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NATIONAL AND SECTORAL GHG MITIGATION POTENTIAL: A COMPARISON ACROSS MODELS

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in Autumn 2009 in response to the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document are those listed in Annex I of the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Korea and Mexico, as OECD member countries, also participate in the Annex I Expert Group. Where this document refers to “countries” or “governments”, it is also intended to include “regional economic organisations”, if appropriate.

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Executive Summary

The 2007 Bali Action Plan, which provides a road map to a post-2012 agreement, calls *inter alia* for "Measurable, reportable and verifiable nationally appropriate mitigation commitments or actions, including quantified emissions limitation and reduction objectives, by all developed country Parties, while ensuring comparability of efforts among them, taking into account differences in their national circumstances." Determining comparability of effort amongst developed countries is a key issue for the upcoming UNFCCC COP-15 negotiations in Copenhagen, as developed country Parties are expected to agree on quantified emissions limitation and reduction objectives for the post-2012 climate change regime. A number of indicators have been proposed to reflect comparability of effort and differences in national circumstances; key amongst these are greenhouse gas (GHG) emissions (per capita), GDP per capita, as well as GHG mitigation potential.

This paper focuses on mitigation potential to provide a comparative assessment across key economies. GHG mitigation potential is defined here to be the level of GHG emission reductions that could be realised, relative to the projected emission baseline in a given year, for a given carbon price. Estimates of GHG mitigation potential projected in the future can be obtained via models. These estimates vary depending on the type of model employed and on the parameters and underlying assumptions used. This comparative analysis of model results aims to:

- Identify areas of agreement in results across different models;
- Enhance understanding of what is driving any differences in results; and
- Indicate possible gaps and areas for improvement in data or modelling analysis.

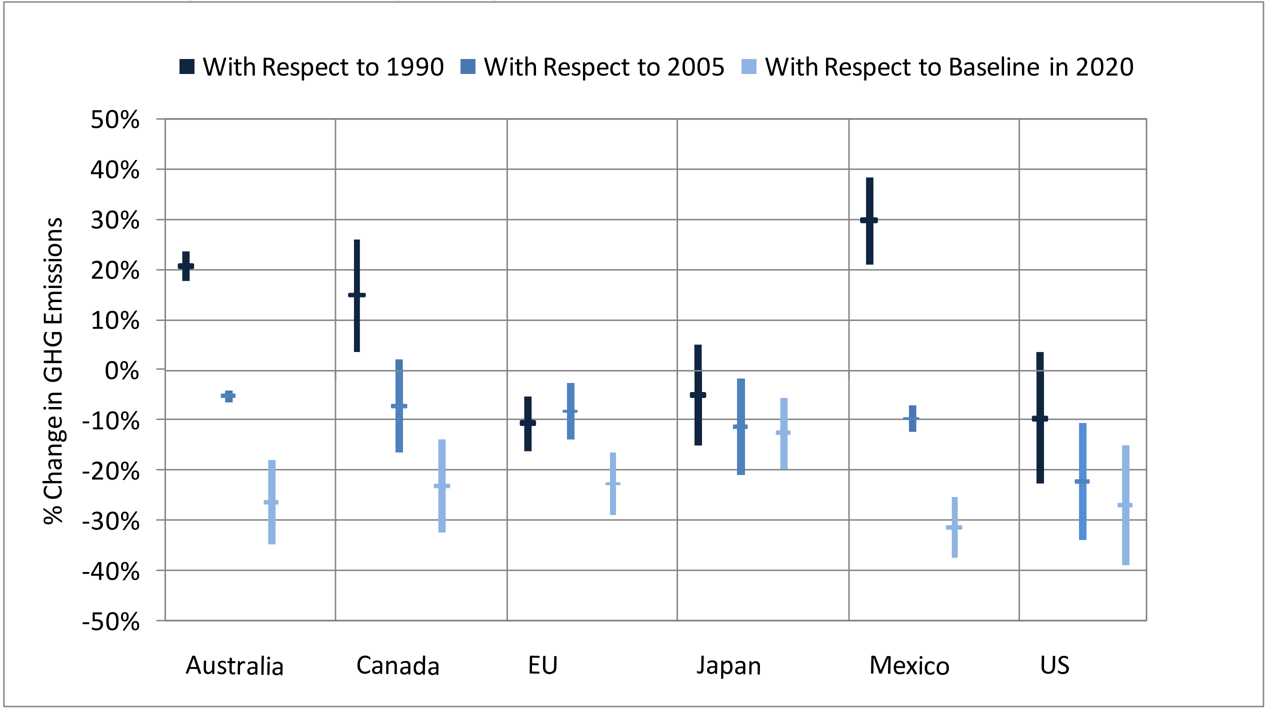
Overall, such a comparative analysis can enhance transparency and contribute to a better informed climate change policy-making process.

This paper compares model estimates of national and sectoral GHG mitigation potential across six key OECD GHG-emitting economies around the world: Australia, Canada, the EU, Japan, Mexico and the US. Data for these countries were obtained across the time horizon of 2005-2050 from a total of 19 models, including models that are used to inform climate policy-makers in each of these economies. For these six economies, this paper examines the model structure, baseline and policy assumptions, and then compares GHG mitigation potential estimates across the available models. Due to differences in regional and economy-wide aggregation across these models, GHG mitigation potential is compared across 5 models for Australia, 9 models for Canada, 12 models for the EU, 8 models for Japan, 5 across Mexico, and 13 models across the US.

GHG mitigation potential is compared for carbon prices of USD 20, 50 and 100/tCO_2e in this paper. Figure ES summarises the range of mitigation potential projections across the models for the year 2020 at a carbon price of USD 50/tCO_2e relative to the baseline. The figure also compares the resulting emissions against historic emissions from 1990 and 2005, scaled according to how well the base year data in the model corresponds to the historic data of the same year. At USD 50/tCO_2e, mitigation potential in Japan is estimated to be relatively lower than for the other five economies, ranging from 5-20% emission reduction from baseline in 2020. Although noticeably fewer models report data for Mexico at this price level, the models show deeper potential reductions in the range of 25-37% at the same carbon price. Mitigation potential estimates for Australia show a wider range of 18-35% reduction, as do Canada and the US, with ranges of 14-32% and 15-39% emission reductions relative to 2020 respectively. The EU shows a relatively tighter range of 16-29% emission reductions from the 2020 baseline.

Across the economies examined ranges of mitigation potential overlap considerably, especially when compared with the 2020 baseline. The majority of models do not have disaggregated data for all six economies. For models that reported data for multiple economies, there was not agreement as to the rank order of the mitigation potential across those economies at USD 50/tCO_2e in 2020, thus the findings with respect to ranking are model dependent.

Figure ES: Summary of Mitigation Potential Estimates at USD 50/tCO2e in 2020



Note: Ranges and median values are shown in the Figure. Ranges are based on results from 5 models for Australia, 8 for Canada, 11 for the EU, 7 for Japan, 3 for Mexico, and 12 for the US. The models included in this analysis are: G-Cubed, GTEM, MMRF (from Australia); EC_IDYGE, E3MC (from Canada); GEM-E3, POLES (from the EU); AIM/Enduse, DNE21+ (from Japan); LEAP/MEDEC (from Mexico); ADAGE, EPPA, MERGE, SGM (from the US); and ENV-Linkages, GAINS, McKinsey, WEM, and WITCH (from international institutions, corporations and inter-governmental organizations).

As expected, the results of this study show greater emission reductions in the year 2050 than in the year 2020 across the six economies examined. This trend reflects structural and technical changes that occur over time, including typically the availability of carbon capture and storage technology in 2030 and beyond. In general, this study finds closer agreement across the models for mitigation potential in 2020 than for later years, reflecting greater uncertainty about structural and technical changes as projections extend into the future.

This study shows that there is agreement across the models for all six economies that greater mitigation potential exists in the electricity supply sector than in the transportation sector, despite the inconsistent sector definitions across the models. This reflects the current availability of more mitigation options for electricity generation at a given carbon price, than for adopting lower-carbon modes of transportation. The actual mitigation potential in the transport sector could be larger than is identified by these models, if policies and measures were adopted that target behavioural changes by consumers or modal shifts towards increased public transport.

The broad range of model results for each economy indicates the variance in underlying assumptions across the models. These differences in mitigation potential result from a number of possible drivers. These include, *inter alia*:

- **Model structure**, such as the type of model (top-down, bottom-up, hybrid), whether the model examines one time period or actions across multiple time periods (static or dynamic), the nature of expectations (myopic or forward-looking), coverage of GHGs and sectors, sector definitions, and mitigation options available in the model (e.g. if, when, and at what capacity carbon capture and storage (CCS) comes into effect);

- **Baseline assumptions** regarding economic growth, energy use and other variables, underlying data sources and versions used, and the existing policies captured in the baseline; and

- **Policy scenarios** implemented, e.g. constant vs. rising carbon prices over time, unilateral vs. multilateral application of carbon prices, and assumptions regarding international action.

Due to the multitude of assumptions embedded within each model, it is difficult to isolate and identify the most important drivers across all of the models. However this paper compares some of the key drivers of baseline emissions such as GDP, population, and energy use, in a transparent and consistent manner, and explores differences in model structure and policy assumptions that impact mitigation potential to shed light on this issue.

Given the existing ranges of estimates resulting from the different models, policy-makers would benefit from looking across a range of model results to help guide and inform the decision-making process. Model comparisons such as this study can help policy-makers identify the largest GHG-emitting sectors, where emissions are expected to grow most rapidly, and where the greatest mitigation potential is for a given carbon price. This can be especially important in designing national and sectoral climate mitigation strategies, and in guiding technology, financing and capacity-building support to bring about mitigation.

1. Introduction

The aim of this paper is to examine how GHG mitigation potential results from models used by countries for policy-making (i.e. own-country models) compare with results from other available models. A comparative analysis of model results can serve to: (i) identify robust results across models; (ii) enhance understanding of what is driving the differences; and (iii) indicate possible gaps and areas for improvement. Overall, such a comparative analysis can contribute to a better informed climate change policy-making process.

1.1 Background

The ultimate objective of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilisation of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In accordance with Article 3.1 of the UNFCCC, Parties should protect the climate system "on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities." The 1997 Kyoto Protocol established quantified emission limitation and reduction objectives (QELROs) for 2008-2012 for the so-called Annex I (industrialised) Parties. In Bali, negotiators agreed on a two year process to finalise a post-2012 regime by UNFCCC COP-15 in Copenhagen (December 2009).

The 2007 Bali Action Plan calls for *inter alia* "Measurable, reportable and verifiable nationally appropriate mitigation commitments or actions, including quantified emissions limitation and reduction objectives, by all developed country Parties, while ensuring comparability of efforts among them, taking into account differences in their national circumstances." A number of indicators have been proposed to reflect comparability of effort and differences in national circumstances. Key amongst these are GHG emissions (per capita), GDP per capita, as well as GHG mitigation potential.[1]

This paper focuses on mitigation potential to provide a comparative assessment across key economies. GHG mitigation potential is defined here to be the level of GHG reductions that could be made, relative to the projected emission baseline in a given year, for a given carbon price (and is expressed in a physical unit such as gigatonnes carbon dioxide equivalent emissions or in percentage difference from the baseline) (IPCC, 2007). Domestic GHG mitigation potential is determined by a variety of factors that are explored in this paper, including national circumstances and policies that are already in place, technological feasibility of mitigation options, and other factors such as international trade and world energy prices. In general, the lower the mitigation potential at a given carbon price, the higher the aggregate costs of reducing emissions to meet a given emission reduction objective within a given timeframe. Identifying the mitigation potential at different carbon prices across countries and sectors can guide actions and resources to target cost-effective emission reductions. Estimates of economic GHG mitigation potential in the future can be obtained via models.[2] These estimates vary depending on the type of model employed and on the parameters and underlying assumptions used.

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[1] A number of proposed indicators are intended to reflect the UNFCCC principles of equity, responsibility and capability. For a full list of proposed indicators, which include geographical characteristics and resource endowments, development priorities, and HDI, see FCCC/AWGLCA/2009/8 para 57 (19 May 2009).

[2] According to the IPCC (2007), the concept of mitigation potential can be further differentiated in terms of "market potential" and "economic potential". Market potential is based on private costs and private discount rates, which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake of abatement. Economic potential takes into account social costs and benefits and social discount rates, assuming that market efficiency is improved by policies and measures and barriers are removed. Studies of market potential can be used to inform policy makers about mitigation potential with existing policies and barriers, while studies of economic potentials show what might be achieved if appropriate new and

1.2 Scope and Approach

In the process of exploring climate policy options and informing decision-making, many countries utilise models from their own governments or institutions to examine their potential for climate change mitigation. A number of international organisations and institutions also model mitigation potential. Given the abundance of modelling data available for many countries, this paper provides some points of comparison for mitigation potential in six key GHG emitting economies. The paper analyses a range of results from models that provide national and sectoral data on: baseline (or business-as-usual) GHG emissions projections, abatement costs, and ultimately mitigation potential relative to the baseline. It examines key underlying assumptions that drive results, including model structure, baseline assumptions, and policy scenarios implemented. The paper identifies areas of consensus and divergence in national and sectoral results across the different models, and concludes with possible areas for further work on data analysis or modelling capacity-building.

Due to time and resource constraints, the scope of the analysis here is limited to the following six key economies: Australia, Canada, the EU, Japan, Mexico and the US. These are all amongst the top twelve GHG-emitting economies in the world.[3] The models examined in this analysis are listed in Table 1.

The data for this analysis was obtained via questionnaires that were sent to model experts in the relevant countries, research institutes and consulting companies.[4] Information and data were requested on model structure, baseline scenario specification, and policy scenarios employed. In order to obtain mitigation potential estimates that are comparable across models and over time, results were requested for mitigation potential estimates for the years 2020, 2030, 2040 and 2050 at an emissions price of USD/tCO_2e of 20, 50, and 100, implemented across each domestic economy as of 2013 and constant throughout the model time horizon. There are several cases where the policy scenarios simulated to obtain mitigation potential estimates are different than the price scenarios requested (see Section 3, Text Box 2 for discussion).

In addition to national mitigation potential, this paper compares estimates on sectoral mitigation potential. Comparing model estimates on sectoral mitigation potential is more complex than national estimates for a number of reasons. Most importantly, models differ in their coverage of sectors, their exact disaggregation and definitions. Comparison of sectoral mitigation potential focuses on electricity and transport for two reasons: these sectors tend to be the largest emitters, and they tend to be the most consistently defined across the models. Sectoral mitigation potential discussed in this paper is defined as the reduction in emissions in the given sector, resulting from an economy-wide implementation of a GHG price.

Previous comparative analysis of modelling efforts has been undertaken by *inter alia* the Intergovernmental Panel on Climate Change (IPCC), IIASA, Energy Modelling Forum (EMF) and Ecofys.[5] The IPCC 4th Assessment Report on Mitigation incorporated results from both top-down models and bottom-up models to compare global mitigation potential across emitting sectors. Van Vuuren et al. (2009) built upon the IPCC work to analyse sectoral mitigation potential across bottom-up and top-down models. Additional groups working to enhance model comparisons include IIASA, which held a workshop

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additional policies were put into place to remove barriers and include social costs and benefits. The economic potential is therefore generally greater than the market potential.

[3] IEA Emissions of CO_2, CH_4, N_2O, HFC, PFC and SF_6, Edition 2008.

[4] The authors gratefully acknowledge the data and inputs received from modelling experts, namely: Robert Ewing (Australia), Nick Macaluso (Canada), Juan-Carlos Ciscar, Peter Russ, Bert Saveyn, Tom van Ierland (EU), Keigo Akimoto, Tatsuya Hanaoka (Japan), Maria Elena Sierra, Mauricio Alarcón (Mexico), Geoff Blanford, Bella Tonkonogy, John Reilly (US), Paul Dowling (IEA), Jens Dinkel (McKinsey), Valentina Bosetti (FEEM) and Markus Amann, Fabian Wagner (IIASA).

[5] See IPCC, 2007; Amman et. al., forthcoming; http://emf.stanford.edu/; and van Vuuren et. al., 2009.

in May 2009 to compare estimates on GHG mitigation potential and costs in Annex I countries across a variety of models.[6] The EMF, housed at Stanford University, has also conducted many in-depth international model comparison studies. The most recent EMF Working Group 22 focuses on post-Kyoto scenarios for global and regional economies. Most of these efforts to date have focused on larger economic regions, or only a few countries at the national level.

This paper expands on these efforts, to compare national and global models across a range of specific countries with different national circumstances and from different regional areas with a specific focus on models that are used by national policymakers. By exploring mitigation potential for specific countries, this study aims to enhance policy-makers' understanding of how models used in their own economy compare with other available international models. The paper provides information on data and assumptions used in a consistent and transparent manner and, to the extent possible, aims to enhance understanding of what is driving differences across model results. The paper is organised as follows: Section 2 provides an overview of the models and summarises their key features, underlying data sources and the available mitigation options. Section 3 compares and analyses national and sectoral GHG baseline emissions and mitigation potential estimates across the six economies. Section 4 summarises and concludes.

2. An Overview of the Models

A total of 19 different models are employed for this analysis, based on data inputs received. The key features of these models are summarised in Table 2.

Models are generally characterised as either top-down or bottom-up approaches (see Text Box 1 for further explanation of model types). Top-down models assess economy-wide impacts of environmental policy, but have less detail on the specific abatement technologies that reduce emissions. Bottom-up models focus on specific abatement options, but cannot take into account feedback effects from adjustment in market mechanisms or prices (Dellink, 2005). More recently, much effort has been focused on integrating essential bottom-up aspects in top-down models and vice-versa; this has led to so-called "hybrid" models that have incorporated technological detail into a macroeconomic context. Given the variety of model types available, this study presents the results from all types (bottom-up, top-down, and hybrid) together, to provide policy-makers with insight regarding the range of results these models exhibit.

Investment and costs are characterized distinctly in different model types. Computable general equilibrium (CGE) models, a subset of top-down models, measure total cost to the whole economy, including the costs to the other industrial sectors, households (in the form of welfare effects) and government, and not only the costs of the affected sectors. In contrast, bottom-up models are generally built upon an engineering cost basis of emitting processes and technologies, and measure only direct costs. Models with higher interest rates or relatively short payback periods (typically bottom-up models), will assess long-lived capital investment with higher costs.

Models also differ in the nature of expectations over time. For example, recursive-dynamic models are those which can be solved sequentially (one period at a time): they assume that behaviour depends only on current and past states of the economy. In contrast, forward-looking (or intertemporally-optimising) models incorporate perfect foresight behaviour, represented by full inter-temporal optimisation. This means that actors in the model are able to anticipate future changes when making consumption, savings, and investment decisions. For example, in a recursive structure agents cannot look ahead to see resource

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[6] For further information see http://gains.iiasa.ac.at.

depletion and hence would, if allowed, produce and consume these resources at marginal cost of production until they suddenly ran out of them. Forward-looking agents look ahead and see the implications of over-consuming depletable resources and hence allocate these scarce resources optimally over time (see Babiker *et al.* 2008). Forward-looking models tend to bring forward some substitution between technologies, lowering the transition costs and thus reducing the carbon price for a given level of mitigation.

Table 1: Summary of Models

Country of Origin/International Organisation	**Model**	**Organisation**
Australia	**MMRF** (Monash Multi-Regional Forecasting)	Centre of Policy Studies at Monash University, as used by Australian Treasury for Australian Government (2008)
Australia	**GTEM** (Global Trade and Environment Model)	ABARE - Australian Bureau of Agriculture and Resource Economics, as used by Australian Treasury for Australian Government (2008)
Australia	**G-cubed**	McKibbin and Wilcoxen, as used by Australian Treasury for Australian Government (2008)
Canada	**E3MC** (Energy-Economy-Environment Model for Canada)	Environment Canada
Canada	**EC_IDYGE** (Environment-Canada Intertemporal Dynamic CGE)	Environment Canada
EU	**POLES** (Prospective Outlook for the Long term Energy System)	IPTS, Joint Research Centre, European Commission
EU	**GEM-E3** (General Equilibrium Model for Energy-Economy-Environment interactions)	IPTS, Joint Research Centre, European Commission
Japan	**AIM/Enduse[Global]** (Asia-Pacific Integrated Assessment Models)	NIES - National Institute for Environmental Studies
Japan	**DNE21+**	RITE- Research Institute of Innovative Technology for the Earth
Mexico	**LEAP/MEDEC**	WB – World Bank
US	**EPPA** (Emissions Predictions and Policy Analysis model)	MIT - Massachusetts Institute of Technology
US	**SGM** (Second Generation Model)	PNNL - Pacific Northwest National Laboratory (used by Environmental Protection Agency)
US	**ADAGE** (Applied Dynamic Analysis of the Global Economy)	RTI - Research Triangle Institute (used by Environmental Protection Agency)
US	**MERGE** (Model for Evaluating Regional and Global Effects of GHG Reduction Policies)	EPRI- Electric Power Research Institute

International Institution	**GAINS** (Greenhouse Gas and Air Pollution Interactions and Synergies)	IIASA - International Institute of Applied Systems Analysis
Inter-governmental Organisation	**ENV-Linkages**	OECD –Organisation for Economic Cooperation and Development
International Institution	**WITCH** (World Induced Technical Change Hybrid)	FEEM - Fondazione Eni Enrico Mattei
Inter-governmental Organisation	**WEM** (World Energy Model)	IEA – International Energy Agency
International Corporation	**McKinsey** Global GHG Abatement Model v2.0	McKinsey

Note: In this analysis, own-country models are compared with models from international organisations and institutions, as well as with models housed in other countries. Not all models are able to disaggregate the countries of focus, for example the ENV-Linkages and WEM models group Australia and New Zealand together, whereas ENV-Linkages groups the EU with EFTA.

The treatment of negative-cost mitigation measures tends to vary across models as well. These measures are so-called “no regret” policies, or mitigation options that imply net benefits, although they may often require substantial up-front investments. Only bottom-up models tend to include this feature (Table 2). Models that include negative-cost measures will, *ceteris paribus*, reduce the carbon price needed for a given level of mitigation (i.e. they will tend to project higher mitigation potentials at a given price).

The more comprehensive a model is with respect to sectoral and GHG coverage, the larger the mitigation potential will be. As can be seen in Table 2, the majority of models include all six GHGs, whereas only a few models include full sectoral coverage, as indicated by the land-use, land-use change and forestry (LULUCF) sector.

Table 3 summarises the underlying data sources across the different models. The use of different data sources will impact estimates of GHG mitigation potential. For some parameters, many models use one particular source (e.g. UN data sets for population projections). The sources of other key parameters, such as economic growth and GHG emissions, tend to vary. Another important driver of baseline differences is the year of the data set used, or how recent the estimates are. For example, the energy price projections are higher in IEA’s World Energy Outlook (WEO) 2008 than in the WEO 2007, which can impact the baseline emissions and thus the relative mitigation potential. Similarly, the recent economic recession could have an impact on baseline emission trends (lowering emissions at least in the short term) and thus lowering the absolute GHG mitigation potential. As can be seen in Table 3, several of the models already reflect the economic recession to some degree in their analyses (e.g. E3MC, EC_IDYGE, ADAGE, EPPA, MERGE, GEM-E3, POLES and WEM).

Table 2: Key Features of Models Employed

Model	Structure	Methodology	Negative cost measures	Technological progress	Gases covered	LULUCF	Time Horizon	Discount Factor	Geographic Scope
MMRF	Hybrid	Recursive-Dynamic	No	Exogenous	All 6	Forestry only	2050	no internal rate of time preference; 4% used for exogenous assumptions	Australia
GTEM	Hybrid	Recursive-dynamic	No	Exogenous	All 6	Yes	2050	no internal rate of time preference; 4% used for exogenous assumptions	Global
G-cubed	Top-down	Forward-looking	No	Yes	CO_2, N_2O, CH_4	Yes	2050	4%	Global
E3MC	Bottom-up	Causal Simulation	No	Exogenous	All 6	No	2020 (with possibility of 2050)	7%	Canada
EC_IDYGE	Top-down	Intertemporal dynamic model	No	Exogenously defined labour-augmenting technical progress	All 6	No	2050	5% benchmark interest rate	Global
POLES	Bottom-up /Hybrid	Recursive-dynamic	No	?	All 6	No	2050 (optional 2100)	?	Global
GEM-E3	Top-down	Recursive-dynamic	No	Exogenous	All 6	No	2050 (optional infinite)	Determined endogenously	Global
AIM/Enduse	Bottom-up	Linear optimisation	Yes	No	All 6	No	2020	5%	Global
DNE21+	Bottom-up	Forward-looking	Yes	Exogenous	All 6	No	2050	5%	Global
LEAP/MEDEC	Bottom-up	Cost-effectiveness	Yes	Exogenous	All 6	Yes	2030	?	Mexico
EPPA	Top-down	Forward-looking	No	Exogenous	All 6	?	2100	4%	Global
SGM	Top-down	Recursive-dynamic	No	Exogenous	CO_2	No	2100	3%	Global
ADAGE	Top-down	Forward-looking	No	Exogenous	All 6	Incorporates emissions from timber and land-use models	2050	5%	Global
MERGE	Hybrid	Forward-looking	No	Exogenous	All 6	No	2100	Utility discount rate is endogenously determined (real interest rate begins at 5%, falls to 4% by 2050)	Global
GAINS	Bottom-up	Static (single year) cost optimization	Yes	Exogenous	All 6	No	2030	4%	Annex I

ENV-Linkages	Top-down	Recursive-dynamic	No	Yes	All 6	No	2050	No internal rate of time preference. Investments are based on net capital flows and savings.	Global
WITCH	Hybrid	Forward-looking	Some	Induced in energy sector	All 6	Yes	2100	The rate of time preference is assumed to be 3% declining to 1% at the end of 2100. The utility function is a log function.	Global
WEM	Bottom-up	Recursive-dynamic	Yes	Endogenous in power sector	Energy-related CO_2	No	2030	8% OECD; 7% non-OECD for power generation investments	Global
McKinsey	Bottom-up	Forward-looking	Yes	Exogenous	All 6	Yes	2030	4%	Global

Note: "?" indicates that data was unavailable or unable to be confirmed at the time of publication.

Text Box 1: Model Types: Bottom-Up, Top-Down and Hybrid[7]

A key distinction between model types is how they characterize technology, emissions, energy and the economy. Many models fall into the two general categories of "bottom-up" or "top-down", although some models contain elements of both approaches and are referred to as "hybrid" models. Bottom-up models are best suited to answer questions about specific low-carbon technology deployment, whereas top-down models are best suited to answer questions about economic impacts of carbon policies.

Bottom-up models typically assess distinct mitigation technologies or practices, including their costs and emission reduction capabilities, as well as their substitutability with other technologies. A combination of mitigation technologies is then used to meet energy demands under an environmental constraint. Bottom-up models tend to focus on the interactions within the energy system, rather than its relationship with the overall economy.

Top-down models usually view the economy as an integrated whole, reaching economic equilibrium under an environmental constraint through substituting capital, energy, and labour. Top-down models tend to focus on economic processes rather than technology detail or market products.

> ***Computable general equilibrium (CGE) models*** are a subset of top-down models that quantitatively simulate the economy. Demand and supply of each commodity and factor across a specified set of markets in the economy are balanced through a price mechanism.

Hybrid models combine elements of both bottom-up technology detail, usually focused on the electricity sector, and top-down economic integration.

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[7] See van Vuuren, D. P. *et. al.* (2009) for more detail.

Table 3: Underlying Data Sources Across the Models

Model	Base year Economic Data	Economic growth	Economic Recession	Population Growth	Energy Use	Electric Power	GHG emissions
MMRF	ABS and Centre of Policy Studies	Treasury projections	Not reflected	ABS, and Treasury projections	MMA	MMA	Australian government
GTEM	GTAP	IMF, OECD, Consensus Economics and Treasury projections	Not reflected	UN	ABARE and IEA	ABARE	ABARE and IEA
G-cubed	Calibrated to the GTEM reference scenario						
E3MC	Most recent historical data (2007)	The Informetrica Model (part of ECM3)	Reflected	The Informetrica Model (part of ECM3)	Projections based on Statistics Canada	Projections based on Statistics Canada	Projections based on historical energy use data from Statistics Canada and emissions data from Environment Canada
EC_IDYGE	GTAP7	EIA International Energy Outlook, IEA WEO	Reflected	UN and Statistics Canada	Projections based on IEA, EIA and Statistics Canada	Projections based on EIA and Statistics Canada	Energy-related CO2 from IEA, non-CO2 from US EPA
DNE-21+	WDI	JERC projections	Partially reflected	UN	IEA	IEA	UNFCCC, IEA
AIM/Enduse [Global]	IMF, GTAP, OECD, World Bank, etc.	Socio-economic Macro Frame model	Not reflected	UN	Base year data from IEA	Base Year data from IEA	Base year data from IEA and UNFCCC
POLES	IMF	CEEPI, EC DG, EC FIN, IMF	Accounts for the IMF forecasts from October 2008	UN	Enerdata	Enerdata, Platts, EPIC	UNFCCC, EDGAR
GEM-E3	GTAP (world model), EUROSTAT (European model)		Accounts for the IMF forecasts from October 2008	UN	IEA	IEA	IEA, UNFCC, database EDGAR v3.3
LEAP/MEDEC	National official statistics (INEGI)	Ministry of Finance (SHCP)	Not reflected	CONAPO	Mexican Energy Ministry (until 2016) and consultants assumptions	Mexican Energy Ministry (until 2016) and consultants assumptions	National Inventory (INEGEI)
SGM	GTAP	PNNL assumptions	Not reflected	UN, US population estimates to 2050 from US Census projections	PNNL assumptions	IEA	Published carbon densities from MiniCAM
ADAGE	GTAP	IEA World Energy Outlook; EIA Annual Energy Outlook	Lower near-term GDP (based on AEO2009)	UN	IEA	EIA Annual Energy Outlook 2009	Energy-related CO_2 from IEA; non- CO_2 from US EPA

EPPA	GTAP	Endogenous, US based on AEO 2009	Lower near-term GDP (based on AEO2009)	UN	?	?	Emission factors based on US EPA GHG inventory
MERGE	IMF	EPRI projections	Yes, based on EPRI projections	Central UN projection	Base year energy balances from EIA for US, and IEA for elsewhere	Base year energy balances from EIA for US, and IEA for elsewhere	Base year CO_2 from ORNL, non-CO_2 from USEPA
WITCH	IMF, GTAP, OECD, World Bank	World Bank	Not reflected	UN	IEA	IEA, EIA	Endogenous
WEM	IMF, OECD	IMF	Lower GDP based on IMF	UN	IEA	IEA	Energy-related CO_2 from IEA; non- CO_2 from OECD
ENV-Linkages	GTAP	Endogenous	Not reflected	UN	IEA (WEO 2006-2008)	IEA (EEB and WEO 2008)	Energy-related CO_2 from IEA; non- CO_2 from US EPA
McKinsey	Global Insight	IEA World Energy Outlook 2007	Not reflected	IEA World Energy Outlook 2007	IEA WEO 2007, several industry reports, McKinsey analysis	IEA WEO 2007	Houghton, IEA, IPCC, UNFCCC, US EPA
GAINS	IMF (GDP and POP)	IEA World Energy Outlook 2008	Not reflected	UN	IEA World Energy Outlook 2008	IEA World Energy Outlook 2008	IEA, FAO, UNFCCC and others

Note: For further information on the Australian model baselines, see Australian Government (2008) pg 46. The McKinsey model results used here are those from version 2.0. Further information on model versions is not available. The information reported in this Table is not static; models are continuously updated and improved. “?” indicates that data was unavailable or unable to be confirmed at the time of publication.

