Organisation for Economic Co-operation and Development

COM/TAD/CA/ENV/EPOC(2018)7/FINAL

Unclassified **English - Or. English**

25 February 2019

TRADE AND AGRICULTURE DIRECTORATE
ENVIRONMENT DIRECTORATE

Joint Working Party on Agriculture and the Environment

A GLOBAL ECONOMIC EVALUATION OF GHG MITIGATION POLICIES FOR AGRICULTURE

This document is one of four technical reports which explore the economic consequences and potentials of greenhouse gas (GHG) mitigation policies for the agriculture sector. It evaluates mitigation potentials, socioeconomic impacts and trade-offs, and competitiveness implications of global mitigation policies over time.

Ben Henderson (OECD) led this analysis, in co-operation with a team of analysts including Monika Verma, Andrzej Tabeau, and Hans van Meijl, from Wageningen Economics Research, part of Wageningen University and Research.

For further information, please contact Ben HENDERSON (ben.henderson@oecd.org).

JT03443639

Table of contents

Executive Summary **3**

1. The importance of agriculture to global mitigation efforts **5**

2. Modelling mitigation policies in agriculture for OECD countries and the world **7**

  2.1. The MAGNET model and scope of analysis 7
  2.2. Designing policies to unlock agriculture's mitigation potential 9

3. GHG emission reductions and economic consequences of mitigation policies in agriculture .. **11**

References **20**

4. Annex **22**

  4.1. Region-specific information and results 22
  4.2. Additional MAGNET model specification details 30

Annex references **38**

Figures

Figure 2.1. The agricultural GHGs in the MAGNET model ($MtCO_2$-eq) in 2020 8
Figure 3.1. Global reductions in agricultural non-CO_2 emissions for dynamic policy scenarios 12
Figure 3.2. Global reductions in agricultural non-CO_2 and land use change emissions for dynamic policy scenarios 12
Figure 3.3. Global reductions in agricultural non-CO_2 and land use change emissions for the global abatement payment 13

Tables

Table 3.1. Summary of annual agricultural non-CO_2 and LUC emission reductions policy instruments assessed under dynamic settings ($MtCO_2$-eq) in 2050 14
Table 3.2. Summary of annual agricultural non-CO_2 emission reductions for policy instruments assessed under static settings ($MtCO_2$eq) in 2050 15
Table 3.3. Changes in agricultural value-added and household food consumption from policies in 2050 16
Table 3.4. Annual changes to government budget from selected global GHG mitigation policies in 2050 (million USD) 17

Executive Summary

There is growing recognition of the importance of reducing greenhouse gas (GHG) emissions from agriculture to meet the ambitious targets of the Paris Agreement goal of limiting global average temperatures to well below 2°C and pursuing efforts to limit the increase to 1.5°C above pre-industrial levels. The challenge for policy makers is to find ways of reducing agricultural emissions that can also minimise the negative consequences of mitigation policies on food security, agricultural income and competitiveness. In this document, the potential of a selection of market-based policy options to unlock the large global mitigation potential of the agricultural sector, while addressing these potential impacts is assessed. All of the policies were assessed using the MAGNET (Modular Applied GeNeral Equilibrium Tool) model, which is a multi-sector, multi-region computable general equilibrium (CGE) model that covers the global economy.

The policies assessed in this study include three measures that directly target agricultural GHG emissions: a tax on GHG emissions, applied globally and to OECD countries only; a tax on GHG emissions combined with a food consumption subsidy to maintain the baseline food consumption levels of households, applied globally; and a payment to producers to precisely cover their costs of adopting abatement technologies and practices, applied both globally and to OECD countries only. For each of these policy options the same increasing carbon price pathway is assumed, with GHG prices of 40, 60, and 100 USD/tCO_2-eq for the 2021-2030, 2031-2040, and 2041-2050 simulation periods, respectively.

Two additional policy instruments also were tested: a GHG-based tax levied on emission intensive production inputs (ruminant animals and nitrogen fertilisers), applied both globally and to OECD countries only; and a GHG-based tax levied on emission intensive consumer products (red meat and dairy products) within OECD countries from domestic and imported sources. These two policies were considered to be potentially practical options for reducing the challenges associated with measuring emissions and, in the case of the tax on consumer products, to manage competition imbalances and emission leakage effects when restricting mitigation policies to OECD countries. These policies were analysed for the year 2050 using a carbon price of 100 USD/tCO_2-eq.

The assessed policies differ considerably in terms of the trade-offs that they generate between mitigation outcomes and their associated impacts on agricultural income, competitiveness, food consumption and government finances. The mitigation effectiveness of the policies is assessed with reference to annual non-CO_2 emission reduction targets of 1 and 2.5 GtCO_2-eq by 2030 and 2050. These are not official targets, however, they have been proposed by some analysts as being commensurate with agriculture's global emission contribution and capacity to mitigate.

A global GHG tax induces large emission reductions that are approximately aligned with the above targets, but it also imposes large economic costs on agricultural producers, particularly in the emission intensive ruminant sectors in many developing country regions. It also slightly reduces household food consumption, however, it should be possible to insulate consumers from associated negative impact linked to higher induced food prices by combining the tax with a food subsidy, which could also potentially be financed by the GHG tax. The global abatement payment offers the prospect of appreciable global emission reductions without harming agricultural producers or food consumers, although it does need to be funded (in this study it was assumed to be government funded). From an economic welfare (or efficiency of economic resource allocation) perspective, the abatement payment performed worse than the GHG tax, relative to the quantity of emissions reduced. Compared to the assessed GHG tax policies, the abatement payment was also only half as effective as the tax at reducing non-CO_2 emissions. The effectiveness of the abatement payment could fall further if land use change (LUC) emissions are also taken into account, due to the small expansion of agricultural land that this policy induces. The potential LUC emission losses from this policy could be managed by coupling this policy option with regulations to prevent the clearing of non-agricultural land, particularly in land types containing high carbon stocks. However, this policy combination was not assessed.

Unlike the GHG tax policies, which can generate government revenue, the global abatement payment would need to be funded (at a cost of 31 billion USD in the year 2050). However, the level of payment needed globally represents a small proportion of the agricultural producer support currently provided by countries for non-environmental purposes.

The policy options which levy GHG taxes on emission proxies, such as more easily measurable and emission intensive production inputs or consumer products, were found to be far less effective than directly taxing emissions. Further, their ineffectiveness appears to worsen when the tax is levied at the consumer stage compared to the input stage.

Among the policies that directly target emissions, abatement payment schemes based on the voluntary enrolment of producers are arguably more feasible than GHG tax policies, with respect to managing the potentially onerous challenges associated with emissions measurement. This is because they limit these challenges to the producers that enrol into such schemes, rather than requiring the measurement of all agricultural producers' emissions.

The geographical scale of policies is critical to both their mitigation effectiveness and, in some cases, their impacts on the regional competitiveness of agricultural sectors. More than a third of the GHG emission reductions from a GHG tax that is limited to OECD countries could be leaked as increases in emissions in non-OECD countries. By instead applying an abatement payment to OECD country emissions, these leakage impacts can be controlled while delivering a similar level of global mitigation. However, it is clear that OECD countries alone cannot make a very meaningful contribution to lowering global agricultural emissions, given non-OECD countries' dominant share of global agricultural emissions.

Finally, a number of caveats are discussed later in this document, including the omission of soil carbon sequestration as mitigation option and of technological changes that could lower the costs of mitigation over time. Both of these omissions lower the projected effectiveness of the assessed mitigation policies. The neglect of mitigation policies in other sectors of the economy related to agriculture is another limitation of the study.

1. The importance of agriculture to global mitigation efforts

Following the Paris Agreement, from the 21st session of the Conference of the Parties (COP 21) to the United Nations Framework Conventions on Climate Change (UNFCCC), stronger mitigation efforts are being embraced worldwide to slow down global warming. Many countries have begun to revisit mitigation plans with the objective to strengthen their effectiveness or discuss new ways to tackle the problem. A clear trend towards inclusion of agricultural emissions in national and regional mitigation efforts is visible. The recent request by the COP for the UNFCCC's technical body (Subsidiary Body for Scientific and Technological Advice (SBSTA)) and implementation body (Subsidiary Body for Implementation – SBI) to jointly address climate change issues in agriculture, including mitigation, through the Koronivia Joint Work on Agriculture (Decision -/CP.23) is further evidence of this progress.

At the international level, the UNFCCC and the Paris Agreement provide the framework for coordinated global action. The Paris Agreement allows countries to decide on their own emission reductions through Nationally Determined Contributions (NDCs) to global mitigation. Among the Parties to the agreement that include mitigation targets in their NDCs, 103 mention agriculture as a contributing sector, however, only a small number of Parties have so far provided specific percentage goals for reducing agricultural emissions.

Agriculture as a sector contributes substantially to climate change, with 5.0-5.8 $GtCO_2eq$ of direct emissions per year during 2000-2010, representing 11% of global anthropogenic GHGs. There were a further 4.3-5.5 $GtCO_2$-eq of emissions from land use and land changes during this period (Smith et al. 2014), much of which was caused by agriculture. The total annual contribution of the Agriculture, Forestry and Other Land Use (AFOLU) to global emissions is 10-12 $GtCO_2$-eq, representing 24% of global emissions. Moreover, global emissions from agriculture are increasing, and developing countries are the largest and the fastest growing source of direct and indirect agricultural emissions. Since 2000, OECD countries as a whole have experienced a slight reduction in emissions, as production efficiency improvements have helped to contribute to a 2% fall in the emission intensity of agricultural output.

In order to tackle climate change effectively and efficiently, agriculture must do its part. This will become increasingly important over time, given that agriculture has so far received less consideration in GHG mitigation policies compared with energy and other sectors (Bajzelj et al. 2014). Scenarios show that non-CO_2 emissions (methane and nitrous oxide), mainly from agriculture, will become the largest source of global emissions as other sectors are projected to mitigate their emissions much more effectively by mid-century (Gernaat et al., 2015; Wollenberg et al., 2016).

In the past, concerns about emissions leakage and loss of competiveness may have prevented countries from taking independent and early action to reduce agriculture emissions. Such leakage occurs when mitigation policies in one region raise agricultural production costs and prices, causing supply from that region to fall, which creates incentives for increases in production and emissions elsewhere to partially fill the shortfall in supply.

The main purpose of this study is to assess the potential economic consequences of policies for delivering ambitious emission reductions in agriculture, including their possible impacts on competitiveness, food security and agricultural income. In the absence of specific details on targets and policy options being put forward both nationally and internationally, this study provides an opportunity to explore how agriculture could make a substantial contribution to global mitigation efforts with a range of market-based policies.

In this study, a global tax on agricultural GHG emissions is the most ambitious policy option assessed, which assumes a willingness by all countries to apply an equally strong GHG tax rate, irrespective of their development status and priorities. This policy therefore represents a high mitigation benchmark which is then compared to a range of arguably more feasible, but less effective policy options. These options include changing the burden of mitigation responsibility to exclude non-OECD countries, as well as applying the "beneficiary pays" principle rather than the "polluter pays" principle to incentivise ambitious mitigation outcomes for the agriculture sector. In recognition of the challenges and costs associated with measuring agricultural emissions, the efficacy of GHG-based payments on emission-intensive producer inputs and products is also examined.

With respect to evaluating the mitigation performance of different policy instruments it is helpful to have in mind a reasonable or "fair" global emissions reduction target for agriculture globally. Taking into account relative mitigation costs and considerations about food security, Wollenberg et al. (2016) suggest a non-CO_2 emission reduction goal of 1 $GtCO_2$-eq yr^{-1} by 2030 for agriculture to contribute to the 2°C warming target by the end of the century. This represents an 11-18% reduction relative to the business-as-usual baselines assumed in their study and an allowable non-CO_2 emissions budget of 6.15 to 7.78 5 $GtCO_2$-eq yr^{-1}. By, comparison a 1 $GtCO_2$-eq yr^{-1} emission reduction in this present assessment represents 14% reduction of the baseline emissions, bringing the baseline non-CO_2 emissions in 2030 down from 7.33 to 6.33 $GtCO_2$-eq yr^{-1}. Wollenberg et al. (2016) also propose stronger longer term target of and 2.5 $GtCO_2$-eq yr^{-1} by 2050 for agriculture's contribution to meeting the 2°C target. These emission reduction targets have since become used as benchmarks in global mitigation assessments for agriculture, including in Frank et al. (2018). Accordingly, they are used throughout this study as one of the performance benchmarks of the assessed policies.

In the next section of this report, the model and data used for the analysis are described, along with the scope of the analysis and the selected mitigation policy instruments. Following this, the quantitative policy findings are presented and explained. In the final section, the key policy messages and recommendations are articulated, along with the main limitations of the study.

