National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Climate Change Research Programme (CCRP) 2007-2013
Report Series No. 12

Integrated Modelling Project Ireland

Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Community and Local Government.

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- the contained use and controlled release of Genetically Modified Organisms (GMOs);
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- Office of Climate, Licensing and Resource Use
- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA Climate Change Research Programme 2007–2013

Integrated Modelling Project Ireland

2007-CCRP-5.5.1.a

CCRP Report

End of Project Report available for download on http://erc.epa.ie/safer/reports

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ACKNOWLEDGEMENTS

This report is published as part of the Climate Change Research Programme 2007–2013. The programme is financed by the Interdepartmental Committee for Strategy for Science, Technology and Innovation and the Department of Environment, Heritage and Local Government. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

The project team are grateful to the Environmental Protection Agency (EPA) for the financial support which enabled this work. Many individuals and organisations provided valuable input to this project, which has been much appreciated. A particular mention must go to the project steering committee which was composed of a highly committed and engaged selection of individuals from government departments, government agencies and academic institutions. Further specific acknowledgements are offered to: the broader EPA staff, members of the United Nations Economic Commission for Europe (UNECE) Task Force on Integrated Assessment Modelling (TFIAM), the Network for Integrated Assessment Modelling (NIAM), the International Institute for Applied Systems Analysis (IIASA) and many other individuals and institutions with whom we interacted.

EPA CCRP PROGRAMME 2007-2013

Published by the Environmental Protection Agency, Ireland

Price: Free

ISBN: 978-1-84095-431-9 **Online version**

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Executive Summary

The Integrated Modelling Project Ireland (IMPI) focused on the development and application of analytical capabilities in respect of climate and transboundary air pollution modelling and policy. The developed capacities include methodological and technical developments for multisectoral emissions, costs, policy and effects analysis, as well as the intellectual capital, contacts and experience necessary for effective applied use of these tools and their derived outputs.

The principal technical research outcomes include two nationally calibrated modelling tools – GAINS Ireland and TREMOVE Ireland. The first is a techno-economic integrated assessment model for climate and air policy; the second is a specialised transport sector policy model. IMPI research has carefully calibrated the systems to be increasingly representative of the Irish economy. In this process, the team engaged regularly with other national experts to exchange evidence and insights related to the work. Furthermore, the two models have been respectively augmented by the development of in-house supporting systems in the case of GAINS Ireland and extensive reprogramming and redevelopment in the case of TREMOVE Ireland. The models now serve as nationally focused mirrors of the core international modelling architecture designed and operated at a European and United Nations Economic Commission for Europe (UNECE) level as key policy development and management tools in the fields of both transboundary air pollution and European climate policy. Both models are maintained through a steady research and integration schedule.

Beyond the principal defined work programme of the project, which was model-related development and capacity-building, the formal deliverables produced exclusively under this project include ten academic papers (four already published in internationally peer-reviewed journals, six in process for international peer review), seven model-focused guides, and over thirty analytical reports and briefs on a range of topics. The project team actively engaged in the formal discussion and dissemination of their work, delivering over thirty national and international presentations and regular official national submission compilations to the international modelling community. Furthermore, the project team designed, developed and launched an open international policy resource database, PolicyMeasures (www.policymeasures.com). Throughout the IMP project, a high value was placed on policy support and to this end the team also participated regularly in extensive direct engagement (e.g. meetings, informal discussions, reporting and representation) nationally and internationally in regard to modelling, analysis and consideration of environmental compliance challenges. In this regard, the team informed and supported the direction and formation of related policy and decisions.

Two recent applied policy contributions from the project in respect of the major thematic areas – (i) climate and (ii) transboundary air pollution policy – have been selected for presentation in this Executive Summary section. These selected research outcomes are derived products from the broader set of research and development in regard to human capital, model development and international engagements. Many further examples are included in the body of the report.

Climate – The Non-traded Sector Challenge

Ireland faces a major challenge in respect of the European non-traded sector (NETS) target for 2020. IMPI-developed modelling capacity was engaged to provide detailed and costed abatement-pathway scenarios. Conclusions identify a persistent gap to target for the latest 'with-measures' baseline scenario in 2020. The first of these optimisations identified the emissions reduction potential under a carbon market price of €50, whereas the second optimisation applied all eligible measures in the model to determine the maximum feasible reductions from a modelled perspective. In the former the target in 2020 is missed by 4.8Mt CO_2e, whereas in the latter the gap to close remains at 3Mt CO_2e. The interim targets from 2013 pose a further challenge.

On a more positive note, the 'menu' of abatement options defined in the modelling system is reviewed in the research, and further options are noted for future consideration that may help bridge the gap. Consideration is also given to the role of Land Use, Land-Use Change and Forestry (LULUCF), net social costs of actions, and the impact of the package of policies and measures in terms of the traded sector's emissions.

Transboundary Air Pollution – National Emissions Ceilings

Ireland is entering into a compliance phase in respect of the European Emissions Ceiling Directive 2001/81/EC. Analysis suggests that official final inventory NO_X emissions will – despite the economic downturn – exceed the ceiling of 65kt in 2010 by a sizeable margin, incurring the risk of financial penalty. IMPI research has examined and identified the reasons underpinning the seemingly insurmountable challenge of the 65kt NO_X ceiling, as well as offering assessments of the most cost-effective pathways to progress towards compliance. The research has *inter alia* identified 15kt of emissions that are attributable to a failure in the European vehicle standard legislation to deliver expected on-road abatement. This research offers strong quantified support to compliance-negotiation discussions. Furthermore, the IMPI team have played a leading role internationally in bringing innovative flexible policy mechanisms onto the agenda for future (and potentially existing) legislation to mitigate the risk of such outcomes leading to high-cost compliance failure situations where exogenous and uncontrolled factors undermine national progress on obligations. The IMPI team have written on this topic in 2009 and 2010, leading the promotion and development of the issues and options at an international level. They have also recently contributed to a 2011 report by the UNECE Task Force on Emissions Inventory and Projections (TFEIP) in regard to the options and modalities of introducing a package of appropriate flexibility and correction mechanisms into the transboundary air pollution policy framework.

In summary, the IMPI project has developed the tools and capacity defined at the outset of the work, supplemented these with additional innovations, contributed to the academic research community, and – significantly – has engaged these developments directly to deliver sustained and applied support to national and international policy development to good effect. Greater detail of the achievements, deliverables and contributions of the IMPI project are presented in the report that follows.

1 Introduction

The modelling capacity developed as part of the Integrated Modelling Project Ireland (IMPI) is focused on providing effective decision support in regard to complex systems. The modelling systems engaged under the IMPI project mirror those used in a European and United Nations Economic Commission for Europe (UNECE) context to respectively evaluate and inform the process by which international transboundary air pollution policy and aspects of European climate policy are set, managed and reviewed.

The RAINS (Regional Air Pollution Information and Simulation)/GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies)[1] model remains the primary modelling system used in the international community analyses for national emission ceilings of transboundary pollutants. Specifically, the RAINS/GAINS model provided the analytical and negotiating framework for the UNECE Gothenburg Protocol[2] and the European National Emissions Ceiling Directive 2001/81/EC[3]. The model is currently being used for the Gothenburg Protocol Revision for 2020 and will almost certainly underpin planned work for the next round of European Emission Ceilings to 2020, 2025 or beyond.

In a climate context, the GAINS model has been used to inform the development, and potential revision, of the non-traded sector (NETS) target across the European Union[4]. The model has furthermore played a wider global role in international climate policy by extending its scope to cover Europe, Asia (including China), Russia, Annex 1 countries and, on a reduced scale, other continents in the rest of the world. This core modelling system is currently the pivotal model in a European-commissioned project[5] to develop a modelling suite that can provide the evidence base for cost-effective climate and air pollution strategies in Europe. Specifically, the project and the GAINS modelling system will directly support both the European Climate Change Programme and the European review of air quality legislation in 2013, which will occur under Ireland's chairing of the presidency of the Council of the European Union.

The IMPI research has developed the capacity to use these tools, and has delivered national refinements and redevelopments over these core modelling systems. This affords Ireland *inter alia* the ability to engage with the international policy development process and negotiations more effectively. In parallel with these advantages IMPI affords Ireland an internationally compatible means of evaluating and refocusing national policies in pursuit of existing defined objectives, using a valuable blend of internationally recognised methodologies and knowledge, refined by national expertise and evidence. In specific terms, the GAINS Ireland system offers the capacity to structure and tailor a desired national scenario from scratch or via sensitivity adjustments, and to thereafter analyse in aggregate or detail the associated emissions, trends, abatement potentials, costs and environmental impacts.

Beyond these values, a unique feature of the GAINS Ireland model is its integrated approach to simultaneously evaluating techno-economic scenario assessments of both climate and air pollution on a national and international scale. This allows more comprehensive decision support because it enables decision-makers to consider policy co-benefits and trade-offs across a wider thematic area than simply climate policy *or* air pollution policy, and do so on a scale that can move beyond or stay within national borders as necessary.

As a complement to the GAINS Ireland work, the TREMOVE Ireland model is a redeveloped and reprogrammed version of the original TREMOVE model. The TREMOVE Ireland model focuses on road transport and allows refined analyses of policy

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1 The RAINS model was the precursor to the GAINS model which extended the capacities of the original system to encompass greenhouse gases (GHG) and the interactions between climate and air pollution policies.

2 The text of the Gothenburg Protocol as well as reference to the current ongoing review process scheduled is available at: http://tinyurl.com/GothProtocol

3 Directive available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0022:0030:EN:PDF

4 The non-traded sector refers to those sectors outside the scope of the European Emissions Trading Scheme. The associated targets in terms of emission reductions for these sectors are covered by the EU Effort Sharing Decision: http://ec.europa.eu/clima/policies/effort/index_en.htm

5 The EC4MACS project can be found at: http://www.ec4macs.eu/home/index.html

interventions that require a specialised sectoral model. TREMOVE Ireland therefore offers an additional analytical capacity to the IMPI project in respect of a particularly significant air and climate emissions source sector. The model delivers results to policy questions on matters such as taxation revisions or relative modal service adjustments. Results are presented in the form of climate and air pollution emissions, vehicle stock changes and welfare adjustments. The TREMOVE Ireland model thus delivers detailed transport policy modelling on a national scale to enhance the capacities available in respect of decision-making for this complex and economically and environmentally significant sector. The system is used as an input-output linked support to the GAINS Ireland system, as well as for independent transport specific assessments.

This final synthesis report of the IMPI project is structured as follows. Section 2 provides details on the two core models developed and applied as part of the IMPI project. Section 3 presents selected examples of applied use of the IMPI models and associated IMPI research. Section 4 concludes with selected recommendations from the project and suggestions for the direction of future research.

2 The Integrated Modelling Project Ireland Models

The European Commission and the UNECE have directly and indirectly supported the development of, and contracted the use of, a number of models that have now become key analytical tools in the development and implementation of European environmental policy. In the past Ireland has lacked the capacity to understand systematically the design features of these models and the roles of data in shaping policy outcomes. In particular, Ireland has been without an operational understanding of the coefficients which inform centrally modelled emissions estimates and the associated menu of relevant abatement options. Therefore, Ireland has lacked the capacity to undertake independent national analyses that can be readily linked to these international decision-support frameworks that are so increasingly relevant in the context of determining future environmental policy and managing existing agreements.

The IMPI project has developed around two core international modelling tools that have been adapted for Irish needs: GAINS and TREMOVE. The decision to adopt and develop existing modelling infrastructure was an important one: it was taken firstly on the basis that the selected models offered the desired functionality, depth and quality for the expected demands of the IMPI project. It remains the view of the project team that the development of independent IMPI national models *de novo* would entail significant additional investment and effort, and would almost certainly fail to capture the full benefits of the existing state of the art internationally. Other advantages of choosing the models were the significant international engagement with the GAINS model from a broad selection of interdisciplinary researchers, over two decades of prior development, and an unrivalled role as a decision-support framework for European climate and air policy. In regard to TREMOVE, the model offers an effectively open source development template from what is a broadly sound academic structure for the analysis of transport policy interventions on a national scale.

In choosing these model frameworks, which are so firmly rooted in European policy, Ireland has gained a solid platform from which to conduct its own independent analyses in relation to international policy. Internally, the addition of this modelling capacity to the existing and developing national capacities in respect of economic, energy and emissions modelling enables Ireland to formalise strategies in a manner consistent with a recognised and accepted international methodology for air- and climate-related emissions research.

The advantages relating to these model choices were:

- Engagement and development of existing modelling tools in an Irish context offers the potential to refine the existing state of the art for Ireland, and to simultaneously enhance international representation of Ireland in these same systems;
- Expertise and technical capacity in respect of the selected models affords the opportunity to rigorously evaluate analysis conducted internationally via these systems which may impact upon Ireland. This strengthens the capacity to negotiate, and supports the evolution of appropriate international policies;
- Development and engagement with these international systems delivers the benefit of the international research communities' efforts in addition to the contributions of the IMPI research team. This enhances the quality of outputs for all stakeholders;
- In the case of TREMOVE, the model offered an ideal basis for further development of a detailed national transport policy model. Through research and programming investments, the system has been built into a powerful tool that can be calibrated for many types of transport-policy-focused questions. This system can play a role in a future national transport-modelling framework.

The two IMPI models are discussed in more detail in Sections 2.1 and 2.2.

2.1 GAINS Ireland

The GAINS model is a techno-economic integrated assessment model which combines information on the sources, interactions and impacts of air pollutants and GHG emissions. The model is equipped with parameters to consider a growing list of over one thousand measures for the control or reduction of emissions to air across all sectors of an economy.

2.1.1 Structure

In simple form the GAINS model can be described as being structured under four segments – (i) activities, (ii) controls, (iii) emissions and (iv) effects. The 'Activities' segment defines the activities in regard to energy use, agricultural data and a number of other relevant processes such as waste treatment or cement manufacture. These data indicate the *activity* in the modelled economy. The 'Control' segment relates to the abatement controls or emission savings options applied or available within the economy to *control* emissions. These controls are detailed in terms of what is currently in place and what is believed feasible, with each control linked further to available data on control costs, as well as synergies or trade-offs with other measures. The 'Emissions' segment of the model combines the information on activities, controls and other interactions to determine the *emissions* to air of a broad range of air pollutants and GHGs. Finally, the 'Effects' segment uses mapping, dispersion and other procedures to estimate the effects associated with a given scenario for a country or region. Effects on the transboundary side are focused upon health and ecosystem impacts,[6] while on the climate side impacts are principally evaluated in terms of emission levels and developing work on radiative forcing indicators, with integration of the corresponding impact of reduced air pollution in this regard. The model can therefore be set up to integrate a broad selection of evidence and to run a wide range of community, national or sectoral specific scenarios or sensitivities. A simplified schema is presented in Fig. 2.1.

More detailed explanations of the model methodology and structure are available through the IMPI project websites (www.impireland.ie and www.policymeasures.com) and from the host institution the International Institute for Applied Systems Analysis (IIASA) (http://gains.iiasa.ac.at/index.php/publications/reports-n/reports-2). These sources will offer a more in-depth perspective on the model form and function. In the context of additional detail, Fig. 2.2 offers a refined perspective on the components and interactions of the GAINS modelling system.

2.1.2 Calibration

Calibration of the GAINS model to establish a baseline scenario or to evaluate alternative scenarios requires careful consideration and adjustment of the model parameters described above. Generally, changes will be focused upon the activity and control elements of the model set-up. In regard to activity, the IMPI research team developed a series of in-house systems to manipulate and adapt the available national data into a structure and form that is compatible with the GAINS Ireland modelling system. Thus, for agriculture, energy and process information, procedures and systems to alter, split and adjust the aggregation of national data were developed and iteratively tested. This first step enabled the IMPI team to integrate available national

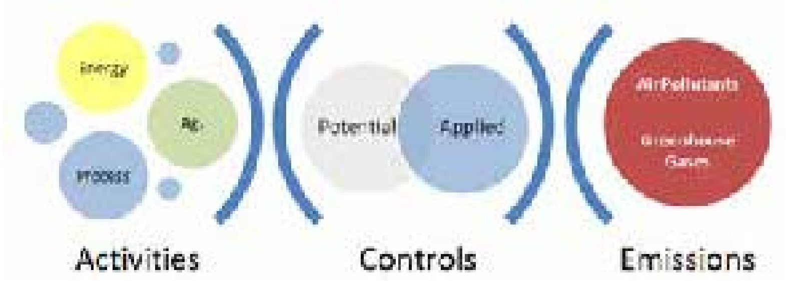


Figure 2.1. Simple schema for major GAINS model elements.

