Energy Policies Influenced by Energy Systems Modelling—Case Studies in UK, Ireland, Portugal and G8

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Abstract A key objective of IEA-ETSAP is to assist decision makers in robustly developing, implementing and assessing the impact of energy and climate mitigation policies. This chapter focuses on four case studies, in which there is clear evidence of a direct link between the use of MARKAL and TIMES scenario modelling activities and the resulting policy decisions. The case studies selected assess how the (i) UK MARKAL model informed the development of energy and climate mitigation policy in the UK, focusing on the Energy White Paper in 2003, the Energy White Paper in 2007 and the Climate Change Act in 2008; (ii) Irish TIMES model informed the development of climate mitigation legislation in Ireland

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in 2014 and Ireland's negotiating position regarding the EU 2030 Climate Energy Package in 2014; (iii) TIMES_PT model informed climate policy in Portugal in the last 10 years and has supported the design of climate mitigation policies; (iv) IEA ETP Model informed the G8 in responding to the 2005 Gleneagles Plan of Action and has supported the work of the Major Economies Forum and Clean Energy Ministerial. This chapter collates methodologies and results from these different case studies and summarizes some key findings regarding (i) policy frameworks and goals; (ii) how policy makers have been intertwined with the modelling tool during the modelling process; (iii) the role of the economic stakeholders dialogue; (iv) main insights from the modelling exercises; (v) lessons learnt: from effective contributions to real limitations and (vi) recommendations.

1 Introduction

This chapter presents a collection of four case studies where this direct linkage between ETSAP modelling tools and the policy-making process took place at national (United Kingdom, Ireland and Portugal) and supra-national level (G8 countries). The purpose is to show how ETSAP energy systems models have informed the environmental and energy policy choices, but also discussing the main lessons learnt, the current limitations, and recommendations both for modellers and policy makers.

The chapter structure is as follows. Section 2 presents the experience of UK MARKAL which informed energy and environmental policy in Great Britain. Section 3 focuses on Irish TIMES model which informed the Irish Government. Section 4 discusses details of TIMES_PT being used to inform climate policy in Portugal in the last decade. Section 5 presents the case of IEA ETP Model, which informed the G8 in responding to the 2005 Gleneagles Plan of Action and supported the work of the Major Economies Forum and Clean Energy Ministerial. Section 6 concludes with some discussions regarding common issues, lessons learned and some recommendations for model developers.

2 The Experience of UK MARKAL

The MARKAL energy systems model has a long history of use in the UK dating back to early versions of the model developed in the late 1970s (Finnis 1980). Yet, for most of the next two decades its impact on the energy policy process was minimal (Taylor et al. 2014). However, around the year 2000 climate change emerged as a key political issue in the UK and, since then, results from MARKAL have been used extensively to inform energy policy as the question of how to reduce greenhouse gas (GHG) emissions has become the defining challenge.

2.1 The 2003 Energy White Paper

In 2000, the Royal Commission on Environmental Pollution (RCEP)[1] recommended that by 2050 the UK should plan to reduce its energy-related carbon dioxide emissions by 60 % (Royal Commission on Environmental Pollution 2000). This conclusion had a significant impact on the Government who set up a review of energy policy in 2001, eventually leading to the publication of an Energy White Paper (EWP) in 2003 (DTI 2003a). As part of this review, the Department of Trade and Industry (DTI) commissioned AEA Technology plc to develop a new UK MARKAL model and to use it to explore future trends in carbon dioxide emissions from the UK energy sector up to 2050 and identify the technical possibilities and costs for the abatement of these emissions. The work considered three levels of abatement by 2050: 45, 60 and 70 % reductions relative to emissions in 2000, combined with three scenarios (Baseline, World Markets and Global Sustainability) for the possible future development of the UK economy and the associated demands for energy related services (DTI 2003b).

The new model database contained a wide variety of low carbon technologies including many types of renewable energy, fossil fuels with carbon capture and storage, nuclear power, efficient demand-side technologies and fuel cells and hydrogen. Two workshops with industry and academic experts were held to review the cost and performance data for low carbon power generation and infrastructure for transmission and distribution of hydrogen.

By running each of the three scenarios without any CO_2 emissions constraints and then with the three level of abatement levels described above, 12 "core" runs of the model were generated. However, these were then supplemented by 70 other "sensitivity" runs to test how the results changed with alternate assumptions on a range of issues including the availability of technologies and fuels, fuel prices and taxes, discount rates and alternative emission paths. While the model results contained a huge amount of information about future technology and fuel mixes, including at the sectoral level, the key use of the modelling in the 2003 EWP was to calculate the costs to the economy of the different abatement levels (DTI n.d.).[2] The results led the 2003 EWP to conclude that "*the cost impact of effectively tackling climate change would be very small—equivalent in 2050 to just a small fraction (0.5–2 %) of the nation's wealth, as measured by GDP*".

The results on costs proved quite controversial, with some experts arguing that they were too low (Great Britain House of Lords 2005). Despite these

[1] The Royal Commission on Environmental Pollution was an independent standing body established in 1970 to advise the Queen, the Government, Parliament and the public on environmental issues.

[2] Ironically, this calculation had to be done off model using output from MARKAL because the choice at the start had been to use the standard MARKAL model (and not MARKAL-MACRO).

controversies, a report by the Institute for European Environmental Policy, an independent institute, concluded that the results from MARKAL "*overcame a key barrier to acceptance of the 60 % target, and appears greatly to have helped develop a positive attitude to carbon reductions in government*" (IEEP 2005).

2.2 The 2007 Energy White Paper

While the 2003 EWP established the principle that emissions reduction was the key policy challenge, it left much of the detail unresolved. In addition, rapid rises in gas and oil prices from mid-2004 led to the issue of energy security joining carbon mitigation as a priority for energy policy (Pearson and Watson 2012). Therefore within a couple of years the government was planning another EWP and once again turned to MARKAL to help inform its decisions.

The UK Energy Research Centre (UKERC), a grouping of UK universities, and AEA Technology worked together on a project commissioned by the DTI using both the standard version of MARKAL and the newly developed MARKAL-MACRO (M-M). The final report focused on a set of 11 M-M model scenarios (Strachan et al. 2007) that were used as the main inputs to the 2007 EWP. The scenarios may be classified as:

1. Base-case, CO_2 emissions in 2050 constrained to 60 % of 2000 levels and alternate CO_2 emission trajectory implemented linearly from 2010;
2. Resource import (high and low) price scenarios, from DTI projections;
3. Technology scenarios: restricted innovation (limited to either 2010 or 2020 levels of improvement), no-nuclear, no-CCS or no-nuclear/CCS scenarios.

Key outputs included primary and final energy mixes, sectoral contributions to CO_2 reductions, detailed technology selection in the electricity and transport sectors, the role of demand side reductions, CO_2 prices, energy system costs and GDP impacts. In total, over 50 scenarios sets were run (including standard model runs) with results from additional scenarios being used to explore key trade-offs between mitigation pathways.