2. Modelling mitigation policies in agriculture for OECD countries and the world

2.1. The MAGNET model and scope of analysis

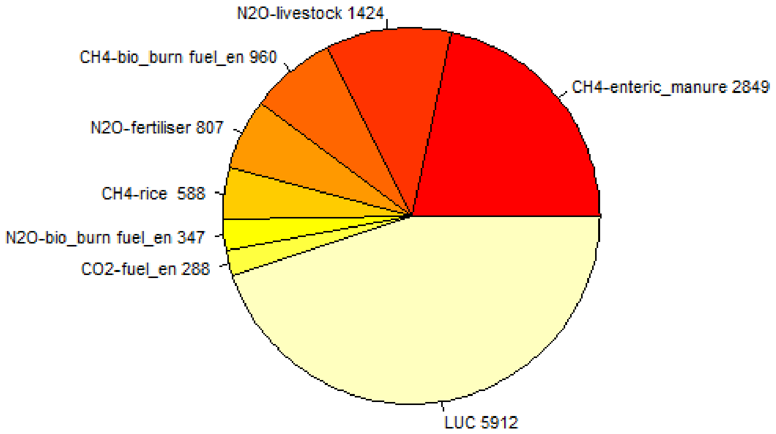
A computable general equilibrium (CGE) model is well-suited to addressing many of the policy questions required to quantitatively assess the economic, competitiveness and food security consequences of ambitious GHG mitigation targets for agriculture. A key strength of the CGE framework is its capacity to capture inter-sectoral relationships within agriculture, and between agriculture and other sectors, including other land use sectors. Other identified strengths included its ability to track: bilateral trade flows that influence competitiveness and leakage outcomes of mitigation policies; and the flow of costs and benefits to different sectors of the economy, including government, consumers and producers.

Given the utility in using a CGE model that can capture land use interactions with an acceptable degree of realism, the MAGNET (Modular Applied GeNeral Equilibrium Tool) model was selected (Woltjer et al., 2014). This model has a long history of use within Wageningen University for assessing the global impacts of policies in agriculture. MAGNET is a recursive dynamic multi-sector, multi-region Computable General Equilibrium (CGE) model that covers the global economy (Woltjer et al., 2014). MAGNET is based on the Global Trade Analysis Project (GTAP) database and model that is developed at Purdue University in the United States (Hertel and Tsigas, 1997). MAGNET and GTAP are originally designed to model the effects of trade policies, such as the Uruguay Round of multilateral trade negotiations, especially on the agricultural sectors. MAGNET has been extended and updated with several modules to improve the modelling of land markets and agricultural policies, biofuel policies, socio-economic and environmental impacts of environmental policies. There are eleven primary production sectors in agriculture, including eight crop sectors and three livestock sectors, and a total of fifty sectors in the model.

MAGNET uses the GTAP 9.2 database (Aguiar et al., 2016), which has a base year of 2011, but is updated in this assessment to create a dynamic baseline, from 2011 to 2050, with yield and economic growth assumptions that conform to the 'middle of the road' Shared Socioeconomic Pathway, SSP2 (Fricko et al. 2017). The model also incorporates emissions from the latest GTAP non-CO2 database (Irfanoglu and van der Mensbrugghe, 2015), including methane (CH4) and nitrous oxide (N2O). This is complemented by CO2 emissions from the GTAP Energy-Environmental database (GTAP-E). Livestock non-CO2 emissions and Rice CH4 emissions are tied to the output variables of these respective sectors within the MAGNET model. Whereas N2O emissions from crop fertiliser use are tied to the fertiliser input variable in these sectors. In addition, data on the marginal abatement costs (MACs) associated with practices and technologies that can be used to reduce GHG emissions are also incorporated. These data are from the US EPA (2013) and they cover measures for lowering the main non-CO2 emission sources including methane (CH4) from enteric fermentation by ruminants (i.e. cattle, sheep and goats), nitrous oxide (N2O) and CH4 from livestock manure, CH4 emissions from paddy rice and N2O emissions from soil associated with fertiliser use by crops. Accordingly, it is these emission sources that are targeted with mitigation policy instruments in this study. It should be noted that the MACs used in this assessment do not include assumptions about technological change, from the development and adoption of new technologies which are likely to lower the costs of mitigation over time. Consequently, the MAC data used in this assessment are conservative with respect to their assumed GHG mitigation potential, especially over the longer term. The CO_2 emissions associated with land use change (LUC) include changes in above and below ground carbon stocks between three aggregate types of land cover: cropland; grazing land; and forest shrub land and savannah land. The coefficients determining these changes in carbon stocks and CO_2 emissions are drawn from the Agro-ecological Zone Emission Factor (AEZ-EF) model described in Plevin et al., (2014).

In this assessment, GHG mitigation policies are only applied to non-CO_2 emissions in the agriculture sector and not GHG emissions in other sectors of the economy. The possible implications of this modelling assumption are discussed in section 3. Within agriculture, the vast majority of GHG emissions are targeted by most of the global mitigation policies considered in this study (78% of total agricultural GHG emissions, in 2020, excluding LUC emissions). With reference to Figure 2.1, these include: CH_4 from enteric fermentation and livestock manure management; N_2O from livestock manure; N_2O from fertiliser applied to crops; and CH_4 from rice production. The remaining 22% of the emissions include: CH_4 and N_2O emissions from the burning of biomass, and from fuel and energy use; and CO_2 emissions from fuel and energy use. The remaining emissions sources that are not targeted by mitigation options considered in this study are still included in MAGNET and the changes in these emissions can also be reported. For instance, changes in LUC emissions due to the expansion or contraction of agricultural land are reported in this study. If information about the technologies and costs of reducing these minor emission sources becomes available in the near future, it may be possible to extend the coverage of the mitigation policies to target all emission sources in agriculture.

Figure 2.1. The agricultural GHGs in the MAGNET model ($MtCO_2$-eq) in 2020



The economic impacts of mitigation policies on the different agricultural sectors and regions depend on the mitigation opportunities embedded in the MACs, and on the economic emission intensity of the sector's output (i.e. the amount of GHG emissions from a sector divided by the economic value of its output). While there is a large variation in emission intensities across countries within a given sector, they are by far highest in the ruminants sector (see Figure A.1 in appendix section 4.1). We therefore expect a GHG tax to have relatively large impacts on this sector.

2.2. Designing policies to unlock agriculture's mitigation potential

Based on considerations about relevant and feasible mitigation policy options for agriculture, a set of eight mitigation policies were selected for assessment in this study. These policies are considered to be sufficiently broad in scope to address the primary objective of identifying policy solutions that can unlock the large mitigation potential of the agricultural sector, without compromising food security in low income regions, and while helping regions to maintain their competitiveness. The first five policy options all directly target the agricultural emissions, whereas the last options target emission intensive production inputs or consumer products.

The assessed policy instruments are listed below:

Policies directly targeting emissions

i. Global tax on agricultural GHG emissions.
ii. OECD tax on agricultural GHG emissions.
iii. Global tax on agricultural GHG emissions combined with a food consumption subsidy
iv. Global abatement payment for agricultural GHG emission reductions.
v. OECD abatement payment for agricultural GHG emission reductions.

Policies targeting emission intensive production inputs and consumer products

vi. Consumer-level GHG tax on ruminant meat and dairy products consumed within OECD countries.
vii. Global GHG-based tax on emission intensive agricultural inputs, including ruminant animals and fertiliser
viii. OECD GHG-based tax on emission intensive agricultural inputs, including ruminant animals and fertiliser

The first five policy scenarios listed above are all assessed under dynamic settings, in which the policies are applied from 2020 through to 2050. In each of these scenarios, the same increasing carbon price pathway is applied: with GHG prices of 40 USD/tCO$_2$-eq, 60 USD/tCO$_2$-eq, and 100 USD/tCO$_2$-eq for the 2021-2030, 2031-2040, and 2041-2050 periods, respectively. These prices were considered to represent a reasonably high level of mitigation ambition compared to the much lower carbon market prices that have been observed to-date, where such markets exist. The 60 USD/tCO$_2$-eq price also approximately corresponds to the value that some modelling studies suggest will be required to limit temperature increases to 1.5°C (Rogelj et al., 2015). For technical reasons, related to the fact that the final three scenarios impose a GHG-based tax on consumer products or producer inputs, rather than directly taxing emissions, it was necessary to assess these scenarios in static mode.[1] For these cases, 2050 was selected as the simulation year and a GHG price of 100 USD/tCO$_2$-eq was applied to be consistent with the prices used in the other scenarios for this year. The mitigation performance of the policies simulated under dynamic settings is evaluated with respect to their capacity to achieve the non-CO$_2$

---

[1] For policies vi, vii and viii small policy shocks are used to restrict the tax revenue generated by taxing either consumption or inputs match the revenue that would be collected GHG tax on the emissions that are associated with these inputs and outputs. Given the small policy shocks, interaction with dynamic features is expected to be limited, so these shocks were implemented in static mode, in 2050.

emission reduction targets of 1 $GtCO_2$-eq yr^{-1} by 2030, and 2.5 $GtCO_2$-eq yr^{-1} by 2050, proposed by Wollenberg et al. (2016).

Beginning with the policies which directly target emissions, the first three follow the "polluter pays" principle by imposing a tax on emissions. The global taxes on GHG emissions, with and without the food consumption subsidy (policy i. and iii.) are the most ambitious policy options, as they assume a willingness by all countries to apply an equally strong GHG tax rate, irrespective of their development status and concerns about food production and food security. The purpose of the first policy, the global tax on emissions, is to provide a high mitigation benchmark, which can then be compared to a range of more feasible, but potentially less effective mitigation policy options. In an attempt to address concerns that low-income countries may have about negative impacts on food production and agricultural incomes, a second scenario is defined where the tax on GHG emissions is limited to OECD countries. This option is however likely to erode the competitiveness of OECD agriculture and cause a leakage of emissions mitigated by OECD countries into non-OECD countries. The third policy is a hybrid instrument that attempts to exploit the large mitigation potential that a global tax on agricultural emissions can provide, by driving the restructuring agricultural production in favour of sectors with lower GHG emissions, while at the same time providing a subsidy to consumers to try to maintain their baseline levels of food consumption.

The fourth and fifth policy options differ from all the previous options by applying the "beneficiary pays" principle and providing an abatement payment to cover the mitigation costs of agricultural producers. This policy option provides the same marginal abatement incentives as the GHG tax, but does not impose any tax burden on agricultural producers. The abatement payment is paid by government to producers and it exactly covers the producer resource costs associated with emission reductions incentivised by the selected GHG price. In the fourth policy scenario, the abatement payment is restricted to OECD countries. This allows comparison with the OECD tax on GHG emissions, to show the differences of their impacts on competitiveness.

The final three scenarios are based on polices that attempt to circumvent the substantial challenge of measuring and monitoring GHG emissions from agricultural producers by applying a GHG-based tax to either emission-intensive production inputs (ruminant animals and fertiliser) or emission intensive consumer products (processed ruminant meat and dairy products). These policies would allow a saving in transaction costs (not quantified in this assessment) related to the measurement of emissions, but they would result in a loss of economic efficiency by failing to reward producers that lower their emissions by adopting mitigation practices that aim to lower emission intensities. The consumer-level GHG tax translates the value of emissions for the given tax rate, into an equivalent tax set at the same rate for both domestic and imported consumer products within each OECD region, based on the economic emission intensity of the domestically produced product. This tax is only applied to ruminant meat and dairy products. The motivation behind this policy is to address the competitiveness and leakage issues that would typically emerge from the non-global application of a GHG tax. It is expected to do this by preserving the competitive position of domestic and imported products, by taxing them at the same rate. This policy design also removes the onerous challenge of applying different tax rates to consumer products sourced from different destinations, according to their emission intensities.

A notable omission from the set of above policy options is an emission trading scheme. It is worth mentioning however that an emission trading scheme could be designed to provide similar mitigation and economic outcomes for agriculture as the GHG tax and abatement payment mechanisms. According to economic theory, the auctioning of emission permits can provide the same mitigation incentives as a GHG tax, while the provision of free emission permits to agriculture could provide similar mitigation incentives as the abatement payment. Consequently, many of the insights about the mitigation effectiveness and economic impacts from the assessed instruments are generalizable to a broader range of market-based mitigation instruments than those assessed in this study.

3. GHG emission reductions and economic consequences of mitigation policies in agriculture

In this section the quantitative impacts of the assessed policy instruments on emission reductions, agricultural producers and food consumers are presented and explained. A more detailed regional breakdown of the modelling results is provided in the appendix in section 4.1.

The global GHG taxes, with and without the food subsidy, appear to be the most effective mitigation policies, narrowly missing the 1 $GtCO_2$-eq, non-CO_2, 2030 mitigation target, and slightly exceeding the 2.5 $GtCO_2$-eq 2050 targets described in the previous sections (Figures 3.1-3.3, Table 3.1). The global abatement payment is less effective, but is still able to go halfway towards achieving these targets. Although the GHG tax and abatement payments provide the same marginal mitigation incentives, the cost and price increases from the tax cause a contraction in the supply of and demand for agricultural products, in aggregate, but particularly from more emission intensive sectors. This contraction is a major contributor to the overall emission reductions induced by this policy in some regions. For the ruminant sector aggregated across non-OECD countries, falls in production account for 42%, 43%, 46% of emission reductions of the global GHG tax in 2030, 2040 and 2050, respectively. Globally, the contribution of falling ruminant output to the total emission reductions of the ruminant sector is more muted at 28%, 26%, and 15%, respectively, as ruminant production in OECD countries increases over all three simulation periods. Accounting for the changes in LUC emissions reveals that the taxation policies could be substantially more effective by 2050 (Figure 3.2, Table 3.1). This results from a global shift in land cover from pasture to forest and shrub land, increasing global carbon stocks over time, as the ruminant grazing footprint contracts, particularly in Sub Saharan Africa and Latin America. Following the global abatement payment, LUC emissions increase relative to the baseline (Figure 3.3, Table 3.1), mainly due an increase in cropland at the expense of forest and shrub land in South East Asia and Latin America. However, these changes in land cover are one to two orders of magnitude smaller than the changes in land cover caused by the GHG tax. This nevertheless illustrates the potential importance of coupling this policy option with regulations to prevent the clearing of non-agricultural land containing comparatively high carbon stocks. Note that the consumer-level tax and tax on input policies (scenarios vi, vii and viii) are not displayed in Figures 3.1 and 3.2, because they were only conducted for the single year period of 2050.

