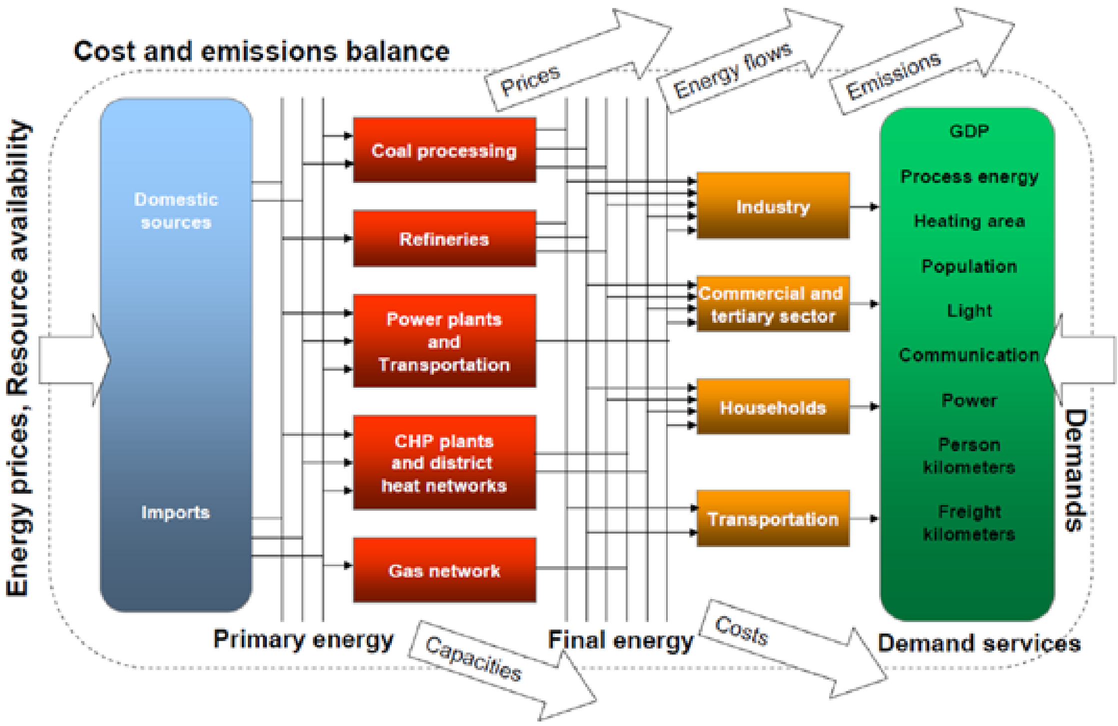

Figure 2.1. TIMES Model Schematic (Remme et al., 2001).

1 International Energy Agency Energy Technology Systems Analysis Programme (www.etsap.org).

The model is designed to determine the optimal energy system that meets the energy service demands over the entire time horizon at least cost, indicating the optimal mix of technologies and fuels at each period, the associated emissions, mining and import activities and the equilibrium level of the demand. The model outputs are shown on the top and bottom of Fig. 2.1, namely energy commodity prices (price of diesel versus biodiesel), energy flows (e.g. petajoules [PJ] of biomass by type), quantities of GHG and transboundary emissions (the current focus in Irish TIMES is on GHG emissions), capacities of technologies (e.g. installed megawatts [MW] of wind power) and energy costs (comprising capital costs, operation and maintenance [O&M] costs, fuel costs, etc.). Running the model in the absence of a policy constraint generates a set of results associated with a 'reference scenario'. This will not normally be completely aligned with national energy forecasts that are generated by simulating the anticipated future energy use, mainly because TIMES optimises the energy systems providing a least-cost solution. When a (single of many) policy constraint is then imposed on the model (e.g. minimum share of renewable energy, maximum amount of GHG emissions or minimum level of energy security), the model generates a different least-cost energy systems. When the results are compared with those from the reference scenario, the different technology choices that deliver the policy constraint at least cost can be identified.

The widest current applications of TIMES are related to the analysis of policies designed to reduce GHGs from energy and materials consumption. Since the framework depicts individual technologies, it is particularly useful for evaluating policies that promote the use of technologies of greater efficiency in energy or materials, or the development and use of new technologies. It provides a means of quantifying the economic cost associated with a range of climate mitigation strategies and the impacts of climate change policies on economic growth.

Originally extracted from the PET[36] model ([Pan European TIMES], which includes EU27, Iceland, Norway, Switzerland and Balkan countries) and then updated with local and more detailed data and assumptions, the Irish TIMES model represents the energy system of Ireland and its possible long-term evolution. The actual system encompasses all the steps from primary resources in place to the supply of the energy services demanded by energy consumers, through the chain of processes which transform, transport, distribute and convert energy into services, as shown in Fig. 2.2.

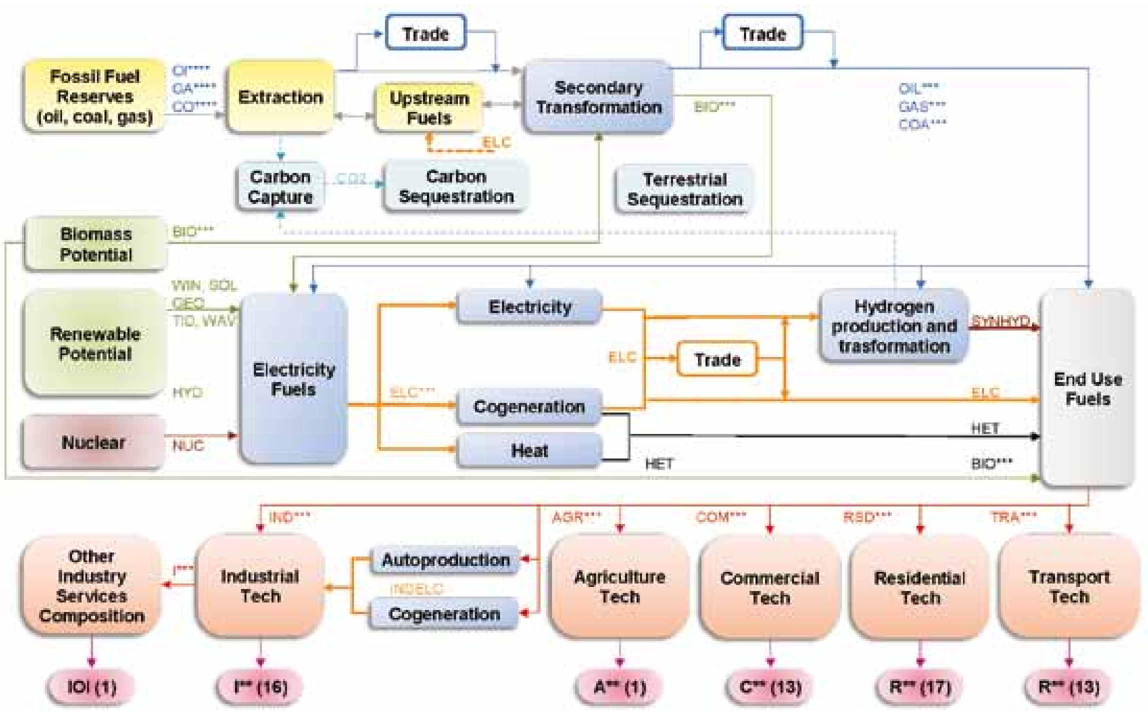

Figure 2.2. Irish TIMES Reference Energy System (Gargiulo et al., 2010).

The Irish energy system is characterised and modelled in terms of its supply sector (fuel mining, primary and secondary production, exogenous import and export), its power-generation sector (including also combined heat and power [CHP]), and its demand sectors (residential, commercial, agricultural, transport, industrial).

As noted above, the key inputs to Irish TIMES are the demand component (energy service demands), the supply component (resource potential and costs), the policy component (scenarios) and the techno-economic component (technologies and associated costs to choose from). The model is driven by exogenous demand specified by the list of each energy service demands (60 in the case of Irish TIMES), actual values in the base year (calibration) and values for all milestone years till 2050 (projection), along with environmental or other constraints (e.g. national and EU targets for Ireland). More details can be found in the full Irish TIMES report (available for download at: http://erc.epa.ie/safer/reports) and in Chiodi et al. (2012a).

2.1 Policy Scenario Definitions

Many types of policy scenarios can be explored using Irish TIMES, and generally developed by imposing constraints on the energy system – for instance, a minimum share of renewable energy or a maximum amount of CO_2 emissions. In addition to undertaking scenario analysis, Irish TIMES may also be used to assess and quantify the impacts of policy measures on future energy use, for example a carbon tax or a renewable energy feed in tariff. This section introduces the main scenarios used in this report, which are linked to Ireland's short-term and long-term targets relating to renewable energy and climate mitigation.

2.1.1 Reference Energy System Scenario

The Reference Energy System (REF) scenario provides a useful starting point for conducting different scenario analyses using the model. It represents the pathway for meeting Ireland's future energy service demands at least cost. The REF scenario is comparable with a baseline or reference energy forecast, although significantly here it represents a least-cost energy system and in that way differs from a simulated energy forecast.

2.1.2 REN-16 scenario

In the REN-16 scenario, the energy system is subject to 2020 renewable target specified by Directive 2009/28/EC (EU, 2009a), including also a minimum 10% renewable energy share of road and rail transport. The pathway comprises 6.6% minimum share of renewable energy by 2010 and 11.7% by 2015 in accordance with Ireland's National Renewable Energy Action Plan (NREAP) (Department of Communications, Energy and Natural Resources [DCENR], 2010). In contrast to the NREAP, however, this scenario does not impose additional constraints for end-use sectors, i.e. no further targets for RES-E, RES-T and RES-H.

2.1.3 NETS-CO2 scenario

In the NETS-CO2 scenario the energy system is subject to the 2020 emissions reduction targets specified by Directive 2009/29/EC (EU 2009b) and Effort Sharing Decision 2009/406/EC (EU, 2009c). Non-ETS energy-related emissions are hence subject to a 19.5 Mt $CO_{2,eq}$ target (-20% relative to 2005), while ETS are subject to a 16.0 Mt $CO_{2,eq}$ target (-21% relative to 2005 levels). By 2015 an interim target of 10% emissions reduction (relative to 2005) is also imposed in both sectors. This scenario makes no reference to targets for non-energy related GHG emissions, thereby implicitly assuming that they also reduce by 20% relative to 2005 levels.

2.1.4 NETS-GHG scenario

This scenario (similar to NETS-CO2) also assumes the national targets for ETS emissions under Directive 2009/29/EC and non-ETS emissions under Decision 2009/406/EC are met, but explores the effect on the energy system of additional GHG emissions reduction measures to compensate lower reduction levels in agricultural non-energy emissions, based on exogenous projections. Agriculture GHG projections are based on EPA projections (EPA, 2011), which assume that total emissions arising from non-energy agriculture will decrease by 4.4% over the period 2005–2020 to 17.8 Mt of $CO_{2,eq}$. In order to meet Decision 2009/406/EC non-ETS energy-related emissions are hence subject to a 31.5% emissions reduction target (16.7 Mt $CO_{2,eq}$) relative to 2005 levels by 2020, while ETS sectors are subject to a 21% emissions reduction target relative to 2005 (resulting in an overall energy-related CO_2 reduction -26.7%). By 2015 an interim of 10% emissions reduction is also imposed.

2.1.5 CO2-20 scenario

This scenario imposes an overall reduction target of 20.5% on energy-related CO_2 emissions by 2020 relative to 2005 levels rather than a separate 21% ETS target and 20% non-ETS target. It is worth nothing that the CO2-20 scenario is not aligned with national or European legislation, but has been presented here to quantify the impact of not having separate ETS or non-ETS targets.

