EPA Climate Change Research Programme 2007–2013

NETS 2020 – Ireland's Non-Traded Sector Target

An Analysis of Non-Emissions Trading Scheme Emissions Using the GAINS Model

CCRP Report

Prepared for the Environmental Protection Agency

by

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The EPA Climate Change Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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This report considerably advances the GAINS Ireland work in the context of climate policy analysis. The exercise has also identified parameters and components where further research or evidence is required to facilitate or validate national measurements and thereafter to enhance national representation in the GAINS Ireland system.

This version of the report has been abbreviated considerably for publication and release by the EPA. The earlier but extended version of this revised report is available via the following link: http://www.tinyurl.ie/NETS2020.

Views expressed are those of the author alone.

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Executive Summary

This report presents an analysis of the challenge Ireland faces in regard to the 2013–2020 greenhouse gas emissions limits established for the Non-Emissions Trading Scheme (NETS) sectors by the European Union (EU). The NETS sectors are those sectors not captured within the EU's Emissions Trading Scheme (ETS) and primarily include agriculture, transport, domestic, commercial and light industry. The original NETS targets were principally established on the basis of ability to pay in 2005, specifically considering the gross domestic product (GDP) per capita of a Member State as an indicator of the capacity to invest in further abatement and the likely rate of future growth. The current Irish economic outlook is far removed from the situation that prevailed at the time when the NETS targets were established. The economic decline has contributed to notable falls in emission levels in the national inventory as compiled by the Environmental Protection Agency (EPA); however, this economic situation will also constrain the availability of finance to invest in abatement and change.

Evidence is required now that informs the choice of abatement options and policies, and that identifies cost-effective pathways towards compliance. In presenting this information, we must also reconcile the cost of investments and actions with the combined savings from efficiency, abatement and contribution towards compliance with environmental objectives. The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) Ireland model affords us the capacity to evaluate a broad range of policies and measures across all sectors of the economy, with a focus on the abatement delivered and associated cost. This report engages the GAINS Ireland model to evaluate a pathway to NETS compliance in 2020.[1] The official 2011 'With Measures' (WM) energy scenario has been paired with official agricultural forecasts of 2011 to provide a baseline activity forecast in the GAINS Ireland model. The principal calibration challenge in this process lay in configuring the 'menu' of abatement options in the model prior to analysis. This involved adjusting the existing, expected and possible abatement measures in the modelling system so as to reflect what is, and what else might be done in Ireland and at what cost. The abatement menu calibration is a blend of in-house estimations by the Integrated Modelling Project (IMP) team, official national estimations, other national research and internationally defined estimates for measures. The type of measure captured is broad but not exhaustive, and it is important to acknowledge, in particular, that non-technical or behavioural measures (e.g. carbon tax) generally remain exogenous to the model. The outcomes of such policies can be integrated in regard to the baseline energy data that are loaded into the model, and in this regard official WM energy forecasts produced by the Sustainable Energy Authority of Ireland (SEAI) and provided by the EPA have been drawn on.[2] However, it should be noted that these types of measures are not included formally in the abatement menu for optimisation due to the complexity associated with determining their impact, feasibility and cost for the optimisation process used in this analysis.[3] Table 1 outlines the principal categories of measure that were used in this NETS analysis. There is further detail on these points within the main body of this report in Chapters 2 and 4.

The primary outcome of the analysis suggests that from the WM baseline starting point and excluding Land Use, Land-Use Change and Forestry (LULUCF),

1. This report recognises that interim annual targets are in place from 2013 to 2020; however, for the purpose of this analysis, the focus remains on the 2020 end point only.

2. The full listing of policies and measures included within the baseline energy data can be sourced in the appendix of http://www.seai.ie/Publications/Statistics_Publications/Energy_Modelling_Group/Energy_Forecasts_for_Ireland_to_2020-2010_report.pdf
3. For example, the model optimisation does not consider the emissions reductions that might be achieved from incrementally higher carbon taxes, e.g. €50, €75, €100/t. Analysis of such interventions and the impact would require specialised modelling. Technological and procedural measures and their potential impact are more readily managed in the GAINS model framework, as they are more predictable in terms of cost and impact.

Table 1. Main categories of abatement measures used in the Non-Emissions Trading Scheme analysis.

Sector	Types of measure
Power plants	Fuel switching, CHP, efficiency improvements, IGCC
Residential & commercial	Three-stage energy-saving packages for HVAC and appliance use in new and old houses, apartments, commercial buildings
Industry	Fuel switching, good practices, three-stage energy-saving packages, various nitrous oxide and F-gas controls
Transport	Advanced engines, efficiency improvements, hybrids, plug-ins, electrics
Waste	Waste diversion and treatment options, flaring and utilisation of gas, wastewater management, waste burning regulation
Agriculture	Fertiliser application controls, animal feed, anaerobic digestion, advanced agro-chemicals, precision farming

CHP, combined heat and power; IGCC, integrated gasification combined cycle; HVAC, heating, ventilation, and air conditioning; F-gas, fluorinated greenhouse gas.

the NETS target of 37.4 Mt of carbon dioxide equivalent (CO_2e) in 2020 cannot be met via the defined menu of options where measures up to a marginal cost limit of €50_{2005}/t CO_2e are taken. Nor can it be met where all of the non-exclusive menu options[4] are taken at marginal costs up to €225_{2005}/t CO_2e. The results show that the €50 cap (LCO/OPT scenario in Fig. 1) on marginal abatement cost delivers NETS emissions of 42.2 Mt, whereas the unrestricted marginal cost cap (Maximum Feasible Reduction (MFR) scenario in Fig. 1) delivers a NETS emissions outcome of 40.4 Mt. The inability of the optimisations to achieve the target in 2020 also signals additional concern for the interim targets from 2013 to 2020, which are not analysed in this report. As part of extended assessments, it was found that only where the national 'With Additional Measures' (WAM) scenario is substituted into the model set-up and

4. In other words, measures that may be combined – not all controls are additive. For example, if we already have 100% of a Stage 2 control, we cannot also add more of a Stage 1 control to obtain further emission reductions in that situation.

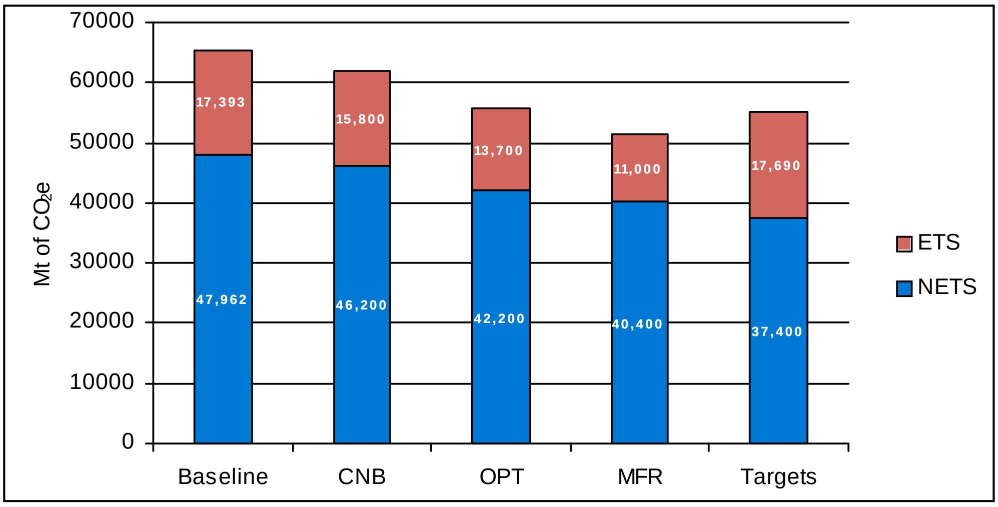

Figure 1. Emissions Trading Scheme (ETS) and Non-Emissions Trading Scheme (NETS) sectoral emissions under the modelled scenarios and baseline with targets. CNB, Cost-Neutral Baseline; OPT, Least Cost Optimisation (LCO/OPT); MFR, Maximum Feasible Reduction.

measures engaged up to a marginal abatement cost of €200/t CO_2e can the 37.4 Mt target be achieved.

Beyond the quantitative results focus, there are four key outcomes from this work in respect of Ireland's ongoing efforts to address this challenge.

1. The GAINS Ireland model offers an excellent framework into which developed research and evidence may be integrated, and will thereby provide a robust methodological platform on which to build both dynamic compliance strategies and sound negotiation positions for both climate and trans-boundary air pollution commitments. This report represents an important development in this context. GAINS Ireland will continue to be developed to provide increasingly robust technical support in regard to the NETS annual target challenges, including the requisite 'corrective plans' that will be necessary where an annual target is missed in the 2013–2020 period.

2. The model excludes certain policy interventions in the optimisation process (e.g. revisions to the carbon tax) that can also contribute to progress on the target. There is also untapped potential in the transport sector that has not been adequately captured in this first calibration of the model for GHG optimisation analysis. Thus, the results do not represent all that can be done and as we develop our knowledge on new options and validate information for others, we can expand and strengthen the analysis offered.