In contrast to the rather narrow use of MARKAL in the 2003 EWP, the 2007 EWP explains its use of M-M in the following terms: "*for the period to 2050, we have used a model of the entire UK energy system (UK MARKAL-Macro model) to explore the changes to the amount and use of energy required if we are to deliver our goal of reducing carbon emissions by 60 % by 2050 at least cost*" (DTI 2007a). This central role given to MARKAL by the 2007 EWP is reflected in over fourteen direct references to various insights from the modelling work, complemented by numerous graphical figures (Fig. 1) in the supplementary material supporting the White Paper (DTI 2007b).

Of particular note, is the fact that the MARKAL results were used to support a significant change in the view of nuclear power compared to the 2003 EWP, with the 2007 EWP noting "*Our modelling indicates that excluding nuclear is a more*

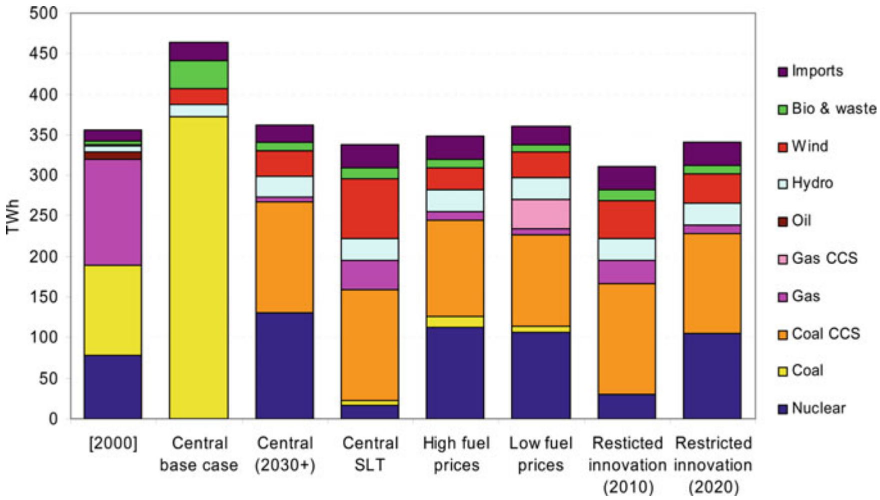

Fig. 1 Example of M-M results for the 2007 EWP: Generation mix in 2050, central and sensitivity scenarios (DTI 2007b)

expensive route to achieving our carbon goal even though in our modelling, the costs of alternative technologies are assumed to fall over time as they mature" (DTI 2007a).[3]

2.3 The 2008 Climate Change Act

Following the 2007 EWP, the Government published a draft Climate Change Bill, which became an Act of Parliament in 2008 (Great Britain 2008). This put in place a new legislative framework of five-year carbon budgets and established an independent Committee on Climate Change (CCC) to advise government on the level of these budgets. A long-term emissions target was written into the Act, but strengthened from the original 60 % recommended by the RCEP to become an 80 % emissions reduction target by 2050.

The impact assessment for the Bill (compulsory for most UK policy proposals) draws on MARKAL-MACRO analysis by AEA Technology looking at the additional impacts (economic and technological) of moving to an increasingly carbon constrained energy system, with reductions in CO_2 of 70 and 80 % by 2050 and the implications of including international aviation within the targets (DECC 2009). In a parallel exercise MARKAL-ED (a variant of MARKAL in which the level of

[3] Interestingly the modelling work for the 2003 EWP had also shown a similar result, but this appears to have been ignored as at the time the Government focus was on delivering carbon reductions through energy efficiency and renewables.

demand for energy services varies according to the costs of meeting them) was used by the CCC to examine the economic and technological implications for reducing carbon emissions by 80 or 90 % by 2050 to inform its advice to government (CCC 2008; AEA 2008a, b).

The MARKAL family of models continues to play an important role informing implementation of the Climate Change Act, including being used to support the 2009 Low Carbon Transition Plan (Her Majesty's Government 2009) and, following a change of government, the 2011 Carbon Plan (Her Majesty's Government 2011) and the setting of 4th carbon budget (CCC 2010; Usher and Strachan 2010; AEA 2011).

2.4 Discussion

Since 2000, the MARKAL family of models have become embedded as key tools used to inform UK climate and energy policy. Three attributes of MARKAL would appear to have been particularly important in facilitating its role to support ambitious climate targets. First, MARKAL is not bound by historical relationships of the kind that underpin econometric and macro-economic modelling and is therefore able to postulate radically different energy system configurations that will be needed for deep reductions in GHG emissions. Second, MARKAL is able to make the necessary changes tangible through its detailed technological representation, which has suited a prevailing techno-centric view of the mitigation challenge. Third, MARKAL's objective function is cost and this accord with the dominance of cost-benefit analysis as a tool for policy appraisal and selection in the UK. Finally, while MARKAL is far from readily comprehensible to all and sometimes criticised for being a "black-box", substantial efforts have been made by the modelling community to increase the transparency and completeness of the model structure and assumptions, including through a range of stakeholder events, expert peer review and publication of the model documentation.

3 The Experience of Irish TIMES

Irish TIMES is a mono-regional model of the entire Irish energy system that was originally extracted from the Pan European TIMES (PET) model (Ó Gallachóir et al. 2012). It has been updated and expanded since 2009 by the Energy Policy and Modelling Group in University College Cork and has been used to build a range of energy and emissions policy scenarios to explore the dynamics behind the transition to low carbon energy systems (Chiodi et al. 2013a, b), to analyse energy security (Glynn et al. 2014), to assess impacts of limited bioenergy resources (Chiodi et al. 2015a) and to explore new modelling approaches (Deane et al. 2012; Chiodi et al. 2015b). However its impact on the policy making process has been limited till 2013, when, over the period June 2013–September 2014, the Irish TIMES model has been extensively used to inform two key policy developments, namely the development of (i) national legislation on climate change and (ii) Ireland's negotiation position regarding the proposed EU 2030 Carbon and Energy Policy Framework.

3.1 Low Carbon Energy Roadmap to 2050

The Irish Government is planning to legislate for Climate Action and Low Carbon Development and published a Heads of Bill (*General Scheme of a Climate Action and Low Carbon Development Bill (CA&LCD Bill))* in 2013 (DECLG 2013). This raises key questions regarding the evolution of Ireland's future energy system to enable the transition to a low carbon future. According to Head 4 of the CA&LCD Heads of Bill, "*the Government shall arrange for the adoption and implementation of plans […] to enable the State to pursue and achieve transition to a low carbon, climate resilient and environmentally sustainable economy in the period up to and including the year 2050. Article 5 stipulates that a key objective of a National Low Carbon Roadmap is to articulate a national vision for the transition to a low carbon, climate resilient and environmentally sustainable economy over the period to 2050*".

In the period June–December 2013, the Department of the Environment, Community and Local Government commissioned UCC to produce a *Low Carbon Energy Roadmap for Ireland to 2050* using the Irish TIMES model (Deane et al. 2013). The focus of this analysis was on technological changes in the energy system and the associated implications. A key policy question underpinning the analysis focused on the dynamics of the energy system moving towards a low carbon economy for two key time horizons, i.e. to 2050 and to 2030. The process involved modelling analysis and regular meetings and discussions with a number of Government Departments providing technical advice and guidance on the development of a long term strategy for Ireland.