2.1.6 CO2-80 scenario

The energy system is required to achieve at least an 80% CO_2 emissions reduction below 1990 levels by 2050 (-86.5% relative to 2005) in the CO2-80 scenario. The pathway includes specific interim targets in line with the EU Low Carbon Roadmap (EC, 2011), i.e. 20% CO_2 emissions reduction by 2020 relative to 2005 levels, 40% and 60% below 1990 levels by 2030 and 2040. It is implicitly assumed here that non-energy GHG emissions (notably agriculture) are reducing on a similar pathway to energy-related emissions.

2.1.7 CO2-95 scenario

In the CO2-95 scenario, an 80% GHG emissions reduction target would apply to the whole economy. This scenario assumes that the energy system will need to achieve deeper emissions cuts to compensate for agriculture not achieving an 80% reduction. According to the EU Low Carbon Roadmap (EC, 2011), GHG emissions in agriculture are capable of reducing by up to 49% by 2050. This scenario assumes a 50% emissions reduction in agriculture is achievable in Ireland and imposes a 95% emissions reduction target below 1990 levels by 2050 on the energy system to ensure the overall 80% target is achieved.

2.1.8 NETS-80 scenario

The NETS-80 scenario imposes an 80% emissions reduction target on energy-related CO_2 emissions by 2050 (similar to the CO2-80 scenario) but in this case assumes that the target will be imposed separately on ETS and non-ETS sectors, i.e. emulating that current EU climate policies, as specified by Directive 2009/29/EC and Decision 2009/406/EC, will be extended beyond 2020. This scenario assumes that energy-related emissions will reduce to 20% of 1990 emissions by 2050 in ETS and separately in non-ETS sectors. Reductions of 40% and 60% below 1990 levels are set for ETS and non-ETS sectors by 2030 and 2040. Non-energy emissions are implicitly assumed to reduce at similar rates to energy-related emissions.

3 Renewable Energy Targets for 2020

This section focuses on scenario results that address the following questions:

- How can Ireland meet its renewable energy targets for the year 2020 as stipulated in EU Directive 2009/28/EC (EU, 2009a) at least cost?
- Is current renewable energy policy aligned with the least-cost results delivered by Irish TIMES?

3.1 How can Ireland meet its Renewable Energy Targets for the Year 2020 at Least Cost?

The scenario results shown in Fig. 3.1 compares the contribution from renewable energy (by mode of energy use) to Ireland's GFC in the REF scenario (i.e. without the mandated 16% target applied) and the REN-16 scenario (i.e. applying the 16% renewable energy target to be achieved by 2020). Also shown in Fig. 3.1 for comparison are Ireland's NREAP targets for each mode (i.e. transport, heat and electricity). The results in Fig. 3.1 suggest an alternative approach to meeting Ireland's renewable energy target to that contained in Ireland's NREAP.

In the NREAP the modal targets are to achieve 10% RES-T (renewable energy representing 10% of road and rail transport energy), 12% RES-H (renewable energy representing a 12% share of thermal energy for heating and cooling) and 42.5% RES-E (i.e. renewable energy representing a 42.5% share of gross electricity consumption, or GEC) by 2020. As indicated in Fig. 3.1, the effect of these modal targets in terms of overall energy use is that RES-E represents 8.5%, RES-H 4.2% and RES-T 3.4% of GFC in 2020. The least-cost solution (REN-16) points to an increased contribution from renewable heat representing 6.9% of GFC, which is equivalent to 18% RES-H compared with the current 12% RES-H target in the NREAP. The results from REN-16 also indicate a lower contribution from renewable electricity (34% RES-E compared with 42.5% in the NREAP). This is an interesting finding that warrants further investigation. In addition, the results from REN-16 suggest a lower contribution from renewable transport (3.1% of GFC compared with 3.4% in the NREAP). It is worth noting however that renewable generated electricity is included in RES-E in Fig. 3.1 even if that electricity is employed

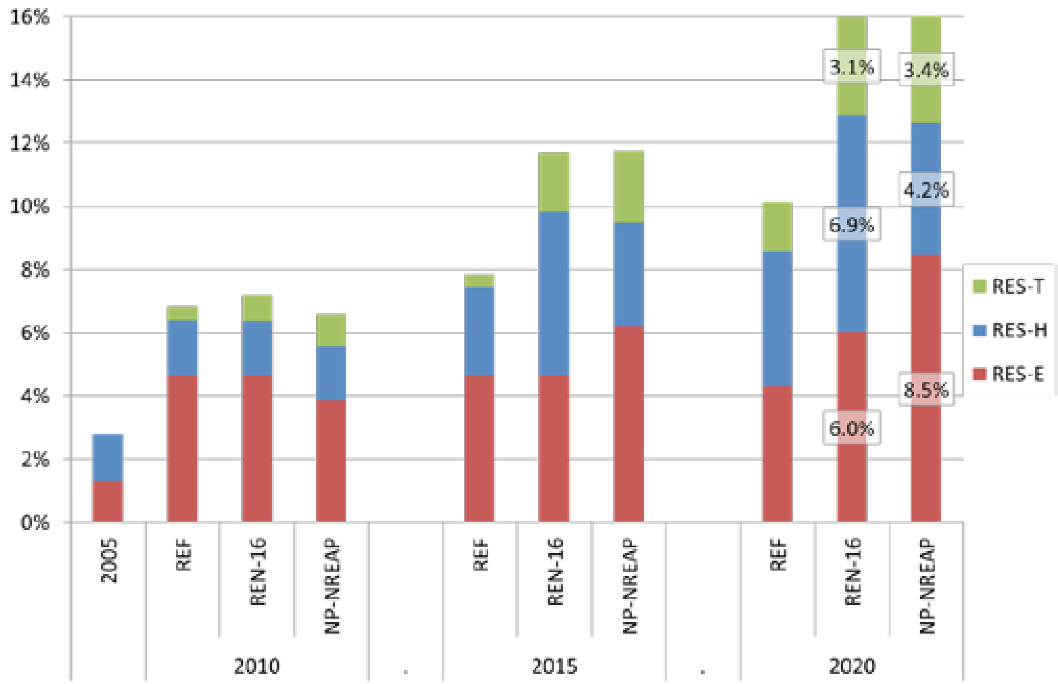

Figure 3.1. Comparing *REF* and *REN-16* renewable shares with the National Renewable Energy Action Plan (NREAP).

to power electric vehicles (EVs). Moreover, because of the different mix of transport renewable energy in REN-16, this 3.1% renewable energy contribution to GFC is equivalent to 13% RES-T, compared with 10% RES-T in the NREAP. This is because when the share of renewable energy to transport energy (RES-T) is calculated, certain renewable sources are weighted more than others.[2] However, this does not apply when calculating the contribution of renewable sources to overall energy use

3.2 Is Current Renewable Energy Policy Aligned with a Least-cost Pathway?

In terms of informing policy choices, analysis of Fig. 3.1 should not lead to the conclusion that Ireland's target for renewable electricity should be reduced and its target for renewable heat increased. There is significant impetus behind – and progress towards – increasing the amount of renewable-electricity generation, which has grown from 5% in 2000 to 18% in 2011 (Howley et al., 2012). It is sensible to continue on this path in the context of longer-term aspirations beyond 2020. What Fig. 3.1 does suggest is that the role that renewable heat can potentially take in Ireland should be re-examined. It also suggests that renewable energy policy in Ireland should be amended. The current policy focuses mainly on achieving the renewable electricity target. There is much less focus on renewable transport, and currently no adequate policy mechanisms for promoting renewable heat. These issues need to be addressed as a matter of urgency.

The Irish TIMES REN-16 results also indicate different technology choices compared with those underpinning the NREAP. The REN-16 results do not include EVs or ocean energy (which are included in NREAP) and do include biogas for transport and heating. The differences are most notable in RES-T, as shown in Fig. 3.2. REN-16 results point to half of biofuels in transport coming from biogas, while the NREAP points to biodiesel and bioethanol. This suggests that the potential for biogas as a transport fuel be re-examined. The results from this least-cost approach concur with other research that focuses on other benefits of biogas as a transport fuel (Smyth et al., 2010; Thamsiriroj and Murphy, 2011; Thamsiriroj et al., 2011). Fig. 3.3 presents the results for RES-H, again comparing the REN-16 results with the

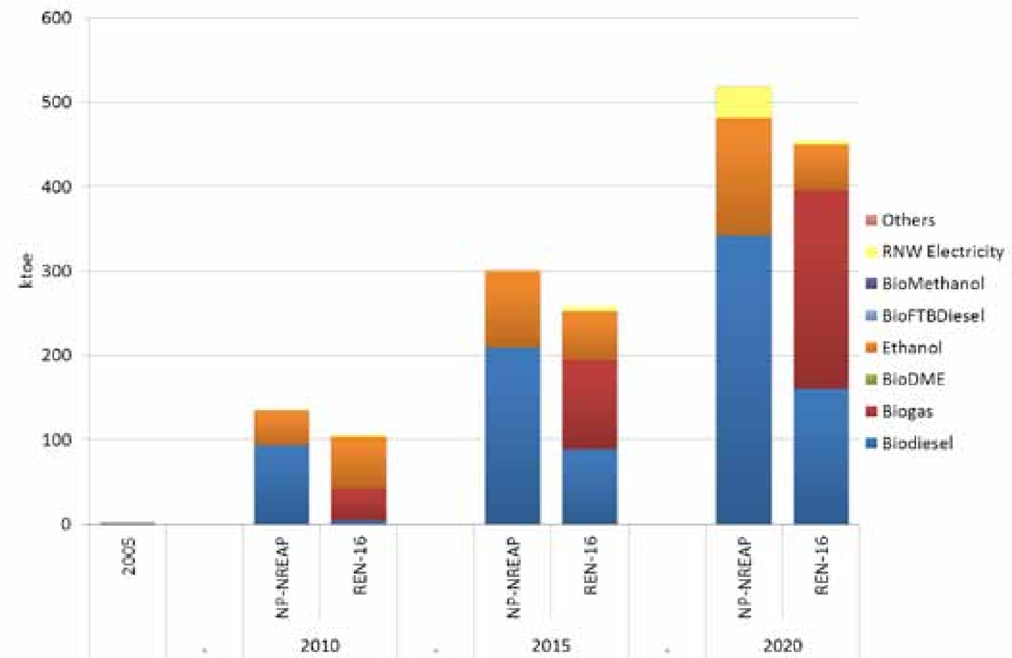

Figure 3.2. Renewable energy consumption for transport sector (ktoe).

2 This is in accordance with EU Directive 2009/28/EC (EU, 2009a). Second-generation biofuels and biofuels generated from waste are allocated a weighting factor of 2. Renewable-generated electricity powering electric vehicles are allocated a weighting of 2.5.

renewable heat pathway stipulated in Ireland's NREAP. The higher volumes of renewable thermal energy in REN-16 are striking, and the different technology choices also noticeable. In particular, REN-16 does not include geothermal or solar thermal energy and chooses solid biomass and biogas as the preferred sources. Further details on the renewable energy scenarios are available in Ó Gallachóir et al. (2012).