3. The cost assessment from a social planner perspective[5] 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/t is taken. This is encouraging, but highlights that whilst social cost analyses indicate worthwhile actions, barriers, such as information asymmetry and financing, persist from a private investment perspective that require innovative solutions if we are to deliver on the potential that has been defined.

4. Whilst the WM optimisations fail to achieve the NETS target, the impact on over-compliance for the ETS sector is notable. In addition, there would be strong co-benefits with trans-boundary air pollution policy objectives where significant progress is made on the NETS target.

5. The social planner perspective is a term used to reflect the approach to cost in the model whereby values to society are the focus. Specifically, this includes an assumption of costs at production level rather than consumer prices. Therefore, all mark-ups, taxes and subsidies are ignored. The full approach to cost is relatively detailed, and an IMP guide on the topic can be found at http://www.policymeasures.com/resources/detail/gains-abatement-cost-guide/.

1 Introduction

It is a globally shared goal to prevent dangerous climate change. The European Union (EU) has adopted a position whereby global temperature rise would, as far as possible, be no more than 2°C above pre-industrial levels. This target has been clearly communicated to the United Nations Framework Convention on Climate Change (UNFCCC) and sets the EU apart as a global leader in climate protection. The actions necessary within Europe to contribute towards attainment of this goal are defined under EU climate change policy, whereby Member States are currently required to collectively reduce the EU's greenhouse gas (GHG) emissions by 20% relative to 1990 over the period 2013–2020. The effort could be increased to 30% should there be a significant commitment in terms of climate ambition from other major developed nations; however, currently the target remains at 20%. In order to achieve the objective of a 20% reduction in GHG emissions in a cost-effective manner, the European Commission (EC) emphasised a need for all sectors of the economy to contribute to achieving these emission reductions.[1] The EU agreed specific targets for the Emissions Trading Scheme (ETS) (traded) and Non-Emissions Trading Scheme (NETS) (non-traded) sectors as follows:

- A 21% reduction in ETS sector emissions by 2020 compared with 2005.[2] This reduction will be achieved through the allocation of an annually declining single EU-wide allowance cap across all ETS sectors between 2013 and 2020. There are no country-specific targets for ETS emissions.
- An overall 10% reduction in NETS emissions by 2020 compared with 2005 levels. Each Member State has agreed a specific emissions limit for the 2013–2020 period.

This report focuses on Ireland's NETS challenge. The Irish ETS sector is also evaluated, as important interactions exist between the ETS and NETS sectors. However, as the ETS is closely regulated by Europe, with the established participation of market players, it presents less of a *direct* concern for Member State policy makers. In contrast, the non-traded sector targets comprise a challenging set of responsibilities for many individual Member State policy makers who must manage these complex multi-agent sectors. Co-benefits for other areas (e.g. trans-boundary air pollution) that are captured within the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) modelling system are not presented in this analysis in order to maintain the focus on the NETS challenge.

The principal objective of this report is to undertake an analysis of Ireland's NETS target challenge, and to identify potential pathways 'towards' compliance. The approach is to utilise a configuration of the 'full'[3] capacities of the GAINS Ireland model[4,5] to determine the scope and costs of potential abatement and mitigation options from the relevant NETS sectors in regard to GHG emissions. Optimisation analysis is used to constrain the system to the specific targeted

1. Point 1 of "*Position of the European Parliament adopted at first reading on 17 December 2008 with a view to the adoption of Decision No. .../2009/EC of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020*"; http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+20081217+SIT+DOC+WORD+V0//EN&language=EN.
2. 2005 was used as the reference year as it was the most recent year for which reliable data were available. It includes verified emissions at installation level within the EU ETS, as well as the overall GHG emissions of Member States as officially reported to the UNFCCC.
3. To date, the GAINS model has rarely been run in a full mode whereby the model engages all abatement options (e.g. fuel switching and efficiency changes, in addition to technical options) and pollutants in an assessment. This mode, in a climate context, is a comparatively more recent development of the system and yet requires a considerable effort for refined calibration to individual Member States. For the purpose of this report, the Integrated Modelling Project (IMP) team has engaged closely with the International Institute for Applied Systems Analysis (IIASA) and national experts in order to establish an initial calibration platform for analyses. Further national research and effort will be required over time to develop and sustain this system for ongoing usage.
4. http://www.policymeasures.com/resources/results/category/models/
5. http://gains.iiasa.ac.at/index.php/publications/reports-n/reports-2

outcome. Specifically, the optimisation focuses on identifying a least cost pathway to attainment of the NETS target in Ireland in 2020. The principal analysis is derived from the GAINS Ireland model framework, calibrated with the most recent national 'With Measures' (WM) energy forecast (SEAI, 2010) and agricultural data provided in 2011 from the Environmental Protection Agency (EPA) projections unit. A sensitivity calibrated on the 'With Additional Measures' (WAM) energy forecast[6] is also run, with summary results discussed. The section below provides a brief upfront introduction to the key methodological concepts that must be understood from the outset in reading through the report.

1.1 Methodology and Report Overview

The analysis in this report draws principally on the GAINS Ireland Model and the associated methodologies of the GAINS modelling framework.[7] The GAINS model is a techno-economic integrated assessment model, focused on climate and trans-boundary air pollution policy. In the context of this report, there are three principal components to the model operations that are particularly relevant to understanding and interpreting the analysis presented in this work. These are activities, controls and optimisation.

1.1.1 Activities

This refers to the activities in regard to energy use, agricultural data (e.g. herd, fertiliser use) and processes such as waste treatment or cement manufacture. These data represent the major drivers of emission levels. In this report, activity levels have been based upon recent official national data where available. As mentioned, the activity component of the model has been calibrated with the most recently available national data on agriculture (direct correspondence spring 2011, EPA) and energy activity (SEAI, 2010).[8] Supplemental information on other emission drivers, such as population, waste generation and cement production, have also been sourced from official data and are included as available. All data in the model are forecast out to a 2020 time horizon. The principal energy scenario choice is the WM or baseline scenario. It includes defined measures in place, and does not presume success with a number of relevant targets, for example national energy efficiency targets or renewable energy targets. A sensitivity using the WAM[9] scenario is also run to indicate the estimated cost and abatement potentials from a more advanced starting point in terms of renewable deployment and energy efficiency progress.

1.1.2 Controls

The control component relates to the 'menu' of abatement controls or other actions available within the calibrated model to *control* emissions. These controls are detailed in the system in terms of what is currently in place, what is expected in 2020, and what is believed to be *technically* feasible by 2020. Each individual control is linked to a specific abatement potential per unit of relevant activity, a corresponding abatement cost function and also the associated synergies or trade-offs with other measures and pollutants. The GAINS Ireland model benefits from a core of international research in its design and *default* calibration of this menu. National specific studies have also been used where available to refine the model in line with *national* research and evidence, though there are many analytical gaps in the national research of 'options' and their cost and potential. Specifically, the preparatory work for this analysis has focused upon:

- Reflecting those measures *implicit* within the national activity scenarios mentioned[10] – so as to limit the risk of double counting of abatement potential in the analysis;

- Researching and defining appropriate boundaries for the potentials of abatement controls – so as to more appropriately reflect what can be done in Ireland; and

6. Also known as the National Energy Efficiency Action Plan (NEEAP)/National Renewable Energy Action Plan (NREAP) scenario.
7. For specific reference material on GAINS Ireland approaches, see AP EnvEcon (2008, 2010a,c), and for information on the general model framework, see, for example, Hoglund-Isaksson et al. (2009) and Klaassen et al. (2004).
8. Actual data files for energy forecasts were sourced from the EPA directly.
9. Defined also as the NEEAP/NREAP scenario in the national projections (SEAI, 2010).
10. For example, accounting for the effect of implicit energy efficiency progress in the two scenarios used. Reflecting the energy change is straightforward, reflecting the controls used to achieve this is more complex.

- Refining and adjusting the cost, efficiency and abatement potentials of measures – so as to improve confidence in the cost and abatement results generated by the model.

1.1.3 Optimisations

The linked structure of activities, costs and controls in GAINS is what allows the optimisations to determine outcomes such as a cost-effective pathway to a given emission constraint[11] or the maximum abatement progress that can be achieved for a given investment. The analytical approach within this report is to run three optimisations over the 2011 WM scenario as follows:

1. **Cost-Neutral Baseline (CNB)**[12]
   An optimised baseline that selects measures with negative or zero marginal abatement cost to reconfigure the baseline to a 'no regret' starting point where savings would be greater than cost.

2. **Maximum Feasible Reduction (MFR)**
   This run presents the maximum level of emission reductions that may be achieved from the analytical perspective of the model. Whilst the title suggests no limit on cost, in practice measures range up to €250_{2005}/t CO_2. No measures above this cost are included in the menu of abatement options.

3. **Least Cost Optimisation (LCO/OPT)**
   The LCO/OPT is an optimised scenario constrained to find the least cost pathway to achieving the NETS target, with a cap imposed on the marginal cost of measures of €50_{2005}/t CO_2.

