Modelling the Long Run Transition to a Low-Carbon Economy: The Contribution and Limitations of Models and Roadmaps

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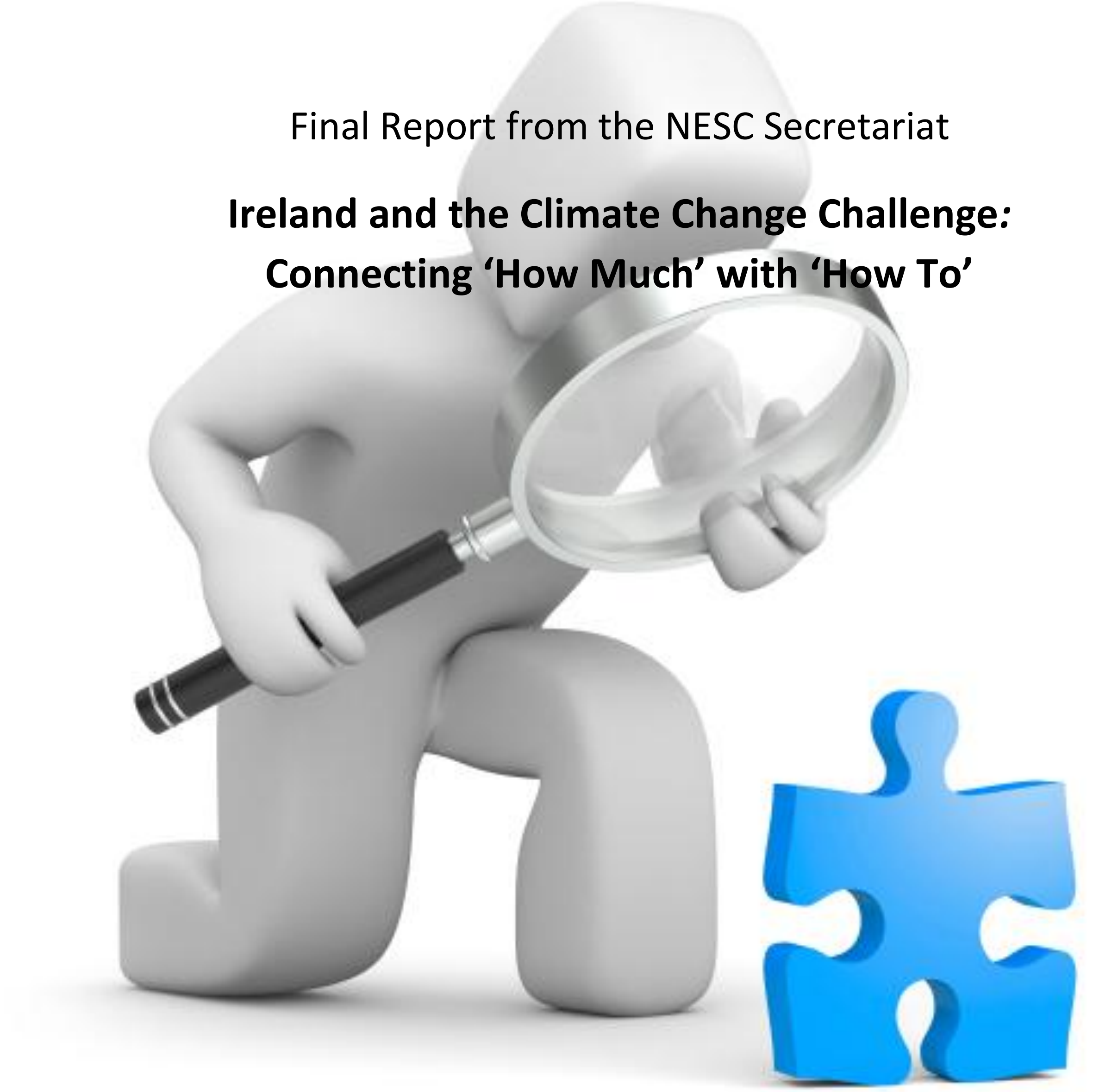

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1. Introduction

In considering Ireland's transition to a low-carbon economy, a range of modelling, forecasting and foresight exercises are available, these include energy-system models, emission forecasts, scenario exercises and roadmaps.