The purpose of the roadmap is to explore possible routes towards decarbonisation of the energy system, with a focus on achieving this at least cost to the economy and to society. The key issue is making well informed policy choices. Hence this roadmap does not stipulate which policies are necessary to achieve the transition; it rather focuses on the key drivers and its implications for the energy system of moving to a low carbon economy. The roadmap presents three distinct scenarios to explore transitions to a near zero CO_2 future.

1. A business as usual (*BaU*) scenario which does not impose emissions targets and efficiency improvements and is used as a base case (counterfactual) against which to compare the two distinct near-zero CO_2 scenarios.
2. An 80 % CO_2 reduction (*CO_2-80)* scenario in which CO_2 emissions are constrained across the entire time horizon to be no greater than 80 % below 1990 levels in 2050.

Table 1 Ireland's low carbon roadmap to 2050

Sector	2030 relative to 1990		2050 relative to 1990	
	BaU (%)	Low carbon (%)	BAU (%)	Low carbon (%)
Electricity	45	−56 to −58	31	−84 to −94
Buildings	−11	−53	−11	−75 to −99
Services	*5*	*−33*	*−6*	*−70 to −99*
Residential	*−16*	*−59*	*−13*	*−77 to −98*
Transport	226	104 to 122	285	−72 to −92
Total	50	−29 to −31	55	−80 to −95

Services and Residential are sub-groups of 'Buildings' chategory

3. A 95 % CO_2 reduction (*CO_2-95*) scenario in which CO_2 emissions are constrained across the entire time horizon to be no greater than 95 % below 1990 levels in 2050.

The roadmap provides insights into when changes in the fuel mix are likely to occur (e.g. transitioning from oil to biogas and biomass), the timing of new technologies (e.g. when and to what extent will electric vehicles penetrate the transport fleet) and the future role of electricity and gas infrastructure. It also emphasizes the scale of the challenge ahead, assessing macro-economic implications of decarbonisation,[4] and points to a number of areas of opportunity for Ireland as it transitions for a low carbon future. Moreover it provides guidance to possible sectoral targets, with the allocation of CO_2 emissions reductions (Table 1), between the key energy sectors in the *BAU* scenario and the range of results arising from the two low carbon scenarios considered (*CO_2-80* and *CO_2-95*).

The analysis also provides useful indications of the impact of different policy metrics to the whole energy systems, resulting with different allocations of fuels, sectors, efficiencies, but also energy dependency, as testified by the energy systems snapshots of alternative future energy systems provided by the Sankey diagrams shown in Fig. 2.

3.2 *Assessment and Implications of EU 2030 Climate and Energy Policy Framework for Energy Policy in Ireland*

In the period January–September 2014, the Irish TIMES model was used to inform Ireland's negotiating position with respect to the European Commission's proposal of a Climate and Energy Policy Framework for 2030 (EC 2014a). Here it was used

[4] The economic impacts were assessed by the Economic and Social Research Institute using outputs from the Irish TIMES model as inputs to the HERMES macro-economic model (Deane et al. 2013).

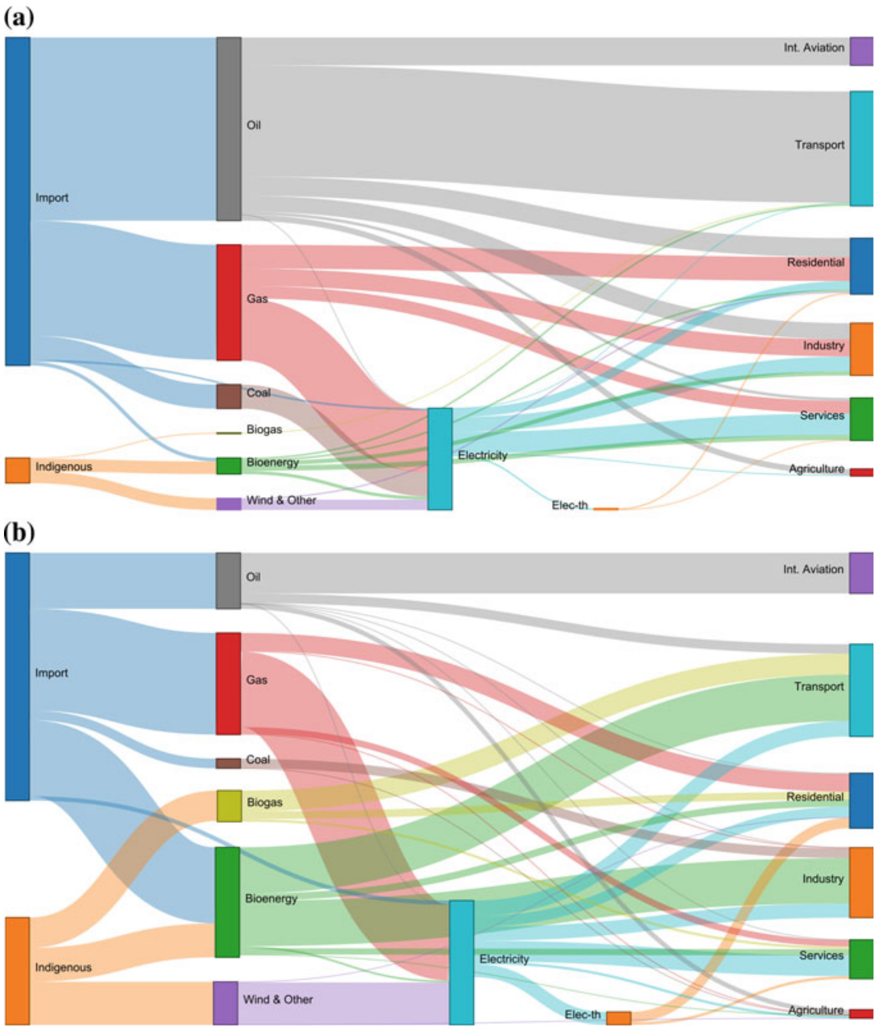

Fig. 2 2050 Sankey Diagrams for Ireland's energy system under BaU, CO_2-80 and CO_2-95 scenarios. **a** BaU scenario. **b** CO_2-80 scenario. **c** CO_2-95 scenario

to examine and provide answers to key questions arising from the proposed targets and in particular to scrutinise the findings of the modelling exercise accompanying the proposal (EC 2014b).