6 In a transboundary context, the critical advantage is the modelling of a broad international region to capture the aggregate deposition and dispersion of pollutants from the wider region Examining transboundary impacts from one country source alone is not particularly valuable as impacts are influenced by the 'stacking' of emissions from multiple international sources to levels that exceed defined thresholds.

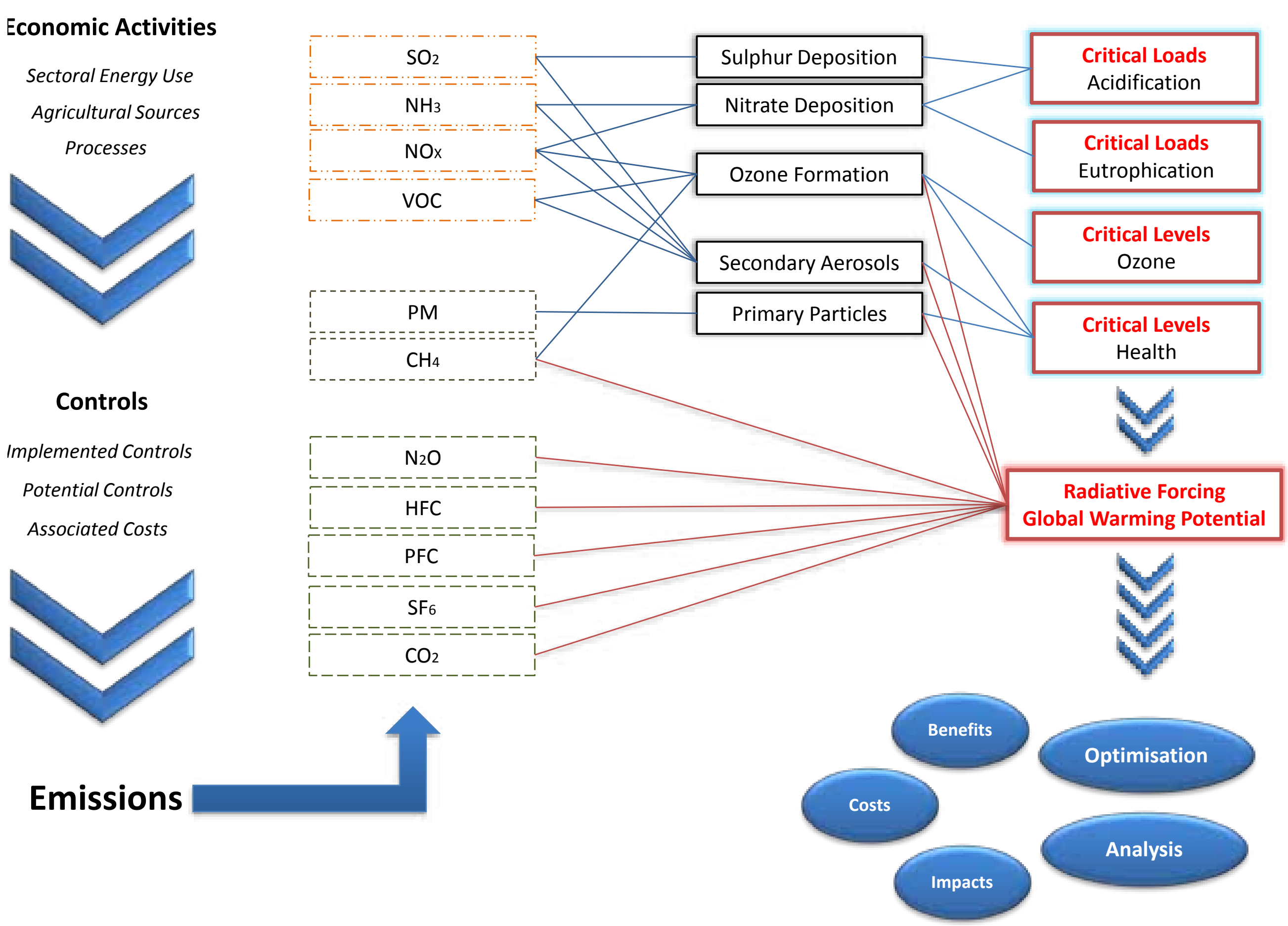


Figure 2.2. More detailed schema of GAINS model components and interactions.

data (e.g. official energy forecasts) into a GAINS Ireland activity pathway file.

In regard to controls, evidence and expert support were engaged to build the profile of abatement controls in Ireland, with further work using this base to project expected controls and potentials into the future. In this latter task the absence of official 'control' forecasting creates a challenging aspect of the work to be managed and improved under further work. Control work was initially advanced in respect of transboundary air pollution controls (often technologies), with later work focusing on GHG-related controls, controls that require consideration of a somewhat different suite of potentials such as fuel switch potentials, energy-saving potentials and efficiency pathways.

In both cases the cost associated with controls is an area that poses yet further challenges. However, it is also an area where the benefits of drawing on the international community research in this area comes to the fore. In the work with the GAINS Ireland model, national data gaps that were identified in respect of cost could be deferred in favour of using reasonably adjusted international values pending further national research and evidence. Thus, progress could be maintained, and methodologies and values at least remain consistent with alternate international estimations pending the availability of alternative robust national evidence.

In summary then, over the course of the project, regular research time was invested in determining appropriate historic and forecast parameters for use in the model. This work encompassed all sectors of the economy and included research and subsequent revisions of:

- Control shares for abatement controls;
- Emission factors of abatement controls;
- Cost data for abatement controls;

- Restrictions over abatement controls;
- Pollutant contents of fuels;
- Distribution and aggregation of scenario activity data (e.g. energy).

Details of this work are captured in various IMPI outputs (e.g. IMP Team, 2008d, 2010a, 2010l) which recorded progress and supported expert interactions nationally and internationally. The three main categories of calibration-related output were the 'Harmonisation' report series, the 'Sectoral Focus' report work, and the 'Emission Comparison' briefs. Examples and a short summary of each of these three categories of output are presented in Figs 2.3–2.5.

2.1.2.1 Harmonisation Report Series I, II, III

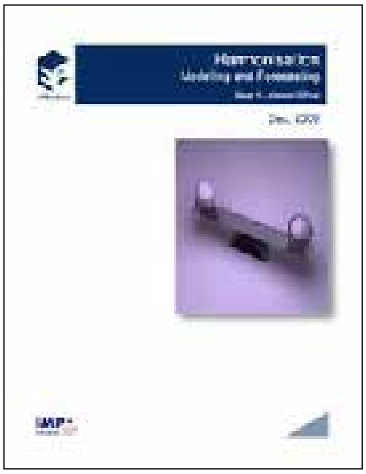


Figure 2.3. Example of Harmonisation report series.

The Harmonisation series (IMP Team, 2009f, 2008f, 2008g) was the initial set of documents that built towards a more appropriate representation of Ireland in the modelling system (see Fig. 2.3). These documents formed the basis of the initial bilateral discussions between the IMPI team and experts in the Environmental Protection Agency (EPA). Through a process of iterative revision and discussion, the IMPI team developed an improved understanding of how national data and methodologies related to the GAINS Ireland modelling structure and thereby iteratively 'harmonised' the systems as appropriate. In certain cases, distinctions were noted, and understood, and the two systems remain varied in their approach. Such outcomes were appropriate where constraints with perhaps the granularity of data or methodological structures restricted reconciliation.

Nonetheless, the guiding principle in such cases was to ensure variations were acknowledged and understood. Whilst further progress on harmonisation is required, these reports set the foundations of an agreement between national and model methodologies and data.

2.1.2.2 Sectoral Focus Reports (e.g. Transport)

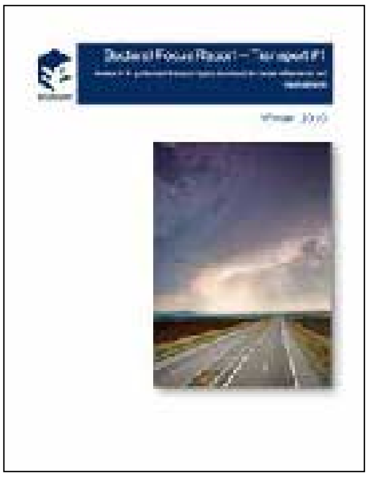


Figure 2.4. Example of Transport brief.

The Sectoral Focus report series departed from the broader nature of the Harmonisation series to a format where five individual topics of relevance to model calibration were described and investigated in greater detail. The chosen topics focused initially on questions of particular significance to model outcomes and were under specific sectors. In the example report (IMP Team, 2011c) shown in Fig. 2.4, transport was the focus, with specific assessments of vehicle kilometres and tyre wear, agricultural machinery controls, the impact of transport taxation on model parameters, issues with the euro standards and expectation of electric vehicle penetration. The format will be continued under further research to continue to develop an increasingly refined modelling system that reflects all available and relevant evidence for each sector in Ireland adequately.

2.1.2.3 Emission Comparison Briefs (e.g. Greenhouse Gases)

Figure 2.5. Example of Emission comparison brief.

The Emission Comparison briefs (Fig. 2.5) were delivered for a given year in respect of both GHGs (IMP Team, 2009g) and transboundary air pollutants (IMP Team, 2010k). The purpose of these briefs was to illustrate – for a given scenario – the outcomes of the GAINS Ireland model relative to the outcomes of the official national forecasts where common (though

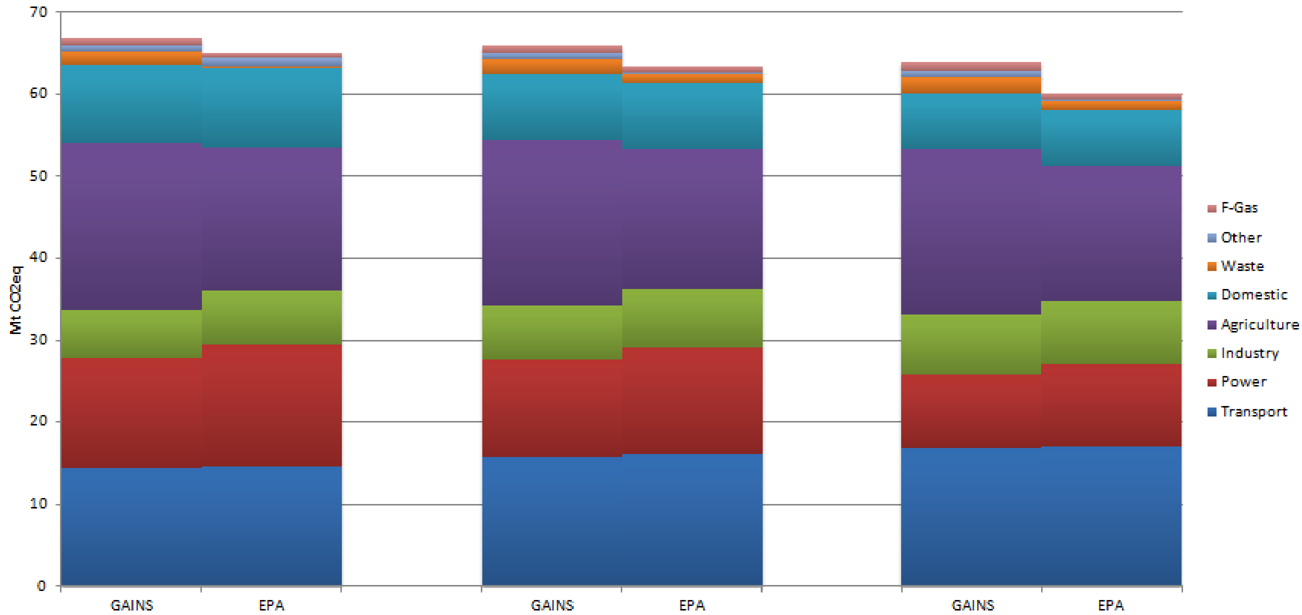


Figure 2.6. Example of CO_2eq emissions forecasts 2010, 2015, 2020: GAINS vs EPA with additional measures (WAM) scenario.

Figure 2.7. (a) Control Strategy guide (b) Agriculture guide (c) Energy guide (d) Cost guide.

adjusted) scenario data was engaged. These briefs allowed a quantified illustration of how the international modelling framework of GAINS compared with national approaches. The briefs delivered a basis for further revision and refinements, as well as an alternative set of emission forecasts. Figure 2.6 illustrates an aggregate CO_2e sectoral comparison from a 2009 scenario. The principal variations illustrated (i.e. agriculture) were subsequently investigated and understood in cooperation with the relevant department.

2.1.3 Accessibility

GAINS is an expansive and complex modelling system. Whilst it is not practical to describe the full level of detail across the system in this report, the IMPI team focused on improving the accessibility to model outcomes (e.g. IMP Team, 2010c, 2009c) and general understanding of the model (e.g. IMP Team, 2008b) so that stakeholders would be in a better position to evaluate inputs, contribute data and understand model processes and outcomes. These efforts were necessary to ensure that stakeholders understood what evidence was required in the modelling framework, what significance parameters held in regard to final outputs, and how best to use and interpret the model outcomes as produced by the IMPI team and the international teams. Guidance documents were the central pillars of this accessibility initiative. Specifically, four major documents (IMP Team, 2010d, 2010f, 2009d, 2008e), building on an earlier model overview report by Kelly (2006), were produced in relation to the GAINS Ireland modelling system. These were detailed guides in respect of:

- **Controls:** A guide to the role and representation of abatement controls in the modelling system (Fig. 2.7a).
- **Agriculture:** The structure and handling of agricultural data in the modelling system (Fig. 2.7b);
- **Energy:** The structure and handling of energy data in the modelling system (Fig. 2.7c);
- **Cost:** A detailed explanation of the methodological approach to abatement cost (Fig. 2.7d);

Beyond the guidance documents, the outputs from the model were further managed into various reporting formats to facilitate access to the results of model runs (Fig. 2.8a–d). Whilst various presentation structures were tested, ultimately these settled on a choice of two formats. These were an extensive full-scenario report capturing every angle of the model analysis for a given scenario (250 pages), and an Executive Summary report format which distilled findings into a more concise format of approximately 20 pages. This is the favoured default format (see sample extract in Fig. 2.9). A number of briefs examining specific sectors or pollutants were also produced on request.

2.2 TREMOVE Ireland

The TREMOVE model is a multi-modal transport policy model designed to evaluate the impact of defined policies or packages of policies on the Irish transport sector. Specifically, the model has been used to evaluate transport pricing and taxation policies, transport technology options and relative improvements in levels of service. An overview of the model, model development and selected analysis with the system is presented in this section.[7]

7 A comprehensive final report focused specifically on TREMOVE Ireland has also been provided as part of the project deliverables.

Figure 2.8. (a) Full Scenario report; (b) Executive Summary report; (c) Transboundary Emissions Comparison report; (d) Greenhouse Gas Emissions Comparison report.