Figure 3.1. Global reductions in agricultural non-CO₂ emissions for dynamic policy scenarios

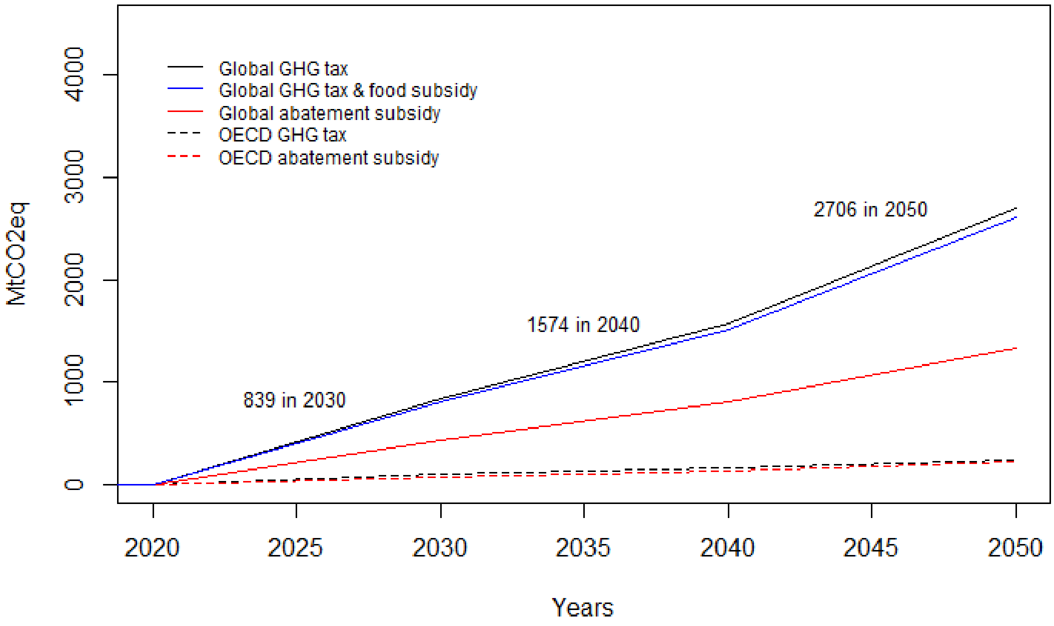


Figure 3.2. Global reductions in agricultural non-CO₂ and land use change emissions for dynamic policy scenarios

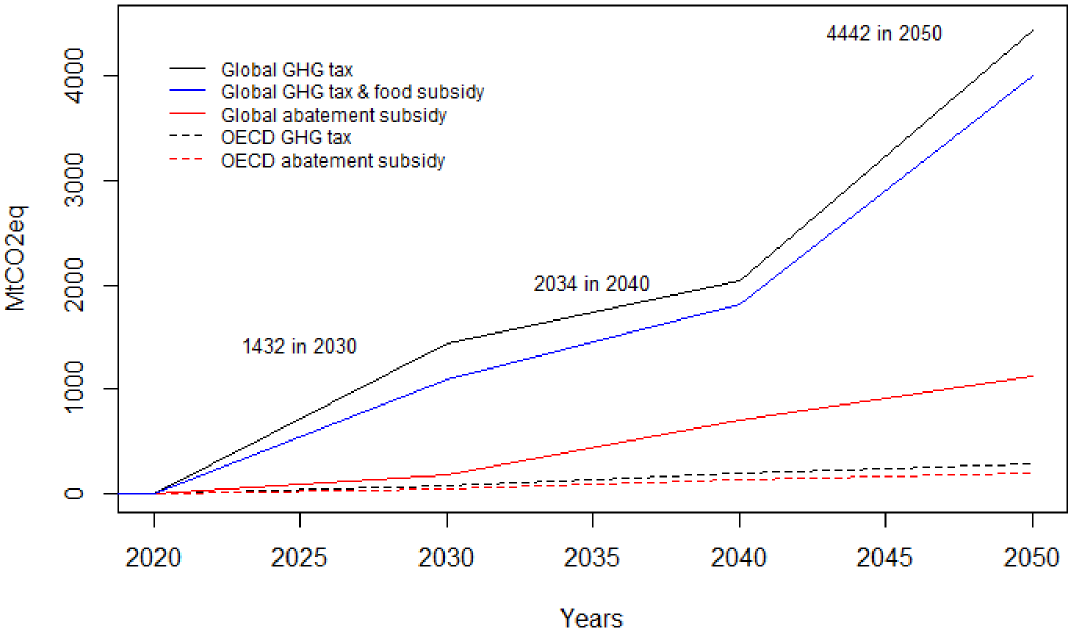
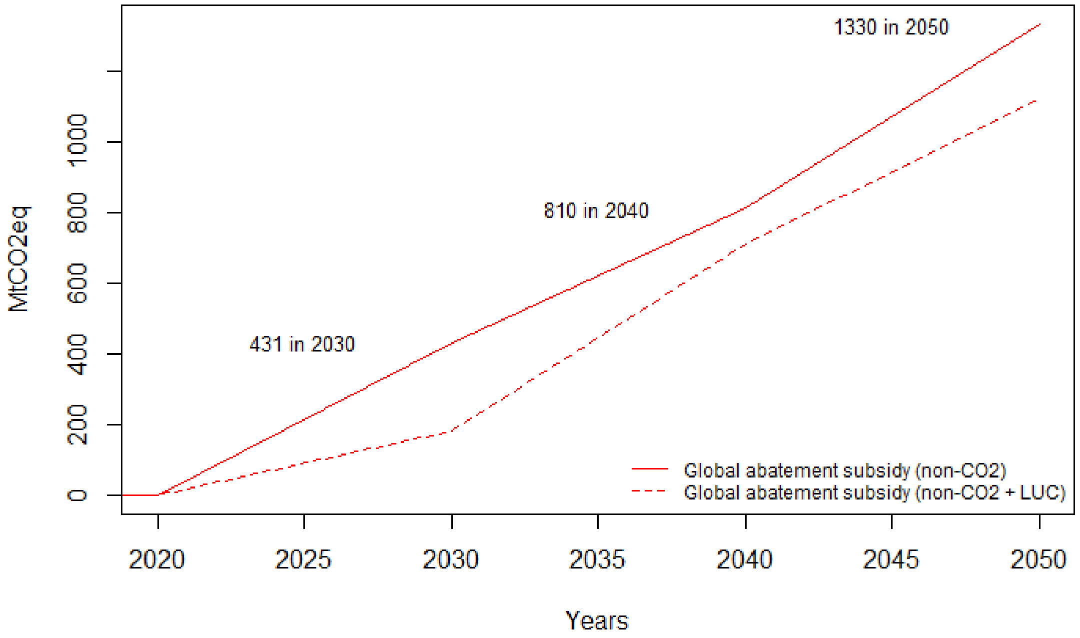


Figure 3.3. Global reductions in agricultural non-CO_2 and land use change emissions for the global abatement payment



As expected, the OECD GHG tax leads to the leakage of, or increases in, emissions in non-OECD countries, partially reducing its effectiveness (Table 3.1). The OECD GHG abatement payment is able to eliminate these leakage effects and provide a similar level of global mitigation as the OECD GHG tax, without the same negative consequences for agricultural production. Nevertheless, the policies that are confined to the OECD are able to make only small progress towards the proposed mitigation targets at the selected carbon prices (Figures 3.1-3.2, Table 3.1).

The results of the consumer-level tax and tax on input policies (scenarios vi, vii and viii) that were assessed in static mode are presented in Table 3.2. For the purposes of comparison, the global GHG tax and the global abatement payment were also assessed in static mode, for the year 2050, because dynamic and static scenario results cannot be meaningfully compared.[2] Turning to these results in Table 3.2, the global tax on ruminants and fertilisers generated less than one fifth of the emission reductions achieved by the global GHG tax and about two-fifths of the reductions from the global abatement payment. This is partly because the global tax on ruminants and fertilisers targets a smaller volume (86 percent) of the emissions than the global GHG tax and the abatement payment. When limited to OECD countries its impact is naturally much smaller, with leakage effects further weakening its effectiveness.

---

[2] The reason is that the agriculture sector is exposed to mitigation incentives over a sustained period (2020-2050) in the dynamic scenarios, causing emissions to diverge quite considerably with the dynamic baseline. In contrast, the emission reductions achieved with a specific mitigation policy applied for single year to the 2050 baseline, as is done with the static simulations, are smaller than the emission reductions achieved in 2050 under dynamic settings.

Table 3.1. Summary of annual agricultural non-CO$_2$ and LUC emission reductions policy instruments assessed under dynamic settings (MtCO$_2$-eq) in 2050

The percentages of the baseline non-CO$_2$ emissions reduced in each broad region are provided in parentheses

		OECD	non-OECD	Global	Leakage*
Global GHG tax	Non-CO$_2$	213	2,492	2,706	0%
		(15%)	(31%)	(28%)	
	LUC change	-70	1,806	1,736	
	Total	143	4,299	4,442	0%
		(8%)	(39%)	(35%)	
Global GHG abatement payment	Non-CO$_2$	224	1,106	1,330	0%
		(15%)	(14%)	(14%)	
	LUC change	-29	-180	-210	
	Total	194	926	1,120	0%
		(12%)	(8%)	(9%)	
OECD GHG tax	Non-CO$_2$	357	-122	235	34%
		(25%)	(-2%)	(2%)	
	LUC change	119	-69	49	
	Total	477	-192	284	40%
		(29%)	(-2%)	(2%)	
OECD GHG abatement payment	Non-CO2	228	-6	223	0%
		(16%)	(0%)	(2%)	
	LUC change	-12	-13	-25	
	Total	217	-19	197	0%
		(13%)	(0%)	(2%)	
Global GHG tax & food subsidy	Non-CO$_2$	199	2,413	2,611	0%
		(14%)	(30%)	(27%)	
	LUC change	-58	1,411	1,353	
	Total	144	3,861	4,005	0%
		(9%)	(35%)	(32%)	

*Note: The leakage rate is calculated as the sum of the increases in agricultural GHG emissions in non-OECD countries, divided by the sum of the reductions in agricultural GHG emissions in OECD countries.

The OECD consumer-level tax can also negate the leakage of emissions, but along with the OECD ruminant and fertiliser tax, it is one of the least effective instruments for lowering emissions. The ineffectiveness of these less targeted approaches appears to worsen when the tax is levied at the consumer stage rather than at the input stage, because the impact of the tax is further weakened by the diversion of affected farm commodities from domestic to export markets, and by the diluting effect of intermediate inputs in the final processed food products.

Table 3.2. Summary of annual agricultural non-CO_2 emission reductions for policy instruments assessed under static settings ($MtCO_2eq$) in 2050

	OECD	non-OECD	Global	Leakage*
Global GHG tax	215	1,380	1,595	0%
Global GHG abatement payment	146	579	725	0%
OECD meat & milk consumer-level tax	33	18	51	0%
Global GHG tax on ruminants & fertilisers	16	285	301	0%
OECD GHG tax on ruminants & fertilisers	59	-13	46	22%

The global GHG tax, abatement payment, and GHG tax with food subsidy, each have differing impacts not only on emission levels, but also on agricultural producers and food consumers. While the GHG tax leads to the largest emission reductions, it has the most detrimental effect on farm income (measured as value-added or returns to the land, capital and labour endowments, at agents prices), particularly in non-OECD regions. It also causes the largest reduction in food consumption (weighted by value at constant 2020 world prices), though not nearly as large as its impact on producers (Table 3.3). Conversely, it also generates the largest increases in government revenue (Table 3.4).

A different, but somewhat improved assembly of trade-offs emerges from the addition of a food consumption subsidy to the GHG tax. The combined policies have similar impacts on reducing emissions and on producers, but this time consumption is maintained and it raises a smaller, but still positive amount of government revenue in all regions apart from one. However, given the substantial negative impact of this policy on producers in low-income countries, it would be very likely to reduce food security for the rural poor in these countries. Note that in Sub Saharan Africa, the global GHG tax does not cause aggregate food consumption to fall. In this region, the crop sector benefits from the reduction in input prices that ensue from the substantial fall in emission intensive livestock production, expanding its production (see Figure A.4 in the Annex). On balance, this has positive net impact on aggregate, value-weighted, food consumption in 2050. Consequently, in this year, this region does not receive a food consumption subsidy in the GHG tax with food subsidy scenario. In all other simulation periods, aggregate food consumption weighted by value declines in all regions.[3]

The global abatement payment offers the prospect of appreciable global emission reductions (Table 3.1) without harming agricultural producers or food consumers (Table 3.3). However, in contrast to the GHG tax policies, the abatement payment needs to be paid for. In this assessment the cost of the abatement payment is paid by governments within each region. These policies not only differ in terms of who incurs the cost of abatement, but also with respect to the size of these costs, with costs of the abatement payment to government being much smaller than the cost of the GHG tax to producers. This asymmetry occurs because the abatement payment only covers the cost of reducing

---

[3] Latin America experiences a similar pattern of production effects, however the substitution effect between crops and livestock is not as strong and the share of its food derived from crop-based sources is lower than in Sub Saharan Africa. So for this region the global GHG tax causes aggregate food consumption to decline.

emissions, whereas the GHG tax is levied on the entire stream of producers' non-CO_2 emissions (i.e. both the abated and unabated portion of emissions).