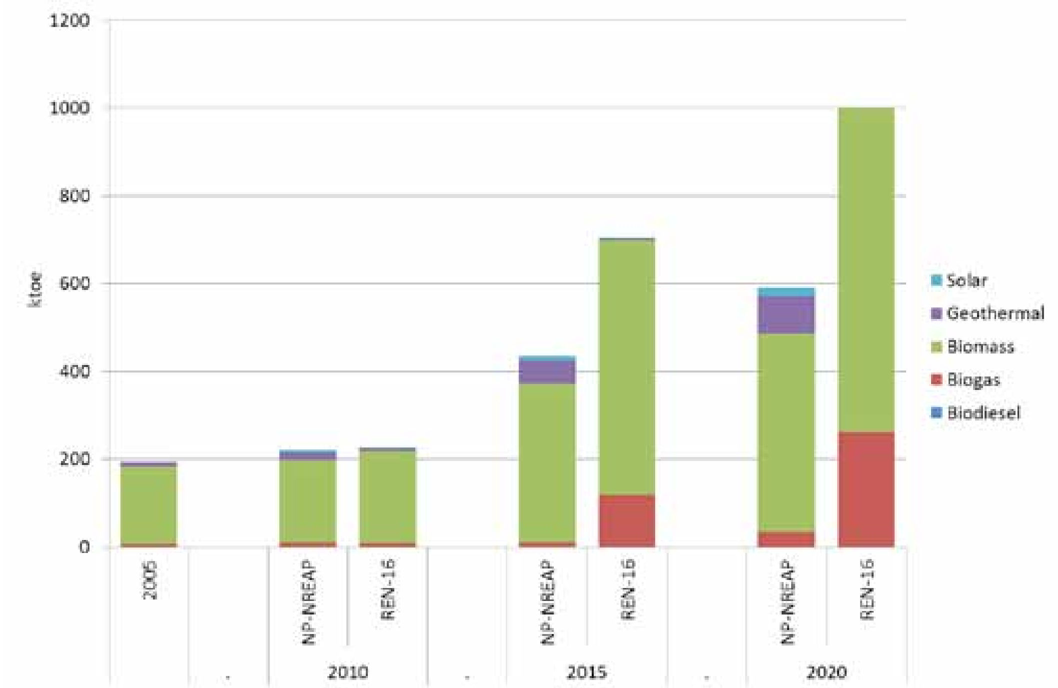

Figure 3.3. Renewable thermal energy consumption (ktoe).

4 Greenhouse Gas Emissions Reduction Targets for 2020

This section focuses on scenario results that address the following questions:

- What are the implications of Ireland's target for greenhouse gas (GHG) emissions reductions, particularly in non-ETS sectors as stipulated in EU Decision 406/2009 (EU, 2009c) for Ireland's energy system?
- If agriculture-related GHG emissions to 2020 are in line with the Ireland's Food Harvest 2020 policy,[3] can Ireland's energy system achieve deeper emissions reductions to compensate for growth in agriculture, and at what cost?

Two scenarios (NETS-CO2 and NETS-GHG) are built in Irish TIMES to inform decisions regarding Ireland's target to reduce non-ETS GHG emissions by 20% below 2005 levels by 2020 as stipulated in EU Decision 406/2009. The NETS-CO2 scenario imposes a 20% constraint on the energy system only. This implicitly assumes that the other non-ETS sectors of the economy (notably agriculture) can also deliver a 20% GHG emissions reduction target by 2020. The NETS-GHG scenario assumes that agriculture-related GHG emissions follow a trend aligned to the Food Harvest 2020 policy. In this case, the non-ETS emissions reduction target for the energy system is increased to 31.5% to compensate for a lower than 20% reduction achieved by agriculture. The purpose of these scenarios is to inform decisions regarding the different sectoral contributions to meeting Ireland's overall non-ETS sector target. Further details are available in Chiodi et al. (2012b).

4.1 Implications of Ireland's 2020 Target for Greenhouse Gas Emissions Reductions for Ireland's Energy System

Figure 4.1 shows Ireland's energy-related non-ETS emissions from 2005 to 2020, comparing the REF scenario results with the NETS-CO2. In particular, Fig. 4.1 indicates which sectors contribute most

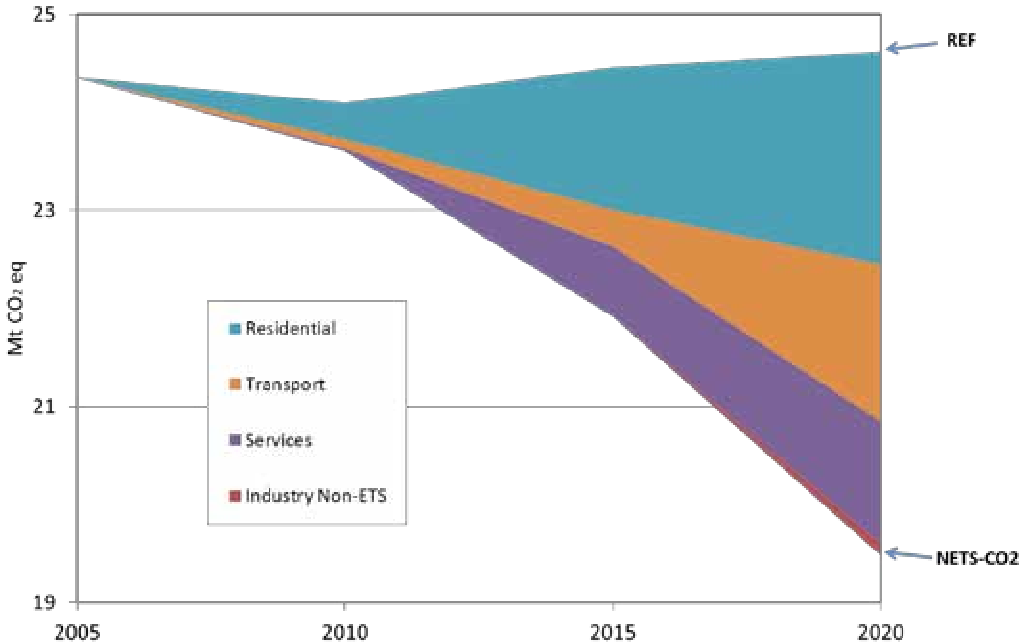

Figure 4.1. Comparing non-ETS CO_2 emissions in REF and NETS-CO2 (Mt).

3 Food Harvest 2020 (DAFF, 2010) envisages significant growth in agri-food output in Ireland to 2020 (including notably a 50% increase in milk production and a 40% increase in food and beverages added value).

to non-ETS emissions reduction. It is important to note that the REF scenario represents a least-cost energy system pathway and hence already includes cost-effective energy-efficiency improvements and renewable energy deployment. The REF scenario also incorporates the effects of the 2008 and 2011 Building Regulations (DEHLG, 2008 and DEHLG, 2011), which means that new buildings in the model have a significantly improved energy performance compared with existing buildings (Dineen and Ó Gallachóir, 2011). In this NETS-CO2 scenario, the results suggest that significant non-ETS emissions reductions may be achieved within the residential (accounting for 42.1% of the emissions reduction compared with REF), transport (accounting for 31.3% of the emissions reduction) and services (24.4% of the emissions reduction) sectors.

The emissions reductions in the NETS-CO2 scenario are achieved through increased energy efficiency and as a result of two key fuel-switching pathways: (i) increasing the amount of biofuels used in transport significantly and (ii) the electrification of heating in buildings. In the case of the latter, electrification of heating shifts CO_2 emissions from the non-ETS sectors (heating in the residential and services sectors) to the ETS sectors (i.e. electricity generation). While electrification of transport (i.e. introducing EVs) delivers a similar result, this technology does not feature significantly in the results because of the current and future anticipated costs of EVs (in particular, the battery costs).

These results again underline the need to reassess Ireland's renewable energy policies in the light of the non-ETS emissions reduction target. The results point to a focus on renewable heat, renewable transport and electrification of heat, in contrast to the current dominant emphasis on wind-generated electricity. In order to meet Ireland's targets for renewable heat and to achieve further emissions reductions it will be necessary to develop effective policy measures for fuel-switching. Two previous schemes have encouraged fuel-switching to renewable heating, namely the Greener Homes scheme in the residential sector[4] and the ReHeat scheme in the commercial, industrial, services and public sectors.[5] However, these schemes ended in 2011.

4.2 Impacts of Agriculture-related Greenhouse Gas Emissions to 2020 on Ireland's Energy System

Figure 4.2 also graphs Ireland's energy-related non-ETS emissions from 2005 to 2020, but in this case comparing the NETS-CO2 with the NETS-GHG results. It captures the effect of the additional burden placed on the energy system to compensate for agriculture. In NETS-CO2, a 20% non-ETS emissions reduction target is imposed on the energy system, whereas in NETS-GHG the energy system faces a 31.5% non-ETS emissions reduction target, due to agriculture not achieving a 20% reduction.

The NETS-GHG scenario points to further use of biofuels for transport, compared with NETS-CO2 (resulting in 21% RES-T) and further electrification of heat in buildings. Figure 4.3 provides an interesting comparison between the renewable energy pathway envisaged in Ireland's NREAP with that arising from the NETS-GHG scenario.

It is important to note that the NREAP is designed to meet Ireland's target under the EU Renewable Energy Directive 2009/28/EC (EU, 2009a) rather than Ireland's target for non-ETS emissions under Decision 406/2009 (EU, 2009c). The renewable energy arising from the NETS-GHG scenario accounts for 18.5% of overall energy use, hence exceeding the EU Renewable Energy Directive target for Ireland of 16%. The scenario results also suggest that the current policy focus will likely result in failure to meet the non-ETS target.

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4 See http://www.seai.ie/Grants/GreenerHomes/Scheme_Statistics/ for more details.

5 See http://www.seai.ie/Grants/Renewable_Heat_Deployment_Programme/ for more details.

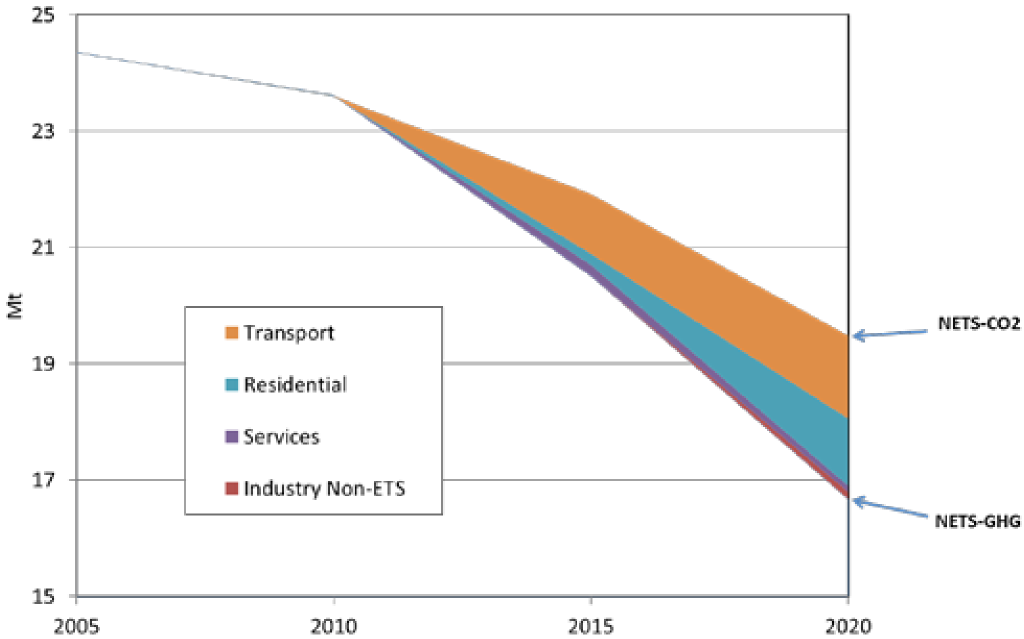

Figure 4.2. Comparing non-ETS CO_2 emissions in NETS-CO2 and NETS-GHG (Mt).

