suprema

REPORT #3

CLIMATE CHANGE SCENARIO

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Glossary / Acronyms

CH_4	Methane
CO_2	Carbon Dioxide
EC	European Commission
EU	European Union
GHG	Greenhouse Gas
N_2O	Nitrous Oxides
ROW	Rest of the World

1 Introduction

This SUPREMA report focuses on the development of long-term global climate change mitigation scenarios. Under task 3.3. of the SUPREMA project, we assessed the GHG mitigation potential of the EU's agricultural sector and related environmental, economic, socio-economic impacts conditional on different levels of GHG mitigation efforts outside the EU. The quantified scenario matrix includes scenarios where the EU only takes unilateral climate actions up to a scenario where 1.5°C compatible mitigation action is adopted globally. The IIASA (applying the GLOBIOM model) is the main author of the report in close collaboration with Wageningen Economic Research (applying the MAGNET model) and EUROCARE/JRC (applying the CAPRI model).

This report is structured in five Chapters and one Appendix as follows: Chapter 2 briefly describes the applied models, Chapter 3 presents the quantified scenario matrix, Chapter 4 presents the climate change mitigation and impact analysis followed by a discussion and recommendation section in Chapter 5.

2 Brief model overview

Next to the two models GLOBIOM and MAGNET, also the CAPRI model joined the exercise and quantified a set of climate change mitigation scenarios described in Chapter 3. The three models have a solid track record in global climate mitigation assessments (Frank et al., 2019; Hasegawa et al., 2018; Van Meijl et al., 2018) while having detailed representation of the EU agricultural sector. The models have been used by the European Commission in assessing the impact of agricultural and land use policies on agricultural markets, land use, emissions, and mitigation potentials such as in the EU's Long Term Strategy towards climate neutrality (EC, 2018) or the EcAMPA study on economic mitigation potentials in agriculture (Pérez Domínguez et al., 2016) and are therefore well positioned for assessing the impact of EU agricultural climate change mitigation efforts.

2.1CAPRI

The Common Agricultural Policy Regionalised Impact (CAPRI) modelling system is a comparative-static partial equilibrium model for the agricultural sector developed for policy and market impact assessments from global to regional and farm type scale (Britz & Witzke, 2012). The core of CAPRI is based on the linkage of a European-focused supply module and a global market module. The regional supply module consists of independent aggregate non-linear programming models combining a Leontief-technology for variable costs of the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. Each programming model optimizes income under constraints related to land availability, nutrient balances for cropping and animal activities, and policy restrictions. Prices are exogenous to the supply module and provided by the market module. The global market module is a spatial, non-stochastic global multi-commodity model for about 60 primary and processed agricultural products, covering about 80 countries in 40 trading blocks. It is defined by a system of behavioural equations representing agricultural supply, human and feed consumption, multilateral trade relations, feed energy and land as inputs, and the processing industry; all differentiated by commodity and geographical units. Agricultural land types of temporary and permanent cropland as well as fodder areas are allocated to activities using yield elasticities to disaggregate the total supply response into contributions from yields and from areas. The shares of broad land types in the country area respond to rents in a multinomial logit system. Bilateral trade and attached prices are modelled based on the Armington approach. CAPRI endogenously calculates EU agricultural emissions for nitrous oxide and methane based on the inputs and outputs of production activities, taking specific technical GHG mitigation options into account.

GHG emissions for the rest of the world are estimated on a commodity basis in the CAPRI market model (Fellmann et al., 2018; Pérez Domínguez et al., 2016).

