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THE COSTS OF ACHIEVING A GLOBAL CLIMATE CHANGE MITIGATION TARGET: AN INTEGRATED ASSESSMENT MODEL INTER-COMPARISON

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Abstract

We use the New Zealand Integrated Assessment Modelling System (NZIAMS) that includes a global dynamic CGE model, a global timber model, and a simple climate model to assess the potential economic and climate change impacts of meeting a range of long-run GHG emissions reduction targets. The model is configured to 6 regions and 18 aggregated sectors (including several energy sources and land activities), and includes several sources of GHG emissions abatement, including forest carbon sequestration and electricity generation with carbon capture and sequestration (CCS). In this paper, we assess the impacts of meeting a Kyoto GHG emissions concentration of 500 and 450 parts per million (ppm) in 2100, with and without GHG prices imposed on the agricultural sector.

We estimate that global net emissions in 2100 would need to be reduced by 85 to 90% relative to the baseline case to achieve 500 ppm and by 98-103% to meet the 450 ppm target. GHG emissions price estimates range from \$44 to 76/tCO2e in 2030 and from \$503 to \$1,816/tCO2e in 2070. Major sources of abatement include the switching most of the world's electricity generation to either renewable energy or CCS and planting several 100s of million hectares of trees. All policy scenarios were estimated to reduce global GDP relative to the baseline, particularly in the second half of the century. For the scenarios that price GHG emissions from all sectors, GDP is reduced by 1.6 to 2.0% in 2030 while GDP in 2070 could be reduced by 7 to 9%. For the scenarios that excluded agriculture from GHG pricing, global GDP impacts decrease by 1.7 to 2.2% in 2030 and by 13 to 18% in 2070. This suggests that excluding agriculture could have a dramatic increase on global economic impacts as the increase in GHG price on all emissions from all other sectors to meet the 2100 GHG concentration target dominate the potential increases in economic output that could be achieved from not pricing agriculture.

Keywords: Climate policy; Agriculture; Forestry; Emissions; General equilibrium

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1 Introduction

For more than a decade the target of keeping global warming below 2°C has received much attention due to the economic implications of achieving it. This target is embedded in the objective of the United Nations Framework Convention on Climate Change (UNFCCC) to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (United Nations, 1992). To reach the target, GHG concentrations have to be limited to a 450 ppm or 500 ppm CO2 equivalent (Edenhofer et al., 2010; Kriegler et al., 2014), which has spurred the scientific debate around the economic feasibility of reaching it (Clarke et al., 2009; O'Neill, Riahi, & Keppo, 2010; UNEP, 2011).

Research on achieving a global climate change mitigation target relies on integrated assessment models (IAM) linking energy-economy-land use-climate models (Kriegler et al., 2014; Weyant et al., 1996). There is an important body of literature on comparing models and the pathways of the economic variables in response to policy scenarios. IAM comparison analysis can help identify pathways to a low carbon economy and shed light on the associated cost estimates and technology options (Edenhofer et al., 2010). However, assumptions and model construction behind each IAM condition the policy prescriptions to reach the 2°C target. Thus, Rogelj, McCollum, Reisinger, Meinshausen, & Riahi (2013) find that a carbon price of about US$20 tCO2e would increase the probability of staying below 2°C to about 50%, and carbon prices of more than US$40 tCO2e would achieve the 2°C objective with a probability of more than 66%. Clarke et al. (2009), in a study using several global IAM, mention that achieving the 450 ppm CO2e target is difficult as only 8 of the fourteen models that attempted the scenario were able to complete it. Similarly, in IPCC (2007) only three models containing 6 out of a total of 177 mitigation scenarios provide results for the lowest IPCC category of a radiative forcing of 2.5 – 3.0 W/m², corresponding to a 445-490ppm CO2e level. O'Neill et al. (2010) use mid-century targets as a guide to climate change policy that can link long-term goals to shorter-term actions. They find that to preserve the technical feasibility of a 50% likelihood of keeping global average temperature at <2°C above preindustrial in 2100, global emissions must be reduced by about 20% below 2000 levels by 2050. Kriegler et al. (2014) provide a model-based assessment of possible outcomes of the Durban Platform negotiations with a focus on emissions reduction requirements, the consistency with the 2°C target and global economic impacts. They assume the implementation of global emission reductions after 2020, but with different levels and long-term concentration targets. Thus, the models outcomes exhibit a probability of exceeding the 2°C limit of 20-40% when reaching 450 (450-480) ppm CO2e, and 35-55% when reaching 500 (480-520) ppm CO2e in 2100.

However, model outcomes are at a highly aggregated level where no role is identified for critical sectors such as agriculture. One way to determine the extent GHG agricultural emissions on global results is to estimate the economic costs when agriculture is also imposed a GHG price within a global reduction target. Hence, this study gives a synthesis of a model comparison assessing the costs of achieving a global climate change mitigation target with a particular focus on agriculture. The target consists on achieving GHG concentration targets that are sufficiently low to keep the increasing global mean temperature below 2°C above pre-industrial levels.

We use the New Zealand Integrated Assessment Model System (NZIAMS) which integrate CliMAT-DGE (a global dynamic computable general equilibrium model), the Global Timber

Model (GTM) and MAGICC. We run four scenarios and evaluate how NZIAMS estimates compare to a range of results from other IAMs used for the IPCC 5th Assessment Report (AR5) and also presented in Kriegler et al. (2014). Two scenarios, 500 and 500 NoAg, estimate the impacts of achieving a Kyoto GHG emissions concentration of 480-530 parts per million (ppm) in 2100, with and without GHG prices imposed on the agricultural sector. The other two scenarios, 450 and 450 NoAg, estimate the impacts of meeting a 2100 concentration of 430-480 ppm under the same pricing assumptions. Carbon sequestration from forestry and carbon capture and storage were both acceptable forms of GHG emissions reductions for all policy scenarios.

This set of scenarios impose a global GHG emissions 'cap' that follows a trajectory similar to the projected emissions from the seven IAMs used in Kriegler et al. (2013)[1], to achieve the target of a 2102 GHG concentration of 450 or 500 ppm. As the policy was imposed globally, all regions and sectors faced the same GHG price to help achieve this target, unless specified otherwise.

2 Methodology

We use the New Zealand Integrated Assessment Modelling System (NZIAMS). NZIAMS integrates the CliMAT-DGE economic model, the Global Timber Model (GTM) and MAGICC. CliMAT-DGE is a multi-regional and multi-sectoral dynamic general equilibrium model that covers all regions of the globe. This type of model is suited to studying the efficient (re)allocation of resources within the economy and over time in response to resource or productivity shocks or policies. Impacts to the forestry sector are modelled using the Global Timber Model (GTM). For some scenarios, anthropogenic emissions are linked to the climate model, MAGICC to estimate the changes in global GHG concentrations, temperature, and radiative forcing. Details of the models are described below.

