International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

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GHG mitigation potentials in Annex I countries
Comparison of model estimates for 2020

Markus Amann
Peter Rafaj
Niklas Höhne

Approved by

Detlof von Winterfeldt
Director

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International Institute for Applied Systems Analysis
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Contents

Abstract

Robust quantification of the future potentials and costs for mitigating greenhouse gases in different countries could provide important information to the current negotiations on a post-2012 climate agreement. However, such information is not readily available from statistical sources, but requires the use of complex models that combine economic, technological and social aspects. In March 2009, the International Institute for Applied Systems Analysis (IIASA) invited leading modelling teams to a comparison of available model estimates of GHG mitigation potentials and costs in the Annex I countries for the year 2020. Eight modelling teams provided input to this comparison exercise.

Although at face value estimates of mitigation potentials and costs show wide variation across models, differences (i) in assumptions on the baseline economic development, (ii) in the definition of which mitigation measures are considered part of the baseline, and (iii) in the time window assumed for the implementation of mitigation measures explain much of the variation in model results. The paper presents a check-list of factors that need to be considered when interpreting model results.

Once corrected for these key factors, two clusters of cost curves emerge for the year 2020: Models that include consumer demand changes and macro-economic feedbacks agree on a mitigation potential of up to 40% reduction below 2005 levels (that is approximately 45% below the 1990 level) for total Annex I emissions in 2020 for a carbon price of 50 to 150 US-\$/tCO_2. Bottom-up models that restrict their analysis to technical measures show only half of this potential.

The model intercomparison demonstrates that future economic development has a strong impact on the efforts necessary to achieve given emission reduction levels. Any delay in the start of implementation of mitigation measures will reduce the mitigation potential that is achievable in the near term and increase the costs. The introduction of measures that mobilize demand adjustments through structural or behavioural changes may increase the short-term mitigation potential significantly.

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About the Authors

Markus Amann and Peter Rafaj work in the Atmospheric Pollution and Economic Development programme of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Niklas Höhne works at Ecofys, Germany.

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1 Introduction

Robust quantification of the future potentials and costs for mitigating greenhouse gases in different countries could provide important information to the current negotiations on a post-2012 climate agreement. However, such information is not readily available from statistical sources, but requires the use of complex models that combine economic, technological and social aspects. During the recent year various modelling teams in different parts of the world have presented their estimates for the year 2020. At face value these estimates seem to span a wide range, so that it is not obvious how robust policy conclusions can be drawn from these calculations.

In March 2009, the International Institute for Applied Systems Analysis (IIASA) initiated an exercise that aims at a comparison of available model estimates of GHG mitigation potentials and costs in the Annex I countries and at identifying the main reasons that lead to differences in these estimates. Modelling teams were invited to submit key data for the comparison, to discuss and interpret results at a workshop at IIASA, and to present the findings to the UNFCCC negotiators at a side event at the Bonn Climate Talks in May 2009.

Eight modelling teams have provided input to this comparison exercise. This report presents results of all models in terms of marginal abatement cost curves (MACs) and identifies a range of key factors that explain much of the differences between model results. The report summarizes key aspects that should be kept in mind when using results from a particular model.

The remainder of this paper is organized as follows. Section 2 provides a brief description of the participating models. Section 3 presents marginal mitigation cost curves for important Annex I countries. Section 4 reviews factors that could potentially explain differences in model results, and estimates to what extent adjustments for such differences could let model results converge. Section 4 includes results by country. In the final section conclusions are drawn.

2 A model intercomparison

In March 2009, IIASA invited key modelling teams that have provided estimates of GHG mitigation potentials and costs to participate in the study and to submit data for the comparison. A meeting was held at IIASA on May 28-29, 2009 to review the results from different models and identify factors that explain differences in model estimates.

2.1 Participating models

Eight modelling teams have provided quantitative results to the intercomparison exercise (Table 2.1).

Table 2.1: Participating models

Model	*Organization*	*Model type*	*Main reference*
AIM	NIES, Japan	Bottom up model	Kainuma M. *et al.*, 2007
DNE21+	RITE, Japan	Bottom-up model	RITE, 2009
GAINS	IIASA, Austria	Bottom-up model	Amann *et al.*, 2008
GTEM	Treasury, Australia	Computable general equilibrium model	Australian Treasury, 2008
IMAGE	PBL, Netherlands	Bottom-up integrated assessment model	MNP, 2006
McKinsey	McKinsey	Bottom-up cost curves	McKinsey & Company, 2009
OECD ENV-LINKAGES	OECD	Computable general equilibrium	OECD, 2009
POLES	IPTS	Linked bottom-up/top down	Russ *et al.*, 2009

2.1.1 AIM (NIES, Japan)

The AIM model, developed by the National Institute for Environmental Studies (NIES), Japan, comprises three main models - the greenhouse gas emission model (AIM/emission), the global climate change model (AIM/climate), and the climate change impact model (AIM/impact). The AIM/emission model estimates greenhouse gas emissions and assesses policy options to reduce them. The AIM model has several distinct characteristics. It integrates emission, climate and impact models, contains country modules for detailed evaluations at the national level and global modules to ensure consistency across individual modules, integrates bottom-up national modules with top-down global modules, and is designed to assess alternative policies. AIM contains a very detailed technology selection module to evaluate the effect of introducing advanced technologies and uses information from a detailed Geographic Information System to evaluate and represent the distribution of impacts at the local level. More detail is provided in Kainuma M. *et al.*, 2007 and at http://www-iam.nies.go.jp/aim/infomation.htm.

2.1.2 DNE-21+ (RITE, Japan)

The Dynamic New Earth 21 plus (DNE21+) model has been developed by the Research Institute of Innovative Technology for the Earth (RITE), Japan. The model covers the entire world divided over 50 regions. The energy systems model is a bottom-up linear programming model minimizing world total costs of energy systems. DNE21+ also treats energy-unrelated CO_2 and five kinds of non-CO_2 GHG emissions. The non-CO_2 GHG model is a proxy model using elasticities that represent bottom-up assessments of mitigation technologies performed by USEPA. More information is provided in RITE, 2009.

2.1.3 GAINS (IIASA, Austria)

The Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model has been developed by the International Institute for Applied Systems Analysis (IIASA), Austria. It uses a bottom-up approach for quantifying GHG mitigation potentials and costs for the major Annex I countries, and estimates co-benefits on air pollution. GAINS employs exogenous activity projections, currently those of the IEA World Energy Outlooks 2007 and 2008 (IEA, 2007, IEA, 2008) . More information is provided in Amann *et al.*, 2008. An interactive version of GAINS is accessible on the Internet (http://gains.iiasa.ac.at/).

2.1.4 GTEM/MMRF (Australia)

GTEM is a recursively dynamic general equilibrium model developed by the Australian Bureau of Agricultural and Resource Economics (ABARE) to address policy issues with long-term global dimensions, such as climate change mitigation costs.

The MMRF model is a detailed model of the Australian economy developed by the Centre of Policy Studies at Monash University. It is a dynamic model which employs a recursive mechanism to explain investment and sluggish adjustment in factor markets.

The marginal GHG abatement cost curves for the GTEM and MMRF models are not produced or derived internally by the models. The information provided by GTEM and MMRF are abatement curves, which shows the amount of abatement that occurs at the average carbon price. An abatement curve can differ from a marginal abatement cost curve, due to different assumptions, environmental targets and emission trajectories.

2.1.5 IMAGE (PBL, Netherlands)

The IMAGE 2.4 Integrated Assessment model (MNP, 2006) (www.mnp.nl/image) consists of a set of linked and integrated models that together describe important elements of the long-term dynamics of global environmental change, such as air pollution, climate change, and land-use change. The global energy model that forms part of this framework, TIMER (van Vuuren *et al.*, 2007), describes the demand and production of primary and secondary energy and the related emissions of GHGs and regional air pollutants. The FAIR-SiMCaP 2.0 model is a combination of the abatement costs model of FAIR and the SiMCaP model (den Elzen *et al.*, 2007). The land and climate modules of IMAGE describe the dynamics of agriculture and natural vegetation, and, together with input from TIMER and FAIR, resulting climate change.

2.1.6 McKinsey

The global McKinsey GHG abatement cost curve was developed since 2006 and results in this paper are based on the second version of the global GHG abatement cost curve (McKinsey 2009). The model is mainly based on external baseline sources IEA WEO, US EPA and Houghton and assesses bottom-up the abatement potential and cost of over 200 abatement levers in 21 world regions. More information and the online version Climate Desk is accessible on the Internet (http://solutions.mckinsey.com/climatedesk).

2.1.7 OECD ENV LINKAGES (OECD)

ENV-Linkages is a top-down model (CGE type). This model is still in development, the version used for the paper is the version 2.1. The ENV-Linkages model is a recursive dynamic neo-classical general equilibrium model, with a standard time horizon from 2005 to 2050. It is a global economic model built primarily on a database of national economies.

The model version used for this study represents the world economy in 12 countries/regions, each with 25 economic sectors (eight energy production sectors), and three representative agents. Six greenhouse gases are modeled; land use and land cover change emissions are not yet taken into account. Capital accumulation is modeled as in traditional Solow/Swan neo-classical growth models.

All production in ENV-Linkages is assumed to operate under cost minimization with an assumption of perfect markets and the CRS technology. The production technology is specified as nested CES production functions in a branching hierarchy. Total output for a sector is actually the sum of two different production streams: resulting from the distinction between production with an ‘‘old’’ capital vintage, and production with a ‘‘new’’ capital vintage. The substitution possibilities among factors are assumed to be higher with new capital than with old capital. International trade flows and prices are fully endogenous and modeled using a Armington specification. Energy efficiency is partly exogenous, as the autonomous energy efficiency (AEE) factor is calibrated to match IEA’s projections on energy demand published in the World Energy Outlook), and partly endogenous with substitution possibility between factors and goods resulting from prices changes and optimizing behavior of agents. For each year the government budget is balanced through the income tax, revenues of the carbon tax are then indirectly rebated to the household, in a lump-sump way since labor supply is exogenous.