2.2 GLOBIOM

The Global Biosphere Management Model (GLOBIOM) (Havlík et al., 2014) is a partial equilibrium model that covers the global agricultural and forestry sectors, including the bioenergy sector. Commodity markets and international trade are represented at the level of 58 economic regions (including EU28 individual member states) (Frank et al., 2015) in the model version applied in this study. Prices are endogenously determined at the regional level to establish market equilibrium to reconcile demand, domestic supply and international trade. For crops, livestock, and forest products, spatially explicit Leontief production functions covering alternative production systems are parameterized using biophysical models like EPIC (Environmental Policy Integrated Model) (Williams, 1995), G4M (Global Forest Model) (Gusti, 2010; Kindermann, McCallum, Fritz, & Obersteiner, 2008), or the RUMINANT model (Herrero et al., 2013). For the present study, the supply side spatial resolution was aggregated to 2 degrees (about 200 x 200 km at the equator) and NUTS2 level for the EU. Land and other resources are allocated to the different production and processing activities to maximize a social welfare function which consists of the sum of producer and consumer surplus. The model includes six land cover types: cropland, grassland, short rotation plantations, managed forests, unmanaged forests, and other natural vegetation land. Depending on the relative profitability of primary, by-, and final products production activities, the model can switch from one land cover type to another. Spatially explicit land conversion over the simulation period is endogenously determined within the available land resources and conversion costs that is considered in the producer optimization behaviour. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions. GLOBIOM covers major GHG emissions (CO_2, N_2O, and CH_4) from agricultural production, forestry, and other land use and different mitigation options for the land use sector. Detailed information on the parameterization of the different mitigation options for the agricultural sector is provided in Frank et al. (2018). For more information on the general model structure we refer to Havlík et al. (2011) and Havlík et al. (2014).

2.3 MAGNET

The Modular Applied GeNeral Equilibrium Tool (MAGNET) model is a multi-regional, multi-sectoral, applied general equilibrium model based on neo-classical microeconomic theory (Nowicki et al., 2009; Woltjer & Kuiper, 2014). It is an extended version of the standard GTAP model (Hertel, 1997). The core of MAGNET is an input–output model, which links industries in value added chains from primary goods, over continuously higher stages of intermediate processing, to the final assembly of goods and services for consumption. Primary production factors are employed within each economic region, and hence returns to land and capital are endogenously determined at equilibrium, i.e., the aggregate supply of each factor equals its demand. On the consumption side, the regional household is assumed to distribute income across savings and (government and private) consumption expenditures according to fixed budget shares. Private consumption expenditures are allocated across commodities according to a non-homothetic CDE expenditure function and the government consumption according to Cobb-Douglas expenditure function.

The MAGNET model, in comparison to GTAP, uses a more general multilevel sector specific nested CES (constant elasticity of substitution) production function, allowing for substitution between primary production factors and (land, labour, capital and natural resources) and intermediate production factors and for substitution between different intermediate input components (e.g. energy sources, and animal feed components). MAGNET includes an improved treatment of agricultural sectors (like various imperfectly substitutable types of land, the land use allocation structure, a land supply function, substitution between various animal feed components, (Van Meijl, van Rheenen, Tabeau, &

Eickhout, 2006), agricultural policy (like production quotas and different land related payments (Nowicki et al., 2009), and biofuel policy (capital-energy substitution, fossil fuels-biofuels substitution (Banse et al., 2011). On the consumption side, a dynamic CDE expenditure function is implemented which allows for changes in income elasticities when purchasing power parity (PPP)-corrected real GDP per capita changes. Segmentation and imperfect mobility between agriculture and non-agriculture labour and capital are introduced in the modelling of factors markets.

The model also incorporates emissions from the latest GTAP non-CO_2 database (Irfanoglu & van der Mensbrugghe, 2015), including methane (CH_4) and nitrous oxide (N_2O). This is complemented by CO_2 emissions from the GTAP Energy-Environmental database (GTAP-E). 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. 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 (Henderson, Verma, Tabeau, & van Meijl 2019) based on the US EPA (2013). They cover measures for lowering the main non-CO_2 emission sources including methane from enteric fermentation by ruminants (i.e. cattle, sheep and goats), nitrous oxide and methane from livestock manure, methane emissions from paddy rice and nitrous oxide emissions from soil associated with fertiliser use by crops.

2.4 Comparison of model methods

In this section we want to document differences in methods and features across model that are important for the assessment of mitigation policies. This should facilitate a better understanding and interpretation of model results in section 4.