Table 4: Summary of Key Mitigation Options Available in the Models

Model	CCS	Nuclear Power (Additional to Baseline)	Hybrid Vehicles	Biofuels
MMRF	Yes (from 2020)	No	Yes	Yes
GTEM	Yes (from 2020)	Yes, but not for Australia	Yes	Yes
G-cubed	No	No	No	No
ECM3	Yes (from 2012)	Yes	Yes	Yes
EC_IDYGE	No	No	No	No
DNE-21+	After 2021	No	Yes	Yes
AIM/Enduse [Global]	No	No	Yes	Yes
POLES	?	?	?	?
GEM-E3	No	No	No	No
LEAP/MEDEC	No	No	No (cost above predefined threshold)	Yes
SGM	Yes (after 2025/2026), no retrofits	Yes	No	No
ADAGE	Yes	Yes	No	Yes
EPPA	Yes	Yes	?	Yes
MERGE	Yes	Yes	Yes	Yes
WITCH	Yes	Yes	No	Yes
WEM	Yes (2020)	Yes	Yes	Yes
ENV-Linkages	No	Yes for some regions	No	No
McKinsey	Yes	Yes	Yes	Yes
GAINS	Yes (used the IEA Blue Tech Scenario)	No	Hybrid vehicles (+advanced hybrid) (at this stage no battery electric vehicles beyond baseline)	Yes (potentials from local GLOBIOM model)

Note: Other key mitigation options such as energy efficiency improvements and renewable electricity generation are typically based on assumptions too complex to represent in this table format. "?" indicates that data was unavailable or unable to be confirmed at the time of publication.

Each model incorporates a variety of assumptions with respect to possible mitigation potential options and the extent to which they take effect. Table 4 summarises some of the key mitigation options available across the models that are available for this study. Carbon capture and storage (CCS) and nuclear power are particularly relevant for mitigation in the electricity sector, while hybrid vehicles and biofuels are important for the transportation sector. In particular, CCS technology is subject to many assumptions regarding feasibility. The ECM3 model is more optimistic, allowing CCS to deploy beginning in 2012, while other models do not allow CCS to deploy until later dates (e.g. after 2025 in SGM).

3. Comparison of GHG Mitigation Potential Results Across Models

National and sectoral mitigation potentials for each of the six economies, namely, Australia, Canada, the EU, Japan, Mexico, and the US, are examined below. For each of these, national baseline emissions[8] are compared, since the baseline assumptions impact the relative amount of mitigation potential. As baseline emission projections are generally driven by assumptions on economic growth, population, and energy use, this information is compared across models. National and sectoral mitigation potentials are then examined.

The 19 models provided "observations" of marginal abatement costs for different points in time. The observations that are expressed in different dimensions and currencies have been normalised in 2005 USD/tCO_2e. When necessary, GDP data was inflated or deflated as appropriate, and data provided in other currencies was converted.[9] Given the different kinds of GDP reported across the models (including real, nominal, and purchasing power parity), and the effect of the exchange rate, GDP data are presented here as relative values (indexed to 2010) instead of in absolute values. To compare mitigation potential, the emission reductions achieved at a given price relative to the baseline are examined. To visually aide the comparison across models, dashed lines are drawn between the data points via linear interpolation. Thus the figures do not necessarily represent an actual MAC curve.

As mentioned above, not all of the policy scenarios received across the models are consistent. While some models reported domestic mitigation potential resulting from a series of carbon prices applied to specific economies as requested, other models were only able to provide results from existing policy scenarios. Several models reported results from policy scenarios that include a global emissions target, some of which allowed for international emissions trading, many of which result in rising carbon prices over time. These different policy scenarios will have different impacts on global emission prices over time (see Text Box 2 for more information). For example, the Australian Garnaut and CPRS scenarios reported from the G-Cubed, GTEM, and MMRF models have different assumptions regarding international participation. The Garnaut scenarios assume that all economies adopt targets and participate in international trading from 2013. The Australian CPRS scenarios assume that all Annex B economies have targets and participate in international emissions trading from 2010, with developing countries gradually joining the scheme (China in 2015, India in 2020 and complete coverage from 2025). In addition, data from some of the US models (ADAGE, EPPA, MERGE and SGM) used in this analysis are based on EMF-22 assumptions which include different levels of international action. Results for the US from ADAGE, EPPA and MERGE assume that Annex I countries adopt targets in 2012, with delayed participation of Brazil, Russia, China and India beginning in 2030, and the rest of non-Annex I countries participating in 2050 (although with no international trading of emission allowances). Results for the EU from MERGE and SGM target 550 and 650 parts per million (ppm), following the most cost-effective pathway. SGM also reports data from a scenario assuming delayed participation from non-Annex I countries. WEM reports results from 450 and 550 ppm targets, with delayed participation assumed for non-OECD countries. The GEM-E3, POLES and WITCH models report results from global carbon tax scenarios, as opposed to carbon taxes implemented unilaterally in a country. McKinsey takes a somewhat different approach, assessing the bottom-up cost of each mitigation measure, the average of which sums up to each carbon price level reported.

Moving from national to sectoral mitigation potential comparisons, many differences are apparent in sectoral definitions. In general, differences in how an emitting sector is defined in a model are particularly pronounced between top-down and bottom-up models. Top-down models tend to aggregate sectors based on homogeneous products, not homogeneous processes. For example, "buildings" is not an economic

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[8] Also sometimes referred to as Business-As-Usual (BAU) emissions.

[9] The International Monetary Fund's World Economic Outlook Database was used for GDP inflation and deflation: http://www.imf.org/external/pubs/ft/weo/2009/01/weodata/index.aspx. The OANDA FX Currency Converter was used to convert currencies using year averages: http://www.oanda.com/convert/classic.

sector but rather a process-related emission category that is not always disaggregated in top-down models. Sectoral categories requested in the questionnaire were those used in the IPCC Fourth Assessment Report, namely: electric energy supply, non-electric energy supply, transportation, buildings, energy-intensive industry, other industry, agriculture, forestry, and waste.

Text Box 2: Policy Scenario Implications

Not all models provided data for constant carbon price scenarios applied unilaterally. Assumptions regarding international action, international emissions trading, and how the carbon price was applied in the model, can all impact the resulting mitigation potential.

International action: Policy scenarios where a larger group of countries is taking climate action (such as the scenarios implemented in G-Cubed, GTEM, MMRF, ADAGE, EPPA, MERGE, SGM, WEM, GEM-E3, POLES, and WITCH) could have an impact on world fossil fuel prices -- demand for fossil fuels will decline and hence world fuel prices will decrease. This can have the initial result of dampening the effect of the carbon price and reducing aggregate emissions reductions, in contrast to scenarios where unilateral carbon prices are implemented. Assumptions regarding climate action in other countries can also impact trade patterns in energy-intensive goods.

International emissions trading: Policy scenarios that include widespread international emissions trading (such as those from G-Cubed, GTEM, MMRF, the EU results from MERGE, SGM, WEM, GEM-E3, POLES and WITCH) could have the effect of lowering the market carbon price. This implies that observation points from these scenarios may be at lower carbon price points along the frontier of national GHG emission abatement than scenarios that do not allow international emissions trading. The approach of this analysis is to compare domestic mitigation potential (rather than the sum of emissions reduction achieved domestically and via offsets purchased internationally) resulting from the imposition of a carbon price. Thus the different assumptions in international emissions trading may result in observations at lower carbon prices.

Carbon price implementation: Policy scenarios that target an emissions goal typically result in a rising carbon price over time which follows the interest rate (such as those from G-Cubed, GTEM, MMRF, ADAGE, EPPA, MERGE, SGM, WEM, POLES, and WITCH). Rising price scenarios will tend to show greater mitigation potential in earlier years at a given carbon price, when it is relatively cheaper to abate, than fixed price scenarios. This is particularly apparent in rising price scenarios from the forward-looking models (G-Cubed, ADAGE, EPPA, MERGE, and WITCH).

3.1 Australia

Key Insights

Several insights emerge from examining mitigation potential in Australia across five models (three Australian models (MMRF, GTEM, and G-Cubed and two international models, GAINS and DNE21+):

- Baseline emissions projections across the models vary substantially ranging from 598-818 $MtCO_2e$ in 2020 and 594-849 $MtCO_2e$ in 2030 (compared to 579 $MtCO_2e$ in 2005). Emissions projections from the MMRF, GTEM and G-cubed models are all higher than those projected under the GAINS and DNE21+ models. Moreover, projected trends in emissions in the MMRF, GTEM and DNE21+ models are increasing throughout 2010-2030, whereas emission in the GAINS model are projected to decrease (albeit slightly) between 2020-2030.

- Mitigation potential estimates (as % reduction from baseline) for 2020 vary between 18-35% at a price of USD 50/tCO_2e. This is *inter alia* due to differences in data sets, in theoretical structure of the models and the flexibility within them.

- Over time, mitigation potential is increasing. For example, in 2050, the models project between 60% and 98% of the emission reductions can be achieved at prices between USD 80-120/tCO_2e.

- Comparing mitigation potential for the Australian electric energy supply and transport sectors across the models suggests a much higher mitigation potential in the electricity sector. The range in estimates is also wide in the electricity sector: about 26-48% reduction from baseline in 2020 at USD50/tCO_2e whereas in the transport sector this ranges between about 6-8%. By 2050 at a price of USD 100/tCO_2e, mitigation potential is approximately 80% in the electricity sector and 17-26% in the transport sector, although fewer models report data for this year.

Model Structure and Underlying Data

There are primarily three models used by the Australian Treasury to help inform them on climate change mitigation policy decisions, namely: the Monash Multi-Regional Forecasting (MMRF) model, the Global Trade and Environment Model (GTEM), and the G-cubed model.[10] These are top-down, computable general equilibrium (CGE) models, with hybrid elements captured in MMRF and GTEM, which have been developed in Australia. These CGE models are whole-of-economy models that capture the supply and demand interactions between different sectors of the economy. GTEM and G-Cubed are models of the global economy whereas MMRF is a model of the Australian economy with state and territory level detail (Australian Government, 2008). The MMRF model draws on international assumptions from GTEM, but augments these with disaggregated bottom-up modelling for three emission-intensive sectors: electricity, transport and forestry.

The MMRF, GTEM and G-Cubed models evaluated four different future pathways for the Australian economy and GHG emission reductions (Australian Government, 2008). Two of the scenarios follow Garnaut assumptions of unified global action from 2013 where all economies participate in a global emissions trading scheme covering all GHG sources, with climate targets of 550 and 450ppm (Garnaut -10 and Garnaut -25, respectively). An additional two scenarios follow the Carbon Pollution Reduction Scheme (CPRS), which assumes multi-stage global action where economies gradually join a global

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[10] Results from the G-cubed model are not directly available for this analysis. Where possible, relevant and comparable data on G-cubed is obtained from Australian Government (2008) and included here.

emissions trading scheme from 2010 to 2025. The CPRS scenarios aim for 550 and 510 ppm (CPRS -5 and CPRS -15, respectively).

This section examines the mitigation potential in these models using the Australian Government scenarios and compares them to those of the IIASA GAINS model and the DNE21+ model developed in Japan.[11] GAINS is a bottom-up model which estimates potential emission reductions for each economic sector through application of the available mitigation measures. This methodology therefore excludes consideration of possible macro-economic feedbacks, *e.g.* those associated with increased prices for energy, and it neglects the mitigation potential that could result from changes in consumers' behaviour (Amann *et al.*, forthcoming). Assumptions in the GAINS model are discussed in more detail in Amann *et al.* (2008). DNE21+ is also a bottom-up model. For an overview of the key features and data sources of these models see Tables 2 and 3.

Baseline Emissions and Assumptions

Baseline projections for GHG emissions across the five models are depicted in Figure 1. Australian GHG emissions projected under the BAU scenario for 2010-2030 are substantially higher in the GTEM and MMRF models (with 1.4% average annual growth rate and 1.6% respectively), than under the GAINS model (with 0.3%). Part of this difference can be explained by the lack of LULUCF emissions reported for the GAINS model.[12] The G-cubed baseline emissions scenario used for the Australian Government (2008) report was aligned with those of the GTEM baseline scenario, using an iterative approach that does not perfectly match the baseline emission levels between the two models. The DNE21+ model also does not cover LULUCF emissions.

The differences in Australian baseline emission projections across the models may also be explained in part by different assumptions on policies implemented in the baseline scenario. For example, the pre-existing Australian policy measures included in the GTEM baseline scenario include the 9,500 gigawatt hour (GWh) Mandatory Renewable Energy Target (MRET), the Victorian Renewable Energy Target (VRET), the NSW and ACT Greenhouse Gas Reduction Scheme and the 15 per cent Queensland Gas Scheme. However, major new mitigation policies, such as the planned expansion of the MRET to 45,000 GWh a year, are not included.

To the extent that different databases are used across the models (see Table 3), this is also likely to influence the baseline emissions projections. Often, even if the same sources are used but models have not been updated to reflect most recently available data, this is also likely to substantially impact results. Significant efforts have been made to coordinate the inputs of the GTEM and MMRF models in Australia. Common database sources are used for many, though not all, key inputs. For example, the MMRF model requires state population assumptions. These are taken from the Australian Bureau of Statistics and scaled up to be consistent with a higher estimated national aggregate population. The population estimates for Australia are higher than the UN projections for Australia, mainly due to recent changes in net migration assumptions not taken into account in the UN projections.

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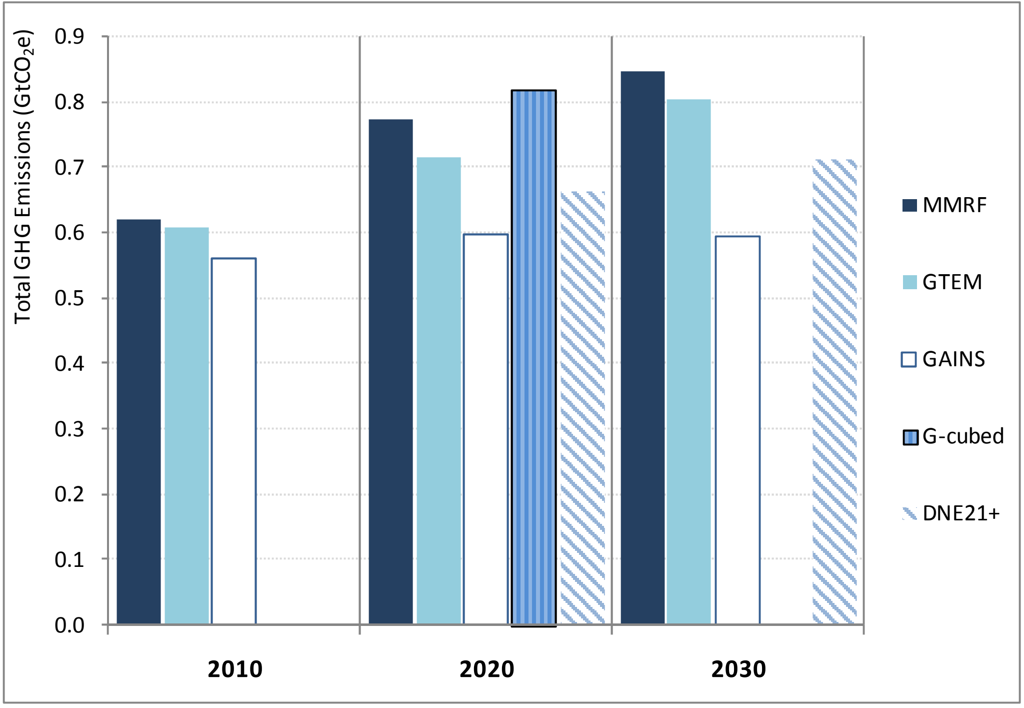
[11] At this time, it is not possible to compare mitigation potential estimates with additional international models such as ENV-Linkages and WEM as both these models aggregate Australia with New Zealand.

[12] In the GAINS model, LULUCF emissions are calculated based on linkage to GLOBIOM model, but these emissions are not reported here.

Figure 1: Australian Baseline Emissions



Note: Data on G-cubed reflected here is obtained from Australian Government (2008), p 146.

Table 5 provides information on some of the key underlying drivers of emissions (e.g. GDP, population, energy use). The BAU scenario in the GTEM and MMRF model projects stronger GDP growth over the period 2010-2030 (with an average annual growth rate of 2.6%) than do the GAINS and DNE21+ models (with rates of 1.7%). Similarly both the GTEM and MMRF model project higher population growth rates (with an average annual growth rate of 1.2%) than the GAINS and DNE21+ models (with rates of 1.0% and 0.8% respectively). This explains why GHG growth is also higher in GTEM and MMRF than in GAINS.

National Mitigation Potential

It is important to note that the policy scenarios reported from the models for Australia, as made available for this analysis, are different from the scenarios reported from the international models (see Text Box 2). The Australian Government 2008 policy scenarios in the GTEM, MMRF and G-cubed models assume coordinated global action to reduce GHG emissions consistent with the stabilisation of atmospheric concentrations (between 450-550 ppm) around 2100. Each of the four independent scenarios in these models (Garnaut -10, Garnaut -25, CPRS -5, CPRS -15) follows different assumptions regarding accession to a global trading scheme and regarding the climate target. However each of these four scenarios assumes global emission trading, in contrast to the scenarios from other models. As countries join the global trading scheme in the Garnaut and CPRS scenarios, the emission allowance market reaches equilibrium at a lower carbon price. Results for the Garnaut and CPRS scenarios are thus interlinked with the international assumptions. In contrast, the GAINS and DNE21+ models report results from scenarios as requested, assuming a flat carbon price in 2020 applied domestically in each Annex I country exclusive of the use of offsets.

At a price of about USD 50/tCO$_2$e in 2020, mitigation potential as a percentage reduction from baseline emissions ranges between 18-35% across the models, although most models are clustered between 23-35%. The GAINS and DNE21+ models also provide mitigation potential estimates for higher prices (around USD 100/tCO_2e), with a mitigation potential of 24-45% emission reduction from baseline, respectively. In general, mitigation potential results across the Australian models are fairly similar.

In contrast to the top-down Australian models, the bottom-up GAINS model shows very different results. For example, to achieve a 20% reduction in GHG emissions from the baseline, a much higher GHG price is required. Mitigation strategies available in the bottom-up GAINS model include *inter alia*, fuel switching, substitution of other inputs for energy, energy savings measures, conversion efficiency improvements on supply side (IGCC, CHP), energy efficiency (in industry, on the demand side, etc.), backstop-technologies, *e.g.* renewable energy, carbon capture and sequestration, biofuels, non-CO_2 abatement options (methane recovery, improved agricultural practices etc.), and carbon sinks (modelled exogenously). However, nuclear power is not part of the set of mitigation measures beyond what is represented in the baseline.[13]

Over time, mitigation potential increases, although fewer models reported for years 2030-2050 than for 2020. By 2050, the models project between 60-98% of emissions reductions at USD 80-120/tCO_2e. The mitigation potential results for the Australian models are fairly well clustered, although the G-Cubed model shows greater mitigation potential for the CPRS scenario. The G-cubed model has a different theoretical structure and data set from the GTEM and MMRF models. Mitigation costs are lower in the G-cubed model because "it is a forward looking model, which brings forward some technological substitution, lowering the transition costs and hence reducing the required GHG price (Migone, 2008). G-cubed is a more flexible model, requiring lower emission prices to transform the economy. Finally G-cubed lacks technological detail and allows a (theoretically) infinite range of options for the electricity and transport sectors, ensuring a greater response to GHG prices" (Australian Government, 2008, pg 95).

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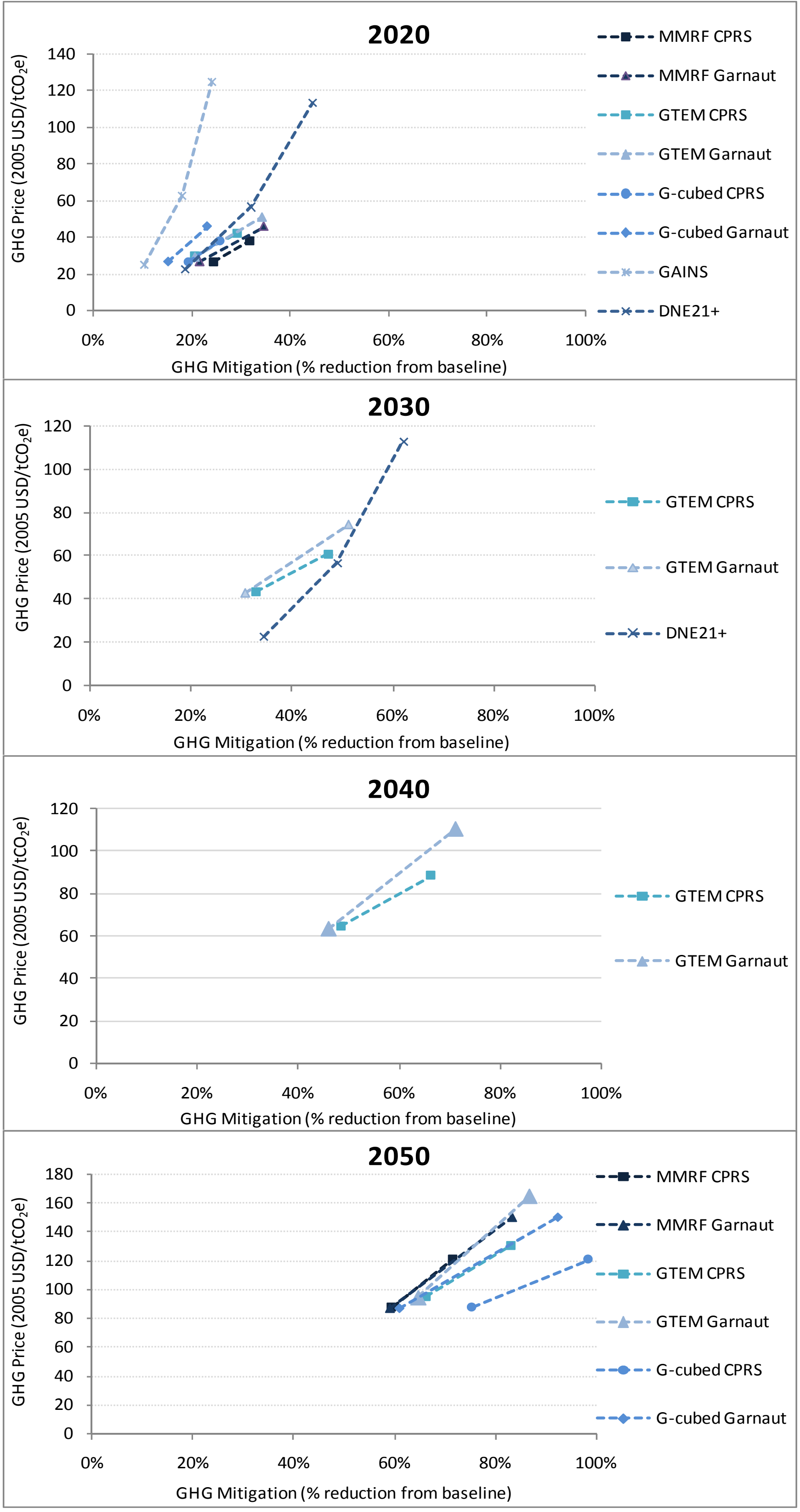
[13] For details see http://gains.iiasa.ac.at/gains/reports/Annex1-methodology-20081129.pdf

Table 5: Australian Baseline Projections Data

	2005	2010	2020	2030	2050	Percentage change 2010-2030	Average Annual Growth Rate 2010-2030
				GDP (Indexed, 2010 = 100)			
MMRF	85	100	132	166	256	66%	2.6%
GTEM	n/a	100	132	167	257	67%	2.6%
GAINS	n/a	100	123	140	n/a	40%	1.7%
DNE21+	n/a	100	123	140	n/a	40%	1.7%
				Population (million)			
MMRF	20.70	22.25	25.19	28.08	33.05	26%	1.2%
GTEM	n/a	21.89	24.83	27.73	32.72	27%	1.2%
GAINS	17.15	19.31	21.57	23.59	25.28	22%	1.0%
DNE21+	n/a	21.36	23.42	25.29	n/a	18%	0.8%
				Energy Use (EJ)			
MMRF	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	5.42	6.05	6.52	n/a	20%	0.9%
DNE21+	n/a	n/a	6.73	7.67	n/a	n/a	n/a
				Energy Intensity (EJ/GDP in billion USD 2005)			
MMRF	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	0.0053	0.0048	0.0046	n/a	-14%	-0.8%
DNE21+	n/a	n/a	0.0072	0.0067	n/a	n/a	n/a
				Total GHG Emissions (MtCO2e)			
MMRF	579	623	774	849	1039	36%	1.6%
GTEM	n/a	609	716	804	958	32%	1.4%
GAINS	n/a	561	598	594	n/a	6%	0.3%
G-cubed	n/a	n/a	818	n/a	1007	n/a	n/a
DNE21+	n/a	n/a	664	712	n/a	n/a	n/a

Note: Only GHG emissions data is available for G-cubed.

Figure 2: Australian Mitigation Potential



Note: Data on G-cubed reflected here is from Australian Government (2008), p 146.

Sectoral Emissions and Mitigation Potential

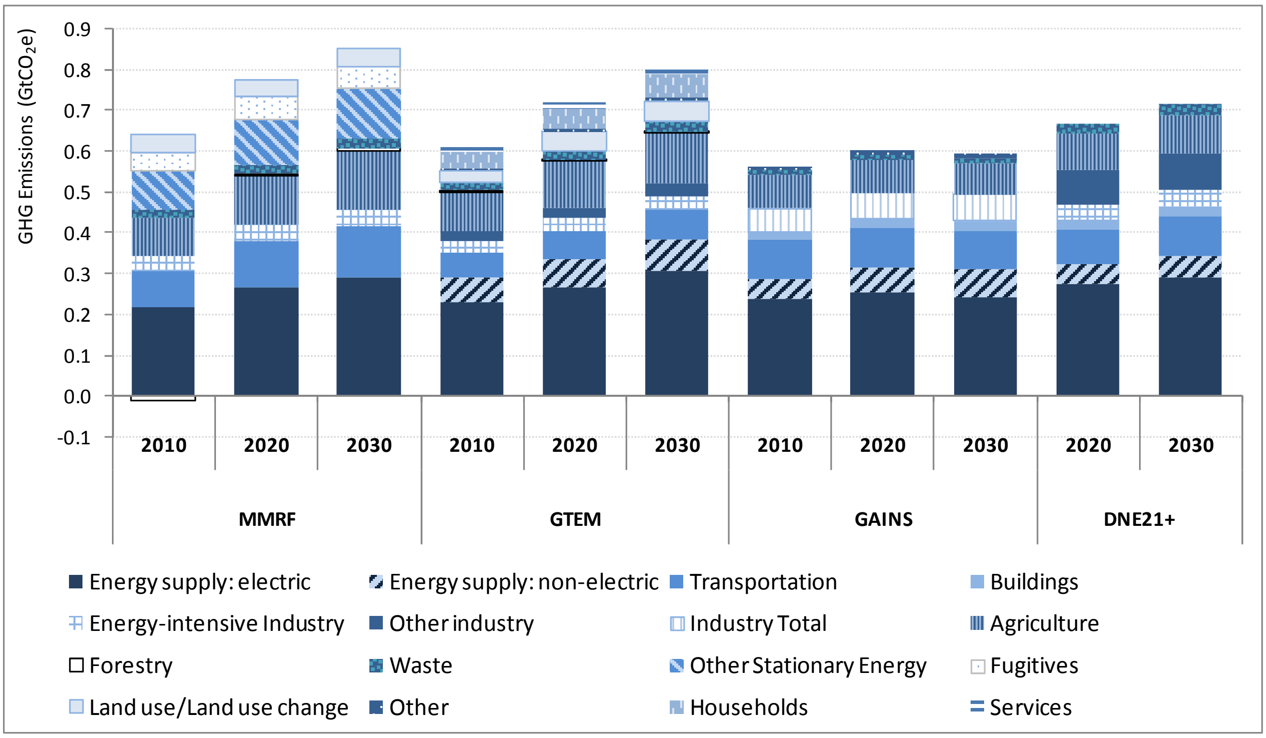
Figure 3 depicts baseline emissions for Australia by sector. The models use different sectoral definitions, making informative comparisons difficult. For example, for this analysis, GAINS and DNE21+ report disaggregated total GHG emissions data into 9 sectors. MMRF reports emissions from agriculture, forestry, and LULUCF, but does not separate emissions from buildings. On the other hand, GTEM disaggregates total emissions into 25 sectors, including LULUCF, which have been aggregated for certain sectors. The authors have aimed to be as consistent as possible in aggregating certain sectors, but uncertainties nevertheless remain.

Electric energy supply is the single largest emitting sector across all models for which sectoral data is available (MMRF, GTEM, GAINS and DNE21+). However, the GTEM, MMRF and DNE21+ models project increasing baseline emissions in electricity, whereas GAINS projects a decrease (albeit small) between 2020-2030. In 2020, the second largest emitting sector in the GTEM, MMRF and DNE21+ models is agriculture whereas in the GAINS model the second largest sector is transportation, followed by agriculture. However the GAINS and DNE21+ models do not include LULUCF, making accurate comparisons for agriculture difficult. Sectoral mitigation potential in the electricity and transport sector across the models are examined and compared below.

Figure 4 depicts the mitigation potential for the electricity supply sector in Australia. In 2020 the models show a large range of mitigation potential, from 26-48% reduction below baseline at about USD 50/tCO_2e. Mitigation potential in the GAINS model is much lower than in the MMRF model, despite the fact that neither model as used for this exercise allows for the expansion of nuclear power generation in Australia beyond what is included in the baseline. By 2030, the DNE21+ model shows emission reductions greater than 100% (i.e. negative emissions) at a price above USD 100/tCO_2e, as both fossil fuel electricity generation with CCS and biomass electricity generation with CCS are cost effective in 2030. By 2050, the models report mitigation potential of approximately 80% at USD 100/tCO_2e. Results in 2050 for the MMRF CPRS scenarios show a more complicated relationship between permit price and emissions. While higher allowance permit prices put downward pressure on emissions from electricity generation, a switch to electricity in other activities can offset either partly or completely this reduction. For example, a switch to electric vehicles can increase electricity demand, and industrial plants may also switch to electricity away from direct combustion in response to higher permit prices. Thus, in some cases emissions can actually increase with higher permit prices (although overall emissions in the economy would be lower).