Table 3.3. Changes in agricultural value-added and household food consumption from policies in 2050

	Global GHG tax		Global GHG tax & Food subsidy		Global abatement payment	
Regions *	value-added	consumption	value-added	consumption	value-added	consumption
N America	-2%	-2%	3%	0%	3%	0%
Australia-NZL	3%	-3%	8%	0%	3%	0%
Europe	0%	-2%	5%	0%	3%	0%
Mexico-Chile	-9%	-1%	-5%	0%	2%	0%
Other OECD	1%	-1%	5%	0%	2%	0%
MENA-Caspian	0%	-2%	4%	0%	2%	0%
S Asia	-13%	-1%	-9%	0%	3%	0%
SS Africa	-36%	1%	-34%	2%	5%	0%
E & SE Asia	-2%	-1%	0%	0%	2%	0%
L America	-9%	-3%	-4%	1%	4%	0%
OECD	**-1%**	**-2%**	**4%**	**0%**	**3%**	**0%**
Non OECD	**-14%**	**-1%**	**-10%**	**1%**	**3%**	**0%**
Global	**-11%**	**-1%**	**-8%**	**1%**	**3%**	**0%**

Note: OECD regions at the top of the table are listed in bold font. N America consists of the US and Canada. Europe covers all OECD European countries. Other OECD includes Japan, Korea, Israel and Turkey. MENA-Caspian includes the Middle East, North Africa and countries of the Caspian region. E & SE Asia includes China, South East Asia, and non-OECD countries in East Asia. Finally, L America includes all non-OECD Latin American countries.

In addition to their impacts of food consumption, producer income and government budgets, these instrument will also generate different economic welfare impacts. To assess these impacts, the welfare measure known as equivalent variation (EV) was used. This approach uses government expenditures as a proxy for welfare obtained for public goods (Keller 1980), and it is often used in CGE analyses to approximate changes in the efficiency with which economic resources are allocated within the economy. Global EV for the global GHG tax and the global abatement payment is -27,944 million USD and -18,430 million USD, respectively, in 2050. These figures are both negative, indicating that there is a loss of welfare associated mitigating GHG emissions with these policies. The welfare loss from the tax is about 50% larger than the loss associated with the abatement payment, however the tax generates about 100% and 300% higher non-CO_2 reductions and total emission reductions (non-CO_2 + LUC emissions), respectively (Table 3.1). Therefore, from an economic welfare perspective, the abatement payment performed worse than the GHG tax, relative to the quantity of emissions reduced. However, this is a partial evaluation of the economic welfare, because it does not consider welfare benefits in terms of the avoided damage costs associated with the emission reductions achieved by each policy.

Table 3.4. Annual changes to government budget from selected global GHG mitigation policies in 2050 (million USD)

	Global GHG tax revenue	Global GHG tax & food subsidy net	Global GHG abatement payment cost
N America	36,915	13,945	-1,863
Australia-NZL	17,096	13,462	-1,228
Europe	39,754	4,054	-1,658
Mexico-Chile	7,349	844	-455
Other OECD	7,859	342	-471
MENA-Caspian	37,873	-3,647	-1,170
S Asia	111,530	67,633	-6,909
SS Africa	111,092	113,781	-3,575
E & SE Asia	108,710	75,096	-8,485
L America	100,760	36,757	-4,859

Another more policy targeted option, which is not assessed in this study, would be to redirect part of the existing producer support that is provided to the sector for non-environmental purposes to pay for the abatement payment instrument. This potential approach for lowering the sector's carbon footprint is gathering support among international experts and agencies including the World Bank (World Bank, 2018).With 2015-2017 agricultural support for the 51 countries considered in the Agricultural Policy Monitoring and Evaluation 2018 report (OECD 2018) calculated to be worth 484 USD, there are arguably sufficient resources available to easily cover annual abatement payments calculated in this assessment for OECD and non-OECD countries, which reach 2,312 and 9,022 million USD, respectively by 2030, and 5,675 and 25,117 million USD, respectively by 2050.[4] The financial burden of this instrument would increase further if a more ambitious carbon price path, capable of reaching the sector's 2030 and 2050 mitigation targets, was assumed.

Other funding arrangements may be feasible, including for example the purchasing of agricultural emission reduction credits by other sectors that are required to pay for emitting GHGs, notwithstanding the political challenges that may be associated with initiating such transfers. This approach would presently be possible in the few locations with operational emission trading schemes (e.g. the EU and New Zealand); however more countries are expected to adopt national carbon pricing schemes in future.

Among the policies that directly target emissions, abatement payment schemes based on the voluntary enrolment of producers are arguably more feasible than GHG tax policies, by limiting onerous measurement challenges to emission reductions by producers that enrol into such schemes, rather than requiring the measurement of all producers' emissions. Perhaps this factor along with an obvious preference by agricultural producers for policies based on the "beneficiary pays" principal rather than the "polluter pays" principal, can explain why the few examples of market-based mitigation instruments for agriculture that have been applied in practice are subsidy or offset schemes. One such example is the Emission Reduction Fund in Australia, which uses a price discriminating auction mechanism to allocate government funds primarily to land use sectors, including

---

[4] Note these 2050 figures for the non-OECD countries do not sum to those presented in the table because Russia and non-OECD European countries are not included in this table.

agriculture. A useful attribute of such auction mechanisms is that they can reveal producers' private costs of abating emissions. Since 2015, the Australian government has used the Fund to contract 18 $MtCO_2$-eq of emission reductions from the agricultural sector (Clean Energy Regulator, 2018). Another includes the provincial level GHG offset scheme in Alberta, Canada, which enables producers in sectors including agriculture to generate emission reduction credits that can be purchased by industrial facilities and public sector organizations with GHG mitigation obligations (Alberta Environment and Parks, 2018). Additionally, the California Compliance Offset Program is a mechanism allowing projects in some sectors, including those that reduce emissions from livestock manure management and rice cultivation, to generate and sell offset credits under the State's Cap-and-Trade Program (Air Resources Board, 2018).

The main benefits from this study are the insights that it provides about the way the different policy instruments work and their various strengths and weaknesses. However, to provide some validation of the model results it is useful to compare the magnitudes of emission reductions from this assessment with comparable global studies. The non-CO_2 emission reduction potentials of 0.43-0.84 $GtCO_2$-eq at 40 USD/tCO_2-eq in 2030, 0.81-1.57 $GtCO_2$-eq at 60 USD/tCO_2-eq in 2030, and 1.33-2.71 $GtCO_2$-eq at 100 USD/tCO_2-eq in 2050, from the global GHG tax and abatement payment policies assessed in this study, are well within the range of potentials from existing studies in the literature. According to the most recent Intergovernmental Panel on Climate IPPC's most recent Assessment Report of the Intergovernmental Panel on Climate Change (Smith et al. 2014) annual non-CO_2 emission reductions for agriculture of 0.03-2.6 $GtCO_2$-eq, at 50 USD/tCO_2-eq,and 0.2-4.6 $GtCO_2$-eq at 100 USD/tCO_2-eq, were reported on the basis of results from different studies (Rose et al. 2012, McKinsey & Co 2009, Golub et al. 2009, Smith et al. 2008), in 2030. A more recent partial equilibrium assessment by Frank et al. (2018) calculated higher non-CO_2 mitigation potentials in 2030 of 1 $GtCO_2$-eq at only 25 USD/tCO_2-eq, but with a slightly lower mitigation potential of 2.6 $GtCO_2$-eq in 100 USD/tCO_2-eq 2050. These figures are comparable to those in this assessment, although the models differ quite significantly in structure and emission baselines and in the way they integrate abatement options.

There may also be substantial additional mitigation potential from policies that focus on changing consumers' dietary preferences to include a less emission intensive basket of food commodities (Bajzelj et al. 2014; Wollenberg et al. 2016; Poore and Nemecek 2018). However, no clear or effective policy options for achieving this have been proposed to-date. The hybrid policy assessed in this report, which combined a GHG tax with a food consumption subsidy, provides one option for incentivising such a dietary shift without sacrificing total levels of food consumption. The assessment of this policy could however be improved by focusing on maintaining the nutritional value of consumption rather than its value at constant world prices. Further, while it is clearly possible to maintain food security with this hybrid policy, greening the food baskets of consumers this way is likely to impose relatively large economic losses on producers in some regions.

As with all modelling assessments, there are caveats worth mentioning. For instance, the mitigation potentials of the policies calculated in this study may be lower than the agricultural sector's full potential, because the mitigation policies only target 78% of the sector's non land use and land use change (LULUC) emissions. Moreover, the mitigation potentials for the non-CO_2 emissions that are included are also conservative because, as discussed in section 2.1, the marginal abatement costs used in this study do not consider technological changes that would lower the costs of mitigation over time. In addition, options for sequestering soil carbon in grasslands and croplands were not considered. This omission was entirely due to the absence of a global data set on the marginal costs of soil carbon sequestration.

Furthermore, including mitigation policies in non-agricultural sectors, particularly land use sectors, as part of the policy simulations could have important implications for the performance of mitigation policies in agriculture. Competition for land between agriculture and forestry can be particularly influential for agricultural production mitigation. Research by Golub et al. (2013), using a similar CGE model showed that providing a carbon sequestration subsidy to the forestry sector can increase sequestration at both intensive margin (e.g. by encouraging management options that sequester carbon on existing forest land) and at the extensive margin (e.g. payments for the conversion of agricultural land to forest land that raises carbon stocks). The extensive margin effects can strongly increase the opportunity costs of grazing-based production and mitigation, causing extensive ruminant production and emissions to contract compared to the baseline. When combined with certain mitigation policies, such as a GHG tax on agricultural emissions, the contraction of emission intensive ruminant grazing sectors that compete with forestry for land is further exacerbated. Conversely, with limited fiscal capacity to pay for mitigation, subsidising forestry-based mitigation options could also reduce the financial resources available to fund mitigation in agriculture. Thus, considering mitigation more broadly for the land use sector as whole would be a very useful extension to this study.

Another limitation of this study is the absence of climate change impacts in the baseline and policy scenarios. It is difficult to speculate what impact climate change might have on agricultural mitigation policies over the next 30 years. The policy insights from the assessment, in terms of the relative magnitudes of the different policies and the types of trade-offs that they induce would, however, be unlikely to change very much if these impacts were taken account. At least at the global level, most studies assessing climate change impacts over time do not predict very large changes in agricultural production between now and 2050. For instance, Nelson et al. (2013) only project a mean global decline in crop production of 2% by 2050, and van Meijl et al. (2018) simulate a similarly small decline in agricultural production (crop and livestock) of between 0.5 and 2.5% by 2050. Still, there will be larger impacts in some regions. Importantly however, van Meijl et al. (2018) found, in a model inter-comparison study covering five global models (IMAGE, CAPRI, GLOBIOM, MAgPIE, MAGNET), that non-CO_2 emission taxes and land-based mitigation policies in agriculture, commensurate with the sector's contribution to a 2ºC global warming target, will have a much larger negative impact on agricultural production than the effects of climate change.

It would also have been instructive to assess the impacts of transferring a portion of existing coupled support payments to agriculture to fund the GHG abatement payment. However, given that the level of support among countries is so variable, some countries could easily fund abatement this way, while others could not. Consequently, this approach could result in quite differentiated impacts, with countries that are able to transfer coupled support to abatement activities possibly experiencing stronger reductions in emissions and output as a consequence of removing support. Further work on quantifying these impacts is recommended, including the calculation of possible emission leakage effects that may arise from the ensuing adjustments in competiveness.

References

Aguiar, A., B. Narayanan and R. McDougall (2016), "An Overview of the GTAP 9 Data Base", *Journal of Global Economic Analysis* Vol. 1, pp 181-208.

Air Resources Board (2018), Compliance Offset Program, https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm (accessed 4 October 2018).

Alberta Environment and Parks (2018), Alberta Carbon Offset System, http://aep.alberta.ca/climate-change/programs-and-services/alberta-carbon-offset-system.aspx (accessed 9 March 2018).

Bajzelj, B., et al. (2014) "Importance of food-demand management for climate mitigation", *Nature Climate Change*, Vol. 4, pp. 924–929.

Clean Energy Regulator (2018), Emissions Reduction Fund, http://www.cleanenergyregulator.gov.au/ERF (accessed 9 March 2018).

Gernaat, D., K. Calvin and P. Lucas (2015), "Understanding the contribution of non-carbon dioxide gases in deep mitigation scenarios", *Global Environmental Change*, Vol. 33, pp. 142–153.