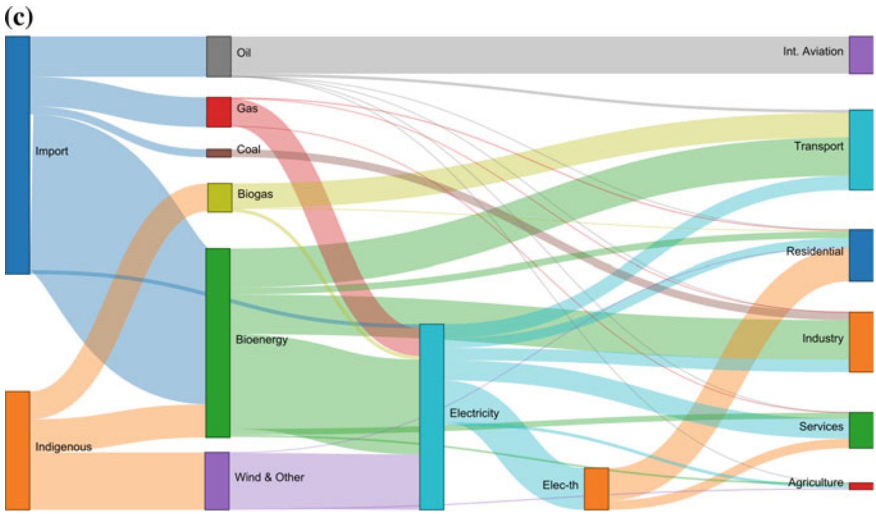

Fig. 2 (continued)

The impact assessment accompanying the proposed climate and energy package is based on the modelling analysis developed using mostly the PRIMES energy system model (NTUA 2011). It provides results for Ireland (and other Member States) arising from a scenario analysis of the EU achieving a 40 % reduction in GHG emissions by 2030 relative to 1990.[5]

The Irish TIMES energy system model has been to scrutinize the impact on the Irish energy system of the reduction in Irish GHG emissions indicated in the impact assessment (Cahill et al. 2014). It addresses a series of key questions that arise from the framework proposal: (i) what level of GHG emissions reduction can be achieved in Ireland up to 2030 at a cost of €40/tonne; (ii) what is the marginal abatement costs in Ireland in 2030 associated with achieving the 33 % emissions reduction relative to 2005 levels; (iii) what is level of effort required (measured as the increase in energy systems cost) to achieve 33 % GHG emissions reduction; (iv) what is the role of renewables in achieving the 33 % emissions reduction; (v) what is the cost optimal effort distribution between ETS and non-ETS sectors of the economy. The analysis addressed these five questions through scenario analysis

[5] The results for Ireland suggest that GHG emissions can be reduced by 33 % below 2005 levels (or 14.8 % below 1990 levels) by the year 2030 at a marginal abatement cost of €40/t CO_2 eq. The impact assessment shows that the contribution from non-ETS sectors of the economy is a 21 % reduction in 2030 relative to 2005 levels. This implies that total non-ETS emissions in 2030 would be 36.4 $MtCO_2$ and ETS emissions would account for the remaining 11.5 $MtCO_2$.

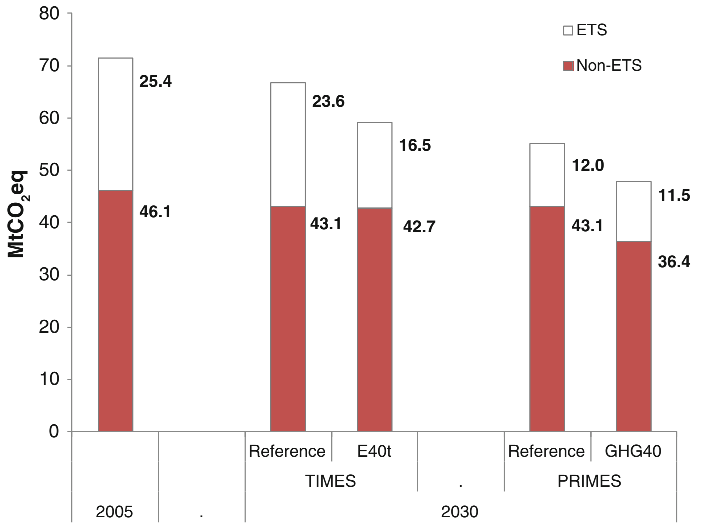

Fig. 3 GHG Emissions Scenario in Ireland in 2030—PRIMES versus Irish TIMES

and a number of sensitivity runs to test impacts of alternative emissions pathways, renewable targets and taxation levels. Additional analysis was undertaken using the outputs of the Irish TIMES scenario analyses as inputs to a macroeconomic model (Bergin et al. 2013) to investigate the macroeconomic impacts of achieving a specific level of emissions reduction by 2030.

Key outputs from Irish TIMES suggest that a 33 % GHG emissions reduction can be achieved at marginal abatement cost of €151/t, significantly higher than the €40/t resulting from the PRIMES scenario analysis, while only 21 % GHG emissions reduction can be delivered at a marginal abatement cost of €40/t (Fig. 3).

Another key difference is also shown in the modal distribution of renewable energy (Fig. 4). Although both analyses indicate renewable energy increases from 7 % currently to 25 % in 2030 as a share of gross final energy consumption, the PRIMES results point to a higher share of electricity from renewables (60 % RES-E compared with 51 % RES-E from Irish TIMES). By contrast, the Irish TIMES scenario analysis points to share of thermal energy from renewables (38 % compared with 17 % in the PRIMES analysis).

The feedback on the analysis undertaken with Irish TIMES was very positive from the Irish delegation negotiating the Climate and Energy Policy Framework for 2030 in the weeks before the European Council meeting in October 2014. It was clear that the modelling analysis was received as being robust and very useful and that is strengthened Ireland's position.

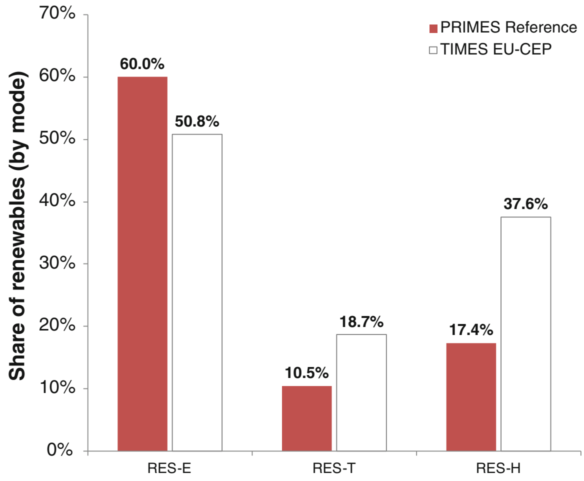

Fig. 4 Modal shares of renewables in gross final consumption in 2030—PRIMES versus Irish TIMES

3.3 Discussion

The use of TIMES modelling tools to inform policy decision is quite recent in Ireland. Before 2009, when Irish TIMES project commenced, no similar modelling tools were in fact available in Ireland. This limited Ireland's negotiating strength in EU deliberations regarding 2020 targets for emissions reduction (Chiodi et al. 2013a). The absence of a *whole energy systems approach* has also contributed to a dominant policy renewable energy focus on wind-generated electricity (Ó Gallachóir et al. 2014). The Irish TIMES model has demonstrated the capacity of the energy system to respond directly to a number of key policy issues, facilitating the comprehension of the key challenges towards a low carbon economy and providing direct evidences on Irish negotiating position regarding new policy developments. However the major challenges have been increasing the trust on the analysis via substantial efforts made in respect of the transparency, the completeness of the model structure and assumptions, through stakeholder events, peer-reviewed publications and the online publication of model documentation and main input assumptions.[6] Moreover stakeholder input contributed directly to the development of the model, proving information and data inputs which have been used to update the model databases, i.e. the techno-economic assumptions of the electricity generation portfolio and bioenergy resource potentials and costs. Including stakeholder engagement and input into model development is challenging; however it does contribute enormous added value in terms of transparency and consistency.