11. Alternatively, in cases where the target cannot be met with all measures, the optimisation will return, inter alia, the remaining gap that must be closed.
12. Note that the CNB corresponds to the 'Cost Optimal Baseline' or COB definition used by IIASA in this context. The COB was renamed, following external review, the CNB. It is important to note that CNB refers to the net annualised cost of measures, but does not include externalities associated with emissions and activities, which are captured in a separate strand of the policy process.

The focus for the optimisations above is the WM scenario; however, summary results from a sensitivity analysis that runs the same optimisations over the more ambitious[13] WAM scenario for 2011 are also presented. These indicate a more advanced starting point in terms of closing the gap on the NETS target, given higher renewable penetrations, achievement of national efficiency targets and so forth. Whilst additional measures are captured in the model calibration for the WAM scenario, the outcomes still deliver a lower level of emissions in 2020 as the WAM includes certain options (e.g. high electric vehicle (EV) penetration) and specific rates of progress (e.g. energy efficiency, renewable shares) that go further than the defined control assumptions of the model for these additional measures.

The report is structured as follows. Chapter 2 provides the contextual setting for the report, describing the climate policy challenge facing Ireland specifically and how this challenge has been distributed between the traded and non-traded sectors. Chapter 3 briefly describes the modalities of the GAINS model, detailing how the model handles emissions, cost calculations and the split and interactions between the traded and non-traded sectors in the model framework. Chapter 4 presents modelled optimisation results, and Chapter 5 offers a brief discussion of further abatement potential. The latter includes areas where additional data are required to refine the national abatement potential in the model (e.g. transport and EVs) and areas where measures that lie outside the methodological framework of the model exist (e.g. carbon taxation) that can support further progress towards the NETS targets. These are discussed with reference to related research nationally by the IMP Team and others. Chapter 6 concludes.

13. In terms of energy efficiency and renewable penetration, for example.

2 The NETS Challenge

Ireland must comply with legally binding GHG emissions reduction commitments established under the EU's Climate and Energy (C&E) package and subsequent Effort Sharing Decision (ESD)[14]. The C&E package requires the EU ETS[15] sectors (principally the power sector and heavy industry) to reduce emissions levels in 2020 by 21% relative to 2005. The ESD requires that in 2020 Ireland will have reduced the GHG emissions of its NETS sectors (e.g. agriculture, transport, waste, residential & commercial, heat) by 20% relative to 2005 levels. The EC has, however, stated that Member State NETS sector targets could be further increased should a suitably ambitious international agreement to replace the Kyoto Protocol be reached. For now, however, Ireland's NETS challenge remains at a level of 20% below 2005 levels in 2020. In quantitative terms, this amounts to a threshold on NETS emissions in 2020 of 37.4 Mt CO_2e (EPA, 2011a) with annually declining, and still legally binding, NETS emission limits from 2013 to 2020 to support the drive to a compliance trajectory. The significance and immediacy of the challenge posed by these inter-annual targets from 2013 is acknowledged; however, this analysis focuses on the end point of 2020.

2.1 The Traded (ETS) and Non-Traded (NETS) Sectors

Currently, the ETS covers CO_2 emissions from large emitters in the heat and power generation industry and in selected energy-intensive industrial sectors.[16] Specifically, the ETS addresses CO_2 emissions from combustion installations with a rated thermal input in excess of 20 MW (except for municipal or hazardous waste incinerators), oil refineries, production and processing of ferrous metals, manufacture of cement (capacity >500 t/day), manufacture of lime (capacity >50 t/day) and ceramics, including brick, glass, and pulp, paper and board (>20 t/day). The ETS sector covers approximately 50% of the EU's CO_2 emissions and 40% of total GHG emissions.[17] The aviation sector is scheduled to join the ETS in 2012. The entry of the ETS into a third phase in 2013 will see further expansion of the scheme to include additional sectors (petrochemicals, ammonia and aluminium) and gases (nitrous oxide and perfluorocarbons).

The NETS sector essentially captures what remains. Specifically, it encompasses the agriculture, transport, residential & commercial, heat, waste and 'light' industry sectors. The EC identified non-ETS sector targets for Member States on the basis of Gross Domestic Product (GDP) per capita, with some acknowledgement of abatement potential[18], the underlying principle being one of solidarity between Member States and the need to allow for balanced and sustainable economic growth across the EU. Member States with relatively low per capita GDP and high per capita GDP growth expectations were permitted to increase their emissions relative to 1990 while those with relatively high GDP per capita must reduce their emissions.

2.2 Ireland's NETS Target

In determining emissions targets for Member State NETS and ETS sectors, the EU assigned Ireland a target requiring it to reduce its non-traded sector GHG emissions by 20% relative to 2005 by 2020. As noted, Ireland's 20% NETS target equates to a 2020 emissions level of 37.4 Mt CO_2e.

Emission reductions for the non-ETS sector will take place between 2013 and 2020. Under the C&E package, the EC proposed a linear emissions

14. Effort Sharing Decision (ESD) adopted jointly by the European Parliament and the Council – http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0136:0148:EN:PDF.
15. See the IMP Ireland Report on ETS at http://www.policymeasures.com/resources/detail/origins-of-emissions-trading-in-the-european-union/.
16. The Netherlands is the only Member State to utilise the ETS Directive's provision allowing Member States to include additional national GHGs in the trading scheme. The Netherlands has 'opted in' emissions from nitrous oxide.
17. See http://ec.europa.eu/clima/policies/ets/index_en.htm.
18. Specifically the GAINS model was used to inform the abatement capacities in respect of the agricultural sector.

reduction path for the national targets for the NETS sector over the period from 2013 to 2020. As a result of the 'effort sharing' approach under the C&E package, Member State annual binding emission budgets were determined in accordance with the EC's emission reduction path. Member State emissions will be subject to annual monitoring and compliance checks to ensure that EU GHG emissions gradually move towards agreed 2020 targets (EC, 2008a). The EC has warned that if in any given year a Member State's NETS emissions are greater than those permitted under the 'effort sharing' emission budgets, then it will be forced to take corrective action. Underachieved emission reductions will have to be realised in the following year, with a deduction from a Member State's emission allocation budget in the following year equal to the amount in tonnes of the emissions reduction underachievement multiplied by a penalty factor of 1.08. In addition, Member States will have to submit a corrective plan to the EC detailing the measures and time frame for getting back on track with a view to meeting their 2020 target (EC, 2008a). This will be an area where the GAINS Ireland model can offer valuable support in an Irish context. In this first report on the subject, the focus is on the final year performance in 2020. However, it is acknowledged that further examination of compliance with annual targets and the associated costs will be important for Ireland.

Figure 2.1 illustrates the NETS challenge facing Ireland. The data presented are based on the official national emissions forecast (EPA, 2012). From the figure, it is evident that the NETS sector is forecast to exceed its emissions target (37.4 Mt CO_2e) from 2016 onwards. According to the EPA (2012) WM NETS emissions are forecast to be 45.3 Mt CO_2e in 2020, thus exceeding the 2020 target by 7.8 Mt CO_2e. These projections exclude carbon sinks[19] (which would amount to approximately 4.8 Mt in 2020 (EPA, 2011a,b, 2012).

19. Carbon sinks, encompassing the storage and removal of GHG emissions associated with land use, land-use change and forestry (LULUCF), are currently excluded from use by Member States as part of their abatement strategy to comply with the 2020 targets. The EC is currently engaged in a consultation process to determine how carbon sinks might be incorporated into Member State emissions target compliance strategies.

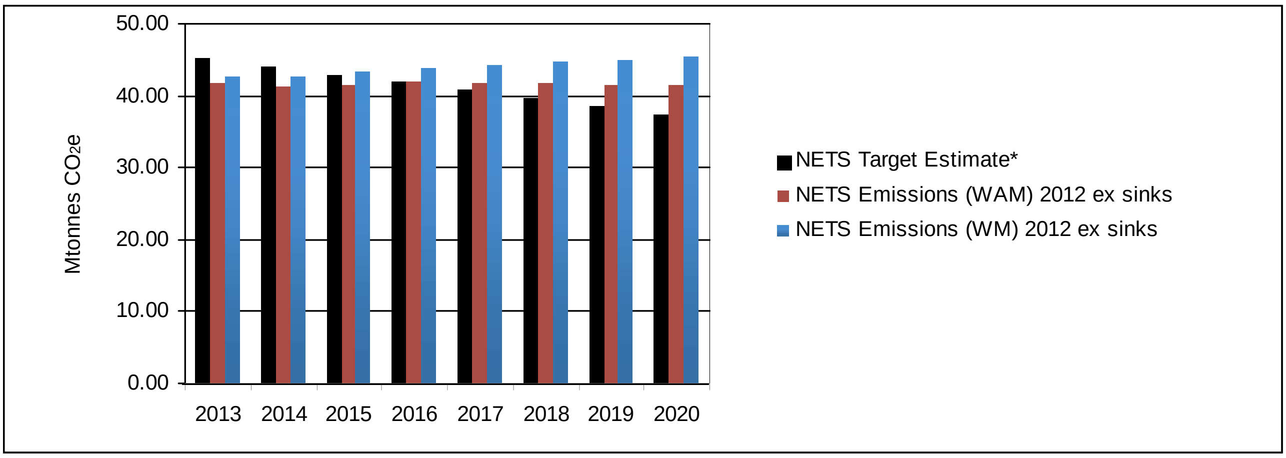

Figure 2.1. Ireland's Non-Emissions Trading Scheme (NETS) sector 2013–2020 greenhouse emissions pathways (EPA, 2012). WAM, With Additional Measures; WM, With Measures. *EPA (2012).