Golub A., T. Hertel, H. Lee, S. Rose, and B. Sohngen (2009), "The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry", *Resource and Energy Economics*, 31, 299 – 319.

Frank, S. et al. (2018), "Structural change as a key component for agricultural non-CO_2 mitigation efforts", *Nature Communications*, Vol. 9, Article 1060.

Fricko, O. et al. (2017), "The marker quantification of the shared socioeconomic pathway 2: a middle-of-the-road scenario for the 21st century", *Global Environmental Change*, Vol. 42, pp. 251-267.

Hertel, T., and M. Tsigas (1997), "Structure of GTAP", in *Global trade analysis: modelling and applications*, Hertel, T. (eds.). Cambridge University Press, Cambridge, UK.

Irfanoglu, Z. and D. van der Mensbrugghe (2015), "Development of the version 9 non-CO2 GHG emissions database", Documentation accompanying dataset. Center for Global Trade Analysis, Purdue University, USA.

Keller, W. (1980), *Tax incidence: a general equilibrium approach.* Amsterdam, The Netherlands.

OECD (2018) Agricultural Policy Monitoring and Evaluation 2018. OECD Publishing.

McKinsey & Company (2009), "Pathways to a low-carbon economy: version 2 of the Global Greenhouse Gas Abatement Cost Curve", McKinsey & Company, London

Nelson, G., et al., (2013), "Assessing uncertainty along the climate-crop-economy modeling chain", *PNAS*, Vol. 111, pp. 3274-3279.

Poore, J. and T. Nemecek (2018), "Reducing food's environmental impacts through producers and consumers", *Science*, Vol. 360, pp. 987 – 992.

Rogelj, J.et al. (2015), "Energy system transformation for limiting end-of-century warming to below 1.5°C", *Nature Climate Change*, Vol. 5, pp. 519-528.

Rose, S. et al. (2012), "Land-based mitigation in climate stabilization", *Energy Economics*, Vol 34, pp. 365-380.

Smith, P., et al. (2008), “Greenhouse gas mitigation in agriculture”, *Philosophical Transactions of the Royal Society B: Biological Sciences*, Vol. 363, pp. 789 – 813.

Smith, P., et al. (2014), “Agriculture, Forestry and Other Land Use (AFOLU)”, in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Edenhofer, O., et al. (eds.). Cambridge University Press, Cambridge, UK and New York, NY, USA.

US EPA (2013), *Global mitigation of non-CO2 greenhouse gases: 2010–2030*. EPA 430-R-13-011. US EPA, Washington DC, USA.

van Meijl H., (2018), “Comparing impacts of climate change and mitigation on global agriculture by 2050”, *Environ. Res. Lett.*, Vol. 13, 064021

Wiebe, K., et al. (2015), “Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios”, *Environmental Research Letters*, ERL-100988, Vol. 10, Nr. 8, pp. 85010-85024.

Wollenberg, E., et al. (2016), “Reducing Emissions from Agriculture to Meet the 2°C Target”, *Global Change Biology*, Vol. 22, pp. 3859-3864. doi: 10.1111/gcb.13340.

Woltjer G, Kuiper M, A. Kavallari, H. van Meijl, J. Powell, M. Rutten, L. Shutes and A. Tabeau, 2014, “The MAGNET model - Module description”. LEI Report 14-057. The Hague: LEI - part of Wageningen UR (University & Research centre).

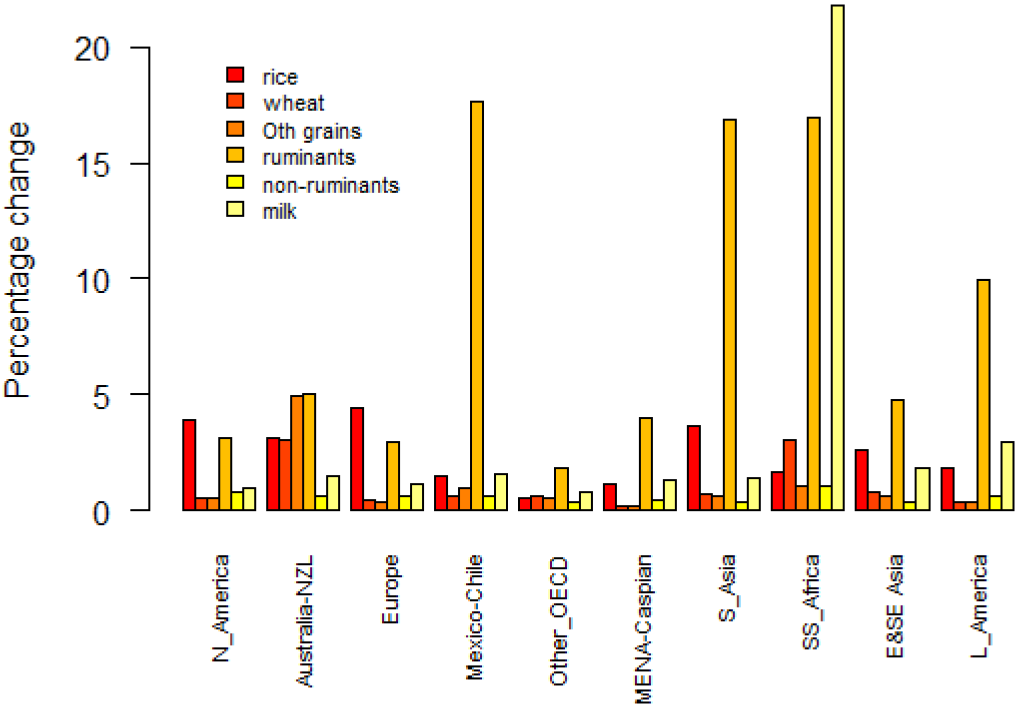
World Bank, (2018) Realigning Agricultural Support to Promote Climate-Smart Agriculture. Agriculture Global Practice Note. Washington, D.C.: World Bank Group.

4. Annex

4.1. Region-specific information and results

The economic impacts of mitigation policies on the different agricultural sectors and regions depend on the mitigation opportunities embedded in the MACs, and on the economic emission intensity of the sector's output (i.e. the amount of GHG emissions from a sector divided by the economic value of its output). A breakdown of these emission intensities by region for the various agricultural sectors is shown in Figure A1. While there is a large variation in emission intensities across countries within a given sector, they are by far highest in the ruminants sector.

Figure A1. The emission intensity of production expressed as kg CO_2-eq per USD value of primary agricultural product in 2020, inclusive price supports and other distortions



4.1.1. Regionally differentiated impacts of the GHG taxes

The global GHG tax provides the largest mitigation potential equivalent to 28% of global non-CO_2 agricultural emissions in 2050, but induces large reductions in agricultural production, particularly in emission intensive livestock sectors in non-OECD regions, such as Sub-Saharan Africa and Latin America. Some agricultural commodities in OECD regions with high levels of export trade, such as ruminant products in Australia – New Zealand are also likely experience relatively large falls in output from a GHG tax, especially if it is restricted to OECD countries. On the other hand, in paddy rice production in East and South East Asia significant emission reductions can be achieved with relatively little impact on output.

Unsurprisingly, the largest emission reductions come from the non-OECD regions with the largest baseline emission levels: Sub-Saharan Africa, South Asia, East & South East Asia and Latin America (Figures A2 and A3). Livestock contribute the most these reductions in these regions except for East and South East Asia, where paddy rice production is important. In contrast, the demarcation in the size of the percentage falls in agricultural output between OECD and non-OECD regions is less apparent (Figure A4). Livestock production experiences the largest changes, however, a similar number regions experience falls in crop production. At this level of disaggregation, the percentage falls in livestock output in Mexico-Chile, Sub-Saharan Africa and Latin America are notable, due to the high emission intensity of production in these regions.

Figure A2. Changes in agricultural non-CO_2 & LUC emissions from the global GHG tax in 2040

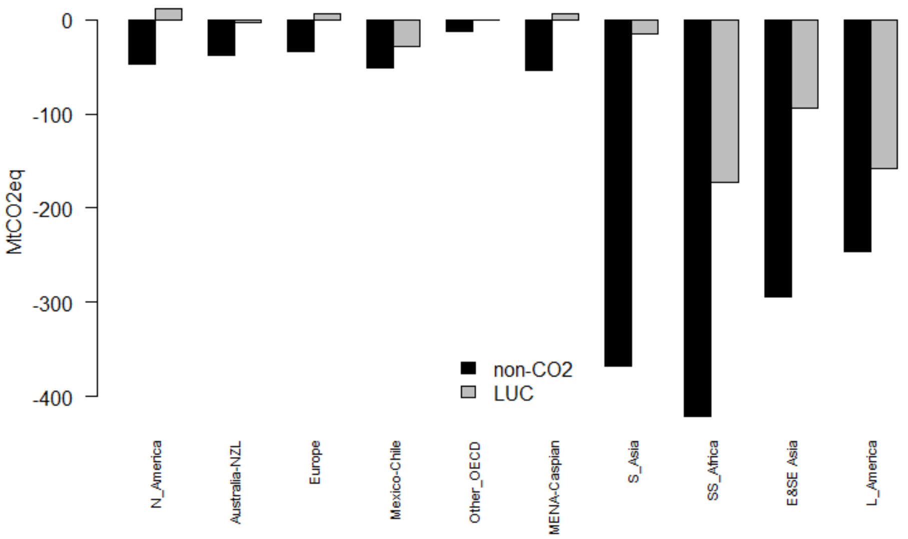


Figure A3. Changes in crop and livestock non-CO_2 emissions from the global GHG tax in 2040

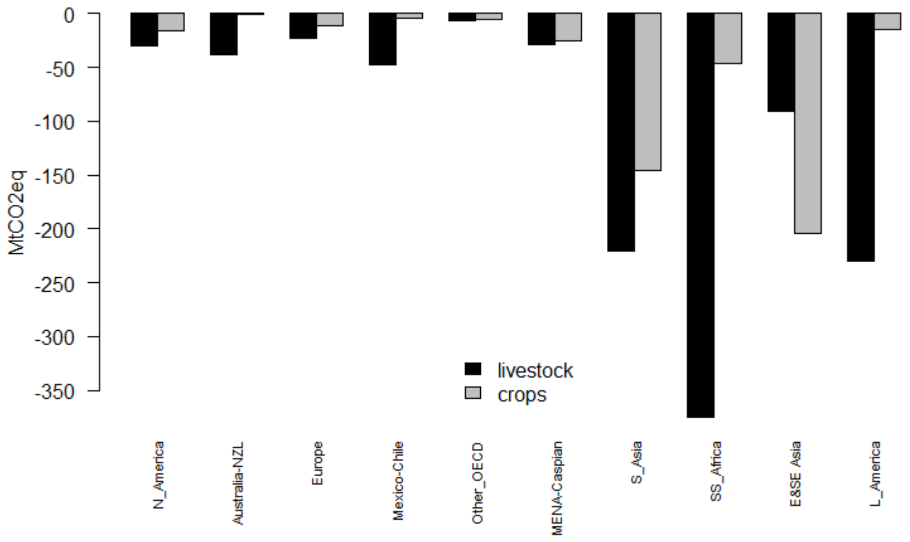
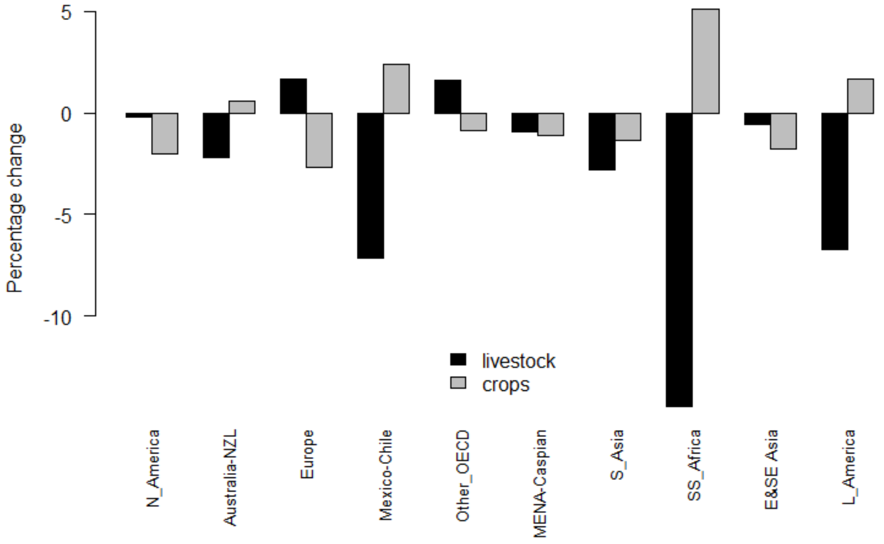


Figure A4. Percentage changes crop and livestock output caused by the global GHG tax in 2040



Given concerns about food security, agricultural development, it is useful to test the scenario in which OECD countries take the lead in adopting an ambitious mitigation policy in agriculture. As expected, restricting the tax to OECD countries caused production in this region to fall and production in non-OECD countries to increase (Figure A6), leading to the leakage of 34% of the 357 $MtCO_2$-eq non-CO_2 emission reductions from OECD countries (Figure A5). The regional pattern of these global leakage effects is clearly visible in Figure A5. Australia-New Zealand and Mexico-Chile experience relatively large livestock production losses, the former in particular owing to its high trade exposure and relatively large ruminant sector. Concerns about food security can also be addressed with the hybrid policy instrument which combines a food consumption subsidy with the GHG emission tax, to maintain food consumption at baseline levels. Since the pattern of GHG emission and output changes by region with this policy are very similar to the changes obtained with the global GHG tax, the results are not reported here.