We develop a baseline scenario which is defined as no international or domestic actions are taken regarding GHG mitigation. We then produce a number of policy simulations to assess the impacts from emissions abatement through 2100). Four scenarios were conducted to evaluate how the NZIAMS estimates, of meeting global climate targets in 2102, compare to results from other IAMs used for the IPCC 5th Assessment Report (AR5) and also presented in Kriegler et al. (2013). Scenarios 500 and 500 NoAg estimated the impacts of achieving a Kyoto GHG emissions concentration of 480-530 parts per million (ppm) in 2100, with and without GHG prices imposed on the agricultural sector. Scenarios 450 and 450 NoAg estimated the impacts of meeting a 2100 concentration of 430-480 ppm under the same pricing assumptions. Carbon sequestration from forestry and carbon capture and storage (as backstop technology) were both acceptable forms of GHG emissions reductions for all policy scenarios. This set of scenarios imposed a global GHG emissions 'cap' that followed a trajectory similar to the projected emissions from the seven IAMs used in Kriegler et al. (2014), to achieve the target of a 2102 GHG concentration of 450 or 500 ppm. As the policy was imposed globally, all regions and sectors faced the same GHG price to help achieve this target, unless specified otherwise.

[1] These models include AIM-Enduse 1.0, GCAM 3.1, IMAGE 2.4, MESSAGE V.4, REMIND 1.5, TIAM-ECN, and WITCH-LIMITS

2.1 CliMAT-DGE

CliMAT–DGE is a multiregional, multi-sectoral, forward-looking dynamic general equilibrium model with a relatively long time horizon of 100 years or more (Fernandez and Daigneault 2015). The model primarily uses the Global Trade Analysis Project (GTAP) version 8 dataset that accounts for 129 regions of the globe and 57 economic sectors[2]. The base year of the benchmark projection is 2007 (the latest year included in GTAP) which is a snapshot of the global and regional economies. The model then develops a benchmark projection of the economic variables and GHG emissions (from human activities), and simulates scenarios to evaluate the impacts of mitigation policies. Based on long-run conditions and constraints on physical resources, which restrict the opportunity set of agents, the model predicts the behaviour of the economy, energy use, and emissions by region and sector (Fæhn, Isaksen, Jacobsen, & Strøm, 2013). CliMAT-DGE is coded using the Mathematical Programming System for General Equilibrium (MPSGE) package in GAMS (Rutherford, 1999)

The model requires information and data on projected changes in regional population, GDP, technology, and consumption growth. For this purpose, the model incorporates realistic projections of key macroeconomic (e.g. labour productivity) and other (e.g. energy efficiency) variables. The economic baseline is constructed from a growth scenario developed by the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (Fouré et al. 2010). Energy supply and efficiency projections are based primarily on several 2009 through 2012 editions of the World Energy Outlook (International Energy Agency 2013).

The sectors covered in this study are listed in

Table 1. Coal, oil, gas, petroleum refining, renewable electricity and fossil electricity sectors are defined as separate sectors. Renewable and fossil electricity generation sectors are disaggregated from the single electricity GTAP sector. For this we allocate fossil fuel inputs to the fossil electricity sector, where the shares are estimated so that they equalize the market shares from IEA generation data (Lennox et al. 2013).

Table 1: CliMAT-DGE Aggregated GTAP Production Sectors

Primary Production Sectors	Secondary Energy Sectors
Grains including rice	Coal
Other crops	Oil
Oil seeds and sugar cane	Gas
Plant based fibres	Petroleum, coal products
Bovine cattle, sheep and goats, horses	Fossil electricity
Raw milk	Carbon-free electricity
Forestry	
Manufacturing and Value-Added Sectors	
Food products	
Harvested wood products	
Energy-intensive manufacturing and	
Non-energy-intensive manufacturing	

[2]For further details, see: https://www.gtap.agecon.purdue.edu/databases/v8/

Transport

All production sectors are modelled using nested Constant Elasticity of Substitution (CES) production functions. The nested-CES functions capture the potential substitution between production technologies. In order to link the production or consumption of a commodity with GHG emissions, the MPSGE code of the nesting structures includes the interaction between GHGs and sector commodities. CliMAT-DGE partly follows the nesting structure of Paltsev et al. (2005). For details of the nesting structure of production sectors, see Fernandez and Daigneault (2015).

Dynamics follow a forward-looking behaviour where decisions made today about production, consumption and investment are based on future expectations. The economic actors have perfect foresight and know exactly what will happen in all future periods of the model's time horizon. Thus, households are able to smooth their consumption over time so that the savings rate varies endogenously. It is assumed that consumers maximise their utility while producers maximise their profits while retaining full knowledge of all present and future prices. As expectations about the future affect current behaviour of agents, the forward-looking approach adds flexibility to adjust savings and consumption over time to partially mitigate the negative impacts of an environmental policy in the short run. Therefore, the model is capable to address policy issues such as banking and borrowing of GHG allowances, international capital flows, and optimal emissions abatement path (Babiker, Gurgel, Paltsev, & Reilly, 2008; Dellink, 2005).

There is no representation of technology vintages in CliMAT-DGE. Though a putty-clay formulation has a lot of merit, it is computationally intensive in the context of a large, forward-looking model. Whereas a vintage specification emphasises technology inflexibility *within* a sector, the purpose of the sector-specific capital formulation in CliMAT-DGE is to emphasise the irreversibility of the allocation of new capital *between* sectors. Thus, sector-specific capital in CliMAT-DGE precludes disinvestment in a sector beyond natural attrition due to depreciation. This assumption is plausible for energy technologies which are most affected by carbon pricing. For example, there are few other uses for much of the equipment used in coal-fired electricity generation. Hence, it is usual to assume that 100% of investment is irreversible

GHG emissions are expressed in carbon dioxide equivalents (CO_2e) based on their 100 year global warming potential (GWP). The GTAP 8.1 database initially listed the non-CO_2 GHGs – methane (CH4), nitrous oxide (N2O) and fluorinated gases (FGAS) – based on GWPs from the IPCC third assessment report (Ipcc, 2001). But in CliMAT-DGE the GWPs come from the fourth assessment report (Pachauri & Reisinger, 2007)[3]. Regional GHGs were adjusted to match the 2007 individual gas emissions published in the 6th National Communications[4] and the EDGAR database[5]. GHG emissions intensity factors were adjusted so that global emissions projections were better aligned with projections by other global IAMs.

The current version of CliMAT-DGE is not designed to study labour market. The supply of labour in each region is undifferentiated by skill level and exogenously specified as part of the baseline scenario. We assume a full employment model closure, where a shock to the

[3] The AR4 GWP for CH4 is 25 and for N2O is 298. The FGAS GWPs vary by gas.