3 The GAINS Model Framework

This chapter is structured into five headings describing a number of aspects of the GAINS model framework in brief that are of particular importance in regard to the analysis presented in this report.[20] These are:

1. A general overview of the model framework;
2. The model handling of emissions;
3. The model handling of abatement options;
4. The model approach to cost estimation; and
5. The model approach to ETS and NETS disaggregation and interaction.

An earlier longer version of this report is available from the http://www.policymeasures.com web resource,[21] which includes further detail in regard to the specific set-up of the GAINS Ireland model for this analysis. This chapter builds on the earlier introductory notes in regard to 'activity', 'controls' and 'optimisation' in the model to offer a somewhat more specific explanation of the methodology.

3.1 Overview of GAINS Framework

The GAINS model provides an analytical framework to evaluate scenarios in respect of emissions, abatement options, costs and impacts (Klaassen et al., 2005; Amann et al., 2009).[22] The model incorporates exogenous information on energy and agricultural activity as well as an internationally researched and evolving menu of abatement options and their costs. The model evaluates multiple pollutants, effects and their interactions, simultaneously offering decision support in respect of climate and trans-boundary air pollution policy negotiation and strategy. Hoglund-Isaksson et al. (2009) provide a concise '4-step' description of the GAINS methodology used, with a focus on GHG and climate. They describe how the GAINS model:

1. Adopts exogenous projections of future economic development and implied activity levels in terms of energy consumption, transport demand, industrial production and agricultural activities as a starting point;
2. Develops a corresponding baseline projection of GHG emissions for 2020[23] with information derived from national GHG inventories and in collaboration with national expert teams to validate country-specific model input data assumptions;
3. Estimates, with a bottom–up approach, for each economic sector in each country the potential emission reductions that could be achieved through to 2020 as a result of the application of the available mitigation measures; and
4. Quantifies the associated costs that would emerge for these measures under the specific national conditions.

In addition to these steps, a non-linear optimisation process has also been developed to work in conjunction with the GAINS model framework. The optimisation process affords the capacity to solve modelled scenarios to defined constraints such as emission limits, effect limits or cost limits. This is achieved by not only utilising the information mentioned in the '4-step' process above, but also taking account of *further* abatement potentials and constraints, pollutant and effect interaction, and costs

20. As detailed previously, additional documentation and literature from the IMP Ireland work and IIASA can be sourced online as linked in Footnotes 4 and 5.
21. http://www.tinyurl.ie/NETS2020
22. The GAINS model includes all six greenhouse gases covered under the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs, SF6) and covers all anthropogenic sources that are included in the emission reporting of Annex I countries to the UNFCCC (Energy, Industrial Processes, Agriculture, Waste, and from LULUCF). GHG pollutants are presented in millions of tonnes of CO_2 equivalents. Covered air pollutants within GAINS include SO_2, NO_x, NMVOC, NH_3, CO, PM.
23. GAINS model analysis presently covers a 40-year period (1990–2030) in 5-year intervals. The focus in this report is on 2020.

and applicability that are captured in the wider modelling system.

3.2 Emissions in GAINS

GAINS takes account of the level of energy used for a given activity, the default emissions associated with that activity, and the presence and performance of any abatement controls. The key parameters/components that are engaged to estimate emissions within the GAINS model framework are presented in Table 3.1. A more elegant presentation of the emission estimation form is provided by Wagner et al. (2010) who describe in detail how the calculations are performed in the GAINS modelling system.

3.3 Abatement Options in GAINS

The GAINS model covers multiple pollutants and incorporates multiple abatement options of relevance to both trans-boundary air pollutants and GHGs. There are five categories of generic abatement measures for GHG reduction:

1. Technical measures (e.g. application of carbon capture and storage);
2. Energy efficiency measures (e.g. application of insulation to homes);
3. Lower carbon substitution measures (e.g. switching from coal to gas);
4. Technology deployment measures (e.g. replacing petrol cars with electric vehicles); and
5. Behavioural change measures (e.g. carbon taxation, behavioural regulation).

In this list, the full GAINS model can capture the role of a broad set of measures in Categories 1 to 4 (see main categories of modelled measures in Table 3.2).

However, behavioural change measures or non-technical measures require exogenous analysis if their role is to be incorporated into a given scenario. As noted earlier, the model can account for the impact of such measures in the baseline (e.g. lower energy use as a result of a carbon tax); however, such abatement options are not included in the optimisation process due to, inter alia, the complexity of bringing such options into a deterministic modelling framework such as GAINS (AP EnvEcon, 2010d). These behavioural measures are unlikely to feature in the GAINS optimisation process in the foreseeable future. Policy makers should, however, remain aware of the potential offered by such non-technical or behavioural measures where seeking to drive a path towards compliance. These points are revisited in Chapters 4 and 6. In regard to the analysis, the following specific assumptions are also noted in the model set-up with regard to the considered abatement potential (the parameters are entirely flexible for future studies):

Table 3.1. Primary elements of emission calculation.

Activity level[1]	The amount of energy used for a particular activity[2]
Fuel type	The fuel type providing the energy for the activity
Unabated emission factor[3]	The emission factors for the activity assuming no abatement technology
Technology	The abatement technology in place for a given activity
Capacity controlled	The proportion of an activity covered by a given ‘control measure’. This can be a technological measure or a fuel switching measure
Abated emission factor	The emissions factor for all pollutants after abatement

[1]There is often confusion regarding the dual use of the word activity in the GAINS modelling context. Activity in the model is used to describe the fuel type involved in a given process. Thus, activity level would be the petajoules of fuel used. However, activity is sometimes also used in the more common sense to describe a polluting activity, for example 4-stroke passenger cars are a sub-sectoral polluting activity.
[2]In the case of agriculture, the activity level often refers to animal numbers, and the activity type relates to the type of animal, for example dairy cattle or poultry.
[3]Emission factors for a given activity are reported as kilotonnes of CO_2 per unit of fuel. In the GAINS model, fuels and energy sources are reported in petajoules. For the fluorinated greenhouse gases, emission factors are reported in units of CO_2 equivalents.

Table 3.2. Main categories of abatement measures used in the Non-Emissions Trading Scheme analysis.

Sector	Types of measure
Power plants	Fuel switching, CHP, efficiency improvements, IGCC
Residential & commercial	Three-stage energy-saving packages for HVAC and appliance use in new and old houses, apartments, commercial buildings
Industry	Fuel switching, good practices, three-stage energy-saving packages, various nitrous oxide and F-gas controls
Transport	Advanced engines, efficiency improvements, hybrids, plug-ins, electrics
Waste	Waste diversion and treatment options, flaring and utilisation of gas, wastewater management, waste burning regulation
Agriculture	Fertiliser application controls, animal feed, anaerobic digestion, advanced agro-chemicals, precision farming

CHP, combined heat and power; IGCC, integrated gasification combined cycle; HVAC, heating, ventilation, and air conditioning; F-gas, fluorinated greenhouse gas.

- Fuel switching to biofuels is included as an option in the analysis, allowing 10% higher for first-generation biofuels than in the defined baseline;
- Switching to wind power is included as an option up to 8.75 PJ beyond the defined baseline;
- Solar and geothermal potentials are not included at this point; and
- Combined heat and power (CHP) for domestic heating and cooling is not included at this point.

3.4 Cost Estimation in GAINS[24]

Principally, the GAINS mitigation cost methodology operates on the basis of two general assumptions. In the first instance, GAINS estimates abatement values by approximating mitigation costs at production cost as opposed to consumer price level. Specifically, GAINS focuses on pure technology, investment and operational costs, ignoring transaction costs, such as taxes, subsidies and profits. Secondly, the GAINS methodology assumes the existence of a free market for abatement equipment. A further important choice in the model is the specific interest rate used in respect of investment costs. By default, the GAINS model uses a social interest rate of 4% $€_{2005}$, in order to reflect societal costs and returns.[25] This is different to private cost rates where higher interest rates on capital investments lead to higher private costs for the implementation of measures.

In regard to what is actually counted when it comes to cost, GAINS differentiates expenditure costs associated with individual abatement options into three standard cost components:

1. Investment costs;
2. Fixed operating costs; and
3. Variable operating costs.

For each of these categories, the model utilises a broad range of data parameters in the cost calculation process with data parameters generally classed as either 'common' or 'country specific'. The model calculates annual mitigation costs per unit of activity level. Costs are then expressed per tonne of pollutant abated.[26] A more comprehensive review of cost methodology by the IMP Ireland team is available in a separate guidance report (AP EnvEcon, 2010a), which highlights further variations when it comes to agriculture, efficiency measures and so on.