Figure A5. Changes in crop and livestock non-CO_2 emissions from the OECD GHG tax in 2040

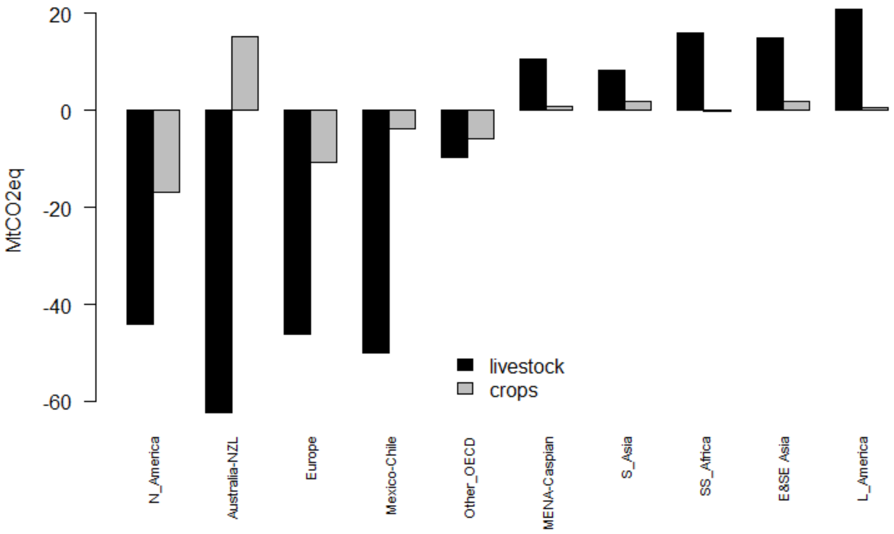
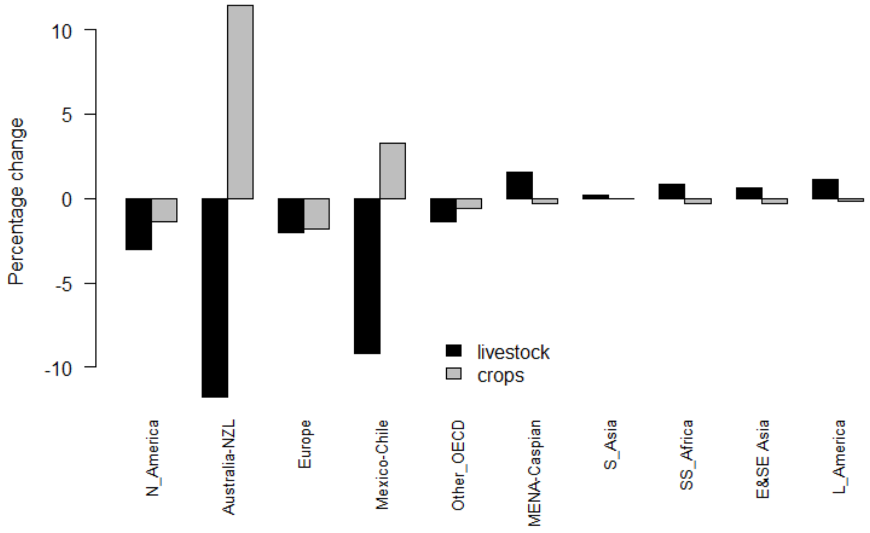


Figure A6. Percentage changes in crop and livestock output caused by the OECD GHG tax in 2040



4.1.2. Regionally differentiated impacts of the GHG abatement payment

The global abatement payment has some similarities with the global GHG tax, with most of the mitigation occurring in non-OECD countries, although the overall reductions are lower with the former. One notable difference is that livestock emission reductions in Sub Saharan Africa are much lower with the abatement payment (Figure A8), which reflects the fact that much of the emission reduction from the global GHG tax in this region was caused by a contraction in output, rather than from a reduction in emission intensity. Further, emission reductions are higher for Europe with the abatement payment compared to the tax, because the latter induces an increase in European livestock production and exports, particularly for ruminant products. This increase is a consequence of trade effects, with large declines in output from more emission intensive regions being partially offset by exports of less emission intensive European livestock. Finally, the two OECD regions in which livestock production was most negatively affected by the global GHG tax (Australia-New Zealand and Mexico-Chile) both experienced extremely small changes in production with the abatement payment (Figure A9).

Figure A7. Changes in agricultural non-CO_2 & LUC emissions from the global abatement payment in 2040

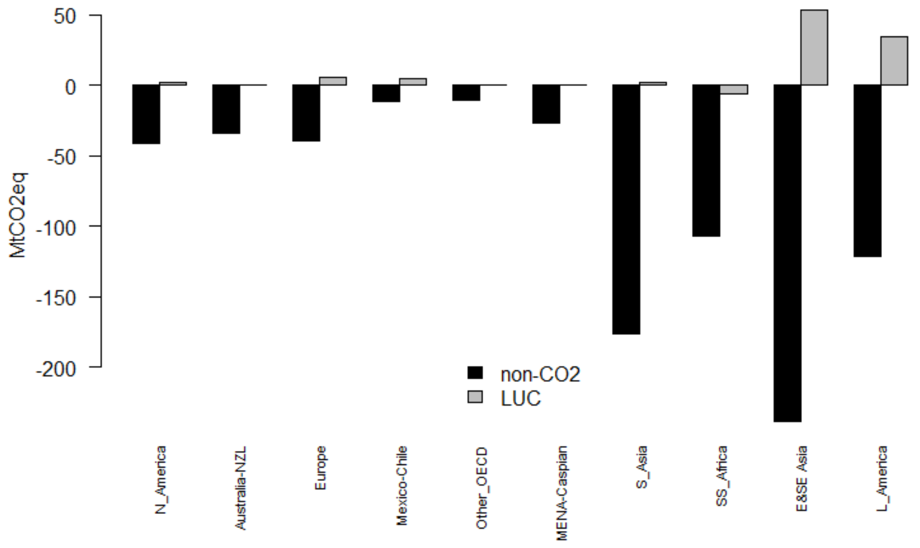


Figure A8. Changes in crop and livestock non-CO_2 emissions from the global abatement payment in 2040

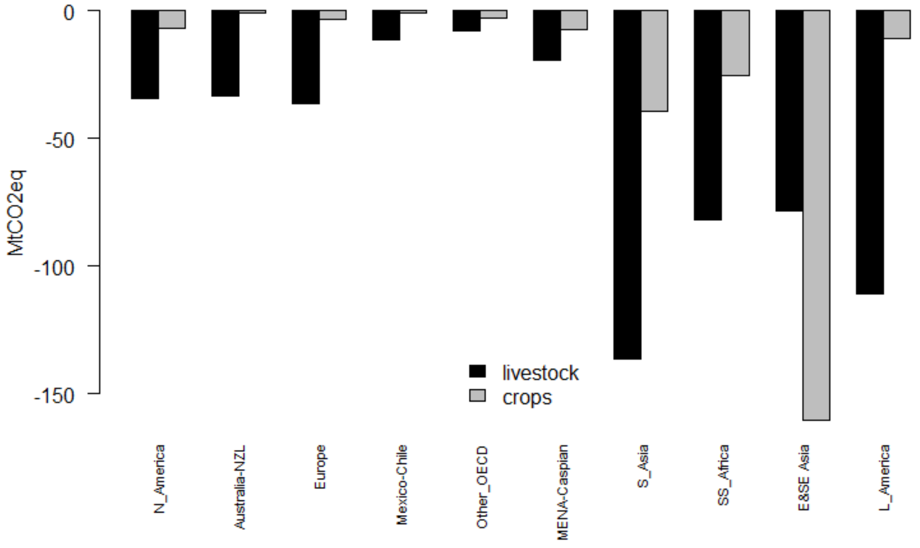
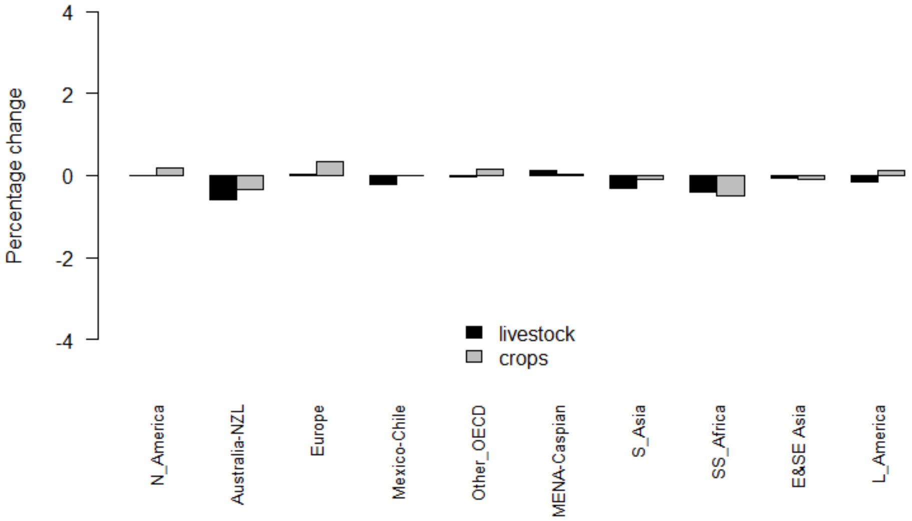
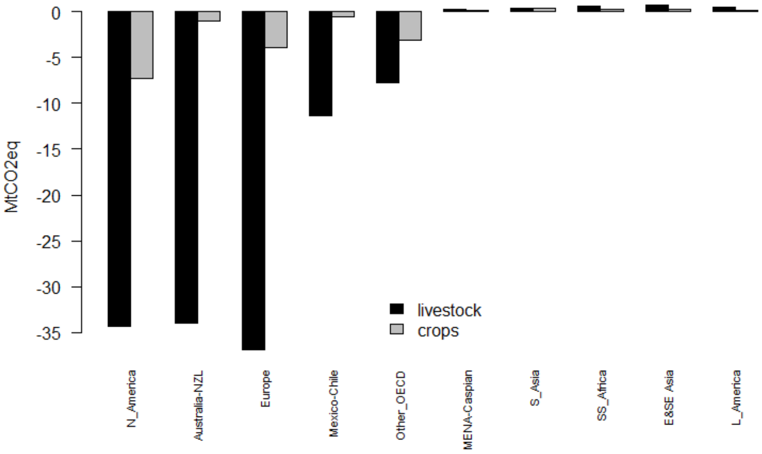


Figure A9. Percentage changes in crop and livestock output caused by the global GHG abatement payment in 2040



The results from the OECD abatement payment shown below in Figure A10 indicate that this policy is clearly effective at maintaining the competitive positions of the OECD countries relative to the non-OECD. The OECD emission reductions are the same in both the global and the OECD versions of this policy, and with the latter there is virtually no evidence of emissions leakage into non-OECD countries.

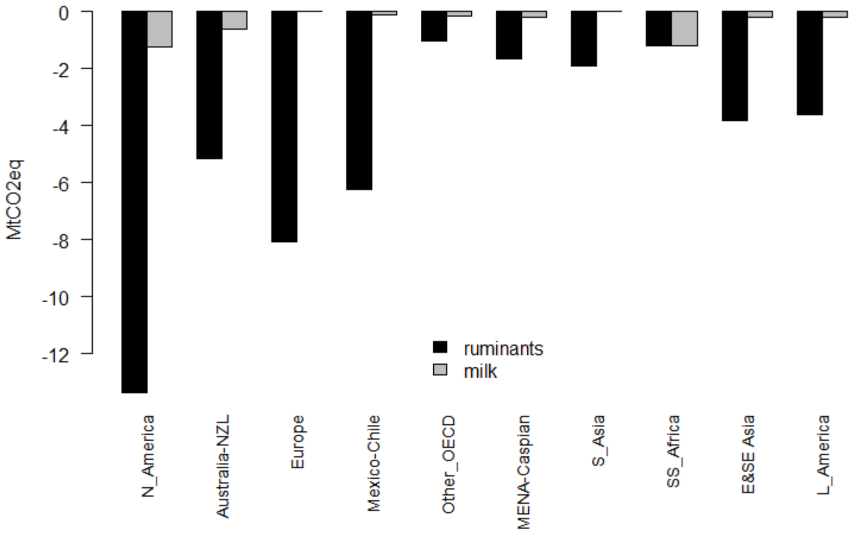
Figure A10. Changes in crop and livestock emissions from the OECD GHG abatement payment in 2040



4.1.3. Trading-off mitigation effectiveness to control leakage, with an OECD consumer-level GHG tax

The consumer-level GHG tax on ruminant meat and dairy products is another policy instrument that aims to control leakage, should the OECD decide to take the lead in the absence of action on mitigation elsewhere in the world. As shown in Figure A11, the policy performs well on the basis of this objective with emissions in non-OECD countries falling slightly rather than increasing. The reductions in non-OECD emissions are caused by the reduction in demand for non-OECD ruminant meat and dairy products, following the introduction of the consumer-level tax. However, this policy instrument does not deliver a much mitigation compared to the OECD tax on GHG emissions. There are several reasons for its relative ineffectiveness. First, the consumer-level tax does not provide producer level incentives to adopt mitigation practices. The mitigation responses are therefore limited to consumers reducing demand for these products in response to price increases caused by the tax. Furthermore, there are numerous inputs used to process cattle meat and dairy productions in addition to ruminant and milk farm products, and not all ruminant and milk farm products go to domestic processors and consumers and in some regions, such as Australia-New Zealand, a large share of both farm and processed ruminant products are exported. Thus, when the consumer-level tax deflates domestic demand, the supply of these products to export markets becomes more attractive and increases, thereby lowering the effectiveness of the policy. Thus, despite the fact that the consumer-level tax generates larger percentage reductions in the consumption of processed ruminant and dairy products than the OECD tax on emissions, its impact on producer level emissions are much lower.