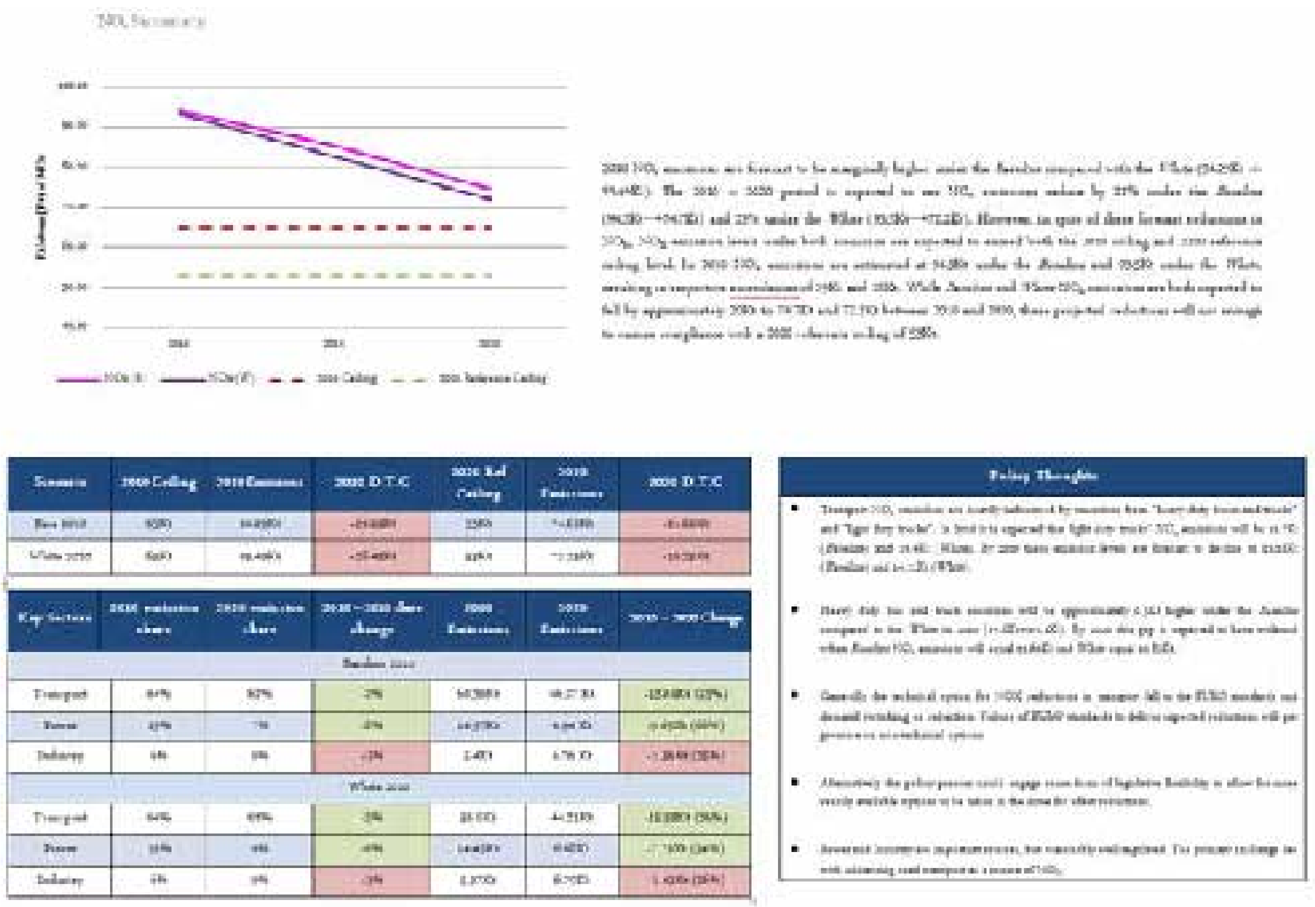


Figure 2.9. A sample summary 'dashboard' for a given pollutant in the Executive Summary report.

2.2.1 Structure

The road transport sector remains a highly significant source of NO_x and CO_2 emissions. These two pollutants are particularly relevant in the context of current international environmental obligations. NO_x emissions present a challenge in regard to national emission ceilings and CO_2 emissions contribute significantly to national GHG emissions. Their policy relevance therefore creates a pressing need for further research on emissions abatement options from the road transport sector. Though the GAINS model incorporates transport and associated technical options into its analyses, the TREMOVE Ireland model serves as a valuable complement and offers the potential for a more detailed analysis of the transport sector, accounting for the emissions, costs and welfare impacts associated with a range of technical and non-technical policy interventions.

If used effectively, TREMOVE has the ability to model and manipulate changes in transport demand, vehicle stock, fuel consumption, emissions, and welfare. It has the capacity to model the effect of fiscal policies such as the introduction or change of a transport tax (i.e. vehicle registration tax [VRT], annual motor tax [AMT]/vehicle ownership tax, fuel value added tax [VAT], fuel excise tax), or to consider the effects of new vehicle technologies and emission standards on vehicle purchase decisions and emissions. The model can thereby offer considerable value to the management and assessment of transport policy in Ireland. As part of the IMP Ireland project, the strategy was to develop TREMOVE for use in conjunction with the GAINS model, so that the model capacities could be integrated to provide improved policy analysis for the transport sector. Similarly, the TREMOVE system can also play a key role in any future plans for a national transport model framework initiative in Ireland.

The TREMOVE Ireland model is developed from the code of the core TREMOVE model presented in Fig. 2.10. While the core modules have remained consistent, the input data and associated functions (centre and right columns) have generally been reviewed, adjusted and reprogrammed as necessary under the TREMOVE Ireland research.

2.2.2 Development

The TREMOVE model underwent extensive development and reprogramming as part of the IMPI research project. These efforts were necessary to adequately adapt the model to the research evidence available and emerging in Ireland, to overcome prior constraints in the system, and to reflect the perspectives of the IMPI modelling team in regard to interpretation of the appropriate transport economics methodologies to be incorporated into the model code. Four principal areas of the model were redeveloped. This required a major restructuring of the model system, and a considerable degree of *ex ante* and *ex post* model processing evaluations to ensure the system still functioned as otherwise intended. These four areas of redevelopment were (i) demand module, (ii) welfare module, (iii) transport costs, and (iv) base year.

2.2.2.1 Demand Module

The IMPI team integrated a toggle into the model set-up menu to allow agents in the model to perceive either all transport costs or only immediate costs associated

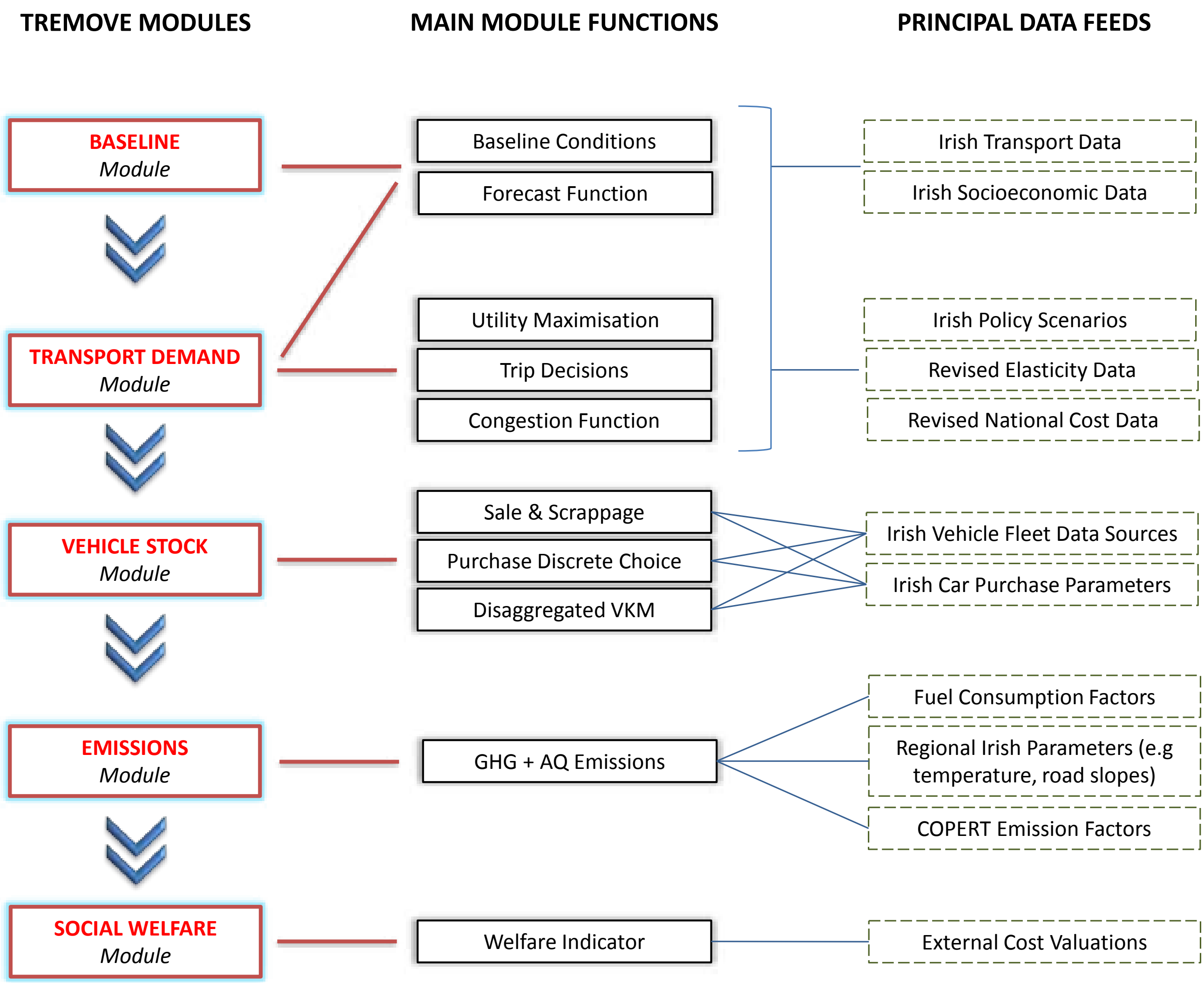


Figure 2.10. TREMOVE Ireland schema.

with a trip. The latter is the favoured approach by the IMPI team for most policy questions as it is believed to be more representative of actual transport trip decision-making. This toggle offers a valuable enhancement over the original system.

2.2.2.2 Welfare Module

The welfare module of the model is connected to calculations in regard to changes in taxation revenue. The IMPI team modified the approach of the model to the use of revenue from taxation in respect of estimated welfare as related research indicated a more appropriate approach.

2.2.2.3 Transport Costs

Costs are an important aspect of the model and influence decisions and choices of agents in the model. The IMPI team have modified the model approach to handling the cost of time in response to IMPI research on the appropriate values to use for analyses.

2.2.2.4 Base Year

The base year in the model was previously a single year from which the model would then project basecase demand, emissions, stock and welfare. A substantial change to the model was to recode the model to enable a move from this single base year approach to a time series approach (e.g. using a 15-year spread as opposed to a single base year). This important revision allowed the IMPI team to integrate historical records of demand, stock and emissions into the model, thereby incorporating a ‘15-year’ baseline in the model as opposed to an individual year.

In each case the model needed to be carefully re-evaluated and tested subsequent to each change to ensure the system was functioning correctly. This required an iterative assessment of extensive modelling procedure calls before and after the changes, and the contrasting of outcomes with manually estimated results.

2.2.3 Calibration

Calibration of the TREMOVE model drew upon a host of national and international evidence, as well as project-developed data resources. A summary list of data sources where evidence has now been incorporated in the TREMOVE Ireland system include:

- National Car Test (NCT) data obtained and analysed by the IMP team;
- Review of car-sales websites in Ireland for price data;
- Review of annual reports of transport and haulage companies;
- Review of Economic and Social Research Institute (ESRI) economic forecasting;
- Tax legislation documentation;
- Data sourced via *Eurostat*;
- Data obtained from the Irish Revenue Office;
- Data sourced and requested from the Central Statistics Office (CSO);
- Data obtained from the Sustainable Energy Authority Ireland (SEAI);
- Data obtained from Vehicle Certification Authority (VCA) UK;
- The academic literature.

Figure 2.11. (a) TREMOVE overview (b) Vehicle registration (VRT) and annual motor tax (AMT) analysis (c) TREMOVE final report.

2.2.4 Accessibility

As with GAINS Ireland, accessibility and understanding of results is important to ensure value from the modelling work is carried into policy arenas. Two iterative overview guides in respect of the TREMOVE Ireland model (IMP Team, 2008h, 2011d) were produced and disseminated under the IMPI project, as well as a comprehensive final model report (Fig. 2.11a–c). Furthermore, TREMOVE Ireland work generated a selection of policy-focused papers in response to Department of Transport-specified research priorities (Fu, Ahern and Kelly, 2011; Fu, Kelly, Clinch and King, 2011; Fu and Kelly, 2011), as well as submitting a taxation policy brief to the Department of Finance (IMP Team, 2011b).

On an international scale, the IMPI project provided technical and troubleshooting support to the development of a generic user interface (GUI) for TREMOVE for the European Commission in cooperation with the modelling team behind the Calculation of Emissions from Road Transport (COPERT) system. Furthermore, as part of the European Consortium for Modelling of Air Pollution and Climate Strategies (EC4MACS) project[8], the IMPI team provided an international review of the model to the EC4MACS partners, and similarly to members of the Network for Integrated Assessment Modelling (NIAM).

8 See www.ec4macs.eu for more on this project.

3 Selected Applications of Integrated Modelling Project Ireland Research

This section presents *selected applications* of the IMPI work to policy and research progress in terms of (i) national policy support, (ii) international policy development and (iii) newly developed capacities derived from the research project.[9]

3.1 Integrated Modelling Project Ireland Research – National Policy Support

The national policy support examples presented here have focused on providing technical and analytical support in respect of Ireland's international environmental commitments and challenges, considering negotiation positions in regard to compliance, and evaluating individual options and integrated pathways towards the requisite level of emission reductions. These policy contributions offer value, as both non-compliance and poor strategic decisions will create costs for Ireland.

3.1.1 National Emission Ceilings – NO_x Ceiling

The IMPI project provided an extensive body of formal research and analysis, as well as informal briefs and memos in regard to Ireland's obligations under the European National Emissions Ceiling Directive 2001/81/EC, and the related UNECE Gothenburg Protocol. This work goes beyond analysis of emissions trends to a detailed investigation of the *reasons* for given trends in emissions – answering questions such as: Why are emissions so different from what was originally projected? Which policies and measures have succeeded and which have failed? What are the drivers of the emissions and where should efforts to deliver further progress be focused? These questions are important as any failure to comply with Irish European air pollution obligations may result in significant fines.[10] As matters stand, NO_X presents the greatest risk of non-compliance for Ireland.

In this context, the project investigated and identified the factors underpinning the NO_X ceiling challenge, in the process quantifying the impact of international policy issues on the apparent lack of national progress towards compliance. Specifically, a major portion of the remaining gap to target is directly attributable to a failure of certain vehicle 'Euro Standards' to deliver on their expected level of NO_X abatement. The pollutant-removal efficiencies for these European measures have been adjusted a number of times over the years, and the quantified impact for Ireland on emissions from the affected portion of the fleet under the changing efficiencies are presented in Table 3.1. An academic paper (Kelly et al., 2010) and numerous related briefs and reports (IMP Team, 2008a, 2009h, 2010j) were produced relating to this topic. The outcomes have supported compliance negotiations and provided decision support in respect of understanding the issues and identifying alternative options where appropriate.

9 In most cases related briefs and reports are available via www.impireland.ie or www.policymeasures.com

10 The cost of non-compliance is dependent on the judicial interpretation of the seriousness of the breach, and the duration for which the infringement persists. Fine calculation parameters include nationally specific function values. There are two types of fine – a lump sum fine, and a periodic/daily fine. There is precedent for issuing a lump sum fine in parallel with a daily fine, and in future the Commission has indicated it will favour the imposition of both. Analysis of the updated parameters for application of Article 228 of the EC Treaty suggests that non-compliance with the NEC Directive 2001/81/EC could result in a lump sum fine of between €1.5 and €4.3m for a one-year infringement. The daily fine cost is again dependent on the seriousness and scale of the breach, and would increase over time as non-compliance persists. This daily cost would amount to an annual average of at least €1m up to a potential maximum cost of €40m per annum. A particular issue with reacting to the fines is the ability to 'quickly' bring emissions into compliance. In practice this is a longer-term process and thus non-compliance could persist for a long period of time, with significant fines in addition to the costs necessary to deliver the required emissions abatement.

Table 3.1. Quantified impact on NO_X of revisions to removal efficiencies in the GAINS model methodology, kilotonnes (kt).

Vehicle category	Based on 2009 Energy Data provided by the Environmental Protection Agency		
	Model Removal efficiencies (kt), 1998	2006 Model removal efficiencies (NO_x emissions Kt)	2010 Model removal efficiencies (NO_x emissions kt)
Cars (diesel)	2.7	6.5	8.5
Heavy-duty trucks (diesel)	4.1	6.3	6.2
Light-duty trucks (diesel)	6.9	17.4	12.4
Buses (diesel)	2.7	4.1	4.8
Total emissions estimate	16.4	34.2	31.9

Furthermore, the analysis has been a valuable exemplar in successfully pressing for the inclusion of flexible mechanisms (see Section 3.2.2) in the transboundary policy framework.