6 Available online at http://www.ucc.ie/en/energypolicy/irishtimes/.

4 The Experience of TIMES_PT

4.1 Use of TIMES_PT in Policy Support

The development of the TIMES_PT (Simões et al. 2008) model started within the EU research project NEEDS and the national research project E^{2}POL during 2004. Although its implementation was motivated by research goals, during the past decade the model has become a major tool supporting national climate mitigation policies (Gouveia et al. 2012a), and to a lesser extent, air pollution policies (Fig. 5). The Low Carbon Roadmap 2050 (Seixas et al. 2012) is a flagship policy document currently used as the Portuguese long term view on mitigation goals, while the PNAC—National Plan on Climate Change (Seixas et al. 2014) includes the visions up to 2030 from stakeholders from other policy areas, as transportation and industry. The negotiations for the revisions of the National Emission Ceilings Directive for 2020 and 2030 (Seixas et al. 2009; Ferreira et al. 2014) were supported by projections generated by TIMES_PT. More recently, TIMES_PT was linked with a national CGE model (Fortes et al. 2014), which has motivated its use in the Green Tax Reform (Seixas and Fortes 2014).

4.2 Portugal CLIMA2020

The CLIMA2020 project was the first policy support study using the TIMES_PT model as a reference tool for national climate and energy analysis. The project's main objective was the development of 2020 GHG national emission scenarios and assessment of technical and economic implications for different targets on emissions (ETS and non-ETS) and renewable energy shares. The results were provided to advise the Executive Committee of the Portuguese Climate Change Commission (CECAC)—Ministry of Environment on the EU Climate and Energy Policy Package negotiation.

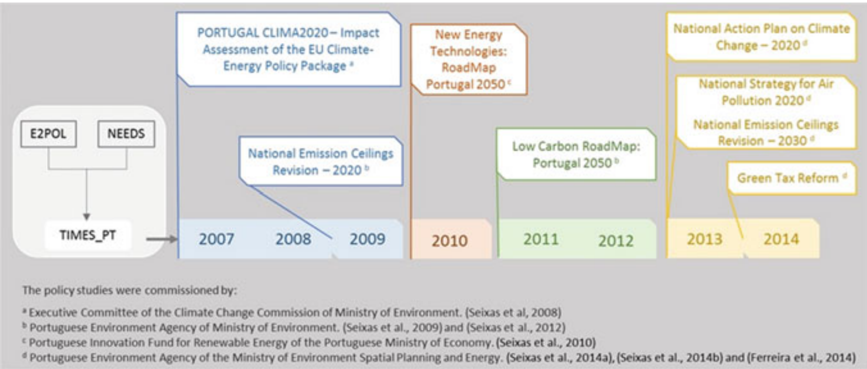

Fig. 5 Overview of the policy support studies using TIMES_PT

4.3 New Energy Technologies: Roadmap Portugal 2050 (NETRP)

The NETRP project assessed the role of new energy technologies, renewable mostly electricity generation, on the national energy system through the development of different national scenarios and focusing on endogenous resources. The work was commissioned by the Portuguese Innovation Fund of the Ministry of Economy. It emphasized the main economic and technical conditions for the competitiveness of the different renewable technologies (solar—PV, CPV and CSP—wind—onshore and offshore—geothermal) in Portugal in the long term. For this, the TIMES_PT model database was upgraded by integrating new technologies or more individual technologies like different photovoltaic and wind offshore technologies. A range of consultations with national industry and experts was held concerning the review and validation of the technical and economic parameters of the TIMES_PT technology database. The scenarios developed included different levels of CO_2 emissions constraints, and progressive reductions on the cost (investment and O&M) of mentioned renewable electricity technologies and electric vehicles.

4.4 Low Carbon Roadmap: Portugal (LCRP) 2050

The ambition to transition to a future low carbon economy in Portugal requires significant effort in achieving the necessary reduction of GHG emissions without compromising the economic and social development. The LCRP—2050 was commissioned by CECAC and established the vision for this by providing an analysis of the technical and economic feasibility of emission reduction trajectories of GHG in Portugal, focusing on modifications in the national energy system and evaluating their economic impact. The scenarios constructed with TIMES_PT covered very different economic growth trajectories and strict GHG emission targets, −60 and −70 % GHG facing 1990 values, in line with the EU low carbon roadmap. The additional co-benefits in terms of improved air quality and creation of "green jobs" were also analysed.

4.5 Portuguese National Action Plan on Climate Change (PNAPCC)—2020

The development of the Portuguese National Action Plan on Climate Change for the CECAC required the projection of GHG emission activities, assuming the implementation of national targets for climate mitigation policy and energy by 2020, and adopting exploratory goals by 2030, inspired by the 2030 framework for climate and energy policies and the positions taken by Portugal in the context of the

EU debate. The GHG national emissions trajectories evaluated by 2030 using TIMES_PT, considered two contrasting socio-economic scenarios, technological evolution scenarios, varied primary energy prices, and the national policy framework. Beyond that, it also analysed the impact of a more conservative view of the national stakeholders on the coal power plants utilization (5 more years than the expected decommissioning), and also a higher availability of the identified cost effective technologies, like solar PV technical and economic potential. Additional runs were made in order to identify potential alternatives on the significant penetration of electric vehicles, the effect of applying a CO_2 tax in sectors not covered by the EU ETS and the potential for renewable production for export, having been based on the assumption of increased interconnections with Europe for the transport of electricity.

4.6 Common Key Findings and Results

A wide number of scenarios were modelled in the policy studies above, depending of the policy requests (Table 2 provides selected examples). Typically two distinct macro-economic scenarios were considered for the long term, encompassing uncertainty. These were combined with different levels of implementation of policies and measures (P&M) according to established policy goals (e.g. National Plan for Energy Efficiency), from deployment of RES power plants to biofuels in transport. The scenarios used common assumptions on primary energy prices (imports of coal, oil and natural gas), on electricity trade with Spain and on hydrological availability, which were then varied in sensitivity analyses. Addition to the reported scenarios, the modellers typically developed more scenarios (often at the request of policy makers) to test how each assumption affects the results. Most of these "extra" scenarios are not directly used in policy support and are instead relevant for research work and model improvements.

The TIMES_PT model, by providing scenarios, has been acting as a central piece for Portuguese policy formulation. The model has been directly used in 7 major national policy development initiatives in climate mitigation, air pollution strategies and green tax reform. The model outputs have supported national communications to the European Commission, the CLRTAP[7] and the UNFCCC and led directly to a number of legislative documents.[8] The transparent approach followed by the modellers and the ongoing engagement with policy makers, has built confidence and trust in model results and contributed for the acceptance of policy proposals.