Table 1. Differences in methods and hypothesis drivers across SUPREMA models

	CAPRI	GLOBIOM	MAGNET
Model type	Partial equilibrium	Partial equilibrium	Computable general equilibrium
Trade representation	Armington spatial equilibrium of quality differentiation, heterogenous goods	Takayama-Judge spatial equilibrium, homogenous goods	Armington spatial equilibrium of quality differentiation, heterogenous goods
Demand side representation	Explicit price and cross-price elasticities, exogenous income elasticities	Explicit price elasticities, exogenous income elasticities	Explicit price and income elasticities
Supply side representation	NUTS2 level non-linear programming models in the EU. Linear system of supply functions in the ROW	Spatially explicit Leontief production systems Leontief covering alternative production systems	Regional/country level multilevel nested constant elasticity of substitution production technology
Land representation	Explicit link to agri. activities in the EU, land supply and demand functions in the ROW, allocated to products	Explicit link to agri. and forestry activities	Land supply function

Agricultural emissions	Product specific emission factors globally, consistent with activity-based accounting in EU	Spatially explicit emission factors for the different production systems	Product and region-specific emission factors
Mitigation options	Technical options, changes in composition of regional activity or product aggregates; international trade	Technical options, changes in production systems, composition of regional activity or product aggregates; international trade	Technical options, changes in composition of regional activity or product aggregates; international trade

3 Scenario development

This scenario section mostly builds on material presented in the SUPREMA milestone 9 (Description and assumptions of the scenarios under climate change) which provided a draft narrative and description of the assumptions and drivers for the climate change mitigation scenarios. In the subsequent section, the final scenario drivers that have been implemented in the three models is described.

3.1 Baseline scenario

The baseline scenario represents a business-as-usual scenario for the EU and global agricultural sector and does not include additional mitigation policies beyond currently adopted policies. For the EU, the baseline scenario relies on macro-economic and bioenergy projections based on the Reference scenario 2016 (EC, 2016). These scenario drivers were also recently used by the EC for building the baseline scenario used for the European Long Term Strategy (EC, 2018).

Outside the EU, the baseline is based on the model specific interpretation of the Shared Socio-economic Pathway 2 (SSP2) from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Fricko et al., 2016; O'Neill et al., 2014). This scenario represents a "business as usual" scenario with continuation of current trends and medium challenges for mitigation and adaptation. World population is projected to increase to around 9.2 billion until 2050 and GDP per capita is expected to more than double globally to around 25,000 year-2005 USD per capita. The macro-economic developments are directly implemented based on data supplied in the SSP database (https://tntcat.iiasa.ac.at/SspDb/) while qualitative elements of the SSP2 storyline such as technological changes, trade policy assumptions or diets, were interpreted and translated into quantitative elements by the individual modelling teams. A comparison of the baseline scenario for the agricultural sector and GHG emissions is provided in Frank et al. (2019).

3.2 Mitigation scenarios

To assess the potential contribution of EU agriculture to the 1.5°C climate change mitigation target, we quantified several global and EU GHG mitigation scenarios that vary with respect to the mitigation efforts adopted outside the EU. While the EU always pursues 1.5°C compatible mitigation efforts, efforts vary outside. The scenario set-up enables to identify potential leakage effects if unilateral mitigation efforts are taken by the EU and allows to quantify the efficiency of EU mitigation policy at global scale with respect to emission savings. To emulate the GHG mitigation potentials a carbon price on non-CO_2 emission from agriculture is implemented in the models corresponding to the average carbon price pathways quantified across five IAMs (AIM, GCAM, IMAGE, REMIND-MAGPIE, MESSAGE-GLOBIOM) in line with a 1.5°C climate stabilization pathway based on Rogelj et al. (2018). The carbon price is implemented in the objective function of each SUPREMA models (CAPRI, GLOBIOM, MAGNET) as a tax on agricultural non-CO_2 emissions and incentivizes the uptake of emission reduction technologies. Carbon prices start with 10 USD/tCO_2eq in 2030 going up to 85 USD/tCO_2eq in 2040, and 245 USD/tCO_2eq in 2050.