2.1.8 POLES (JRC-IPTS, EU)

POLES is a global simulation model of the energy system. The dynamics of the model is based on a recursive simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through the international energy price. The model is developed in the framework of a hierarchical structure of interconnected modules at the international, regional, and national levels. It contains technologically-detailed modules for energy-intensive sectors, including power generation, iron and steel, the chemical sector, aluminum production, cement making, non-ferrous minerals and modal transport sectors (including aviation and maritime transport). All energy prices are determined endogenously. Oil prices in the long-term depend primarily on the relative scarcity of oil reserves. The world is broken down into 47 regions, for which the model delivers detailed energy balances. The model is continuously being enhanced in both detail and in the degree of regional disaggregation. Recent modifications include the addition of detailed modules for energy-intensive sectors and an extension to cover non-CO_2 greenhouse gases (GHG).

2.2 Data provided for the model intercomparison

As an input for the quantitative model intercomparison, modelling teams provided a set of data to IIASA that describe sectoral GHG emissions that emerge for a range of carbon prices (i.e., for the base year 2005, for the baseline case in 2020, and for 2020 with carbon prices of 0, 20, 50, 100 and >100 US-$/t CO_2, respectively.) Such data were delivered for individual Annex I parties and for Annex I in total.

It is important to note that only the GTEM model provided data for the LULUCF sector.

As not all models cover all countries, not all teams provided a complete set of data:

- AIM: No data have been provided for Canada and Australia.
- IMAGE: Australia and New Zealand have been aggregated into one region, and sectoral emissions are not included in the provided data. The IMAGE emissions data are not harmonised with the UNFCCC emissions, and comes directly from the different IMAGE submodels, which are calibrated for the year 2000. In policy applications with the IMAGE and FAIR model harmonised data is used.
- OECD: Australia and New Zealand have been aggregated into one region.
- McKinsey: No data have been provided for Australia separately.
- GTEM calculations include LULUCF emissions; for Australia, results of the MMRF model were provided as well.
- POLES did not provide data for the Australia, New Zealand and Canada. Furthermore, POLES data do not include emissions from agriculture.
- GAINS and POLES data were recalculated from € to US-$.

3 Model estimates of mitigation potentials and costs

As a first step in the model comparison the data points (i.e., emission levels for a range of carbon prices) obtained from each model have been combined into marginal abatement cost curves. Figure 3.1 displays the cost curves aggregated for total Annex I for 2020, plotted against absolute emission levels. At face value such a comparison reveals large differences in model outcomes. Cost curves exhibit different starting points, slopes of the curves are different, and mitigation potentials show large variations. The analysis shows that the spread in total Annex I results does not originate from discrepancies for a single country only, but that substantial variations prevail for all countries analyzed (Figure 3.2). However, particularly large differences emerge for Russia, where for instance 2020 baseline emission projections span a range from 0% to 45% relative to 2005. It is interesting to note that in many cases models developed by governmental institutions suggest for their country higher baseline emissions than other models from international institutions of other countries.

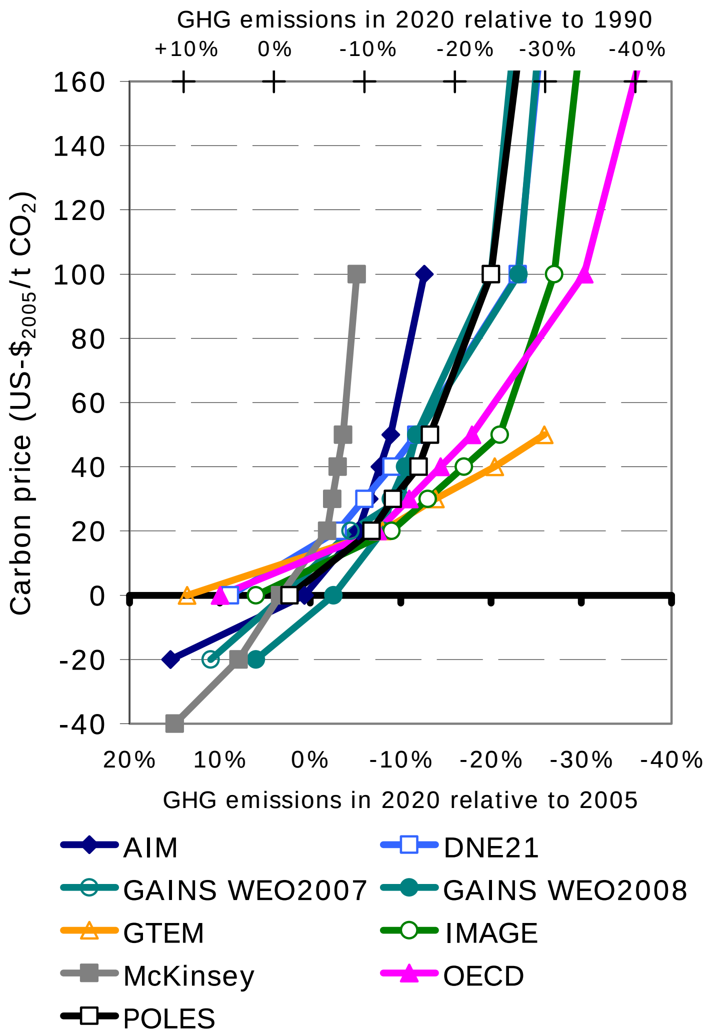

Figure 3.1: Marginal cost curves for GHG mitigation in 2020 for total Annex I, plotted against the 2005 and 1990 emission levels computed by each model

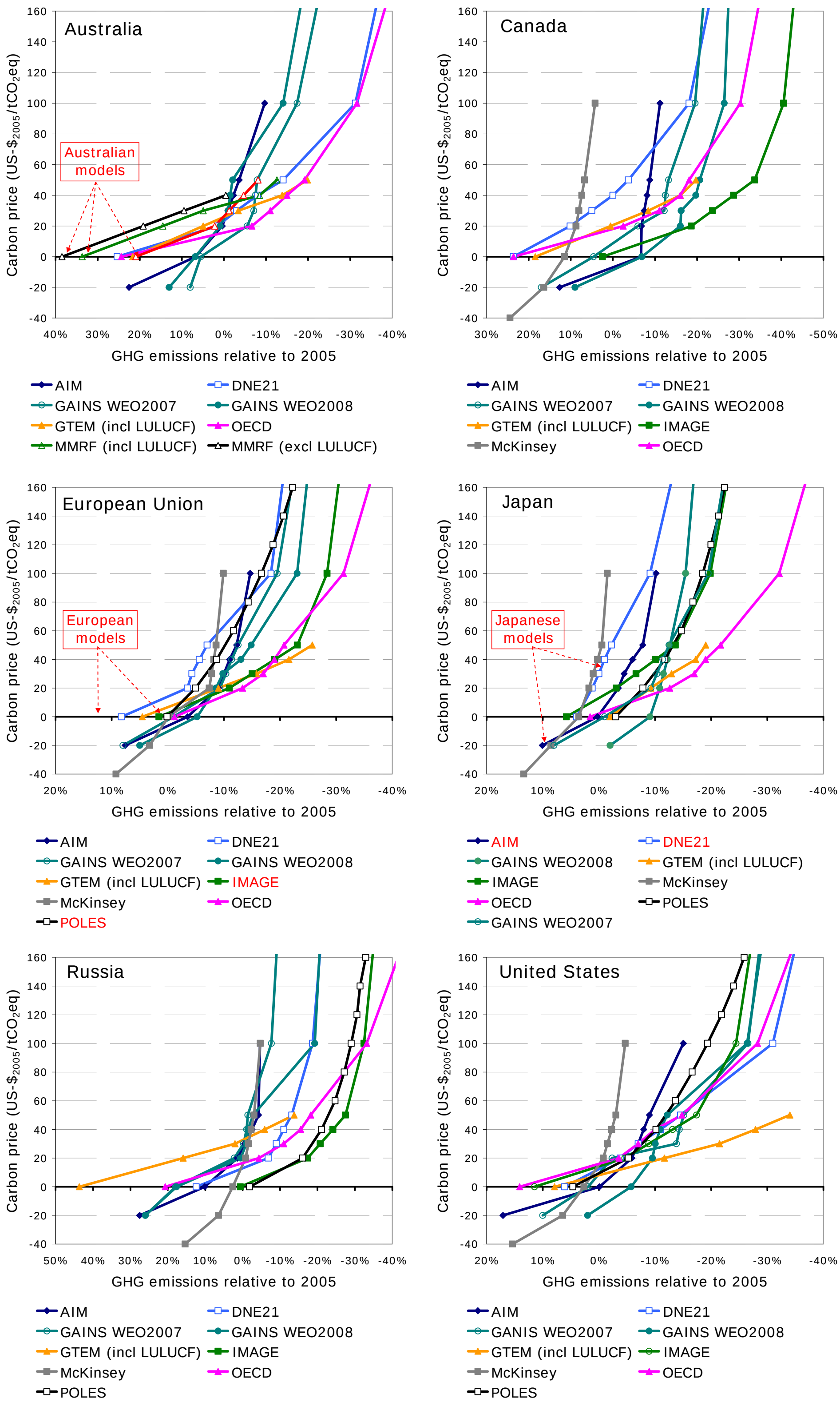

Figure 3.2: Marginal GHG abatement cost curves for 2020 for major Annex I countries plotted against the models' 2005 emissions estimates. Names of models developed by domestic national institutions are printed in red.

4 Factors explaining differences in model results

Differences in model results, both in terms of mitigation potentials and associated costs, hamper a robust international evaluation of modelling studies. The question arises whether factors can be identified that explain (parts of) these apparent discrepancies in model results, and in particular whether differences are caused by different subjective input assumptions of modelling teams or by different modelling approaches. Understanding these factors will help to judge whether models provide, in principle, consistent answers to the same question asked, or whether answers to the same question depend on the model.