[7] United Nations Convention on Long-Range Trans boundary Air Pollution.

[8] Such as the Council Minister Resolution (RCM) 119/2004 of July 31st, RCM 104/2006 of August 23rd, or the RCM º 1/2008 of January 4th.

Table 2 Overview of selected studies using TIMES_PT for policy support

Project name (time horizon)	Project goals	Main TIMES_PT assumptions
Portugal Clima 2020 (2000–2020)	Assess impact of EU 20-20-20 policy package (Seixas et al. 2008)	Two macro-economic scenarios (2–3 % GDP growth), 84 USD_{2010}/bbl in 2020. No GHG caps
New energy technologies: roadmap Portugal 2050 (NETRP) (2005–2050)	Assess competitiveness of renewable technologies within the Portuguese energy system, identifying the critical drivers for their deployment (Seixas et al. 2010)	Two macro-economic scenarios (1–3 % GDP growth), 101 USD_{2010}/bbl in 2020. −20 % GHG cap from 1990 in 2020. Cost reduction in specific renewable technologies
Low carbon roadmap: Portugal (LCRP) 2050 (2005–2050)	Assess the feasibility of achieving a low carbon scenario for Portugal in the long term. Identification of the energy drivers/technologies for achieving a reduction of −60 % and −70 % of energy related and process GHG emissions in 2050 (Seixas et al. 2012)	Two macro-economic scenarios (0.7–3 % GDP growth), 118 USD_{2010}/bbl in 2020. +1 % GHG cap from 1990 in non-ETS in 2020
Portuguese national action plan on climate change (PNAPCC)—2020 (2005–2030)	Develop cost-effective GHG mitigation policies and measures for 2020 (Seixas et al. 2014)	Two macro-economic scenarios (0.39–3 % GDP growth), 115 USD_{2010}/bbl in 2020. +1 % GHG cap from 1990 in non-ETS in 2020. Explicit EU-ETS prices

We believe this has been fundamental to success, since during the past decade several changes have been influencing the model leading to different results for the same modelled year (Fig. 6). For example, there has been a successive downwards adjustment on the GHG projections and upwards on the RES electricity share. These differences are driven by a number of factors, e.g. differences in scenario formulation, expectations on macro-economic growth; primary energy prices, discount rates, etc. Energy systems are intrinsically dynamic and are affected by a myriad of stakeholders and factors. Therefore, any valuable energy system model has to be continually updated and improved. This is only possible if there are enough resources allocated to this time/consuming task and if there is a dedicated modelling team ensuring continuity. In our experience, such has been possible because of the continued model usage for policy making.

On a different note, common key-findings of all the policy support scenario modelling work are the cost-effectiveness of hydro and wind electricity generation technologies from 2020 onwards, and of the PV electricity plants only with the

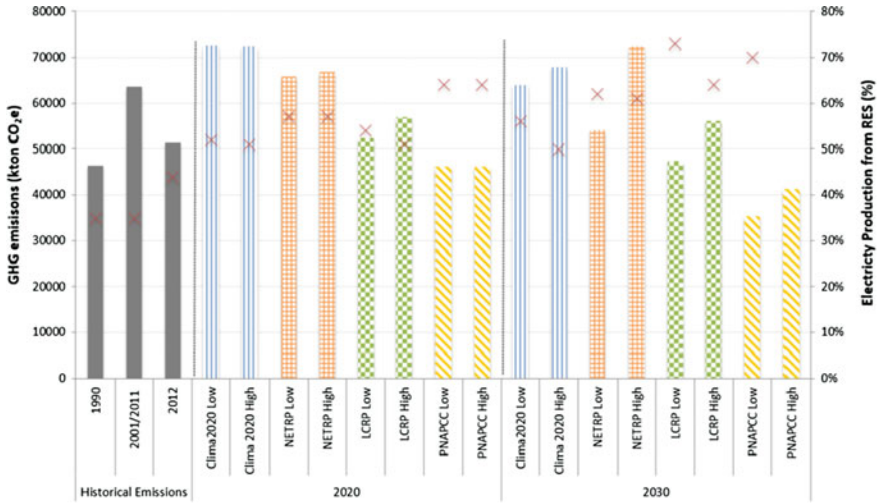

Fig. 6 Projections of GHG emissions (*left axis*) and share of electricity production from RES (*right axis*) for 2020 and 2030 from TIMES_PT within different policy support studies

more recent lower cost data. On the end-use sectors the deployment of electric vehicles is selected, subject to variations in investment costs of around 30 %. On the other hand, the deployment of heat pumps is cost-effective regardless of the several cost updates.

4.7 Discussions and Lessons Learnt

The development of policy studies relies in close cooperation between the modellers and the policy makers that commission them, complemented with frequent meetings with other policy makers and private agents. This process has proven extremely effective for strengthening the role of modelling for policy making, since it enabled the establishment of trust and a common language.

Most of the model inputs have been defined in cooperation with the policy makers that commissioned the studies, particularly the macro-economic assumptions, primary energy import prices, availability of hydrological resources and defining which P&M are in each scenario. The assumptions on energy technologies have been validated with other stakeholders, through a consolidated process (Fortes et al. 2015) including workshops, bilateral meetings and extensive information exchange with the following: Bank of Portugal, Ministry of Economy, Ministry of Transport, associations for production of pulp and paper, chemicals, ceramic, glass and cement; refining companies; electricity utilities; consumer organizations; local and national energy agencies; academia; renewable technologies manufacturers and suppliers and architects. As part of the stakeholder validation process, the files that constitute the model inputs are provided to the stakeholders for validation. Furthermore, extensive work has been done reporting the model inputs and outputs including how the data is generated when applicable (see for example Gouveia et al. (2012b) for the residential energy services demand). This process, albeit substantially time consuming, has been extremely relevant to ensure maximum transparency regarding the model. All the studies have included the opportunity, some within public events, to present results and obtain feedback.

During this process of engaging stakeholders and policy makers a number of challenges has been encountered, in particular the need to find the correct balance between a sufficiently disaggregated model structure, allowing the stakeholders to recognize it and provide useful feedback, and the need to ensure confidentiality in some industry processes coupled with very time consuming data compilation processes.