Since agricultural markets are connected through international trade, regional mitigation policies may impact other regions outside Europe. Even though the EU's agricultural sector is amongst the most GHG efficient ones worldwide, a unilateral EU mitigation policy may have adverse effects on the sector and may, through emission leakage, decrease overall efficiency of the EU policy at global scale. Hence, the level of mitigation action taken outside the EU can be an important factor that determines the impact of domestic mitigation efforts on EU farmers. For example, if ambitious action is taken also in the rest of the world, EU farmers could benefit from increasing exports to regions that produce currently with high GHG intensity. We test the impact of several levels of mitigation action taken outside the EU (ranging from 100% effort – "full buy-in" and hence achieving the 1.5°C target at global scale down to 0% effort taken in the "00%buy-in" scenario) while the EU pursues efforts in line with the 1.5°C target in all mitigation scenarios. For example, 50% effort taken outside the EU meaning that only 50% of the carbon price needed to achieve the 1.5°C target is implemented in the models in the rest of the world (ROW). Table 2 describes the scenario set-up and acronyms.

Table 2. SUPREMA scenario matrix for the climate change mitigation assessment.

SCENARIO NAME	EU MITIGATION EFFORT	ROW MITIGATION EFFORT
REFERENCE	NO CC MITIGATION	NO CC MITIGATION
00%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	NO CC MITIGAITON
05%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	5% EFFORT
10%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	10% EFFORT
25%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	25% EFFORT
50%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	50% EFFORT
75%BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	75% EFFORT
FULL BUY-IN	1.5 C COMPATIBLE - 100% EFFORT	100% EFFORT

4 Results

4.1 Impacts of a unilateral mitigation policy

Here we focus on the EU and ROW impacts in the 00%buy-in scenario where only the EU pursues ambitious mitigation efforts compatible with the 1.5°C target (if adopted globally). By comparing scenario results with our reference scenario without mitigation efforts, we quantify the marginal impact of the EU mitigation policy in- and outside the EU and potential emission leakage effects. The 00%buy-in scenario (245 USD/tCO_2eq) results on average across the three models in 145 MtCO_2eq/yr domestic agricultural non-CO_2 emission reduction compared to the reference scenario in 2050. Across models, GLOBIOM shows lower domestic EU emission reductions with 100 MtCO_2eq/yr due less pronounced decreases in beef production, while CAPRI (170 MtCO_2eq/yr) and MAGNET (150 MtCO_2eq/yr) show higher agricultural GHG abatement potentials (Figure 1). The lower mitigation potential in GLOBIOM is partly explained by the lower baseline emissions for ruminants in the EU as compared to e.g. MAGNET (210 MtCO2eq as compared to 130 MtCO2eq in GLOBIOM by 2050) and a more inelastic parameterization of beef trade which prevents further reallocation of production to the ROW (see Figure 2). Despite these differences, all models anticipate the highest abatement potential being realized in the livestock sector, which contributes on average 130 $MtCO_2eq/yr$, mainly through ruminants (beef and milk contribute 80% of total mitigation).