A number of factors have been identified that could potentially explain differences in model outcomes. These include, inter alia,

- how well models have been calibrated to reproduce base year emission inventories,
- assumptions on the baseline economic development and the implied evolution of energy use, industrial production and agricultural activities up to 2020,
- the time window for implementation of mitigation measures considered by models,
- definitions of which autonomous efficiency improvements are included in the counter-factual baseline against which mitigation costs are evaluated,
- treatment of the costing perspectives of private actors (e.g., about expected pay-back period for investments) and of transaction costs,
- different portfolios of mitigation measures that are considered by models,
- assumptions about cost of mitigation measures, especially on the impact of technological progress on future costs, and
- inclusion of macro-economic feedbacks from higher carbon prices on consumer demand and the structure of industrial production, including potential carbon leakage effects.

These factors fall into four groups:

- Some factors relate to the exact definition of the policy question of interest (e.g., on which cost concept the answer should rely, against which counter-factual baseline the assessment should be carried out, whether the potential for fundamental behavioural changes should be included in the assessment, etc.),
- others relate to the genuine uncertainties of future development (e.g., about future economic development, about the future rate of technological progress and the associated decrease in technology costs),
- others are linked with a thorough and factually accurate implementation of a model for a specific country (e.g., how well models reproduce historic emission inventories or current prices for technological options),
- while others are connected with the basic methodological approach that is used for estimating mitigation potentials and costs (e.g., where the systems boundaries are drawn

for the assessment, for instance whether macro-economic feedbacks and adjustments are included in the analysis).

The following sections explore how these factors contribute to observed differences in model results. The analysis is carried out for the aggregate of Annex I countries.

4.1 Model calibration to base year emission inventories

Model estimates of future emissions and mitigation potentials could differ if models start from different base year emission inventories. Thus, sectoral emission estimates of all models for the year 2005 were compared to the data held in the inventory of UNFCCC (Figure 4.1). For total Annex I emissions, the differences between estimated and reported total emissions for the year 2005 range within a few percentage points for most models. Larger differences, however, are observed for the IMAGE (+18%) model as well as for the GTEM model that includes LULUCF emissions. Sectoral estimates show larger variations for some countries, potentially due to different sectoral accounting for some sources (e.g., for electricity production in industry). For instance, the McKinsey model allocates all emissions from the power sector to the end use sector where electricity is consumed, and the IMAGE and GTEM model did not provide data on a sectoral level.

In conclusion, most models show rather good agreement between their estimated base year emissions and the emission inventories reported by countries to UNFCCC. Existing disagreements of sectoral estimates are mainly caused by different sector definitions of some models.

Nevertheless, especially for models with larger variations in base year emission inventories, the robustness of calculations is likely to be higher if results are considered in relative terms, i.e., if future emissions and mitigation potentials are related to the 2005 inventory as calculated by each model. Thereby, the importance of biases in base year inventories would be diminished.

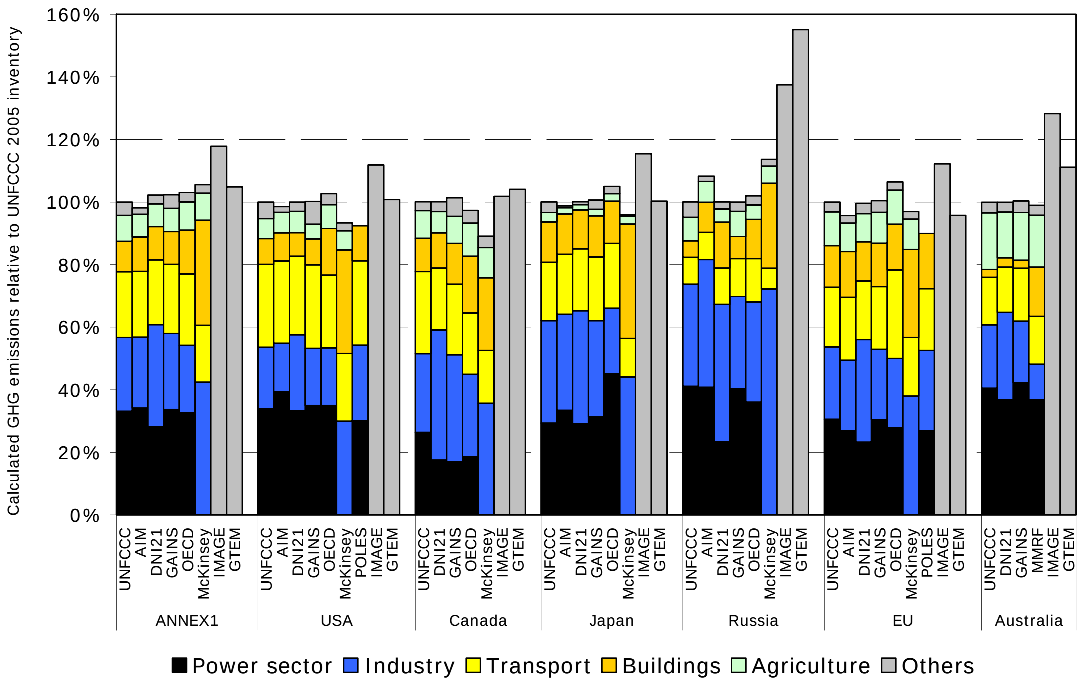

Figure 4.1: Sectoral GHG emissions in 2005, UNFCCC inventory compared against model estimates. Note that (i) the GTEM model includes LULUCF emissions and covers the entire former Soviet Union under Russia; (ii) IMAGE and OECD calculations for Australia include emissions from New Zealand.

4.2 Assumptions on economic development and other driving forces

The assumed future development of emission generating activities has a critical impact on costs for achieving a given GHG emission level in the future. Activity levels are driven by a wide range of factors, such as population growth, the general economic development, energy and agricultural policies and technological progress. The evolution of many of these driving forces is difficult to predict with certainty, as the past has shown that surprises occur frequently. Thus, models need to adopt assumptions on these driving forces as an input to their calculations of future mitigation potentials and costs. While such assumptions can be based on more or less elaborated quantitative frameworks, a variety of different opinions prevails and each estimate is associated with considerable uncertainties.

A comparison of assumed economic development reveals significant variations across models. For total Annex I, the assumed increase in GDP ranges from 20% to 45% between 2005 and 2020, corresponding to average annual growth rates between 1.1% and 2.5%/year. However, such a comparison is hampered by the fact that some models express GDP in terms of purchasing power parity (PPP), while other models use the market exchange rates (MER) concept for quantifying GDP. An implied change of PPP over time could explain some of the variation. It is noteworthy that most of the model calculations employ activity projections that have been developed before the current economic crisis (Figure 4.2).

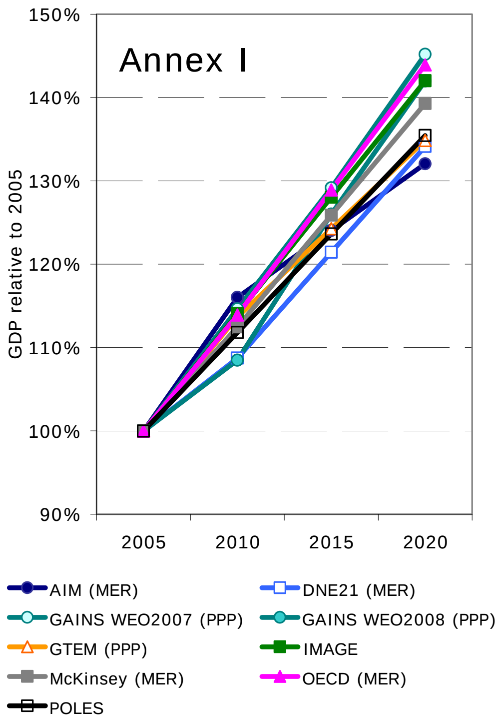

Figure 4.2: Development of GDP assumed by the models for total Annex I (relative to 2005)

Differences in GDP projections also prevail for individual Annex I countries (Figure 4.3). Particularly large variation occurs for Russia, where assumptions for 2020 range from a 45% increase to a 110% growth compared to 2005, and for the EU, where growth assumptions differ by a factor of four.

As GDP is an important factor determining future levels of emission generating activities, the revealed differences in assumptions for 2020 will have profound impacts on the resulting estimates of mitigation potentials and costs.

Different assumptions on overall economic development also imply different quantifications of the future composition and the levels of emission generating activities to which mitigation measures can be applied. These factors have direct impact on the starting points and shapes of mitigation cost curves, as they determine baseline emission levels and the potential for mitigation measures.

As for this model intercomparison most participating models provided only estimates for a single baseline projection, the GAINS model has been used to illustrate the implications of different baseline assumptions. This sensitivity analysis has been carried out for the IEA World Energy Outlooks published in 2007 and 2008 (IEA, 2007; IEA, 2008).