From a climate-change perspective, such models, forecasts, scenarios and roadmaps provide information about possible future energy, emission and policy pathways that might support emission reduction in the medium term, and indeed, the more challenging, long run transition to a low-carbon economy. Such models and roadmaps are typically developed to focus on particular countries, technologies, areas or questions of interest, and by design they can have significant methodological differences.

Evidence from such exercises can provide useful insights about a range of possible futures, particularly in a context where so much is both unknown and uncertain. However, in using such models for policy making purposes, a clear understanding of both their contribution and limitations, and how to interpret the evidence that emerges from them, is required. The importance of this for policy makers cannot be overstated.

This paper describes a number of modeling and foresight exercises. It considers the contribution of a number of models and roadmaps as an information source to support Ireland's transition to a low-carbon economy. Section 2 provides a general overview of a number of models, forecasts, scenarios and roadmaps which can and have been used to support climate-change policy, some of which we draw on in our interim and final reports. Section 3 focuses, in particular, on two distinct and separate modelling exercises, as sources of evidence for Ireland, which have a long-term perspective to 2050, the Irish TIMES model of the energy system and the SEAI Energy Roadmaps. This section describes both models and outlines the main insights which emerge from their findings. Section 4 considers the contribution and limits of models and roadmaps as an information source to support the transition to a carbon-neutral economy, with particular reference to their use by policymakers. Section 5 concludes.

2. Models and Roadmaps: A General Overview

In considering the transition to a low-carbon economy, policymakers can draw on a variety of energy-system models, forecasts and scenarios, as well as country- and technology-specific roadmaps, some of which are, or have components which are, specific to Ireland. We outline a number of such tools which have contributed to the discussion around the development of our interim and final reports.

2.1 Energy-System Models

A number of system level models have been developed in a European context which aim to contribute to our understanding of future energy systems, policy options and associated emissions. Results from such models have and are being used as a guide, or indeed a determining factor, for policy.

The results from EU Commission's PRIMES model, for example, has been central in determining EU 2020 emission targets for member state countries. A partial equilibrium model for the European Union energy markets, it simulates the entire energy system, both demand and supply. PRIMES is used for forecasting, scenario construction and policy impact analysis. While this model is used by the European Commission, a significant weakness of PRIMES is the lack of transparency and availability in respect of its database (Gargiulo & Ó Gallachóir, 2013).

The PET or Pan European TIMES model is another example of a detailed member state energy model at European level (Gargiulo & Ó Gallachóir, 2013). TIMES is a regional model covering the EU 27, Iceland, Norway, Switzerland and the Balkan countries. It has been described as generic model which is tailored by the input data to represent the evolution of a specific energy system, it can be used at regional or country level. The TIMES model is an evolved version of the MARKAL model. The MARKAL model, developed over a period of 2 decades by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency[1] (Ó Gallachóir *et al.*, 2012b: 13). It facilitates an exploration of possible long-term energy futures. The model will choose an optimal technology mix to meet future energy system demands at minimum cost (Ó Gallachóir *et al.*, 2012b: 13). One advantage of TIMES is the number of users and the transparency of the model and related data (Gargiulo & Ó Gallachóir, 2013). More recently, the Irish-specific component of TIMES which has been extracted from their larger regional model including many European countries, is undergoing significant development to incorporate more detailed data and assumptions for Ireland. We discuss Irish TIMES in more detail in the Sections to follow.

[1] See http://www.iea-etsap.org

2.2 Forecasts and Scenarios

A number of forecasts and scenarios for Ireland use alternate methods to predict future emissions, among other things.

For policy purposes, two widely utilised forecasts are the GHG emission projections for Ireland produced by the EPA, and the SEAI Energy Forecasts which underpin them (EPA, 2012a); (EPA, 2012b). In both forecasts, the ESRI's macro-economic HERMES model drives assumptions about the economy.