3.1.2 Transport Taxation

Transport is a large multi-agent source of both transboundary and GHG emissions. Ireland's capacity to control and ultimately reduce emissions from this sector is therefore important in the context of regulating national emissions for international agreements. Utilising the TREMOVE Ireland model and exogenous desk-research analysis, the IMP project has conducted an independent and combined evaluation of the projected impact of three recently introduced transport tax measures in Ireland. Specifically, these are the changes in VRT, AMT and the carbon tax. The results of this analysis were compiled into an academic paper currently in the review process with an international transport journal. The findings in Table 3.2 present the relative impact on CO_2 emissions and energy consumption between the basecase and the simulations. Thus, the proportional reductions are between the emissions level as forecast under the basecase relative to the evaluated policy simulation. The policy simulations included three combinations of the interventions. These were the €15 carbon tax alone, the VRT and AMT changes as a pair, and all three policies together. The impacts in each case included three sensitivity analyses as follows:

Table 3.2. CO_2 emission and energy consumption reductions between simulation and basecase.

Scenario		Carbon tax only			VRT and AMT			VRT, AMT and carbon tax		
		All costs (%)	Imm. costs (%)	High EOS (%)	All costs (%)	Imm. costs (%)	High EOS (%)	All costs (%)	Imm. costs (%)	High EOS (%)
CO_2	2015	-1.79	-3.46	-3.79	-0.01	-0.45	-0.44	-1.78	-3.87	-4.18
	2020	-1.80	-3.53	-3.86	0.06	-0.65	-0.62	-1.70	-4.12	-4.42
	2030	-1.75	-3.50	-3.82	0.06	-0.89	-0.86	-1.62	-4.29	-4.58
Egy	2015	-1.81	-3.47	-3.79	-0.06	-0.51	-0.49	-1.85	-3.93	-4.24
	2020	-1.84	-3.56	-3.89	-0.02	-0.73	-0.71	-1.81	-4.22	-4.52
	2030	-1.79	-3.55	-3.86	-0.05	-0.99	-0.97	-1.77	-4.44	-4.72

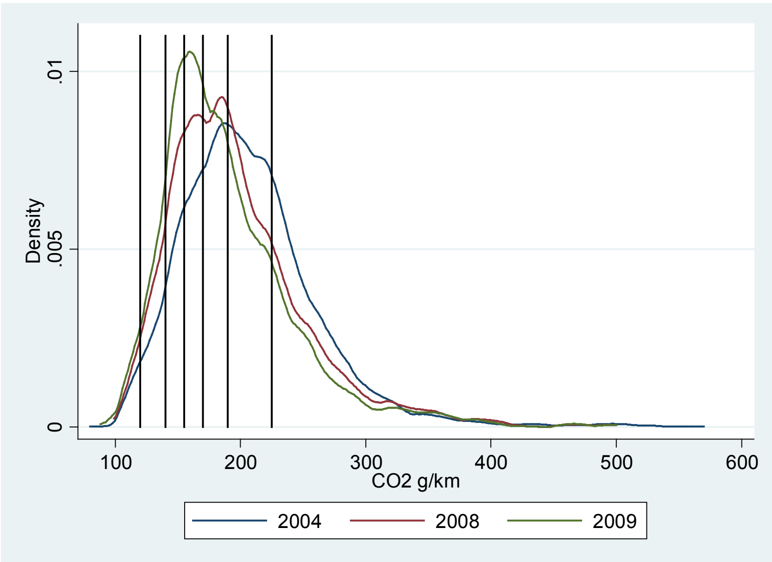
VRT=vehicle registration tax; AMT= annual motor tax; Egy = energy; EOS = elasticity of substitution; Imm. = immediate.

- All costs: Where individuals consider all transport-related costs in their trip decision processes;
- Imm. (Immediate) costs: Where individuals decide trips on the basis of immediate (e.g. fuel, time) costs only;
- High elasticity of substitution (EOS): Where the relative attraction of alternative public transport modes was improved.

The findings highlight a synergy between the policies but indicate that carbon tax is by far the most effective intervention in this analysis. The complete analysis is presented in the submitted paper by Fu and Kelly (2011).

In a related piece of work, the IMP team responded to an invitation from the Department of Finance to submit recommendations in respect of potential revisions to the VRT and road tax system. The report identified the expected progression of the national vehicle fleet under the current conditions and suggested revisions to the distribution of the tax bands to take account of a shift in the distribution of vehicle emission performance (see Fig. 3.1). The submission considered the expected evolution of the fleet under the carbon tax alone, and identified the imbalance in the incentive created by a CO_2-only focus that ignores the higher external costs associated with NO_x emissions (and indeed particulates) that would arise from having more diesel vehicles on the road.

In regard to AMT, the report proposed that owners of diesel cars would pay for the additional external costs of NO_X from their vehicles, calculated as the external costs of diesel car NO_X emissions less the corresponding external costs of petrol cars. Results are presented in Table 3.3. The revised and recommended VRT rates and AMT are given in Table 3.4. This new taxation system would target the internalisation of the additional external costs of NO_X emissions by diesel cars. It is important to be clear that this does not internalise all of the NO_X costs, nor any of the particulate costs (though this could be evaluated). Instead, this approach would contribute towards correcting the imbalance in the incentive which will steer fleet development onto a path that will yield relatively higher NO_X and PM emissions into the future. Further details are provided in the submitted report, *VRT and Motor Tax – Reform Submission* (IMP Team, 2011b).



Source: Based upon VCA data 2004, 2008 and 2009. Split lines are the current tax bands in Ireland.

Figure 3.1. Distribution of new cars in the international market with regards to CO_2 emission factors.

Table 3.3. Differences between the annual external costs of NO_x emission of diesel and petrol cars.

Bands	A	B	C	D	E	F	G	H	I	J
Petrol NO_x g/km	N/A	0.0168	0.0200	0.0220	0.0281	0.0279	0.0280	0.0242	0.0250	0.0293
Diesel NO_x g/km	0.224	0.1950	0.1820	0.1838	0.1837	0.1933	0.1990	0.2451	0.2896	0.3150
Annual external costs, petrol (€)	N/A	1.45	1.86	2.10	2.71	3.46	3.66	3.15	3.13	3.67
Annual external costs, diesel (€)	38.76	33.74	28.28	28.75	28.93	33.66	36.82	39.10	47.70	51.88
Diesel-minus petrol (€)	37.31	32.29	26.42	26.67	26.22	30.20	33.16	35.95	44.57	48.22

Table 3.4. Vehicle registration tax (VRT) rates and annual motor tax (AMT) suggested for new bands.

Band	A	B	C	D	E	F	G	H	I	J
CO_2	<=95	96–120	121–135	136–145	146–155	156–170	171–190	191–225	226–255	>255
Current VRT rates	14%	14%	16%	16%–20%	20%	24%	28%	32%	36%	36%
VRT rates suggested	0%	14%	16%	18%	20%	24%	28%	32%	36%	38%
Current AMT (€)	104	104	156	156–302	302	447	630	1050	2100	2100
AMT suggested Petrol & other (€)	69	104	156	229	302	447	630	1050	2100	2200
AMT suggested Diesel (€)	106	136	182	256	328	477	663	1086	2145	2248

3.1.3 *Flexible Working Policy Proposals*

In this piece of research the team considered the potential for individuals to work from home one or more days a week, and the associated impact this might have on energy savings and associated emissions. The research considered *inter alia* the nature and location of employment, family make-up, availability of commuting services, the role of broadband, 'cloud computing' and a number of other factors in its assessment of potential. The methodology employed POWCAR data, information from TREMOVE Ireland, and related geographical information system (GIS) mapping work.

The analysis indicated that on average at least 9.33Kwh net per day can be saved where an individual converts to work from home as opposed to travelling to the office. This research identified the priority categories of worker that should be encouraged to at least partially work from home, and indicated other conditions that would support a successful implementation of a supporting policy with the objective of increasing the level of working from home. A paper detailing the methodology and results (Fu, Kelly, Clinch and King, 2011) has been submitted to an internationally peer-reviewed journal.

3.1.4 *Organisation for Economic and Co-operative Development Environmental Performance Review*

At the request of the Department of Environment, Housing and Local Government (DoEHLG), the IMP project provided a presentation and material input to the international Organisation for Economic and Co-operative Development (OECD) team that visited Ireland to conduct an updated Environmental Performance Review in November 2008. This visit fed into the *Environmental Performance Reviews: Ireland 2010* book (OECD, 2010).

3.1.5 *Non-Emissions Trading Sector Greenhouse Gas Target*

The NETS target that Ireland faces in 2020, with interim targets from 2013, poses a significant challenge to national policy-makers. The range of non-compliance costs for the non-traded sector targets, based on the most recent national forecast of emissions from the EPA, is estimated to lie between €90m and €600m for the period from 2013 to 2020. The GAINS Ireland model mirrors the system used to inform the setting of aspects of the non-traded sector target in Europe, and thereby offers a particularly valuable system with which to evaluate pathways towards compliance or with which to provide revised strategies where interim targets are missed.

The IMP project undertook a significant calibration of the 'full' GAINS Ireland model to establish a methodological platform from which to evaluate this challenge and the potential pathways to compliance. The calibration work and results were described in a comprehensive report submitted to the EPA at the close of the project *N-ETS 2020 Ireland's non-traded sector target* (IMP Team, 2011a) and a related paper (Redmond et al., 2011) has been composed that is to be submitted to an international journal.

Conclusions identified a persistent gap to target for the 'with measures' baseline scenario in 2020 under both the least-cost optimisation where the market price of carbon is capped at €50 per tonne, and the maximum-feasible reductions optimisation where all available and eligible measures in the model as setup are applied to achieve reductions beyond the baseline emission level. In the former, the target in 2020 is missed by 4.8Mt CO_{2e}, whereas in the latter the gap to close remains at 3Mt CO_{2e}. The interim targets from 2013 pose a further challenge. On a more positive note, the 'menu' of abatement options defined in the modelling system is reviewed in the research, and further options are noted for future consideration that may help bridge the gap. Consideration is also given to the role of LULUCF, the net social costs of actions, and the impact of the package of policies and measures in terms of the traded sector's emissions.

3.1.6 National Submissions and Sustained Scenario Research

Over the course of the project lifetime there have been a number of requests for information and validation by the European modelling team at IIASA in respect of national calibration of the GAINS Europe model. These requests came in respect of the various policy agendas such as the Gothenburg Protocol Review, National Emissions Ceiling Directive-related work, and the calibration of the model in regard to a potential 'step-up' in the non-ETS GHG ambitions within Europe.

In each case the team were required to collate a national submission, adapt it for the GAINS model system, test the outcomes and obtain official sign-off for the final submission. Furthermore, the team also attended bilateral meetings with the Commission, conducted reviews of third-party scenarios and submitted comments in respect of their being fit for purpose or otherwise (e.g. in relation to PRIMES/CAPRI-based scenarios). Each submission and validation was accompanied by a cover letter and details of the methodological approach taken.

3.1.7 Climate Market Analysis

On a broader level than the NETS work, the IMP team have delivered a number of climate market and climate policy-related analysis pieces. This work includes:

- A pair of annual reports (IMP Team, 2010b, 2009a) related to climate and air policy evolution on a European and global scale;
- A review of international marginal abatement cost curves for GHGs (IMP Team, 2009e) in advance of the SEAI/McKinsey report (2009) for Ireland;
- Briefs relating to the history of the ETS (IMP Team, 2009g) and the theory of pollution control (IMP Team, 2008c);
- Briefs relating to the GHG capacities of GAINS (IMP Team, 2008b) and the functions of the Annex 1 calculator (IMP Team, 2010e).

Furthermore, two papers (Redmond 2010a, 2010b) related to climate market developments are currently in submission with international peer-reviewed journals.

3.2 Integrated Modelling Project Ireland Research – International Policy Development

The IMPI research project is formally engaged in a number of key international forums. These include the Task Force on Integrated Assessment Modelling (TFIAM), NIAM, the Expert group on Techno-economic Issues (EGTEI) and the Network of Experts on Benefits and Economic Instruments (NEBEI). Further to these regular engagements the IMPI project has participated in the meetings of the EC4MACS project, TFEIP, the Working Group on Strategies and Review (WGSR) and has made direct submissions to the European Commission as well as national presidency representatives (e.g. Spain, Sweden) in regard to international policy. In addition to active participation and presentation at meetings of these groups, below a selection of examples where IMPI has contributed directly to shaping international policy development are identified.

3.2.1 *Lessons from the Gothenburg Protocol*

The Gothenburg Protocol set national emission ceilings for transboundary air pollutants in 2010. These ceilings were formulated in 1999 using the RAINS model and national forecast data. The process shared much common ground with work to underpin the binding European National Emissions Ceiling Directive 2001/81EC. The 2010 ceiling compliance checks are imminent, as are the revision and review processes which are expected to lead to the setting of emission ceilings for 2020 and beyond.

The IMPI team have been heavily involved in this field of work internationally. One example of this work was the leading of an internationally published journal paper (Kelly et al., 2010) considering 'lessons' from the Gothenburg Protocol. The piece was authored in collaboration with five international colleagues (Italy, Netherlands, Portugal, Spain, and Sweden). The work considered the original 1999 projections of each of the six countries that were used within the RAINS model to inform the setting of their respective Gothenburg Protocol 2010 emission ceilings. The policy lessons were identified through a quantitative *ex ante* and *ex post* assessment of data, national experts and relevant unexpected outcomes. These lessons included:

- Acknowledgment and quantification of a prior underestimation of activity growth levels and a recommendation to ensure a consistent approach to growth forecasting across all parties for the future (e.g. coherent approaches to growth projections – use of optimistic or conservative forecasts);
- Acknowledgment of a prior overestimation of the effectiveness of abatement measures, with specific quantification of the euro standard issue (Section 3.1.1) for each case country;
- A recommendation to include, in certain cases, indicators-based comparisons as a support to negotiations where new ceilings are proposed, for example, per capita or per gross domestic product (GDP) assessments of expected emission performance;
- A recommendation for the national and international research communities to advance the scope of the modelling frameworks to include the cost and potential of measures that are modelled or estimated exogenously from core systems such as RAINS/GAINS;
- Recommendations to more rigorously consider the role of flexible policy mechanisms or correction mechanisms in the transboundary policy process (Section 3.2.2).

3.2.2 *Flexible Policy Mechanisms*

The IMPI team have significantly advanced the international research agenda in regard to flexible compliance mechanisms for transboundary air pollution policy. This work has involved qualitative reporting on a selection of a variety of such 'Flexmex' concepts, including many newly developed options from the IMPI team in 2009. The work subsequently quantified the relevance and role of selected measures through an examination of the data on emissions projections and associated impacts. This used desk research and the developed modelling capacities to support the analysis of how domestic and international Flexmex may work in practice and at what benefit to the process. The specific 'short-listed' flexibilities from the work were collated in a policy brief for the European Commission and Spanish presidency in 2010 (Kelly and Vollebergh, 2010), and are discussed in a forthcoming paper (Kelly and Vollebergh, 2011). Furthermore, the IMP project has recently made a significant contribution to the development of an official report on flexibilities as a member of the 'Ad hoc group on Flexibility Mechanisms'. The report published by the TFEIP (TFEIP ad hoc group, 2011) is available at the www.policymeasures.com site and builds on many of the recommendations and suggested mechanisms put forward under earlier IMP project work on this topic in 2009 and 2010.

The motivation for inclusion of flexibility in regard to compliance is to account for the uncertain and the unknown. There is no methodology or model that can guarantee accuracy and precision in regard to historical, current or forecast emissions. The transboundary air pollution policy process is dealing with complex systems on an appropriately aggregate scale, and absolute certainty cannot be reasonably expected. The approach is to build common methodological frameworks which provide a pivotal point from which negotiations and decisions can be made, and a process by which progress can be measured. There are five principal reasons why flexibility and correction mechanisms are necessary in this form of environmental regulation:

1 Scenarios are illustrative. They are not predictions. Related to this, modelled sensitivities do not actually incorporate any flexibility into the process. Thus, neither of these aspects of the ceiling setting process addresses the potential for unforeseen events to influence the expected outcomes. Contemporary evidence highlights the potential for the unexpected across a range of issues – for example, economic crisis, ash clouds, further euro standard issues and so forth;

2 To proceed without flexibility is to place undue confidence in long-range forecasting and assumptions. This approach may limit support and restrict new participants. Specifically, this may dissuade engagement from developing economies where – in the case of the Gothenburg Protocol – ratifications could offer significant and cost-effective benefits to the wider community;

3 Related to this point, recently joined EU member states, and bordering countries, including Eastern Europe, Caucasus and Central Asia countries (EECCA), which are relevant to the transboundary pollution problem may lack the capacity and expertise for the technical engagement in setting new ceilings (indeed, many established countries still face this challenge). This highlights the importance of national capacities, but also indicates a potential source of additional uncertainty for the future;

4 Technical solutions alone may not offer sufficient scope for future abatement plans to achieve defined targets. Thus abatement strategies may increasingly turn toward the use of 'non-technical' or behavioural measures. Such measures will introduce an added degree of uncertainty, such as temporal and spatial variability of measure effects.