[4] http://mfe.govt.nz/publications/climate/nz-sixth-national-communication/index.html

[5] http://edgar.jrc.ec.europa.eu/overview.php?v=GHGts1990-2010

economy causes wages and rents to adjust until the fixed supply of each factor is again fully employed. If labour is fully employed, then producers must compete for workers with other industries in order to expand production. This competition drives up wages and increases manufacturers' cost of production which are passed on to consumers through higher prices (Burfisher, 2011). An exogenous growth of labour supply is assumed to reflect increases in the population and more efficient use of labour due to improving technology.

Similarly, the supply of land and natural resources are assumed to be fixed in each period. Rents vary accordingly to keep full-employment.

Because of the forward-looking dynamics, the representative household in each region chooses its path of consumption versus saving over time to maximize the discounted value of the utility attained from consumption in each period. From Babiker, Gurgel, Paltsev, & Reilly (2008), utility maximization is subject to an income constraint over the time horizon. This constraint implies that in a policy scenario the present value of all future changes (positive and negative) in a region's current account balanced must be zero. Any region may run a current account surplus or deficit in any period but subject to the constraints that (i) global savings must equal global investment and that (ii) the present value of a region's current and future surpluses must equal the present value of its current and future deficits. For this, capital flows are allowed among regions in response to differences in real rate of returns. Model closure regarding the balance of payments requires the capital flows to be equal to the current account deficit (or surplus), and equal to the differences between aggregate expenditures (private and public consumption plus investments) and aggregate income (returns to labour, capital, energy resources and tax revenues) (Babiker et al., 2008). That is, if one country has a current account deficit there must be a compensating current account surplus in other countries. Furthermore, in every region any excess of aggregate expenditure over aggregate income today must be paid back in the future so that there is no net change in indebtedness over the model horizon.

In common with other CGE models, international assets positions are not explicitly modelled in CliMAT-DGE. Financial stocks and flows of financial assets (debt, equity, currency) are not modelled either. Thus, while a current account deficit is financed by a capital account surplus, we cannot say anything about the composition of the capital account. Foreign trade allows countries to temporarily run foreign accounts imbalances in response to environmental policies, as long as that imbalance is made up for in later years (Babiker et al., 2008).

CliMAT-DGE has explicit growth rates for energy-augmenting and GHG-augmenting technological change that vary by region and sector. We relate these forms of input-augmenting technological to projections of labour-augmenting technological change. The latter are based on total factor productivity projections developed by CEPII. We model the level of energy-augmenting and GHG-augmenting technological change, $B(t)$, as

$$B(t) = 1 + c\ln\big(A(t)\big) \qquad (1)$$

where $A(t)$ is labour productivity in year t (equal to one in the base year). This relationship is arbitrary, but it captures two important ideas. First, forms of technological change face strongly diminishing returns, for example, because of thermodynamic limits to the efficiency of energy conversion. The natural logarithmic function allows for continuing improvement, but at a slowing rate. In addition, the coefficient c accounts for the evaluation of the likely scope of such improvements over the years. For energy end-uses we choose $c = 1$ as there is considerable potential to improve energy efficiency in end-uses in the long run. By contrast, we assume there is much less potential to improve the efficiency of energy conversions (e.g. in the electricity sector) because of the nature of these processes and the large cost of energy in these sectors. Thus, we choose $c = 0.1$ in these cases. We also use this value for output-linked GHG emissions (discussed in section **Error! Reference source not found.**). Second, $A(t)$ and c will be positively correlated with by $B(t)$ and the rate of more specific types of technological improvement.

These forms of 'directed' technical change are exogenous in the model. Though technical change and adoption are responsive to price signals, they are also are driven by research and development, which require real resources and time. These considerations are difficult to allow for in CGE models, although some relatively small-scale models have incorporated aspects of endogenous growth theory in which some of these phenomena are modelled. These make emissions intensity an exogenous function of the emissions price, so that as the price rises the intensity falls.

2.2 Global Timber Model

Additional impacts to the forestry sector are modelled using the partial equilibrium dynamic Global Timber Model (GTM) (Daigneault et al 2012; Sohngen and Mendelsohn 2003) . The GTM is an economic model capable of examining global forestry land-use, management, and trade responses to policies. In responding to a policy, the model captures afforestation, forest management, and avoided deforestation behaviour. The model estimates harvests in industrial forests and inaccessible forests, timberland management intensity, and plantation establishment, all important components of both future timber supply and carbon flux. The model also captures global market interactions, global timber supply and the associated carbon accounting, including carbon stored in harvested wood products[6]. The version of the forestry model used in this paper tracks more than 200 forest types across 17 timber regions.

Variations of the data and structure of the forestry model have been used in other global climate change policy analyses (e.g., Tavoni et al 2007; Golub et al 2012). In our case, we have opted to use a soft-link or loosely coupled model approach such that the GTM and CliMAT-DGE baseline for forestry and harvested wood products are closely aligned, confirming that it is suitable to use. For this analysis, we feed the regional GHG prices estimated with CliMAT-DGE into GTM. The timber model then estimates the change in regional forest stock and carbon sequestration as a result of the proposed GHG emission reduction policy.

2.3 MAGICC

MAGICC is a (relatively) simple model of the global atmosphere and ocean system (Meinshausen, Raper, & Wigley, 2011), designed to emulate the responses of global climate variables in very complex Atmosphere Ocean General Circulation Models (AOGCMs). While an AOGCM typically takes weeks to run on a supercomputer, MAGICC runs in

[6] Note that carbon accounting in GTM may differ from the more complex UNFCCC rules for land use land use change and forestry (LULUCF) used for the latest the NZ GHG emissions inventory (MfE, 2014)

seconds on a desktop computer. This study uses MAGICC version 6.3, which has been calibrated to emulate the responses of any of the AOGCMs and carbon cycle models used in the IPCC Fifth Assessment Report. It was also used for the study by Kriegler et al (2013) that is the source of the model inter-comparison in this study.

MAGICC is integrated in NZIAMS to translate net global emissions from CliMAT-DGE and GTM into global atmospheric GHG concentrations and mean temperatures. For this analysis, MAGICC was only used to estimate climate change indicators between 2007 and 2100, and hence did not estimate any direct impacts of climate change on the specific sectors in NZIAMS. Key indicators at the global level include total radiative forcing (W/m^2), Kyoto-GHG concentrations (ppm), and mean temperature.

3 Results

3.1 Baseline

Baseline estimates of GDP for CliMAT-DGE and other global IAMs used in recent IPCC reports are shown in **Error! Reference source not found.**. GDP for CliMAT-DGE in 2007 is estimated to be about $85 trillion, which is close to the average of other IAMs. We estimate that global GDP reaches about $184 trillion by 2045, although it increases at a rate of 3.6%/yr, which is less than most of other IAMs (average of 5.8%/yr).