Other more recently developed tools include the GAINS model for Ireland which facilitates the calculation of emission and abatement options[2]. GAINS Ireland is the Irish version of this techno-economic analytical tool which provides an integrated assessment of emission control strategies for both air pollution and greenhouse gases which covers the entire of Europe.

A further addition is Irelands Sustainable Development Model or ISus[3]. This input-output model was developed to allow environmental accounts to be projected into the future on a sectoral level. It is based on assumptions about developments in the economy, in technology and in policy. The purpose of this model is to forecast environmental emissions (to air, soil and water) and natural resource use (energy, land, water) until 2025.

Other scenario-building work (carried out on behalf of NESC) which contributes to our final report, includes a decomposition analysis (historical and future) of both macro and sectoral change (O' Mahony *et al.*, 2012). The analysis of macro change is based on the Kaya identity[4]. While the sectoral decomposition analysis is a data intensive process requiring data on energy fuel types, CO_2 and activity indicators. This work is developed from O'Mahony (2010) and allows consideration of future sustainability scenarios and related emissions (O' Mahony *et al.*, 2012).

2.3 Roadmaps

A variety of detailed roadmaps have been developed as a guide to future planning and policy to support a transition to a low-carbon economy. These roadmaps include regional, for example the EU 2050 Low-Carbon Roadmap, and country specific roadmaps. They also include technology roadmaps, as outlined by the IEA and indeed as undertaken for Ireland by the SEAI.

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2 http://www.apenvecon.com/work/project/gains-ireland-modelling/
3 http://www.esri.ie/research/research_areas/environment/isus/
4 http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=50

The EU and a number of European countries have developed detailed roadmaps to support their transition to a low-carbon economy. Approaches taken in the EU 2050 Low-Carbon Roadmap, as well as country specific roadmaps carried on in the UK, Denmark and Germany, demonstrates the use of modelling and scenario-building work to support a transition to a low-carbon economy. Such roadmaps can be used to suggest:

- Technologies that might become attractive at various staging posts along the road to 2050 (based on various assumptions on cost, fossil fuel prices etc);
- Their potential impact on emissions, investment requirements and policy options or action points.

There are many kinds of roadmaps, but technology roadmaps (one of which is considered in the sections to follow) are intended to support the development of a particular technology. They are can be viewed as a strategic planning tool for government and industry to address future challenges, and the priority actions required to achieve stated goals in near, medium and long term.

> Technology roadmaps identify priority actions for government, industry, financial partners and civil society that will advance technology development and uptake.... Each roadmap contains milestones for technology development, legal/regulatory needs, investment requirements, public engagement/outreach and international collaboration (IEA, 2012: 479).

An effective roadmap process attempts to maximize participant engagement (stakeholders, experts etc) in order to gain consensus around the vision embodied in the Roadmap. Roadmaps must evolve, and there is therefore a requirement to update roadmaps on a periodic basis, and this can best be achieved if metrics to measure progress are clearly set out and timelines established (IEA, 2010).

According to the IEA, a successful roadmap contains a clear statement of the desired outcome followed by a specific pathway for reaching it. The IEA believe goals must be clear and concise set of targets that, if achieved, will result in the desired outcome; quantified goals provide the most specific guidance. Milestones are interim performance targets for achieving the goals, pegged to specific dates. Gaps and barriers can be gaps in knowledge, technology limitations, market structural barriers, regulatory limitations, public acceptance or other barriers to achieving the goals and milestones (IEA, 2010).

The SEAI have developed a number of technology roadmaps in order to highlight technological and resource potential available in Ireland and to enable us to exploit indigenous, clean energy sources in a way that generates positive returns and employment while producing the sustainable energy system we need for the future. These roadmaps aim to highlight what is possible in terms of resource potential across a number of different technologies and identify how that resource potential might be achieved. We consider these roadmaps in more detail in the sections to follow.

3. Thinking about 2050

In thinking about a future possible energy system and associated emissions for Ireland in 2050, we draw on two distinct and separate modelling exercises, the Irish TIMES model of the energy system and the SEAI's technology roadmaps. In this section we describe both models and briefly outline the main insights which emerge from their findings.