24. A detailed description of the handling and role of cost data in the GAINS model is provided in AP EnvEcon (2010a).

25. The system is, however, flexible and alternative higher rates can be introduced, e.g. 20%, that would be more representative of private investor cost perspectives.

26. Costs are generally expressed in constant euro values of a given year (e.g. 2000, 2005).

3.5 ETS and NETS Sectors in GAINS

The IMP Ireland team has applied a 'splitting file' to the model, which filters results between the ETS and NETS groupings. The specific disaggregation is informed principally by the EPA's 2011 *Monitoring Mechanism* report (EPA, 2011b) or MMR. Ultimately, the splitting file approach enables revisions to the split as required down to a sub-sectoral technology level if necessary.

For now, the split applied assigns all transport, commercial, residential, agricultural and waste activity to the NETS, and all power generation to the ETS. The ground on which a split occurs is industry, wherein broadly the split transfers all large and heavy industry activity to the ETS and the balance to the NETS. Specifically the MMR allocates 55% of industry CO_2 emissions to the traded sector with 45% to the non-traded. For the purpose of this report, therefore, 55% of GAINS industry emissions were allocated to the traded sector and 45% to the non-traded. Splits can be reviewed and adjusted via the splitting file as necessary into the future.

4 Results

This chapter discusses the baseline and the CNB[27] outcomes, followed by the results of the LCO/OPT and MFR scenarios. In regard to the baseline, the set-up of the GAINS Ireland model for this analysis using the WM scenario delivers a total of 65.10 Mt CO_2e in 2020, whereas the official national projections come in at 64.05 Mt CO_2e.[28] Just under 1 Mt of the variation is explained by higher emissions associated with higher milk yield under the GAINS methodology, with the balance attributable to moderate variations in other sectors such as waste. The varied categorisation of certain emission sources in GAINS also gives rise to some apparent distributional variation in the emissions, but these are generally well understood and have little impact on the results presented. Figure 4.1 illustrates how the 65.1 Mt are distributed across the sectors in GAINS Ireland.

The CNB is the first result presented. It is effectively a first-stage optimisation, whereby all measures with no net annualised cost are engaged and deployed. Thus, measures that deliver an annualised net saving are assumed to be taken under the CNB. For this reason, the model estimates the CNB first as it is intended to be representative of what could and 'should' be done anyway from a societal perspective. The outcome of the CNB analysis over the baseline is captured in Fig. 4.2, the result being a reduction in both ETS and NETS CO_2e emissions of 3.1 Mt combined, with NETS emissions coming down to a level of 46.2 Mt CO_2e. The specific measures taken (more/less of marginal cost curve format) are presented in Appendix 1 of the report for all marginal cost levels.[29] The CNB options are captured in the €0 marginal cost row.

In regard to the CNB though and the general presentation of abatement costs, it is worth reiterating the approach to cost in the model and in this specific assessment as described in Chapter 3. All costs presented here are calculated on a social interest rate of 4% on 2005 price levels and exclude transfer payments and transaction costs. It is principally these assumptions that give rise to the significant negative costs.[30] However, the observed potential in this analysis is by no means unique. Significant negative cost abatement options under comparable evaluation criteria are in line with the outcomes presented under the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Barker et al., 2007).

The next result presented is the LCO/OPT scenario. The LCO/OPT is a cost-minimising optimisation whereby the scenario seeks the lowest cost package of available measures that can be engaged to achieve a given target level of emissions. In the case of this report, the LCO/OPT target is the NETS emission target of 37.4 Mt CO_2e, with a marginal cost cap of less than €50_{2005}/t CO_2e imposed. The outcome of the LCO/OPT analysis is a total national emissions level of 55.9 Mt CO_2e, with the NETS emissions reduced to a level of 42.2 Mt CO_2e. In this case, we again fail to meet the NETS target under the prescribed conditions.

The final result presented is the outcome of the MFR scenario. In this case, the optimisation applies all available measures to determine the MFRs possible under the model conditions. In this assessment, the listed measures do not exceed a marginal cost of €250/t CO_2e; however, in time, the menu can be extended to include even higher cost potentials for abatement as well as other options not currently

27. Technically, the cost-neutral baseline is an optimisation.
28. Further detail on the set-up and sectoral calibration is found in Chapter 4 of the extended report: http://www. tinyurl.ie/NETS2020.
29. Some care is required in interpreting the marginal cost curve in the format presented in the appendix. Notes on this point are included within the appendix itself.

30. It is a common question to ask why, where such measures exist, they have not been taken. Briefly, this can be due to other barriers and failures other than cost. Whilst these other barriers are not discussed in this report, it is noted that it may be of interest to utilise a 20% rate to present a cost outcome representative of the cost investment under a private investment interest rate. This latter analysis would paint a different picture of the abatement options and can be conducted under further research in this area. Specifically, it would offer a perspective on the indicative scale of the financial barrier to private investment and would substantially reduce the cost savings relative to the social interest rate analysis presented.

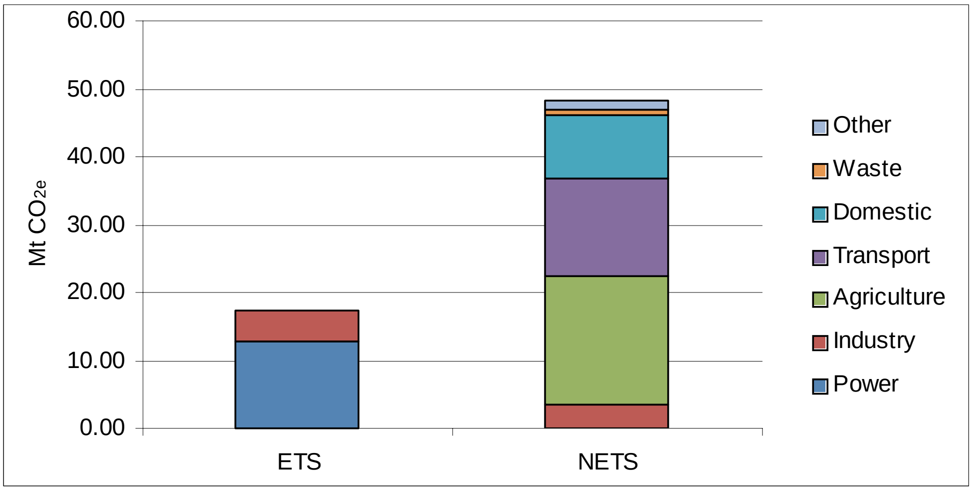

Figure 4.1. 2020 emission breakdown for the With Measures scenario in GAINS Ireland.

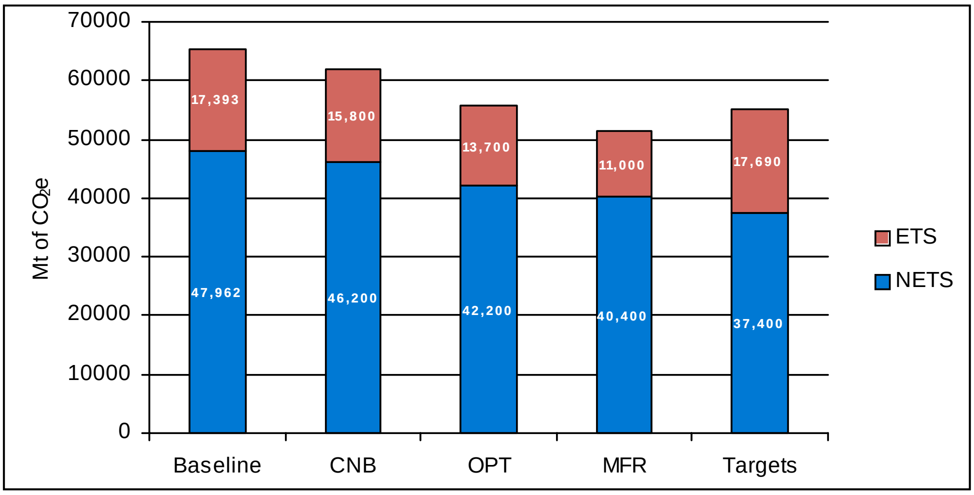

Figure 4.2. Emissions Trading Scheme (ETS) and Non-Emissions Trading Scheme (NETS) sectoral outcomes for the With Measures scenario baseline and defined optimisations in 2020. CNB, Cost-Neutral Baseline; OPT, Least Cost Optimisation (LCO/OPT); MFR, Maximum Feasible Reduction.

defined or considered. The result of the MFR optimisation is a total national emission level of 51.4 Mt CO_2e, with NETS emissions of 41.4 Mt CO_2e. Therefore, even under the MFR conditions described, Ireland fails to meet the NETS target of 37.4 Mt CO_2e. The summary results of all scenarios and the cumulative cost of different levels of marginal abatement cost thresholds are presented in Figs 4.2 and 4.3. Of note, Fig. 4.2 illustrates the connected impact of the optimisations on the ETS sector, where the CNB, LCO/OPT and MFR scenarios all deliver significant over-compliance for the ETS objective, whilst Fig. 4.3 demonstrates that from a *social planner's perspective*, the cumulative annualised net social cost of options taken remains negative up to the €150/t marginal abatement cost level.