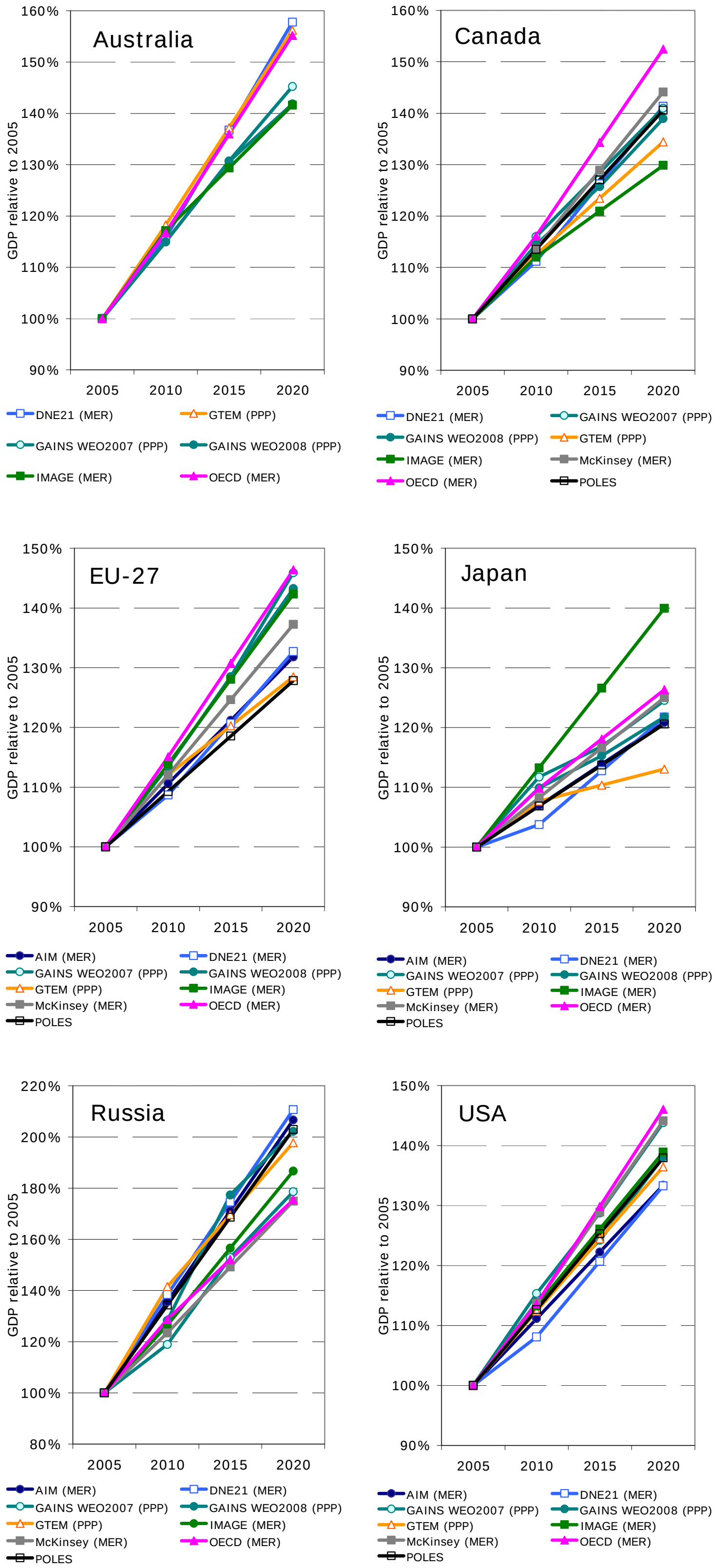

Figure 4.3: GDP development assumed by the models for key countries, relative to 2005

These IEA World Energy Outlooks assume, inter alia, different oil price developments and explore their impacts on the economy in general and on energy use in particular. The 2007 World Energy Outlook projects, for an assumed oil price of 46 US-$/barrel in 2020, a GDP growth in total Annex I of 44 %. The 2008 World Energy outlook explored the implications of an oil price of 83 US-$/barrel, suggesting GDP to increase by 42% relative to 2005.

The different structures in energy consumption of these two projections have profound impacts on baseline greenhouse gas emissions and the associated mitigation potentials and costs. Keeping all other factors equal, the GAINS model computes for the higher energy 2007 projection an increase in baseline GHG emissions of 11% in the Annex I countries compared to 2005. For the lower 2008 energy projection GAINS calculates an increase in baseline emissions of six percent.

Different assumptions on baseline activity rates result not only in different starting points; mitigation potentials and shapes of cost curves are different too, inter alia due to different mitigation potentials associated with different coal use projections. Figure 4.4 compares two mitigation cost curves computed with the GAINS model for the activity projections of the IEA World Energy Outlooks published in 2007 and 2008. While the cost curves show similar mitigation potentials up to a carbon price of about 20 $/t CO_2, the cost curve for the 2007 projection, which relates to a higher level of coal consumption, sees more mitigation potentials between 20 to 30 $/t CO_2 (mitigation measures in coal power plants). The mitigation potential above 50 $/t CO_2 is larger in the 2008 projection. Overall, the cost curve starting from a higher baseline level (i.e., the 2007 curve) sees a slightly higher mitigation potential that the curve computed for a lower energy projection.

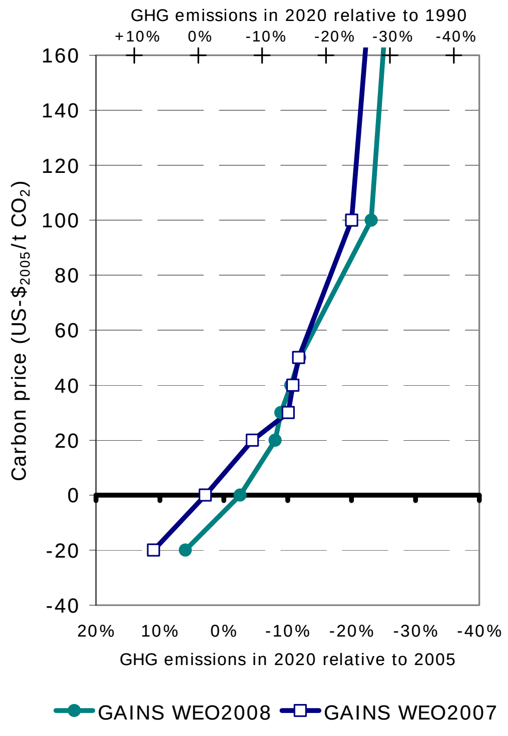

Figure 4.4: Marginal mitigation cost curves computed with the GAINS model for the activity projections of the IEA World Energy Outlooks published in 2007 and 2007

4.3 Measures assumed in the baseline development

Estimates of future mitigation potentials and costs are also influenced by the definition of the portfolio of measures that is considered for mitigation. A critical aspect here relates to the definition of the baseline, i.e., which measures are considered to occur autonomously and are thus included in the baseline of a model, and which measures are part of the portfolio of additional measures. This is particularly important for autonomous energy efficiency improvements, which have been shown for the past to occur to some extent autonomously as a consequence of technological progress. Nevertheless, models apply different concepts for allocating future efficiency improvements:

- Some models (e.g., AIM) adopt a 'frozen technology' concept for their baseline projection. These models assume that without further intervention the historically observed rates in energy efficiency improvements would stop. All future improvements are accounted as the consequence of dedicated actions to reduce greenhouse gas emissions.
- In contrast, other models (such as the GAINS and the OECD models, which rely on the energy projections of the IEA World Energy Outlook) assume in their baseline a continuation of the historically observed trends in autonomous energy efficiency improvement, and consider only additional measures that would accelerate this autonomous trend for mitigation.
- Other models adopt for their baseline projection definitions between these two prototypical concepts. For instance, the DNE-21+, POLES and IMAGE models include all measures that result in cost savings over their lifetime in the baseline, and consider only measures with positive carbon prices in their mitigation portfolio.
- A similar concept is also used by computable general equilibrium models, where the baseline includes all measures that are adopted in an equilibrium solution without a carbon constraint.

These differences in baseline definitions lead to a considerable spread in energy and greenhouse gas intensity improvements implied in the baseline projections of the various models. For 2020, autonomous improvements in GHG intensities range from 12% to 26% compared to 2005 (Figure 4.5). It is interesting to note that there occurs a general pattern in the sense that models that assume lower GDP growth also imply lower GHG intensity improvements in their baseline, and vice versa.

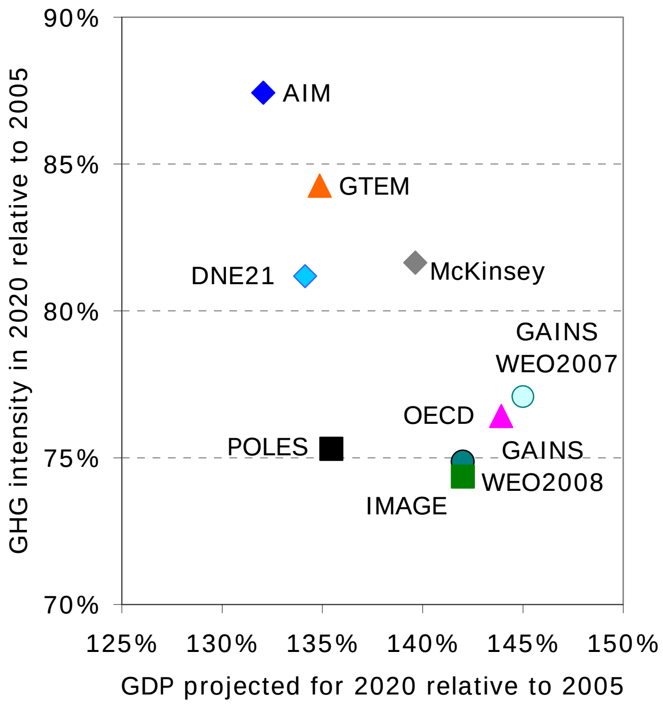

Figure 4.5: Change in GHG intensities of the baseline projections versus assumed GDP growth in 2020 (for total Annex I)

4.4 Baseline emission projections

The baseline emission projections (without additional climate measures) serve as starting points for model calculations of mitigation potentials and costs. Obviously, baseline projections are critically influenced determined by future activity levels, which emerge as a result of assumed economic growth and the choice of measures that are included in the baseline.

As models take different assumptions on economic growth and employ different concepts for the inclusion of measures in their baseline, resulting baseline emissions are rather different. For 2020, baseline emission projections of the participating models range from a 6% to a 16% increase relative to emissions calculated for 2005 (Figure 4.6).

Obviously, different starting points for mitigation measures result in different marginal mitigation cost curves. Figure 4.7 adjust the cost curves of the participating models for these different starting points by plotting curves against the respective baseline emission levels. Thereby the graph illustrates the mitigation potentials that are estimated by the different models, ignoring the fact that models start from different baseline emissions.