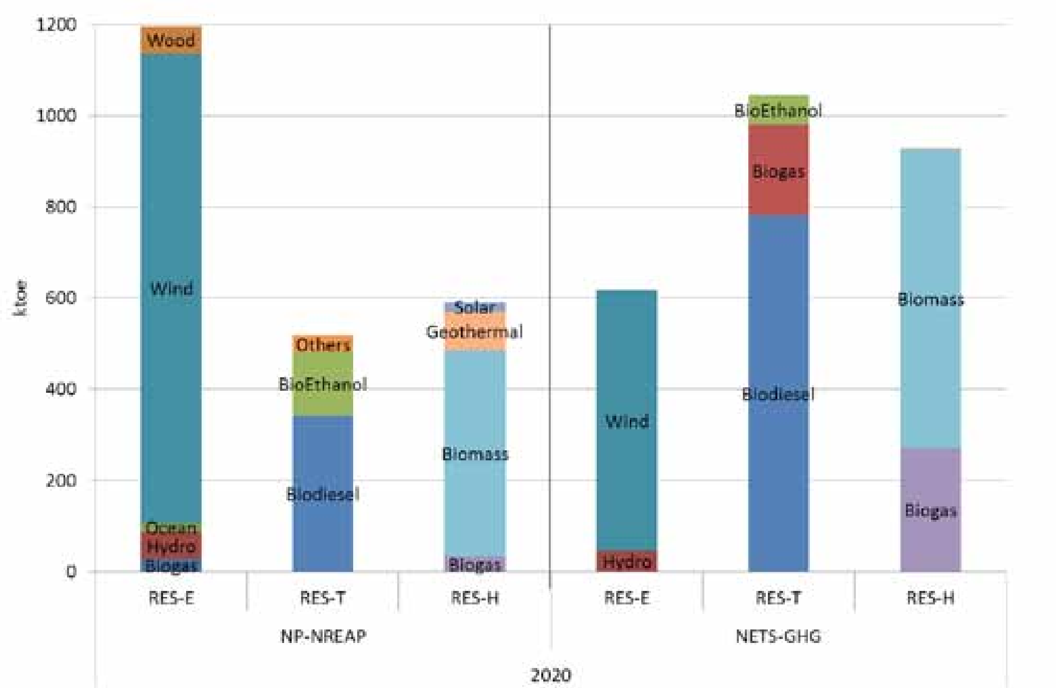

Figure 4.3. Comparing renewable energy in the National Renewable Energy Action Plan (NREAP) and NETS-GHG (ktoe).

Other interesting facets of Fig. 4.3 relate to the different technology choices. The NETS-GHG scenario understandably points to greater contributions from renewable heat and renewable transport technologies as these are the non-ETS sectors. The contribution from renewable electricity in the NREAP is double that shown in the NETS-GHG scenario. Given the fact that wind-generated electricity does not contribute directly to the non-ETS target, this again is understandable. As mentioned earlier, the key message from these results is not that the momentum in wind-energy deployment is arrested, but that the resolve to increase renewable transport and renewable heat energy is augmented, if Ireland intends meeting the non-ETS target. It is also worth recalling that, in the NETS-GHG scenario, the energy system emissions reduction is 31.5% compared with 2005 levels, compensating for agriculture emissions growing in line with the Food Harvest 2020 policy.

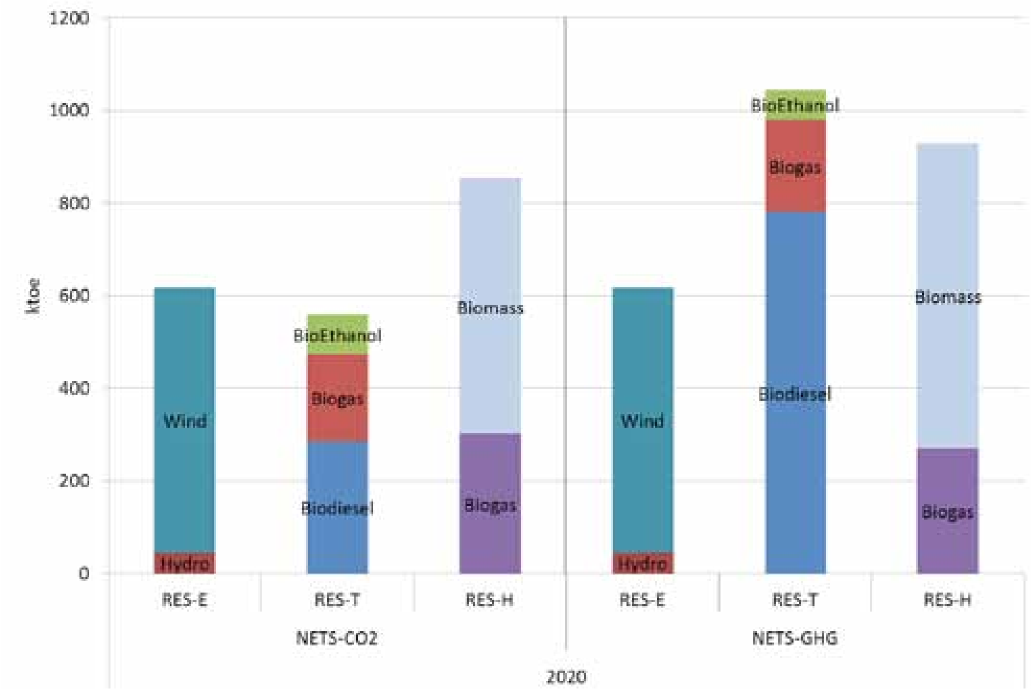

Figure 4.4. Renewables consumption by mode in NETS-CO2 and NETS-GHG (ktoe).

Figure 4.4 captures the explicit impact of this in terms of renewable energy, by comparing the renewable energy results for NETS-CO2 and NETS-GHG. In NETS-CO2, the amount of biofuels required is similar to the NREAP (if compared with the left-hand side of Fig. 4.3), although the mix is quite different because of the penetration of biogas as a transport fuel in NETS-CO2. Moving from NETS-CO2 to NETS-GHG requires almost a doubling of biofuels, which is necessary to compensate for agriculture not meeting a 20% emissions reduction target.

This raises a further interesting policy issue – if more biofuels are used to enable the agriculture sector to generate GHG emissions in line with Food Harvest 2020, separate to the issue of costs, to what extent will this result in land-use competition issues that may in turn impact on Food Harvest 2020?

There is a significant challenge in quantifying the costs of climate-mitigation policies, in determining how these costs should be allocated and in developing an effective mechanism to ensure that the costs are then allocated as they should be. To date, the Irish TIMES project has focused on shedding light on two aspects that do not purport to meet this challenge but do provide some useful inputs to discussions and analysis. The CO_2 marginal abatement costs can be extracted readily from the model results, that is, the cost of delivering the last (marginal) tonne of abatement in a particular scenario. The second metric developed is a crude measure of the cost of mitigation as a proportion of GDP in a particular time period. This is estimated by calculating the difference in total energy system costs between a mitigation scenario and the REF scenario in each time period and by then dividing this by the cumulative GDP generated in that period.

Table 4.1 shows the marginal cost of CO_2 abatement in 2015 and in 2020 for three scenarios. Focusing on the 2020 results, the marginal cost of meeting non-ETS target increases from €$_{2000}$158/tCO_2 to €$_{2000}$213/tCO_2 moving from a 20% non-ETS CO_2 emissions reduction to a 20% non-ETS GHG emissions reduction. This increase quantifies the effect of the energy system facing a 20% target compared with a 31.5% target (compensating for a lower emissions reduction in agriculture). One way to interpret these numbers is to consider no policy measures other than a carbon tax being applied. In this scenario, the marginal cost is equivalent to the level of tax that would need to be applied to meet the scenario target. For comparison in terms of the scale these costs represent, the current level of carbon tax in Ireland is €20/tCO_2. This suggests that it will be very expensive to meet the non-ETS mitigation target for 2020.

Table 4.1. CO_2 shadow prices in CO2-20, NETS-CO2 and NETS-GHG.

[$€_{2000}$/ton CO_2]	Scenario	2015	2020
Non-ETS emissions	CO2-20	0	46
	NETS-CO2	89	158
	NETS-GHG	97	213

A third scenario – the CO2-20 scenario – is also shown in Table 4.1. This imposes an overall reduction target of 20.5% on energy-related CO_2 emissions by 2020 relative to 2005 levels rather than a separate 21% ETS target and 20% non-ETS target. It is worth nothing that the CO2-20 scenario is not aligned with national or European legislation, but has been presented here to quantify the impact of not having separate ETS or non-ETS targets. The CO2-20 emulates the approach adopted by the European Commission (EC) at EU level to determine the EU ETS and non-ETS targets (EC, 2008). Firstly, the least-cost pathway for meeting the overall EU 2020 20% GHG emissions reduction targets (relative to 1990 levels) was established, pointing to a 21% emissions reduction target for ETS sectors and a 10% reduction target for non-ETS sectors (in both cases relative to 2005 levels). Initial individual Member State non-ETS emissions reductions targets were then determined using a least-cost optimisation approach. In the results of this 'cost efficient policy case' Ireland's non-ETS GHG emissions reduction were 17% below 2005 levels (Table 4 of SEC(2008) 85 Vol. II). The EU analysis indicated that the cost-efficient policy case can be achieved at a marginal abatement cost of €40–€50/tCO_2. The ability of individual Member States to invest in mitigation was then taken into account to ensure an equitable distribution of effort. Ireland had a relatively high level of GDP per capita in 2005 and was thus allocated a target to achieve a 20% reduction relative to 2005.

The Irish TIMES results in Table 4.1 raise a number of questions regarding the analysis that underpinned Ireland's obligations under Decision 2009/406/EC. One significant finding is that imposing a 20% target on non-ETS energy-related CO_2 emissions target results in a high marginal abatement cost ($€_{2000}$158/tCO_2), which suggests the target set for Ireland is far from cost optimal. This is before incorporating the fact that agriculture represents nearly half of non-ETS emissions in Ireland, with few mitigation options. When this is taken into account (by imposing a larger target emissions reduction on the energy system), the marginal abatement cost increases further to $€_{2000}$213/tCO_2. This abatement cost is more than four times higher than the marginal abatement cost of €40–€50/tCO_2 deemed sufficient for Ireland to achieve a 17% non-ETS GHG emissions reduction in the analysis carried out (EC, 2008) to inform the Effort Sharing Decision 2009/406/EC. The CO2-20 scenario however points to a marginal abatement cost of $€_{2000}$46/t CO_2, which aligns much more closely with the EU analysis figures. Figure 4.5 illustrates the implications of this in terms of Ireland's non-ETS emissions reduction target. The energy-related CO_2 emission trajectories for the NETS-CO2 scenario and the CO2-20 scenarios to 2020 are compared in Fig. 4.5 (along with the REF scenario results). Focusing on the non-ETS emissions reduction only, Fig. 4.5 suggests that a return to 2005 levels by 2020 in non-ETS emissions would have been significantly more cost optimal than the 20% emissions reduction target allocated to Ireland. It is worth noting here that these scenarios focus on the energy system only and hence implicitly assume that agriculture can meet an equivalent emissions reduction target. A 0.3% reduction in emissions relative to 2005 levels by 2020 for agriculture is however consistent with the analysis underpinning the emissions associated with the Food Harvest 2020 policy.