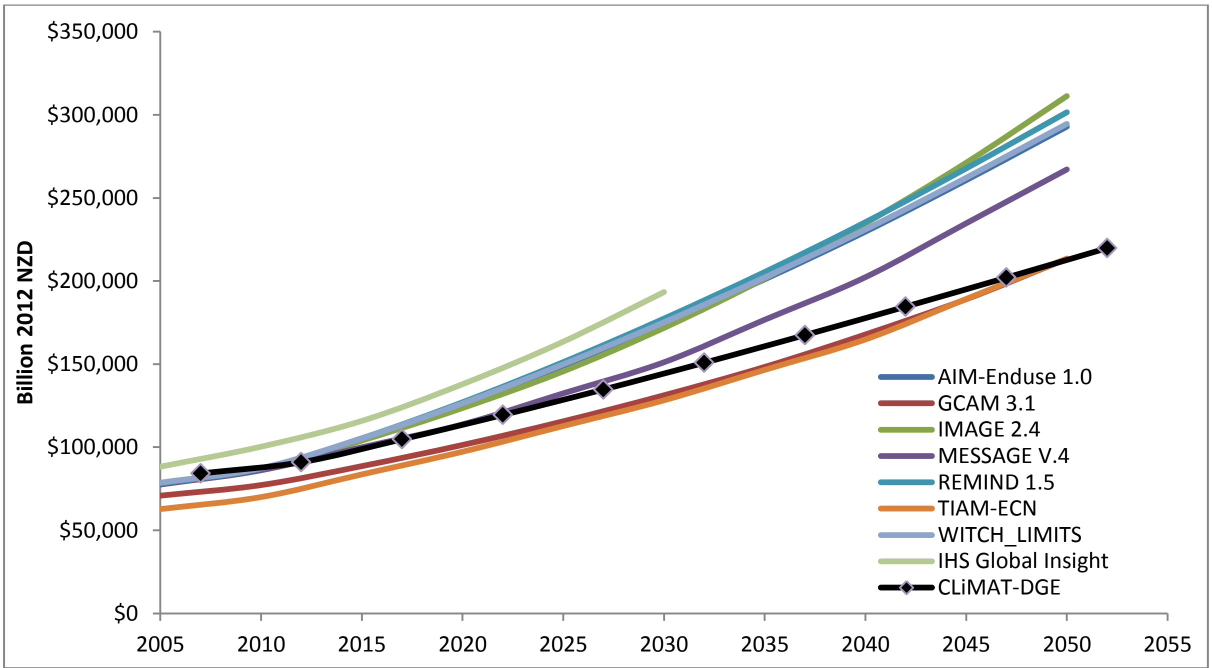

Figure 1. Baseline Global GDP (BillionNZD)

Baseline global GHG emissions for CliMAT-DGE and select IAMs are shown in Figure 2. World emissions in CliMAT-DGE are estimated to be about 44 $GtCO_2$-e in 2007 and reach 82 $GtCO_2$-e by 2052, an increase of about 2% per annum. These projections are closely aligned with other global IAMS.

Sector-based global GHG emissions through 2100 are shown in Figure 3. All aggregated sectors of the economy produce emissions in the baseline, including forestry (primarily via deforestation). Electricity and manufacturing produce the bulk of the emissions, on average, due to its reliance on fossil fuels. Agriculture produces about 19% of total global emissions over the 21st century.