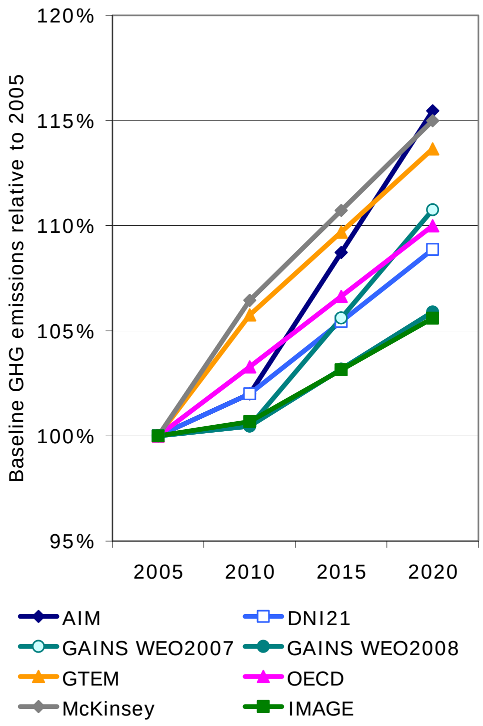

Figure 4.6: Baseline projections of GHG emissions for total Annex I for 2020, relative to UNFCCC inventory for 2005 (left panel) and the emissions calculated by each model for 2005 (right panel). Note that the values for 2015 have been interpolated from the data provided by modelling teams.

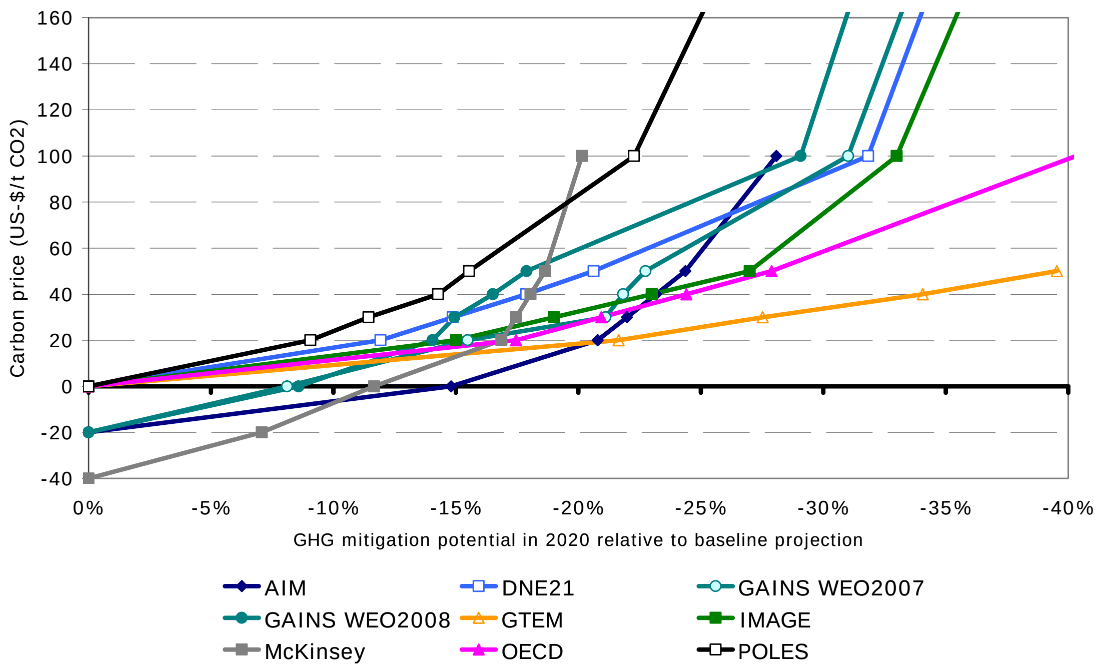

Figure 4.7: Marginal mitigation cost curves for 2020 plotted relative to the baseline emission projection for total Annex I

Such a comparison reveals a rather wide spread in estimated mitigation costs (i.e., the slopes of the curves) and mitigation potentials (i.e., the range they span on the x-axis for a given carbon price). For instance, for a carbon price of 40 US-$/t CO_2, models suggest a mitigation potential ranging from 13% below baseline (in case of the POLES model) up to 32% below baseline (for the GTEM model).

The following sections explore to what extent different factors can explain the observed differences in mitigation potentials and costs.

4.5 Time window for implementation of mitigation measures

Another factor that determines the mitigation potential that can be realized by a given point in time relates to the assumed time window during which mitigation measures can be implemented. As annual penetration rates are limited (as most models assume), the time window has immediate impact on the achievable penetration of mitigation measures. It also affects the potential for cheaper re-investments that can be implemented at new plants in the course of the natural turnover of existing equipment, compared to retrofit measures that are usually more expensive. In CGE models, the time window also connects to short- and long-term elasticities that are used to describe changes in consumer demand and structural adaptations.

The participating models apply rather different time windows for their analysis in 2020, ranging from a 20-year period (2000-2020) in case of the IMAGE model to a seven-year period (2013-2020) for the OECD and GTEM models. Thereby, periods considered for implementation of mitigation measures vary by up to a factor of three (Figure 4.8).

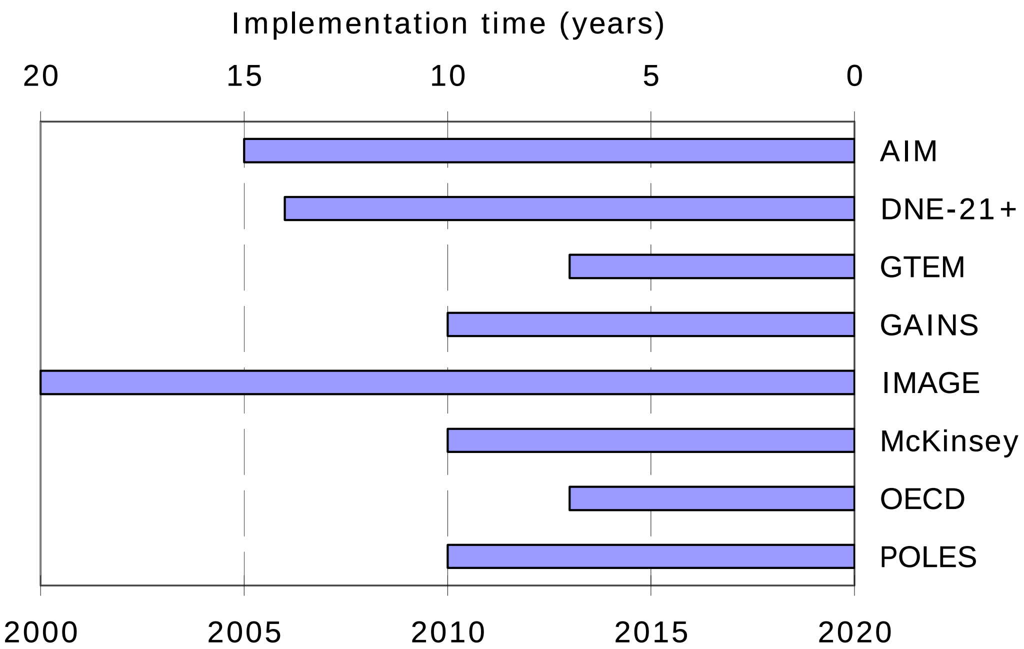

Figure 4.8: Time windows assumed for implementation of mitigation measures used by the various models

As - at the time of writing this report – measures can realistically only start in 2010 at the earliest, an attempt has been made to adjust the mitigation potentials estimated by different models for 2020 to a common time window of 10 years. Since it was not possible to collect a full set of revised model runs from all models, a rough procedure has been developed to obtain indicative results for the various models. For bottom-up models, which consider constraints on penetration rates and the natural turnover of the existing capital stock, the procedure applies a linear scaling of the mitigation potentials proportional to the assumed 10-year time frame relative to the originally assumed length of the mitigation window. (Bottom-up models participating in this exercise employ an implementation window of 10-20 years). Obviously, such a rough adjustment can only be seen as a first-order estimate as it does not accurately reflect temporal dynamics in the replacement of existing capital stock. No adjustment has been applied to the results of computable general equilibrium models, as such models describe the response of the economic actors to increased carbon prices through price elasticities, which inherently include restricted implementation rates.

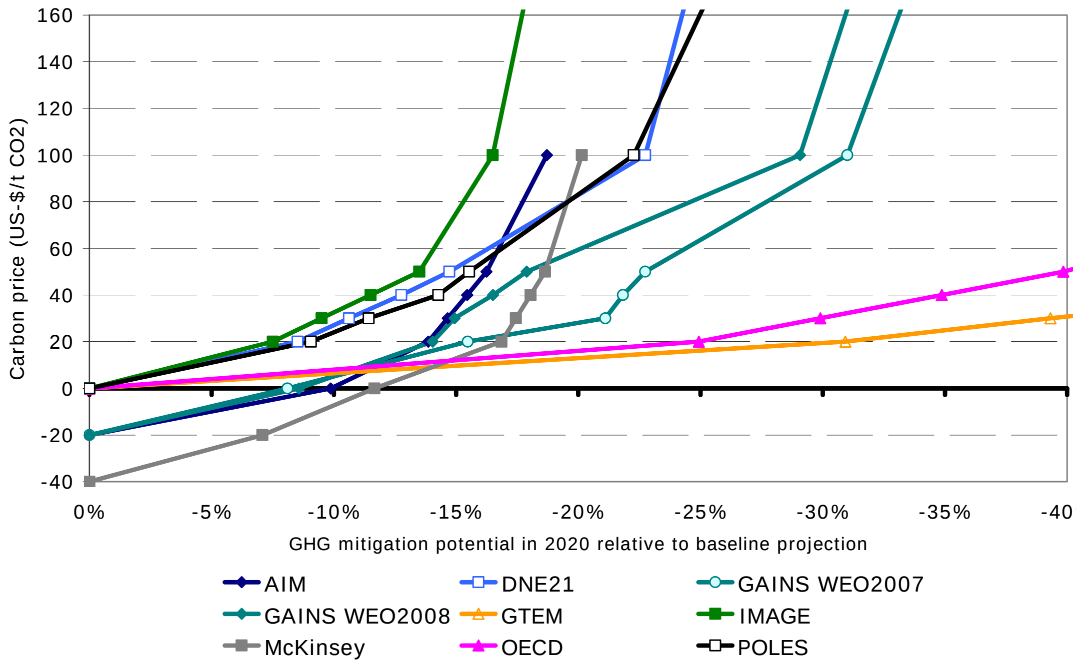

Figure 4.9: Mitigation cost curves (relative to baseline emission levels) adjusted to an implementation time window of 10 years, for total Annex I in 2020

With these adjustments for implementation time, marginal cost curves cluster into two groups:

- The cost curves produced by bottom-up models (the bluish lines in Figure 4.9) similar mitigation potentials for medium carbon prices (e.g., -12% to -22% below baseline for a carbon price of 50 US-$/t CO_2) and exhibit a similar shape. Thus, differences in assumed time windows explain much of the observed differences in mitigation potentials estimated by bottom-up models.