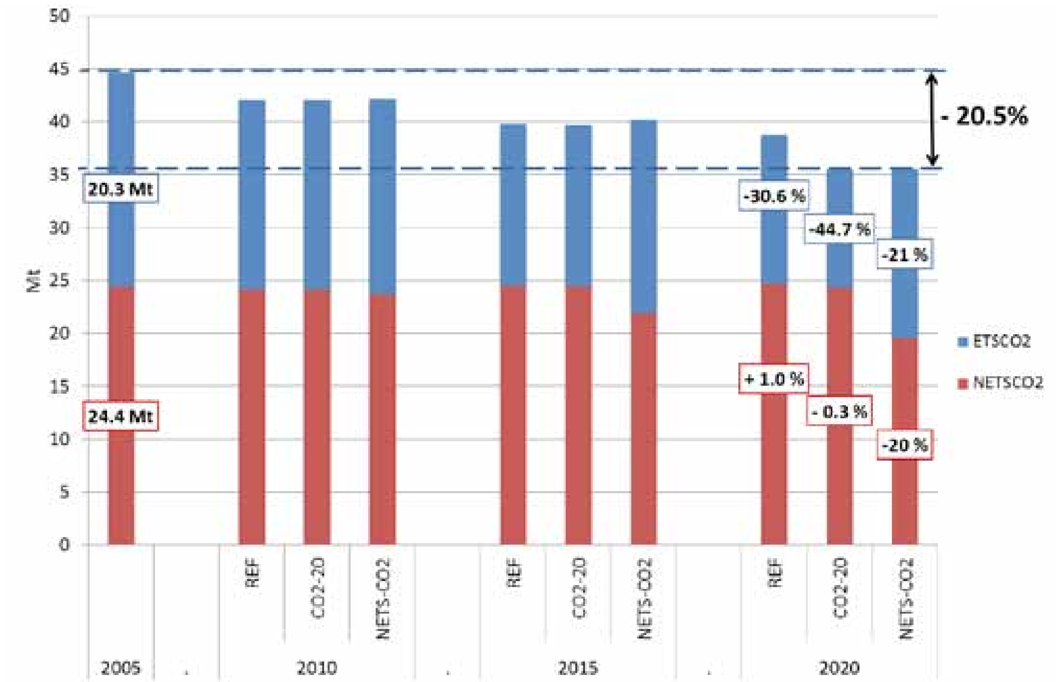

Figure 4.5. ETS and non-ETS CO_2 emissions trajectories in REF, CO2-20 and NETS-CO2 (Mt).

Table 4.2 provides a simple metric to indicate the impacts of the energy system and of mitigation policies on Ireland's economy, comparing the total system costs (including investment costs, operation and maintenance costs, fuel costs, transmission and distribution costs, delivery costs, etc.) with economic activity (GDP) for the scenarios generated. The first row in Table 4.2 estimates that Ireland's energy system costs will be reduced over the time horizon to 2020 from over 10% of GDP to less than 8%. Focusing on the last column in Table 4.2, the results suggest that the mitigation costs associated with the most ambitious scenario (NETS-GHG) will represent 0.7% of GDP in 2020. A key caveat to these results is the assumption in this model that energy service demands in the REF scenario are maintained as constant in the mitigation scenarios. This means the increased energy costs associated with mitigation do not have a direct impact on GDP, which is assumed to be the same across all scenarios.

Table 4.2. Energy system costs (GDP) – the cost of mitigation.

		2005 (%)	2010 (%)	2015 (%)	2020 (%)
SysCost	REF/GDP	11.21	10.44	9.42	7.87
	CO2-20		+0.25	+0.21	+0.23
	NETS-CO2		+0.27	+0.30	+0.44
	NETS-GHG		+0.27	+0.42	+0.69

5 Greenhouse Gas Emissions Reduction Targets for 2050

This section focuses on scenario results that address the following questions:

- Can Ireland's energy system deliver our Irish energy service demands to 2050 and also achieve an 80% reduction in energy-related GHG emissions relative to 1990 levels?
- If the agriculture sector does not achieve an 80% GHG emissions reduction by 2050, what are the implications for the energy system?
- What are the cost implications of deep decarbonisation and of the energy system compensating for agriculture achieving lower emissions reductions?

During this project, UCC developed the first detailed energy and energy-related CO_2 emissions scenarios for Ireland, based on new macro-economic projections for Ireland to 2050 that were generated by the ESRI.

Ireland does not have a specific target for GHG emissions reduction beyond 2020. The Climate Change Response Bill 2010 (DEHLG, 2010) proposed the target of 80% emissions reduction by 2050 relative to 1990 levels. The EU has committed to achieving emissions reduction in the range of 80–95% below 1990 levels by 2050. The scenarios here were developed in order to inform the discussions regarding Ireland moving towards a low-carbon economy by 2050 and are illustrated in Fig. 5.1. In the CO2-80 scenario, an 80% emissions reduction target is applied to the energy system only. Further scenarios were developed to compensate for agriculture not meeting an 80% emissions reduction target. In the absence of agriculture emissions projections for Ireland beyond 2020, initially a projection was developed based on assuming that agriculture GHG emission levels in 2050 were the same as 2020 levels. Based on this assumption, the energy system would be required to meet a 127% CO_2 emissions reduction by 2050 relative to 1990 levels. This is the CO2-127 scenario shown in Fig. 5.1. The energy system would be required to generate -8 Mt CO_2 emissions in 2050. Biomass carbon capture and storage (CCS) is a technology that delivers negative emissions but this is not yet available in Irish TIMES. An alternative approach was adopted whereby Ireland's agriculture emissions were assumed to achieve a 50% reduction by 2050. This is the same percentage reduction as suggested in the EU Low Carbon Roadmap (EC, 2011) for agriculture emissions within the EU as a whole. Using this exogenous assumption, the energy

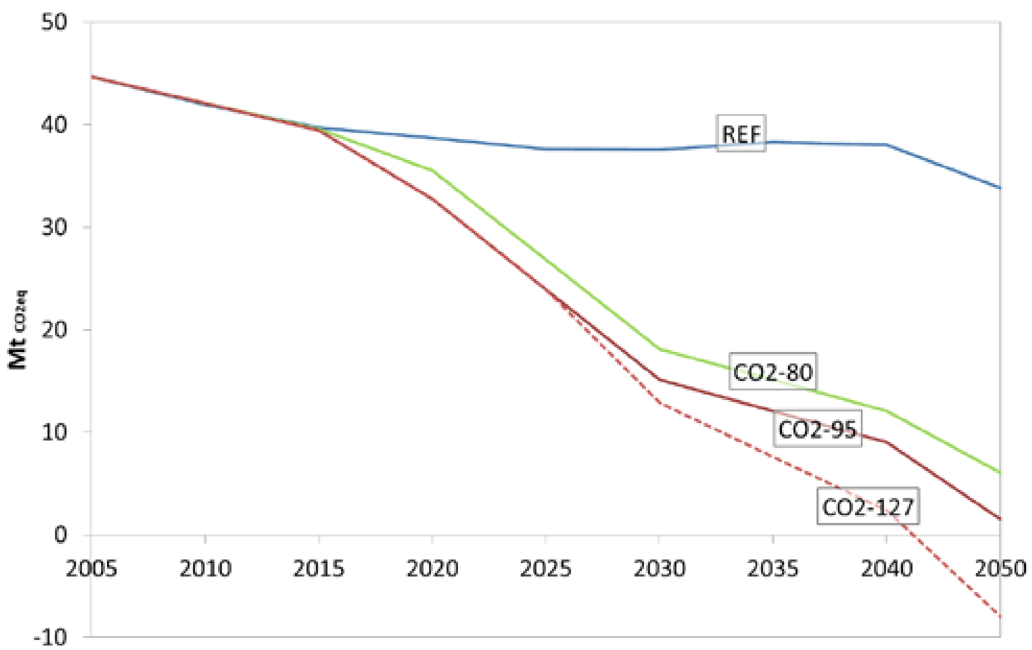

Figure 5.1. Mitigation scenario pathways to 2050 (Mt).

system is then required to deliver a 95% emissions reduction by 2050 and this was adopted here as the CO2-95 emissions scenario. The emissions reduction is applied to total CO_2 emissions. A further scenario not shown here (NETS-80) was also developed, in which the 80% emissions reduction target is imposed separately on ETS and non-ETS emissions.

Figure 5.1 underlines the scale of the long-term challenge facing Ireland. If agriculture can achieve a 50% reduction in GHG emissions by 2050, the entire energy system must achieve a 95% reduction in CO_2 to deliver an overall GHG emissions reduction of 80%. This means the maximum energy-related CO_2 that the energy system can produce in 2050 is 1.5 Mt. This is equivalent (in terms of today's energy system) to less than 10% of current emissions from electricity generation, noting that electricity accounts for just 18% of Ireland's energy use.

5.1 Can Ireland's Energy System meet Energy needs in 2050 and Achieve an 80% Reduction in Energy-related Greenhouse Gas Emissions?

The model results from the 2050 scenarios indicate that these deep emissions cuts are technically possible, while also meeting Irish future energy service demands by incorporating radical changes in energy demand-side and supply-side technologies. The results point to which energy efficiency and renewable energy technologies will have a determining role in delivering the target at least cost. Figure 5.2 shows the CO_2 emissions results from these long-term scenarios, comparing the REF scenario with CO2-80 and CO2-95. The results illustrate the contribution of individual sectors to CO_2 emissions reduction. Reductions are important in the whole energy system, but mainly in transport, electricity generation and industry.

5.2 What are the Implications for the Energy System if Agriculture does not achieve 80% Greenhouse Gas Emissions reduction by 2050?

Figure 5.3 compares the final energy use in the REF, CO2-80 and CO2-95 scenarios. The results in the period 2030–2050 show differences in each scenario in terms of the amount of energy required to meet future energy service demands. This illustrates the improvement in end-use energy efficiency as Ireland moves increasingly towards an increasingly low-carbon energy system. It is worth noting that the REF scenario also already includes cost-effective efficiency improvements delivered over the time horizon. Comparing the results in 2050, final energy use in the CO2-80 and CO2-95 scenarios is 20.5% and 23.1% less than REF.

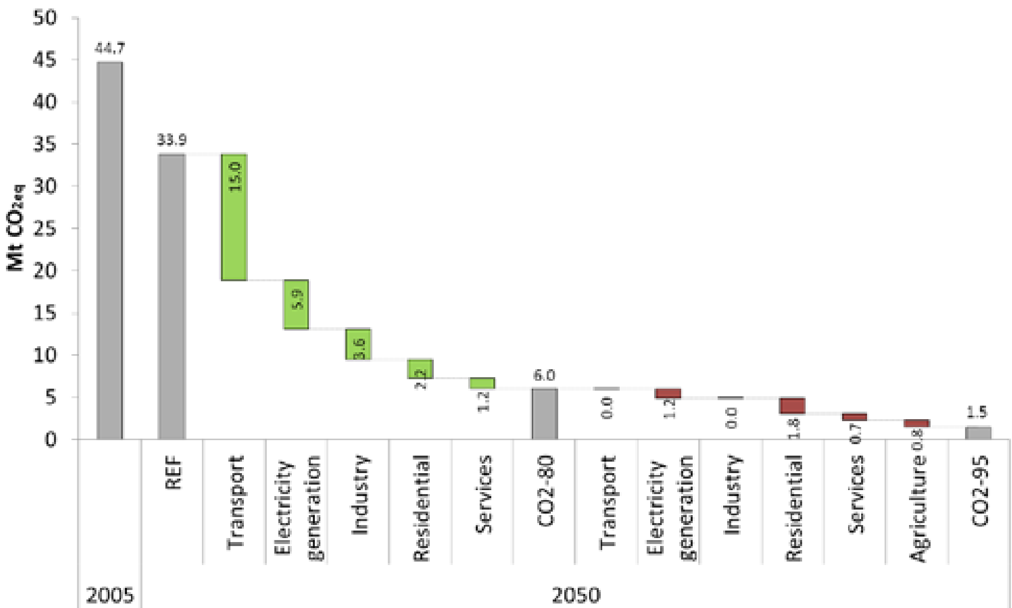

Figure 5.2. Decomposition of 2050 CO_2 emissions between REF, CO2-80 and CO2-95 (Mt).