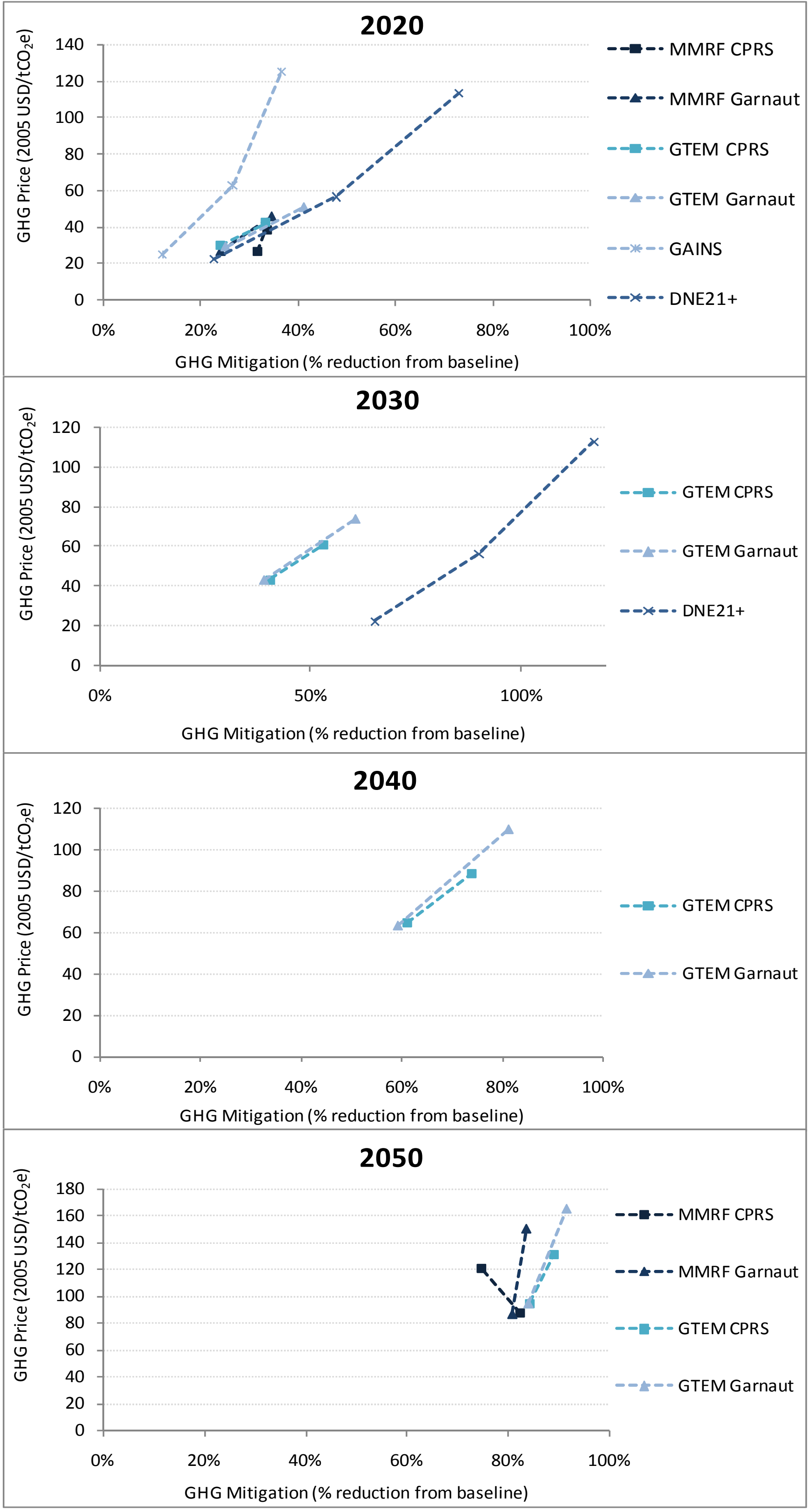
Mitigation potential in the transport sector (see Figure 5) is much smaller, ranging between 6-8% at a price of USD 50/tCO_2e. The DNE21+ model projects the lowest mitigation potential of nearly 0% mitigation potential at USD 20/tCO_2e in 2020. In the GAINS and DNE21+ models, mitigation options in 2020 for the transport sector seem to be nearly exhausted at a GHG price of USD60/tCO_2e, beyond which mitigation potential relative to the baseline increases only very slightly. Over time, the mitigation potential increases in the transportation sector. By 2050, mitigation potential is 17-26% at USD 100/tCO_2e.

Figure 3: Australian Sectoral Baseline Emissions



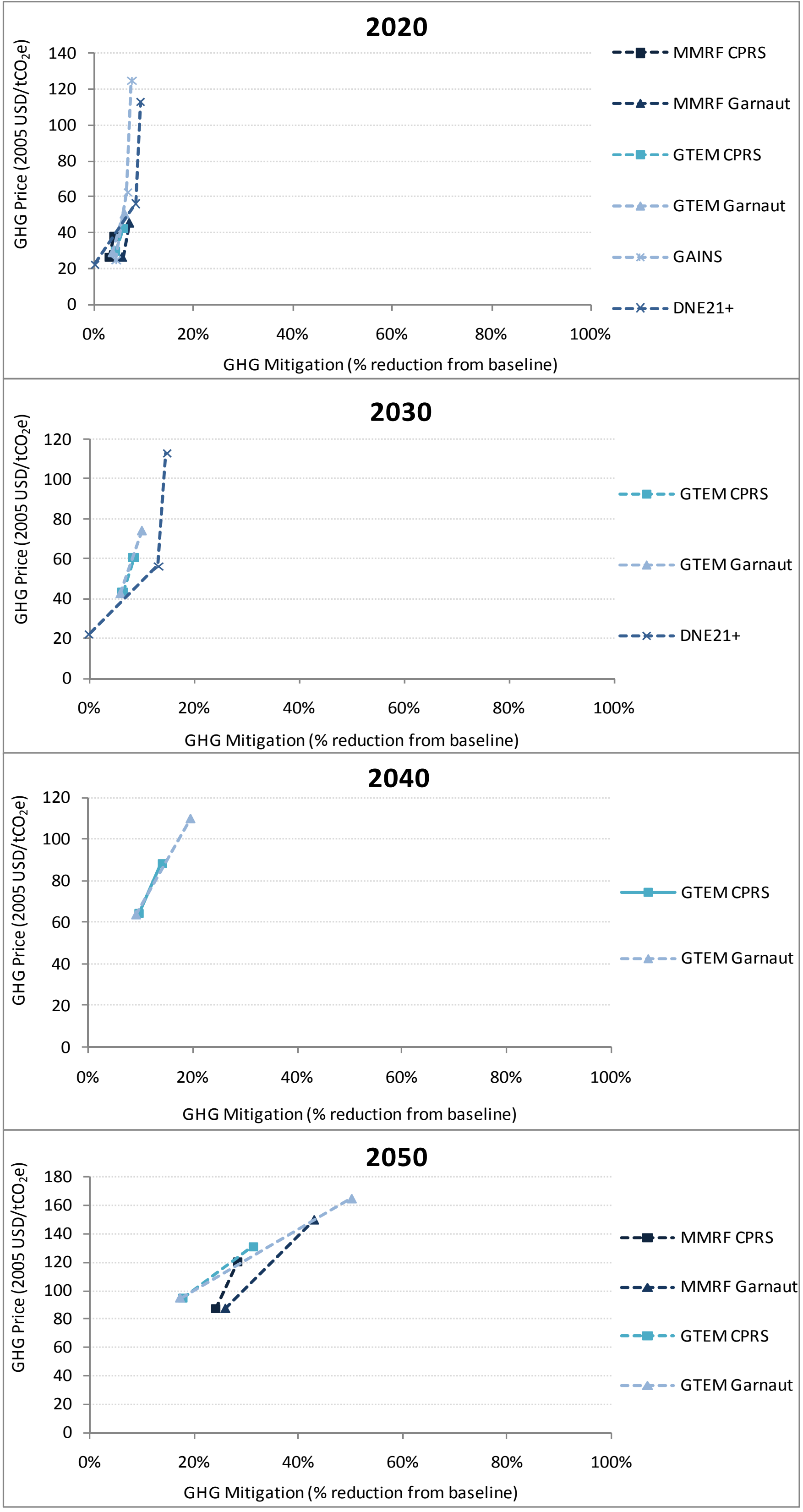
Note: The original 9 sectors as reported by GAINS and MMRF are depicted above. The 25 sectors reported by GTEM have been aggregated for certain sectors. GHG emissions for G-cubed by sector are not available for this study.

Figure 4: Australian Mitigation Potential for the Electric Supply Sector



Note: In 2030, the scale of the horizontal axis extends beyond 100% to accommodate the MMRF CPRS results.

Figure 5: Australian Mitigation Potential for the Transport Sector



3.2 Canada

Key insights

A total of 9 economic models are examined to compare national and sectoral mitigation potential estimates for Canada. These are E3MC and EC_IDYGE (Canadian models) and ENV-Linkages, GAINS, McKinsey, WEM, DNE21+, GTEM and POLES. Several insights emerge from examining mitigation potential estimates across these models.

- Baseline GHG emission projections across the models vary, ranging from 0.74-0.91 $GtCO_2e$ in 2020 and 0.80 – 1.01 $GtCO_2e$ in 2030 (compared to 0.65 - 0.74 $GtCO_2e$ in 2005), reflecting an absolute range of approximately 0.2 $GtCO_2e$ in both 2020 and 2030.

- Mitigation potential estimates (as % of reduction from baseline) in 2020 are substantial, ranging between 14-32% at a price of USD 50/tCO_2e.

- In 2050, the models project mitigation potential ranging between 18-24% at a price of USD 50/tCO_2e (though there are substantially fewer models that report data for this time period). At higher prices, such as at USD 100/tCO_2e, the range increases substantially to 27-60% emission reduction from the baseline.

- At the sectoral level, mitigation potential in the Canadian electric energy supply sector at a price of USD 50/tCO_2e is projected to higher than that of the transport sector. In 2020, the data from 8 models show substantial variation in mitigation potential in the electricity sector, ranging from 18% to about 60%. Mitigation potential estimates (relative to the baseline) for the Canadian transport sector across the different models are more clustered, showing a much smaller range from 5% to 22%.

Model Structure and Underlying Data

There are several models employed by the Canadian government to help inform them with their climate change mitigation policies. Two of the models are the Energy-Economy-Environment Model for Canada (E3MC) and the Environment-Canada Intertemporal Dynamic CGE model (EC_IDYGE), both of which are run by Environment Canada. E3MC is a bottom-up model that is national in scope, consisting of a combination of the Energy 2020 model and the Informetrica Model (TIM). The E3MC model contains detailed representation of all electricity generating units in Canada, calibrated to historical data and including distinct capital vintages. EC_IDYGE is a global top-down, multi-region, multi-sector intertemporal computable general equilibrium (CGE) model of global trade and energy use (Boringer et al. 2008).

This section examines the mitigation potential in these models alongside a number of other available models that also provide mitigation potential estimates for Canada, including top-down, bottom-up, and hybrid models. ENV-Linkages is the only other top-down model that reports estimates for Canada for this study, whereas GAINS, McKinsey, WEM, DNE21+ are all bottom-up models. GTEM and POLES are hybrid models that report results for Canada. For an overview of the key features of these models, see Tables, 2, 3 and 4.

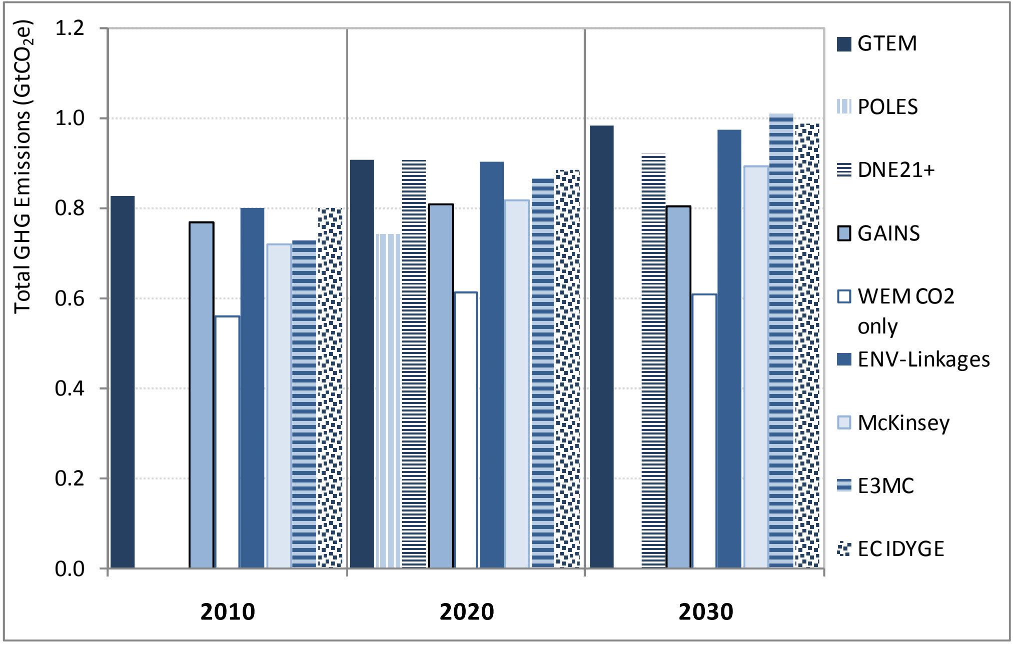
Baseline Emissions and Assumptions

Though there are common data sources used across several models for historic and base year calibration (see Table 3), the different model structures, underlying assumptions and parameters result in different baseline GHG emission projections across the models. Figure 6 depicts the various baseline emission projections for Canada across the 9 models available here. E3MC and EC_IDYGE, the two Canadian models, project the highest absolute GHG emissions in 2030 (i.e. 1.01 and 0.99 $GtCO_2e$ respectively).

E3MC also projects the highest growth in emissions over the 2010-2030 time horizon, with an increase of 39%. This is followed by a cluster of models that project growth of 19-24% (i.e. GTEM, ENV-Linkages, McKinsey and EC_IDYGE). Two other models, namely GAINS and WEM (for energy-related CO_2 emissions only), project much lower emissions growth over the same time period, of 5% and 9% respectively.

Some of these differences are likely to be explained by the policy assumptions that are implicit in the baseline. For example, the WEM model includes all the policies and measures that were enacted by mid-2008 in its baseline scenario. In contrast, to enable the Government of Canada to respond to its reporting requirements under the Kyoto Protocol Implementation Act, the baseline scenario used in the E3MC model here reflects only programs and policies that were announced and implemented prior to January 1, 2006.[14]

Figure 6: Canadian Baseline Emissions



An examination of the assumptions behind the models provide further insights on what is driving differences across the emissions projections. The data available in Table 6 suggests that GDP and energy use projections across the models play a role. For example, the average annual growth rate of GDP over the 2010-2030 time horizon varies between 1.6% (GTEM) and 2.6% (ENV-Linkages). Though data on energy use projections are only available for 5 of the models, average annual growth rates between 2010-2030 vary from 0.8% to 1.8%. Energy intensity improvements vary from 6% in E3MC to 26% in ENV-Linkages over the period from 2010-2030. In contrast, average annual population growth rate projections are similar across the models, from 0.6 – 0.8% over the same timeframe.

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[14] Two alternate BAUs include programs implemented up to March 2009 and strengthened programs, but these are not reported here.

Table 6: Canadian Baseline Projections Data

	2005	**2010**	**2020**	**2030**	**2050**	**Percentage Change 2010-2030**	**Average Annual Growth Rate 2010-2030**
				GDP (Indexed, 2010 = 100)			
GTEM	n/a	100	120	138	199	38%	1.6%
POLES	95	100	133	n/a	n/a	n/a	n/a
DNE21+	n/a	100	127	158	n/a	58%	2.3%
GAINS	n/a	100	121	144	n/a	44%	1.8%
WEM CO_2 only	n/a	100	124	148	n/a	48%	2.0%
ENV-Linkages	n/a	100	131	166	247	66%	2.6%
McKinsey	88	100	127	158	n/a	58%	2.3%
E3MC	n/a	100	130	153	n/a	53%	2.1%
EC IDYGE	86	100	122	149	n/a	49%	2.0%
				Population (Million People)			
GTEM	n/a	33.8	36.6	39.1	42.8	16%	0.7%
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	33.8	36.6	39.1	n/a	16%	0.7%
GAINS	n/a	33.8	36.6	39.2	n/a	16%	0.7%
WEM CO_2 only	32.3	33.8	36.6	39.2	42.8	16%	0.7%
ENV-Linkages	32.3	33.8	36.6	39.1	42.8	16%	0.7%
McKinsey	32.3	33.7	36.5	39.2	n/a	16%	0.7%
E3MC	n/a	33.9	36.8	39.4	n/a	17%	0.8%
EC IDYGE	31.2	32.3	34.6	36.8	39.5	14%	0.6%
				Energy Use (EJ)			
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	13.9	14.3	n/a	n/a	n/a
GAINS	n/a	12.6	14.0	14.9	n/a	18%	0.8%
WEM CO_2 only	11.6	11.9	13.2	14.0	n/a	17%	0.8%
ENV-Linkages	13.9	14.8	16.5	18.2	18.8	23%	1.1%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
E3MC	n/a	13.2	16.2	18.9	n/a	43%	1.8%
EC IDYGE	16.2	17.6	19.2	21.1	25.7	20%	0.9%
				Energy Intensity (EJ/GDP in Trillion USD 2005)			
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	10.6	8.8	n/a	n/a	n/a
GAINS	n/a	10.1	9.2	8.2	n/a	-18%	-1.0%
WEM CO_2 only	10.2	9.4	8.4	7.5	n/a	-21%	-1.1%
ENV-Linkages	15.0	13.7	11.7	10.2	7.0	-26%	-1.5%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
E3MC	n/a	11.4	10.8	10.7	n/a	-6%	-0.3%
EC IDYGE	16.1	14.9	13.4	12.1	10.2	-19%	-1.1%
				Total GHG Emissions ($GtCO_2e$)			
GTEM	n/a	0.83	0.91	0.98	1.17	19%	0.9%
POLES	0.65	n/a	0.74	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	0.91	0.92	n/a	n/a	n/a
GAINS	n/a	0.77	0.81	0.80	n/a	5%	0.2%
WEM CO_2 only	0.56	0.56	0.61	0.61	n/a	9%	0.4%
ENV-Linkages	0.73	0.80	0.90	0.98	1.06	22%	1.0%
McKinsey	0.66	0.72	0.82	0.89	n/a	24%	1.1%
E3MC	n/a	0.73	0.87	1.01	n/a	39%	1.6%
EC IDYGE	0.74	0.80	0.89	0.99	1.19	23%	1.1%

National Mitigation Potential

Mitigation potential for Canada in different years varies depending on the model employed and the carbon price that is simulated (see Figure 7). In 2020, the 9 models show a substantial potential for emissions reduction, although across a fairly wide range at a price of USD 50/tCO_2e, between 14% (E3MC) and 32% (GTEM Garnaut) relative to the baseline. The E3MC model is the only model that includes specific representation of the operating parameters of existing electricity-generating capital stock, which results in lower mitigation potential. POLES, McKinsey and WEM also show mitigation potential in the lower end of this range. The WEM results shown here reflect CO_2 emission reductions only, and thus do not include non-CO_2 mitigation options that tend to fall in the lower end of the cost range. EC_IDYGE and ENV-Linkages, as the only top-down models reporting results for Canada, do not uniformly show higher mitigation potential. At USD 50/tCO_2e, EC-IDYGE shows mitigation potential in the middle of the range of models examined here, whereas results at higher prices such as USD 100/tCO_2e fall closer to ENV-Linkages results. The DNE21+ and GAINS models also tend to project high mitigation potential at this price (i.e. both about 25% reduction relative to the baseline), which may be partly explained by the fact that these models include negative cost measures. The GTEM results show the highest mitigation potential in 2020. As there are multiple drivers of GHG mitigation potential across each of the models, it is difficult to isolate and identify which ones are the most significant.

A total of 6 models provide mitigation potential estimates for 2030. At a price of USD 50/tCO_2e, the range of mitigation potential is higher than in 2020, 20% to 36%. In this time period, the WEM model clearly shows less mitigation potential in CO_2 emissions than the other models show in across all GHGs. The McKinsey model shows nearly double the amount of mitigation in 2030 than in 2020 at the same price, partially reflecting the deployment of CCS technology. The two top-down models, ENV-Linkages and EC_IDYGE, show nearly the same percentage of mitigation potential from the baseline across the two time periods, although both models reflect increasing levels of absolute emission reductions over time.

Only 3 models provide GHG mitigation potential estimates for Canada in later years (i.e. 2040 and 2050), namely EC_IDYGE, ENV-Linkages and GTEM. The EC-IDYGE model projects a consistent, albeit small, decline in mitigation potential across all carbon price ranges (about USD 20-100/tCO2e) and across all time periods (2020-2050). In the ENV-Linkages model, mitigation potential is fairly constant throughout the 30 year time horizon across each of the carbon prices. Only the GTEM model shows increasing mitigation potential over time (relative to the baseline) at constant carbon prices. For example, at a carbon price of about USD100/tCO_2e, GTEM projects a mitigation potential of roughly 50% in 2040 and 60% in 2050.

Sectoral Emissions and Mitigation Potential

Figure 8 shows baseline emissions by sector across Canada according to the sectors reported, which varied somewhat across the models. For example, the E3MC models reports emissions according to the IPCC categories: from electricity supply, non-electric energy supply, transport, buildings, energy-intensive and other industry, agriculture, forestry and waste. However the EC_IDYGE model, reports emissions according to categories better reflected in its top-down structure that models emissions by process rather than by product, including the additional categories of households, other CO_2 emissions and other non-CO_2 emissions. All of the models, however, report sectoral emissions for electric energy supply and transportation.

While the differences in sectoral definitions and disaggregation make it difficult for robust comparisons across sectoral data, the data does provide useful insights regarding the role of the largest contributing sectors in Canada’s national emissions. In general, though there is consensus across models that both electricity and transport sector constitute a large fraction of total emissions, the rank orders vary considerably across models. For example, in 2020 the two largest contributing sectors in the E3MC model are transportation and non-electric energy supply, whereas in the EC_IDYGE model, they are other non-CO_2 gases, followed by transportation and the non-electric energy supply sector. The EC_IDYGE model reports emissions aggregated in terms of non-CO_2 gases, and does not include sectors such as buildings. However, in the ENV-Linkages model, the largest emitting sector is electricity followed by other industry; in both McKinsey and DNE21+, it is electricity followed by transport; where as in GAINS this ranking is reversed. Though general trends are therefore discernable, there is not a clear consistency across sectoral emissions in the models for Canada. The analysis below concentrates on sectoral mitigation potential across two key emitting sectors: electricity and transport.

Figure 9 depicts the range of mitigation potential across the available models for the electricity supply sector in Canada. In 2020, the data from 8 models show substantial variation in mitigation potential at a price of USD50/tCO_2e, ranging from 18% (E3MC) to about 60% (GAINS). Looking at the cost “curves” for 2020 as a whole, E3MC and McKinsey project relatively low mitigation potential; EC-IDYGE, DNE21+ and WEM are in the mid-range; and GAINS, ENV-Linkages and GTEM are on the high end of the range. Part of these differences can be explained by the different underlying structures and assumptions across the models. For example, in E3MC which is a national model, the electricity sector is highly disaggregated (i.e. unit by unit) and is fully aligned to provincial circumstances and operating conditions. The E3MC model is the only model that includes specific representation of existing capital stock in the Canadian electricity sector, which determines when electricity generating plants might be re-furbished or retired, resulting in lower mitigation potential. The E3MC model also explicitly identifies transmission nodes, thereby conditioning electricity exchange between provinces and exports between Canada and the US. The McKinsey model results, which also show lower mitigation potential, assume a much greater deployment of CCS after the 2020 time period. The other models which are global in scope have a more aggregate treatment of electricity and do not necessarily reflect provincial circumstances. ENV-Linkages and EC_IDYGE are the two top-down models reporting for Canada, but they show fairly different results for the electricity sector: EC_IDYGE shows less mitigation potential, in part due to provincial “green” electricity policies included in the baseline.

Fewer models report data for 2040 and 2050. EC_IDYGE and ENV-Linkages project nearly identical mitigation potential at low carbon prices across both time periods, though these diverge as the carbon price increases. The GTEM mitigation potential projections are higher across the carbon price range for which data is available.

It is likely difficult to mitigate GHG emissions to a greater extent in the electricity sector. Canada exports and imports a fair amount of its electricity supply.[15] As a carbon tax is implemented unilaterally, national fossil fuel electricity generation is reduced, as electricity exports decrease and imports increase. Thus, once domestic electricity generation reaches its maximum mitigation potential of near-zero GHG emissions, it is difficult to reduce emissions further given the level of trade in electricity supply in Canada.

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[15] The Canadian electricity system is part of an integrated North American electricity grid but, Canada's electricity markets have primarily developed along provincial or regional boundaries. In 2007, total Canadian exports and imports of electricity account for some 8.6% and 2.4% of total electricity generation respectively, with Ontario, Québec and Manitoba exporting the greatest volumes of electricity. Canada is a net exporter of electricity to the U.S. mainly due to the availability of low cost hydro electric resources.

Figure 7: Canadian Mitigation Potential

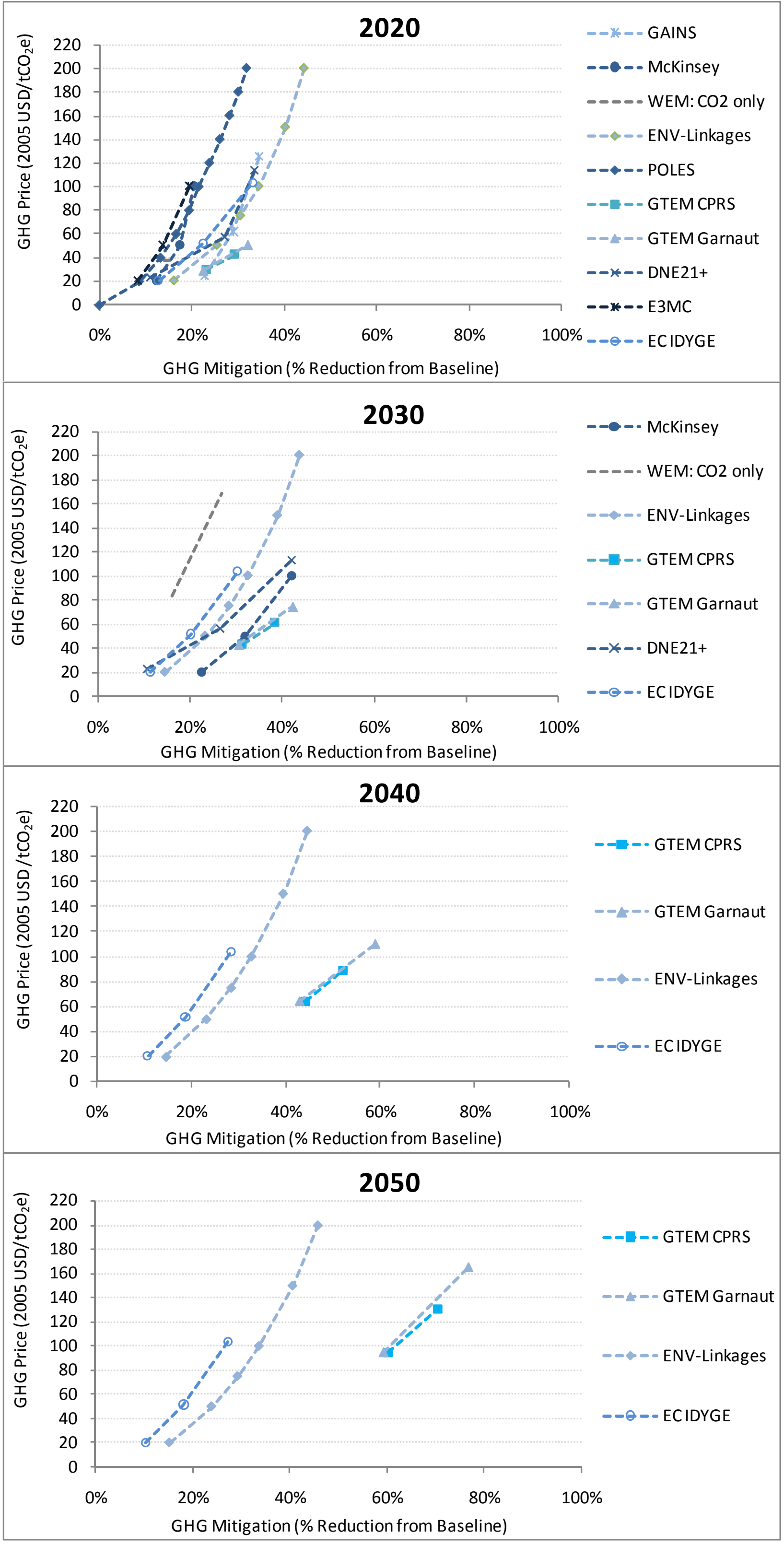
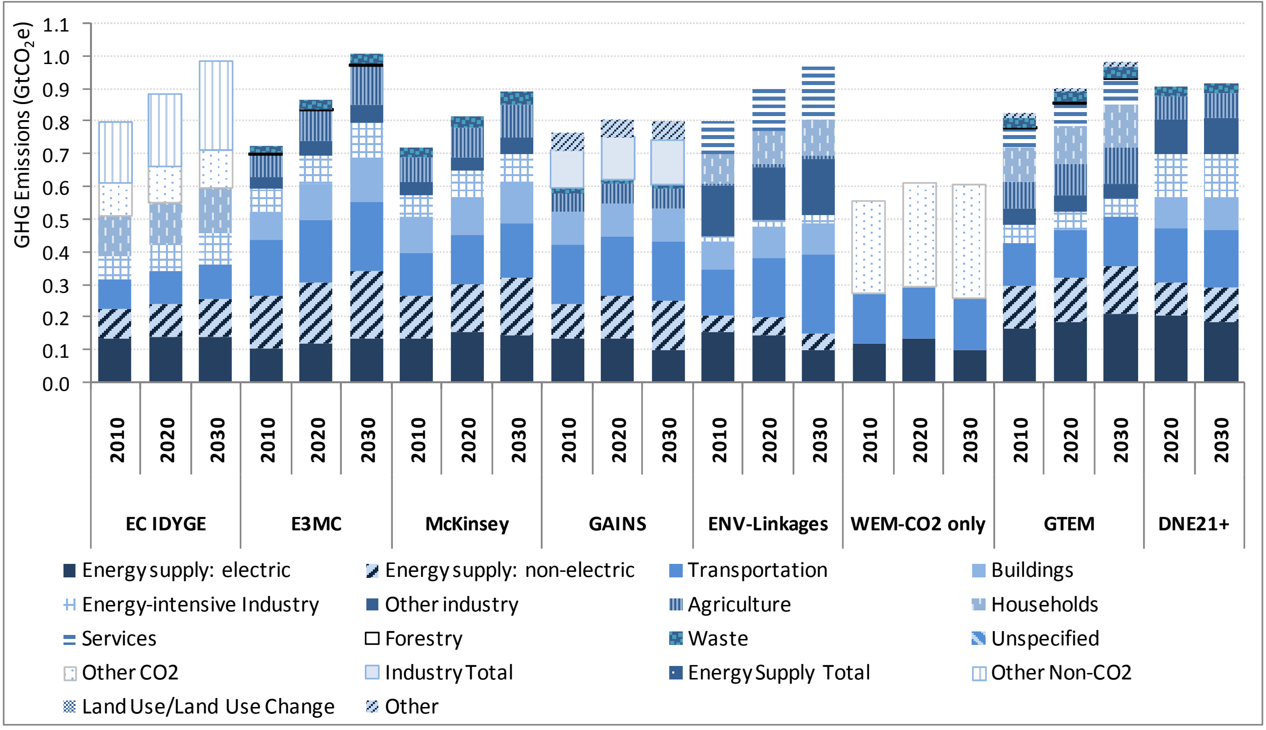


Figure 8: Canadian Sectoral Baseline Emissions



In contrast, mitigation potential estimates (relative to the baseline) for the Canadian transport sector across the different models are more clustered with a range between 5% (GTEM Garnaut) and 22% (DNE21+) at a USD50/tCO$_2$e carbon price in 2020 (see Figure10). Thus, on the whole, mitigation potential in the transport sector is estimated to be substantially smaller than in the electricity sector, and the cost “curves” are generally much steeper.