- The general equilibrium models (the reddish lines in Figure 4.9) consistently suggest substantially larger mitigation potentials (up to -40% below baseline projection) for typically only half of the costs of the bottom-up models.

The analysis highlights that the time window considered for mitigation measures is an important factor for interpreting model estimates of mitigation potentials and costs, in particular for bottom-up models. As current calculations employ rather different (and partly unrealistic) assumptions about the starting time of mitigation measures, care must be taken to derive correct conclusions for mitigation paths to 2020. The analysis also emphasizes the importance of the available implementation time for the achievability and costs of emission reduction targets – each delay will reduce the mitigation potential and/or increase costs.

4.6 Model approaches

Figure 4.9 reveals systematic and substantial differences obtained from technology-based bottom-up and general equilibrium top-down models. As mentioned above, general equilibrium models suggest substantially larger mitigation potentials for typically only half of the costs of the bottom-up models.

General equilibrium models consider, in addition to direct GHG mitigation measures, demand adjustments to changed prices, the diversion of resources to mitigation purposes away from other productive uses, changes in trade-balances (e.g., due to less fossil fuel imports), and potential transfers of production to countries without constraints on greenhouse gas emissions (carbon leakage). In contrast, bottom-up models employ a rather narrow system boundary for their calculations with a focus on technical mitigation measures and typically keep volumes and structure of demand fixed.

The analysis suggests that such feedbacks can substantially increase the potential for GHG mitigation in Annex I countries. As costs calculated by the participating CGE models (GTEM, OECD) are systematically and significantly lower than the estimates of the bottom-up models, such feedbacks could compensate for a substantial fraction of the (positive) direct mitigation costs.

While uncertainties associated with the quantification of changes in consumer demand and economic structures cannot be quantified from the data available for this model comparison, these different responses of the two model types constitute a central finding of the analysis. It highlights the potential importance of measures that achieve demand adjustments through structural or behavioural changes, both for the mitigation potential and for the costs for reducing greenhouse gas emissions.

4.7 Cost concepts

While Figure 4.9 indicates the importance of different modelling approaches for estimated mitigation potentials, it does not entirely resolve discrepancies in cost estimates of bottom-up models. A closer inspection of the costing concepts of bottom-up models reveals substantial differences in the approaches adopted by the participating models:

- Most models use a private investor's perspective for quantifying national mitigation costs, while some (e.g., McKinsey) adopt a social planner's perspective that aims at maximizing social welfare.
- Not all models (e.g., McKinsey) include transaction costs in their calculations, i.e., non-technical costs that are necessary to overcome institutional or technical implementation barriers.

4.7.1 Social planner's versus private investor's perspectives

Models can quantify costs from a social planner's or from a private investor's perspective. A *social planner's perspective* would quantify costs of resources that are diverted from other productive use in the economy for the purposes of greenhouse gas mitigation. Resource costs include investments and operating costs, as well as costs (or savings) from modified fuel and material input. Profits that occur to individual actors and transfer payments such as taxes and subsidies are excluded as they do not reflect actual resource use of a society. Costs are accounted over the full life cycle, i.e., pay-back periods for investments cover the full technical lifetime, and savings are accounted over the full period a plant is in operation. A social discount rate that reflects the long-term productivity of capital (i.e., typically 2% to 4%/year) is employed.

In contrast, a *private perspective* would quantify costs as they are seen by private actors and include, in addition to the direct mitigation costs, profits, taxes and subsidies. In particular, such a perspective applies short pay-back periods that reflect profit expectations of private actors (often much shorter than the technical lifetime of an investment) and uses market interest rates for quantifying the cost of capital. Savings that occur during the technical lifetime after the pay-back period are accounted as profits.

These two perspectives can lead to very different results for measures that require high up-front investments and/or lead to energy savings over their full technical lifetime. For instance, insulating a house with high initial investments but long-term energy cost savings appears very cost effective under a social planner's perspective, while it can be "expensive" from the perspective of a private actor. To illustrate how different costing perspectives affect resulting cost estimates, Figure 4.10 compares marginal mitigation cost curves for total Annex I estimated by the GAINS model based on the private investor's perspective (with short pay-back periods) and the social planner's perspective (using a long pay-back period).

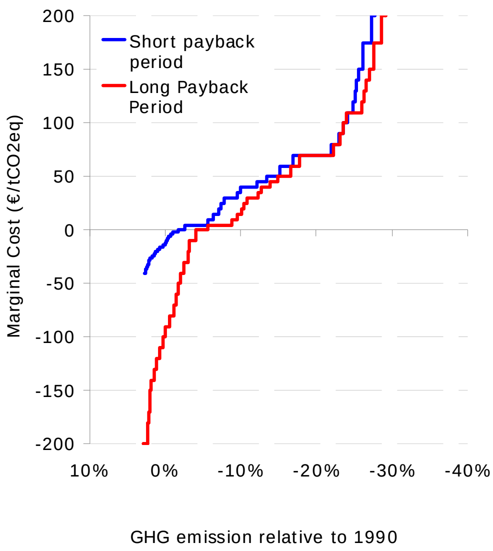

Figure 4.10: Comparison of marginal mitigation cost curves with short (private perspective) and long (social planner's perspective) pay-back periods, curves derived with the GAINS model for total Annex I in 2020

The economic literature argues for a social planner's perspective as the appropriate basis for long-term policy decisions. In contrast, e.g., for simulating the behaviour of individual actors, the private investor's perspective will be more relevant (e.g., to determine the carbon price resulting from trading among private enterprises).

4.7.2 Transaction costs

Many mitigation measures involve *transaction costs* in addition to the direct investments and operating costs. Such transaction costs include costs for conveying necessary technical information to investors and for overcoming technical and institutional implementation barriers (e.g., for resolving the 'principal agents' problem, when benefits of a measure do not occur to the investor but to other persons). Such transaction costs are notoriously difficult to quantify.

All participating bottom-up models with the exception of the McKinsey model include estimates of transaction costs.

4.7.3 Treatment of measures with negative costs

Irrespective of the applied concept, calculated costs of some mitigation measures turn out to be negative, i.e., they result in cost savings over the full life cycle. (This is the case, e.g., when the savings from fuel efficiency improvements accumulated and discounted over the technical lifetime are higher than the initial investments). In such cases the participating bottom-up models apply different approaches:

- Some models (e.g., DNE21+) subsume (per definition) measures with negative costs in their (cost-optimal) baseline, and consider only measures with positive costs in the portfolio that is available for additional mitigation. This leads to the situation that marginal cost curves start at zero costs.

- Other models (e.g., IMAGE, POLES) calibrate costs of mitigation measures in such a way that the baseline simulation reproduces observed behaviour. This is achieved through specifying “hidden” (or transaction) costs that explain why consumers do not exploit this so-called no-cost energy saving potential (see below). As a consequence, marginal cost curves produced by these models contain only positive costs.

- Other bottom-up models (AIM, GAINS, McKinsey) do not calibrate transaction costs in such a way, so that their baseline projection is not necessarily cost-effective. As a consequence, measures for which negative costs are calculated, but which are not adopted by consumers for other reasons, will be still available for mitigation of greenhouse gas emissions. The AIM model defines its baseline as a ‘frozen technology’ case, while the GAINS and McKinsey models assume for their baseline a continuation of the historically observed trend in autonomous efficiency improvement. Thus the AIM model has all measures for which negative costs are calculated available for further mitigation, while GAINS and McKinsey assume that some of these measures are taken autonomously and thus included in the baseline. Only the remaining measures that would lead to higher than historically observed rates of efficiency improvements are considered in the mitigation portfolio. As a consequence, marginal cost curves calculated with these models start with negative marginal costs.

These different cost accounting schemes explain much of the differences in the marginal mitigation cost curve shown in Figure 4.7. After adjustments for implementation periods, models with the same cost concepts produce very similar results (e.g., the three CGE models in Figure 4.11, right panel, and the bottom-up models that do not consider negative cost measures - Figure 4.12, left panel). Differences between the results of the three bottom-up models with negative costs (i.e., AIM, GAINS, McKinsey) are explained by the facts

- that the McKinsey model uses a social planner’s perspective and ignores transaction costs, while the other two models employ a private investor’s perspective with transaction costs (correction for these factors would shift the McKinsey cost curve up), and

- that the AIM model starts from a ‘frozen technology’ baseline and includes (negative cost) measures in the mitigation portfolio, while the other two models consider some of these measures as autonomous technological change in their baseline (adjustment for this difference in baseline definition would shift the AIM cost curve to the left).

With such adjustments also the three cost curves of the AIM, GAINS and McKinsey models would show close agreement, and converge to the curves of the three other bottom-up models.