Figure A11. Changes in Ruminant and milk non-CO_2 emissions from the OECD consumer-level GHG tax on ruminant meat and dairy products in 2050



4.2. Additional MAGNET model specification details

4.2.1. Overview of the MAGNET model structure

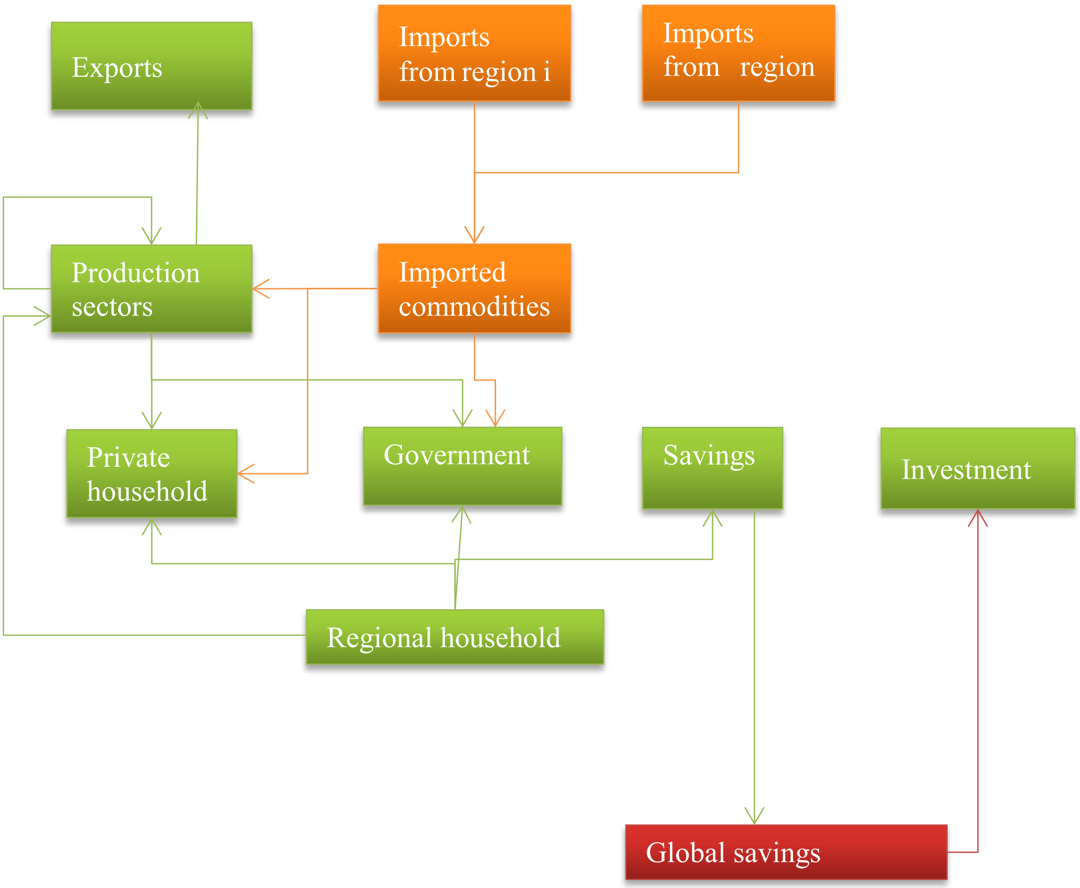
As explained in section 2.1, the MAGNET (Modular Applied GeNeral Equilibrium Tool) model is a recursive dynamic multi-sector, multi-region Computable General Equilibrium (CGE) model that covers the global economy (Woltjer et al., 2014). MAGNET has the standard GTAP model (Hertel and Tsigas, 1997) at its core, which is a CGE model covering all major countries and sectors in the world. A simplified diagrammatic representation of the GTAP model is provided in Figure A12. Here it is shown that the production sectors are supplied with factors (skilled and unskilled labour, capital, land, and natural resources) by the regional household. Commodities are produced by combining these factors with intermediate inputs from other sectors. These commodities are either exported or supplied to domestic markets to meet the demand for commodities by government and the private household sector (Woltjer et al., 2014). There is a single representative household in each region that demands consumption goods (including savings) on the behalf of both the government and private household sectors. Total demand is driven by income earned from value-added factors (land, labour and capital) and from taxes, while this is met by national producer sectors or imports (Woltjer et al., 2014).

Agriculture and all other production sectors are connected through the various input and commodity markets in the economy. For example, agricultural sectors compete with other sectors for value-added factors and intermediate inputs (e.g. fuel, energy, transport, financial services etc.). There are also complementary relationships between agriculture and other production sectors which supply intermediate inputs to agriculture and vice versa (e.g. in the case of food processing and biofuel sectors). The impact of policies supporting agricultural production could cause production in other sectors to either increase (where complementary effects dominate) or decrease (where competition effects dominate).

The model captures trade between all regions in the model and includes trade barriers between regions via tariffs, which can create a wedge between prices in regions. All bilateral flows in international trade are traced in the model and all international capital flows are modelled by a global bank, which makes international investments with collected savings. Further information on GTAP can be found in (Hertel and Tsigas, 1997) and details on the specific modifications made to GTAP in developing MAGNET are outlined in (Woltjer et al., 2014).

The regional aggregation scheme used in this assessment is outlined in Table A1.

Figure A12. A simplified representation of the GTAP model



Source: Woltjer et al., (2014)

Table A1. The 21 region aggregation scheme for the MAGNET model assessment, showing the correspondence between model regions and countries

Region or country	Countries in regional aggregates
1. Australia – New Zealand	Australia, New Zealand
2. Brazil	
3. Chile	
4. Mexico	
5. Other Latin America	Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Guyana, Suriname, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Belize, Caribbean
6. Canada & Rest of North America*	Canada, Greenland, Saint Pierre and Miquelon
7. USA	
8. Caspian region	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgystan, Tajikistan,Turkmenistan Uzbekistan
9. China-Hong Kong & Other East Asia	China-Hong Kong, Mongolia, Macao, Taiwan, North Korea
10. Japan – Korea	Japan, Republic of Korea
11. South-East Asia	Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Brunei Darussalam, Myanmar, Timor-Leste, Rest of Oceania (excluding Aust-NZL)
12. Central EU(27+OECD)	Austria, Belgium, Germany, Luxembourg, Netherlands, Switzerland, Czech Republic, Poland Slovakia, Hungary, Romania
13. Northern EU(27+OECD)	Denmark, Estonia, Finland, Iceland, Liechtenstein, Ireland, Latvia, Lithuania, Norway Sweden, UK
14. Southern EU(27+OECD)	Croatia, Greece, Italy, Malta, Portugal, Slovenia, Spain, Cyprus,[1,2] France, Bulgaria
15. Israel-Turkey	Israel, Turkey
16. Russia	
17. Other Europe	Albania, Andorra, Belarus, Bosnia and Herzegovina, Gibraltar, Montenegro, Former Yugoslav Republic of Macedonia, San Marino, Serbia, Moldova, Ukraine
18. India	
19. Other South Asia	Afghanistan, Bangladesh, Nepal, Pakistan, Sri Lanka, Afghanistan, Bhutan, Maldives
20. Middle East & North Africa	Oman, Bahrain, Islamic Republic of Iran, Kuwait, Qatar, Saudi Arabia, United Arab Emirates, Iraq, Lebanon, Syrian Arab Republic, Yemen Egypt, Morocco, Tunisia, Algeria, Libya, Western Sahara
21. Sub-Saharan Africa	Angola, Botswana, South Africa, Lesotho, Namibia, Swaziland, Malawi, Mozambique, United Republic of Tanzania, Zambia, Zimbabwe, Madagascar, Uganda, Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Mauritius, Mayotte, Niger, Nigeria, Réunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Togo

Note: Greenland is combined with the Rest of North America in the GTAP database upon which all global CGE models depend. However, compared to Canada its agricultural output is miniscule.

1. Note by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus" issue.

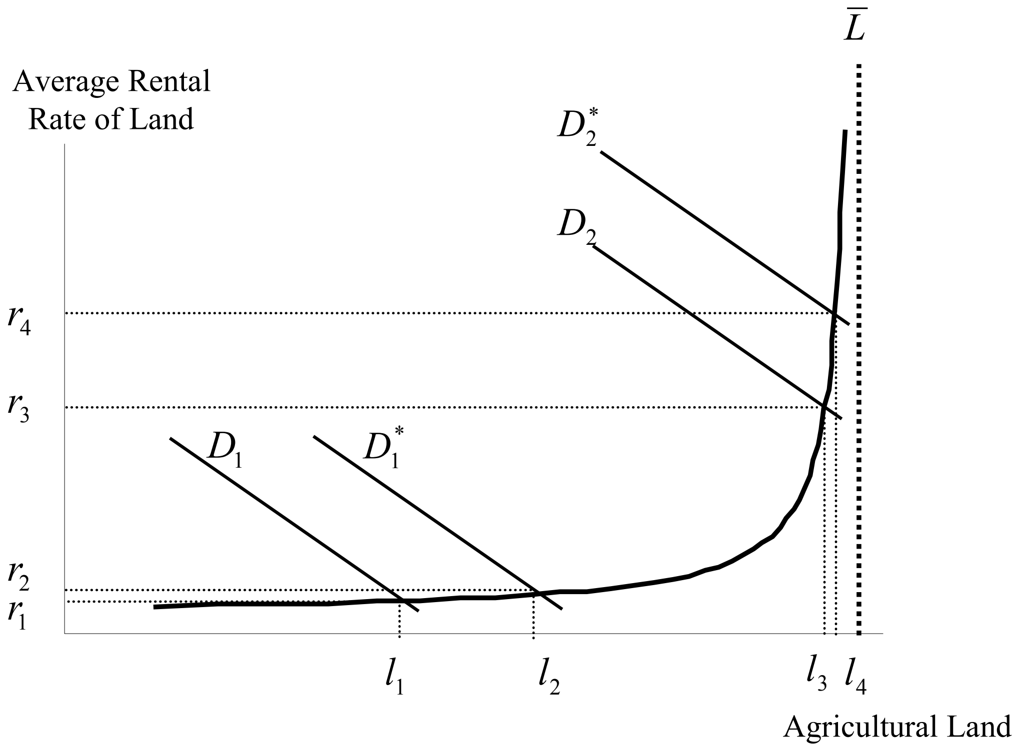
2. Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

4.2.2. Land supply

MAGNET implements a land supply curve which specifies the relationship between land supply and land price. As demand increases, more land will be used for agricultural production leading to land scarcity and therefore increased land prices. Total land supply is exogenous in the standard GTAP model. In this extended version, total agricultural land supply is modelled using a land supply curve specifying the relationship between land supply and a land rental rate in each region (van Meijl et al., 2006, Eickhout et al., 2009). Land supply to agriculture can be adjusted by idling agricultural land, converting non-agricultural land to agriculture, converting agricultural land to urban use, and agricultural land abandonment.

Figure A.13 gives the general idea behind the land supply curve. When agricultural land use approaches potential land use $(\bar{L})$, farmers are forced to use less productive land with higher production costs (strongly increasing part of the supply curve). As a consequence, in land-abundant regions like South America and for members of NAFTA, an increase in demand for crops from D_1 to D_1* (left-hand side of Figure A.13) results in a large increase in land use (from l_1 to l_2) and a modest increase in rental rates (from r_1 to r_2), while land scarce regions like Japan, Korea and Europe experience a small increase in land use and a large increase in the rental rate (right-hand side of Figure A.13; shift from D_2 to D_2*). The key problem is the empirical implementation of this land supply curve for all major regions in the world, as land price data are not available on a global scale and estimates of agricultural land potential are uncertain. Information used to determine the total potential land that could be available for agriculture we take from IMAGE modelling system (Mandryk et al., 2015) and land supply elasticities from Tabeau at al. (2017).