5 Environmental policy should be governed by principals of cost effectiveness. Actions have opportunity costs and broader policy should seek effective and rational allocations of resources. Where the future differs from the modelled projections, the burden of cost may rise, and the benefit may fall. Flexibility and correction mechanisms can provide a means of appropriate response.

3.2.3 Uncertainty Presentation

National outlooks of emission levels are important components of international environmental policy-making and associated national policy development. This is the case for both GHG emissions and transboundary air pollutants. However, there is inherent uncertainty in the production of forecasts. In the climate context, the Intergovernmental Panel on Climate Change (IPCC) guidelines have been established to support national teams in quantifying uncertainty within national inventory reporting of historic emissions. These are presented to indicate the potential range of deviation from reported values and to offer added evidence for policy decisions. However, the method and practice of accounting for uncertainty amongst emission *forecasts* is both less clear and less common. In this particular work, the IMPI team posited that the role of forecasts in setting international targets and planning policy action renders the management of 'forecast' uncertainty as important as addressing uncertainty in the context of inventory and compliance work (Section 3.2.2).

A failure to explicitly present uncertainty in forecasting leads to an implicit and misplaced confidence in a given future scenario – irrespective of parallel work on other scenarios and sensitivities. As a result, it is necessary to ensure that uncertainty is captured when presenting forecasts to decision-makers. A related issue is that

Box 3.1. Uncertainty presentation and propagation of variance (POV) based on controls and activity.

It is necessary to formally display how emissions are calculated. Eq. 3.1 is:

$$\mathrm{em}_{x,i} = \sum_j \mathrm{act}_{x,i,j} \sum_k \mathrm{AEF}_{x,i,j,k}\, \mathrm{cap}_{x,i,j,k} \quad \text{(Eq. 1)}$$

Where: 'act' refers to activity, 'AEF' is the abated emission factor, and 'cap' is capacities controlled. Furthermore, this equation applies to pollutant x, in country i, for sector j, and for control technology k (where applicable). In Eq. 3.2, AEFs are obtained by applying the removal efficiency to the original (unabated) emission factor (EF), i.e.:

$$\mathrm{AEF}_{x,i,j,k} = \mathrm{EF}_{x,i,j}\,(1\text{-reff}_{x,i,j,k}) \quad \text{(Eq. 3.2)}$$

Where: 'reff' refers to the removal efficiency. The POV method (from Schöpp et al., 2005) is described as: first a deterministic model term *A* is considered (i.e. either a model variable or parameter). Uncertainty for this term is represented by an uncertainty factor *x*, with the expected value of 1 and the standard deviation of σ_x, so the uncertain term is defined as A_x. Thus, as Eq. 3.3 shows, the coefficient of variation (CV) of the uncertain term A_x is σ_x:

$$\mathrm{CV}_{A_x} = \frac{\sigma_{A_x}}{A} = \frac{A\sigma_x}{A} = \sigma_x \quad \text{(Eq. 3.3)}$$

In order to redefine the model to include uncertain terms it is necessary to return to Eq. 3.1 and include in Eq. 3.4 the uncertainty factors associated with 'act' and 'cap' (i.e. α and ε, respectively) as follows:

$$e\tilde{m}_{x,i} = \sum_j \mathrm{act}_{x,i,j} \sum_k \mathrm{AEF}_{x,i,j,k}\,\mathrm{cap}_{x,i,j,k} \quad \text{(Eq. 3.4)}$$

There is no correlation assumed between these two uncertainty factors since the causes of uncertainty from activity data and capacities controlled arise from different sources. Uncertainty from activity levels results from inaccuracies in the measurement of consumed fuels, errors and biases in regard to the heat content of fuels, while uncertainties from capacities controlled result from inaccurate assumptions and incorrect estimations of penetration rates. As such, the expected emissions em¯_(x,i) emerge from Eq. 3.4 as Eq. 3.5:

$$e\tilde{m}_{x,i} = \sum_j \mathrm{act}_{x,i,j}\,\alpha_{x,i,j} \sum_k \mathrm{AEF}_{x,i,j,k}\,\mathrm{cap}_{x,i,j,k}\varepsilon_{x,i,j,k} \quad \text{(Eq. 3.5)}$$

It can also be assumed that the penetration rates for abatement technologies for different pollutants, regions, sectors and control technologies are independent, as penetration rates are mostly regulated and the estimated errors of these rates can be considered as random terms following the independent distribution. However, activity data (i.e., energy consumption) for different pollutants, regions and sectors are probably correlated because they are economically or technologically linked. Activity data are common input for the calculation of emissions, so it is likely that covariances exist between emission estimates for different regions and pollutants covered by the model. This covariance equation in Eq. 3.6 is given by:

$$\mathrm{Cov}\left[e\tilde{m}_{x,i}, e\tilde{m}_{y,p}\right] = \sum_j \sum_q \left(\mathrm{act}_{x,i,j}\mathrm{act}_{y,p,q}E\left[\alpha_{x,i,j}\alpha_{y,p,q}\right]\right) \sum_k \sum_m \left(\mathrm{AEF}_{x,i,j,k}\mathrm{AEF}_{y,p,q,m}\mathrm{cap}_{x,i,j,k}\mathrm{cap}_{y,p,q,m}E\left[\varepsilon_{x,i,j,k}\varepsilon_{y,p,q,m}\right]\right) - \bar{\mathrm{em}}_{x,i}\bar{\mathrm{em}}_{y,p} \quad \text{(Eq. 3.6)}$$

Where: $E[\varepsilon_{x,i,j,k}\, \varepsilon_{y,p,q,m}] = 1$ *if* $x \neq y$, $i \neq p$, $j \neq q$, *or* $k \neq m$

Based on Eq. 3.6, the estimate for the standard deviation of Eq. 3.7 as;

$$\sigma_{e\tilde{m}_{x,i}} = \sqrt{\mathrm{Cov}\left[e\tilde{m}_{x,i}, e\tilde{m}_{x,i}\right]} \quad \text{(Eq. 3.7)}$$

Uncertainty bands can then be estimated through the application of the POV method and applying the equation below to obtain the confidence intervals in Eq. 3.8:

$$\Pr\left(-t_{\alpha/2} \leq (\mathrm{e\tilde{m}}_{x,i} - \mathrm{em}_{x,i})/\sigma_{e\tilde{m}_{x,i}} \leq t_{\alpha/2}\right) = 1 - \alpha \quad \text{(Eq. 3.8)}$$

Where: α is the significance level. As it is assumed that the upper bound and lower bound follow different normal distributions, Eqn 3.1 – 3.8 are calculated twice for upper bound and lower bound independently. Therefore, in each run of the calculation, just one side of the confidence interval in Eq. 3.8 is used. The probability component in Eq. 3.8 can be rearranged to give Eq. 3.9:

$$\Pr\left(\mathrm{e\tilde{m}}_{x,i} - t_{\alpha/2}\sigma_{e\tilde{m}_{x,i}} \leq \mathrm{em}_{x,i} \leq \mathrm{e\tilde{m}}_{x,i} + t_{\alpha/2}\sigma_{e\tilde{m}_{x,i}}\right) = 1 - \alpha \quad \text{(Eq. 3.9)}$$

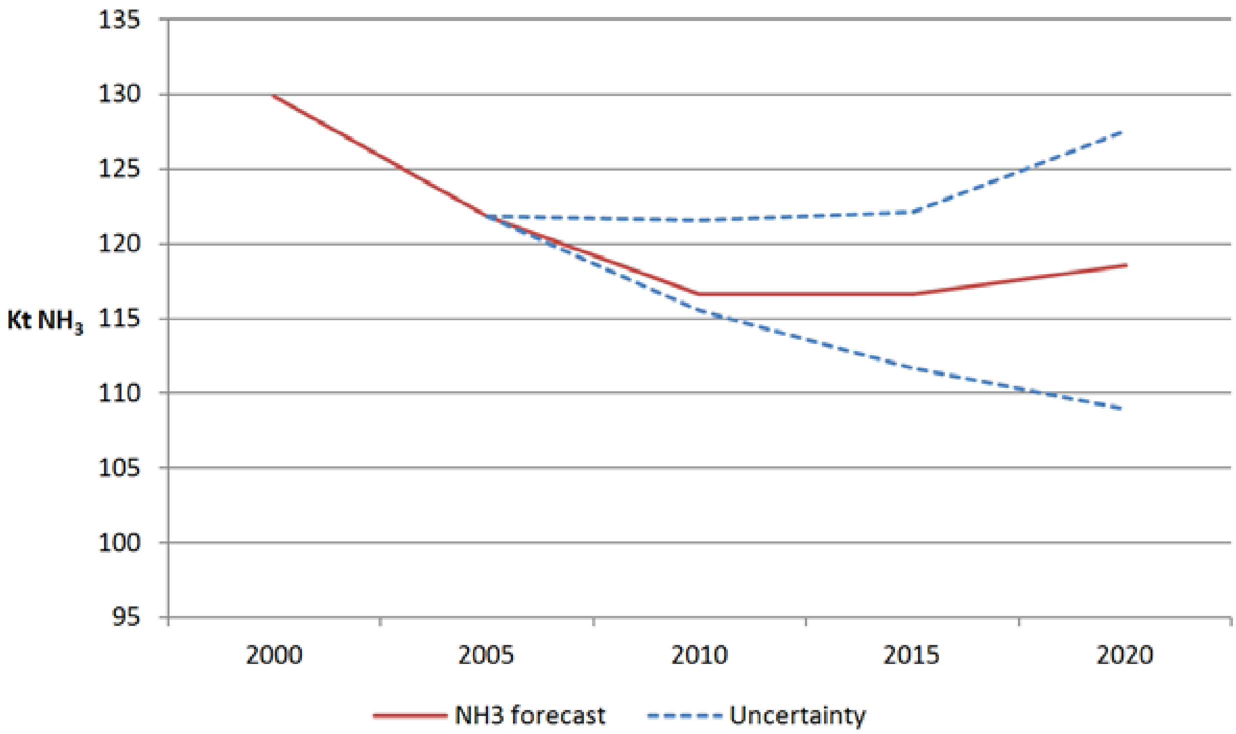


Figure 3.2. Illustration of an agricultural NH_3 emission forecast with uncertainty bands.

approaches to uncertainty analyses within the literature are often highly technical and the models used are both computationally demanding and time intensive. This can limit broader adoption where national capacities are limited and scenario development is frequent. The deliverable from this research strand of the IMPI work included an academic publication (King, Fu and Kelly, 2011) and a functional methodology for presenting uncertainty based around a 'propagation of variance' method. The approach is built around functional equations detailed in Box 3.1.

The objective was to strike a balance between the technical and temporal demands of uncertainty estimation against the need to deliver a regular and practical estimation and presentation of uncertainty for any given scenario and any given country. The developed methodology is applied in a case study of Irish agricultural data with expert elicitation as a key support. This work provides the basis for an enhanced presentation of modelled emission forecasts, such that the inherent uncertainty is visually apparent to decision-makers and policy negotiators, as illustrated in Fig. 3.2.

3.2.4 Non-Technical Measures Modelling

Non-technical measures (NTM) represent an important part of international efforts to control and reduce emissions. These measures can have associated (and potentially significant) costs and benefits such as societal welfare changes or administrative costs. Research under the IMPI project (IMP Team, 2010h) proposed that in principle these measures should warrant the same analytical respect as that given to technical abatement options in the process. By accounting for these measures in the same analytical policy framework used for technical measures in the transboundary air pollution and climate context, the assessment can be broadened to more accurately reflect:

1 The level of emission reductions that could be achieved;

2 The net cost or benefit of actions taken.

This is important for improved policy design and the development of effective legislation. There are also further benefits in so far as a formal assessment and the inclusion of such measures in the modelling and policy framework internationally can promote further debate on the true potential of such options, means to improve them, and a generally improved awareness of what can be achieved in terms of further abatement.

The research has illustrated that NTMs carry with them some challenging considerations, suggesting they will not be modelled in the same homogenised fashion as technical measures. It is therefore recommended that the 'impact' of a given NTM or package should be distilled into one or a combination of the following parameters:

- **Activity factor**: the influence on the level of activity, for example, energy use;
- **Control factor:** the influence on the related control parameters, for example penetration of an option;
- **Switch factor:** the influence on the shift between activities or controls.

There is also a final corresponding value for the net cost or benefit associated with the introduction of the measure. This accounts for those direct costs and benefits that would otherwise not be captured in the current modelling process, but which are relevant to evaluating the measure fully.

In this manner, it is possible to capture for a given NTM the influence it will have on emissions and the additional cost or benefit associated with the action. The research suggests a guiding structure for how to summarise the impact of a given NTM that is consistent with the principal modelling tools. Ultimately, however, there is no single prescribed methodology given for assessing an NTM appropriately, because the appropriate methodology will vary depending on the measure in question. For example, national taxes may be assessed with a computable general equilibrium (CGE) macro model whilst a modal shift in transport may be evaluated by a regional transport planning model.

A further conclusion was that member states should select the NTMs they wish to assess and include in the process. Hundreds of measures for individual countries cannot be defined in the model as is currently the case for technical measures. There are simply too many possible sources of variability within NTMs for this to be in any way practical. However, if member states were to include only those NTMs they were considering or implementing, then independent national analysis on the options that could provide some of the evidence needed to include them in the policy-framework process described under the IMPI research could be carried out.

As a support to this work, the IMPI team have also established the PolicyMeasures web resource (www.policymeasures.com), which serves as an open resource for discussing and evaluating all manner of policies and measures, with a specific focus on parameters and modelling of specific measures.

3.2.5 Policy Measures Resource

Research relies upon evidence. Enhancing the accessibility of research findings is particularly important as this allows research to build upon experience, corroborate or question findings, and gradually progress towards increasingly robust analysis. In the field of environmental policy and research, policy demands and questions are evolving and this requires a dynamic and contemporary international research response.

The IMPI project recognised the need for an improved open source international database that could offer the means to share, edit and discuss the evidence and concepts of environmentally focused policies and measures. With a focus on determining an appropriate content structure, an intuitive and accessible open format, a flexible and scalable back-end system and an extremely high-quality of presentation, the IMPI team designed and delivered the PolicyMeasures resource (www.policymeasures.com). The website has been iteratively populated with new data and evidence towards the latter stages of the IMPI project and will be further developed and maintained into the future where resources allow. Ultimately, the vision is to deliver sufficient content and value such that current users of the site are encouraged to become active contributors, thus broadening the scope of the content, enhancing the evidence base, and increasing the value of the system for environmental policy, modelling and general decision support (see Fig. 3.3).

The web resource has been successfully launched with an accompanying guidance report for contributors (IMP Team, 2010i). Beyond IMPI contacts and colleagues, the site has further attracted global unsolicited membership. With further content development internationally

Figure 3.3. Screen captures of PolicyMeasures – Example of a measure and report in the system.

and the planned delivery of a quarterly newsletter, it is believed that the resource can prove valuable to modellers, academics, interested individuals and policy-makers. PolicyMeasures has the potential to become an important medium for research dissemination and discussion with only a moderate investment of time and effort.

3.3 Integrated Modelling Project Ireland Research – Developed Capacities and Methodological Progress

National capacities in the field of transboundary air pollution and climate policy modelling in Ireland were somewhat limited at the outset of the IMPI project in 2008. In the intervening years a number of interconnected and complementary capacities have been developed to greatly enhance independent national analytical capabilities, as well as to enable effective collaborative international engagement in regard to the evolution, evaluation and execution of climate and air policy across the wider European region. The development of these capacities is important, but means little if there is a failure in the subsequent phase to sustain the developed capacities. As Ireland enters a phase of increasingly stringent environmental policy, shadowed by an array of more and more complex policy choices, the country must ensure that it is adequately equipped to make informed and cost-effective national policy decisions, as well as being positioned to ensure that overarching international obligations develop with robust national evidence and adequate national representation. Beyond the national and international contributions of the project noted in the previous two sections, the subsequent section identifies four examples of the newly developed capacities derived from the IMP project research and core model development.