In terms of specific measures, at the CNB level, national GHG emissions are reduced by 3.1 Mt CO_2e by taking measures from the zero marginal cost category. These are measures that offer net cost savings and emission reductions under the defined methodology. In terms of the main actions at this level, the CNB scenario adopts a range of measures principally associated with the increased efficiency of commercial and residential appliances and space

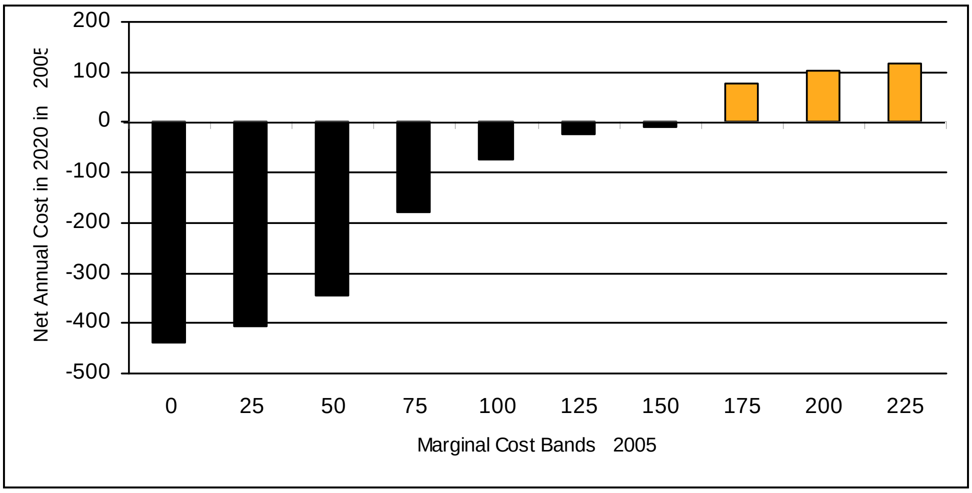

Figure 4.3. Net social cost of cumulative marginal cost band measures for the With Measures scenario in 2020.

heating, and the adoption of advanced efficiency and hybrid diesel trucks and buses into the transport fleet. Further measures in other sectors include the deep injection of manure into soils in the agriculture sector, and further investment in leak control for gas distribution networks and compressor stations.

The LCO/OPT scenario selects measures up to a marginal cost of €50/t CO_2e and develops from the CNB. The LCO/OPT scenario reduces total national GHG emissions by 9.2 Mt CO_2e from the baseline. At this level, changes in the power sector can be seen, with coal-fired generation being replaced by new gas-fired plants, and further adoption of biofuels and wind power in the sector. This further decarbonisation of the power generation sector in turn influences the penetration of efficient appliances and heating services in the domestic and commercial sectors, specifically slowing some of the change, as higher cost advanced stages of energy-efficient appliances and heating become less significant in terms of associated CO_2e reductions. At this level, changes in industry can also be seen, with the introduction of more industrial CHP, the use of alternative solvents and refrigerants, and the adoption of more efficient processes in production. In the agricultural sector, the introduction of farm-scale anaerobic digestion, a mix of feed changes and improvement of nitrogen efficiency via 'precision farming' can be seen.

Under the MFR scenario all measures (within the model menu of abatement options) that may be combined to achieve emission reductions are taken, with a view to identifying the greatest reduction in emissions possible under the current model framework conditions. In the MFR, some constraints remain in place over the potential change as described in Chapter 3 (e.g. no more than an additional 8.75 PJ of wind power beyond the baseline), and the menu of measures draws on those summarised earlier in Table 3.2. Under the MFR, a large number of 'more of'/'less of' changes take place in terms of abatement options, ultimately delivering a reduction in national GHG emissions of 13.7 Mt CO_2e from the baseline, with NETS emissions at 40.4 Mt CO_2e, some 4 Mt CO_2e above the target level for 2020.

4.1 Sensitivity

As a matter of interest, the CNB, LCO/OPT and MFR optimisations were also applied over the alternative WAM scenario, which is underpinned by the NEEAP/NREAP scenario. In this scenario, the energy data implicitly account for a far higher degree of renewables deployment nationally and the successful attainment of a number of policy targets, particularly in relation to energy efficiency.

The WAM scenario therefore presents a more advanced (in terms of emission reductions) starting point for the analysis, although the effect of commercial and residential efficiency measures are captured in the model set-up process by way of greater penetration of improved efficiency stage controls. Under the WAM scenario, the baseline emissions from the calibrated model are 59.2 Mt CO_2e. The CNB run delivers total national emissions of 56.8 Mt CO_2e, with NETS emissions down to 42.9 Mt CO_2e. The LCO/OPT run delivers a national emissions total of 51.2 Mt CO_2e, with a corresponding NETS emission level of 38.7 Mt CO_2e – still in excess of the national NETS target. Finally, however, the MFR brings national emissions to a level of 47.2 Mt CO_2e, with NETS sector emissions reduced to exactly 37.4 Mt CO_2e – the NETS target.

Caution is, however, required when using the WAM/NEEAP/NREAP scenario, given the inherent ambition of a number of the scenario assumptions, particularly the assumed success of undefined policies to achieve challenging energy efficiency and renewable targets across the sectors. As noted at the outset, it is felt that the WM scenario offers a more rational basis from which to plan and evaluate strategies and pathways to compliance.

5 Note on Additional Mitigation Options

As a point of information related to the results presented in Chapter 4, it is important to understand what these results represent in terms of potential. Simply put, they represent the menu of abatement options as defined in the modelling system used for the analysis. Therefore, there are a number of considerations with respect to abatement potentials and compliance with the NETS target that should also be discussed. Specifically, two brief discussions will be presented in relation to:

1. Additional technical potential and the core menu of measures; and

2. Non-technical and behavioural measures.

5.1 Additional Technical Potential of the Menu of Measures

This report presents the analytical outcomes of a first calibration of the full GAINS Ireland model for an assessment of GHG abatement potential. This introduces numerous additional challenges beyond those addressed whilst using the model previously to inform trans-boundary air pollution policy, as it extends the system into a new area with new information requirements. It is noted in the results that there is an apparent untapped potential from certain sectors which the current set-up of the model does not identify. Specifically, the transport sector should offer significantly greater emission reduction potential than identified in this first analysis, and this will be addressed in further work where a blend of model improvements and exogenous research can be combined to integrate the potentials and costs associated with options such as high levels of EV penetration, retrofitting and so forth. Similarly, it has been acknowledged earlier that the model has not included the potential for certain options, such as CHP in domestic heating, solar or geothermal, and has constrained certain potentials (e.g. wind energy and biofuels) to a degree. Of course these constraints can and will be changed in time as the system is further developed, and as new evidence and research to inform the set-up are gathered.

Indeed, on this first calibration exercise, a number of areas were identified where national data are lacking in respect of calibration requirements. This is not exclusively an Irish problem, and the difficulties are quite common at an international level also. The driver of this challenge is principally that the decision-support demands on the models require increasing levels of detail in calibration to enable their analysis of complex issues.[31] However, whilst a requirement for increased detail may prompt concern from some quarters, there is cause for optimism in regard to this 'calibration challenge', as it is expected that a number of research and technology initiatives, unknown or untested a decade ago, will be a great support in delivering the requisite data at a high resolution, that will offer a more robust evidence base into the future (e.g. advanced ICT in transport, smart metering in the home). Similarly, the higher level of funded research and monitoring that prevails nowadays will also facilitate the availability of an international evidence base for calibration that simply did not exist a decade or more ago. For the time being, however, we remain at an earlier stage in this process, and recognise that the calibration of the model requires additional evidence and research. Improvements in this regard will remain an iterative process, and it is acknowledged that calibration of certain measures in the modelling system (e.g. the cost and potential for insulation to reduce energy demands in the domestic sector) represent significant bodies of work in their own right that will take time to address. Nonetheless, this report presents initial results on the basis of available evidence, and the model framework offers a sound basis on which to integrate further evidence for analysis over time.

31. A major motivation for the development of the http://www.policymeasures.com resource was to support progress on this 'calibration challenge' in a coherent and internationally co-operative manner.

5.2 Non-Technical and Behavioural Policy Measures

There are many behavioural measures (e.g. road pricing, carbon taxation) that are not incorporated into the GAINS methodological framework explicitly for optimisation. However, in the context of GHGs and specifically the NETS target, such measures are of particular relevance to national progress on targets and stimulating the necessary investments and change. Such measures can be evaluated exogenously and subsequently be incorporated back into the GAINS modelling framework[32] (AP EnvEcon, 2010d).

Analysis to deliver quantified abatement potential estimates of such exogenous measures, as well as policy interactions, has been conducted as part of parallel research under the IMP Ireland project. Of particular relevance is that the team has conducted detailed measure analyses and written papers on topics such as:

- The factors influencing vehicle purchase decisions in Ireland (Fu et al., 2011);
- Carbon, vehicle registration and road tax policies for transport (Fu and Kelly, 2012); and
- The scope for flexible working policies to reduce emissions (Fu et al., 2012).