Both DNE21+ and McKinsey, which project relatively high mitigation potential for the transport sector in 2020, include hybrid vehicles in their mitigation options. More specifically, the McKinsey model includes significant improvements in conventional internal-combustion engines, deployment of hybrid vehicles and plug-in vehicles and a high penetration of CO$_2$-efficient biofuels. On the other hand, the GAINS model also includes hybrids, although it projects lower mitigation potential (8%) at the same price, reflecting a less dramatic deployment of hybrid vehicles and biofuels in 2020. As these types of technology and mitigation options have time to take effect in the economy, GHG mitigation becomes less costly over time. In other words, mitigation potential at a given carbon price is expected to increase over time. This is most apparent in the McKinsey model results, which show mitigation potential in the transport sector at a price of USD 50/tCO$_2$e increasing from 15% in 2020 to 37% in 2030. The ENV-Linkages model also shows an increase in transportation mitigation potential from 11% in 2020 to 16% in 2030. The GTEM results show a dramatic increase in potential in 2050 at prices above USD 130/tCO$_2$e, with emission reductions from 60 to 80%. On the other hand, this is not the case in the EC_IDYGE and DNE21+ models, which actually show decreasing potential, in absolute emission reductions, over time.

Figure 9: Canadian Mitigation Potential for the Electricity Supply Sector

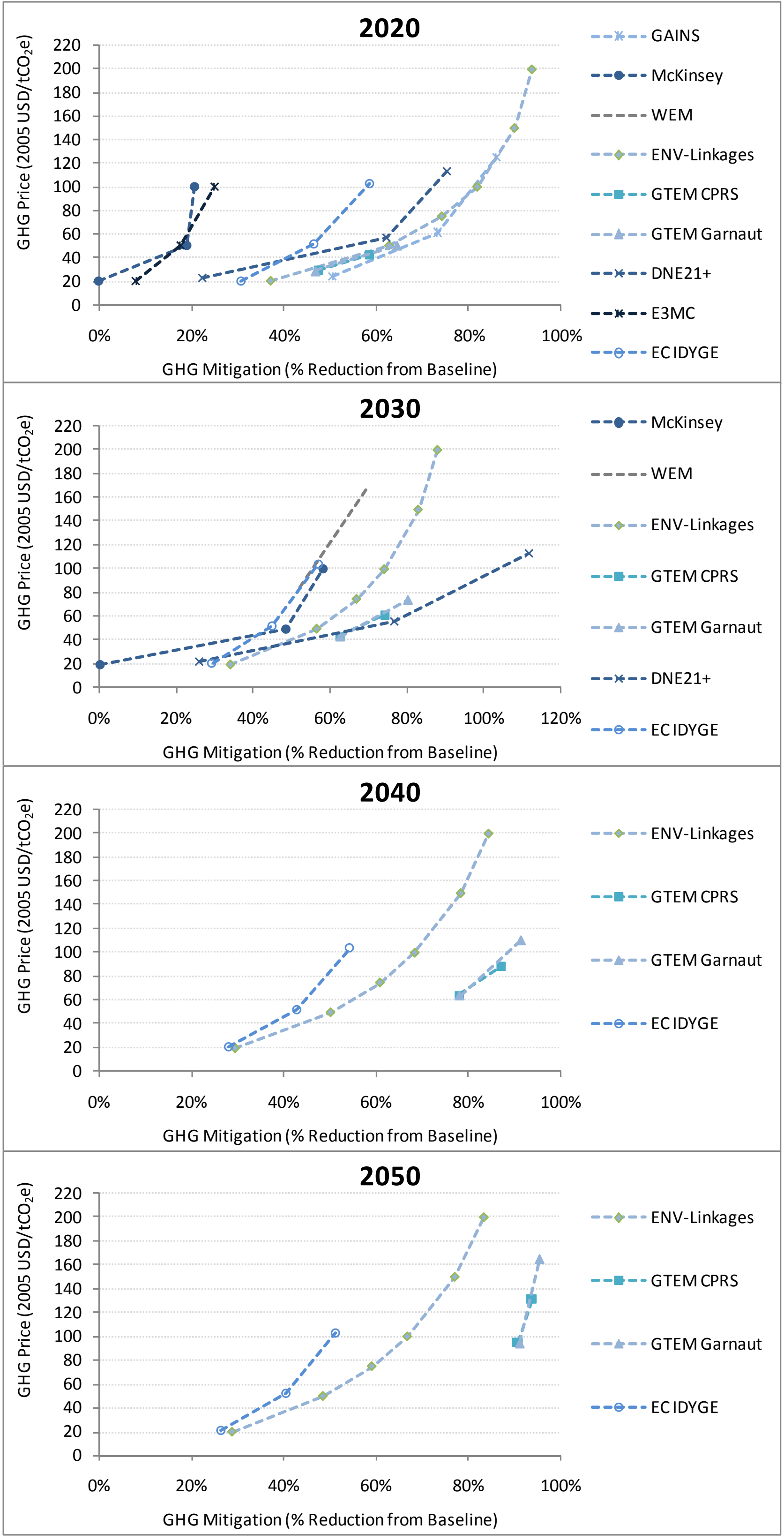
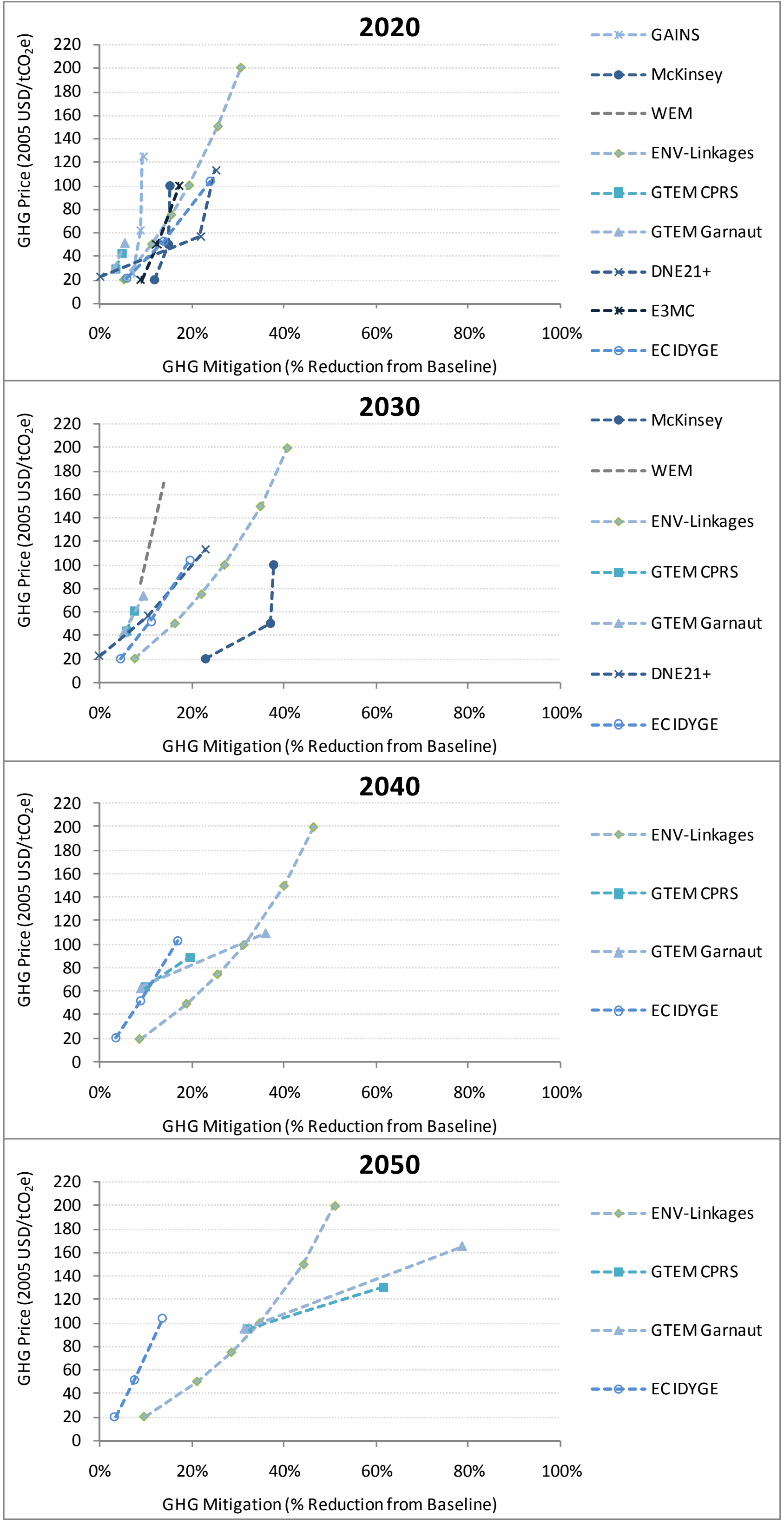


Figure 10: Canadian Mitigation Potential for the Transport Sector



3.3 European Union

Key Insights

Several key insights emerge from examining mitigation potential in the EU across 12 economic models (2 EU models, namely POLES and GEM-E3, and 10 other models, namely AIM, DNE21+, ENV-Linkages, GAINS, GTEM, McKinsey, MERGE, SGM, WEM and WITCH):

- Baseline emissions vary between 4.8-6.3 $GtCO_2e$ in 2020 and 4.9-6.6 $GtCO_2e$ in 2030 (compared with 4.7-5.4 in 2005) for all GHGs.

- All models show considerable mitigation potential for the EU in 2020 for a marginal cost of USD 50/tCO_2e, ranging from approximately 16 to more than 30% reduction in GHG emissions from the baseline. Nonetheless, given the ongoing implementation of the energy and climate policies in the EU that several models incorporate in their baseline, the lower-cost mitigation opportunities seem to be fully used in early years, and particularly from 2030 it becomes relatively costly (compared to other regions) to reduce emissions by more than 40% compared to the baseline.

- In 2050 for example, the models show that approximately 25-50% reduction could be achieved in the EU at a marginal cost of USD 50/tCO_2e. However, results across models differ to a large extent, reflecting the uncertainty in modelling over longer time horizons.

- In 2020, at USD 50/tCO_2 mitigation potential in the electricity sector ranges between 19-44%, and in the transport sector between 3-19%. Models indicate a significant range of mitigation potential in the electricity sector, depending primarily on available mitigation options – most importantly at what price carbon capture and sequestration technology will become commercial – and assumptions related to technical progress. Nonetheless, there is convergence across the models showing that more than 80% of the GHG emissions in the electricity sector can be reduced at a carbon cost between USD 50-150/tCO_2e in 2050. Mitigation potential in the transport sector appears to be much smaller in the long run, implying that mitigation options in this sector are more difficult to implement. In 2050, and at a price of up to USD 150/tCO_2e, models indicate a mitigation potential of up to 30% in the transport sector.

Model Structure and Underlying Data

There are many different types of models employed by the EU governments, the European Commission (EC), academic institutions, and other organisations. Several of these models are key instruments whose results are used by climate change policy makers. As the executive branch of the European Union, the EC is responsible for proposing legislation, which is based on comprehensive analysis using two quantitative models: POLES and GEM-E3 (run both by the EC Joint Research Centre – Institute for Prospective Technological Studies). POLES is a world energy sector simulation model and provides a detailed analysis of technologies of the energy sector, including direct costs of reducing emission in the energy sector. GEM-E3 is an applied multi-sector general equilibrium model, which therefore provides a broad evaluation of the economic consequences in the whole economy, including direct and indirect effects except emissions from land use change (Capros et al, 1997). The two models complement each other and therefore provide important insights to climate policy decision-makers in the EU.

This section examines the mitigation potential in these models alongside a number of models from international organisations and research entities that specifically include the EU[16]. The set of models used covers a range of model structures including both top-down and bottom-up models. Top-down models included are GEM-E, GTEM, SGM, MERGE, AIM and ENV-Linkages. Bottom-up models include POLES, GAINS, DNE21+, WEM and McKinsey. Finally, the set of models includes the WITCH model, which is based on a hybrid approach. For an overview of the key features and data sources of these models see Tables 2, 3 and 4.

Baseline Emissions and Assumptions

While the models are based on a number of common data sources for historic and base year calibration (see Table 3), the different model structures, underlying assumptions and parameters imply that the EU's economy and baseline GHG emissions evolve in different ways. Figure 11 depicts the baseline emission projections for GHG emissions in the EU and shows the wide range of trends predicted by the set of models. For example, the WITCH model has the highest growth in GHG emissions over the 2010-2030 time horizon, with a growth of 16%. On the other extreme, MERGE predicts a negative growth of 4% while the POLES model shows emissions growth of 3% over the same period. Also the two models that focus on CO_2 emissions only differ in results: WEM predicts a decline in emissions by 6% while SGM expects emissions to increase by 7% over the same period. The variation in absolute emissions across the models grows over time, from 1.7 $GtCO_2e$ in 2010 to 2.9 $GtCO_2e$ in 2030. The variation narrows to 1.7 $GtCO_2e$ in 2030 if the WEM and SGM results for energy-related CO_2 emissions are excluded.

For the specific case of the EU, some of the differences can also be explained by the fact that models are not consistent in their regional configurations for the EU. In particular, while most models specify the EU-27 (e.g., all the current 27 Member States of the European Union), the AIM model and the GTEM model report data for the EU25 (without Bulgaria and Romania), and WITCH and ENV-Linkages[17] don't specifically model the EU25 or EU27 but provide data for several European regions, which combined represent the EU27+EFTA region.

It is important to note the policy assumptions that are implicit in the baseline as this is likely to be a key driver of emission projections. The WEM model includes all the policies and measures that were enacted by mid-2008 in its baseline scenario. This implies that *e.g.* the EU ETS and its carbon cost are included in the baseline. Similarly, the McKinsey model relies on IEA WEM 2007 baselines, and thus includes the information on the EU ETS available in 2007. The baseline scenarios calibrated by the POLES and GEM-E3 models also take into account the existence and continuation of the EU ETS. The inclusion of the EU ETS results in lower baseline emissions and therefore lower mitigation potential, as computed from the baseline, for a given CO_2 price.[18] The GTEM model projects baseline emissions assuming that no new climate change mitigation policies are introduced, but capturing existing EU climate policies to the extent that they have altered historical emission intensity or influenced technology shares in sectors producing energy services (Australian Government, 2008). Other models, such as GAINS (which relies on IEA WEM 2008 energy baseline projections) and WITCH have a similar approach, *i.e.* the baseline projection is a continuation of the past trends, without considering any new policies.[19] The MERGE and SGM model data

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[16] The set of models used for decision-making in EU climate policy is certainly much larger than the ones considered here. Nonetheless they provide a good overview of modelling approaches and corresponding results.

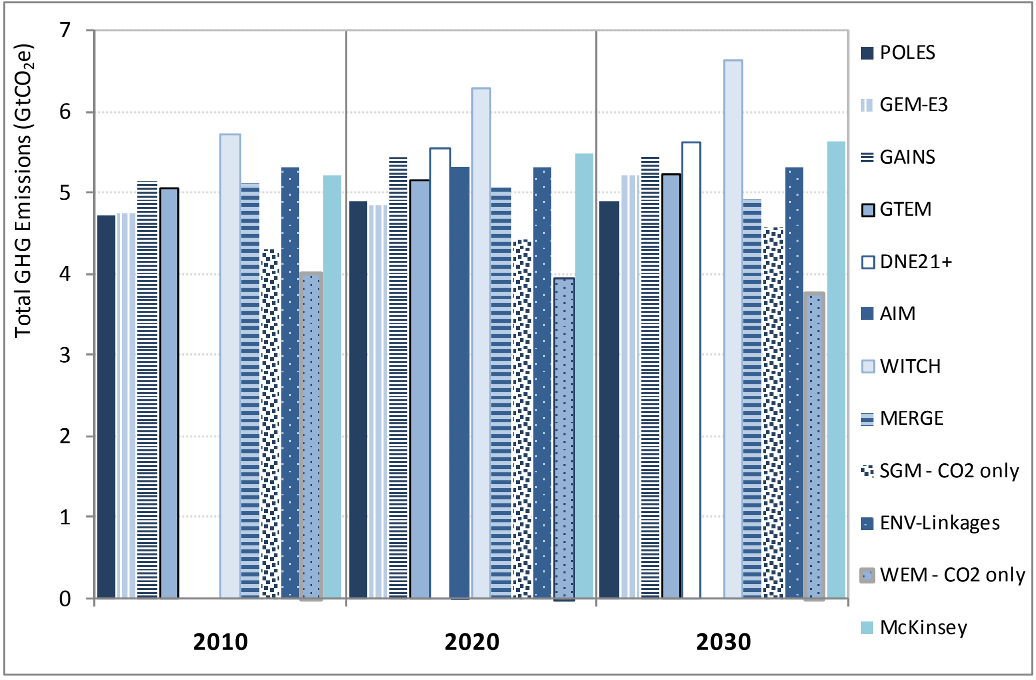
[17] For EU country specific mitigation potential estimates (for France, Germany, Italy, Poland, Spain and UK) from ENV-Linkages, see Annex Tables.

[18] Note that other metrics, such as reduction from 1990 levels, are unaffected by the inclusion of the EU ETS in the baseline.

[19] The GAINS baseline continues historically observed trends in autonomous energy efficiency, while WITCH includes endogenous technological progress in line with past trends.

reflects Energy Modelling Forum (EMF) assumptions on EU climate action, assuming the EU's 2020 emissions target[20] is met in a cost-effective way through trading within the EU, but without allowing international emissions trading. The DNE21+ model assumes that all measure that result in cost savings are included in the baseline. Instead, the AIMS model assumes that the future share and energy efficiency of standard technologies are fixed at the same level as in the base year, setting the baseline as a so-called 'frozen technology' case. In other words, without further intervention the historically observed rates in energy efficiency improvements stop. The advantage of this technology is that the increase of GHG emissions is explained directly by the increase of future energy service demands.

Figure 11: EU Baseline Emissions



A closer look at the assumptions behind the models sheds light on the reasons for the differences. Available data suggests that the uncertainties regarding the economic growth rates across the models play an important role (see Table 7). Indeed, while the population projections are similar across all models, with average annual growth rates of 0% over 2010-2030, annual growth rates for the EU economy (as measured in GDP) over 2010-2030 vary between 0.9 % (SGM model) and 2.2% (ENV-Linkages model). The SGM model has the lowest growth in GDP, as most models assume annual GDP growth rates between 1.2 and 1.9%. This can partly be explained by the fact that SGM is also the only model that assumes that the population will decline by more than 1% over this period. The available data for energy use also indicate that energy use projections vary widely. The POLES model projects an increase in energy consumption by 20% from 2010-2030, whereas WEM projects an increase of only 2% from 2010-2030, reflecting the high energy efficiency uptake in WEM's baseline and thus the improvements in the carbon intensity of the EU's economy. The ENV-Linkages model is characterised by higher energy use in absolute terms, reflected also in relatively high GHG emissions in absolute terms. Both the GEM-E3 and WITCH models project a higher growth in GHG emissions over 2010-2030 compared to other models.

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[20] In December 2008, the European Council and the European Parliament endorsed an agreement on the climate change and energy package, which translates into details a political commitment by the European Union to reduce its GHG emissions to at least 20% below 1990 levels by 2020.

Table 7: EU Baseline Projections Data

	2005	2010	2020	2030	2050	Percentage Change 2010-2030	Average Annual Growth Rate 2010-2030
GDP (Indexed, 2010 = 100)							
POLES	n/a	100	124	146	188	46%	1.9%
GEM-E3	89	100	114	127	n/a	27%	1.2%
GAINS	n/a	100	126	126	n/a	26%	1.2%
GTEM	n/a	100	115	129	162	29%	1.3%
DNE21+	n/a	100	122	142	171	42%	1.8%
AIM	92	100	121	n/a	n/a	n/a	n/a
WITCH	n/a	100	125	152	207	52%	2.1%
MERGE	n/a	100	120	142	180	42%	1.8%
SGM	n/a	100	107	119	164	19%	0.9%
ENV-Linkages	87	100	127	154	212	54%	2.2%
WEM	88	100	120	140	n/a	40%	1.7%
McKinsey	89	100	122	146	n/a	46%	1.9%
Population (Billion People)							
POLES	n/a	0.50	0.50	0.50	0.48	0.2%	0.0%
GEM-E3	0.49	0.49	0.49	0.49	n/a	-0.4%	0.0%
GAINS	n/a	0.49	0.50	0.49	n/a	0.4%	0.0%
GTEM	n/a	0.47	0.47	0.47	0.46	1.0%	0.0%
DNE21+	n/a	0.49	0.50	0.49	0.48	0.2%	0.0%
AIM	0.46	n/a	0.47	n/a	n/a	n/a	n/a
WITCH	n/a	0.51	0.51	0.51	0.49	0.4%	0.0%
MERGE	n/a	0.51	0.51	0.51	0.49	0.4%	0.0%
SGM	n/a	0.48	0.48	0.47	0.45	-1.1%	-0.1%
ENV-Linkages	0.50	0.51	0.51	0.51	0.49	0.4%	0.0%
WEM	0.49	0.50	0.50	0.50	0.48	0.2%	0.0%
McKinsey	0.49	0.49	0.50	0.50	n/a	0.5%	0.0%
Energy Use (EJ)							
POLES	n/a	80.1	89.1	96.4	111.2	20%	0.9%
GEM-E3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	78.9	85.7	90.6	n/a	15%	0.7%
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	81.3	82.7	n/a	n/a	n/a
AIM	n/a	n/a	76.6	n/a	n/a	n/a	n/a
WITCH	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MERGE	n/a	67.6	67.4	67.5	68.9	0%	0.0%
SGM	n/a	70.2	71.5	73.3	77.4	4%	0.2%
ENV-Linkages	104.2	102.0	101.6	101.1	260.7	-1%	0.0%
WEM	76.4	78.2	79.9	79.9	n/a	2%	0.1%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Energy Intensity (EJ/GDP in Trillion USD 2005)							
POLES	n/a	5.7	5.1	4.7	4.2	-17%	-1.0%
GEM-E3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	5.1	4.4	4.6	n/a	-9%	-0.5%
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	4.6	4.0	n/a	n/a	n/a
AIM	n/a	n/a	4.6	n/a	n/a	n/a	n/a
WITCH	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MERGE	n/a	5.7	4.8	4.0	3.2	-29%	-1.7%
SGM	n/a	7.4	7.0	6.5	4.9	-12%	-0.7%
ENV-Linkages	10.5	9.0	7.1	5.8	10.8	-36%	-2.2%
WEM	5.9	5.3	4.5	3.8	n/a	-27%	-1.6%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total GHG Emissions ($GtCO_2e$)							
*POLES**	n/a	4.7	4.9	4.9	4.9	3%	0.2%
GEM-E3	4.7	4.7	4.8	5.2	n/a	10%	0.5%
GAINS	n/a	5.1	5.4	5.4	n/a	6%	0.3%
GTEM	n/a	5.0	5.2	5.2	5.5	4%	0.2%
DNE21+	n/a	n/a	5.6	5.6	n/a	n/a	n/a
AIM	4.9	n/a	5.3	n/a	n/a	n/a	n/a
WITCH	n/a	5.7	6.3	6.6	6.1	16%	0.7%
MERGE	n/a	5.1	5.1	4.9	4.7	-4%	-0.2%
SGM-CO_2 only	n/a	4.3	4.4	4.6	4.7	7%	0.3%
ENV-Linkages	5.4	5.3	5.3	5.3	7.1	0%	0.0%
WEM-CO_2 only	3.9	4.0	3.9	3.8	n/a	-6%	-0.3%
McKinsey	5.0	5.2	5.5	5.6	n/a	8%	0.4%

** POLES does not include emissions from agriculture.*

National Mitigation Potential

Mitigation potential for the EU in different years depends on the model used and the carbon price imposed (see Figure12). In 2020, all models show a significant mitigation potential at USD 50/tCO_2e, ranging from around 16% (GEME3) to 30% (GTEM-Garnaut scenario) reduction from baseline. [21] In 2030, the mitigation potential at USD 50/tCO_2e across the models is larger than in 2020, ranging from approximately 20% (DNE21+ and ENV-Linkages models) to over 40% (McKinsey model) reduction from baseline.

Mitigation potential at a price of USD 50/tCO_2e increases over time. This is an expected result, as a longer time period allows new capital stocks to adjust to the price signal. Moreover, the implications of technological change and energy efficiency improvements becomes visible as does the success of measures that require a longer lead time and decisions that involve capital turnover. For example, the most important reasons for the high mitigation potential in the McKinsey model in 2030 are the significant presence of the carbon capture and storage (CCS) technology, which is almost non-existent in 2020, and efficient mitigation options in the transport sector. This insight is also confirmed when looking at the shape of the marginal abatement cost "curves."

In early years, the marginal abatement cost curves are very steep, indicating that it becomes expensive to implement measures that reduce emissions by more than 40%. This result can be explained by the fact that

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[21] The WEM model shows mitigation potential of 13%, however it only focuses on energy-related CO_2 emissions, which explains a generally lower mitigation potential than models that cover all GHG emissions.

the EU is already implementing an energy and climate package aimed at significant emission reductions. Some of the policies needed to achieve these reductions are already adopted or are in the process of being adopted. In addition to a continuation of efficiency improvements in line with past trends, particularly the cornerstone of EU climate policy – the EU ETS – is represented in several models' baselines (WEM, McKinsey, POLES, and GEM-E3). This implies that by 2020 the least-cost mitigation options will have been implemented (and, hence, have been taken up in the baseline of these models). The economy will by then have become more energy efficient, and therefore the remaining mitigation options are relatively expensive. This trend in the EU seems to be generally accepted, as shown by the well-aligned mitigation potential across models in 2020, and especially by the POLES model that is closest to EU policy-making.

Over time, the curves become flatter, indicating that the EU economy has undergone extensive structural changes due to the mitigation measures, which allow larger increases in abatement at relatively modest costs. It is interesting to note that amongst the models that achieve these results is the WITCH model that has a sophisticated representation of technical change. Nonetheless, particularly in 2050 the mitigation potential across the models is not very well aligned across the few models with available data, in part because uncertainties become larger the further models project into the future.

Sectoral Emissions and Mitigation Potential

Figure 13 shows baseline emissions by sector across the models for the EU according to the sectors reported.[22] The POLES model reports emissions from the power sector, other conversion, the transport sector, the industry sector, and a combined category including residential plus services. Both the GTEM and ENV-Linkages reported data for more than 20 sectors. The GTEM and ENV-Linkages are the only models that reported separate data for the household and services sectors. Yet, similar to the POLES model, the GTEM model did not break out emissions from the buildings sector. The AIM model reports CO_2 emissions for energy, industry, transport and buildings, while the remaining emissions are reported by gas rather than sector. Both the McKinsey[23] and GAINS models report emissions for electricity and non-electric energy supply, transportation, industry, buildings, waste, and agriculture. DNE21+ reported the same sectors except for forestry. WEM reports only energy-related CO_2 emissions, but breaks out emissions from power generation and transportation. Given that the GAINS and DNE21+ models report energy-related CO_2 emissions as a share of the total GHG emissions, these emissions can be compared to those from the WEM; in 2020 the energy-related CO_2 emissions in the GAINS model are 5% higher and those in the DNE21+ model and 8% higher than the ones reported by WEM.