3.3.1 *Climate and Air Synergies*

A particular strength of the GAINS Ireland system is the integrated nature of the model with regard to both GHGs and air pollution. This system integration allows the model to evaluate and present the synergies or trade-offs of actions influencing one or both of these areas. In other words, for any given scenario focused on examining GHG emissions and associated actions, the model can also illustrate the corresponding impact across transboundary air pollution and vice versa. This capacity allows a broader integrated assessment of scenarios and policy interventions and can thereby inform better decision-making at a national policy level.

3.3.2 *Effect Mapping*

The IMPI GAINS Ireland system offers the facility to map and analyse transboundary effects for a given scenario package. The potential exists to redevelop an entire European scenario, or to investigate the impact of a revised national scenario in respect of national and international impacts. The categories of impacts evaluated by the GAINS model include health effects, acidification and eutrophication. This is achieved by estimating levels of exposure and exceedance beyond defined thresholds. Figure 3.4 presents an example from the GAINS Ireland system of a variation in health impacts across Europe between two modelled scenarios.

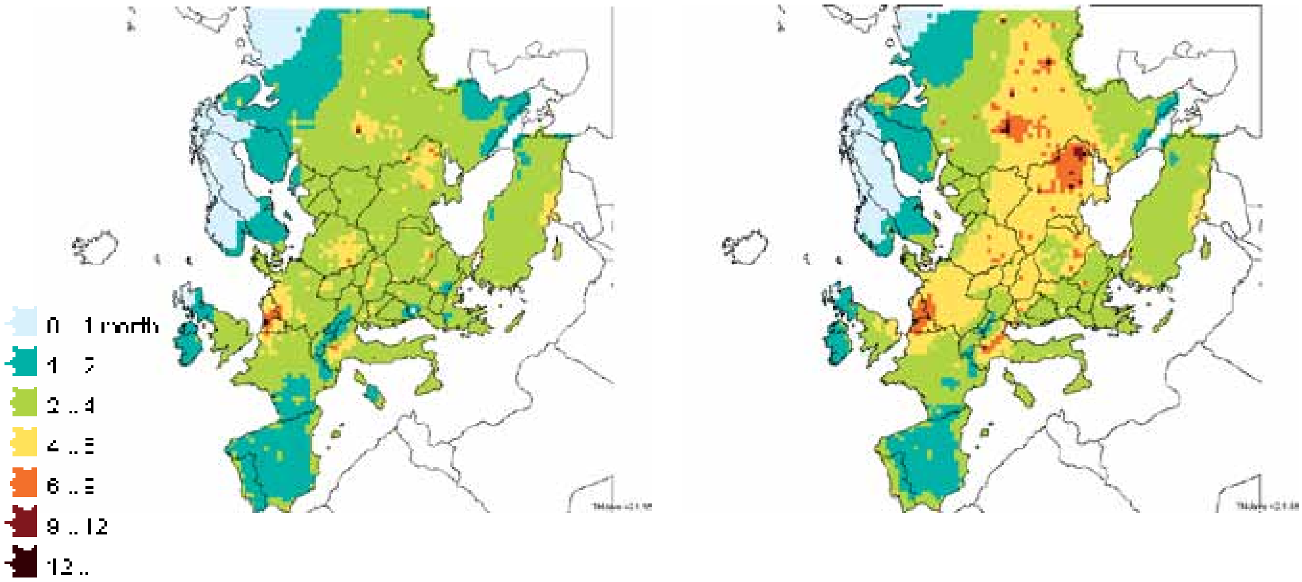


Figure 3.4. Baseline health effects in 2020 and months of life lost change.

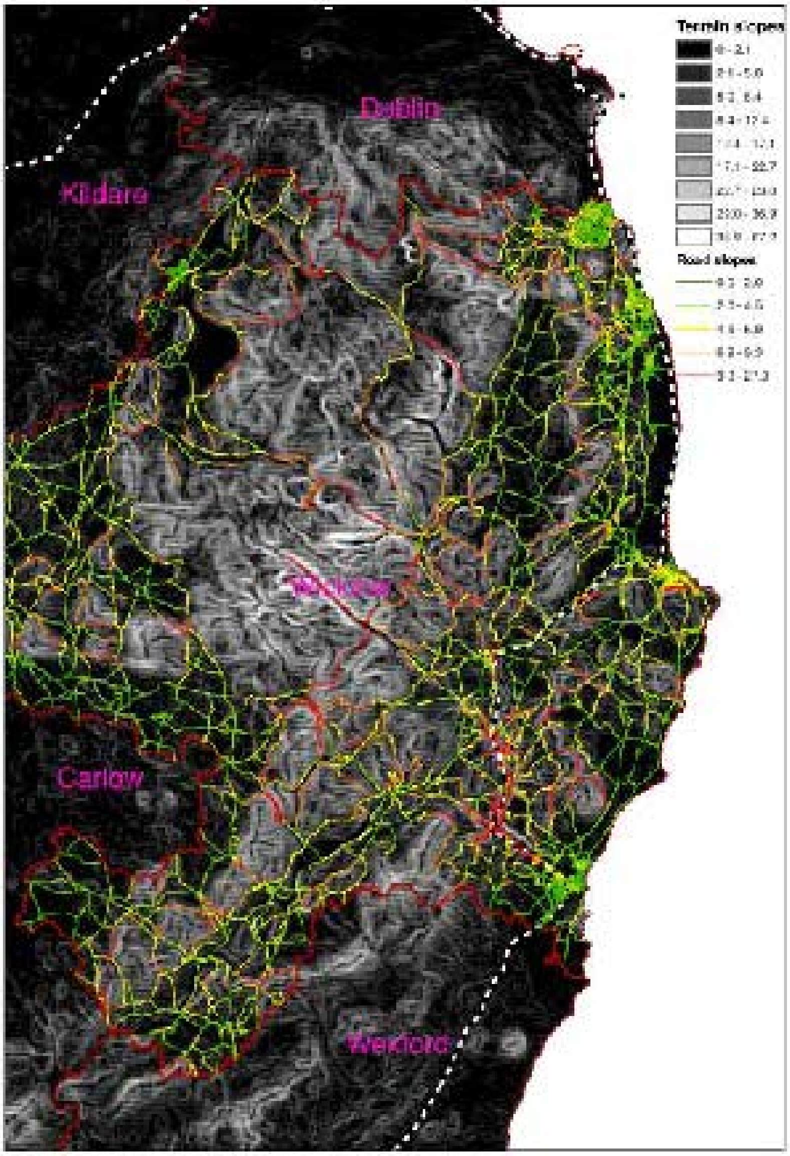


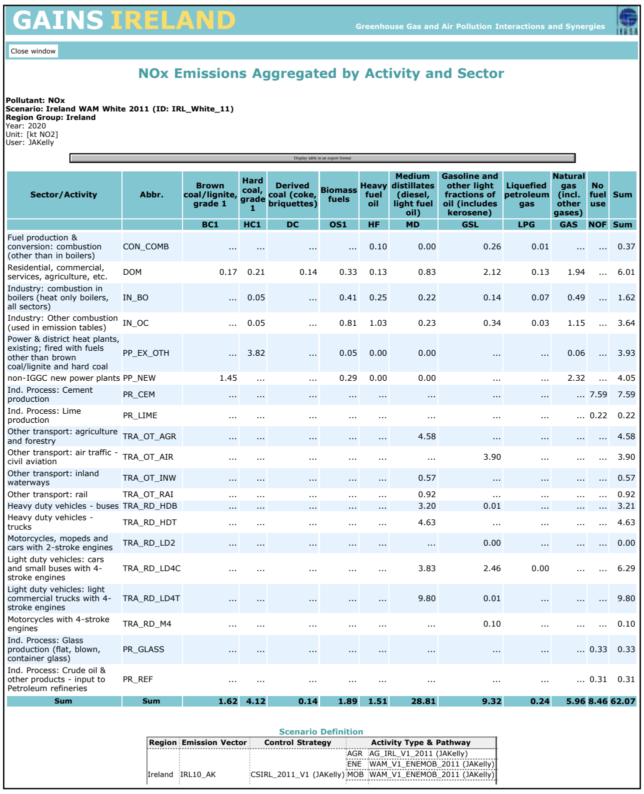
Figure 3.5. Illustration of GIS mapping work for road networks and slopes.

3.3.3 Geographical Information System Connection and Research Application

As part of the IMPI project, and specifically the TREMOVE Ireland strand of the work, efforts were invested in utilising GIS and associated mapping data to enhance the analysis and understanding of policy issues, and to improve the manner in which findings and results were communicated. One example of this use of GIS is the flexible working policy paper discussed in Section 3.1.3. A second example was the use of GIS in a now published paper focused on understanding how regional characteristics influence the purchase decisions of consumers in respect to car engine sizes (Fu, Ahern, Kelly, 2011). Within that piece of work the Irish road network was overlaid with geographic elevation to understand the nature of roads and road slopes in specific areas as a means of understanding the 'needs' of vehicle users in certain regions. Additionally, transport services and economic data were mapped to regions as part of the analysis and modelling undertaken in the piece. Such innovative use of GIS and linking to model systems offers the potential for further advanced analysis in the future, and more rapid and effective sharing of developed knowledge and datasets (see Fig. 3.5).

3.3.4 Detailed Forecasting, Disaggregated Analysis and Methodological Advancement

The GAINS model framework incorporates a comprehensive data-structuring system which enables the model to carry out a wide variety of analytical functions (see Fig. 3.6). As part of the IMP project the team have developed in-house methodologies to facilitate the porting of official national data (e.g. energy and agricultural data) into the model. The team have also developed guidelines and process stages for the revision and verification of other parameters (e.g. control strategies, emission factors). These methodologies and processes enable the IMP team to calibrate the model relatively quickly. This allows the IMP team to generate an alternative set of emissions forecasts for GHGs and transboundary air pollutants via an internationally supported methodology, and also to manipulate and modify the underlying scenarios for sensitivity analyses as necessary.



GAINS IRELAND — Greenhouse Gas and Air Pollution Interactions and Synergies

Close window

NOx Emissions Aggregated by Activity and Sector

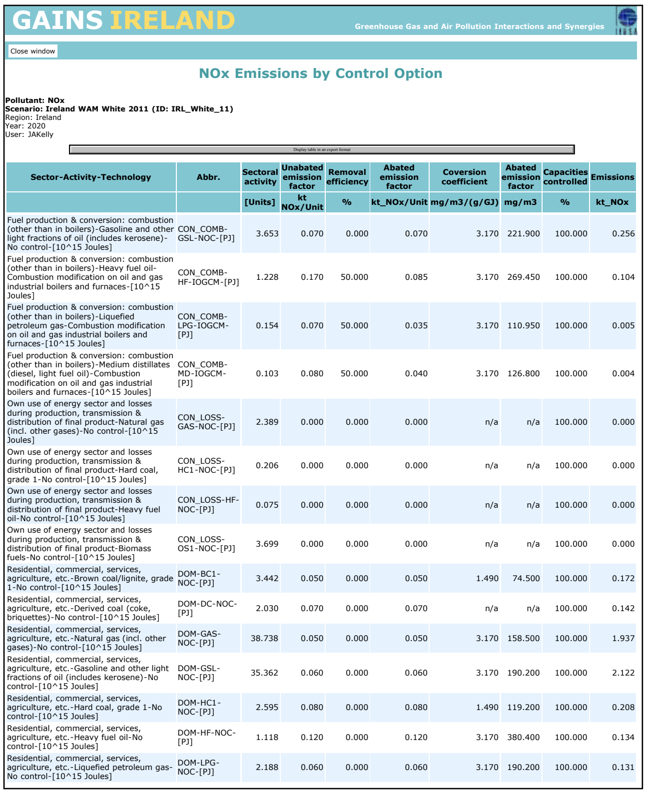
Pollutant: NOx
Scenario: Ireland WAM White 2011 (ID: IRL_White_11)
Region Group: Ireland
Year: 2020
Unit: [kt NO2]
User: JAKelly

Display table in an export format

Sector/Activity	Abbr.	Brown coal/lignite, grade 1	Hard coal, grade 1	Derived coal (coke, briquettes)	Biomass fuels	Heavy fuel oil	Medium distillates (diesel, light fuel oil)	Gasoline and other light fractions of oil (includes kerosene)	Liquefied petroleum gas	Natural gas (incl. other gases)	No fuel use	Sum
		BC1	HC1	DC	OS1	HF	MD	GSL	LPG	GAS	NOF	Sum
Fuel production & conversion: combustion (other than in boilers)	CON_COMB	...	...	...	...	0.10	0.00	0.26	0.01	...	...	0.37
Residential, commercial, services, agriculture, etc.	DOM	0.17	0.21	0.14	0.33	0.13	0.83	2.12	0.13	1.94	...	6.01
Industry: combustion in boilers (heat only boilers, all sectors)	IN_BO	...	0.05	...	0.41	0.25	0.22	0.14	0.07	0.49	...	1.62
Industry: Other combustion (used in emission tables)	IN_OC	...	0.05	...	0.81	1.03	0.23	0.34	0.03	1.15	...	3.64
Power & district heat plants, existing; fired with fuels other than brown coal/lignite and hard coal	PP_EX_OTH	...	3.82	...	0.05	0.00	0.00	...	...	0.06	...	3.93
non-IGGC new power plants	PP_NEW	1.45	...	...	0.29	0.00	0.00	...	...	2.32	...	4.05
Ind. Process: Cement production	PR_CEM	...	...	...	...	...	...	...	...	...	7.59	7.59
Ind. Process: Lime production	PR_LIME	...	...	...	...	...	...	...	...	...	0.22	0.22
Other transport: agriculture and forestry	TRA_OT_AGR	...	...	...	...	...	4.58	...	...	...	...	4.58
Other transport: air traffic - civil aviation	TRA_OT_AIR	...	...	...	...	...	...	3.90	...	...	...	3.90
Other transport: inland waterways	TRA_OT_INW	...	...	...	...	...	0.57	...	...	...	...	0.57
Other transport: rail	TRA_OT_RAI	...	...	...	...	...	0.92	...	...	...	...	0.92
Heavy duty vehicles - buses	TRA_RD_HDB	...	...	...	...	...	3.20	0.01	...	...	...	3.21
Heavy duty vehicles - trucks	TRA_RD_HDT	...	...	...	...	...	4.63	...	...	...	...	4.63
Motorcycles, mopeds and cars with 2-stroke engines	TRA_RD_LD2	...	...	...	...	...	...	0.00	...	...	...	0.00
Light duty vehicles: cars and small buses with 4-stroke engines	TRA_RD_LD4C	...	...	...	...	...	3.83	2.46	0.00	...	...	6.29
Light duty vehicles: light commercial trucks with 4-stroke engines	TRA_RD_LD4T	...	...	...	...	...	9.80	0.01	...	...	...	9.80
Motorcycles with 4-stroke engines	TRA_RD_M4	...	...	...	...	...	...	0.10	...	...	...	0.10
Ind. Process: Glass production (flat, blown, container glass)	PR_GLASS	...	...	...	...	...	...	...	...	...	0.33	0.33
Ind. Process: Crude oil & other products - input to Petroleum refineries	PR_REF	...	...	...	...	...	...	...	...	...	0.31	0.31
Sum	**Sum**	**1.62**	**4.12**	**0.14**	**1.89**	**1.51**	**28.81**	**9.32**	**0.24**	**5.96**	**8.46**	**62.07**

Scenario Definition

Region	Emission Vector	Control Strategy	Activity Type & Pathway	
Ireland	IRL10_AK	CSIRL_2011_V1 (JAKelly)	AGR	AG_IRL_V1_2011 (JAKelly)
			ENE	WAM_V1_ENEMOB_2011 (JAKelly)
			MOB	WAM_V1_ENEMOB_2011 (JAKelly)



GAINS IRELAND — Greenhouse Gas and Air Pollution Interactions and Synergies

Close window

NOx Emissions by Control Option

Pollutant: NOx
Scenario: Ireland WAM White 2011 (ID: IRL_White_11)
Region: Ireland
Year: 2020
User: JAKelly