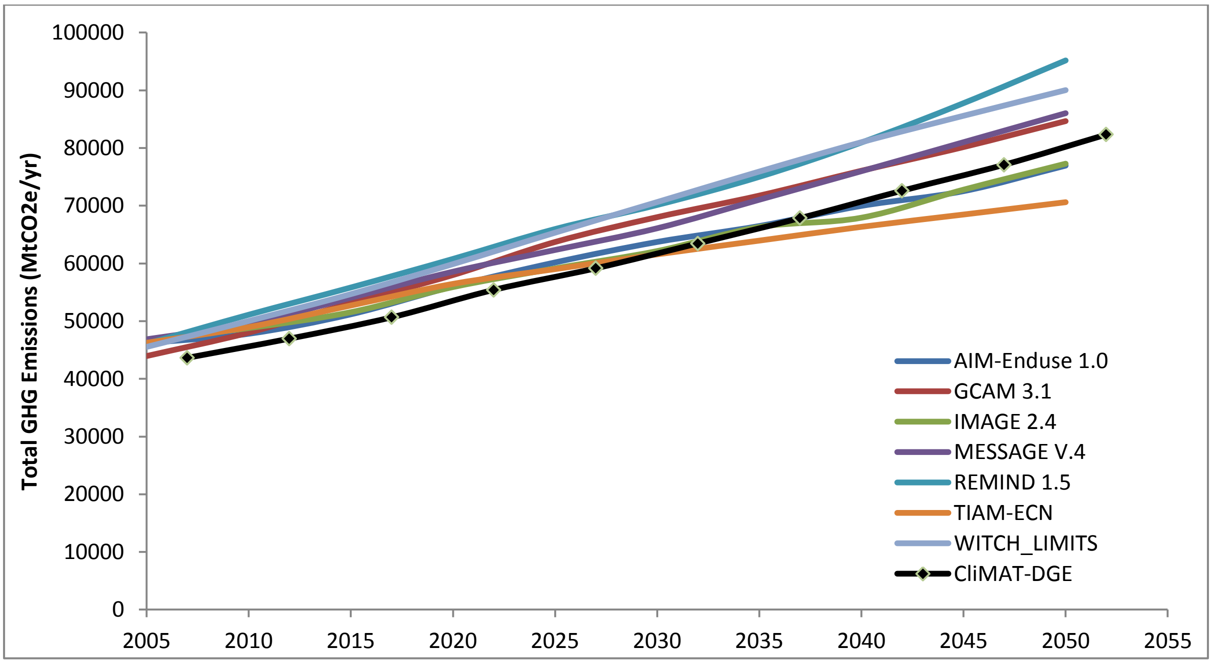

Figure 2. Baseline annual global GHG emissions projections

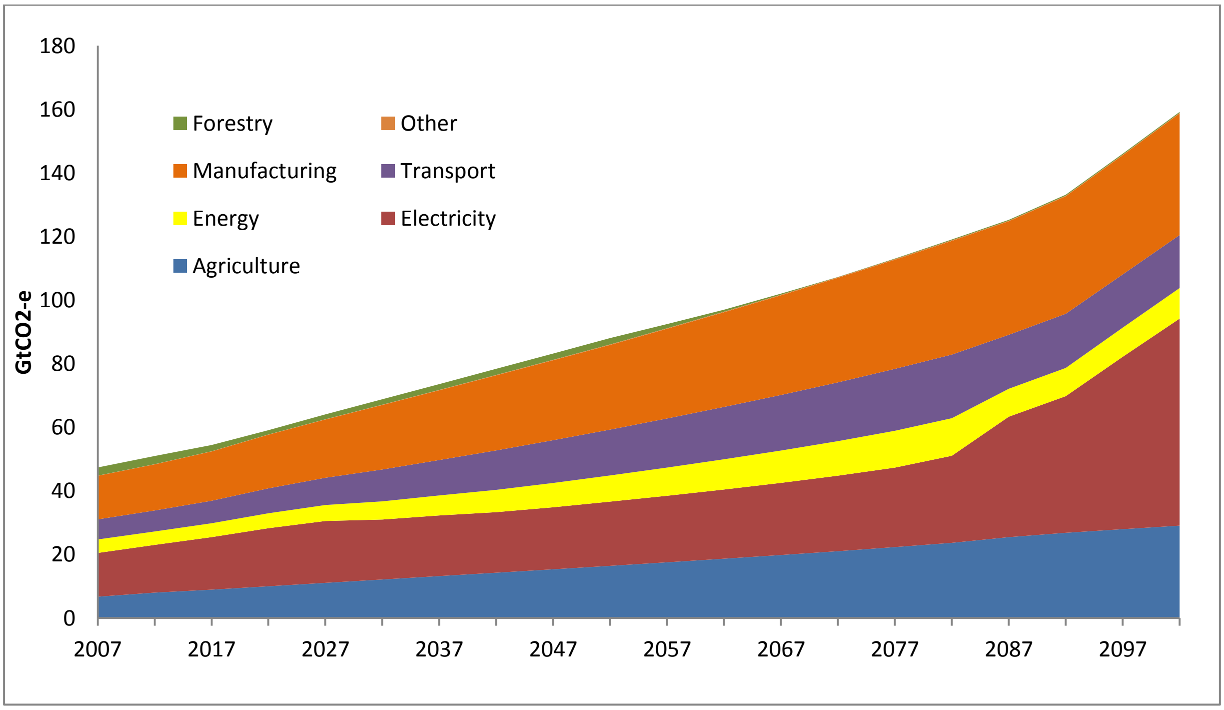

Figure 3. Baseline annual global GHG emissions projections, by sector

Figure 4 shows the mix of electricity generation between fossil fuel sources and carbon-free electricity (i.e. nuclear, hydro, thermal, wind).Though most of generation still relies on fossil fuel, the share carbon-free electricity increases over time. The decline in carbon-free electricity after 2090 is likely caused by the terminal conditions, which incentivises an increase in the extraction and consumption of fossil fuels.

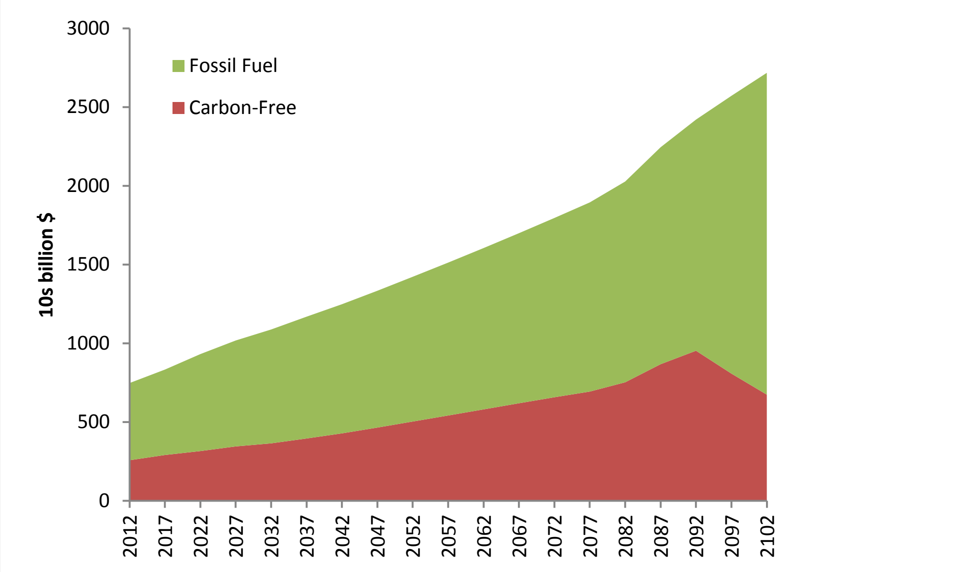

Figure 4. Baseline Electricity Generation (2012 NZ $)

3.2 Policy Scenarios

Figure 5 shows the NZIAMS estimate of gross and net GHG emissions for the entire world. Gross emissions follow a steady decline over time such that they are reduced to 20 GtCO2e and 24 GtCO2-e for the 450 and 500 ppm scenarios[7], a 90 and 85% respective reduction from the baseline. Forest carbon sequestration reduces emissions by at least an additional 22 GtCO2e for the two emissions pathways, resulting in net emissions of about -3 GtCO2e for the 450 ppm scenario and 2 GtCO2e for the 500 ppm scenario. The net GHG emissions from NZIAMS also align closely with the seven IAMs used in Kriegler et al. (2013), as shown in Figure 6.

In general, four different types of mitigation costs can be distinguished (IPCC, 1995): direct engineering costs, economic costs for a specific sector, macroeconomic costs and welfare costs. The first major result of the analysis of the mitigation pathways is that each of the models can achieve the three stabilization targets, even in the case of the 400ppm CO2 eq stringent mitigation scenario.

[7] Note that the GHG trajectory is the same when agriculture is not priced. This is because the total level of emissions that needs to be reduced remains the same, but the sectors covered to achieve this reduction (and hence overall costs) vary.