While the differences in sector definitions makes it difficult to establish robust conclusions from sectoral data at this point, the available data nonetheless provides some interesting insights regarding the role of the most important sectors in terms of GHG emissions. Across all models, the largest emitting sector in the EU is the electricity sector. However, models do not converge on which sector is second largest. All but the POLES model rank the transport sector as the second-largest source of GHG emissions. Instead, the POLES model reports slightly higher GHG emissions from industry than from transport – this is due to the fact that it aggregates energy-intensive and other industry. Figure 9 shows that the differences between emissions from the industry and transport sector are relatively small, especially when aggregating the energy-intensive and other industries together.[24] Indeed, the boundaries and exact definitions of the sectors differ across models and underscore the difficulty of comparing models at a sectoral level. As a

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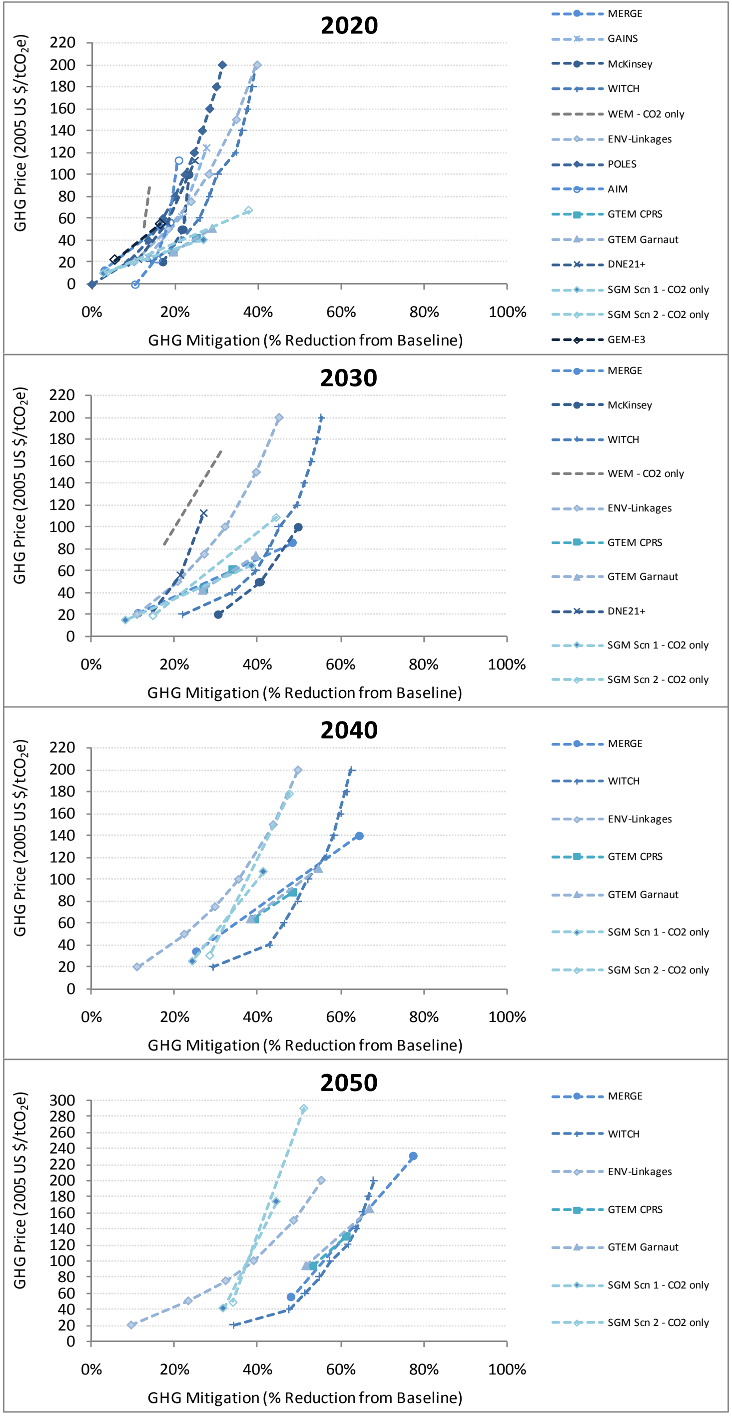
[22] The WITCH model did not report emissions by sector.

[23] The McKinsey model also reports indirect emissions by sector, which are not shown in this figure to avoid double counting of emissions with the energy supply: electric sector.

[24] In the industry sector, most models (GAINS, DNE21+, McKinsey, AIM) distinguish between energy-intensive and other industries (and sometimes in greater detail), but a few such as the GTEM, and ENV-Linkages models have very detailed distinctions, while the POLES model reports only one industry category.

consequence, analysis here focuses on sectoral mitigation potential in the EU in two sectors, namely electricity and transport.[25]

Figure 12: EU Mitigation Potential



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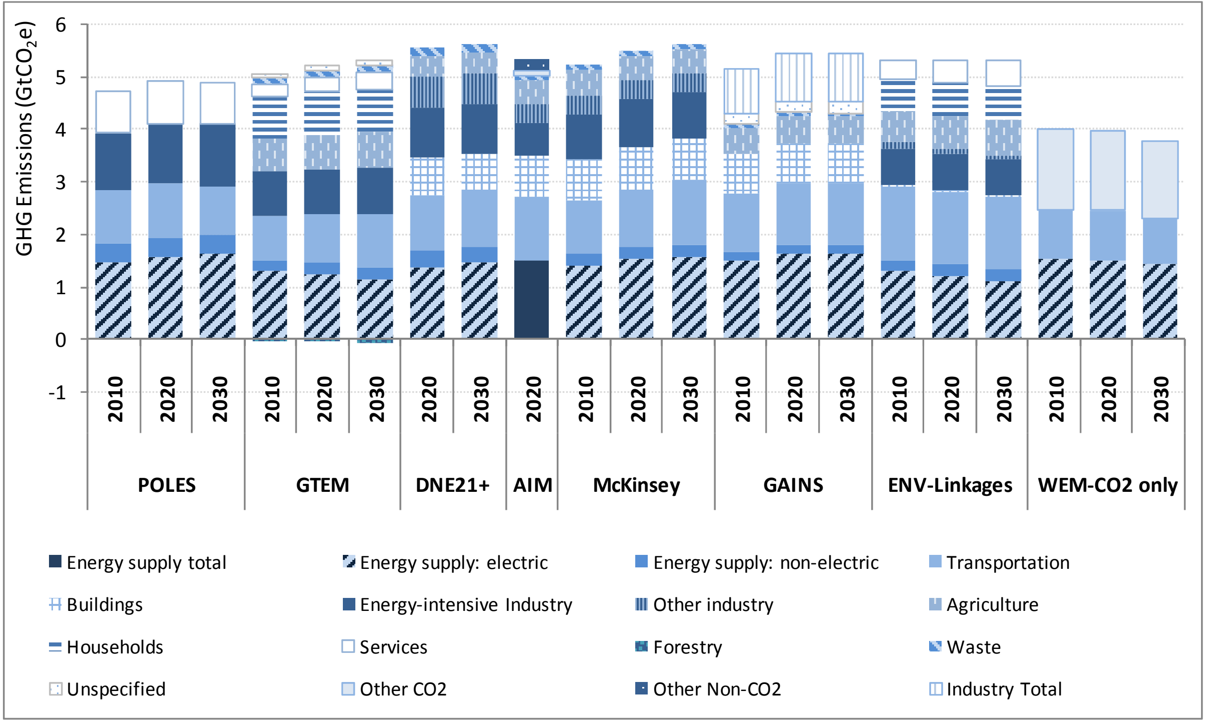
[25] Note that where different categories of transport are reported, they are all combined. However, consistency is not guaranteed as certain models treat particular categories in different ways. For example, the SGM model includes personal vehicles in the household category, whereas the McKinsey model includes personal vehicles in the transportation sector.

Figure 13: EU Sectoral Baseline Emissions



Note: The McKinsey model also reports indirect emissions by sector that are not shown in this figure to avoid double counting of emissions with the energy supply: electric sector. WEM only reports CO_2-emissions.

Figure 14 shows the range of mitigation potential for the electricity supply sector in the EU. In 2020 the models show a wide range of mitigation potential from approximately 19-44% emission reduction at USD 50/tCO_2e. The McKinsey model has a relatively low mitigation potential at prices up to USD 50/tCO_2e, likely driven by a substantially low available capacity to replace with low-emitting technologies, along with a negligible presence of CCS and a strong increase of renewables between now and 2020. WEM, also on the lower side of mitigation potential, only includes energy-related CO_2 emissions and already has significant efficiency improvements in its baseline (i.e., the implementation of the energy and climate policies that were enacted or adopted by mid-2008 in the EU). GTEM, a top-down model, provides the highest estimates of mitigation potential, driven by a more flexible rate of capital movement in the electricity sector that is characteristic of this model type, and the specific policy scenario (see Text Box 2).

Fewer models reported data for 2040 and 2050. In the later years, the models with available data show mitigation potential ranging from 25% to over 60%. This large span is driven by *inter alia* the uncertainty of when certain key technologies, most importantly CCS, become commercially available. Models assume different price levels for triggering CCS, reflecting the current uncertainty on this technology and its costs. It is interesting to note that a large part of the emissions in the electricity sector could be reduced at a carbon cost between USD 50-100/tCO_2e by 2040-2050, while the final 10-25% seems to require significantly higher carbon prices, particularly in ENV-Linkages. Mitigation potential in ENV-Linkages is lower than in other models in the long run. This reflects both the absence of CCS technologies in the version of the model used here and the reduction in nuclear power generation after 2025, induced by the decision of German and other EU countries to stop it after 2020.

The EU transport sector is characterised by a very different situation (see Figure 15). Most models concur in showing a lower mitigation potential than in the electricity sector over the years. At a price of USD 50/tCO_2e, emissions from the transport sector decline by approximately 3-19% in 2020. Only a few models provide higher projections of mitigation potential, generally driven by specific mitigation options included. For example, the AIM model shows a mitigation potential of about 19% at USD 50/tCO_2e in 2020. The McKinsey model, which includes significant improvements of conventional internal-combustion engines, deployment of hybrid and plug-in electric vehicles and a high penetration of CO_2-efficient biofuels, projects an even higher mitigation potential at the same price in 2030. Yet, even the models that predict slightly higher mitigation potentials show the same trend regarding the shape of the marginal abatement curves: all of these are steep, underscoring that emission reductions in the EU transport sector come at high carbon costs. Only few models reported data for 2040 and 2050. In 2050, the maximum amount of mitigation at prices up to USD 150/tCO_2e consists only of 15%-30%. An exception is the results from ENV-Linkages, which indicate a larger mitigation potential in transportation in the long run. These results can be partly explained by the greater flexibility that consumers have in this model to change their mode of transportation.

The actual mitigation potential in the transport sector could be larger than is identified by these models. These reflect technical mitigation options, which basically provide improved vehicles or other hardware to continue the same growth pattern as foreseen by the baseline projections. However, while assuming certain elasticities of substitution, the models do not explicitly reflect actions by individuals and governments to approach transport, urban planning, and mobility needs differently, which could result in behavioural changes by consumers or modal shifts towards increased public transport and intelligent transportation systems.

Figure 14: EU Mitigation Potential for the Electricity Supply Sector

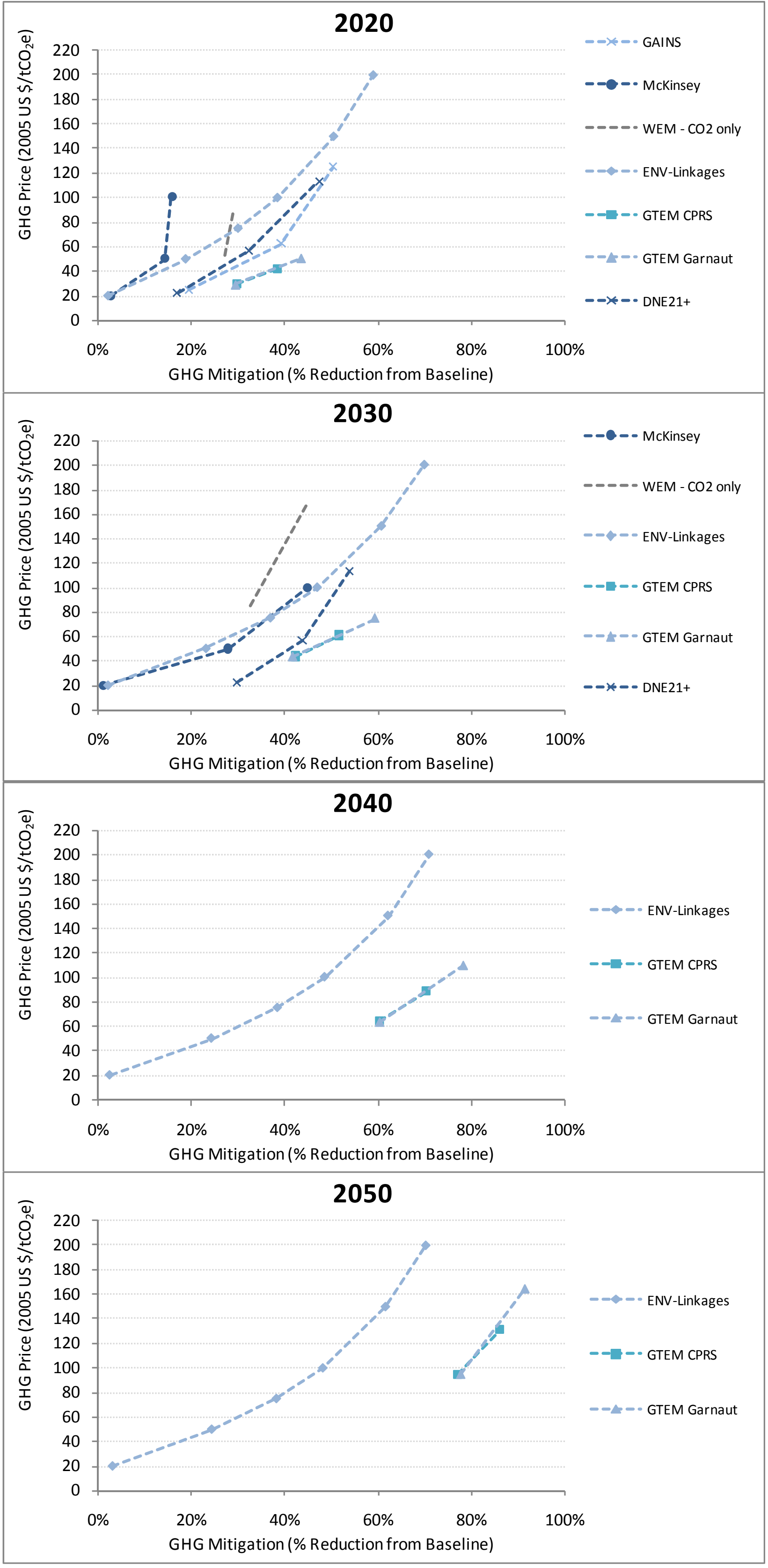
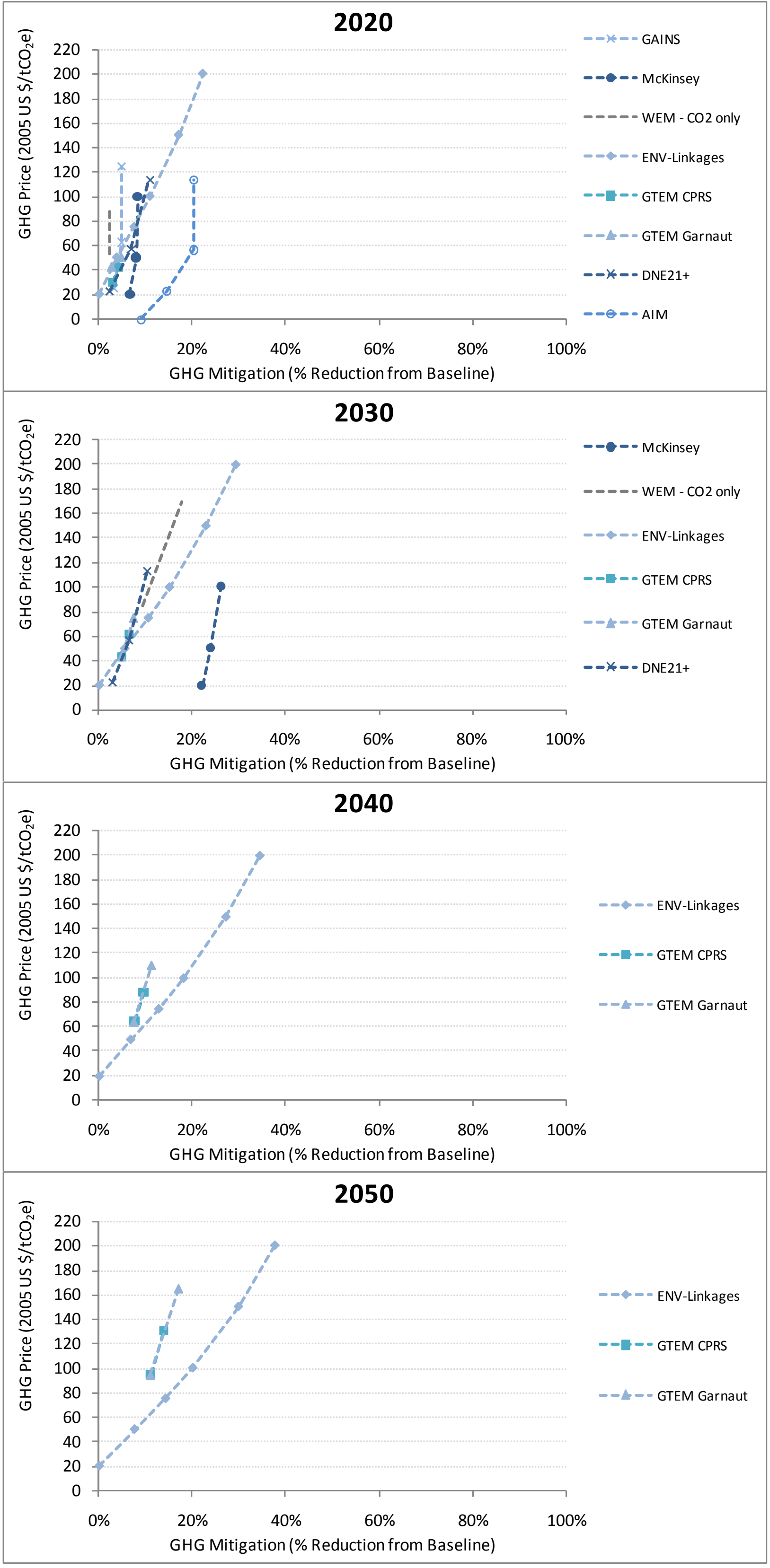


Figure 15: EU Mitigation Potential for the Transport Sector



3.4 Japan

Key insights

A number of insights emerge when examining GHG mitigation potential across 8 economic models for Japan (2 models used in Japan, namely DNE21+ and AIM/Enduse, as well as other models, namely GAINS, GTEM, ENV-Linkages, McKinsey, POLES, and WEM):

- Baseline GHG emissions throughout the time period 2010-2030 are somewhat consistent across the models ranging from 1.2 to 1.5 $GtCO_2e$ in 2020 and 1.3 to 1.4 $GtCO_2e$ in 2030 (compared with 1.3 to 1.4 in 2005). GHG emissions are projected to decline somewhat over this time horizon, due in part to a decline in population.

- Estimated mitigation potential in 2020 compared to the baseline is relatively low across all the models, ranging from 5-20% at USD 50/tCO_2e.

- Over time, mitigation potential increases somewhat, ranging from 9-32% in 2030 for the same carbon price. By 2050, mitigation potential is 37-39% at a higher price of USD 100/tCO_2e, although fewer models report data for this year.

- Comparing mitigation potential results across the electric energy supply sector, the largest emitting sector, the models compared do not show much consistency. At a carbon price of 50 USD/tCO_2e in 2020 for example, mitigation potential ranges between 7-30% from the baseline; in 2030 this range is 18-34%. At the same price, mitigation potential in the transport sector appears to be much smaller, between 2-10% in 2020 and 4-13% in 2030. By 2050, the maximum mitigation potential is 63% at USD 100/tCO_2e in the electricity sector, and 24% for transportation, reflecting less flexibility in the models in the transportation sector.

Model Structure and Underlying Data

GHG mitigation potential results across eight models for Japan are examined here: two models used by Japan, DNE21+ and AIM/Enduse; four international models, ENV-Linkages, WEM, GAINS and McKinsey; as well as GTEM and POLES.

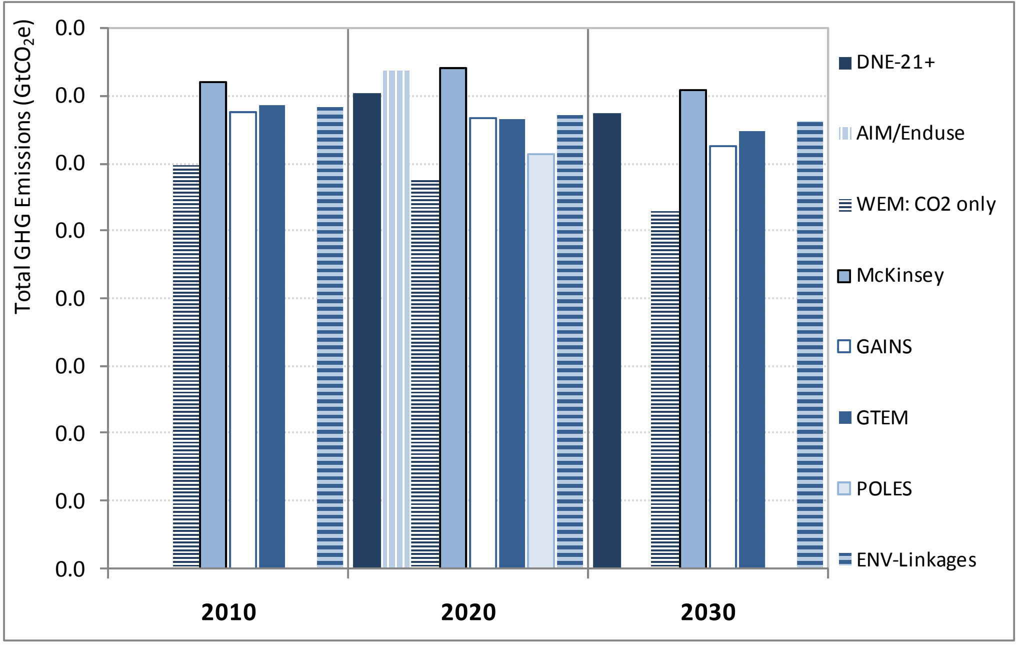
The two models used by the Japanese government that are examined here, DNE21+ and AIM/Enduse, are bottom-up models, although they differ in their approach to estimating GHG mitigation. DNE21+ is an energy systems model based on intertemporal linear programming. The model determines the most cost-effective measures under the given conditions, using perfect foresight. To do this, the model minimises the sum of discounted costs of world energy systems between 2000 and 2050 (a discount rate of 5% per year is adopted) for meeting various types of assumed production, services and energy demands (Akimoto *et al.* 2008). In the AIM/Enduse model, GHG mitigation potential is estimated using a marginal abatement cost tool with a detailed mitigation options database, which consists of around 300 options based on currently existing technologies.

There are differences across all of the models examined here in terms of the sectoral coverage, and the GHGs included. WEM only covers energy-related CO_2 emissions. The McKinsey model covers both CO_2 and non-CO_2 emissions, including emissions from LULUCF (from Houghton), as does the GTEM model. The remaining models that report data for Japan exclude LULUCF emissions. For more detail regarding model structure and underlying data sources, see Tables 2, 3 and 4.

Baseline Emissions and Assumptions

Figure 16 shows baseline GHG emissions throughout the time period 2010-2030 are fairly consistent across the models, with a range of 0.1 $GtCO_2e$ in 2010 and 0.2 $GtCO_2e$ in 2030 across models reporting all GHGs. All models project constant or slightly declining emissions during the 2020-2030 time horizon.

Figure 16: Japanese Baseline Emissions



The DNE21+ baseline assumes that all of the negative cost measures for energy-related CO_2, and low cost measures for other GHGs which are already utilised, are adopted. The AIM/Enduse baseline is set as a technology frozen case, where the future share and energy efficiency of standard technologies are fixed at the same level as in the base year.

Table 8 provides underlying data for some of the key baseline emission drivers. Across the models, population in Japan is projected to drop slightly across the 2010-2030 horizon, with a very consistent average annual growth rate of -0.4% per year. Economic projections are less consistent across the models, with the average annual growth rate for GDP ranging from 0.6-1.5% for the same time period. The highest GDP growth is projected by the DNE21+ model, while the lowest growth is projected by the GTEM model.

National Mitigation Potential

In 2020, mitigation potential at USD 50/tCO_2e ranges from about 5% (for DNE21+) to 20% (ENV-Linkages) reduction from baseline (see Figure 17). ENV-Linkages, a top-down model, shows greater flexibility in response to the same carbon price. The McKinsey model also shows higher mitigation potential, with nuclear energy being the single largest driver, accounting for 20% of total abatement in 2020.

In 2030, mitigation potential at USD 50/tCO_2e ranges from 9-32% (for DNE21+ and McKinsey respectively). Thus, as expected, the range of mitigation potential at a given price increases over time, as more technological options are assumed to take effect. In the McKinsey model for example, CCS has nearly no effect in 2020, whereas it accounts for 10% of total mitigation potential in 2030. CCS technologies are also modelled in DNE21+ and are assumed to become deployed after 2021. (CCS is not included in the AIM/Enduse model, as the model time horizon does not extend beyond 2020). By 2050, mitigation potential is 37-39% at a higher price of USD 100/tCO_2e, although only two models (GTEM and ENV-Linkages) report for this time period. Mitigation potential results from other models are not available for the 2040 and 2050 time period. The majority of models reporting results for Japan implemented unilaterally applied, constant price scenarios. One exception is the GTEM model, which reported results from the Australian government scenarios, which reflect international assumptions regarding accession to a global emission trading scheme. In general, models allowing for international emissions trading tend to show greater mitigation potential for a given carbon price. Another exception is the POLES model, which implemented a global carbon tax (see Text Box 2).

Sectoral Emissions and Mitigation Potential

Figure 18 shows baseline emissions for Japan as reported by sector. It is important to recall that the models differ with respect to the coverage of sectors, how emissions are allocated to the different sectors, and their definitions. With the exception of McKinsey and GTEM, the models reporting here do not include LULUCF emissions. The WEM model covers energy-related CO_2 emissions only. DNE21+ reported emissions for the original 9 sectors specified in the questionnaire, whereas the AIM/Enduse model reported CO_2 emissions for energy, industry, transport and buildings, while the remaining emissions were reported by gas rather than by sector.

Despite the lack of consistency across the coverage of different sectors and reporting, the largest emitting sector across all the Japanese and international models is electric energy supply. The second largest emitting sector according to the DNE21+, GAINS and McKinsey models is energy-intensive industry; in contrast the second largest emitting sector in the AIM/Enduse, GTEM and ENV-Linkages models is transportation. The buildings sector is also important across all the models, though the ranking varies somewhat between third and fourth largest sector across the different models that reported for this sector.

Given the differences in sectoral reporting definitions, sectoral mitigation potential in Japan is only examined for the electric energy supply and transportation sectors in this paper. Figure 19 depicts the range of mitigation potential for electric energy supply. In 2020, mitigation potential at USD 50/tCO_2e ranges between 7-30% relative to baseline emissions (for DNE21+ and GTEM respectively). The slight increase in emissions shown in the GAINS model results for 2020 is a contrived consequence of accounting emissions from combined heat and power plants in the electricity sector. Overall energy system emissions are actually being reduced consistently as carbon prices increase in the GAINS model. In 2030, models with available data show mitigation potential ranging from 18-34% at the same price. By 2050, the maximum mitigation potential across the two models reporting (GTEM and ENV-Linkages) is 63% at USD 100/tCO_2e.

Mitigation potential results for the transport sector are depicted in Figure 20. These “curves” are much steeper than those for the electricity sector, indicating that higher costs are needed to reduce transport emissions in Japan. In 2020, mitigation potential at USD 50/tCO_2e ranges between 2 – 10% across the models. In 2030, mitigation potential ranges between 4 - 13%. In both 2020 and 2030, McKinsey has the highest mitigation potential at lower prices, explained in part by the mitigation options that are assumed in the model. These include for example the higher internal combustion efficiency and the deployment of hybrids and plug-in vehicles. At higher prices in later time periods such as 2040 and 2050, the ENV-Linkages model also shows greater price responsiveness in the transportation sector. By 2050, the maximum mitigation potential is 24% at USD 100/tCO_2e, reflecting less flexibility in the models in the transportation sector than in the electricity sector, although only two models reported results for this time period (GTEM, ENV-Linkages).