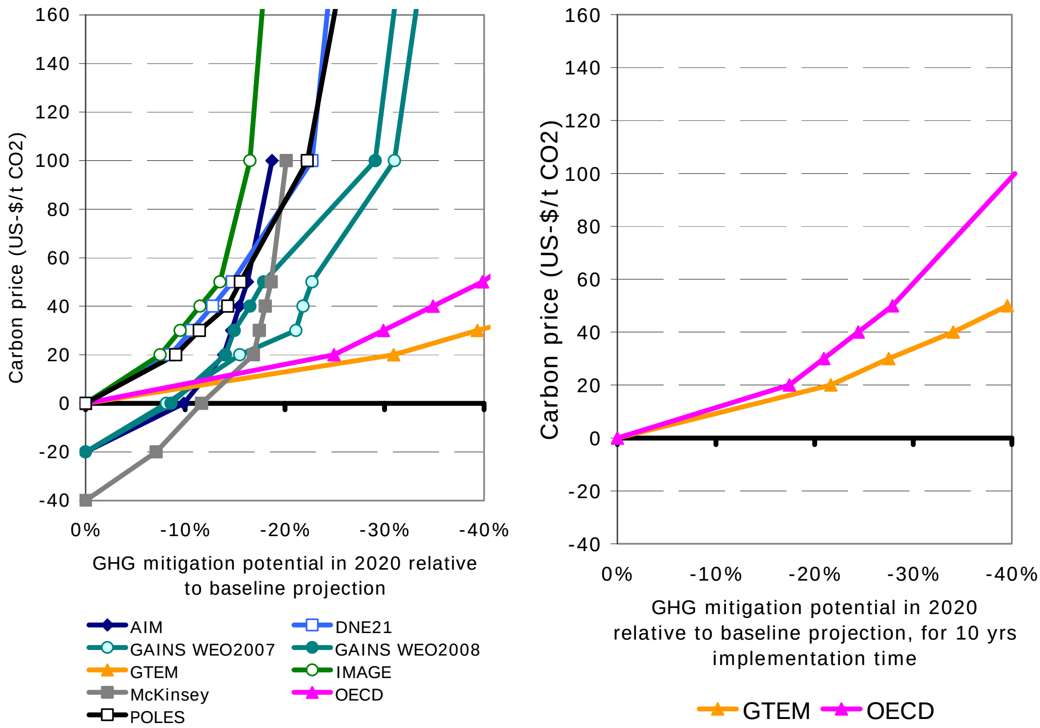

Figure 4.11: Marginal abatement cost curves for all models (left panel) and the computable general equilibrium models (right panel), after adjustment for a 10 years implementation window

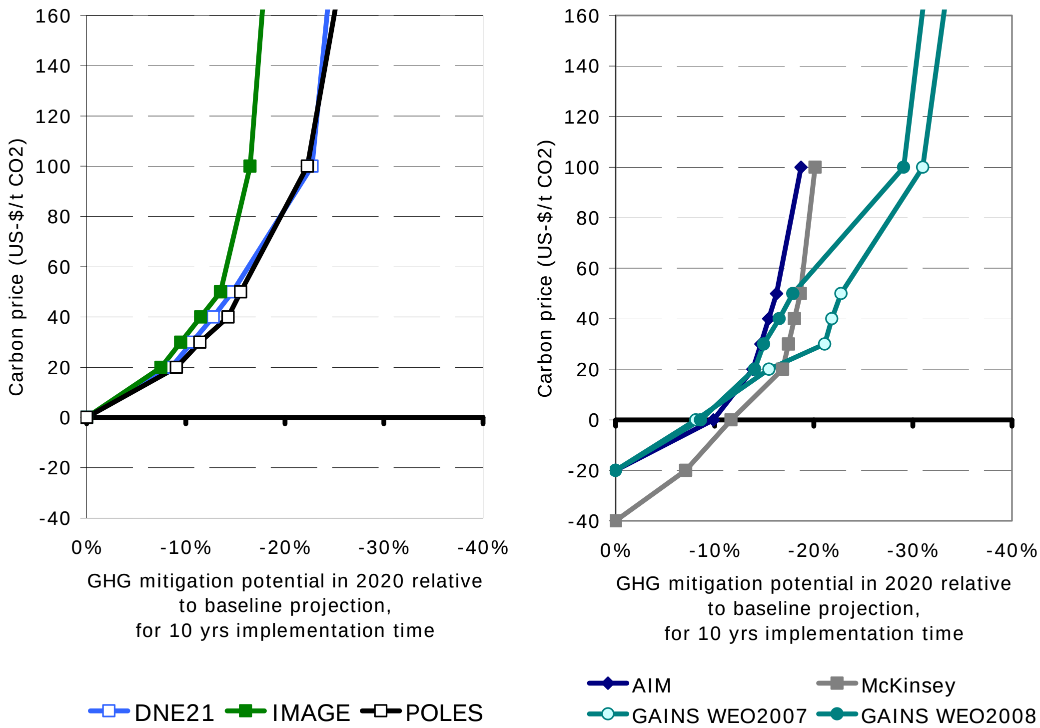

Figure 4.12: Marginal abatement cost curves for bottom-up models that apply a private investor's perspective and consider only mitigation measures with positive costs (left panel) and bottom-up models that include measures with negative costs (right panel)

4.8 Portfolios of mitigation measures

As demonstrated above, differences in (a) the baseline definition and the assumed economic baseline development, (b) implementation time windows, and (c) costing concepts explain much of the variations in the estimates of mitigation potentials and costs. Consideration of demand adjustments, macro-economic feedbacks and carbon leakage emerges as another important factor that reduce mitigation costs compared to estimates that do not account for these measures.

It is interesting to note that model assumptions also differ on the availability and costs of potentially important mitigation measures. Models make different assumptions on carbon capture and storage (CCS), on the social acceptance of additional nuclear power, the premature scrapping of existing capital stock and on the future rate of technological progress in mitigation technologies, and the expected decline in technology costs (Table 4.1). However, differences in these assumptions appear less relevant for low to medium cost reductions, but explain variations in the feasibility of ambitious mitigation targets at higher costs.

Table 4.1: Assumptions on availability of mitigation options

	AIM	DNE21	GAINS	GTEM	McKinsey	OECD	IMAGE	POLES
Carbon capture and storage (CCS)	No	After 2021	As in IEA 'Blue map' scenario	After 2026	Yes	No	Yes	Yes, but not at large scale in 2020
Premature scrapping	No	Yes	No	Yes(1)	Yes	Yes	No	Yes
Additional nuclear power as a mitigation measure	No	No	No	Yes	Yes	Yes	No	Limited
Demand adjustments	No	Partially	No	Yes	No	Yes	No	Yes (but no feedback on GDP)
Transfer of production to non-Annex I countries (carbon leakage)	No	No	No	Yes	No	Yes	No	Partially

(1) GTEM allows for premature scrapping and transfer of production in some circumstances, depending on the relative performance of industries and regions in a particular scenario. Whether scrapping or transfer of production occurs in a given scenario would require additional analysis.

5 Discussion and Conclusions

5.1 Discussion

While at face value model estimates of greenhouse gas mitigation potentials and costs show wide divergence, this paper identifies a limited set of key factors that explain much of the observed differences. Once adjusted for such differences, the analysis suggests that estimates produced by different models show strong convergence and enable very consistent policy conclusions.

Key factors that explain much of the differences can be broadly grouped into four categories:

- Some factors relate to the exact definition of the policy question of interest (e.g., on which cost concept the answer should rely, against which counter-factual baseline the assessment should be carried out, whether the potential for fundamental behavioural changes should be included in the assessment),
- others relate to the genuine uncertainties of future development (e.g., about future economic development, about the future rate of technological progress and the associated decrease in technology costs),
- others are linked with a thorough and factually accurate implementation of a model for a specific country (e.g., how well models reproduce historic emission inventories or current prices for technological options),
- while others are connected with the basic methodological approach that is used for estimating mitigation potentials and costs (e.g., where the systems boundaries are drawn for the assessment, for instance whether macro-economic feedbacks and adjustments are included in the analysis).

As it is impractical to recalculate cost curves with different models for one harmonized set of assumptions and methodologies, an attempt has been made to compile a ‘check list’ that highlights the key aspects that should be kept in mind when interpreting results from a particular model.

For instance, for interpreting results it is important to keep in mind whether a given model

- takes a private costing perspective (i.e., includes profits for individual actors) or social perspective,
- includes transaction costs or not,
- has fixed or dynamic demand projections adjusted to increases in carbon prices,
- considers macro-economic feedbacks of a carbon constraint and potential carbon leakage to non-Annex I countries,
- includes a baseline with autonomous technological progress, and
- considers measures with negative life cycle costs in its portfolio.

Furthermore, it is relevant for a quantitative interpretation of results that

- a model is well-calibrated to the UNFCCC inventory for 2005,
- that a realistic choice is made for the available time for implementing mitigation measures, and
- that assumptions on economic development and baseline emissions are clearly laid out.

Quantitative model results are only valid in the context of these factors. These factors are compared for each model in Table 5.1.

Table 5.1: Summary of key model features and assumptions that explain differences in marginal mitigation cost curves – Methodology

	AIM	DNE21	GAINS WEO2008	GTEM	IMAGE	McKinsey	OECD	POLES
Model type	Bottom-up	Bottom-up	Bottom-up	CGE	Bottom-up	Bottom-up	CGE	Bottom-up
Costing perspective	Private	Private	Private	Private	Private	Social planners	Private	Private
Transaction costs	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Demand projections	Exog. fixed	Partially adjusted	Exog. fixed	Endog. adjusted	Exog. fixed	Exog. fixed	Endog. adjusted	Partially adjusted (no GDP feedback)
Macro-economic feedbacks	No	No	No	Yes	No	No	Yes	No (only prices)
Carbon leakage	N.A.	N.A.	N.A.	Yes	No	N.A.	Yes	No
Baseline includes autonomous technological progress	No	Partially	Yes	Yes	Yes	Yes	Yes	Yes
Negative cost measures	Included in portfolio	Part of baseline	Included in portfolio	Part of baseline	Part of baseline	Included in portfolio	Part of baseline	do not exist
Difference with UNFCCC inventory for 2005[1)]	-1.9%	+2.2%	+2.3%	+4.9%	+17.8%	+5.5%	+3.1%	-1.4%
GDP growth assumed for 2020 (relative to 2005) [1)]	+32%	+34%	+42%	+35%	+42%	+39%	+44%	+35%
Baseline increase in GHG emissions in 2020 (relative to 2005)	+15%	+9%	+6%	+14%	+6%	+15%	+10%	+2%
Time window for mitigation measures up to 2020	15 yrs	14 yrs	10 yrs	7 yrs	20 yrs	10 yrs	7 yrs	10 yrs

[1)] for total Annex I, without LULUCF

5.2 Conclusions

Robust quantification of the future potentials and costs for mitigating greenhouse gases in different countries could provide important information to the current negotiations on a post-2012 climate agreement. However, such information is not readily available from statistical sources, but requires the use of complex models that combine economic, technological and social aspects. During the recent year various modelling teams in different parts of the world have presented their estimates for the year 2020. At face value these estimates seem to span a wide range, so that it is not obvious how robust policy conclusions can be drawn from these calculations.