3.1 Irish TIMES

Irish TIMES is an energy-systems model, developed for Ireland, to facilitate an exploration of possible long-term energy futures. Irish TIMES has its genesis in the Pan European Times (PET) Model, a regional model covering the EU 27, Iceland, Norway, Switzerland and the Balkan countries, and has been adapted for Ireland by the Environment Research Institute at UCC (Ó Gallachóir *et al.*, 2012b: 13). The model will choose an optimal technology mix to meet future energy-system demands at minimum cost (Ó Gallachóir *et al.*, 2012b: 13)[5]. It also allows for the imposition of certain policy constraints, such as restrictions on emissions. The model then suggests the least cost technology mix for the energy system, given a particular emission restriction. It thus allows the impact of alternate energy-policy choice scenarios to be explored.

TIMES, an evolved version of the MARKAL model, can be described as a generic model which is tailored by the input data to represent the evolution of a specific energy system. It will choose an optimal technology mix to meet that demand at minimum cost. The model is data-driven, this means that it is the data input as opposed to modifications to the model's equations that produce alternate model runs (Loulou *et al.*, 2005a). The data input is essentially a set of data files which describes the underlying energy system—technologies, commodities, resources and demands for energy services. In short, all TIMES model runs exploit the same mathematical structure but each instance of model then varies according to the data inputs. TIMES can be described as a 'model generator' which 'processes' each set of data files, which in turn specifies a model solution (or instance of the model). The

[5] See http://www.iea-etsap.org

term, TIMES model, thus, can refer to (1) the model generator or (2) an instance of the model.

TIMES can be classified as a bottom-up, techno-economic, partial equilibrium, linear optimisation model. The bottom-up classification derives from the fact that the model represents energy sectors and technologies in detail, describing current and future technological options[6]. Indeed, in TIMES, each technology is described by a number of technological and economic parameters, this can include up to several thousand technologies (more than 1300 in the Irish TIMES model). The model is a linear optimisation model where the energy system is optimised and where future energy demand is delivered at least cost. It is computed using linear programming techniques. As an energy-system model where the energy system is described in detail, it is classified as a partial equilibrium model, modelling both the energy flows and their prices (Gargiulo & Ó Gallachóir, 2013); (Loulou *et al.*, 2005a); (Loulou *et al.*, 2005b); (Loulou & Labriet, 2008). The TIMES model

- Allows for price elastic demand where demands for energy services can be elastic to their own prices, capturing the main feedback effect from the economy to the energy system
- Computes flows of energy and their prices, it does so in such a way that the suppliers of energy produce exactly the quantities demanded by consumers
- Assumes competitive markets for all commodities (but can include user-defined constraints or market imperfections)
- Assumes perfect foresight where all investment decisions are made in each period with full knowledge of future events (Gargiulo, 2012); (Loulou & Labriet, 2008, Loulou *et al.*, 2005a, 2005b)

The TIMES model facilitates an exploration of possible long-term energy futures based on a comparison of scenarios. It thus supports the testing of energy-policy choice scenarios. It is noted that this scenario based approach, as distinct from a forecasting exercise, does not assume, in advance, knowledge of the main drivers of the energy system. Instead, it builds scenarios based on a set of 'coherent assumptions', through a credible storyline, about the future trajectories of these drivers (Loulou & Labriet, 2008: 9). In TIMES, a complete scenario is based on four

[6] A recent paper highlighting the differences between bottom and top down energy models states "In top down models, energy is generally modelled at an aggregate sectoral level as a derived demand that varies according as economic output and energy prices vary via elasticities. Bottom-up models represent energy sector and technology choice in detail" (Gargiulo & Ó Gallachóir, 2013)

input component parts; energy-service demands, primary resource potentials, a policy setting or scenario, a description of a set of technologies.