While involving policy makers, it has been difficult to ensure that TIMES_PT is used as much as possible as an optimization model when it is constrained with assumptions and parameters imposed by policy makers, usually reflecting their expectation of near-term developments, their knowledge on policies that are not fully included in the model or even concerns with eventually politically unacceptable model outcomes. Examples of such assumptions are for example renewable technologies availability factors and minimum activity for certain fossil fuel power plants (Simões et al. 2013). Additionally, policy makers are very demanding on testing new scenarios, perceived as relevant by the policy makers, and are not aware on how time-consuming this task can be. Some of these scenarios do not translate in substantial differences in model outcomes (Simões et al. 2014), particularly CO_2 emissions, which sometimes is very disappointing for policy makers. Finally, a difficulty that should be underlined refers to the need to educate policy makers on the fact that model results provide insights much more than deterministic answers to questions. Although a range of scenarios and results are generated in each policy support process, in several occasions, policy makers have stated: "*Yes, I see all these results, but I just want a number!*"

In conclusion, after ten years of supporting policy makers we have learned the following lessons: (i) opening the model to the stakeholders, public and private, involved in the policy framework is essential to ensure trust and understanding on the model outcomes; (ii) the knowledge on the continuous updates of the model data bases creates a sense of confidence on its outcomes, although they can be different from one modelling exercise to another. This is especially important if the same policy body commissions similar works along the years; (iii) the generation of disruptive scenarios totally different from possible future pathways as perceived by policy makers, usually proposed by the modellers, is very important to give the sense of true alternatives for policy goals and to assess how conservative are the "new" P&M being proposed by policy-makers; (iv) a continuous work with a policy body allows for a high-level cooperation and the recognition that a modelling tool as TIMES_PT, although with limitations, is crucial for policy design, which is directly related with policy evidence.

5 The Experience of IEA ETP Model

5.1 Model Development, Scenarios and Key Findings

In 2001, the Secretariat of the International Energy Agency in Paris launched the Energy Technology Perspectives (ETP) project, with the support of the Energy Technology Systems Analysis Programme (ETSAP) to develop a 15 region global MARKAL model that would be at the heart of the ETP modelling framework.[9] The purpose was to analyse how the deployment of new energy technologies could affect fuel markets, greenhouse gas emissions and energy security (IEA-ETSAP 2001). Over the following four years the model was progressively developed and used to help inform a number of IEA technology studies (IEA 2004, 2005). The ETP project was given significant impetus by the G8 meeting held in Gleneagles, Scotland in July 2005. This meeting launched the G8 Gleneagles Plan of Action on climate change, clean energy and sustainable development and asked the IEA to "*advise on alternative energy scenarios and strategies aimed at a clean clever and competitive energy future*" (G8 2005). As part of its response the IEA began working on a new publication: *Energy Technology Perspectives: Scenarios and Strategies to 2050* (IEA 2006a), which was published in June 2006. This used the ETP MARKAL model to create a "*series of scenarios to demonstrate the role energy technologies that are already available or under development can play in future energy markets*".

The main scenarios were:

1. *Baseline* scenario: includes the effects of technology developments and improvements in energy efficiency that can be expected on the basis of government policies already enacted.
2. *ACT Map* scenario: investigates the potential of energy technologies and best practices aimed at reducing energy demand and emissions, and diversifying energy sources. Focuses on technologies which either exist today or will become commercially available in the next two decades and assumes the successful implementation of a wide range of policies and measures aimed at overcoming barriers to their adoption. Four variants of the ACT scenario were also developed that explore more limited progress in each of four technology areas: renewables, nuclear, carbon capture and storage (CCS) and energy efficiency.
3. *TECH Plus* scenario: makes more optimistic assumptions about the progress for promising energy technologies. Specifically, the scenario assumes greater cost reductions for fuel cells, renewable electricity generation technologies, biofuels and nuclear technologies compared with the ACT Map scenario.

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[9] The ETP modelling framework has evolved over time, with the ETP MARKAL (later TIMES) model being supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors and MARKAL/TIMES models for individual countries and regions.

Based on the results of these scenarios, ETP 2006 concluded that the world was not on course for a sustainable energy future, but that this outlook could be changed. Specifically it proposed a way forward based on strong energy efficiency gains in the transport, industry and buildings sectors, significantly decarbonising the power-generation mix through shifts towards nuclear power, renewables, natural gas and coal with CCS and increased use of biofuels for road transport. The publication highlighted that this would require strong policy action including making energy efficiency the top priority, increasing the budgets for well-focused R&D programmes, creating stable policy environments that promote low carbon options and bridge the *valley of death* between R&D and deployment and increasing international co-operation including between developed and developing countries (Fig. 7).

The key findings from ETP2006 were reported to the St Petersburg G8 summit held in July 2006 and welcomed in a statement from world leaders on Global Energy Security (IEA 2006b). Over the following two years, work continued to develop the ETP model in preparation for a second edition of the ETP publication, including responding to a request from IEA countries for an even more ambitious scenario to address climate change. The next edition of the ETP publication released in June 2008 therefore replaced the *TECH Plus* scenario with a scenario known as *BLUE Map* (plus variants) which envisages a very rapid change in direction of the energy sector leading to a halving of global CO_2 emissions by 2050—consistent with a long term temperature rise of 2–3 degrees (IEA 2008). The ETP2008 modelling showed that halving CO_2 emissions would not be possible with the technologies currently available. Using relatively optimistic assumptions about progress in technology performance and costs, the *BLUE Map* scenario had a marginal cost in 2050 of USD

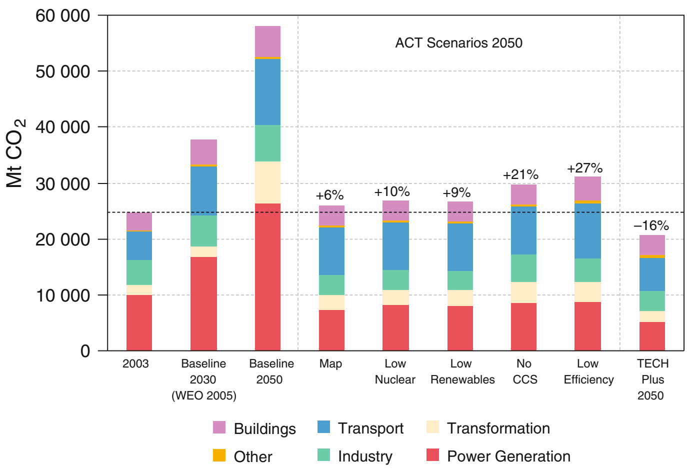

Fig. 7 Global CO_2 emissions in the Baseline Scenario, ACT scenarios and TECH Plus scenario of ETP2006. Based on IEA data from Energy Technology Perspectives © OECD/IEA 2006, IEA Publishing, Fig. 2.1 page 46, License: www.iea.org/t&c/termsandconditions

200 per tCO_2 saved and the technology mix included wide deployment of CCS in the fuel transformation and industry sectors and hydrogen fuel cell vehicles in transport.

By the time the next ETP was released in July 2010 there was a growing realisation that historically high oil prices were starting to impact the world economy. The issues of energy security and economic growth were therefore of significant interest to IEA member countries and this edition used the detailed technological and fuel cost information in the MARKAL model to demonstrate that tackling climate change and improving energy security through lower dependence on fossil fuels were not incompatible with economic priorities. The analysis showed that while realizing the *BLUE Map* scenario would require investments of USD 46 trillion more than the *Baseline* scenario over the period to 2050, over the same period, fuel savings of USD 112 trillion would result. Even if both the investments and fuel savings over the period to 2050 are discounted back to their present values using a 10 % discount rate, the net savings amounted to USD 8 trillion (IEA 2010).