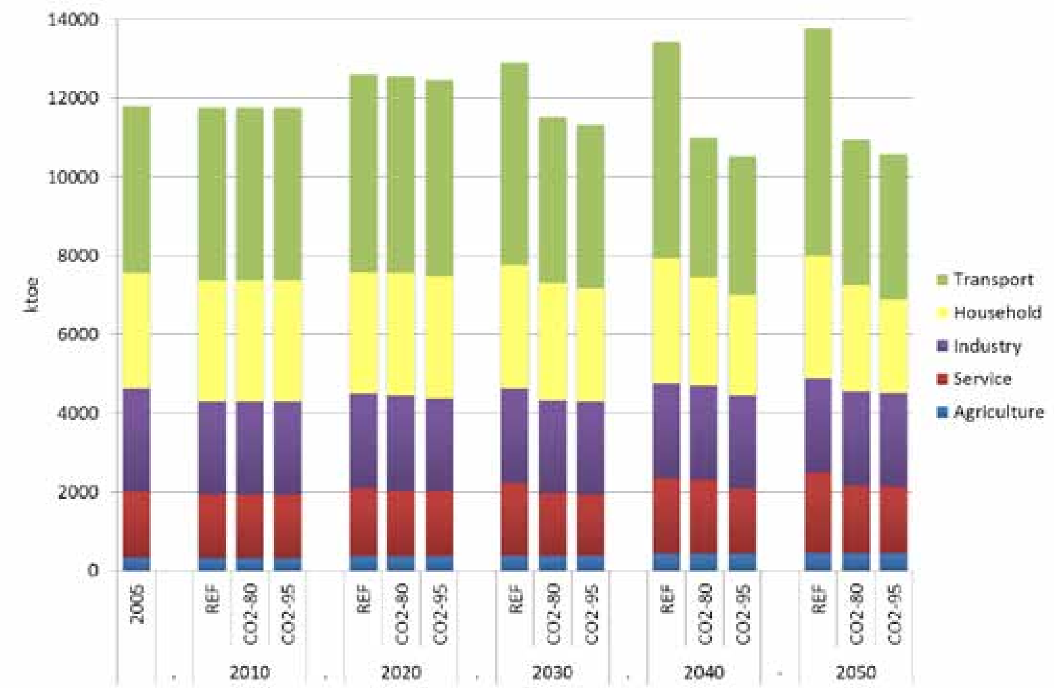

Figure 5.3. Final energy demand by sector in REF, CO2-80 and CO2-95 (ktoe).

Figure 5.4 shows the changes in the fuel mix for electricity generation for the period 2005–2050 comparing the three scenarios. The REF scenario points to significant decarbonisation and the mitigation scenarios deepen this further. The CO2-80 scenario is dominated by renewable energy, with natural gas CCS and natural gas combined cycle gas turbine (CCGT) power plants also contributing. Renewable generated electricity in 2050 accounts for 71.9% of GEC in CO2-80, compared to 100% renewable electricity generation (in addition to imports of 2.3% of GEC) in CO2-95. The remaining electricity in CO2-80 is provided by gas CCS (accounting for 18% of GEC). The additional efforts required to move from CO2-80 to CO2-95 (i.e. delivering further reductions of 4.5 Mt) are mainly concentrated in the power sector (gas CCS displaced by biomass) and increased electrification of heating in the residential and services sector.

In the CO2-95 scenario, a complete decarbonisation of the Irish electricity system in 2050 can be seen (comprising 67% wind and 28% biomass, including biogas, a small contribution from hydro power and the remainder from electricity imports). Also evident in Fig. 5.4 is the increase in total electricity generation across the scenarios because of the electrification of heating.

This electrification is more clearly visible in Fig. 5.5, which shows the growth in electricity usage. Moving from REF to CO2-80 electrification of transport starts to take place in 2030, as does the growth in electrification of residential heating. In CO2-95 more significant electrification of residential heating occurs and the impact of this is that electricity demand more than doubles between 2005 and 2050.

Electrification of heat in particular but also of transport results in the share of energy use delivered by electricity increasing from 18.8% in REF (similar to current levels) to 31.0% in CO2-80 and 46.7% in CO2-95.

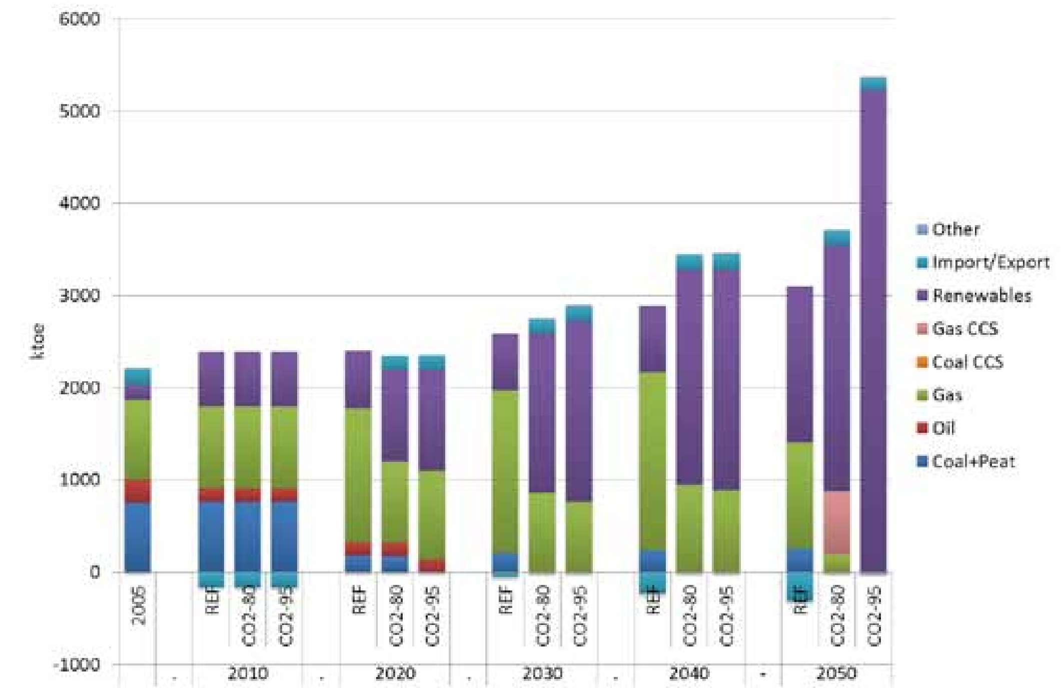

Figure 5.4. Electricity generation by fuel in REF, CO2-80 and CO2-95 (ktoe).

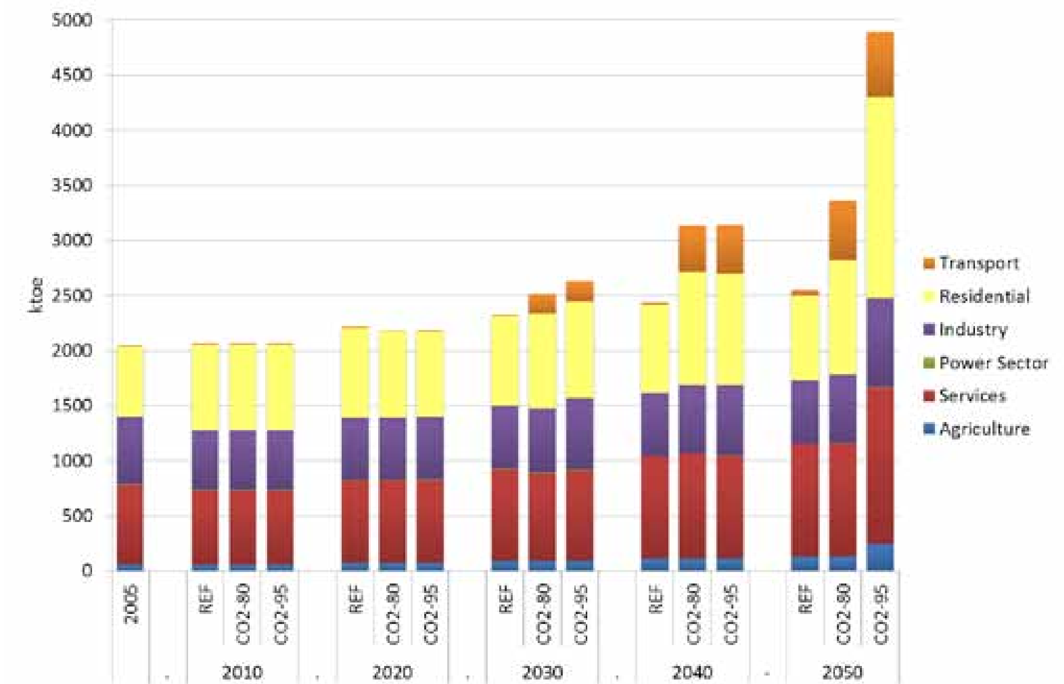

Figure 5.5. Electricity consumption by sector in REF, CO2-80 and CO2-95 (ktoe).

Regarding transport energy use, Fig. 5.6 compares the different scenario results in 2050, distinguishing between private transport, freight and public transport. Most of transport energy is also decarbonised with private cars diverting to EVs, freight and public transport to biofuels (comprising biodiesel and biogas).

Figure 5.7 compares the CO2-80 and CO2-95 results in terms of renewable energy usage in 2050 by mode. Renewable energy in 2050 is 8.4 Mtoe in the CO2-80 scenario (accounting for 67.8% of GFC, compared with 25.3% of GFC in the REF scenario). In the CO2-95 scenario, renewable energy reaches 10.4 Mtoe, representing 85.1% of GFC. The main renewable energy resources used are biomass (biodiesel and biogas for transport and biomass for heat) and wind.

The significant difference between the scenarios is the full move to renewable generated electricity in CO2-95. Some of the biomass that was used for thermal energy in CO2-80 is used for electricity generation in CO2-95.

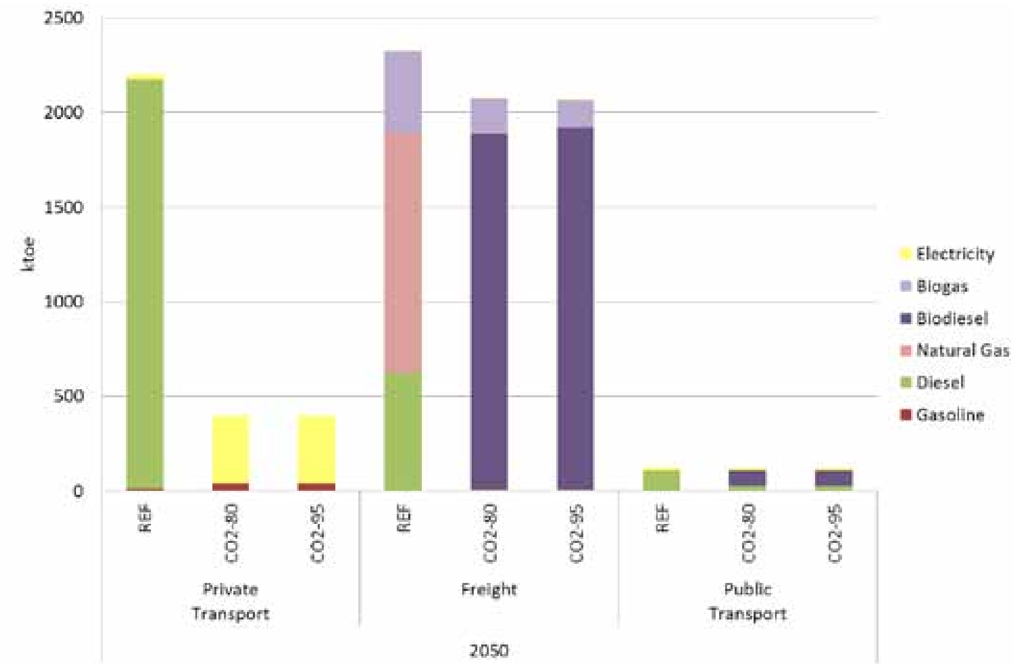

Figure 5.6. 2050 transport energy by end-use in REF, CO2-80 and CO2-95 (ktoe).