The key inputs into Irish TIMES are 4 main component parts:

- **The demand component**: consisting of over 70 energy-service demands (e.g. cooking, space heat, road freight) determined by assumptions on drivers such as population, GDP, no. of households etc, and related elasticities of demand to the drivers and their own prices[7].
- **The supply component**: estimation of the primary resource potential for a range of renewables - wind (onshore and offshore), ocean (wave and tidal), bio-energy, hydro-energy, solar and gas geothermal. In each case, the potential is estimated using current data combined with an evaluation of the possible potential based on research and policy documents.
- **The techno-economic component:** including more than 1300 technologies (e.g. onshore wind, offshore wind, tidal, wave etc) and an estimation of associated costs[8].
- **Policy scenarios:** estimation of least cost policy scenarios to 2050, examples include a reference scenario, emissions constrained scenarios, renewable energy scenarios, energy security scenarios etc.

The results handling system for TIMES produces numerical and graphical (mainly via excel) output for the user. The Irish TIMES model output provides energy, emissions and economic data. This includes such information as the least cost solution to satisfy energy-service demands and constraints, technology pathways, emission trajectories, as well as energy system and investment costs and marginal abatement curves. As such, results from Irish TIMES can be used to inform policy on such things as renewable energy, energy efficiency, electrification of transport or heat, climate mitigation. It may also provide a knowledge base to inform negotiation, such as evidence on cost-optimal emission reduction targets.

3.2 SEAI Roadmaps

SEAI have developed a number of technology roadmaps in order to highlight technological and resource potential available in Ireland and to enable us to exploit indigenous, clean-energy sources in a way that generates positive returns and employment while producing the sustainable energy system we need for the future. These roadmaps aim to highlight what is possible in terms of resource potential across a number of different technologies and identify how that resource potential

7 exogenous and taken from other sources

8 see (Ó Gallachóir *et al.*, 2012b: 24) for detail on costs

might be achieved. All roadmaps assume an 80 per cent reduction in emissions by 2050. The roadmaps consider the maximum resource potential in a number of technologies, each is taken as a discrete exercise and they are mutually exclusive. For each technology, the contribution of the roadmap is to highlight what is possible, the maximum potential, and the measures, action and policies to be put in place to deliver this potential. It is important to note however that the roadmaps are not a full or integrated strategy, neither do they answer whether or the extent to which government should undertake such actions.

SEAI has developed 6 technology roadmaps using IEA methodology, all of which consider a possible future for these technology in the period to 2050. The six Roadmaps are as follows:

- Wind;
- Smartgrid;
- electric Vehicles;
- residential;
- ocean energy and
- bio-energy.

According to SEAI the objective of developing the roadmaps were:

- To accelerate low-carbon technology development
- To underpin the identification of policies and measures and highlight necessary deployment policies and incentives
- To communicate key challenges, actions to be made and milestones to reach
- To identify and address technology specific barriers—technical, regulatory, policy, financial, and public acceptance
- To coordinate view points from diverse stakeholders
- To focus R&D and investments to accelerate technology development

The detailed content of these roadmaps, their insights and findings, will not be discussed in detail here, although some general statements are made[9].

Three of these roadmaps, wind, smart grid and electric vehicles, can be considered the most sophisticated because they work together, and also because they are an

[9] see SEAI Roadmaps; http://www.seai.ie/Publications/SEAI_Roadmaps/

integrated suite with common assumptions across the three. Some common characteristics can be observed across the roadmaps. They all include:

- Timelines to 2050
- Employment, green economy benefits and value to the economy of each technology is evaluated, though no investment requirements are given
- Scenarios for deployment generally used (low, medium, and high deployment or other)
- Policy, technical, legal, regulatory, and infrastructural and other requirements are identified along the pathway to 2050 in each case (though these barriers are categorised differently for each technology)
- Total contribution to energy and CO_2 savings are also evaluated for 2050 in each case
- Assumption that policy to 2020 would be achieved
- Varying levels of stakeholder consultations

While there are similarities, there are also some differences. For example, the methodology differs across the roadmaps. It is also the case the 'technology' section refers to international developments needed (eg: EV roadmaps), whereas in others (eg: ocean energy) this section relates more to Irish R&D capacity and requirements.