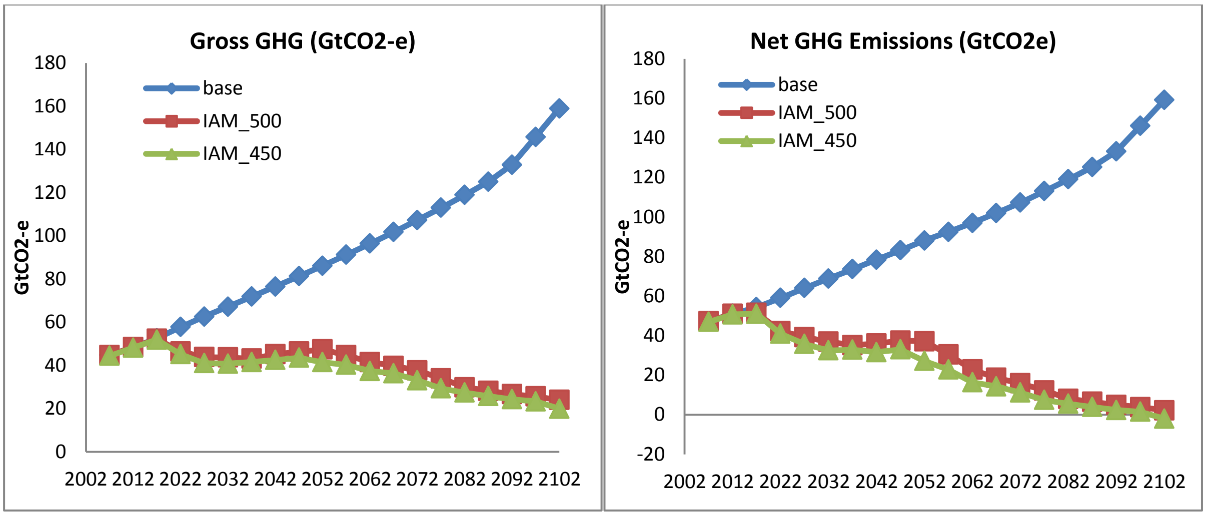

Figure 5. Policy estimates on Gross and Net Global GHG Emissions

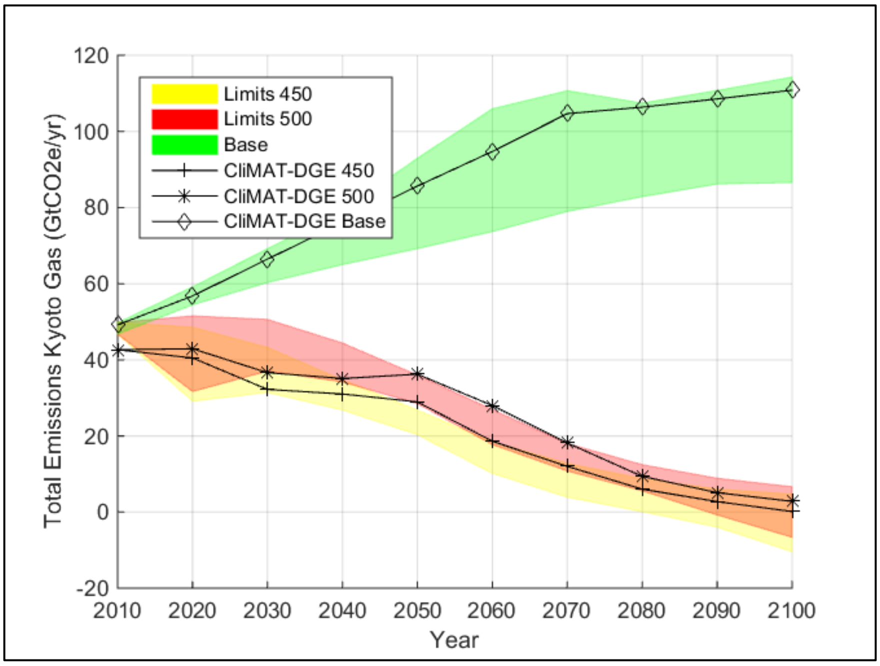

Figure 6. Net GHG emissions for CliMAT-DGE and Kriegler et al (2013) LIMITS scenarios

Sector-based GHG emissions for the IAM scenarios are displayed in Figure 7. The largest reductions occur in the electricity sector as fossil fuel generation is converted to carbon-free and coal-fired electricity with CCS. Additional forest carbon sequestration also has a large impact on net emissions.

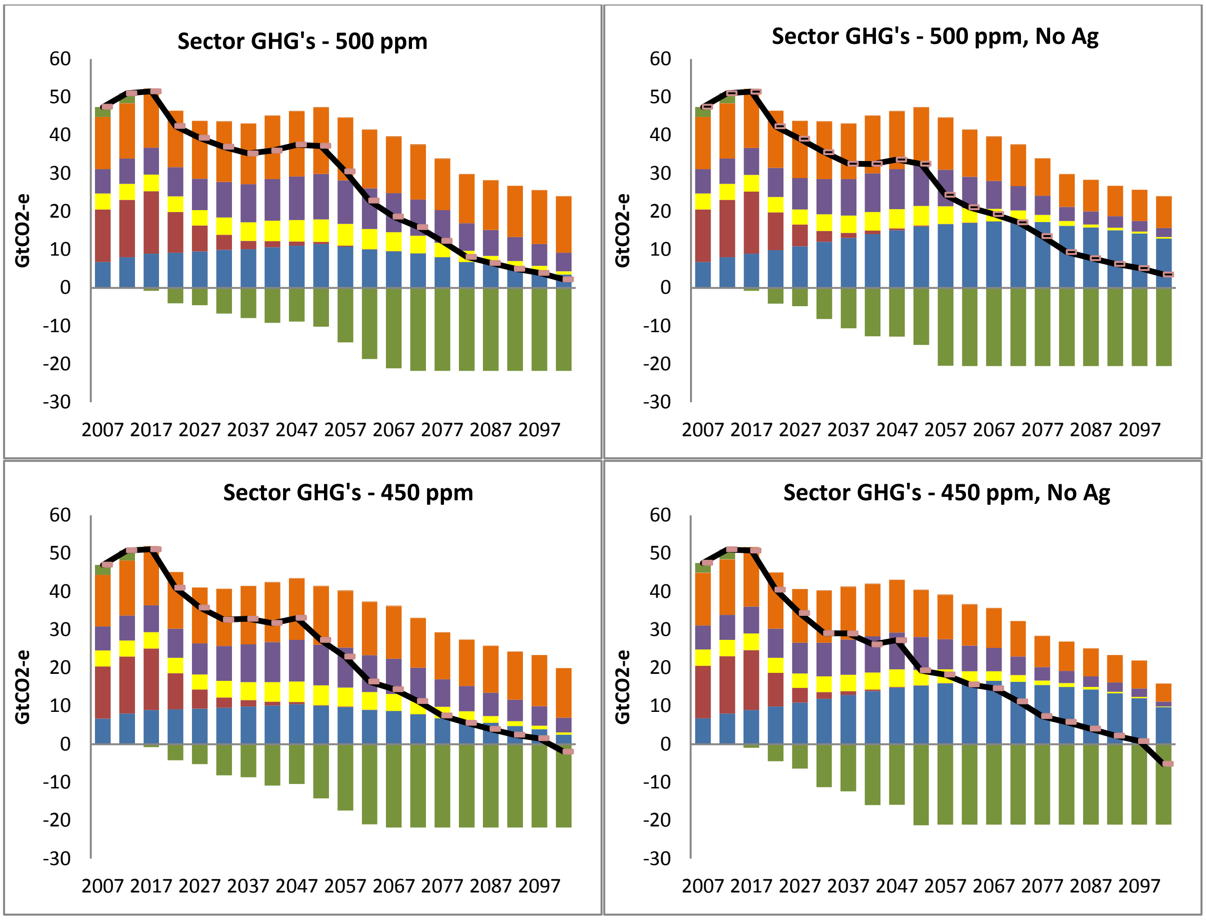

Figure 7**.** Global sector GHG Emissions (GtCO2-e), 450 and 500 ppm policy analyses