Furthermore, the IMP project has developed and launched a policy and measures resource at http://www.Policymeasures.com to serve as an accessible community repository of information relating to theoretical and empirical environmental policies and measures across all sectors, both technical and non-technical. Over time, these potentials and the evidence from this system can be integrated into the modelling system and into broader model frameworks to offer more comprehensive and internationally coherent evaluations of abatement potential and policy synergies and trade-offs.

32. Though this process remains somewhat complex and challenges persist in regard to accounting for exogenously evaluated measures appropriately in the context of optimisation analyses such as those presented in this report.

6 Conclusions

This report presents an analysis of Ireland's NETS target challenge. Having been principally established on the basis of ability to pay in 2005, the recent economic turmoil has altered the backdrop to the NETS target significantly. The recessionary impacts may have contributed to sectoral emission reductions, but they have also constrained investment resources and arguably shifted political priorities. As a result, evidence and focused action are required now that identify options, and reconcile the cost of investments with the value of returns from increased efficiency, abatement and compliance. This report has engaged the GAINS Ireland model to evaluate a pathway to NETS compliance in 2020. The model was calibrated with official WM national energy and activity data, and a hybrid compilation of information and values for abatement measures, abatement potentials and costs. The results point to a significant deficit in the defined abatement potentials with respect to reaching the NETS target of 37.4 Mt CO_2e in 2020. The LCO/OPT optimisation, which introduces measures up to a marginal cost of €50/t, left a remaining gap to target for the NETS of 4.8 Mt CO_2e in 2020, notwithstanding the expected interim challenges that are posed from 2013 onwards, and the ultimate format of a European decision in regard to how the role of LULUCF will be addressed in this context.

However, whilst the headline results are not particularly encouraging, there are four additional conclusions from this report in respect of Ireland's efforts to address this challenge. Firstly, the analyses do not represent all that can be done. The model excludes certain policy interventions (e.g. revisions to the carbon tax) that could also contribute to progress on the target, and there remains additional extension and calibration of the abatement menu to be conducted over time. Furthermore, there is certainly untapped potential in the transport sector that has not been adequately captured in this first calibration of the model and requires further research attention. 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/t are taken. This is encouraging, but highlights that, whilst social cost analyses indicate worthwhile actions, barriers such as information asymmetry and financing persist from a private investment perspective that require innovative solutions. Thirdly, whilst the WM optimisations 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 trans-boundary air pollution policy objectives where significant progress is made on the NETS target. 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 these data are identified, and the progressive collating and integration of this information into the model framework will offer a still stronger analytical tool for navigating a pathway to compliance with NETS from 2013 to 2020.

Beyond these conclusions, it is also important to map out the direction of further work in this area. Whilst calls for further research are common to many research reports, it is important to understand the reasons why further research is required in this area. Specifically, further work is required as we are dealing with a comparatively new area of research and new policy challenges where we have yet to establish an adequate foundation of knowledge and evidence on which to base decisions. A decade ago the monitoring and management of GHG emissions, both nationally and internationally, was at a far less advanced level. The methods, the science and the driving policy frameworks have all advanced considerably in the intervening years. As one outcome, we find ourselves in a position where we face significant policy challenges such as the NETS target, which represent high cost and high stakes agreements, and where we must be appropriately equipped to respond. A platform for integrated modelling of choices across climate and air pollution policy is one important tool in managing cost-effective responses. GAINS is used at a European level by the EC, as well as at national levels in a number of countries and regions to inform this field of policy. Therefore the GAINS Ireland model is well placed to contribute to the national efforts on these specific policy challenges.

However, the GAINS Ireland model can only continue to support these policy challenges where the system is actively managed. In regard to the model methodology, this is evolving and GAINS Ireland will continue to be based on the best insights from the national and international research community wherein Ireland is now an active participant. It is instead the data and the detail that present arguably the greatest challenge nationally in regard to applying this decision-support tool in the next phase of work. The level of detail required in regard to data for calibration may seem onerous, but again this is a function not of the desire to operate complex models, but rather out of necessity for addressing broad and complex issues. In practice, the information required is not particularly complex – it is instead simply detailed and deep. As noted though, there are new sources and new research that will deliver a more solid foundation of detailed information for all stakeholders and modellers in this area in the coming years.

It is absolutely certain though that the economic outlooks, technological potentials and policy directions will change, and consequently that the tools that provide associated decision support, such as GAINS Ireland, must be similarly dynamic. Through the sustained integration of new research and information the GAINS Ireland model will become an established and increasingly relevant and valuable analytical tool in this national policy context as we plot a course to meet our goals.

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Acronyms

C&E	Climate and Energy
CH_4	Methane
CHP	Combined heat and power
CNB	Cost Neutral Baseline
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EC	European Commission
EPA	Environmental Protection Agency
ESD	Effort Sharing Decision
ETS	Emissions Trading Scheme
EU	European Union
EV	Electric vehicle
F-gas	Fluorinated greenhouse gas
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GDP	Gross Domestic Product
GHG	Greenhouse gas
HFC	Hydrofluorocarbon
HVAC	Heating, ventilation, and air conditioning
ICT	Information and communications technology
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IIASA	International Institute for Applied Systems Analysis
IMP	Integrated Modelling Project
LCO/OPT	Least Cost Optimisation
LULUCF	Land use, land-use change and forestry
MFR	Maximum Feasible Reduction
MMR	Monitoring Mechanism report
N_2O	Nitrous oxide

NEEAP	National Energy Efficiency Action Plan
NETS	Non-Emissions Trading Scheme
NH_3	Ammonia
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
NREAP	National Renewable Energy Action Plan
PFC	Perfluorcarbon
PM	Particulate matter
SEAI	Sustainable Energy Authority of Ireland
SF6	Sulfur hexafluoride
SO_2	Sulfur dioxide
UNFCCC	United Nations Framework Convention on Climate Change
WAM	With Additional Measures
WM	With Measures

Appendix 1 Marginal Abatement Cost Measures

Table A1 provides the measures at various marginal cost price ranges as selected by the model under optimisation. Generally, measures are transparent and should be easily interpreted; however, in certain cases, for example certain agricultural measures (e.g. Feed), the specified measure is a proxy for a package of measures related to that category heading. The list was obtained by comparing GAINS Ireland model results at consecutive marginal cost values. Thus, this table provides a list of incremental steps of measures. It takes into account the fact that the combination of mitigation measures may not be as effective as the sum of the measures taken individually. For example, from a systems perspective, reducing electricity consumption is a less effective mitigation measure per se if it is accompanied by a decarbonisation of the supply fuel mix.

With regard to interpretation, the *More of...* column describes the measures that would be taken in addition to those taken at the previous marginal cost. Likewise, measures under the heading *Less of...* are being reduced relative to the previous marginal cost. At each marginal cost, the list also shows:

- The remaining GHG emissions (in Mt CO_2e) for the ETS and NETS, and the NETS alone; and
- The total amount of GHG emissions reduced relative to the baseline (in Mt CO_2e).

In interpretation of the marginal abatement list, it is also important to reiterate that the table has been shortened to the *additional or changed* measures at a given marginal cost level so as to avoid considerable repetition. Therefore, the measures are built on from the baseline level, adding or changing the portfolio at each cost level. Thus, for a given marginal cost price level there is generally a larger portfolio of options than is listed. Furthermore, there are some complexities to interpreting the outcomes. For example, in a small number of cases the model calls for less of a higher efficiency standard (e.g. Stage 2) and more of a lower efficiency standard (e.g. Stage 1). Whilst apparently counter-intuitive to the task at hand, the outcome is a function of cost. Specifically, as noted above, at a low carbon price, electricity savings offer a cost-effective GHG mitigation measure. However, as the carbon price rises, Ireland is decarbonising its power system, with the outcome that the actual per tonne cost of carbon is reduced by the electricity-saving measure and has now become more expensive.

In regard to the actual marginal cost values, costs are annual marginal cost of abatement per tonne of CO_2e in 2020. As noted in Chapter 5, the cost methodology employed excludes transaction and transfer costs, and is based on an interest rate of 4% €$_{2005}$.

Table A1. Abatement measures at various marginal cost price ranges.