3.3 Insights from Irish TIMES and SEAI Roadmaps

While the evidence from models such as Irish TIMES and the SEAI Roadmaps need to be considered within the context of assumptions made and methodology employed, using different types of analysis and cross referencing conclusions can yield important insights[10]. As such, we draw on this evidence in both the interim and final reports, in conjunction with other evidence and data sources. Such insights, and what can be concluded from them, must always be tempered by the high degree of uncertainty and unknowns about a 2050 future.

Electricification and renewables both come out strongly from the TIMES scenario modelling. By 2050, electricity consumption is estimated to contribute a significant

[10] It is also the case that deeper insights can be gained using complementary models. Some of the results from Irish TIMES scenarios suggest large scale penetration of renewable energy in electricity supply and electrification of residential heating and car transport. These results can be further assessed in an electricity dispatch model to shed light on the feasibility of and challenges associated with these scenario results (See Deane et al., 2012).

proportion of final energy demand under emission constrained scenarios, with wind energy playing an important role in electricity generation. With respect to wind for electricity generation, the model suggests on-shore wind will dominate, with off shore wind expected to play a a greater role as on-shore wind potential is exhausted and under increasing levels of emissions constraint. Other renewables, namely bio-energy, also come to the fore as a direct source of energy[11]. Efficiency measures play an important role in residential and in services.

Focusing on technologies that emerge strongly from Irish TIMES (electricity, wind and bio-energy) and which are also examined via the SEAI Roadmaps, a number of brief points can be made.

3.3.1 Electrification

Electricification comes out strongly from the Irish TIMES scenario modelling. The model suggests an important or dominant role in transport (for private vehicles), in residential heat and in the services sector, with a smaller relative role in industry. By 2050, electricity consumption is estimated to amount to between one third and a half of final energy demand under emission constrained scenarios. This electricity generation is expected to be dominated by wind. As such, this points to the possible importance of the contribution of new technologies such as smart grid towards supporting such a 2050 future, and indeed the role of EV's in private vehicle transport. The SEAI Roadmaps on smart grid and EV's highlight policy considerations, as wells as policy measures aimed at maximising the potential from such technologies. The potential from new technologies, that such as smart meters, storage and batteries, the electrification of transport, to support a transition to a low-carbon economy is also highlighted by other commentators (Helm, 2012).

3.3.2 Wind

Both Irish TIMES and SEAI Roadmaps suggest a strong role for wind energy for electricity generation. Under both models the maximum potential for on-shore wind is delivered before off shore wind is exploited. Thus, a similar trend emerges from both, that is, a move to off shore wind after the exhaustion of the potential from on-shore wind. On-shore wind is considerably less expensive than off shore wind. However, the anticipated scale of deployment is very different in both models. The assumptions about the limits imposed on both on- and off shore wind differs significantly. The SEAI limit for onshore wind is nearly twice that imposed by Irish

[11] New and revised estimates from Irish TIMES in respect of bio-energy potential and land use suggest that while the resource potential from bio-energy will be maintained that it will be supported by a movement from cropland to grassland.

TIMES, while the limit for off shore more than four times greater, the SEAI Roadmap thus suggests significantly greater potential from both on-shore and off shore wind.

3.3.3 Bio-energy

Although the SEAI Bio-energy roadmap outlines a higher overall bio-energy consumption (indigenous and imported) compared to Irish TIMES, both exercises suggest a similar indigenous contribution from bio-energy, recent revisions to Irish TIMES (incorporating new assumptions about land use) suggest that while the resource potential of bio-energy remains at previously estimated levels, it does so with a different mix of commodity shares (Ó Gallachóir *et al.*, 2012b). As such, this points to an impact on the type, as opposed to the amount, of land use, in essence more grassland than cropland. Similarly, SEAI also concludes that grass and wastes have significant resource potential in coming decades.

Finally, it is important to acknowledge that new, emerging and future technologies could be a game changer, leading to a very different energy system configuration than we can possibly imagine or indeed forecast today. Thus, policy should proceed in a manner which does not undermine the potential for new and future technologies to play a (possibly significant) future role in delivering both energy system and emission requirements in a 2050 future. This requires further consideration of what seems sensible in the short to medium term, given associated costs and accounting for unknowns and uncertainties, to underpin this long term transition to a low-carbon future.