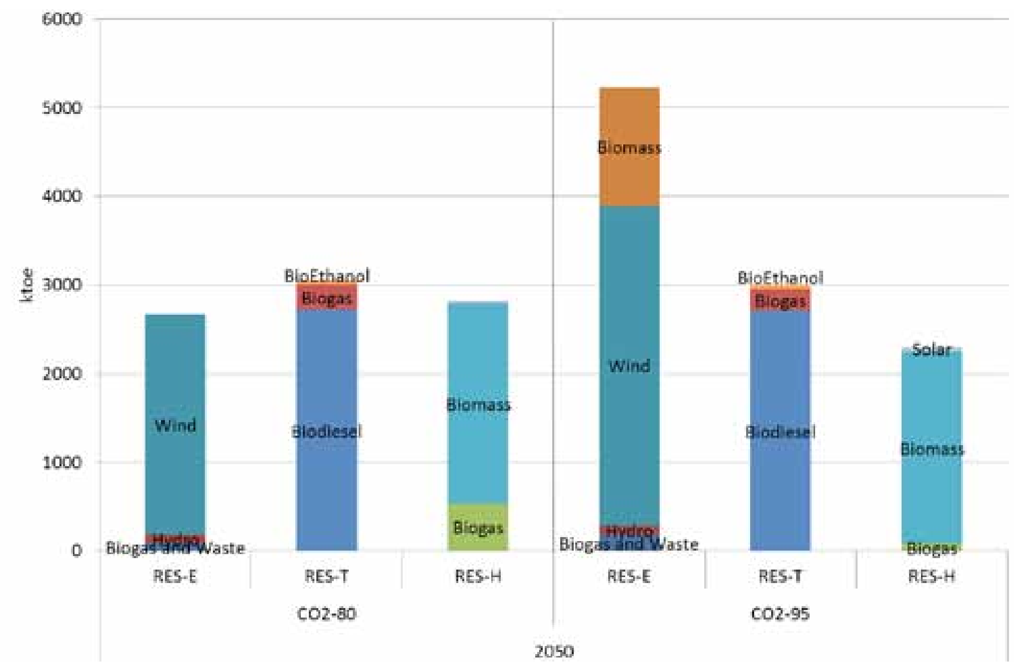

Figure 5.7. Renewables consumption by mode in CO2-80 and CO2-95 (ktoe).

5.3 What are the Cost Implications of Deep Decarbonisation and of the Energy System Compensating for Agriculture achieving Lower Emissions Reductions?

The economic impacts of these scenarios use the same metrics as those used for the 2020 GHG emissions reduction scenarios, namely the marginal cost of CO_2 abatement and the ratio between energy-systems costs and GDP. Table 5.1 summarises the marginal abatement costs for the CO2-80 and CO2-95 scenarios relative to REF. The results suggest a significant increase in marginal abatement costs by 2050 from €$_{2000}$273 to €$_{2000}$1308 in the CO2-80 and CO2-95 scenarios respectively. Two additional intermediate scenarios with different emissions reduction target (-85% and -90%) are also included for comparison. This indicates the challenge in moving beyond an 80% CO_2 emissions reduction scenario.

A further scenario result is also provided here: the NETS-80 scenario. This underlines the impacts of extending current EU mitigation policies (Directive 2009/29/EC and Decision 2009/406/EC) beyond 2020 with separate targets between ETS and non-ETS sectors, resulting in greater electrification (already important in the previous cases) to reduce emissions in end-use sectors (mainly the residential sector). The results confirm that emission reductions are generally cheaper in the ETS sector. This means that applying the same target to ETS and non-ETS sectors separately results in higher overall costs. More work is required to elaborate further the impact on long-term pathways of changing the short-term targets. In this analysis, the 20.5% total CO_2 emissions reduction target in 2020 is imposed relative to 2005 levels in CO2-80 and the 2020 target to 26.8% for CO2-95 increased, compensating for agriculture not meeting a 20% emissions reduction target in 2020. In the NETS-80 scenario, separate 2020 targets of 21% for ETS and 20% for non-ETS energy-related CO_2 emissions are imposed.

Figure 5.8 presents the ratio of energy-systems costs (and of investment costs) and economic growth levels (GDP) in the same period. This provides an indication of the impact, as a percentage of GDP, of delivering emissions reduction targets. In the REF scenario the energy system costs are reduced in the period 2005–2020, passing from 11.2% to 7.9% of GDP. This reduction continues in the following periods, reaching 7.0% of GDP by 2050. Investments, which accounted for about 2.3% of GDP in 2010, grow to 3.9% of GDP in the period 2020–2040 and then slightly reduce to 3.7% by 2050.

In the CO2-80 scenario, the energy system costs account for about 7.7% of GDP by 2050, suggesting that (relative to the REF scenario) the costs of mitigation are less than 1% of GDP in 2050. The energy system costs to deliver 95% of emissions reduction account for 8.6% of GDP by 2050: hence, the costs of the CO2-95 mitigation scenario (again relative to the REF scenario) are less than 2% of GDP in 2050. The NETS-80 and NETS-20/CO2-80 deliver higher system costs in the period 2020–2030.

Table 5.1. CO_2 shadow prices.[6]

Scenario	2020	2030	2040	2050	
CO2-80	33	136	99	273	€$_{2000}$/tonne CO_2
CO2-85	33	131	158	523	€$_{2000}$/tonne CO_2
CO2-90	33	127	158	694	€$_{2000}$/tonne CO_2
CO2-95	65	185	173	1308	€$_{2000}$/tonne CO_2
NETS-80	141	97	87	554	€$_{2000}$/tonne CO_2

6 Equivalent European studies such as WETO-H2 (EC, 2006) and SECURE (EC, 2010) indicate for similar policy assumptions (Johannesburg Agreement scenario and Carbon constraint case) CO_2 marginal prices for EU27 and EU27+ (Europe including Balkans and Turkey) of €$_{2000}$312/ton (392 €$_{2005}$/ton) and €$_{2000}$159 ton (€$_{2005}$200 /ton) for the year 2050.

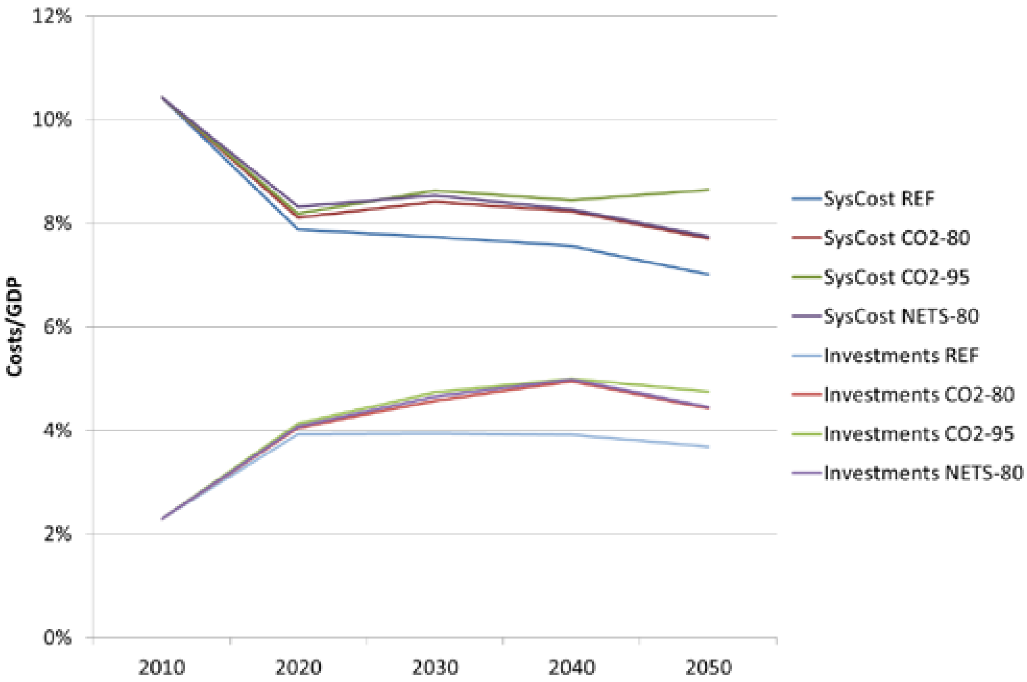

Figure 5.8. Comparing system costs with gross domestic product (GDP).

In all mitigation scenarios, increased systems costs are driven by investments that will range between 4.4 and 5.0% of GDP in the period 2030–2050. Further details on the 2050 scenarios and results can be found in Chiodi et al. (2012a).

6 Conclusions

This project provides Ireland for the first time with energy-system configurations and technology pathways that deliver short- and medium-term policy targets at least cost, namely, how Ireland can meet the requirements under the EU Renewable Energy Directive, the EU Effort Sharing Decision 2009/406/EC on non-ETS emissions and long-term emissions reduction targets at least cost.

Section 3 indicates that the EU 16% renewable energy target[7] could be optimally achieved by 2020 with a different pathway to that currently being followed under Ireland's NREAP. Notably, the results here suggest a higher amount of biomass usage for renewable heat than current targets (i.e. 18% RES-H rather than 12% RES-H). Moreover, the policy focus in Ireland is dominated by achieving 40% of renewable electricity, while renewable transport receives a much lower focus and there are no current policy mechanisms in place to promote renewable heat. The results for renewable heat highlight the importance of developing reliable production chains to allow this potential to be achieved. Furthermore, the Irish TIMES model indicates negligible contributions of ocean energy in the electricity sector by 2020 due to their high costs, while EVs will have a marginal role in the transport sector, which instead relies on increasing shares of biofuels. The results also indicate half of biofuels in transport coming from biogas, while the NREAP points to biodiesel and bioethanol, suggesting that this focus should be re-examined. Achievement of the renewables target also contributes to a GHG reduction of 3.0 Mt of $CO_{2,eq}$ by 2020, delivered mainly by savings in the power sector and industry.

The analysis in Section 4 raises a number of questions regarding Ireland's obligations under Decision 2009/406/EC to reduce non-ETS GHG emissions by 20% below 2005 levels. The results from the NETS-CO2 scenario suggest that significant non-ETS emissions reductions may be achieved within the residential, transport and services sector through two key pathways: (i) electrification of heating in buildings (i.e. shifting CO_2 emissions from the non-ETS sectors to the ETS sectors, namely electricity generation) and (ii) significantly increasing the amount of biofuels used in transport. This points to the need to reassess Ireland's renewable energy policies in the light of the non-ETS emissions reduction target. The results suggest a focus on renewable heat, renewable transport and electrification of heat, in contrast to the current dominant focus on wind-generated electricity. The results also show that ETS companies in Ireland are likely to have a significant amount of emissions allowances to sell and trade with other companies across the EU. Comparing NETS-CO2 with CO2-20 demonstrates the additional costs in meeting separate ETS and non-ETS targets compared with an overall emissions reduction target. The NETS-GHG scenario underlines the significant role of agriculture in non-ETS sector emissions and quantifies the costs associated with imposing a 31.5% non-ETS emissions reduction target on Ireland's energy system to compensate for the fact that agriculture delivers a reduction of 4% by 2020 relative to 2005 levels. The results point to further renewable energy use in transport and further electrification of heat in buildings.