Marginal cost	Sector(s) affected	More of…	Less of…	Remaining emissions	Remaining NETS emissions	Cumulative reductions relative to baseline
€0/t CO_2e	**Domestic (Residential & Commercial)**	**Residential:** *Stage 1 efficiency measures:* • HVAC (new houses and apartments) • Small appliances • Thermal water heating *Stage 2 efficiency measures:* • Cooking with electricity • Thermal fuels • Electric water heating • Thermal water heating **Commercial:** *Stage 1 efficiency measures:* • HVAC (existing buildings) • Large appliances • Cooking with electricity • Thermal fuels • Commercial lighting • Thermal water heating *Stage 2 efficiency measures:* • HVAC (new buildings) • Small and large appliances • Cooking with electricity • Thermal fuels • Commercial lighting	**Residential:** *Standard efficiency:* • Heating and cooling (new apartments and houses) • Small appliances • Cooking with electricity • Electric water heating • Thermal water heating *Stage 1 efficiency measures:* • Cooking with electricity • Thermal fuels • Electric water heating **Commercial:** *Standard efficiency:* • Heating and cooling (new and existing buildings) • Small and large appliances • Cooking with electricity • Thermal fuels • Lighting • Thermal water heating *Stage 1 efficiency measures:* • Heating and cooling (new buildings) • Small appliances	62.0 Mt CO_2e	46.2 Mt CO_2e	–3.1 Mt CO_2e
	Transport	• Light duty gasoline and diesel trucks with advanced internal combustion engine • Highest efficiency diesel buses and heavy duty diesel trucks • Advanced hybrid diesel light duty trucks • Light duty hybrid gasoline and diesel trucks • Improved efficiency diesel buses and heavy duty diesel trucks	• Heavy and light duty diesel trucks with standard efficiency • Light duty gasoline trucks with standard efficiency • Diesel buses with standard efficiency			
	Waste	• Food waste incineration	• Landfill with gas recovery and flaring and utilisation			
	Agriculture	• Deep injection of manure into soils				
	Other	• Alternative refrigerant • Reduced gas losses at compressor stations for gas transmission • Doubling of leak control frequency at gas distribution networks	*Refrigeration good practice:* • Leak control and end-of-life collection • Replacement cast iron gas distribution networks.			

Table A1 ***contd***

Marginal cost	Sector(s) affected	More of…	Less of…	Remaining emissions	Remaining NETS emissions	Cumulative reductions relative to baseline
€25/t CO_2e	**Power**	• Biofuels • Wind energy	• New conventional coal-fired power plants • New gas-fired power plants	57.2 Mt CO_2e	42.6 Mt CO_2e	–7.9 Mt CO_2e
	Domestic (Residential)	*Standard efficiency:* • Small appliances *Stage 2 efficiency measures:* • Thermal water heating	*Stage 1 efficiency measures:* • Small appliances • Residential thermal water heating			
	Industry	*Stage 1 efficiency improvements:* • Energy conversions industry • Non-ferrous metals industry	*Efficiency improvements:* • Best current practice (energy conversions industry, non-ferrous metals industry)			
	Waste	• Anaerobic digestion with gas recovery and utilisation (food industry waste) • Optimising wastewater treatment to abate N_2O emissions	• Landfill with gas recovery and flaring and utilisation (food industry waste)			
	Agriculture	• Farm-scale anaerobic digester (manure management) • Mix of feed changes (enteric fermentation) • Optimising agricultural nitrogen efficiency by 'precision farming'	• Deep injection of manure into soils as fertiliser			
	Other	• Alternative propellant (aerosols) • Alternative blowing agent (other foams) • Process modifications, including alternative refrigerants (industrial refrigeration) • Increased flaring of associated gas (oil and gas production) • Flaring (oil refining) • Product use as in anaesthetic abolished by full replacement	• Industrial refrigeration good practice – end-of-life recollection • Product use in anaesthetic reduced by combination therapy			

Table A1 ***contd***

Marginal cost	Sector(s) affected	More of…	Less of…	Remaining emissions	Remaining NETS emissions	Cumulative reductions relative to baseline
€50/t CO_2e	**Power** **Domestic (Commercial)** **Industry** **Other**	• Biofuels • New gas-fired power plants *Standard efficiency:* • Cooking with electricity *Stage 1 efficiency measures:* • Lighting *Stage 1 efficiency improvements:* • Non-metallic minerals industry *Stage 2 efficiency improvements:* • Non-ferrous metals industry • CHP plants used in industry *Alternative refrigerant:* • Pressurised CO_2 (mobile air conditioner) *Alternative solvent:* • NF_3 (semiconductors), industrial refrigeration: process modifications including alternative refrigerants.	• New conventional coal-fired power plants *Stage 2 efficiency measures:* • Cooking with electricity • Lighting *Efficiency improvements:* • Best current practice (non-ferrous metals industry, non-metallic minerals industry) *Stage 1 efficiency improvements:* • Non-ferrous metals industry. *Mobile air conditioner:* Good practice – end-of-life recollection Industrial refrigeration: good practice – leak control	**55.9 Mt CO_2e**	**42.2 Mt CO_2e**	**–9.2 Mt CO_2e**
€75/t CO_2e	**Power** **Domestic (Commercial)** **Industry** **Other**	• New gas-fired power plants *Standard efficiency:* • Large appliances *Efficiency improvements:* • Best current practice – non-ferrous metals industry *Stage 2 efficiency improvements:* • Non-ferrous metals industry *Commercial refrigeration:* • Process modifications including alternative refrigerants	• Existing power plants using fossil fuels, new oil-fired power plants *Stage 2 efficiency measures:* • Large appliances *Stage 1 efficiency improvements:* • Non-ferrous metals industry *Commercial refrigeration:* • Good practice – end-of-life recollection	**53.3 Mt CO_2e**	**42.1 Mt CO_2e**	**–11.8 Mt CO_2e**
€100/t CO_2e	**Power** **Industry** **Agriculture** **Other**	New gas-fired power plants *Efficiency improvements:* • Best current practice – energy conversions industry *Stage 2 efficiency improvements:* • Non-ferrous metals industry *Manure management:* • Farm-scale anaerobic digester *Commercial refrigeration:* • Process modifications including alternative refrigerants	Existing power plants using fossil fuels *Efficiency improvements:* • Best current practice – non-ferrous metals industry *Stage 1 efficiency improvements:* • Energy conversion industry. – *Commercial refrigeration:* • Good practice – leak control	**52.4 Mt CO_2e**	**41.2 Mt CO_2e**	**–12.7 Mt CO_2e**

Table A1 *contd*

Marginal cost	Sector(s) affected	More of…	Less of…	Remaining emissions	Remaining NETS emissions	Cumulative reductions relative to baseline
€125/t CO_2e	**Domestic (Residential & Commercial)**	*Stage 1 efficiency measures:* • Electric water heating (residential) *Stage 2 efficiency measures:* • Thermal water heating (commercial)	*Standard efficiency:* • Thermal water heating (commercial) *Stage 2 efficiency measures:* • Electric water heating (residential)	52.1 Mt CO_2e	41.0 Mt CO_2e	
	Industry	*Stage 1 efficiency improvements:* • Chemical industry • Energy conversions industry • Iron and steel industry • Paper and pulp industry *Stage 2 efficiency improvements:* • Non-ferrous metals industry	*Efficiency improvements:* • Best current practice: – Chemical industry – Energy conversions industry – Iron and steel industry – Non-ferrous metals industry – Paper and pulp industry			
	Agriculture	*Enteric fermentation:* • Mix of feed changes	–			
	Other	*Mobile air conditioning:* • Alternative refrigerant (pressurised CO_2)	*Mobile air conditioning:* • Good practice – leak control			
€150/t CO_2e	**Power**	• New gas-fired power plants	–	52.1 Mt CO_2e	41.0 Mt CO_2e	
	Industry	• CHP plants used in industry *Stage 1 efficiency improvements:* • Paper and pulp industry	*Efficiency improvements:* • Best current practice – Paper and pulp industry			
	Other	*Stationary air conditioning:* • Process modification, including alternative refrigerant *Gas distribution networks:* • Replacement grey cast iron networks	*Stationary air conditioning:* • Good practice – end-of-life recollection *Gas distribution networks:* • Doubling of leak control frequency			
€175/t CO_2e	**Domestic (Residential)**	*Stage 2 efficiency measures:* • Heating and cooling (new and existing houses) • Electric water heating	*Standard efficiency:* • Heating and cooling (new houses) *Stage 1 efficiency measures:* • Heating and cooling (existing houses) • Electric water heating	51.5 Mt CO_2e	40.5 Mt CO_2e	

Table A1 *contd*

Marginal cost	Sector(s) affected	More of…	Less of…	Remaining emissions	Remaining NETS emissions	Cumulative reductions relative to baseline
€200/t CO_2e	**Domestic (Residential & Commercial)**	*Stage 1 efficiency measures:* • Residential electric water heating *Stage 2 efficiency measures:* • Commercial cooking – thermal fuels	*Stage 1 efficiency measures:* • Commercial cooking – thermal fuels *Stage 2 efficiency measures:* • Residential electric water heating	**51.4 Mt CO_2e**	**40.4 Mt CO_2e**	
	Industry	*Stage 2 efficiency improvements:* • Chemical industry *Stage 3 efficiency improvements:* • Non-ferrous metals industry • Non-metallic minerals industry	*Stage 1 efficiency improvements:* • Chemical industry • Non-metallic minerals industry *Stage 2 efficiency improvements:* • Non-ferrous metals industry			
	Waste	*Food industry waste:* • Incineration	*Food industry waste:* • Anaerobic digestion with gas recovery and utilisation			
€225/t CO_2e	**Power**	• New gas-fired power plants	• Existing power plants using fossil fuels	**51.4 Mt CO_2e**	**40.4 Mt CO_2e**	

NETS, Non-Emissions Trading Scheme; CO_2e, carbon dioxide equivalent; HVAC, heating, ventilation, and air conditioning; N_2O, nitrous oxide; CHP, combined heat and power; CO_2, carbon dioxide; NF_3, nitrogen trifluoride.