Table 8: Japanese Baseline Projections

	2005	**2010**	**2020**	**2030**	**2050**	**Percentage Change 2010-2030**	**Average Annual Growth Rate 2010-2030**
GDP (Indexed, 2010 = 100)							
DNE-21+	98	100	119	134	132	34%	1.7%
AIM/Enduse	97	100	117	n/a	n/a	n/a	n/a
WEM	92	100	112	124	n/a	24%	1.2%
McKinsey	92	100	115	131	n/a	31%	1.6%
GAINS	n/a	100	108	117	n/a	17%	0.9%
GTEM	n/a	100	105	113	116	13%	0.7%
POLES	101	100	122	n/a	n/a	n/a	n/a
ENV-Linkages	91	100	115	130	150	30%	1.5%
Population (Million People)							
DNE-21+	128	128	124	118	103	-7%	-0.4%
AIM/Enduse	128	n/a	124	n/a	n/a	n/a	n/a
WEM	128	128	124	118	n/a	-7%	-0.4%
McKinsey	128	127	123	117	n/a	-8%	-0.4%
GAINS	n/a	128	124	118	n/a	-7%	-0.4%
GTEM	n/a	128	124	118	103	-7%	-0.4%
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ENV-Linkages	128	128	124	118	103	-7%	-0.4%
Energy Use (EJ)							
DNE-21+	n/a	n/a	23.2	22.5	n/a	n/a	n/a
AIM/Enduse	n/a	n/a	23.4	n/a	n/a	n/a	n/a
WEM	22.2	22.2	22.4	21.8	n/a	-2%	-0.1%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	24.0	25.5	26.2	n/a	9%	0.5%
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ENV-Linkages	31.3	30.6	29.3	27.8	21.4	-9%	-0.5%
Energy Intensity (EJ/GDP in Trillion USD 2005)							
DNE-21+	n/a	n/a	4.1	3.6	n/a	n/a	n/a
AIM/Enduse	n/a	n/a	4.2	n/a	n/a	n/a	n/a
WEM	5.7	5.3	4.8	4.1	n/a	-21%	-1.2%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GAINS	n/a	5.2	5.1	4.8	n/a	-7%	-0.3%
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ENV-Linkages	7.0	6.2	5.2	4.4	2.9	-30%	-1.8%
Total GHG Emissions ($GtCO_2e$)							
DNE-21+	n/a	n/a	1.4	1.4	n/a	n/a	n/a
AIM/Enduse	1.3	n/a	1.5	n/a	n/a	n/a	n/a
WEM: CO_2 Only	n/a	1.2	1.2	1.1	n/a	-0.1	-0.6%
McKinsey	1.3	1.4	1.5	1.4	n/a	0.0	-0.1%
GAINS	n/a	1.4	1.3	1.3	n/a	-0.1	-0.4%
GTEM	n/a	1.4	1.3	1.3	1.1	-0.1	-0.3%
POLES	1.3	n/a	1.2	n/a	n/a	n/a	n/a
ENV-Linkages	1.4	1.4	1.3	1.3	1.2	0.0	-0.2%

Figure 17: Japanese Mitigation Potential

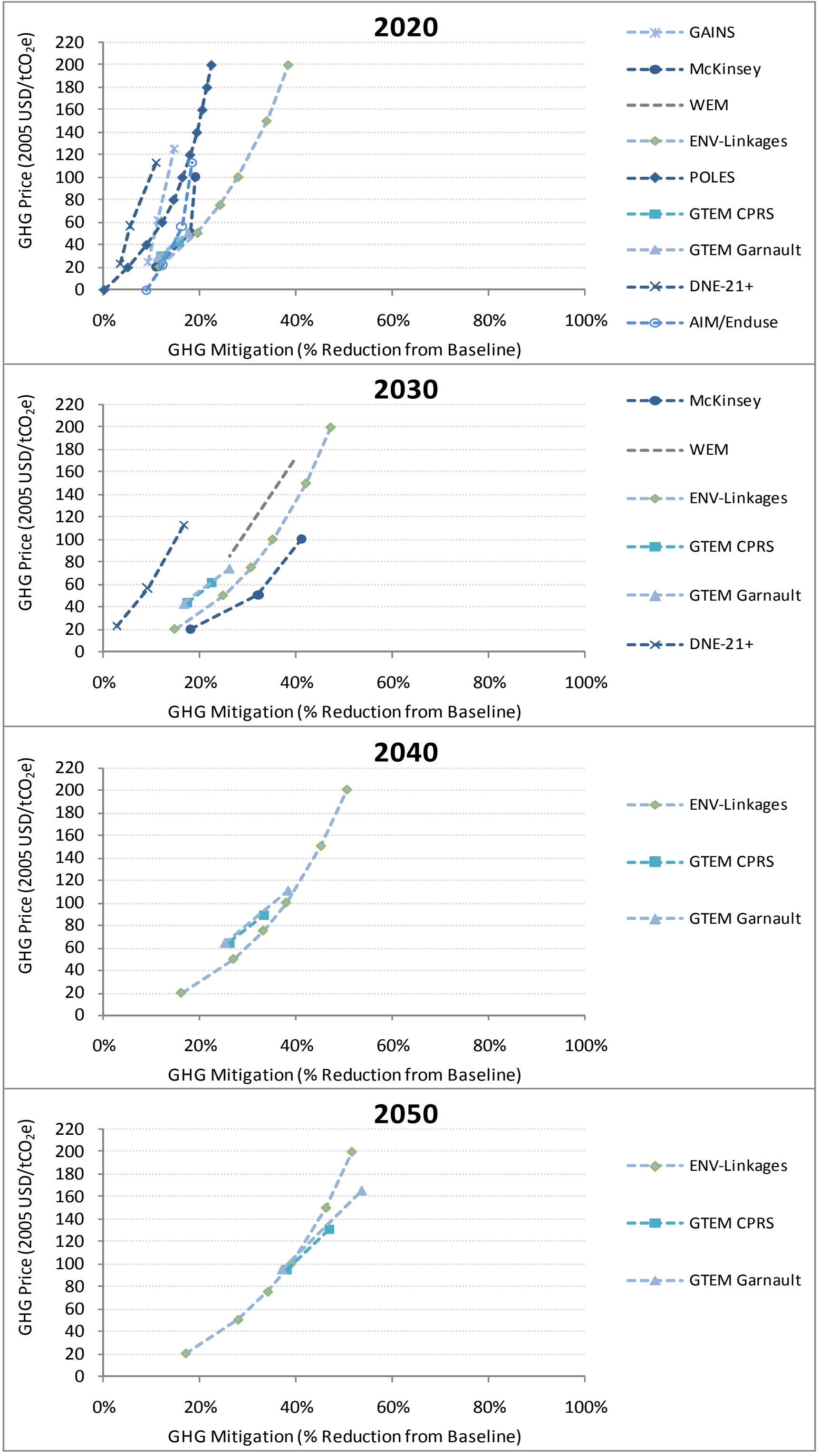


Figure 18: Japanese Sectoral Baseline Emissions

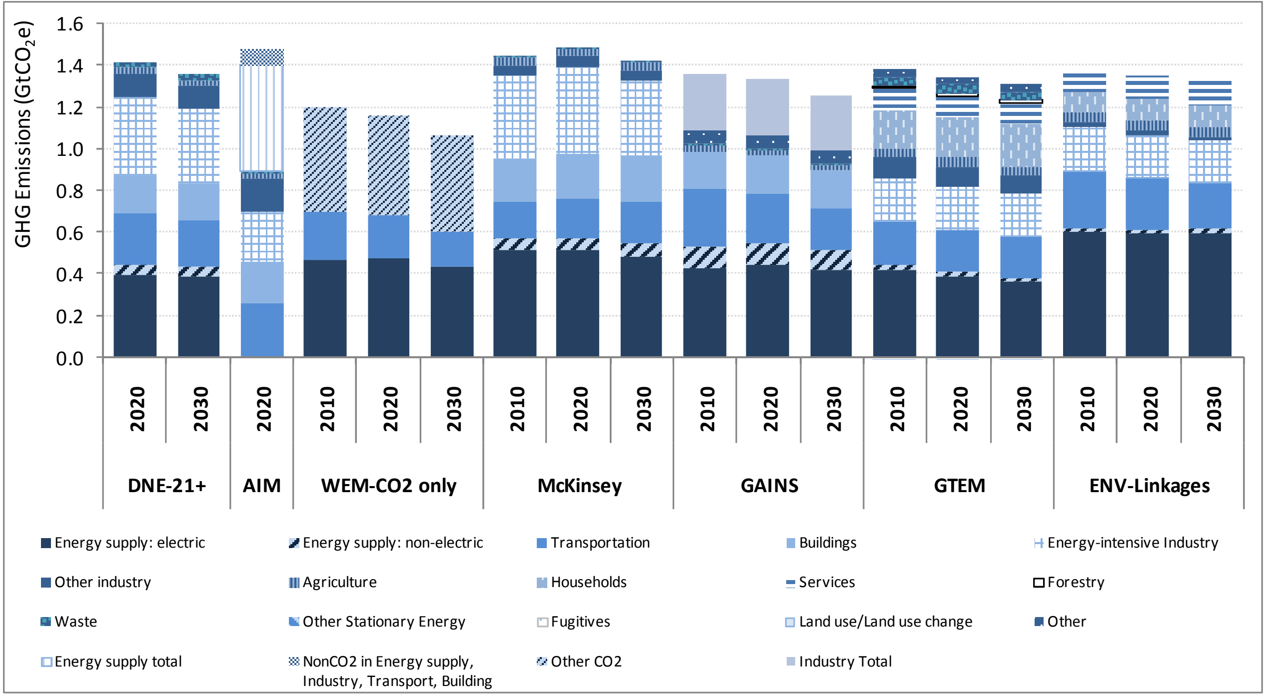


Figure 19: Japanese Mitigation Potential for the Electric Energy Supply Sector

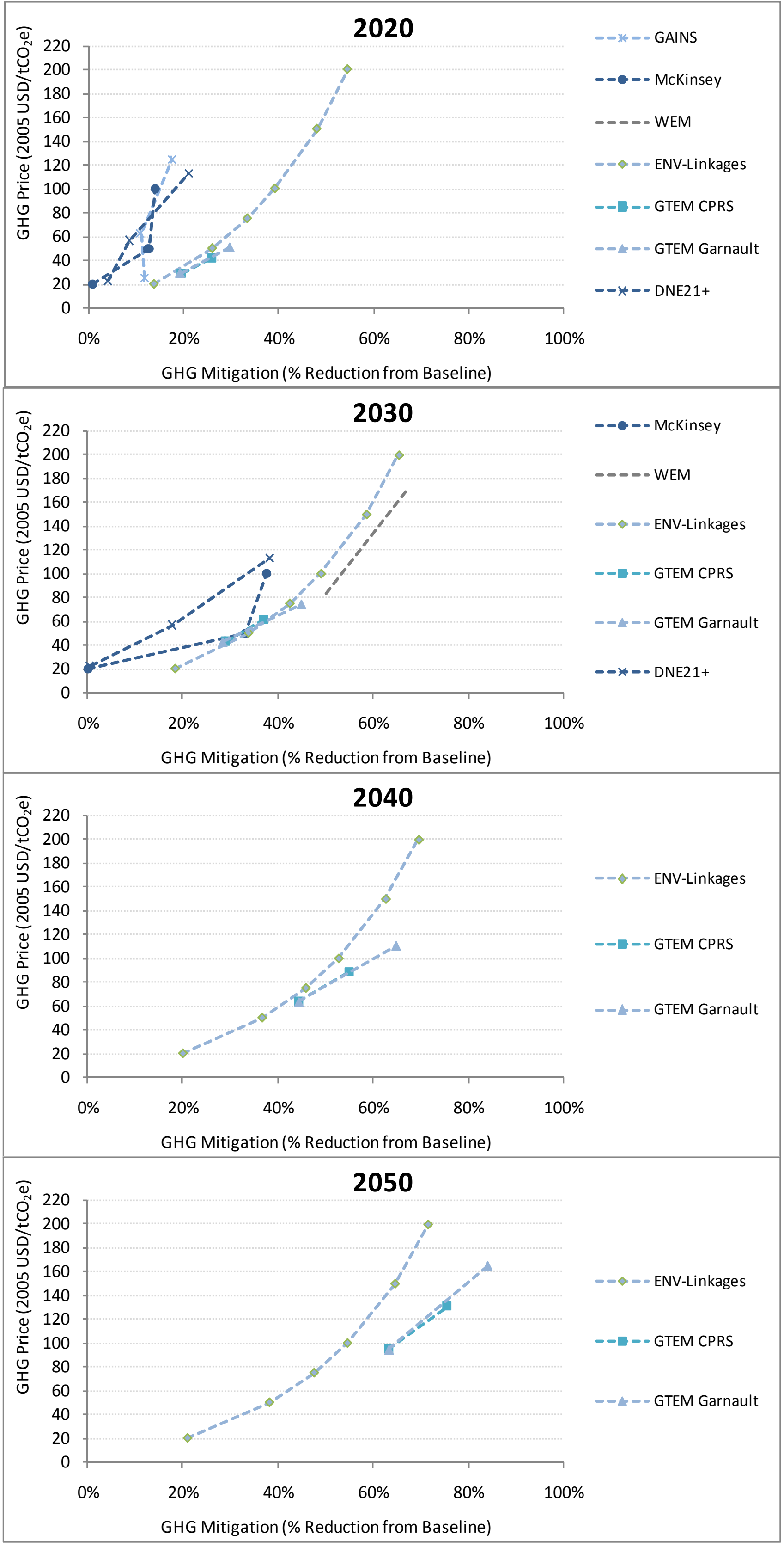
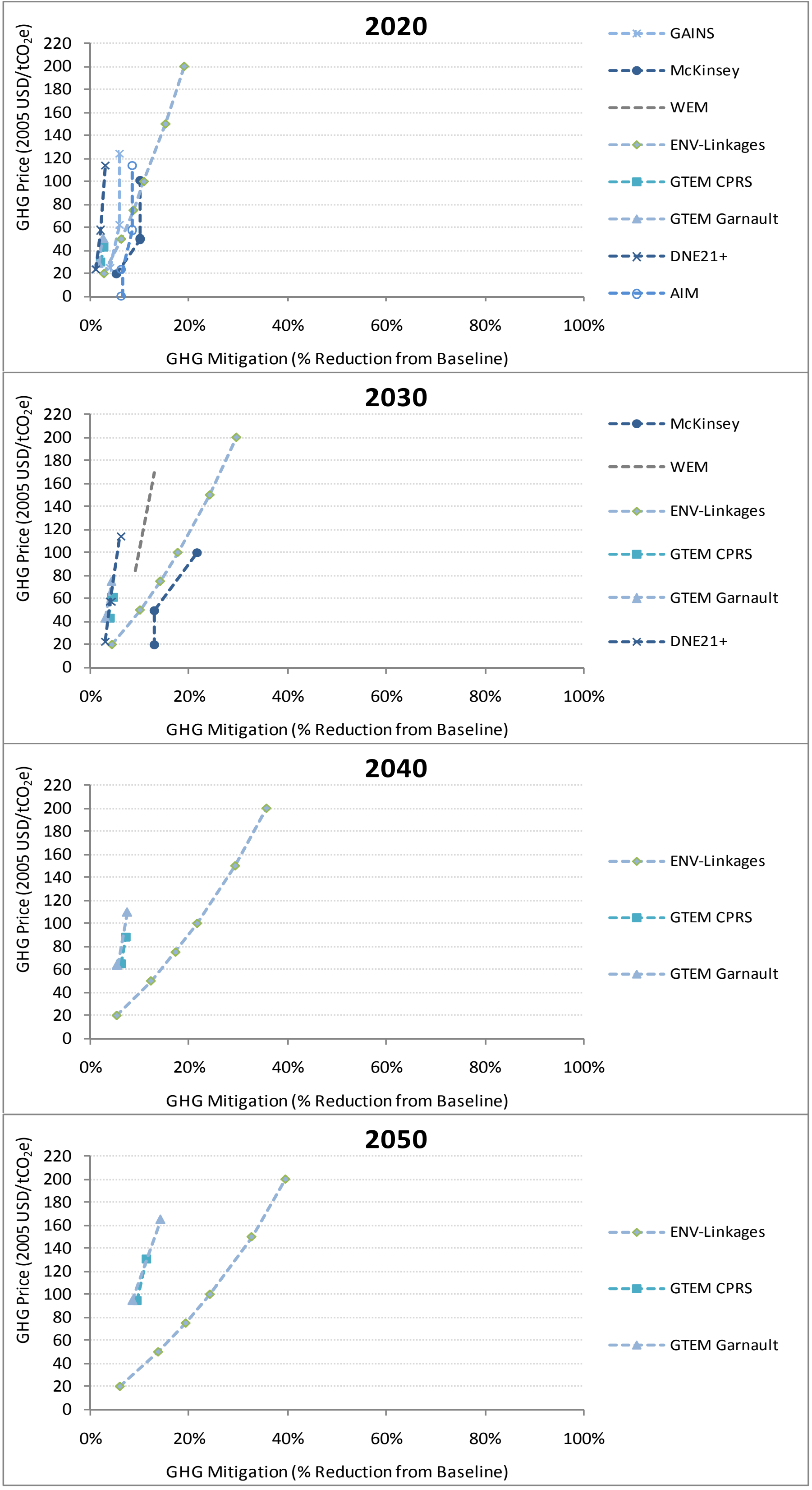


Figure 20: Japanese Mitigation Potential for the Transport Sector



3.5 Mexico

Key Insights

Some insights emerge from examining baseline GHG emissions and mitigation potential across five models for Mexico, including the Mexican model LEAP/MEDEC and other economic models (DNE21+, ENV-Linkages, McKinsey v2.0, and WEM), as well as the baseline projections from SEMARNAT:

- Baseline GHG emissions projections range substantially between 561-937 $MtCO_2e$ in 2020 and 647-1200 $MtCO_2e$ in 2030 (compared with in 517-640 in 2005). Average annual growth rates for the period 2010-2030 range from 1.2% (SEMARNAT) to 2.5% (for MEDEC and ENV-Linkages).

- At a price of USD 50/tCO_2e, mitigation potential across the available models for Mexico in 2020 ranges between 25-37% reduction in GHG emissions from the baseline.

- In 2030, the range is between 35-47% at the same carbon price. These ranges are based on 5 models for which mitigation potential estimates were available for this study. No mitigation potential data was available for later years.

- There are substantial differences in estimated mitigation potential in the electric energy supply sector across the models. At a price of USD 50/tCO_2e, mitigation potential ranges between 12-65% below baseline emissions in 2020 in the electricity sector. In the transport sector, models report steep trajectories for mitigation potential. At USD 50/tCO_2e in 2020, the mitigation potential for transport ranges from 6-20%.

Model Structure and Assumptions

Results from five models on GHG baseline emissions and mitigation potential in Mexico are examined and compared here. These include data provided by the MEDEC study by the World Bank[26], the OECD ENV-Linkages model, the IEA WEM, the McKinsey global GHG abatement model v2.0, , and the DNE21+ model. Data was also provided on baseline emission projections by SEMARNAT (the Mexican Ministry of Environment and Natural Resources).

ENV-Linkages is the only top-down model in this study with disaggregated data for Mexico. In comparison, MEDEC, WEM, McKinsey, and DNE21+ are bottom-up models (see Tables 2, 3, and 4 for other key features of these models). The SEMARNAT study includes a baseline scenario for national GHG emissions in Mexico, but to date the study has not yet simulated GHG mitigation potential.

Baseline Emissions and Assumptions

Comparing baseline emissions for Mexico across the models indicates fairly large variations (see Figure 21) that tend to increase over time. In 2010, estimates range between 594-767 $MtCO_2e$ (446 for WEM which reports CO_2 emissions only); by 2030 estimates range between 844-1192 $MtCO_2e$ (647 for WEM CO_2). The ENV-Linkages model shows the highest emission projections, with a growth of 64% from 2010-2030, with MEDEC showing a similar growth of 65% over the same period. Both of these models assume similar assumptions regarding higher rates of GDP growth for Mexico (see Table 9). SEMARNAT projects the lowest emissions growth of 26% from 2010-2030. Absolute emissions projections from WEM are substantially lower as only energy-related CO_2 emissions are covered. Both the McKinsey and MEDEC baselines include emissions from LULUCF. The average growth rate in emissions across the models also

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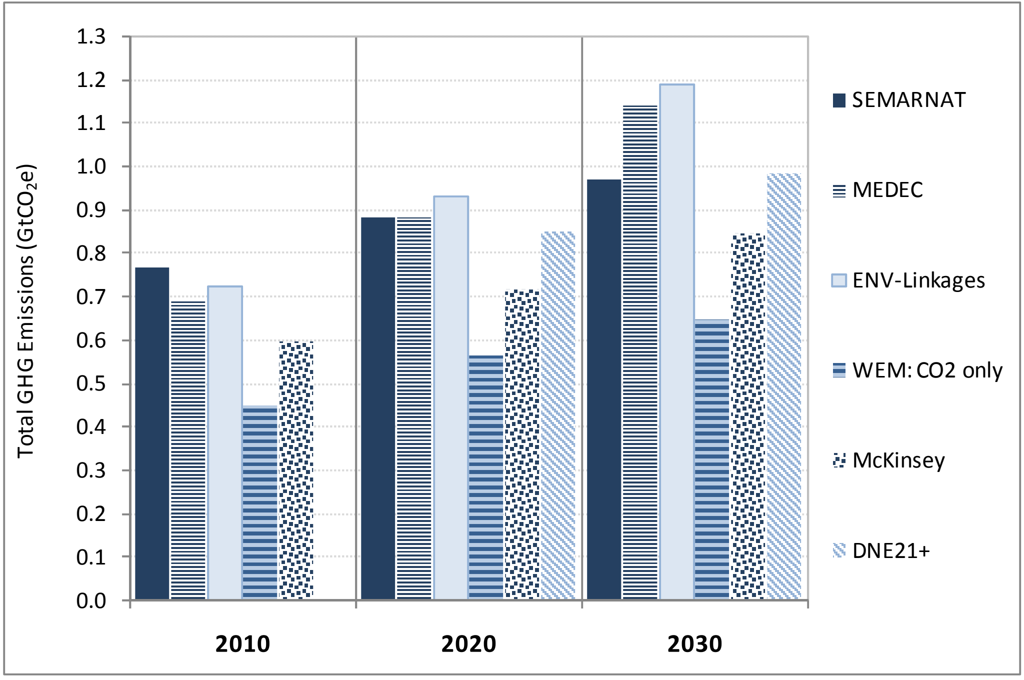
[26] Low Carbon Development Study for Mexico (México: Estudio sobre la Disminución de Emisiones de Carbono – MEDEC)

varies substantially: MEDEC projects over twice the average annual growth rate of the SEMARNAT projections (2.5% vs. 1.2% annually).

Historic data sources for the SEMARNAT study, *i.e.* for 1990 and 2000 CO_2e emissions, are based on information from the preliminary version of the 1990-2006 National Greenhouse Gases Inventory (INEGEI). The two main inputs for the forecast data are the national energy outlook documents (2008-2017) published by the Energy Ministry and the global CO_2 emissions as projected by the OECD Environmental Outlook to 2030 (OECD, 2008). The gases covered are CO_2, CH_4 and N_20, and HFCs from industry.

The MEDEC (World Bank) study baseline was generated using the LEAP (Long-range Energy Alternatives Planning) model, based on macro-economic assumptions for GDP, population growth, and fuel prices in line with Mexican government estimates. Emissions from activities not associated with energy, such as industrial processes and land-use, were modelled separately.

Figure 21: Mexican Baseline Emissions



Data on some of the key drivers of emissions are summarised in Table9. In particular, GDP growth over the period 2010-2030 varies widely from 74 – 127% across the models. This highlights the uncertainty in projecting economic growth, which is perhaps even greater for emerging economies. Population estimates also vary, ranging from an average annual growth rate of 0.5 – 1.0% from 2010-2030. The difference in initial 2005 emission levels between the models is also quite striking, reflecting a 26% difference in historical base year emissions. More harmonized base year emissions for Mexico across the models would enhance the comparison of mitigation potential estimates.

National Mitigation Potential

Given data reported for this analysis, it is only possible to compare mitigation potential across a few models, namely ENV-Linkages, WEM, McKinsey, DNE21+, and MEDEC models for the years 2020 and 2030 (Figure 22). Mitigation potential estimates for later years were not available for this study. At a carbon price of USD 20/tCO_2e in 2020, ENV-Linkages, McKinsey, DNE21+, and MEDEC suggest fairly similar GHG mitigation potential for Mexico, ranging between a 22-30% emission reduction from baseline. The curves diverge sharply at higher carbon price scenarios, with McKinsey projecting lower mitigation potential than ENV-Linkages. ENV-Linkages, as the only top-down model reporting disaggregated data for Mexico for this study, shows a higher mitigation potential than the other models. At a carbon price of approximately USD 50/tCO$_2$e, the models predict between 25-37% reduction from baseline; at a carbon price of USD 100/tCO$_2$e, the models predict between 28-49% reduction from baseline for the year 2020.

Table 9: Mexican Baseline Projections Data

	2005	**2010**	**2020**	**2030**	**2050**	**Percentage Change 2010-2030**	**Average Annual Growth Rate 2010-2030**
GDP (Indexed, 2010 = 100)							
SEMARNAT	n/a	100	141	199	396	99%	3.5%
ENV-Linkages	82	100	153	227	400	127%	4.2%
WEM	83	100	145	195	n/a	95%	3.4%
McKinsey	83	100	138	182	n/a	82%	3.1%
MEDEC	n/a	100	n/a	203	n/a	103%	3.6%
DNE21+	n/a	100	134	174	n/a	74%	2.8%
Population (Million People)							
SEMARNAT	104	108	116	121	122	12%	0.5%
ENV-Linkages	104	110	121	128	132	16%	0.8%
WEM	104	110	120	127	132	15%	0.7%
McKinsey	106	112	125	137	n/a	22%	1.0%
MEDEC	104	108	116	121	122	12%	0.5%
DNE21+	n/a	110	121	128	n/a	16%	0.8%
Energy Use (EJ)							
SEMARNAT	7.7	8.7	11.8	15.6	26.4	79%	3.0%
ENV-Linkages	9.5	10.2	11.9	13.8	17.5	36%	1.6%
WEM	7.4	8.0	10.0	11.8	n/a	48%	2.0%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MEDEC	8.5	8.1	11.1	15.3	n/a	89%	3.2%
DNE21+	n/a	n/a	9.1	10.4	n/a	n/a	n/a
Energy Intensity (EJ/GDP in Billion USD 2005)							
SEMARNAT	n/a	0.009	0.009	0.008	0.007	-10%	-0.5%
ENV-Linkages	0.013	0.011	0.008	0.007	0.005	-40%	-2.5%
WEM	0.006	0.006	0.005	0.004	n/a	-24%	-1.4%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MEDEC	0.010	0.010	0.010	0.010	n/a	-7%	-0.4%
DNE21+	n/a	n/a	0.008	0.007	n/a	n/a	n/a
Total GHG Emissions (MtCO$_2$e)							
SEMARNAT	707	767	883	969	1089	26%	1.2%
ENV-Linkages	640	726	930	1192	1426	64%	2.5%
WEM: CO2 only	n/a	446	561	647	n/a	45%	1.9%
McKinsey	517	594	714	844	n/a	42%	1.8%
MEDEC	609	689	880	1137	n/a	65%	2.5%
DNE21+	n/a	n/a	849	983	n/a	n/a	n/a

Note: SEMARNAT GDP data reported for 2005 in this table is from 2006.

In 2030, McKinsey shows substantially higher mitigation potential than in 2020, and also higher than that of DNE21+ in 2030. The mitigation potential shown at USD 20/tCO_2e in the MEDEC model is very similar to that of the McKinsey model, at approximately 40% emission reduction. The WEM model projects lower mitigation potential than the other models, which can in part be explained by the lack of full GHG emissions coverage in the model. At USD 50/tCO_2e, the mitigation potential ranges form 35-47% in 2030. ENV-Linkages is the only model that reported data for later years, showing a 34% reduction in 2050 at USD 50/tCO_2e.

Sectoral Emissions and Mitigation Potential

Figure 23 shows baseline emissions according to the sectors reported. It is difficult to compare emissions across sectors due to the variety of definitions used across these models as well as how emissions have been attributed to different sectors. Sectors such as electricity generation and transport seem comparable across several models. Other sectors such as agriculture and forestry include LULUCF emissions in some models and not in others, making for a less robust comparison. It is also less clear how to compare across the industry sector, which in some models includes energy-intensive industry, other industry, or electric power and oil and gas industry.

Across the models, there is not a great degree of consistency as to which will be the most important emitting sectors in Mexico going forward. Both SEMARNAT and MEDEC show both the energy supply and transportation sectors as equally important emitting sectors from 2010-2030. On the other hand, ENV-Linkages projects the energy supply sector to emit nearly double that of the transportation sector by 2030, largely due to growth in energy supply outside of the electricity sector.

Mitigation potential in the electricity and transport sector are examined below. As can be seen in Figure 24, there are substantial differences in estimated mitigation potential in the electric energy supply sector across the models for which this data is available. At a price of USD 50/tCO_2e, mitigation potential for the electricity supply sector ranges between 12-65% below baseline emissions in 2020, and between 38-65% in 2030. The McKinsey shows a somewhat concave curve for the electricity sector in 2020 because there is no mitigation option that kicks-in between USD25-50/tCO_2. MEDEC shows higher mitigation potential at lower prices (42% reduction at USD 20/tCO_2e in 2020), as it includes the effects of both supply and demand side interventions in the model. In both years, the DNE21+ model projections are higher than those of the other models, partially reflecting a high rate of penetration of CCS technology. Only ENV-Linkages reports data for Mexico in 2040 and 2050, showing a 57% reduction in 2050 at USD 50/tCO_2e.

Figure 25 illustrates that McKinsey, DNE21+ and ENV-Linkages show steep trajectories for mitigation potential in the transport sector. At USD 50/tCO_2e in 2020, mitigation potential ranges from 6-20%. The McKinsey data shows nearly no additional mitigation potential achieved between USD 50-100/tCO_2e. MEDEC shows higher mitigation potential of 30% at lower carbon prices of USD 20/tCO_2e, but does not report data for higher prices. MEDEC includes biofuels in the transport sector; and unlike other studies it addresses emission reductions in modal shift and urban development interventions. By 2030, the same GHG prices yield a slightly higher mitigation potential range of 6-30% reduction from baseline emissions. While the McKinsey model shows higher mitigation potential in 2030 than in 2020, the WEM and DNE21+ models do not show much change from 2020. These differences are driven by *inter alia* the mitigation options available in the McKinsey model, which includes aggressive deployment of hybrid vehicles and other efficiency improvements by 2030, which are less prevalent in the other models. Only ENV-Linkages reported data for 2040 and 2050, showing at 19% reduction from baseline at USD $50/$tCO_2$e in 2050.