Display table in an export format

Sector-Activity-Technology	Abbr.	Sectoral activity	Unabated emission factor	Removal efficiency	Abated emission factor	Coversion coefficient	Abated emission factor	Capacities controlled	Emissions
		[Units]	kt NOx/Unit	%	kt_NOx/Unit	mg/m3/(g/GJ)	mg/m3	%	kt_NOx
Fuel production & conversion: combustion (other than in boilers)-Gasoline and other light fractions of oil (includes kerosene)-No control-[10^15 Joules]	CON_COMB-GSL-NOC-[PJ]	3.653	0.070	0.000	0.070	3.170	221.900	100.000	0.256
Fuel production & conversion: combustion (other than in boilers)-Heavy fuel oil-Combustion modification on oil and gas industrial boilers and furnaces-[10^15 Joules]	CON_COMB-HF-IOGCM-[PJ]	1.228	0.170	50.000	0.085	3.170	269.450	100.000	0.104
Fuel production & conversion: combustion (other than in boilers)-Liquefied petroleum gas-Combustion modification on oil and gas industrial boilers and furnaces-[10^15 Joules]	CON_COMB-LPG-IOGCM-[PJ]	0.154	0.070	50.000	0.035	3.170	110.950	100.000	0.005
Fuel production & conversion: combustion (other than in boilers)-Medium distillates (diesel, light fuel oil)-Combustion modification on oil and gas industrial boilers and furnaces-[10^15 Joules]	CON_COMB-MD-IOGCM-[PJ]	0.103	0.080	50.000	0.040	3.170	126.800	100.000	0.004
Own use of energy sector and losses during production, transmission & distribution of final product-Natural gas (incl. other gases)-No control-[10^15 Joules]	CON_LOSS-GAS-NOC-[PJ]	2.389	0.000	0.000	0.000	n/a	n/a	100.000	0.000
Own use of energy sector and losses during production, transmission & distribution of final product-Hard coal, grade 1-No control-[10^15 Joules]	CON_LOSS-HC1-NOC-[PJ]	0.206	0.000	0.000	0.000	n/a	n/a	100.000	0.000
Own use of energy sector and losses during production, transmission & distribution of final product-Heavy fuel oil-No control-[10^15 Joules]	CON_LOSS-HF-NOC-[PJ]	0.075	0.000	0.000	0.000	n/a	n/a	100.000	0.000
Own use of energy sector and losses during production, transmission & distribution of final product-Biomass fuels-No control-[10^15 Joules]	CON_LOSS-OS1-NOC-[PJ]	3.699	0.000	0.000	0.000	n/a	n/a	100.000	0.000
Residential, commercial, services, agriculture, etc.-Brown coal/lignite, grade 1-No control-[10^15 Joules]	DOM-BC1-NOC-[PJ]	3.442	0.050	0.000	0.050	1.490	74.500	100.000	0.172
Residential, commercial, services, agriculture, etc.-Derived coal (coke, briquettes)-No control-[10^15 Joules]	DOM-DC-NOC-[PJ]	2.030	0.070	0.000	0.070	n/a	n/a	100.000	0.142
Residential, commercial, services, agriculture, etc.-Natural gas (incl. other gases)-No control-[10^15 Joules]	DOM-GAS-NOC-[PJ]	38.738	0.050	0.000	0.050	3.170	158.500	100.000	1.937
Residential, commercial, services, agriculture, etc.-Gasoline and other light fractions of oil (includes kerosene)-No control-[10^15 Joules]	DOM-GSL-NOC-[PJ]	35.362	0.060	0.000	0.060	3.170	190.200	100.000	2.122
Residential, commercial, services, agriculture, etc.-Hard coal, grade 1-No control-[10^15 Joules]	DOM-HC1-NOC-[PJ]	2.595	0.080	0.000	0.080	1.490	119.200	100.000	0.208
Residential, commercial, services, agriculture, etc.-Heavy fuel oil-No control-[10^15 Joules]	DOM-HF-NOC-[PJ]	1.118	0.120	0.000	0.120	3.170	380.400	100.000	0.134
Residential, commercial, services, agriculture, etc.-Liquefied petroleum gas-No control-[10^15 Joules]	DOM-LPG-NOC-[PJ]	2.188	0.060	0.000	0.060	3.170	190.200	100.000	0.131

Figure 3.6. Example of aggregated and disaggregated emission outputs from GAINS Ireland.

A further advantage of the system is that the underlying data in the model are captured in a carefully constructed relational database management system. Existing or newly developed model processes can thereby call on any data within this system to manipulate or present outputs in a specific form or level of detail. For example, emissions can be presented by sector, fuel type, technology and even by a number of specific international reporting formats such as CORINAIR SNAP, or UNECE NFR1 (akin to the IPCC reporting system).

A connected advantage of this alternative available modelling methodology and system are the insights it can provide into how emissions, policies and costs are processed nationally relative to certain international methodologies. Both the international and national processes can benefit from a structured exchange of information and knowledge. The GAINS Ireland system facilitates progress in regard to related forecasting and modelling by providing a middle ground where each side can question values and methods, thereafter updating as appropriate to a more robust representation of reality.

4 Conclusions and Recommendations of Integrated Modelling Project Ireland Research

The following are the eight primary recommendations selected from the full spectrum of research and developments under the IMPI project.

4.1 Capacity and International Engagement

National capacity in regard to the specific type of integrated assessment modelling utilised to inform, revise and review international policy in respect of transboundary air pollution and climate policy is necessary to allow balanced, informed and effective engagement with these international processes. Participation in the gradual evolution and revision of policy is critical. For example, engagement with the TFIAM offers an opportunity to participate in the development of ambition levels, analytical methodologies, compliance assessment design, and ultimately the creation of the scenarios and analysis which offer the evidence base for negotiators to decide policy. Such sustained engagement is arguably as significant in terms of outcomes as the subsequent *reactions* to the proposed international policy. As part of the IMPI project, Ireland is now directly engaged internationally across a number of such forums, and is playing an active role in the development and improvement of research that goes on to inform policy decisions directly. The IMPI project has established a strong presence in a number of important groups where Irish involvement was previously absent. IMPI engagement, contributions and communication in these groups should be maintained in order to sustain the channels of communication in both directions, which is to the benefit of the international policy development processes and the efficacy and feasibility of subsequent national responses to these challenges.

4.2 National Modelling Strategy and Forum

No individual model can inform the decisions to be made in respect of all of Irish national policy questions; therefore, diversity in analytical capacities is required. Through initiative, investment and vision, there are now a number of models and modelling centres established across Ireland that can support decisions across the full spectrum of climate and air policy. This developing spread offers a well-balanced set of complementary capacities that must continue to work in support of one another and an increasingly cohesive national modelling vision. IMPI would recommend that a transparent, yet adaptable, coordinating strategy for the further development of various 'satellite' centres of modelling capacity be established. This strategy could include broadly defined common efforts, such as:

- Extending modelling horizons to exploratory timeframes such as 2050 in line with international ambitions;
- Defining shared analytical objectives such as pathways to a given target which can support policy decisions.

These are only examples: coordination of such shared efforts in the national interest would facilitate organisation of a coherent meeting or workshop. This would allow both modellers and policy-makers to interact (akin to prior EPA initiatives in this area), to enable modellers to discuss their work with one another, and share results directly with policy-makers, and allow policy-makers to offer direct feedback and insights in regard to the political perspective.

In the same breath, whilst some clearer structure for selected collaborative goals is recommended in addition to the sharing of outputs, evidence and developed data, it is important that such centres maintain adequate independence to conduct alternative research, use varied methodologies, and run independent scenario assessments. This will prevent the development of a close-knit group cyclically reinforcing the apparent robustness of outcomes through excessive integration. Varied methodological approaches and assumptions are more appropriate for decision support as they offer guidance within a *plausible range*, as opposed to a point-specific outcome for the future that belies inherent uncertainty. A degree of central coordination of satellite capacities to this end would be helpful.

4.3 Air Pollution – Flexible Policy Mechanisms for Transboundary Air Pollution

Transboundary air pollution regulation in the broader European region presently lacks any defined compliance assessment flexibility mechanism. This is in contrast to a generally more advanced approach to climate targets. The issue therefore is that transboundary policy is ultimately set in rigid terms without adequate provision for unexpected outcomes or events. A failure to recognise the potential for either the unknown or the uncertain to alter the path into the future may lead to legislative constraints which are impractical and cost inefficient.

The impacts of such outcomes can be significant. For example, IMPI research identified that the failure of certain Euro standards to deliver the expected on-road abatement performance for NO_X is currently the dominant factor threatening Irish compliance with the National Emissions Ceiling Directive 2001/81/EC. Quantification of the difference between the originally anticipated abatement performance and actual on-road abatement performance for the specific categories of vehicle were conducted. These modelled assessments utilised updated Irish fleet and activity data, and illustrated that the revised abatement performance ratings accounted for approximately 15kt of NO_X. This sum accounts for the major share of the gap between current expected estimates of official 2010 NO_X emissions and the 65kt ceiling. Further research and promotion of the role of flexibility provision in the context of setting and testing for compliance of transboundary emission ceilings is required.

Building on the IMPI research that has driven this ‘FlexMex’ agenda (IMP Team, 2009b, Kelly and Vollebergh, 2010, 2011, TFEIP ad hoc group, 2011), Ireland should continue to show leadership on these issues, as a peripheral nation with a keen appreciation of the need to include appropriate mechanisms for the future. An opportunity is presented in so far as Ireland will again hold the presidency of the Council of the European Union for the first half of 2013. The presidency role will require working with the prior and subsequent presidential holders, thus requiring engagement in 2012. This Irish position will coincide with the scheduled comprehensive review of European air quality ambitions in 2013, a process which will determine outcomes that influence or decide the next set of European National Emissions Ceilings. Further development of national research and evidence in the area of transboundary air pollution research and associated topics of flexible policy mechanisms is recommended to facilitate a substantial evidence-led progression of this policy topic during Ireland’s term of influence.

4.4 Climate – Non-Traded Sector Target

Ireland is presented with a set of challenging targets in regard to climate change. As distinct from those major sources captured under the EU ETS, the non-traded sector target for 2020 poses a challenge for a group of sectors that may be difficult to regulate, monitor and direct. IMPI research has worked with international colleagues to determine an international perspective on abatement potentials and least-cost abatement pathways in Ireland, whilst also acknowledging the role of other ‘non-modelled’ policy measures for further consideration. The conclusions of the first phase of this GAINS Ireland work on the NETS target suggest a significant deficit in the defined abatement potentials for the ‘with measures’ scenario with respect to reaching the NETS target of 37.4M tonnes of CO_2e in 2020. Under an optimisation scenario seeking to achieve the target with a market carbon price of €50 per tonne, the available menu of measures leaves a remaining gap of 4.8Mt CO_2e to target. Applying the maximum amount of emissions reductions options identified using the GAINS Ireland modelling system suggests a remaining gap of 3Mt CO_2e to the target in 2020.[11] In addition, Ireland will face annual challenges in regard to NETS emissions from 2013 onwards.

However, whilst the headline results are not particularly encouraging, there were four added conclusions from this work in respect of Ireland’s efforts to address this challenge. Firstly, the analyses do not (yet) represent all that can be done. The model excludes certain policy

11 The ultimate outcome of a European decision on the role of LULUCF within the process of calculating net emissions will be relevant to this challenge.

interventions (e.g. revisions to the carbon tax) that could also contribute to progress on the target, and additional extension and calibration of the abatement menu remain to be conducted. In particular, there is certainly untapped potential in the transport sector that has not been adequately captured in this first calibration of the model. Secondly, whilst the target is not met under the WM analysis, the cost assessment from a social planner perspective indicates no net annual cost, due to cumulative cost savings on certain measures, where the package of measures up to a marginal cost of €150 per tonne are taken. Thirdly, whilst the optimisations on the 'with-measures' scenario fail to achieve the NETS target, the impact on over-compliance for the ETS sector is notable. Similarly, there would be strong co-benefits with transboundary air pollution policy objectives. Finally, whilst the process has identified many areas where additional data and evidence are required, there is cause for optimism in respect of this calibration challenge. A number of potential sources for this information are identified in the work, and the progressive collating and integration of these data into the model framework is recommended, which will offer a still stronger analytical tool for navigating a pathway to compliance with NETS from 2013 to 2020.

4.5 National Transport Model

The transport sector is heavily intertwined with economic and environmental performance. On a national, regional and local scale, there are significant challenges and opportunities with regard to the more efficient operation of the transport sector. Capacities nationally encompass local expertise, regional models and national scale systems of varying types. None of these individual capacities has the features to respond to all transport-related policy questions, nor is that a realistic objective. However, a *soft linked* national transport modelling framework (as investigated by the EPA and partners) would be a highly valuable initiative in terms of establishing systems that can interact in regard to informing transport policy decisions. Such a system would link in terms of sharing the best available evidence relevant for calibration. For example, there are many core parameters (e.g. passenger kilometres, vehicle efficiency rates, vehicle stock by gross vehicle weight, etc.) which would be of great importance in a number of modelling systems used nationally. These parameters are based on estimates from varying data sources and may often go beyond the excellent range of data provided through official channels such as the CSO. As a result, the independent analyses to improve or develop estimates for selected parameters could offer value to a number of research groups. Whilst scenarios can of course continue to vary, and parameters, robust baseline values should be researched, refined and shared. The systems can thereby maintain their operational independence and development paths, whilst still moving towards a more robust and coherent representation of the sector across all systems. IMPI research has developed TREMOVE Ireland, a national scale model with the capacity to inform a range of pricing, technology and incentive-based policy interventions in this sector. The capacity of this model, outputs from this model and supporting research for calibration are recommended for inclusion in any proposed national transport nodelling initiative.

4.6 Taxation Policy for Transport

Recent years have seen the introduction of a number of transport taxation-focused policies as a way to deliver improved environmental performance from the sector. IMPI research has examined independently, and as a collective package, the short- and longer-term impacts of tax-change policies for VRT, AMT and the fuel carbon tax. The approach captures the relative change between a basecase and simulation scenario, thereby focusing on *isolated relative improvements* between policies and packages as opposed to considering purely absolute changes over time. This work has been made available through policy reports, a paper currently in submission to an international journal, and a direct policy report submission to government on suggested revisions. On a general level, the research indicates synergies between these three tax policies, but highlights the following specific considerations and recommendations in terms of policies for (i) emissions, (ii) revenue and (iii) welfare.

4.6.1 Emissions

Revisions to AMT and VRT in respect of rated grams per kilometre of carbon alone are expected to have a comparatively small additional impact in regard to actual on-road carbon emissions over time. Reasons include the lack of focus on vehicle use, a moderate degree of rebound effect, and distinctions between the gaps in rated emission bands and the gaps in actual on-road emission performance. The carbon tax on fuel use is shown to be a far more potent, efficient and direct instrument with which to achieve carbon emission reductions. However, on a broader scale the revisions to VRT and AMT will no doubt influence consumers at point of sale and will to some extent feed back into manufacturer research and development strategies.

It is further noted that an exclusive focus on carbon is expected to direct sales firmly towards diesel vehicles delivering a relative increase in emissions of NO_X and particulates relative to a progression of the current balance in the fleet between the fuel types. A quantified recommendation for a practical revision of taxation policy design that acknowledges the relevance and costs of other pollutants and their associated externalities in addition to CO_2 emission levels has been submitted to government. The recommended policy adjustment can be readily integrated into a new AMT structure.

4.6.2 Revenue

The recent revisions to AMT and VRT alone are shown to reduce associated tax revenue by an estimated €400m$_{(Euros2000)}$ in 2025 relative to the basecase assessment whereas the fuel carbon tax alone offers a relative increase in the region of €700m$_{(Euros2000)}$ in 2025 relative to the basecase assessment. It is important to acknowledge that as technology and vehicle efficiencies improve, the taxation bands will have to be revised to tighter groupings at lower thresholds in order to maintain relative positions for the improved performance distribution of new vehicles in a given time frame. A submission on this topic was also made to government.