3.2 Global climate change

Global climate change indicators can be estimated by running the net GHG estimates from NZIAMS through MAGICC. The estimated Kyoto-GHG emissions and concentrations, global mean warming, and total radiative forcing for NZIAMS and the IAMs used in the LIMITS study are shown in Figure 8. The figures indicate that the GHG emissions cap imposed in NZIAMS was an adequate method to constrain GHG concentrations to the 450 and 500 ppm targets in 2100. This is estimated to result in a global mean warming of about 1.6 to 1.8 degrees Celsius a total radiative forcing of about 3.0 to 3.4 W/m2 at the end of the model simulation. The figures for radiative forcing are on the high range of estimates from the LIMITS study. This may be attributed to the fact that Kriegler et al (2013) indicate that combined radiative forcing in their study exclude nitrate aerosols, mineral dust aerosols, and land use albedo changes, which can have net negative forcing in the range of -0.2 to -0.4 W/m2, and hence reduce total radiative forcing by a similar amount. Note that for this analysis that, although we modelled the potential climate change, these impacts were not fed back into NZIAMS to estimate and feedback effects of climate change (e.g., change in agricultural productivity) on the global economy.

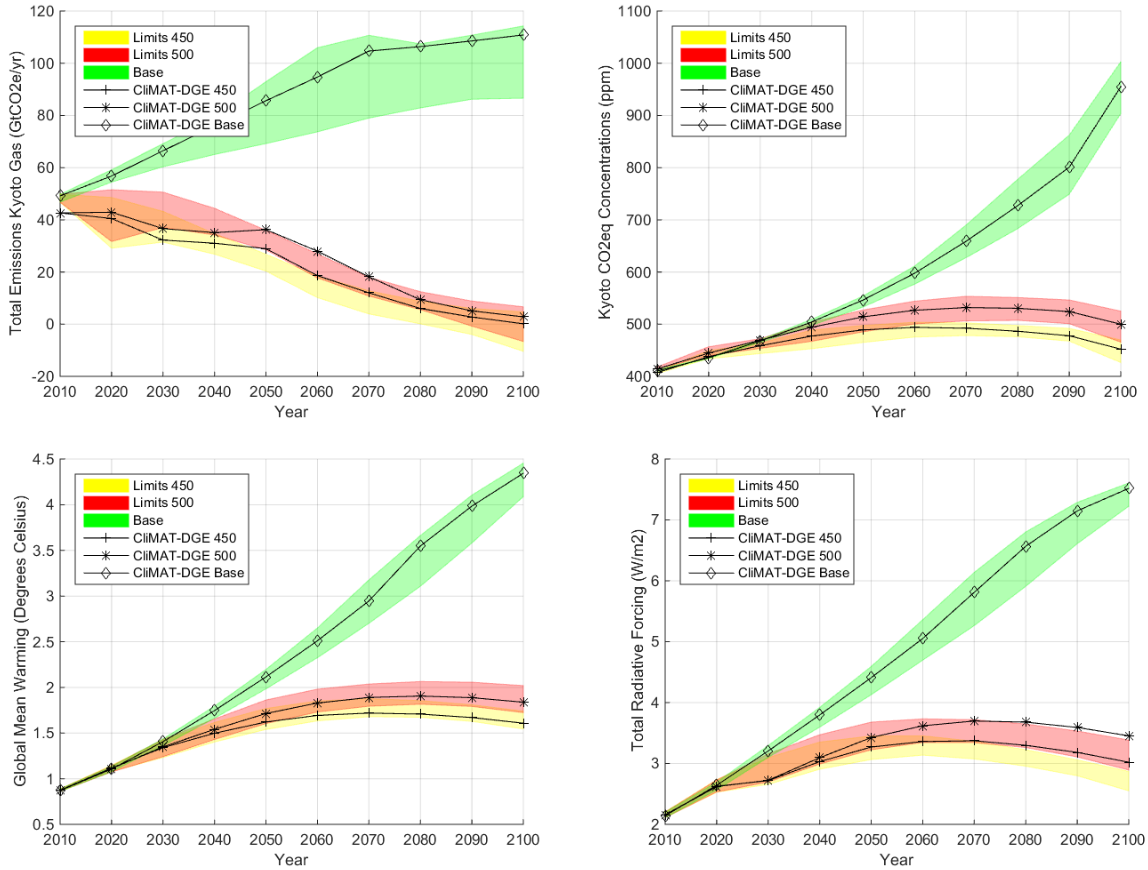

Figure 8. Kyoto-GHG emissions, Kyoto-GHG concentration**,** global mean warming and total radiative forcing for CliMAT-DGE IAM scenarios and Kriegler et al (2013) LIMITS scenarios

3.3 Global GHG price

The cost of emissions reductions needed to achieve the specified cap is analogous to the GHG price estimated in the other policy scenarios of this report. A summary of the estimated GHG emissions prices estimated to meet the target set in CliMAT-DGE and the IAMs in Kriegler et al (2013) are plotted in Figure 9. Prices are relatively small for the first 3 decades of the policy, but then begin to increase rapidly from 2050 onwards as the target becomes more difficult to achieve through basic input substitution and changes to the electricity sector. In addition, not putting a price on agricultural emissions raises the GHG price as other sectors must reduce their emissions even further to achieve the target.

GHG prices for CliMAT-DGE are relatively close to those in the LIMITS study through 2060, particularly in the scenarios where agriculture is priced[8]. Prices for CliMAT-DGE start to reach the upper end of model estimates from 2060 onwards. This is likely as a result of (a) the lack of large mitigation sources available beyond 2060 besides continuing to shift the electricity sector to ‘carbon free’ sources or afforest more land and/or (b) the potential influence from terminal conditions that are imposed in 2102. As a result, we only present economic impacts up to 2070.

[8] Note that agriculture was priced for all scenarios in the LIMITS study.