The results in Section 5 indicate that challenging CO_2 emissions reductions such as 80% and 95% (equivalent to 80% GHG emissions reduction) relative to 1990 levels can be achieved technically in Ireland. They underlined which energy-efficiency and renewable-energy technologies will have a determining role in delivering the target at least cost. Reductions are important in the whole energy system, but mainly in transport, power sector and industry sectors.

Comparing the final energy use in the CO2-80 scenario with REF shows a 21% improvement in end-use energy efficiency, increasing further to 23% in the CO2-95 scenario. Renewable energy accounts for 25.3% of GFC in the REF scenario, increasing to 67.8 in CO2-80 and 85.1% in CO2-95. The main renewable energy resources used are biomass (biodiesel and biogas for transport and biomass for heat) and wind. Electrification of heat in particular but also of transport results in the share of energy use delivered by electricity increasing from 18.8% in REF (similar to current levels) to 31.0% in CO2-80 and 46.7% in CO2-95. Renewable generated

7 Under the EU Renewable Energy Directive (2009/28/EC)

electricity accounts for 71.9% of GEC in CO2-80, compared with 100% renewable electricity generation in CO2-95. The remaining electricity in CO2-80 is provided by gas CCS (accounting for 18% of GEC). The additional efforts required to move from CO2-80 to CO2-95 (i.e. delivering further reductions of 4.5 Mt) are mainly concentrated in the power sector (gas CCS is displaced by biomass) and increased electrification of heating in the residential and services sector.

Although the Irish TIMES model is currently not able to endogenously include non-energy agriculture emissions, the CO2-95 scenario underlines the implications for Ireland of failing to reduce emissions within agriculture. The energy sector is forced to compensate for any under-achievement in mitigation. The results suggest a significant increase in system costs from 48 to 66% relative to 2005 levels and marginal cost from €273 to €1,308 in the CO2-80 and CO2-95 scenarios respectively.

Further work is required in a number of areas to improve the results and to extend the scope of the analysis. An important step in this regard is the Irish TIMES Phase 2 project that commenced in November 2011 and will focus on:

1 Updating the model with new projections of Ireland's economy to 2050, new fuel price and resource availability projections and new technology options and costs.

2 Investigating the impacts of high levels of renewable generated electricity on the power system by soft-linking Irish TIMES with a higher temporal resolution power systems model (PLEXOS). This research has already generated a novel approach and some interesting results (Deane et al., 2012).

3 Developing economy-wide mitigation scenarios. The work to date has focused on modelling the energy system in isolation with exogenous assumptions regarding emissions reduction in agriculture. This research will cover both the energy system and the agriculture system together.

4 Incorporating behaviour into Irish TIMES. The model can currently choose technology solutions to achieved mitigation targets. Incorporating elastic demand will also enable the option of energy-service demand reduction to compete with technology change as energy costs increase. In addition, separate work funded by the IEA-ETSAP (Daly et al., 2012) has begun on a methodology for introducing modal choice into the transport sector.

5 Further elaborating the impact on long-term pathways of changing the short-term targets, building on the current analysis, which:

   a Imposes the 20.5% total CO_2 emissions reduction target in 2020 relative to 2005 levels in CO2-80;

   b Increases the 2020 target to 26.8% for CO2-95, compensating for agriculture not meeting a 20% emissions reduction target in 2020; and

   c Imposes separate 2020 targets of 21% for ETS and 20% for non-ETS energy-related CO_2 emissions in the NETS-80 scenario.

6 Improving the representation of interconnection and energy imports and exports. This is being achieved by reintegrating Irish TIMES within the Pan European TIMES model and scenario analysis.

It is worth noting that the Research Prioritisation Steering Group (Forfás, 2011) published its report as this project was being completed. While the focus of the steering group was not on research that informs policy choices, this was discussed and the Irish TIMES project is very well aligned with their conclusions:

> Research plays an important role in helping Government to achieve its policy objectives ... facilitates us in meeting our objectives at minimum cost ... Research programmes designed to inform the policy process play a vital role in agenda setting and increase the likelihood of translating important findings in relation to ... , environment and other research domains into feasible and implementable services and systems. In a number of areas, policy is negotiated with the European Union, out of which emerge obligations, regulations and income transfers. The quality of our negotiating effort is directly shaped by the quality of the evidence-based research that we bring to the negotiating table. High quality research, informing both our negotiating position and then the implementation of decisions, is required if we are to succeed.

The results in Section 3 challenge the underlying basis for Ireland's obligations under Decision 2009/406/EC to reduce non-ETS GHG emissions by 20% below 2005 levels. Irish negotiating effort at the time was diminished because of the absence of a modelling tool such as Irish TIMES. As Ireland enters negotiations regarding its contribution to 2030 and 2050 EU targets for energy efficiency, renewable energy and climate mitigation, this modelling tool provides the capacity to improve both the Irish negotiating position and then the implementation of decisions.

References

Chiodi A., Gargiulo M., Rogan F., Deane J.P., Lavigne D., Rout U. K., Ó Gallachóir B. P. 2012a Modelling challenging 2050 European mitigation targets on Ireland's energy system. *Energy Policy* (In Press doi:10.1016/j.enpol.2012.10.045).

Chiodi A., Gargiulo M., Deane J.P., Lavigne D., Rout U. K., Ó Gallachóir B.P. 2012b Modelling the impacts of challenging 2020 non-ETS GHG emissions reduction targets on Ireland's energy system. *Energy Policy* (in review).

Department of Agriculture, Fisheries and Food (DAFF) 2010 Food Harvest 2020 – A vision or Irish agri-food and fisheries. Published by the Department of Agriculture, Fisheries and Food 2010. Available from: www.agriculture.gov.ie/media/migration/agri-foodindustry/foodharvest2020/2020FoodHarvestEng240810.pdf

Daly H.E., Ramea K., Chiodi A., Yeh S., Gargiulo M., Ó Gallachóir B.P. 2012 Modelling modal choice behaviour within a linear energy system model. *Energy* (in review).

Department of Communications, Energy and Natural Resources (DCENR) 2010 Ireland's National Renewable Energy Action Plan. Published by the Department of Communications, Energy and Natural Resources under Article 4 of Directive 2009/28/EC. See: www.dcenr.gov.ie/NR/rdonlyres/C71495BB-DB3C-4FE9-A725-0C094FE19BCA/0/2010NREAP.pdf

Deane J.P., Chiodi A., Gargiulo M., Ó Gallachóir B.P. 2012 Soft-Linking of a Power Systems Model to an Energy Systems Model. *Energy*, 42, 303–12.

Department of the Environment Heritage and Local Government (DEHLG) 2008 Building Regulations (Part L Amendment) Regulations 2008 (S.I. No. 259 of 2008) Published by Department of the Environment Heritage and Local Government.

DEHLG 2010 Climate Change Response Bill 2010. DEHLG.

DEHLG 2011 Building Regulations (Part L Amendment) Regulations 2011 (S.I. No. 259 of 2011). DEHLG.

Dineen D. and Ó Gallachóir B.P. 2011 Modelling the Impacts of Building Regulations and a Property Bubble on Residential Space and Water Heating. *Energy and Buildings*, 43 (1) 166–78.

European Commission (EC) 2006 World Energy Technology Outlook – 2050. WETO-H2. Luxembourg: Office for Official Publications of the European Communities.

EC 2008 Commission Staff Working Document. Impact Assessment. Document accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020. SEC(2008) 85/3. Available from: http://ec.europa.eu/energy/climate_actions/doc/2008_res_ia_en.pdf

EC 2010 SECURE (Security of Energy Considering its Uncertainty Risk and Economic implications). Available from: http://www.secure-ec.eu/. Project co-funded by the European Commission within the Seventh Framework Programme.

EC 2011 A Roadmap for moving to a competitive low carbon economy in 2050. COM/2011/112 Brussels: Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the committee of the Regions.

European Union (EU) 2009a Union Directive 2009/28/EC of the European Parliament and of the Council (EC) of 23 April 2009 on the promotion of the use of energy from renewable sources. *Official Journal 2009*; L 140, 16–42.

EU 2009b DIRECTIVE 2009/29/EC the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community in: European Parliament and Council (Ed.). Official Journal of the European Union, 25.

EU 2009c DECISION No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020, in: European Parliament and Council (Ed.). Official Journal of the European Union, p. 13.

EPA 2011 Ireland's Greenhouse Gas Emissions Projections. Environmental Protection Agency. Technical Analysis Steering Group, February.

Gargiulo M., Kanudia A., Loulou R., Giannakis G., Tosato G., 2010 Application of the Pan-European TIMES Model, Proc 11th IAEE European Conference, 25–28 August, Vilnius, Lithuania.

Forfás 2011 Report of the Research Prioritisation Steering Group. Published by Forfás, November.

Howley M., Dennehy E., Ó Gallachóir B.P. and Holland M. 2012 *Energy in Ireland 1990–2011. 2012 Report*. Sustainable Energy Authority of Ireland.

International Energy Agency Energy Technology Systems Programme (IEA-ETSAP) (IEA-ETSAP) 2011 Joint Studies for New and Mitigated Energy Systems. Final Report of Annex XI. Edited by Kathleen Vaillancourt and GianCarlo Tosato. Available at: www.iea-etsap.org/web/FinReport/ETSAP-Annex-XI-final-report-final%20version-June-2012-v03.pdf

Ó Gallachóir B.P., Chiodi A., Lavigne D., Rout U.K., Gargiulo M. 2012 Determining least cost sectoral renewable energy targets using the Irish TIMES Model, *Energy* (in review).

Remme U., Goldstein G.A., Schellmann U., Schlenzig C., 2001 MESAP/TIMES – advanced decision support for energy and environmental planning, In P. Chamoni, R. Leisten, A. Martin, J. Minnemann, H. Stadtler (Eds.), Operations Research Proceedings 2001. Selected Papers of the International Conference on Operations Research (OR 2001), 3–5 September, Springer, Duisburg, Germany (2001), pp. 59–66

Smyth B.M., Ó Gallachóir B.P., Korres N.E. and Murphy J.D. 2010 Can we meet targets for biofuels and renewable energy in transport given the constraints imposed by policy in agriculture and energy? *Journal of Cleaner Production*, 18 (16–17) 1671–85.

Thamsiriroj T. and Murphy J.D. (2011) A critical review of the applicability of biodiesel and grass biomethane as biofuels to satisfy both biofuel targets and sustainability criteria. *Applied Energy*, 88 (4) 1008–19.

Thamsiriroj T., Smyth H., Murphy J.D. (2011) A roadmap for the introduction of gaseous transport fuel: A case study for renewable natural gas in Ireland. *Renewable and Sustainable Reviews*, 15 (9) 4642–51.

Acronyms

CCS	Carbon capture and storage
CCGT	Combined cycle gas turbine
CJHP	Combined heat and power
ESRI	Economic and Social Research Institute
EV	Electric vehicles
IEA-ETSAP	Energy Technology Systems Programme
GEC	Gross electricity consumption
GFC	Gross final energy consumption
NREAP	National Renewable Energy Action Plan
non-ETS	Non- emissions trading sectors
PET[36]	Pan European TIMES
RES-E	Renewable energy representing a 42.5% share of gross electricity consumption
RES-H	Renewable energy representing a 12% share of thermal energy for heating and cooling
RES-T	Renewable energy representing 10% of road and rail transport energy
UCC	University College Cork