Figure 22: Mexican Mitigation Potential

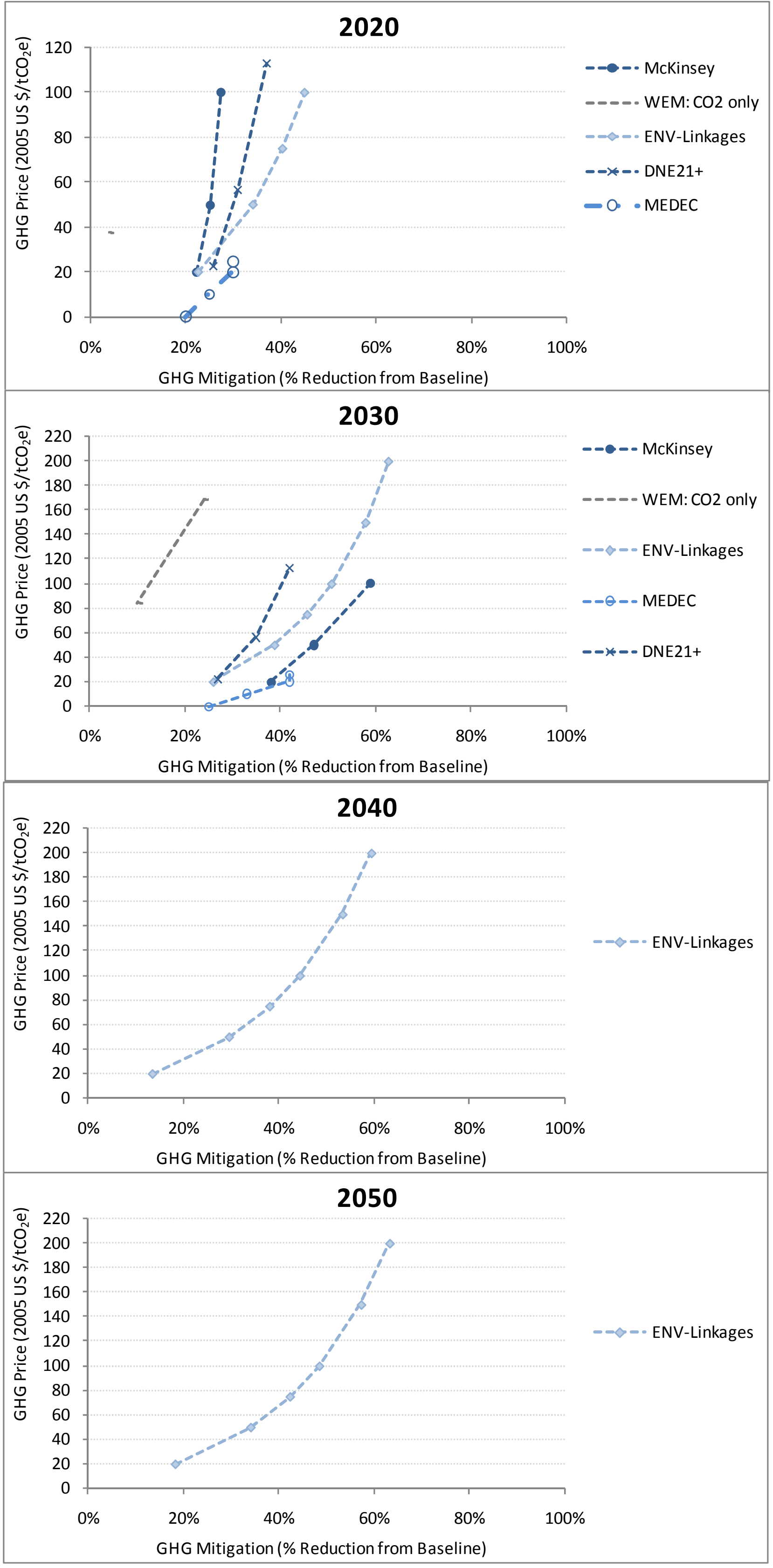


Figure 23: Mexican Sectoral Baseline Emissions

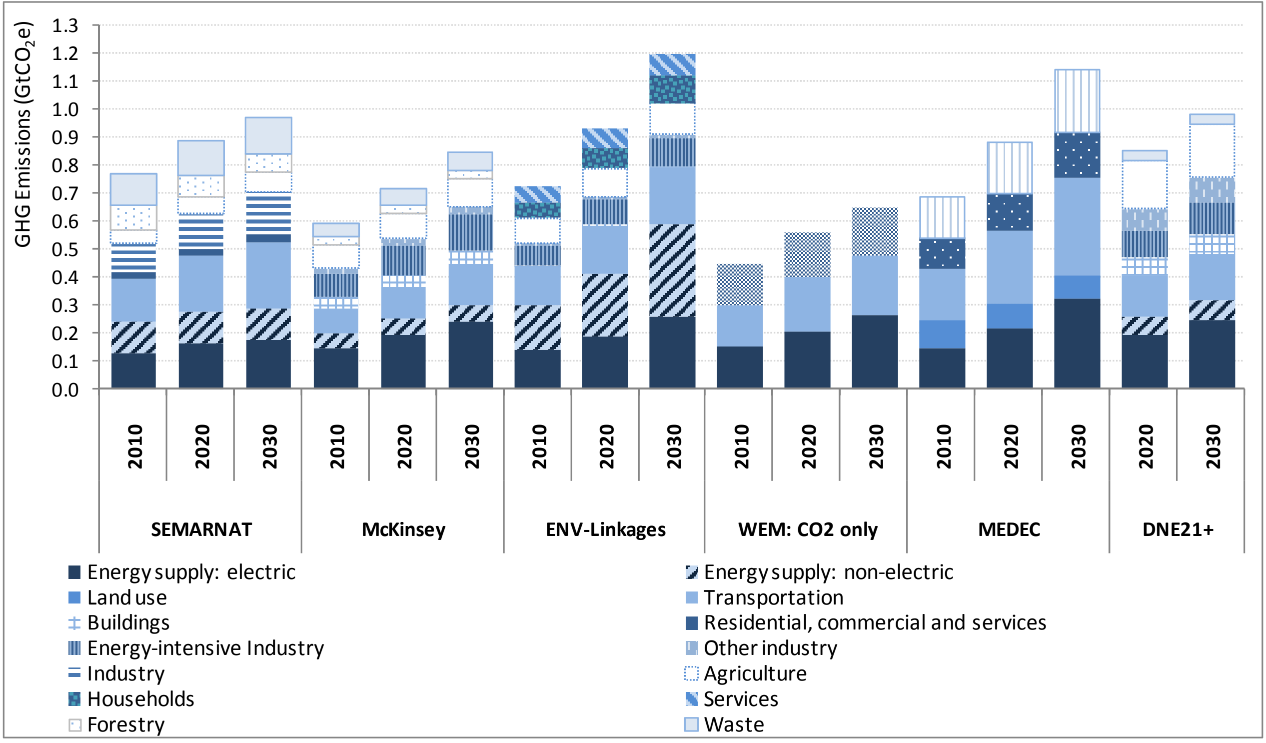


Figure 24: Mexican Mitigation Potential for Electricity Supply Sector

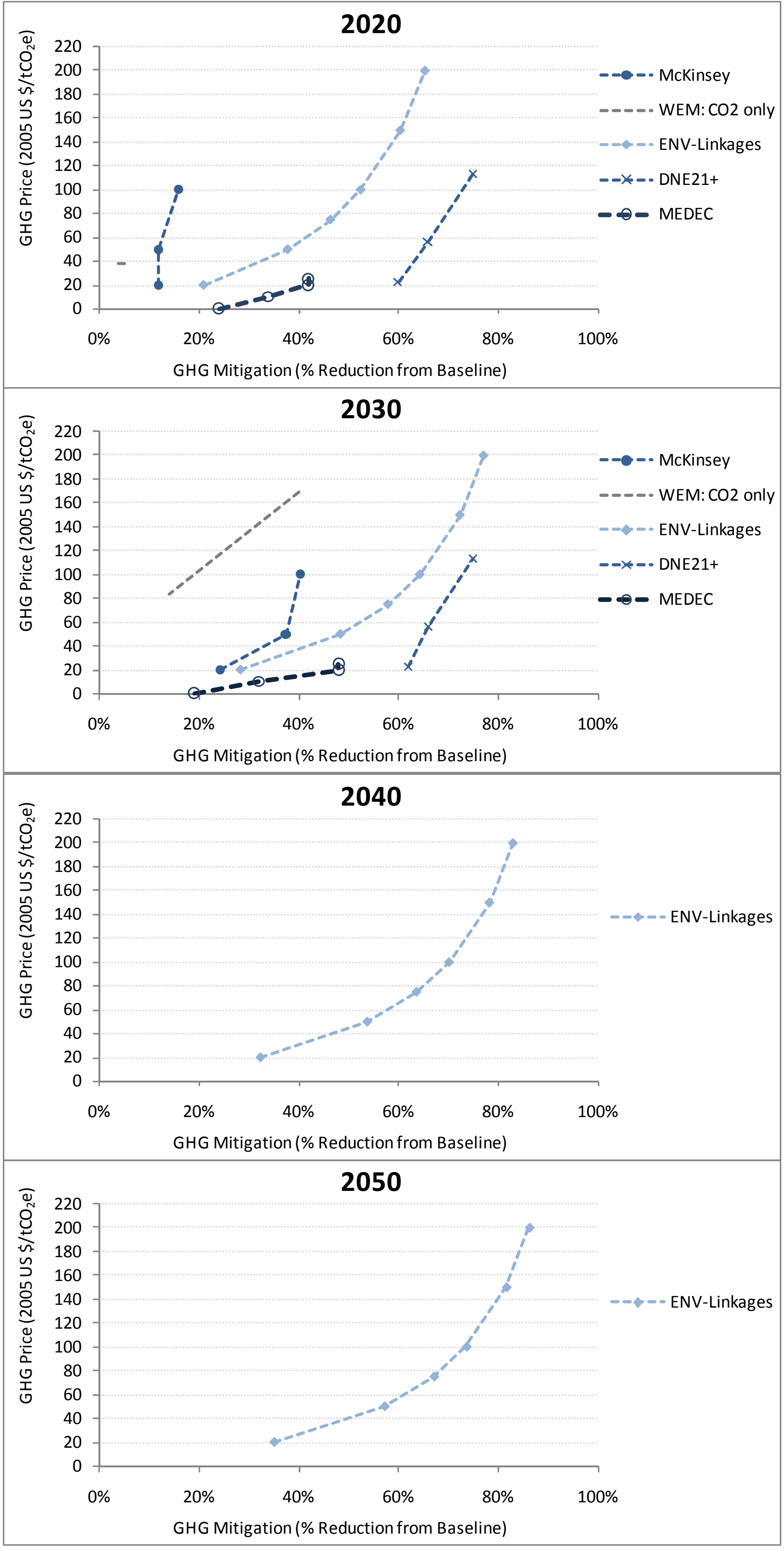
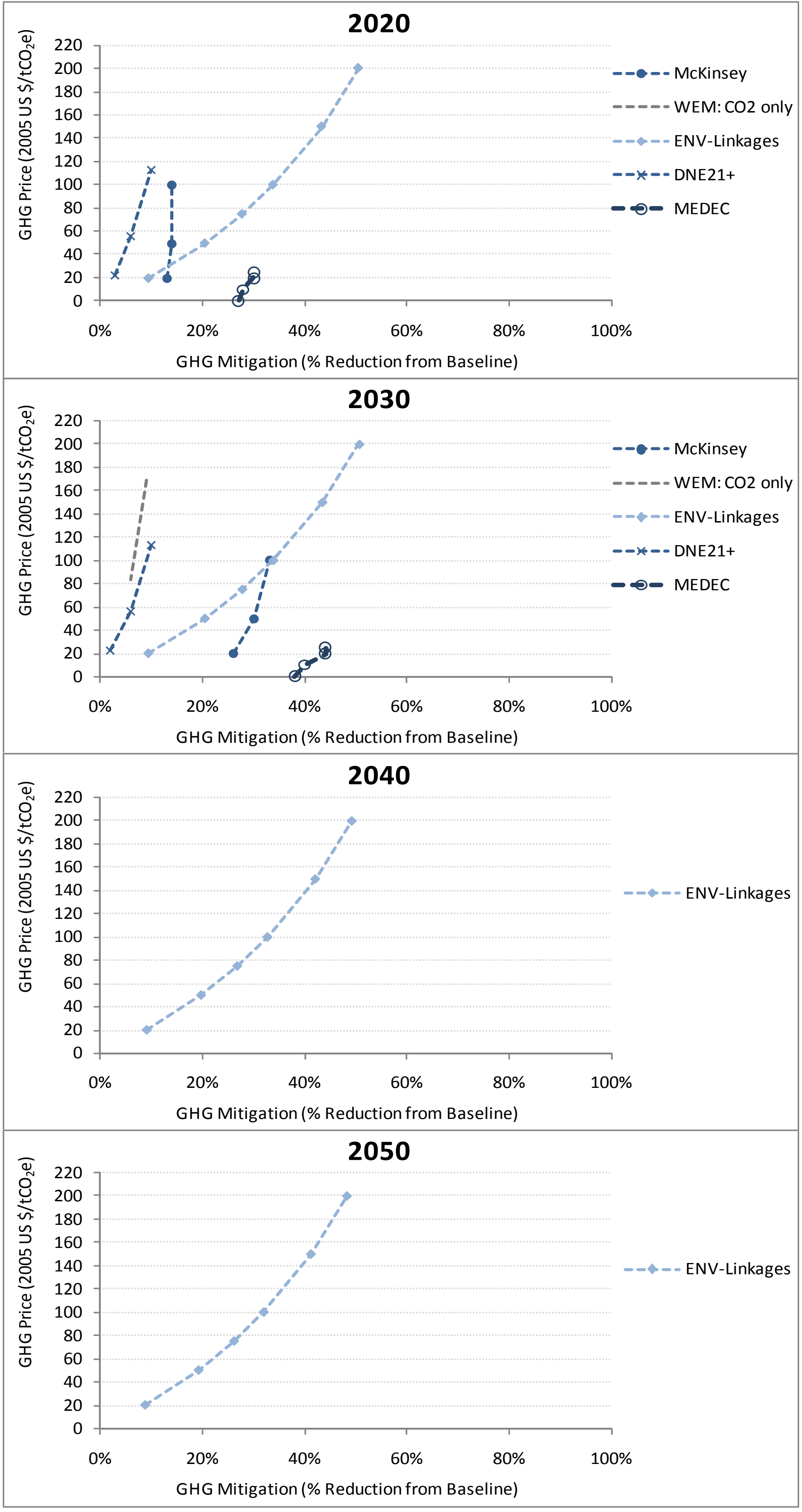


Figure 25: Mexican Mitigation Potential for the Transport Sector



3.6 United States

Key Insights

Several key insights emerge from examining mitigation potential across 13 US and other economic models (4 US models namely ADAGE, SGM, EPPA and MERGE, and 9 other economic models namely POLES, AIM/Enduse, GTEM, DNE21+, GAINS, WITCH, ENV-Linkages, WEM, and McKinsey v2.0):

- Baseline GHG emission projections range from 6.5-9.3 $GtCO_2e$ in 2020 and 7.2-10.4 $GtCO_2e$ in 2030 for all greenhouse gasses (in comparison with 6.6-7.0 $GtCO_2e$ in 2005).

- All models show significant mitigation potential for the US in 2020 for a marginal cost of USD50/tCO_2e, ranging from approximately 15-39% reduction in GHG emissions from the baseline.

- Mitigation potential is greater in later years as more technologies are available, and more time is available to implement mitigation measures. For example, the models show that 28-43% reduction could be achieved in the US at a marginal cost of USD 50/tCO_2e in 2030. However there is less convergence across the models in the later years, reflecting the uncertainty in modelling future projections.

- Mitigation potential in the electricity sector ranges from 15-47% at a price of USD 50/tCO_2e in 2020.The models are in agreement that, over time, between 80 to 93% of the electricity sector emissions in the US could be abated, although they diverge as to the cost of achieving this mitigation, ranging from USD 100-200/tCO_2e in 2050. Far less mitigation potential is seen across the models for the transportation sector, with the models showing mitigation potential of 3 to 17% at USD 50/tCO_2e in 2020, with a maximum of 30% at the same price in 2050.

Model Structure and Underlying Data

There are many different types of models employed by the US government, academic institutions, and other organisations. Several of these models are key instruments whose results are used by climate change policy makers. The US EPA employs several models, including the ADAGE model (developed and run by Research Triangle Institute) which is used for US Congressional analysis, and the SGM model (developed and run by Pacific Northwest National Laboratories) which to date has been more focused on long-term (2050-2100) policy analysis. The EPPA model at Massachusetts Institute of Technology also plays a key role in providing insight for Congressional testimony, as does the MERGE model from Electric Power Research Institute.[27]

This section examines the mitigation potential in these US models alongside models from international organisations and entities that specifically model the US. The US models represented here (ADAGE, SGM, EPPA and MERGE) are all top-down models. However, several bottom-up models also provide key insight to climate policy decision makers in the US that are not included here. For example, the US EPA runs a bottom-up detailed electricity sector model coupled with the top-down ADAGE model for Congressional analysis, as does the US Energy Information Administration. Several models from international organisations and entities also model the US explicitly, including the OECD and IEA models (ENV-Linkages and WEM), IIASA's GAINS model, FEEM's WITCH model and the McKinsey model. In addition, the POLES, AIM/Enduse, DNE21+ and GTEM models include a disaggregated US region. These models represent a range of model structures including top-down (the US models and ENV-Linkages),

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[27] The models that are included in this study certainly do not provide an exhaustive list of all the models used for decision making in US climate policy, but nonetheless provide a range of modelling approaches.

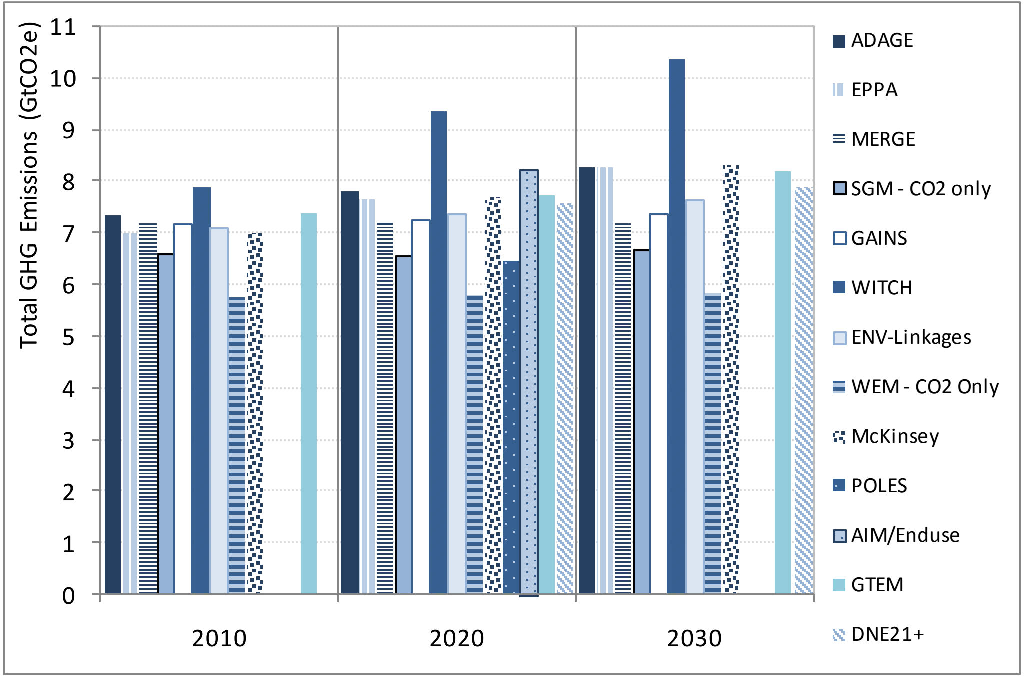
bottom-up (GAINS, WEM, McKinsey, POLES, AIM/Enduse, DNE21+), and hybrid approaches (WITCH, GTEM).

These models rely on several common data sources to guide their historic, base year, and projection calibrations. The GTAP database for economic data, the UN population projections, IEA's energy and emissions data are commonly used for model calibration across the models. However, each model has different structural formats and parameters, resulting in diverse baseline emission projections. Tables 2, 3 and 4 of this paper outline the key features of these models.

Baseline Emissions and Assumptions

Each model projects a different upward trend in GHG emissions for the US (see Figure 26). While the models are generally based upon common data sets for historic and base year calibration, each model reflects a different viewpoint on how baseline economic growth and emissions will evolve over time. For example, the WITCH model shows the highest GHG emissions, as well as the highest growth in GHG emissions, over the horizon 2010-2030, with a growth rate of 32%. On the other hand, the MERGE model has a growth rate of 0% over the same period. The range in absolute baseline emissions for all GHGs across the models (excluding the WEM and SGM results which include CO_2 emissions only) is 0.9 $GtCO_2e$ in 2010, growing to 3.2 $GtCO_2e$ in 2030.

Figure 26: US Baseline Emissions



The differences in baseline emissions projections across the models can largely be explained by examining the underlying assumptions of GDP, population, and energy use. In particular, the growth rates for the US economy vary significantly across the models, reflecting a high rate of uncertainty. For example, the EPPA model assumes an average annual growth rate for US GDP of 2.7% across the period from 2010-2030, whereas SGM assumes an average annual growth rate of 1.5% for the same period (see Table10). It is interesting to note that while the ADAGE, EPPA, MERGE, WEM and POLES models account for the recent economic recession by reflecting lower GDP in the near term, their GDP growth rates looking out to 2030 tend to fall within the range of growth shown in all the models. Population projections are generally in line across the models. However, energy use projections vary widely. The EPPA and GAINS models show an increase in energy use by 17% from 2010-2030, while the MERGE model shows a 6% decrease over the same period, reflecting a greater improvement in energy intensity of the economy (GHG emissions per unit of GDP) in the MERGE model.

Table 10: US Baseline Projections Data

	2005	2010	2020	2030	2050	Percentage Change 2010-2030	Average Annual Growth Rate 2010-2030
				GDP (Indexed, 2010 = 100)			
ADAGE	n/a	100	128	162	249	62%	2.5%
EPPA	n/a	100	132	170	283	70%	2.7%
MERGE	n/a	100	124	152	214	52%	2.1%
SGM	n/a	100	114	134	202	34%	1.5%
GAINS	n/a	100	121	148	n/a	48%	2.0%
WITCH	n/a	100	132	167	244	67%	2.6%
ENV-Linkages	88	100	129	161	245	61%	2.4%
WEM	91	100	125	153	n/a	53%	2.2%
McKinsey	88	100	127	158	n/a	58%	2.3%
POLES	96	100	132	n/a	n/a	n/a	n/a
AIM/Enduse	92	100	123	n/a	n/a	n/a	n/a
GTEM	n/a	100	121	146	217	46%	1.9%
DNE21+	n/a	100	123	152	n/a	52%	2.1%
				Population (Billion People)			
ADAGE	n/a	0.31	0.34	0.36	0.40	18%	0.8%
EPPA	n/a	0.31	0.34	0.37	0.44	20%	0.9%
MERGE	n/a	0.31	0.34	0.36	0.40	16%	0.8%
SGM	n/a	0.31	0.34	0.36	0.42	18%	0.8%
GAINS	n/a	0.31	0.34	0.37	n/a	18%	0.8%
WITCH	n/a	0.31	0.34	0.37	0.40	16%	0.8%
ENV-Linkages	0.30	0.31	0.34	0.37	0.40	16%	0.8%
WEM	0.30	0.32	0.34	0.37	0.40	16%	0.8%
McKinsey	0.30	0.31	0.34	0.36	n/a	16%	0.7%
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AIM/Enduse	0.3	n/a	0.3	n/a	n/a	n/a	n/a
GTEM	n/a	0.31	0.34	0.37	0.40	16%	0.8%
DNE21+	n/a	0.32	0.35	0.37	n/a	16%	0.8%
				Energy Use (EJ)			
ADAGE	n/a	97.9	102.4	107.9	120.3	10%	0.5%
EPPA	n/a	92.4	101.1	108.6	134.3	17%	0.8%
MERGE	n/a	96.6	91.0	90.4	97.3	-6%	-0.3%
SGM	n/a	97.3	98.1	101.0	108.5	4%	0.2%
GAINS	n/a	104.9	114.5	122.7	n/a	17%	0.8%
WITCH	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ENV-Linkages	124.7	124.3	127.2	129.9	134.3	5%	0.2%
WEM	98.3	99.4	103.3	107.8	n/a	8%	0.4%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AIM/Enduse	n/a	n/a	89.6	n/a	n/a	n/a	n/a
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	105.6	111.1	n/a	n/a	n/a

			Energy Intensity (EJ/GDP in Trillion USD 2005)				
ADAGE	n/a	7.0	5.7	4.7	3.4	-32%	-1.9%
EPPA	n/a	7.0	5.8	4.8	3.6	-31%	-1.8%
MERGE	n/a	7.4	5.6	4.5	3.5	-39%	-2.4%
SGM	n/a	7.1	6.3	5.5	3.9	-23%	-1.3%
GAINS	n/a	7.4	6.7	5.8	n/a	-21%	-1.2%
WITCH	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ENV-Linkages	10.1	8.8	7.0	5.7	3.9	-35%	-2.1%
WEM	7.9	7.3	6.0	5.1	n/a	-29%	-1.7%
McKinsey	n/a	n/a	n/a	n/a	n/a	n/a	n/a
POLES	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AIM/Enduse	n/a	n/a	5.4	n/a	n/a	n/a	n/a
GTEM	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DNE21+	n/a	n/a	6.4	5.4	n/a	n/a	n/a
			Total GHG Emissions (GtCO$_2$e)				
ADAGE	n/a	7.3	7.8	8.3	9.1	13%	0.6%
EPPA	n/a	7.0	7.6	8.3	10.9	18%	0.8%
MERGE	n/a	7.2	7.2	7.2	8.2	0%	0.0%
SGM-CO$_2$ only	n/a	6.6	6.6	6.7	7.4	1%	0.1%
GAINS	n/a	7.2	7.3	7.4	n/a	3%	0.1%
WITCH	n/a	7.9	9.3	10.4	11.0	32%	1.4%
ENV-Linkages	7.0	7.1	7.4	7.6	8.1	8%	0.4%
WEM-CO$_2$ only	5.8	5.7	5.8	5.8	n/a	1%	0.1%
McKinsey	6.7	7.0	7.7	8.3	n/a	19%	0.9%
POLES	6.6	n/a	6.5	n/a	n/a	n/a	n/a
AIM/Enduse	7.0	n/a	8.2	n/a	n/a	n/a	n/a
GTEM	n/a	7.4	7.7	8.2	9.4	11%	0.5%
DNE21+	n/a	n/a	7.5	7.9	n/a	n/a	n/a

National Mitigation Potential

Mitigation potential for the US varies not only by model, but also by price and by year, as can be seen in Figure 27. In the year 2020, all models show a significant mitigation potential at USD 50/tCO$_2$e, ranging from 15-39% reduction from baseline, although the mitigation potential across the models is not very well aligned. One of the factors affecting mitigation potential and cost across the different models is the mitigation options available in each model. For example, the GAINS model does not allow for nuclear growth above what is assumed in the baseline scenario, which partially accounts for the lower mitigation potential in 2020.The WEM data shown here includes energy-related CO$_2$ emissions only, which results in a lower mitigation potential than other models that include mitigation options for the full range of GHGs. Mitigation potential also depends on model structure: most of the top-down or hybrid models such as GTEM, EPPA, ADAGE, MERGE, WITCH and ENV-Linkages show higher mitigation potential for a given carbon price than the bottom-up models.

Varying policy assumptions across the scenarios also drive some of the differences across the models. The ADAGE, EPPA, MERGE and SGM model data reflects Energy Modelling Forum (EMF) assumptions on international climate actions, which target a 50% reduction in Annex I countries from 1990 emission levels by 2050, but do not allow for international emissions trading. The SGM model reflects EMF assumptions for the international scenarios, which targets 550 and 650 ppm CO$_2$e for two scenarios: Scenario 1 targets the most cost-effective pathway, and Scenario 2 with delayed participation from non-Annex I countries. In contrast, the WITCH model data reflects constant price scenarios in which international trading of emissions allowances is allowed. The Australian Government GTEM scenarios included here reflect international assumptions regarding accession to a global emission trading scheme. In general, models allowing for international emissions trading tend to show greater mitigation potential for a given carbon price.

In 2030, the mitigation potential at USD 50/tCO_2e across the models is larger than in 2020, ranging from 28-43% reduction from baseline. By 2030, there will have been more time to implement mitigation measures, particularly those that require a longer implementation period or that require turnover of existing capital stock. Higher allowance prices in later years can also drive more deployment of advanced technologies such as CCS and second generation biofuels in a model.

In 2040 and 2050, the marginal abatement cost "curves" become steeper as greater than 50% emission reductions are achieved. Once the least-cost abatement options are implemented, the remaining mitigation options are relatively more expensive. The differences in mitigation potential at a particular price across the models are even greater in these later years, reflecting the increased uncertainty of modelling over distant time horizons.

Sectoral Emissions and Mitigation Potential

Figure 28 shows baseline emissions by sector across the models for the US according to the sectors reported.[28] The ENV-Linkages model is the only model that specifically reports emissions from the service sector and the household sector. The ADAGE, EPPA and MERGE models report CO_2 emissions for electricity and transportation, while the remaining emissions are delineated by gas rather than sector. The McKinsey[29], GAINS and DNE21+ models report emissions for electricity, transportation, industry, buildings, waste, forestry and agriculture. The GTEM model reports emissions from land use. Only CO_2 emissions from energy are reported from the WEM model, and SGM only reports total CO_2 emissions. However it is possible to compare these with CO_2 emissions from energy as reported from the GAINS model, which are approximately 2% lower in 2020.

While a thorough examination has not been undertaken here, it is still possible to gain some general insight about the relative magnitude of the largest emitting sectors. Across the models, the largest source of GHG emissions in the US is from electricity generation. Transportation emissions are the second largest source across the models. However, differences still remain in definitions of the transportation sector. For example, the ADAGE model does not include personal vehicles in the transportation category, but rather in the household category, whereas the McKinsey model does include personal vehicles. It is difficult to draw robust conclusions at this stage across the rest of the sectors (e.g. in buildings, industry or agriculture).

Given the complexity in comparing sectors across models, mitigation potential is only examined here for electric energy supply and transportation for the models that reported consistently across those sectors. Figure 29 shows the range of mitigation potential estimates for the electricity supply sector in the US. In 2020, the models show a wide range of mitigation potential from approximately 15-47% emission reduction at USD 50/tCO_2e.

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[28] The WITCH, POLES and SGM models did not report emissions by sector.

[29] The McKinsey model also reports indirect emissions by sector that are not shown in this figure to avoid double counting of emissions with the energy supply: electric sector.