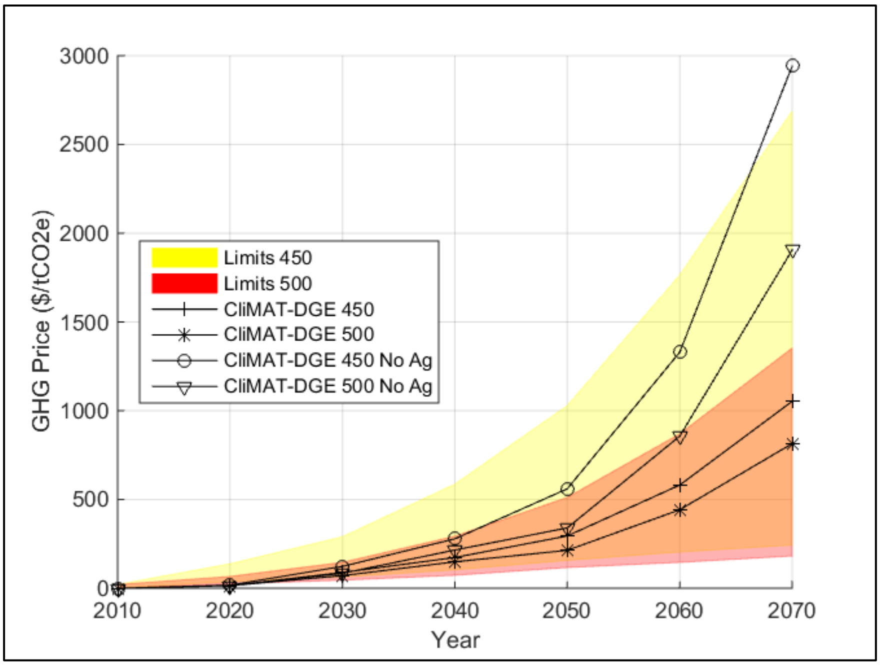

Figure 9. GHG emissions prices ($/tCO2e) for CliMAT-DGE and select IAMs from Kriegler et al. (2013)

3.4 Global economic impacts

All IAM scenarios result in a noticeable reduction in global GDP, particularly in the second half of the century (Figure 9). The figures from CliMAT-DGE indicate that for the scenarios that place a GHG price on emissions from all sectors (450 and 500), GDP is likely to be reduced between 1.6 and 2.0% by 2030 while GDP in 2070 could be reduced by 7 to 9%. For the case where agriculture is excluded from GHG pricing (450 and 500 No Ag), GDP impacts decrease by 1.7 to 2.2% in 2030, and by 13-18% in 2070. This suggests that excluding agriculture could have a dramatic increase on global economic impacts, as the increase in GHG price on all emissions from all other sectors on the economy in order to meet the 2100 GHG concentration target dominate the potential increases in output that could be achieved from not pricing agriculture. For the two comparable scenarios that price all sectors of the economy (450 and 500), the estimated GDP impacts from CliMAT-DGE fall within the range of estimates from the other IAMs used in the Kriegler et al. (2013) LIMITS study.

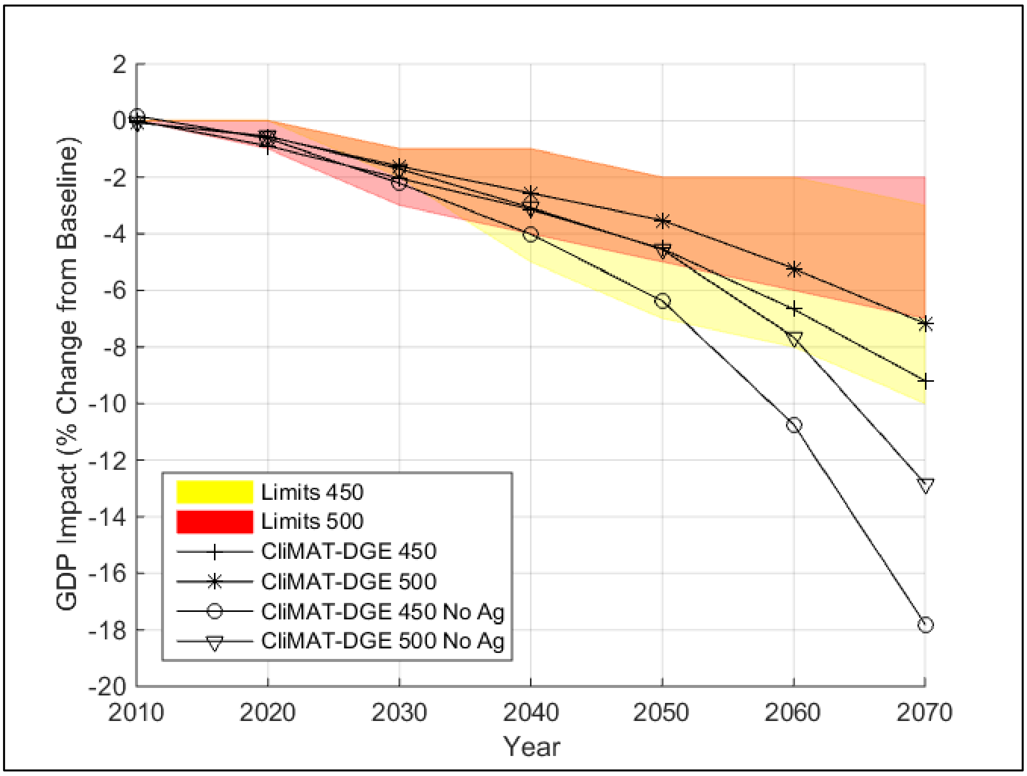

Figure 10. Percent change from baseline in global GDP and income for CliMAT-DGE and select IAMs from Kriegler et al. (2013)

4 Conclusion

In this paper we use a global dynamic integrated assessment model assess the impacts of meeting a Kyoto GHG emissions concentration of 500 and 450 parts per million (ppm) in 2100, with and without GHG prices imposed on the agricultural sector. The model estimates that global net emissions in 2100 would need to be reduced by 85 to 90% relative to the baseline case to achieve 500 ppm and by 98-103% to meet the 450 ppm target. GHG emissions price estimates range from $44 to 76/tCO2e in 2030 and from $503 to $1,816/tCO2e in 2070. Major sources of abatement include the switching most of the world's electricity generation to either renewable energy or CCS and planting several 100s of million hectares of trees.

All policy scenarios were estimated to reduce global GDP relative to the baseline, particularly in the second half of the century. For the scenarios that price GHG emissions from all sectors, GDP is reduced by 1.6 to 2.0% in 2030 while GDP in 2070 could be reduced by 7 to 9%. For the scenarios that excluded agriculture from GHG pricing, global GDP impacts decrease by 1.7 to 2.2% in 2030 and by 13 to 18% in 2070. This suggests that excluding agriculture could have a dramatic increase on global economic impacts as the increase in GHG price on all emissions from all other sectors to meet the 2100 GHG concentration target dominate the potential increases in economic output that could be achieved from not pricing agriculture. Future work will evaluate impact of including/excluding other sectors of the economy from GHG emissions pricing, and the effect of technological change and additional backstop technologies on meeting global emissions targets.

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