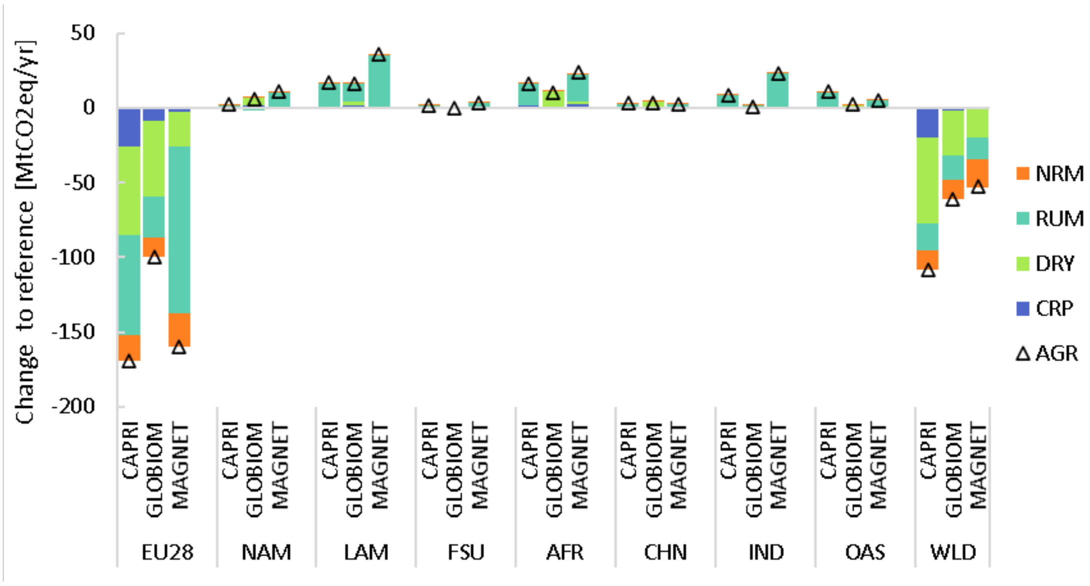

Figure 1. Change in agricultural GHG emissions in MtCO2eq/yr in the 00% buy in scenario in 2050 compared to the reference scenario. EU28 – European Union, NAM – North America, LAM – Central and South America, FSU – Former Soviet Union countries, AFR – Africa and Middle East, CHN – China, IND – India, OAS – Other Asia, WLD – World. NRM – non ruminant meat and eggs, RUM – ruminant meat, DRY – milk, CRP – crops. AGR – total agricultural emissions.

At global scale the ambitious unilateral EU mitigation efforts in the 00% buy-in scenario result in emission savings even though mitigation potentials are substantially reduced due to emission leakage (on average -48%) as part of the EU production is reallocated outside. Emission leakage is closely tied to the impact of the unilateral EU mitigation policy on domestic production levels and the response in international trade. Hence, the 00%buy-in scenario yields emissions savings of only 75 $MtCO_2eq/yr$ on average across models at global scale. Emission leakage is highest in MAGNET (-67%) while it is more moderate in CAPRI (-36%) and GLOBIOM (-39%). This shows the higher sensitivity of international trade and supply side responses in MAGNET with respect to a change in prices and competitiveness across regions related for beef to higher trade elasticity of processed meat. Overall, regional production reallocation effects vary across models. However, all models a anticipate stronger increases in emissions in Latin America and Africa and less emission leakage to regions like North America, Former Soviet Union countries or China. Models also agree that emission leakage mostly occurs for beef where emission increases outside the EU can be observed while EU dairy related emission reductions are not compensated in the ROW, except for some increase in Africa according to GLOBIOM. The reason is that besides GLOBIOM (-22%), the other models do not anticipate as significant milk production decreases (CAPRI no impact, MAGNET -5% only, Figure 3) as a result of a more inelastic milk trade parameterization and therefore hardly any reallocation of production to the ROW takes place also.