Figure 27: US Mitigation Potential

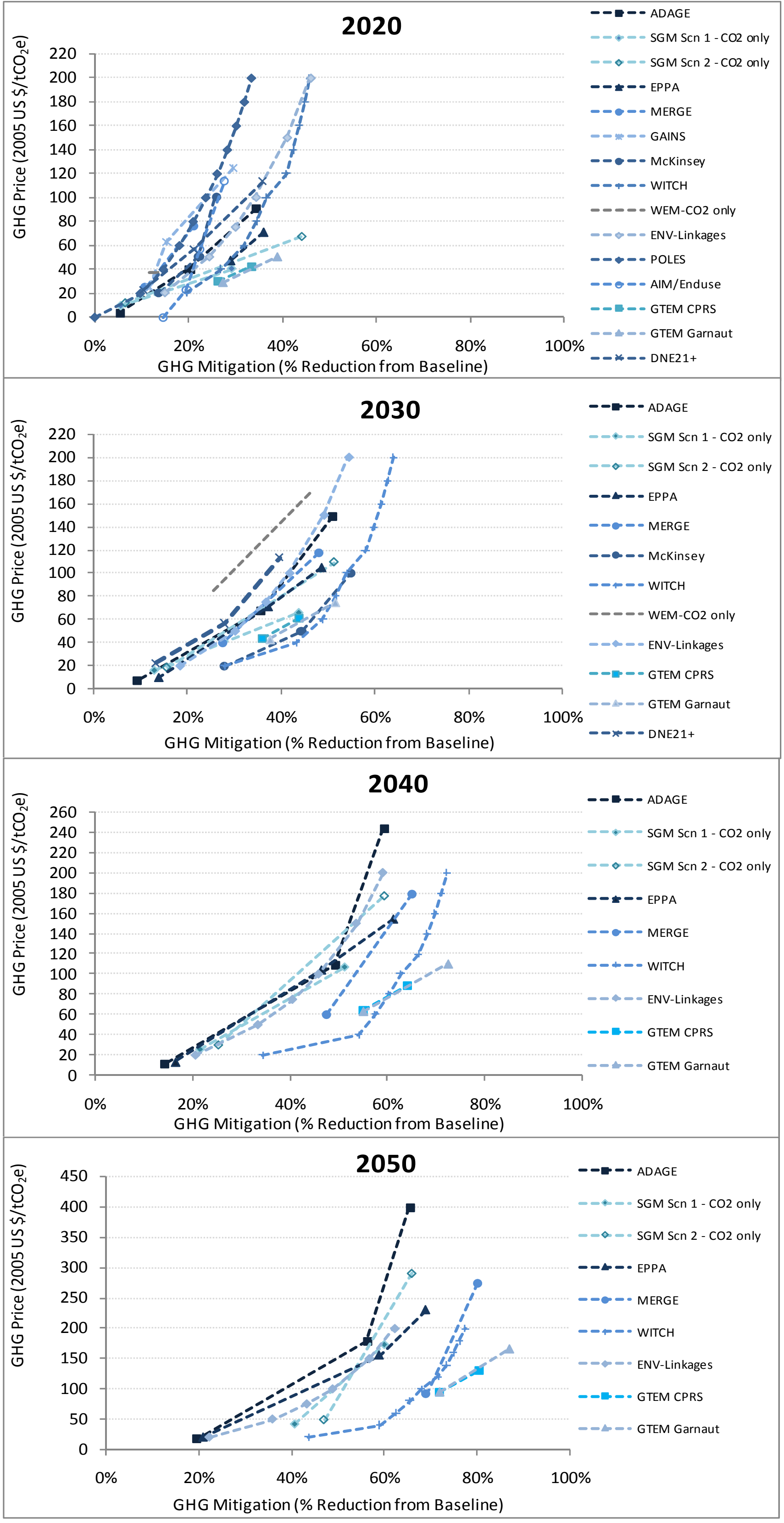
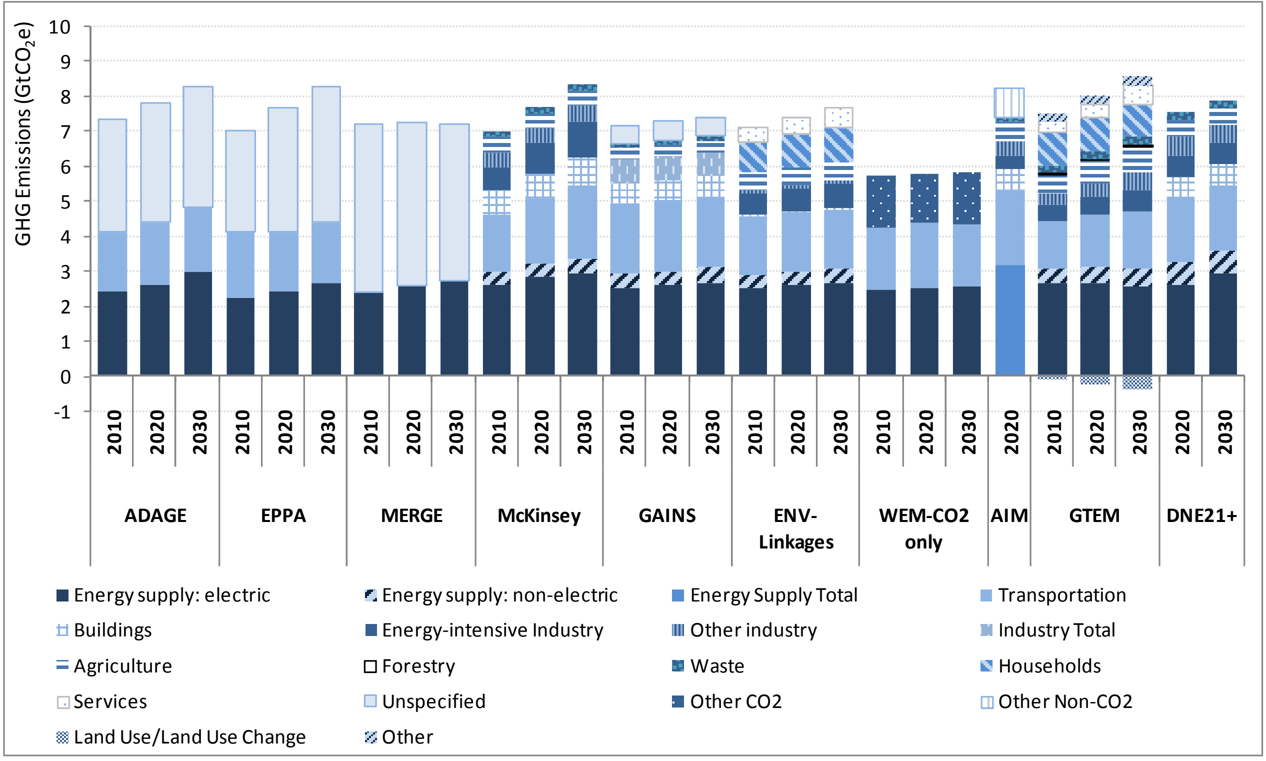


Figure 28: US Sectoral Baseline Emissions



The GAINS and McKinsey models show a lower mitigation potential at this price in part due to their bottom-up model structure. In addition, GAINS does not allow for the expansion of nuclear power generation beyond what is included in the baseline. ENV-Linkages, GTEM, ADAGE and EPPA models show greater mitigation potential, partially due to their top-down and hybrid structures. In the years 2040 and 2050 the flat part of the marginal abatement "curve" shows a wide range of emission reductions from 30-50% at USD 50/tCO_2e. This wide range reflects the uncertainty in the price level at which carbon CCS technology becomes available and economic in each model. At prices between USD 100-200/tCO_2e in 2050, the maximum amount of reduction in the electricity sector of 80-93% appears to be reached in the models.

The models tell a very different story about the mitigation potential in the US transportation sector, as shown in Figure 30. In 2020, the models show a range of mitigation potential from approximately 5-20% reduction for a price of USD 50/tCO_2e. In the years 2030, 2040, and 2050 a much steeper marginal abatement "curve" can be seen. The amount of mitigation potential in the transportation sector is largely influenced by the mitigation options available in the model. For example, the McKinsey model includes significant deployment of hybrid and plug-in electric vehicles and a high penetration of CO_2-efficient biofuels, resulting in a maximum mitigation potential of nearly 40% at USD 20/tCO_2e in 2030[30]. In contrast, DNE21+ shows a 3% reduction at USD 50/t CO_2e in 2030. The top-down models ADAGE, EPPA, SGM, GTEM and ENV-Linkages reported data for 2040 and 2050. The range of mitigation potential grows somewhat over time, with a maximum mitigation potential of 29%at USD 50/tCO_2 in 2050, and a maximum of 64% at USD 200/tCO_2.

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[30] While the emissions reduction potential in the transportation sector is significantly larger in 2030 in the McKinsey model than in other models, the baseline emissions in that year are similar to those shown in other models.

Figure 29: US Mitigation Potential for Electricity Supply Sector

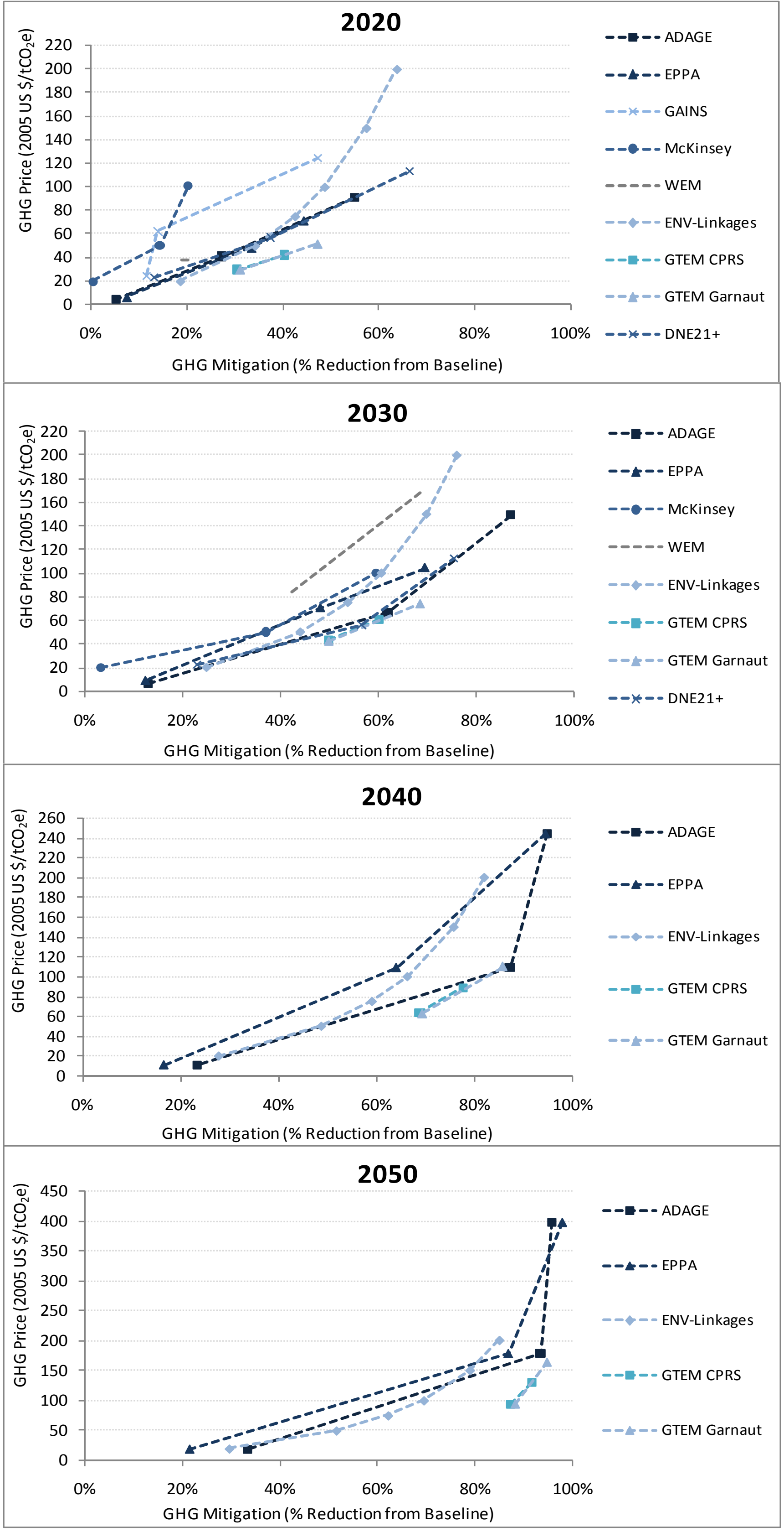
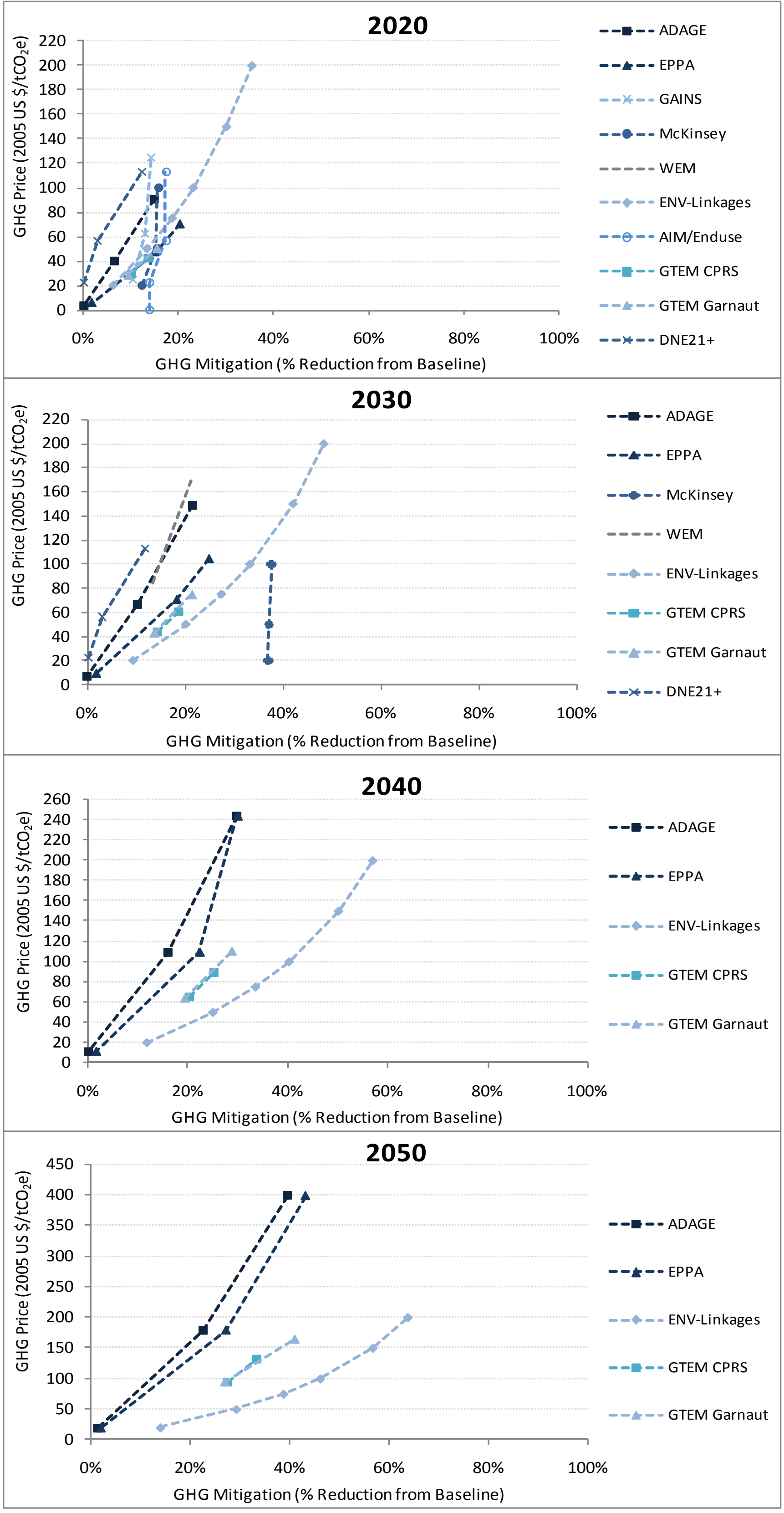


Figure 30: US Mitigation Potential by Transportation Sector



4. Model Comparisons: Understanding Results

4.1 Summary of Results

A total of 19 models have been examined in this paper to compare national and sectoral GHG mitigation potentials across six major economies. The analysis provides some general insights on the order of magnitude of mitigation potential across the different economies and sectors over time. Such modelling comparisons are informative in providing a range of estimates given different model structures and underlying assumptions. It is important to caveat however that models should not be viewed as a "crystal ball" through which the future can be predicted. Models are always an approximation of the real world, and the further out into the future a model projects, the greater the uncertainty in the projections. Also, differences in assumptions for the baseline can lead to substantial differences in projected mitigation potentials. Actual mitigation resulting from the establishment of a carbon price or emission trading schemes will depend on many variables, including the design of the climate policy, interaction with other countries, and the extent to which market barriers exist and are addressed through targeted measures. Bearing this caveat in mind however, the mitigation potential estimates across the models examined in this study provide an indication of the range of national (and sectoral) emission reductions that might be achieved at different carbon prices. By comparing estimates across a large number of models, this analysis provides a more comprehensive picture of GHG mitigation potential than relying on just one model, and can therefore lead to better informed decision-making processes.

Table 11 summarises the range of mitigation potential seen across the models reporting for each economy at USD 50/tCO_2e, in terms of percentage changes in emissions relative to baseline emissions in 2020. The table also compares the resulting emission levels relative to emissions in 1990 and 2005, scaling the emissions according to how well the base year data in the model corresponds to the historic data of the same year.[31] Since not all models reported data at a price of USD 50/tCO_2e in 2005 year dollars, the range of prices over which the mitigation potential was estimated are noted in the table. The number of models reporting in this price range for each economy is also noted.

To facilitate comparison, Figure 31 shows a summary of mitigation potential ranges in 2020 for an approximate price of USD 50/tCO_2e (using data from Table 11) with respect to 2020 baseline emission levels, and a comparison of resulting emissions levels against 2005 and 1990 historic data. For example, the mitigation potential range for Australia at this carbon price is 18-35% reduction from the 2020 baseline emissions, while the resulting emissions at this price correspond to an 18-24% *increase* over 1990 emission levels. Thus the 2020 resulting emissions as compared with historic emission levels are sometimes higher. This can be seen clearly in the case of Mexico, where emissions grew by 48% from 1990 to 2005, reflecting the highest growth rate across the six economies over this time period, resulting in a greater difference in the mitigation potential range as compared with the emissions in these two historic years. On the other hand, the EU emissions decreased from 1990 to 2005, reflecting a different trend than the other economies.

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[31] Base year data from the same historic year was not available from all models. The following base years were used to scale the emissions: year 2000 data for EPPA, SGM, MERGE, GAINS, WEM, and E3MC; year 2001 data for GTEM and GEM-E3; and year 2005 data for MMRF, POLES, AIM/Enduse, ENV-Linkages, McKinsey, and EC_IDYGE. No base year data was available from G-Cubed, DNE21+, LEAP (MEDEC), ADAGE, or WITCH, thus a ratio of historic emissions to base year emissions of 100% was assumed. Across the models, the ratio of the models' base year emissions to the historic emissions from that year ranged from 82% to 132% of historic emissions.

Across the models, mitigation potential in Japan is estimated to be relatively lower than for the other economies, ranging from 5-20% emission reduction from baseline in 2020 at a price of USD 50/tCO_2e. Although noticeably fewer models report data for Mexico, the models show deeper potential reductions, in the range of 25-37%, at the same carbon price. Mitigation potential estimates for Australia show a wider range of 18-35% reduction, as do Canada and the US, with similar ranges of 14-32% and 15-39% reductions. The EU shows a relatively tighter range of 16-29% emission reductions relative to 2020 baseline emissions. There is also wider variation in mitigation estimates with respect to the 2020 baseline in certain economies than in others: estimates for the US vary by 24 percentage points, as compared with estimates for Mexico which vary by 12 percentage points.[32]

Across the economies, there is considerable overlap of the mitigation potential ranges, especially when compared with the 2020 baseline. The majority of models do not report disaggregated data for all six economies. For models that reported data for multiple economies, there was not agreement as to the rank order of mitigation potential across the economies at USD 50/tCO_2e in 2020, thus the findings with respect to ranking are model dependent.

Mitigation potential estimates for an economy can be viewed as more robust if there is consistency in results across a large number of models. While many models report data for Canada, the EU, Japan and the US, fewer models report data for Australia and Mexico. As the only non-Annex I country of focus in this study, Mexico had the least number of models reporting data. However, the spread of the range of mitigation potential does not correspond well to the number of models reporting data at this USD 50/tCO_2e price level (i.e. more models reporting data does not necessarily equate to a larger range in mitigation potential).

As expected, over time the mitigation potential across the models increases. The results of this study show greater emission reductions in the year 2050 than in the year 2020 across the six economies examined. This trend reflects structural and technical changes that occur over time, including typically the availability of carbon capture and storage technology in 2030 and beyond. In general, this study finds closer agreement across the models for mitigation potential in 2020 than for later years, reflecting greater uncertainty about structural and technical changes as projections extend into the future.

This study shows that there is agreement across the models for all six economies that greater mitigation potential exists in the electricity supply sector than in the transportation sector, despite the inconsistent sector definitions across the models. This reflects the current availability of more mitigation options for electricity generation at a given carbon price, than for adopting lower-carbon modes of transportation. The actual mitigation potential in the transport sector could be larger than is identified by these models, if policies and measures were adopted that target behavioural changes by consumers or modal shifts towards increased public transport.

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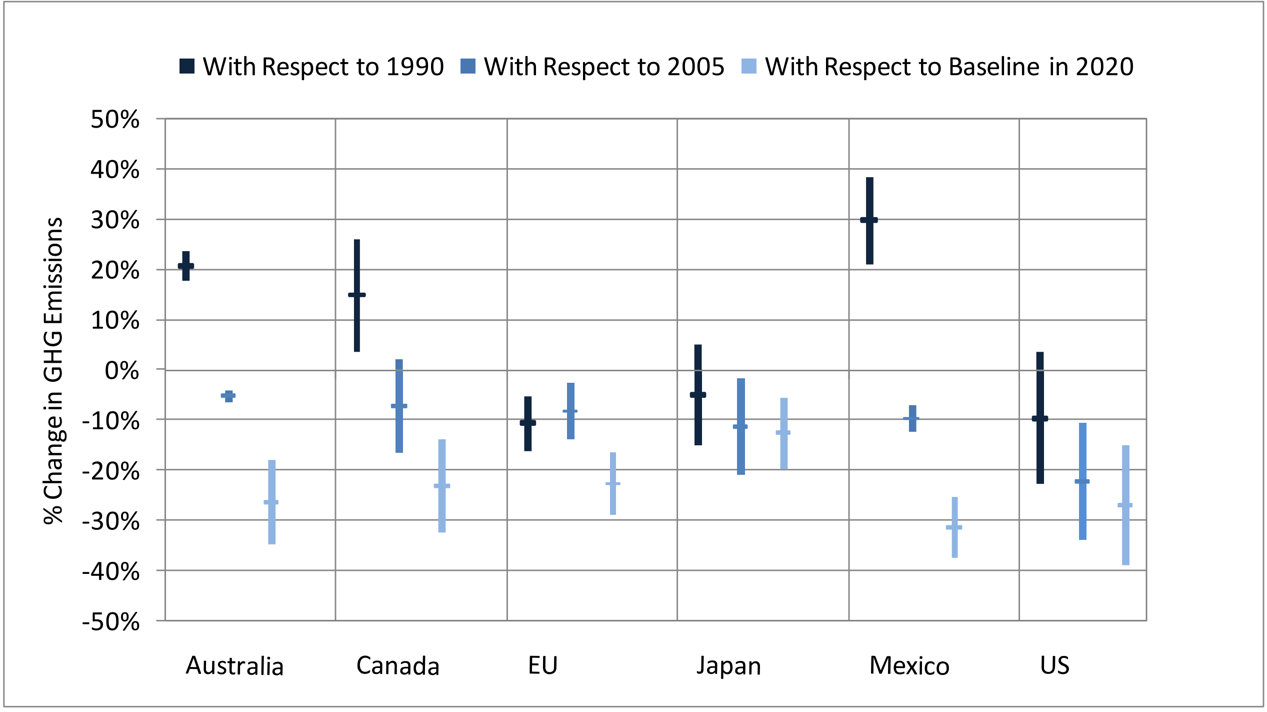
[32] The variance in the range of mitigation potential changes with respect to 1990 and 2005 emissions more widely than in some economies than in others, as can be seen in the results for Mexico and Australia. This is due to the variance in 2020 baseline and mitigation potential projections from different models depicting the low end and the high end of the mitigation potential range in 2020, which when compared against a single historic data point in percentage terms changes the width of the range. If the resulting 2020 emissions from the models are close in absolute value to the historic emissions, then the percentage change is smaller, narrowing the width of this range.

Table 11: Summary of Mitigation Potential Estimates at USD 50/tCO$_2$e in 2020

At Approximately USD 50/t CO$_2$e					
Country/ Region	Number of Models Compared	Price Range (2005 USD/tCO$_2$e)	Mitigation Potential Relative to 2020 Baseline Emissions	Ratio of Emissions at USD 50/tCO$_2$e in 2020 Relative to 2005 Historic Emissions	Ratio of Emissions at USD 50/tCO$_2$e in 2020 Relative to 1990 Historic Emissions
Australia	5	$46 - 63	-18% to -35%	-6% to -4%	18% to 24%
Canada	8	$50 - 51	-14% to -32%	2% to -16%	26% to 4%
EU	11	$51 - 55	-16% to -29%	-3% to -14%	-5% to -16%
Japan	7	$50 - 57	-5% to -20%	-2% to -21%	5% to -15%
Mexico	3	$50	-25% to -37%	-12% to -7%	21% to 39%
US	12	$51 - 62	-15% to -39%	-11% to -34%	4% to -23%

Note: Many models did not report results at exact prices of USD 50/tCO$_2$e; thus price ranges are indicated. Annex I 1990 and 2005 emissions are from 2009 Inventory Submissions to UNFCCC: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php. Mexico 1990 emissions are from 3rd National Communication to UNFCCC: http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php. Mexico 2005 emissions are from CAIT 6.0: www.cait.org. All historic emissions are excluding LULUCF.

Figure 31: Summary of Mitigation Potential Estimates at USD 50/tCO2e in 2020



Note: Ranges and median values are shown in the Figure.

4.2 Key Drivers of Results

The broad ranges of model results indicate that there are a multitude of different assumptions and approaches used in models which can drive the differences in the estimates of mitigation potential. Sections 3.1 to 3.6 of this paper describe some of the drivers of mitigation potential ranges for each of the six economies. In general, the key drivers of the differences in model results include those related to model structure, baseline assumptions and policy scenarios:

- **Model structure**, including the type of model as well as coverage in terms of both sectors and gases, can drive mitigation potential differences across models.
  - **Top-down, bottom-up, and hybrid models:** In general, top-down models tend to reflect greater mitigation potential at specific carbon prices than bottom-up models, due to the capital movement between a wide range of economic sectors that allows for a more flexible response to carbon prices (see Text Box 1).
  - **Model methodology**, such as whether the model is forward-looking or recursive-dynamic, will also impact mitigation potential estimates. For example, forward-looking models, such as DNE21+, EPPA, ADAGE, and WITCH examined here, tend to show greater mitigation in earlier years, recognising the carbon price signal in later years.
  - **Time horizon and rate of time preference** varies across models. For example, models such as WEM, McKinsey and GAINS project out to 2030, whereas the WITCH, MERGE, SGM and EPPA models project out to 2100. A longer time horizon gives a longer planning horizon with a clear carbon price signal, allowing for more capital turnover and technological progress.
  - **Geographic scope:** In general, models that are geographically limited in scope, e.g. E3MC and MMRF which are national models, do not capture all of the international trade effects of a carbon price scenario, but are better suited to capture detailed existing capital. This can result in lower mitigation potential from national models, although it depends largely on the magnitude of the trade effects.
  - **Negative cost measures** (i.e. mitigation options that are cost-effective below USD 0/tCO_2e such as some non-CO_2 and energy efficiency options) are typically not included in top-down models. *Ceteris paribus*, models that include negative cost measures, which tend to be bottom-up in nature (e.g., AIM/Enduse, DNE21+, GAINS, WEM and McKinsey), will project higher mitigation potential, particularly at lower carbon prices. This can be seen in the AIM model results for Japan, which show mitigation potential of 9% at USD 0/tCO_2e.
  - **Model coverage** is also clearly an important factor in driving mitigation potential results across models. The more comprehensive the coverage is (in terms of sectors and gases), the higher the mitigation potential results are likely to be. WEM for example, which covers only energy-related CO_2 emissions, tends to report consistently lower mitigation potential estimates than other models. Comprehensive sectoral coverage is likely to be more important for certain economies than for others. For example, MMRF and GTEM include LULUCF emissions for Australia, which is one of the drivers of mitigation potential.
  - **Sectoral definitions** vary across models, making it difficult to accurately compare sectoral emissions and mitigation potential. For example, many of the models analysed here attribute emissions from personal vehicles to the transport sector. Other models however, such as SGM, ADAGE and ENV-Linkages attribute personal vehicles to the household sector.
  - **Availability of mitigation options** also drives differences in mitigation potential. For example, the GAINS model does not include nuclear power generation beyond what is included in the baseline as a mitigation option. On the other hand, carbon capture and storage, hybrid vehicles and low-carbon biofuel technologies tend to be deployed fairly aggressively in the McKinsey model in 2030, resulting in higher mitigation potential for that time period as can be seen in the US example. The treatment of non-CO_2 GHGs also varies across models, which can impact the extent to which these lower-cost (and negative-cost) mitigation options are deployed.

- **Baseline assumptions**, including economic growth rates, technological innovation assumptions, and policy impacts included, will also drive the amount of mitigation potential available at a given price. This study has compared mitigation potential relative to baseline emissions to control for the influence that baseline assumptions have on the mitigation potential results.

  - **Underlying data sets** are fairly consistent across models, especially for population and base year economic data assumptions. However, there is no one global GHG emissions database that is used consistently. In some cases, even historic base year data is not always consistent. For example, historical GHG data in Mexico for 2005 across the models varies by 24%.
  - **Economic growth** estimates for a particular economy range across the models. Lower GDP growth in the baseline can result in lower emissions but also in lower absolute mitigation potential. In addition, the fact that not all of the models have yet incorporated the impact of the current economic recession in their baselines will also drive differences across results. Many of the models that incorporate the impacts of the current recession show economic growth rates that are on par with those in models that do not include the impacts, so it is difficult to isolate the impact of these assumptions.
  - **Energy use and prices** assumed in the baseline can also drive the mitigation options deployed at a particular carbon price. Energy use and energy intensity rates varied widely across the models. Due to data constraints, energy prices were not examined specifically in this study.
  - **Technological innovation** assumptions drive how fast efficiency and cost improvements develop, impacting the timing and rate of deployment in each model for technologies that could have a significant impact on an economy's mitigation potential such as carbon capture and storage and second generation biofuels. For example, ENV-Linkages has optimistic assumptions regarding technological progress particularly in the transportation sector, showing higher mitigation potential.
  - **Existing policy impacts** included in the baseline vary by model. For example, the EU ETS is frequently included in model baselines (e.g. in GEM-E3 and POLES), lowering the amount of abatement additional to the baseline that is possible at a given cost.

- **Policy scenarios**, such as constant versus rising carbon prices over time, unilateral versus multilateral application of carbon prices, and assumptions on international action, will impact mitigation potential estimates across models (see Text Box 2).
  - **International action assumptions:** Policy scenarios where a larger group of countries is taking mitigation action could dampen world energy prices, which may increase emissions globally.
  - **Widespread international emissions trading**, or allowing international offsets to meet an emissions target, can lower the market carbon price for participating countries.
  - **Carbon price application:** Policy scenarios that include a carbon price that is rising over time tend to result in greater mitigation potential in earlier years, when it is relatively cheaper to abate (particularly in forward-looking models), then in fixed carbon price scenarios.

Given this large number of variables, it is difficult to isolate which of these are the most important drivers of GHG mitigation potential across each of the different models. However, by providing information on data and assumptions in a consistent and transparent manner, this paper provides important insights on what these drivers may be. In particular, this paper shows that model type, baseline assumptions, and the mitigation technologies available in each model to be important, among other assumptions.

It is clear that given the different possible assumptions and parameters of each model, policy-makers would benefit from looking across a range of model results to help guide and inform the decision-making process. Further, it is important for policy-makers to consult projections from different models to avoid the potentially distortive effects of relying on one model's assumptions about the future.

4.3 Further Work

Comparisons across model results are not only important to help better inform climate change policy-makers on comparability of effort, but can have other useful applications as well. Model comparisons and robust results can help policy-makers identify which are the largest emitting sectors, where emissions are projected to grow most rapidly, and where there is greatest mitigation potential for a given carbon price. This could be especially important for emerging economies and for other developing countries in the context of designing policies, including the use of new mechanisms such as sectoral approaches, NAMAs, or guiding and prioritising support (whether finance, capacity building or technology), in areas where there is the largest GHG mitigation potential. Given the multiple applications of models, further investments and efforts in this area are likely to be warranted to improve the strength of the results.

In order to enhance the robustness of results, and to facilitate the comparison of results across economies, the results of this study highlight possible areas for further work and improvement. These include, *inter alia*:

- the use of the most recent database inputs, to take into account latest trends;
- the harmonisation of baseline assumptions, to reduce a major source of variation across models;
- the harmonisation of sectoral definitions, to encourage more consistent sectoral disaggregation across similar model types, being aware that sectoral “mapping” between top-down and bottom-up models will never be perfect;
- the inclusion of all GHGs and sectors in models, including LULUCF, to improve the understanding of the role of different sectors and gases; and
- the simulation of identical policy scenarios in the models to enhance the comparisons.

These improvements could be achieved in a number of ways. Two promising ideas are:

- an examination and revision of current National Communications reporting requirements for emission projections, including guidelines for baseline assumptions and data sources; and
- a more concerted effort to bring modellers together, and to share data, information, and modelling approaches amongst modellers across countries, including both industrialised and emerging as well as developing economies.

Future efforts could thus focus on how to implement these improvements to facilitate comparisons of model results. In order to provide a broader context of mitigation potential in the economies examined here, these efforts could also incorporate analysis of and interaction with additional OECD countries, and possibly non-OECD countries.

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