4.6.3 Welfare

Welfare estimates associated with the policy evaluations account for changes in tax revenues, emissions and externalities. Upper and lower bounds are estimated, with averages presented as the central case. AMT and VRT alone deliver much reduced revenue with limited emission reductions, thereby delivering modest net welfare benefits. Fuel carbon tax delivers generally double the positive welfare impacts over time of the AMT and VRT package alone. Combining all policies delivers the greatest net benefit – an estimated average of over €220m$_{(Euros2000)}$ in 2025. Double dividend benefits (e.g. replacing labour taxes) are also quantified and offer the potential to deliver an additional €100m$_{(Euros2000)}$ of welfare improvements in 2025, with a near doubling of the positive effects delivered at an early stage out to 2015.

4.7 Uncertainty Presentation and Non-Technical Measures

In regard to the modelling work conducted under the IMPI research, two of the more prominent topics which were identified and advanced by the research were:

- The approach to uncertainty presentation in emissions modelling work;
- The absence of certain 'non-technical' policy measures from the broader modelling frameworks.

4.7.1 Uncertainty Presentation

IMPI research has advanced a formal methodology (King, Fu and Kelly, 2011) in respect of the presentation of uncertainty associated with forecasts from the transboundary air pollution modelling work. The methodology blends a POV approach with expert elicitation as a means of establishing a more readily accessible means of conducting the necessary analysis. In practice, the work advocates a shift, and offers an alternative, to the single point line forecasts that are generally produced once scenario decisions and sensitivities have been discussed. The recommendation is that this approach is adopted formally in official scenario forecasts to provide decision-makers with an improved perspective on the expectations of the research community.

4.7.2 Non-Technical Measures

IMPI research acknowledged the impracticalities of including certain complex measures as part of the 'menu of options' within the GAINS Ireland modelling frameworks. Reasons include the asymmetry of responses to certain *non-technical* policy interventions (e.g. road pricing) where multiple case-specific parameters will influence the degree of impact and how outcomes develop over time. However, it remains important to capture the cost, potential and merit of such measures in the broader policy process, as non-technical options are certain to play a significant role in emission control policy, particularly in a climate context. As part of the IMPI research a methodology and report were produced to illustrate how this would operate in practice. Further formal work is recommended to appropriately account for and integrate such policy measures into the decision-making processes for national environmental commitments.

4.8 Policy Analysis and Evidence Sharing

Analysis of policies and sharing of the outcomes of that analysis is important on both a national and international scale. It affords the benefit of experience from a wider pool of knowledge, with corresponding opportunities to avoid costly errors, improve upon policy interventions, and understand the most effective and appropriate options available. An innovation under the IMPI research has been to develop a professional, accessible and flexible database resource framework for sharing research and evidence in regard to all manner of policies and measures. The resource is designed to be a repository for evidence that can adjust its presentation of data so as to offer value to both policy-makers and technical modelling teams alike. The IMPI team will continue to channel research into the www.policymeasures.com resource as a novel and innovative dissemination channel for research into policies and measures engaged in regard to environmental challenges. The focus is on communication and collaboration, and specific support has been acquired from the research community in this field, for example, Network of Experts on Benefits and Economic Instruments (NEBEI), colleagues from the TFIAM, academic colleagues internationally, and interested registrants. IMPI would recommend and encourage participation with this resource to enable steady and ultimately significant growth over a longer period of time, which delivers an increasingly refined and expansive evidence base in relation to environmentally focused policies and measures.

References

Fu., M., Ahern, A. and Kelly, J.A. (2011) Regional characteristics and the distribution of car engine sizes: A case study of Ireland, *Transportation Research Part D*, (16) 509–14.

Fu., M., Kelly, J.A., Clinch, J.P. and King, F. (2011) Environmental policy implications of working from home: modelling the impacts of land-use, infrastructure and socio-demographics. Manuscript submitted for publication.

Fu, M. and Kelly, J.A (2011) Carbon related taxation policies for road transport: Efficacy of ownership and usage taxes, and the role of public transport and motorist cost perception on policy outcomes. Manuscript submitted for publication.

IMP team (2011a) N-ETS 2020: Ireland's non-traded sector target, AP EnvEcon Report, Dublin, Ireland.

IMP team (2011b) Submission on potential reforms for VRT and Motor Tax in Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2011c) Sectoral Focus Report I – Transport, AP EnvEcon Report, Dublin, Ireland.

IMP team (2011d) TREMOVE Ireland Final Report, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010a) Activity Rebalancing – Notes for development and initial testing results, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010b) Climate and Energy report #2 Copenhagen, Ireland and International Developments, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010c) Executive Summary Report 2010 from GAINS Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010d) GAINS Ireland, Cost Guide: Version 1, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010e) GAINS Mitigation Effort Calculator, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010f) GAINS Ireland, Energy Guide: Version 1, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010g) GHG Comparison brief – GAINS vs. National Forecast 2010, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010h) Non-technical measures I – Consideration of an initial framework for the integrated evaluation of non-technical measures in climate and transboundary air pollution modelling and policy, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010i) Policymeasures.Com, Editor Guide: Version 1, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010j) The NO_X National Emission Ceiling for Ireland – review of progress, options and factors that militate against compliance, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010k) Transboundary Comparison brief – GAINS vs. National Forecast 2010, AP EnvEcon Report, Dublin, Ireland.

IMP team (2010l) Vehicle Stock Forecasting – Use of a modified TREMOVE based methodology, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009a) Climate, air and Energy report #1 Decisions and Developments in the fields of climate and air quality policy, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009b) Flexibilities – An initial review of potential flexible compliance mechanisms for emission ceiling type regulation, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009c) Full Scenario Report 2009 from GAINS Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009d) GAINS Agricultural Guide: Version 1, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009e) Greenhouse Gases Marginal Abatement Curve Brief, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009f) Harmonisation Report 3 – Improved calibration of GAINS Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009g) Origins of the Emissions Trading Scheme in the European Union Brief, AP EnvEcon Report, Dublin, Ireland.

IMP team (2009h) Pathway – NO_x 2010–2015 Consideration of Ireland's NO_x emission trend and opportunities to accelerate progress on the path toward compliance with the NECD, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008a) A Brief on Examples of NO_x taxation, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008b) A Brief on the GHG Capacities within GAINS, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008c) A Brief on the Theory of Pollution Control, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008d) Brief on Vehicle Weight Classifications in Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008e) Control Strategies in the GAINS model – a Case Study Example, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008f) Harmonisation Report 1 – Improved Calibration of GAINS Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008g) Harmonisation Report 2 – Improved Calibration of GAINS Ireland, AP EnvEcon Report, Dublin, Ireland.

IMP team (2008h) TREMOVE and TREMOVE Ireland - Model Overview, AP EnvEcon Report, Dublin, Ireland.

Kelly, J.A. (2006) An Overview of the RAINS Model. Environmental Research Centre Report, Environmental Protection Agency, Dublin, Ireland.

Kelly, J.A., Lumbreras, J., Maas, R., Pignatelli, T., Ferreira, F. and Engleryd, A. (2010) Setting National Emission Ceilings: Ex-post evaluation of the Gothenburg Protocol from the country perspective, *Environmental Science and Policy* (13) 28–41

Kelly, J.A. and Vollebergh, H. (2010) Adaptive Policy Mechanisms – A preliminary discussion of adaptive and flexible options for environmental target setting in the context of transboundary air pollution. Interim report communicated to Spanish Presidency, accessed online 1/1/2011 at: http://www.policymeasures.com/resources/

Kelly, J.A and Vollebergh, H. (2011) Adaptive policy mechanisms for transboundary air pollution regulation: Reasons, Reviews and Recommendations. Manuscript submitted for publication.

King, F., Fu, M. and Kelly, J.A (2011) A practical approach for the assessment and illustration of uncertainty in emissions modelling: A case study using GAINS Ireland, *Environmental Science and Policy* (14) 1018–27

Organisation for Economic and Cooperative Development (2010) Environmental Performance Reviews: Ireland 2010, OECD, Paris, France.

Redmond, L. (2010a) Competitiveness and allowance allocation in Phase 3 of the EU ETS: a review. Manuscript submitted for publication.

Redmond, L. (2010b) The clean development mechanism (CDM) – contemporary review of CDM critiques & perceived weaknesses. Manuscript submitted for publication.

Redmond, L. Kelly, J.A, Clinch, J.P and King, F. (2011) The abatement challenge of complying with a member states non-ETS emissions target – Ireland a case study. Manuscript submitted for publication.

Schopp, W., Klimont, Z., Suutari, R., Cofala, J., (2005) Uncertainty analysis of emission estimates in the RAINS integrated assessment model. *Environmental Science & Policy* (8) 601–13.

Sustainable Energy Autority of Ireland (SEAI)/ McKinsey (2009) Ireland's Low-Carbon Opportunity, SEAI, Dublin, Ireland.

TFEIP Ad hoc group (2011) A technical assessment of incorporating correction and flexibility mechanisms into the Gothenburg Protocol Revision Process, accessed online 1/1/2011 at: http://www.policymeasures.com/resources/

Acronyms and Annotations

IMPI	Integrated Modelling Project Ireland
AEF	Abated emission factor
AMT	Annual Motor Tax
CGE	Computable general equilibrium
COPERT	Calculation of Emissions from Road Transport
CSO	Central Statistics Office
CV	Coefficient of variation
EC4MACS	European Consortium for Modelling of Air Pollution and Climate Strategies
EECCA	Eastern Europe, Caucasus and Central Asia
EOS	Elasticity of substitution
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GUI	Generic user interface
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
Kt	Kilotonnes
LULUCF	Land Use, Land Use Change and Forestry
NETS	Non-Traded Sector (European GHG Targets context)
NIAM	Network for Integrated Assessment Modelling
NTM	Non-Technical Measures
POV	Propogation of variance
RAINS	Regional Air Pollution Information and Simulation
TFEIP	Task Force on Emissions Inventory and Projections
TFIAM	Task Force on Integrated Assessment Modelling
UNECE	United Nations Economic Commission for Europe
VAT	Value Added Tax
VRT	Vehicle Registration Tax
WAM	With additional measures
WM	With measures

Appendix I: Formal Project Outputs

This appendix lists the formal project outputs by category. Published papers are available from their respective journals, submitted papers are not yet released. In regard to reports, briefs, guides, presentations and other outputs these may, in most cases, be sourced through the www.impireland.ie website or the www.policymeasures.com web resource. Certain documents have been provided solely to the project steering committee during the evolution of the work.

Published Papers

Kelly, J.A., Ryan, L., Casey, E. and O'Riordan, N. (2009) Profiling road transport activity: Emissions from 2000–2005 in Ireland using national car test data. *Transport Policy* 16, (4), 183–92.

Kelly, J.A., Lumbreras, J., Maas, R., Pignatelli, T., Ferreira, F. and Engleryd, A. (2010) Setting National Emission Ceilings: Ex-post evaluation of the Gothenburg Protocol from the country perspective, *Environmental Science and Policy* (13) 28–41.

Fu., M., Ahern, A. and Kelly, J.A. (2011) Regional characteristics and the distribution of car engine sizes: A case study of Ireland, *Transportation Research Part D*, (16) 509–14.

King, F., Fu, M. and Kelly, J.A (2011) A practical approach for the assessment and illustration of uncertainty in emissions modelling: A case study using GAINS Ireland *Environmental Science and Policy* (14) 1018–27.

Submitted Papers and Working Papers

Redmond, L., Kelly, J.A., Clinch, J.P. and King, F. (2011) The abatement challenge of complying with a member states non-ETS emissions target – Ireland a case study. Manuscript submitted for publication.

Kelly, J.A and Vollebergh, H. (2011) Adaptive policy mechanisms for transboundary air pollution regulation: Reasons, Reviews and Recommendations. Manuscript submitted for publication.

Fu., M., Kelly, J.A., Clinch, J.P. and King, F. (2011) Environmental policy implications of working from home: modelling the impacts of land-use, infrastructure and socio-demographics. Manuscript submitted for publication.

Fu, M. and Kelly, J.A (2011) Carbon related taxation policies for road transport: Efficacy of ownership and usage taxes, and the role of public transport and motorist cost perception on policy outcomes. Manuscript submitted for publication.

Redmond, L. (2010) Competitiveness and Allowance Allocation in Phase 3 of the EU ETS: A Review. Manuscript submitted for publication.

Redmond, L. (2010) The Clean Development Mechanism (CDM) – Contemporary Review of CDM Critiques & Perceived Weaknesses. Manuscript submitted for publication.

Reports

Kelly, J.A. (2011) IMP Project Final Report

IMP team (2011) TREMOVE Ireland Final Report

IMP team (2011) N-ETS 2020: Ireland's non-traded sector target

TFEIP Ad hoc group (2011) A technical assessment of incorporating correction and flexibility mechanisms into the Gothenburg Protocol Revision Process

IMP team (2011) Submission on potential reforms for VRT and Motor Tax in Ireland

IMP team (2011) Sectoral Focus Report I – Transport

IMP team (2010) Non-technical measures I – Consideration of an initial framework for the integrated evaluation of non-technical measures in climate and transboundary air pollution modelling and policy

IMP team (2010) The NO_X National Emission Ceiling for Ireland – review of progress, options and factors that militate against compliance

Kelly, J.A. and Vollebergh, H. (2010) Adaptive Policy Mechanisms – A preliminary discussion of adaptive and flexible options for environmental target setting in the context of transboundary air pollution

IMP team (2010) Climate and Energy report #2 Copenhagen, Ireland and International Developments

IMP team (2010) Executive Summary Report 2010 from GAINS Ireland

IMP team (2009) Full Scenario Report 2009 from GAINS Ireland

IMP team (2009) Flexibilities – An initial review of potential flexible compliance mechanisms for emission ceiling type regulation

IMP team (2009) Pathway – NO_x 2010–2015 Consideration of Ireland's NO_x emission trend and opportunities to accelerate progress on the path toward compliance with the NECD

IMP team (2009) Climate, air and Energy report #1 Decisions and Developments in the fields of climate and air quality policy

Kelly, J.A. (2007) Making GAINS: Towards the Development of GAINS Ireland. Report.

Kelly, J.A. (2007) A Disproportionate Challenge? A retrospective assessment of the factors underpinning the 2010 ceiling for oxides of nitrogen under the NECD. Dublin: Report.

Kelly, J.A. (2007) 2020 Ceiling Analysis – A review of the 2020 National Emissions Ceilings for Ireland under the EU NEC Directive. Report.

Briefs

IMP team (2010) Activity Rebalancing – Notes for development and initial testing results

IMP team (2010) Vehicle Stock Forecasting – Use of a modified TREMOVE based methodology

IMP team (2010) GHG Comparison brief – GAINS vs. National Forecast 2010

IMP team (2010) Transboundary Comparison brief – GAINS vs. National Forecast 2010

IMP team (2009) Greenhouse Gases Marginal Abatement Curve Brief

IMP team (2009) Origins of the Emissions Trading Scheme in the European Union Brief

IMP team (2009) Harmonisation Report 3 – Improved calibration of GAINS Ireland

IMP team (2008) Brief on vehicle weight classifications in Ireland

IMP team (2008) A Brief on examples of NO_X taxation

IMP team (2008) A Brief on the theory of pollution control

IMP team (2008) A Brief on the GHG capacities within GAINS

IMP team (2008) Harmonisation Report 2 – Improved calibration of GAINS Ireland

IMP team (2008) Harmonisation Report 1 – Improved calibration of GAINS Ireland

Guides

IMP team (2010) PolicyMeasures.Com, Editor Guide: Version 1.

IMP team (2010) GAINS Ireland, Cost Guide: Version 1.

IMP team (2010) GAINS Ireland, Energy Guide: Version 1.

IMP team (2010) GAINS Mitigation Effort Calculator

IMP team (2009) GAINS Agricultural Guide: Version 1.

IMP team (2008) TREMOVE and TREMOVE Ireland - model overview

IMP team (2008) Control strategies in the GAINS model – a case study example

Presentations and Submissions

Over 30 international and national presentations were delivered in respect of this project during the course of the work. Many of these can be accessed via the www.impireland.ie project website. Many informal briefs, reviews and submissions as well as official data submissions were also made as part of the project work.

Models and Systems

GAINS Ireland model and associated systems

TREMOVE Ireland model and associated systems

www.PolicyMeasures.com web resource

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Climate Change Research Programme (CCRP) 2007-2013

The EPA has taken a leading role in the development of the CCRP structure with the co-operation of key state agencies and government departments.
The programme is structured according to four linked thematic areas with a strong cross cutting emphasis.
Research being carried out ranges from fundamental process studies to the provision of high-level analysis of policy options.

For further information see
www.epa.ie/whatwedo/climate/climatechangeresearch

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government