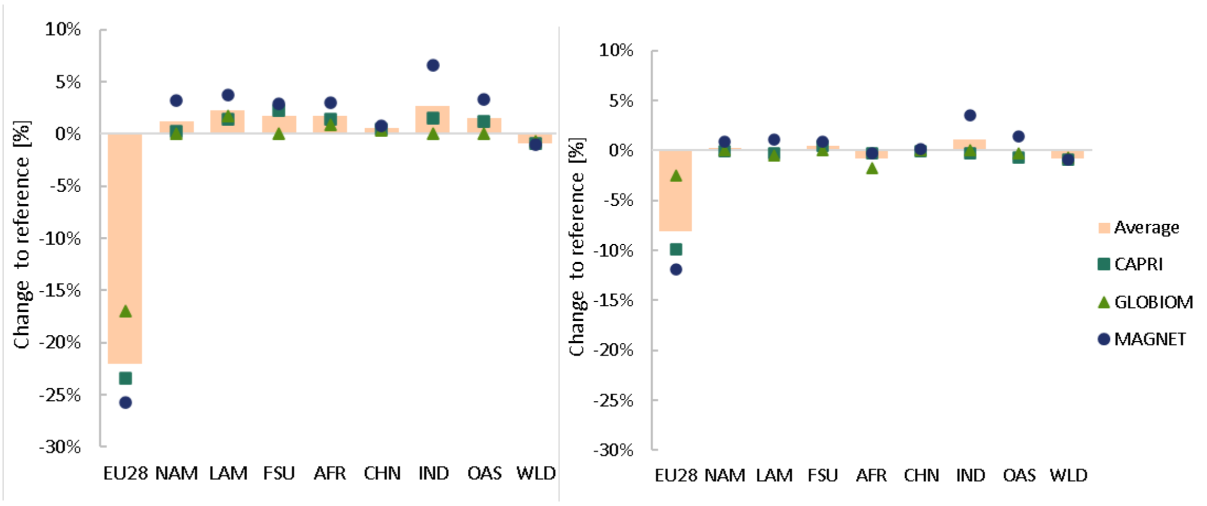

Figure 2. Relative change in ruminant production (left panel) and consumption/domestic use (right panel) in the 00% buy in scenario in 2050 compared to the reference scenario across world regions. EU28 – European Union, NAM – North America, LAM – Central and South America, FSU – Former Soviet Union countries, AFR – Africa and Middle East, CHN – China, IND – India, OAS – Other Asia, WLD – World.

Looking at emission leakage related to beef production, Figure 2 shows relative production and consumption/domestic use changes across world regions in response to the unilateral EU mitigation policy. As EU farmers decrease beef production (on average -21%) in response to the EU mitigation policy that penalizes the production of GHG intensive products, farmers in the ROW benefit as they become relatively more competitive compared to the EU since they are not impacted by the mitigation policy and can increase their production to compensate for the drop in the EU. In response to the unilateral mitigation policy in the EU, domestic beef prices are projected to increase on average by 40%. While GLOBIOM shows lower leakage rates for beef due to the more inelastic response in trade in response to the unilateral EU mitigation policy, CAPRI and MAGNET show higher sensitivity of beef trade and reallocation effects across regions. In MAGNET, the unilateral mitigation policy even results in increasing domestic use of beef in ROW. This can be explained by the CGE nature of the MAGNET model capturing endogenous income effects, covering endogenously all sectors of the economy, and distinguishing between primary (agricultural) beef sectors and processed beef meat sectors. Very high difference in market prices of beef commodities between EU and ROW in 00% buy scenario drives EU demand for beef meet imports from ROW. This leads to increasing domestic use of primary beef meat in the growing beef industry in ROW. At the same time, domestic consumption of beef by household and government in ROW slightly decreases to compare with reference scenario. Despite the similar flexibility in beef trade in MAGNET and CAPRI (Figure 2), impacts on ROW GHG emissions differ between the models (Figure 1). Here MAGNET shows the highest emission increases in the ROW given the higher production reallocation (and related emission). While CAPRI and GLOBIOM show similar GHG leakage rates of around one third of domestic EU GHG abatement, domestic EU GHG reduction is reduced by two thirds at global scale in MAGNET.

Looking at product group specific impacts in the EU, Figure 3 displays the impacts of the 00%buy-in scenario on EU agricultural production and consumption in 2050. Across commodity groups, the response of the 3 models to the EU mitigation policy is rather consistent with two out of three models showing similar magnitudes in the response across product groups (except for oilseeds). On average the models anticipate a strong decline for beef production (-21%), rice (-17%), oilseeds (-16%) whereas impacts on milk (-9%), coarse grains and wheat (-12%) and non-ruminant production (-6%) are much less pronounced. While the spread across models is small for ruminant and non-ruminant meat, higher variation is observed for the crop sector where MAGNET anticipates lower impacts on production levels (related to a more limited set of mitigation options) as compared to CAPRI and GLOBIOM. For milk, GLOBIOM projects higher production decreases as compared to the other models, in particular CAPRI which does not anticipate any impact on milk production. The high impact on milk production in GLBIOM is likely related to differences in the allocation of ruminant emissions to the beef and dairy herd which impacts emission factors and would also partly explain the lower impact on ruminant production as compared to the other models.