In March 2009, the International Institute for Applied Systems Analysis (IIASA) invited leading modelling teams to a comparison of available model estimates of GHG mitigation potentials and costs in the Annex I countries. Eight modelling teams provided input to this comparison exercise.

5.2.1 Conclusions on the interpretation of model results

Although at face value model estimates of mitigation potentials and costs show wide variation (see Figure 5.1, left panel), differences

(i) in assumptions on the baseline economic development,

(ii) in the definition of which mitigation measures are considered part of the baseline, and

(iii) in the time window assumed for the implementation of mitigation measures

explain much of the variation in model results (Figure 5.1, right panel). Once corrected for these key factors, two clusters of cost curves emerge for the year 2020:

- Models that include consumer demand changes, macro-economic feedbacks and carbon leakage (i.e., computable general equilibrium models) agree on a mitigation potential of up to 40% reduction below 2005 levels for total Annex I emissions in 2020 for a carbon price of 50 to 150 US-$/t$CO_2$. (Results from these models are plotted with reddish lines in Figure 5.1.)
- Also estimates of bottom-up models, which do not consider such effects, show striking agreement (bluish lines). However, they reveal that only half of the mitigation potential is available at comparable cost when only considering technology options to reduce emissions, keeping demand for services unchanged.

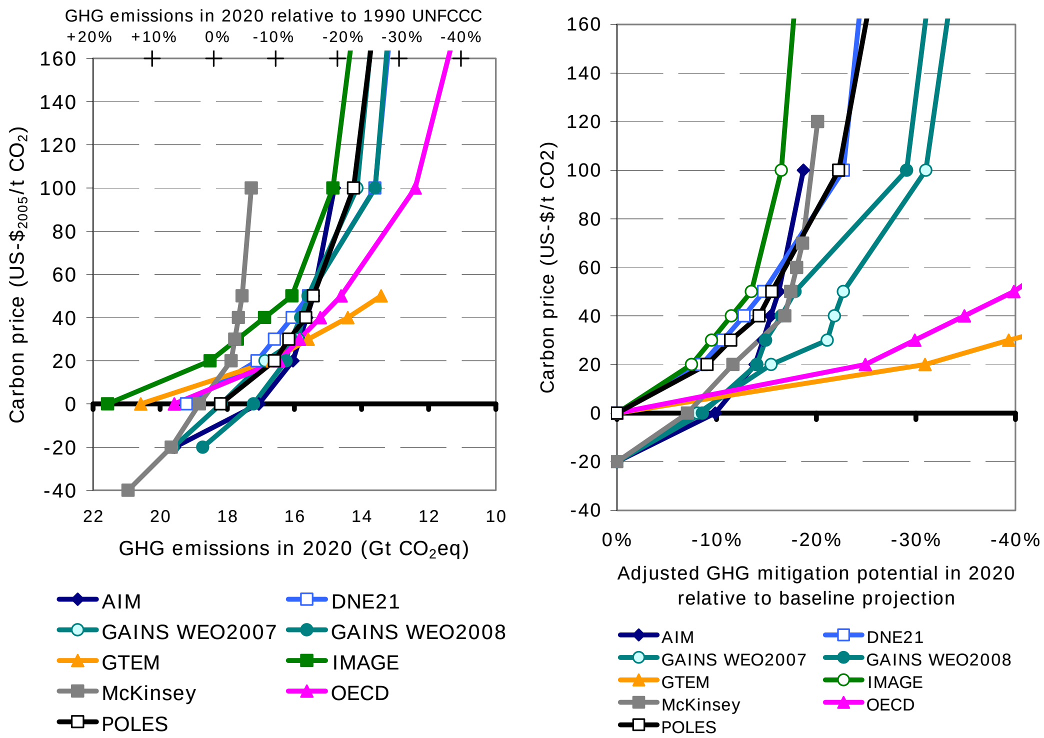

Figure 5.1: Mitigation cost curves for total Annex I in 2020.
***Left panel*: Original model results plotted against absolute emission levels in 2020;**
***Right panel*: Cost curves adjusted (i) for differences in baseline emission projections, (ii) for different baseline definitions regarding negative cost measures, and (iii) to a 10 years implementation time window.**

However, such agreement can only be established among models if their results are adjusted for a number of factors that are treated differently by different models:

Models employ different concepts of how autonomous energy efficiency improvements and mitigation options that result in cost savings are accounted for. While some models assume a continuation of historically observed trends and thus consider some of these measures in their baseline, others include these measures in their mitigation portfolio. As a consequence of such different baseline definitions, estimated mitigation potentials can differ, although in reality the same measures might be applied.

In addition, assumptions on future economic development show considerable spread across models. Differences in assumed GDP growth have a major influence on the starting point for mitigation measures and thus on the potentials and costs for achieving given reduction targets. Lower GDP growth leads to lower levels of emission generating activities, but also implies less penetration of new (and potentially less emitting) technologies. With only one exception, the calculations provided for this model comparison do not yet consider potential impacts of the current economic crisis. Further analysis should explore to what extent different post-crisis economic development paths would influence greenhouse gas mitigation potentials and costs.

It is also important to note that models employ different costing concepts. Quantitative cost estimates differ depending on whether models quantify mitigation costs from a private investor's perspective (including profits, taxes, etc.), or from a social planner's view that excludes transfer payments within the economy.

Furthermore, models employ different rigour to calibrate their calculations to national emission inventories for the base year and to reflect the time window that is realistically available for mitigation measures before 2020. Policy-relevant conclusions about mitigation potentials and costs require close representation of reality in the models.

Of particular policy relevance appears the finding that top-down models that include, inter alia, demand adjustments, macro-economic feedbacks and carbon leakage envisage systematically larger mitigation potentials and lower mitigation costs compared to estimates obtained with bottom-up models that do not include these aspects. However, to confirm the realism of this finding comprehensive uncertainty analysis would be desirable to establish the robustness of model assumptions to behavioural changes.

5.2.2 Conclusions on GHG mitigation potentials and costs for 2020

Once corrected for a limited set of exogenous assumptions and methodological aspects, model estimates show striking agreement about the mitigation potential and costs in Annex I countries. Top-down models that include consumer demand changes, macro-economic feedbacks and carbon leakage suggest a mitigation potential of up to 40% reduction below 2005 levels (i.e., ~45% below 1990 levels) for total Annex I emissions in 2020 for a carbon price of 50 to 150 US-\$/tCO_2. Bottom-up models that restrict their analysis to technical measures show only half of this potential.

All models agree that in the short run energy efficiency improvements and substitution of fossil fuels are the main elements of cost-effective mitigation strategies. Research and development for new technologies will be essential for achieving deep GHG emission reductions in the longer term.

Results from individual models can differ to some extent mainly due to different exogenous assumptions on assumed economic growth, about the time available for the implementation of mitigation measures before 2020, the definition of which autonomous improvements are part of the baseline, and the applied costing perspective. In contrast, uncertainties on the near-term availability of advanced technological mitigation measures, such as carbon capture and storage (CCS), about the social acceptance of additional nuclear power and the future decline in costs due to technological progress have less influence on differences in mitigation potentials and costs estimated for 2020.

These findings support some important policy conclusions:

- The future economic development has strong impact on which emission reductions are achievable at what costs. While mitigation potentials are influenced to some extent by differences in economic development, absolute emission levels that can be achieved depend crucially on the assumed baseline development. This means that lower baseline projections that could result as a consequence of the current economic crisis would shift the starting point for mitigation measures downwards, and thereby enable the achievement of lower emission levels at less cost.

- The time that is available for implementing mitigation measures before a given target date has direct impact on achievable emission reductions and associated costs, especially for near-term targets. Any delay in the start of implementation of mitigation measures will reduce the potential and increase the costs.
- Measures that mobilize demand adjustments through structural or behavioural changes are necessary to achieve high mitigation potential and reduce costs. Analysis with models that include such measures suggests that such measures could double the mitigation potential and halve the costs compared to portfolios that do not include such instruments.
- The robustness of information on available mitigation potentials and costs can be enhanced by considering how the key assumptions listed in Table 5.1 influence the quantitative outcomes of the model at hand. In general, analyses that address relative changes (in comparison to the situation calculated by the same model for the base year, or in comparison with other countries) will provide more robust findings than results in absolute terms.
- A systematic dialogue between national experts and modelling teams would be most useful to enhance the accuracy and reliability of model estimates.

5.2.3 Conclusions on how to use estimates of mitigation potentials

Information on mitigation potentials can be used in various ways in a policy process:

- To obtain robust information on *mitigation potentials and associated costs* in absolute terms, results from more than one model should be used. This will provide a range of estimates that reflects uncertainties due to different assumptions and assessment methods. Using the checklist of differences between models given in Section 5.1 helps to identify reasons for differences.
- Information on *relative mitigation potentials across countries* is more robust compared to absolute estimates. Again, bringing together estimates from several models will illustrate uncertainties resulting from different assumptions and modelling methodologies.
- When identifying *cost-effective measures in each country or across sectors*, model results are quite robust and consistent across models. For analyses of national strategies, national models are usually most comprehensive.

5.2.4 Further work

Due to limited resources and time, this intercomparison exercise could only address a limited set of issues. A variety of aspects remain that are important for policy analysis, but require further work. These include comparison of estimates of mitigation potentials in non-Annex I countries, and the inclusion of emissions from the LULUCF sector. Furthermore, an international model comparison that extends the analysis to the global carbon market could provide a wealth of policy-relevant information.

A dialogue among modelling teams as performed under this exercise helps to enhance the accuracy and reliability of model estimates. A future comparison exercise would greatly benefit from general guidance on how to prepare and present results.

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