4. Contribution and Limitations

By design, different models, forecasts, scenarios and roadmaps can have significant differences. For example, in their economic rationale or assumptions, in respect of variables considered including their level of disaggregation, in respect of time horizons considered, geographic scope including related regional or country specific detail, as well as the detail in which commodities and technologies are represented. Methodologies employed and related model assumptions can also have significant bearing on results.

Models provide a useful starting point for thinking about the energy system in 2050, however there are dangers inherent in modelling approaches, particularly if the results are interpreted in an overly deterministic way in the face of uncertainty. A number of points are worth noting:

Energy-system models and roadmaps do not and cannot predict the future, what they can provide are (potentially) useful nudges through highlighting technologies that seem to increase or decrease in importance given particular energy, emission, economy and/or technology related assumptions. They can also help shed light on the policy actions that may result in particular outcomes. One significant caveat with respect to the ability of any future-orientated model or foresight exercise to support policy are the unknowns; what will be the contribution of new technologies? what future renewables will emerge? Indeed, one commentator observes ‘if in 1980 similar foresight exercises were carried out with respect to the telecommunications industry, this would have occurred with no knowledge of mobile phones, the internet or fax machines’ (Helm, 2012).

Different models are developed for different purposes, thus it is important when drawing on such work that both the model most appropriate to requirements is chosen and the associated limitations recognised (Gargiulo & Ó Gallachóir, 2013).

Models typically provide insights not answers, thus the nature and limits of their contribution needs to be understood. Significant caveats may arise from availability and reliability of input data, and from modelling assumptions; they also arise because so much is either unknown or uncertain with respect to the climate change, the economy, current and future technologies, as well as associated costs in a 2050 context. As such, it is important when considering evidence from any such modelling and foresight exercises, particularly out to 2050, that the results are treated with a degree of caution. One significant caveat with respect to the use of models for policymaking purposes relates not to models, forecasts or scenarios themselves but to the potential for inappropriate use of the evidence as a result of limited understanding of particular models, their contribution and their limits. The importance of this point for policymakers cannot be overstated.

Nonetheless, despite such caveats, the importance and value of models in supporting policy under high levels of uncertainty needs to be recognised. By design, models are imperfect. However, where used correctly and interpreted with care, they can make a significant contribution to knowledge, not just in respect of the final results but also in regards to driving a wider discussion about data inputs, parameters and relationships. From a policy perspective, targets and goals need to be met, models can contribute to our understanding about what is required to meet to those goals. Thus, it is argued that the contribution of robust, well bounded, models is to avoid chaotic solutions, provide useful insights regarding the future and generate a knowledge base to underpin policy. It is also noted that they can help point to least risk choices via scenarios, as well as used to support Ireland’s negotiating position at EU level (Ó Gallachóir *et al.*, 2012a). For example, on this latter point, the PRIMES model is used within the European Commission as the basis for determining the legally binding targets of member states, however recent estimates using TIMES (a similar type model) suggests that the anticipated marginal abatement cost by 2020 for Ireland to meet the non-ETS target is in the order of four times that as calculated by PRIMES (Chiodi *et al.*, 2013).

In terms of shaping future policy and moving forward on a no-regrets basis, it is important to keep sight of that which we don't already know. It is also important with respect to what we do know, while drawing from what are always imperfect modelling exercises, that we take away general insights to underpin movement towards 2050 but do so without closing off future options.

5. Conclusions

While the evidence from energy-system models, forecasts and scenarios, and roadmaps need to be considered within the context of assumptions made and methodology employed, drawing from this evidence and cross referencing conclusions can yield important insights to help frame our understanding of what a transition to a low-carbon economy might entail. As such, we draw on this evidence, in particular from the Irish TIMES and SEAI Energy Roadmaps and in conjunction with other evidence and data sources, in our work. However, such insights, and what can be concluded from them, must always be tempered by the high degree of uncertainty and unknowns about a 2050 future.

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