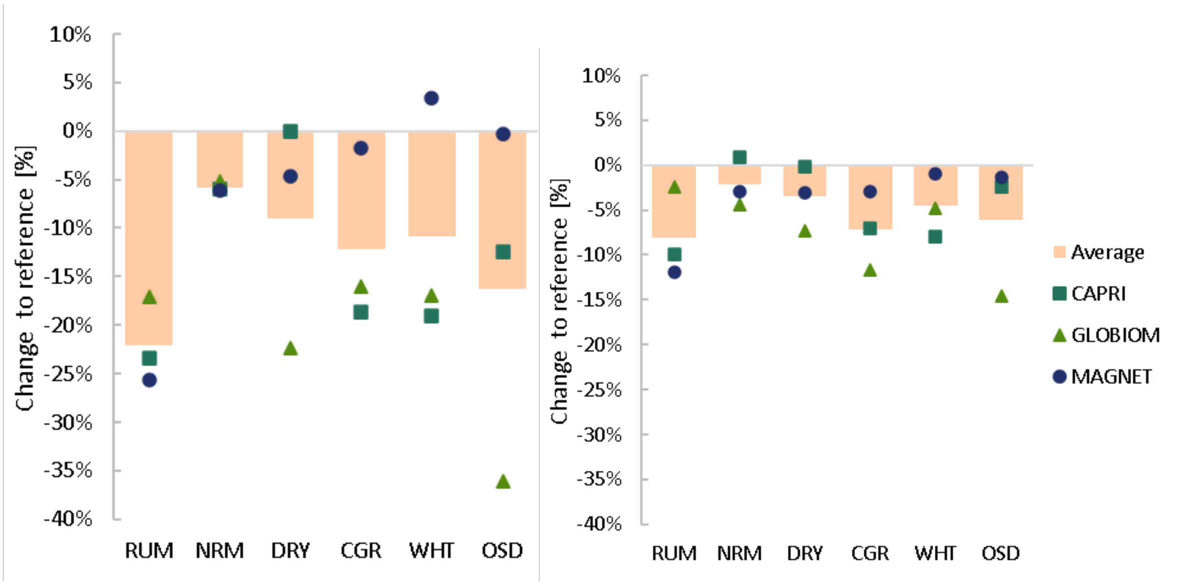

Figure 3. Relative change in EU agricultural production (left panel) and consumption/domestic use (right panel) in the 00% buy in scenario in 2050 compared to the reference scenario. RUM – ruminant beef, NRM – non ruminants (pig and poultry), DRY – milk, CGR – coarse grains, WHT – wheat, OSD - oilseeds

As the supply curve is shifted upward in response to the unilateral mitigation policy, prices increase for GHG intensive products. Price increase are highest for beef (on average +40%), while other commodity prices are less impacted on average across models e.g. only around 13-15% for non-ruminant, dairy, coarse grains and wheat. Impacts on total consumption levels are quite consistent across models with GLOBIOM being more price sensitive whereas CAPRI usually shows rather price inelastic food consumption behaviour. This is in line with previous literature (Hasegawa et al., 2018; Valin et al., 2014) and related to the different demand side parameterization in the models. For example, in GLOBIOM the absence of cross-price elasticities (as compared to CAPRI) or endogenous income effects (as compared to MAGNET).

A trade sensitivity analysis was conducted in CAPRI, GLOBIOM and MAGNET where we assume a liberalization of international trade and phasing out of tariffs by 2030 (Figure S1 in the Appendix). The sensitivity analysis however reveals a slightly different response to trade liberalization in the two models. While in GLOBIOM and MAGNET, EU mitigation decreases by 5 and 17 $MtCO_2eq$/yr, in CAPRI mitigation potentials increase by 12 $MtCO_2eq$ /yr. Outside the EU, emission leakage declines in GLOBIOM and MAGNET, while leakage increases substantially in CAPRI related to beef emissions in Latin America. While leakage rates for MAGNET (-64%) and GLOBIOM (-26%) are slightly less pronounced in the trade sensitivity as compared to the default scenarios, emission leakage is substantially higher in CAPRI (-72%).