ETP2010 also broke new ground by working with MARKAL analysts and experts in key countries and regions to further develop the regional representation in MARKAL and so present detailed results for OECD Europe, United States, China and India. In the *BLUE Map* scenario, all countries show considerable reductions from the *Baseline* scenario: emissions in 2050 (compared to 2007) were 81 % lower for the United States, 74 % lower for OECD Europe and 30 % lower in China, while India's emissions rose by 10 %.

The 2012 edition of ETP renamed the scenarios according to the long-term temperature rise that was likely to result from each emissions pathway. The baseline scenario therefore became the *6DS* (6° scenario), while the *BLUE Map* scenario became *2DS* and a *4DS* was introduced (somewhat analogous to the previous *Act MAP* scenario). The heart of the modelling framework covering the conversion sector (i.e. transformation of power and fuel) in ETP 2012 was transferred from MARKAL to The Integrated MARKAL-EFOM System (TIMES) model generator, which covered 28 regions and a more detailed depiction of load curves for electricity and heat. The new model was used by ETP2012 to explore the development of three important sub-systems within the energy sector: electricity, heating and cooling and hydrogen. Expanded regional coverage also allowed results to be presented for the first time for Brazil, Russia, South Africa and the ASEAN[10] region (IEA 2012).

The latest edition of ETP published in 2014 focused on the role of electricity in a decarbonized energy system, examining the actions needed to support deployment of sustainable options for generation, distribution and end-use consumption (IEA 2014). All the ETP2014 scenarios showed that electricity's role in the energy system grows faster than any other source and in ETP2014 refined chronological load curves in the TIMES model were used to explore the challenge of balancing supply and demand in greater detail than had previously been possible.

[10] Association of South East Asian Nations.

5.2 Impact of ETP on Global Energy Policy

Over five editions, Energy Technology Perspectives has established itself as the IEA's most important technology publication and a leading source of information for the global energy community. The technology scenarios have been used extensively by a wide range of stakeholders including national governments, international organisations and initiatives, the IEA itself and by academics and other researchers. This success has been due to (i) a flexible framework provided by ETSAP's MARKAL/TIMES model that combines the ability to analyse the technology characteristics of energy systems incorporating both economic and environmental performance data and (ii) access to technology expertise and up-to-date data through the IEA's technology network, consisting of more than 40 multilateral technology initiatives (Implementing Agreements) and more than 6000 specialists covering almost every conceivable energy technology.

A number of national governments have made significant use of the ETP scenarios to support policy-making. For instance, the 2010 and 2011 versions of the US Department of Energy Critical Materials Strategy used the ETP2010 scenarios to develop low and high estimates for materials consumption over the short and medium terms (USDOE 2010, 2011). The report find that many clean energy technologies in the ETP scenarios rely on raw materials with potential supply risks and identifies strategies for addressing these risks. The UK Department of Energy and Climate Change has used the results from ETP2010 to help frame its 2012 science and innovation strategy, highlighting, in particular, the likely large market for clean energy technologies based on the global investment figures from the *BLUE Map* scenario (DECC 2012).

The ETP scenarios are also a key input to many IEA publications including the technology roadmap series, which themselves have proved highly influential in informing the international debate about how best to accelerate the development and deployment of a range of clean energy technologies.[11] Over 20 roadmaps have been published for key low carbon and enabling technologies, describing the potential for transformation across various technology areas, and outlining actions and milestones for the levels of deployment seen in the *BLUE Map/2DS* scenario.

Progress with technology deployment is also monitored in a regular IEA publication *Tracking Clean Energy Progress* that has become an annual input to the Clean Energy Ministerial (CEM).[12] This report tracks each technology and sector against the progress needed to achieve in the IEA BLUE/2DS scenarios. A number of the CEM initiatives have also drawn heavily on ETP scenarios to inform their activities and work programmes including the Bioenergy Working Group, the Carbon Capture, Use and Storage (CCUS) Action Group and the Electric Vehicle Initiative.[13]

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[11] See http://www.iea.org/roadmaps/.

[12] See http://www.iea.org/etp/tracking/.

[13] See http://www.cleanenergyministerial.org/Our-Work/Initiatives.

The ETP publications have also been referred to extensively in the peer reviewed literature, with over 1500 citations in the peer reviewed literature since 2006, including internationally leading journals such as *Nature* and *Science*.

6 Conclusions

This chapter has presented a selection of case studies which recognize the value of ETSAP modelling tools in providing guidance to decision makers on developing energy and climate mitigation policies. The four case studies showed not only the value of providing quantitative assessments of the key challenges and decisions facing governments in the energy and climate policy space. They also provide insights which helped on overcoming the key barriers to acceptance of the transition to a low carbon future.

6.1 Key Lessons for Modellers

The development of powerful, detailed and robust energy systems model expands the capability for developing and analysing technology roadmaps and assessing the impacts of key climate and energy policies. However this is generally not sufficient in itself to establish trust with policy makers and to underpin policy decisions. Energy systems models are by nature complex, very detailed and not easily accessible, and ensuring transparency and understanding of the model outcomes is not simple. However, the experiences presented in this chapter recognize engagement and dialogue to achieve confidence as a key element for a successful outcome. An open and ongoing engagement between modellers, policy makers and stakeholders; frequent meetings and extensive information exchange via peer-reviewed and online publications have proven to be extremely effective for strengthening the role of modelling for policy making, even though this is very time and resource consuming. Sensitivity analysis and runs are also time consuming, but as was demonstrated they generally contribute to increase the robustness perception of the modelling analysis.

Recent analysis also points to need for expanding the range of outputs from energy systems analysis, from a technology-oriented analysis to a more comprehensive approach, assessing the macro-economic impacts (e.g. impacts on GDP, employment, etc.), impacts on land-use patterns, on non-CO_2 emissions, and the impacts of specific sets of technologies (e.g. storage, wind energy, …), etc. of low carbon economies. Additional insights are needed beyond the direct results that are generated by ETSAP models. Further work is required to investigate new methods for gaining additional insights about these new areas.

6.2 *Indications for Policy*

This chapter demonstrates how IEA-ETSAP energy systems models can provide unique insight to policy makers. They provide a mean of testing the impacts of single (or groups) of policy targets and assessing the implications of alternative future energy system pathways. They also expand the capability of understanding dynamics behind the interactions between the economy (technology choices, prices, output, etc.), the energy mix and the environment. Energy systems models can contribute to move from a *silos-based* approach (focused on single sets of technologies or specific sectors), to a *whole system* approach, where wide sets of technologies, sectors, and regions are analysed together in a robust and integrated manner. The case studies showed how energy systems model can support policy, how they can point to the feasibility of undertaking challenging climate and energy targets and can also help to change the perception of these challenges to governments, stakeholder and public opinion.

However the development of these modelling tools is extremely complex and time consuming; in which the production of scenarios and the analysis represents only a minimal part of the process. To allow models to continue to expand and increase in capability and robustness, sustained resources need to be allocated to establish and maintain a dedicated modelling team, ensuring continuity. The costs associated with energy systems modelling are dwarfed by the economic benefits of robust, well informed policy decisions.

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