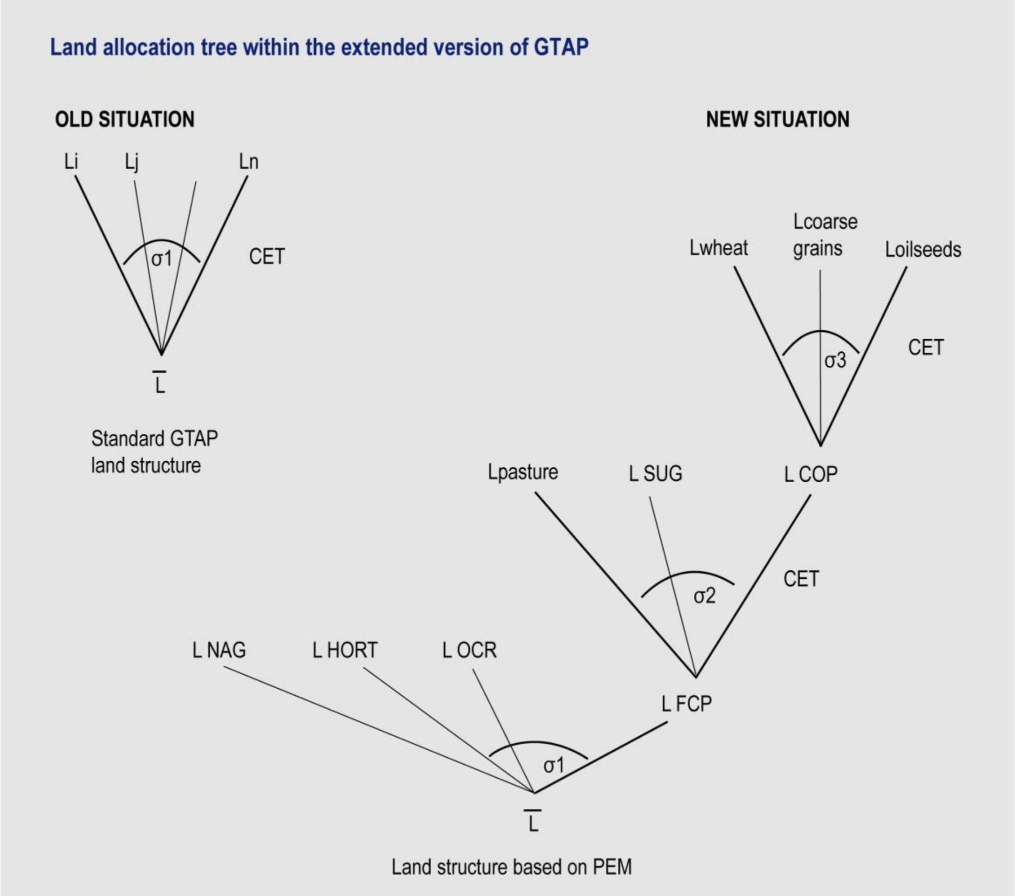
Figure A.13. Impact of an increase in crop demand on agricultural land markets



4.2.3. Land allocation

MAGNET assumes different substitutability amongst groups of land use types, with the degree of substitutability varying across but not within the groups and considers three hierarchical land use type groups (nests). Land heterogeneity is introduced by using a Constant Elasticity of Transformation (CET) function. To analyse the impact of biofuels and fertilizers, the functioning of the land market is particularly crucial. Birur et al. (2007) used agro-ecological zones in combination with an exogenous land supply, following the methodology outlined in Lee (2005). We propose an alternative to traditional methods by introducing a new demand structure that reflects the different degrees of substitutability between agricultural land uses according to the crops considered (Huang et al., 2004). The standard version of GTAP represents land allocation in a CET structure (Figure A.14 assuming that the various types of land use are imperfectly substitutable, but with equal substitutability among all land use types. For our purposes, the land use allocation structure is extended by taking into account that the degree of substitutability differs between types of land (Huang et al., 2004) using the more detailed OECD's Policy Evaluation Model (PEM) structure (OECD, 2003) (Figure A.14). It distinguishes different types of land in a nested 3-level CET structure. The model covers several types of land use with different suitability levels for various crops (i.e. cereal grains, oilseeds, sugar cane/sugar beet and other agricultural uses).

Figure A.14. Land allocation tree within the extended version of GTAP



Note: Following the PEM approach (OECD, 2003), there is nested substitutability between land for horticulture (LHORT), other crops (LOCR) and field crops and pasture (LFCP), between land for pasture (Lpasture), sugar crops (LSUG) and cereal, oilseed and protein crops (LCOP), and between land for wheat (Lwheat), coarse grains (Lcorse grains) and oilseeds (Loilseed).

The lower nest assumes a constant elasticity of transformation between 'vegetables, fruit and nuts' (HORT), 'other crops' (e.g. rice, plant-based fibers; OCR) and the group of 'Field Crops and Pastures' (FCP). The transformation is governed by the elasticity of transformation σ1. The FCP-group is itself a CET aggregate of Cattle and Raw Milk (both Pasture), 'Sugarcane and Beet' (SUG), and the group of 'Cereal, Oilseed and Protein crops' (COP). Here, the elasticity of transformation is σ2. Finally, the transformation of land within the upper nest, the COP-group, is modelled with an elasticity σ3. In this way, the degree of substitutability of types of land can be varied between the nests. Agronomic features are captured to some extent. In general it is assumed that σ3> σ2 >σ1, which implies that it is easier to change the allocation of land within the COP group, while it is more difficult to move land out of COP production into, say, vegetables. The values of the elasticities are taken from PEM (OECD, 2003).

A post simulation calculation procedure is used in the MAGNET model to account for CO_2 emissions from land use change (LUC), associated with changes in above and below ground carbon stocks between three aggregate types of land cover: cropland; grazing land; and forest shrub land and savannah land. The coefficients determining these changes in carbon stocks and CO_2 emissions are drawn from the AEZ-EF model described in Plevin et al., (2014).

4.2.4. A flexible CES tree production structure and linkage between crop and livestock sectors

All types of CES trees can be easily implemented. At this moment most sectors have the possibility to substitute between different production factors and between capital and energy. The petroleum sector has the possibility to substitute between ethanol, biodiesel and fossil fuels. The animal feed sector can substitute between (grass) land and animal feed from crops, and within animal feed from crops between different types of animal feed, including relevant by-products that change with biofuel production like DDGS, oilcake and molasses. The agricultural sectors can also substitute between land and fertilizer, while the ethanol sector can substitute between different feedstocks. In this study, a two-level nested structure is used to represent substitution possibilities between pasture land and compound feed for animal production (first level) and substitution between compound feed feedstocks (second level). Furthermore, we use a one-level nested CES structure to account for substitution among ethanol feedstocks. The blending sector and the fertilizer composite are explained below.

Livestock sectors are linked in various ways to the crop sectors. First, livestock sectors use crops (e.g. wheat, coarse grains, oilseeds, other crops) in their feed mix to raise the animals. In the feed mix agricultural crops compete with compound feed, oilcakes, molasses and by-products from biofuel production (DDGS). Secondly, crop and livestock sectors both compete in the land, labour and capital factor markets. Pasture land can be converted to crop land and vice versa (see, Figure A.14). The nested land structure implies that it is more difficult to convert pasture land into crop land and vice versa than to convert for example wheat in coarse grains land within the LCOP nest. There is no link in the model that allows using organic fertilizers (e.g. manure) from the animal sectors in the crop sectors.

4.2.5. Specification of trade flows, taxes and subsidies

MAGNET assumes that that products traded internationally are differentiated by country of origin following the Armington assumption. This assumption generates smaller and more realistic responses of trade to price changes than implied by models of homogeneous products (Armington, 1969). The Trade or Armington elasticities are taken from the GTAP database (Aguiar et al., 2016).

Additional taxes and subsidies (including the GHG taxes, abatement payments and food consumption subsidies model in this study), are not a priori (by design) redistributed within the economy, but they induce a higher government deficit or surplus. The GHG taxes lead to a lower deficit or higher surplus and the abatement subsidies to the opposite.

4.2.6. Incorporation of marginal abatement cost curves

As discussed in section 2, the model incorporates non-CO_2 emissions data, including methane (CH_4) from enteric fermentation and manure management in the livestock sectors and from paddy rice production, as well as and nitrous oxide (N_2O) from livestock manure and urine, and from crop fertiliser use. Livestock non-CO_2 emissions and Rice CH_4 emissions are tied to the output variables of these respective sectors within the MAGNET model. Whereas N_2O emissions from crop fertiliser use are tied to the fertiliser input variable in these sectors. Data on the percentage reductions of these main non-CO_2 emission sources for a given GHG price, along with the costs of abatement at that price, were obtained from the MAC curves reported in USEPA (2013). These MAC curve data have a global coverage and they were aggregated to match the 21 regions used in the MAGNET for this assessment. The MAC curve data for livestock non-CO_2 emissions and rice CH_4 emissions were incorporated into the MAGNET model by applying the same percentage changes from the USEPA MAC curves within the relevant agricultural sectors of the MAGNET model. The corresponding abatement costs were included by using negative total factor productivity shocks, which require each of the livestock and rice sectors to use more production resources to produce the same amount of output. The additional costs imposed by these shocks were set at a level that matched the positive portion of the abatement costs reported in the USEPA MAC curves. A caveat related to this approach is that the input resource changes associated with implementing the abatement practices in the USEPA MAC curves will not be precisely matched to the agricultural input changes in MAGNET. Importantly, however, the approach used in this assessment incorporates costs that match the positive costs in the USEPA MAC curves, and ensures that the abatement responses in MAGNET entail the use of additional input resources. The USEPA MAC curves also include negative costs for the initial levels of abatement in each sector, however, these negative costs were assumed to be zero in this assessment. This conservative assumption inflates the costs of the abatement options in this model relative to the USEPA MAC curves. A similarly conservative approach is applied in other CGE studies that use USEPA MAC data (Golub et al., 2013; Golub et al., 2009). The USEPA MAC curves were available for the years 2020 and 2030, and these were matched to the corresponding simulation years in the MAGNET model. The year 2030 marginal abatement cost data from USEPA (2013) were also applied for the 2040 and 2050 simulation years in MAGNET. For N_2O emissions from fertiliser use by crops, the standard substitution relationships between fertilisers and other intermediate inputs, and between intermediate inputs and value-added, which are governed by the price elasticity of substitution parameters in the model, where considered to provide an adequate representation of the abatement responses and costs in the model. Therefore, no additional abatement structure was added to the model to manage the abatement responses of this emission source. Similar assumptions were also used in CGE assessments by Golub et al., (2013) and Golub et al., 2009).

Annex references

Aguiar, A., B. Narayanan and R. McDougall (2016), "An Overview of the GTAP 9 Data Base", Journal of Global Economic Analysis, Vol. 1, pp. 181-208.

Armington, P. (1969), “A Theory of Demand for Products Distinguished by Place of Production”, Staff Papers (International Monetary Fund) Vol. 16, No. 1 (Mar., 1969), pp. 159-178

Birur, D., T. Hertel and T. Wallace (2007), “The biofuels boom: Implications for world food markets”, Food Economy Conference, The Hague, October 18-19, 2007.

Eickhout, B., van Meijl, H., Tabeau, A., 2009. The impact of environmental and climate constraints on global food supply. In: Hertel, T., Rose, S., Tol, R. (Eds.), Economic Analysis of Land Use in Global Climate Change Policy. Routledge (Chapter 9).

Golub, A., T. Hertel, L. Huey-Lin et al. (2009) “The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry”, Resour Energ Econ, Vol. 31, pp. 299–319.

Golub, A., B. Henderson, T. Hertel T et al. (2013) “Global climate policy impacts on livestock, land use, livelihoods, and food security”, Proc Natl Acad Sci USA, Vol. 110, pp. 20894–20899.

Hertel, T., and M. Tsigas (1997), “Structure of GTAP”, in *Global trade analysis: modelling and applications*, Hertel, T. (eds.). Cambridge University Press, Cambridge, UK.

Huang, H., F. van Tongeren, J. Dewbre and H. van Meijl, 2004, A New Representation of Agricultural Production Technology in GTAP, paper presented at the 7th Annual Conference on Global LEI 14-057 | 77 Economic Analysis, Washington D.C., USA.

Lee, H.-L. (2004), “Incorporating Agro-ecologically Zoned data into the GTAP framework”, In: Paper Presented at the SeventhAnnual Conference on Global Economic Analysis, June, The World Bank, Washington, D.C.

Mandryk, M., J. Doelman and E. Stehfest (2015), “Assessment of global land availability and suitability: land supply for agriculture”, FOODSECURE working paper no. 7. http://www3.lei.wur.nl/FoodSecurePublications/TP7_Mandryk.pdf.

OECD (2003), “Agricultural Policies in OECD Countries 2000. Monitoring and Evaluation, Organization for Economic Co–operation and Development”, Paris.

Plevin, R., H. Gibbs, J. Duffy, S. Yui and S. Yeh (2014), “Agro-ecological Zone Emission Factor (AEZ-EF) Model: A model of greenhouse gas emissions from land-use change for use with AEZ-based economic models”, GTAP Technical Paper No. 34.

Tabeau, A., J. Helming, G. Philippidis (2017), “Land Supply Elasticities, Overview of available estimates and recommended values for MAGNET”, JRC Technical Report No EUR 28626 EN, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC106592/kj-na-28626-en-n_.pdf

US EPA (2013), *Global mitigation of non-CO2 greenhouse gases: 2010–2030*. EPA 430-R-13-011. US EPA, Washington DC, USA

Van Meijl, H., T. van Rheenen, A. Tabeau, B. Eickhout (2006), “The impact of different policy environments on land use in Europe”, Agriculture, Ecosystems and Environment, Vol. 114, pp. 21-38.