4.2 Impacts of ROW mitigation efforts on the EU

Now we want to focus on the impact of ROW mitigation efforts on the EU farmers while the EU continues to pursue 1.5°C compatible mitigation efforts. Figure 4 shows the impact of various ROW mitigation scenarios on EU producers, consumers, and emissions. Across all models, ROW mitigation efforts are shown to have a positive impact on domestic EU producers as compared to the situation where only the EU takes mitigation action. Once the ROW starts to pursue mitigation efforts, EU farmers benefit as they are able to produce relatively more GHG efficient food as compared to other regions in the ROW and hence EU crop but especially livestock producers are not impacted as much as compared to the unilateral EU mitigation policy. In MAGNET, EU livestock farmers can even significantly increase their production levels (+12%) compared to the reference scenario without mitigation efforts in the full buy-in scenario given their high GHG efficiency as compared to ROW. The less pronounced EU production decreases with increasing ROW mitigation efforts are also mirrored in the EU emission reduction potentials which decrease. Not surprisingly, impacts on EU consumers are limited across mitigation scenarios as given their high-income level and lower price elasticities.

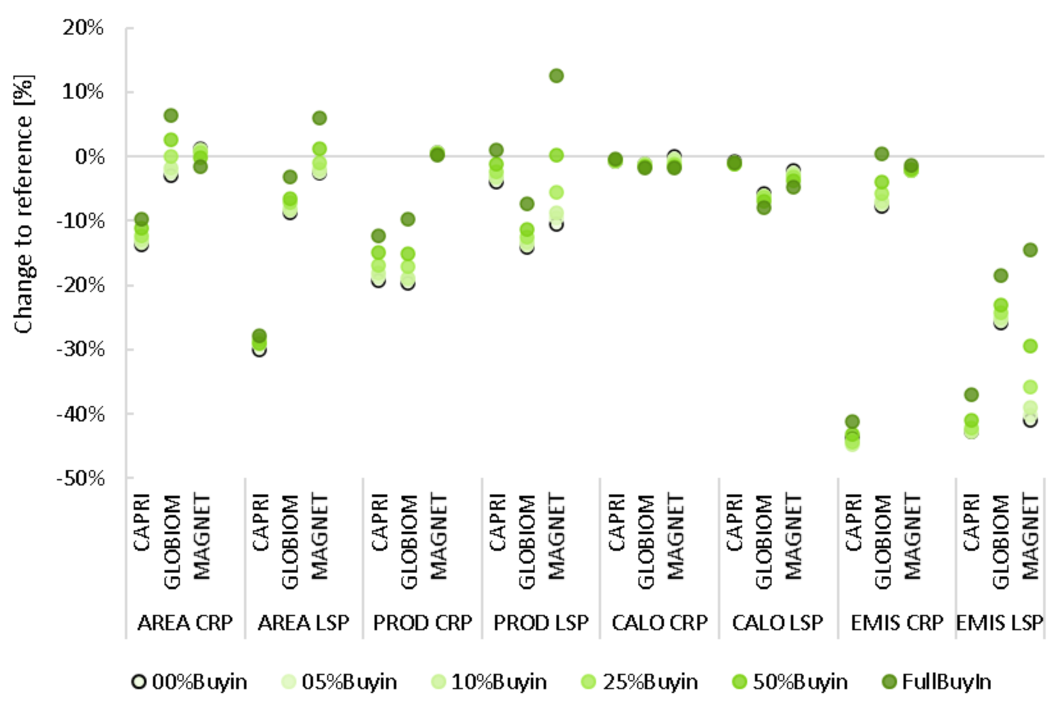

Figure 4. Impact of different levels of ROW mitigation ambition on EU agricultural sector in 2050 across models. AREA CRP – crop areas, AREA LSP – pasture areas, PROD CRP – crop production, PROD LSP – livestock production, CALO CRP – crop calorie consumption, CALO LSP – livestock calorie consumption, EMIS CRP – crop emissions, EMIS LSP – livestock emissions.

If the ROW would at least adopt 50% of a 1.5°C compatible mitigation effort level (Figure 5, left panel) the impact of the EU mitigation efforts on domestic production could be limited to around -10% (for oilseeds and coarse grains) on average across models. Beef, dairy, pork and poultry producers would be impacted even less (around -5%).For ruminants this represents a substantially lower impact of the EU mitigation policy as compared to the 00%buy-in scenario (Figure 3). Pursuing 1.5°C compatible mitigation efforts globally (full buy-in scenario) would further decrease the impact on EU producers and for MAGNET even result in production gains as compared to the reference scenario.

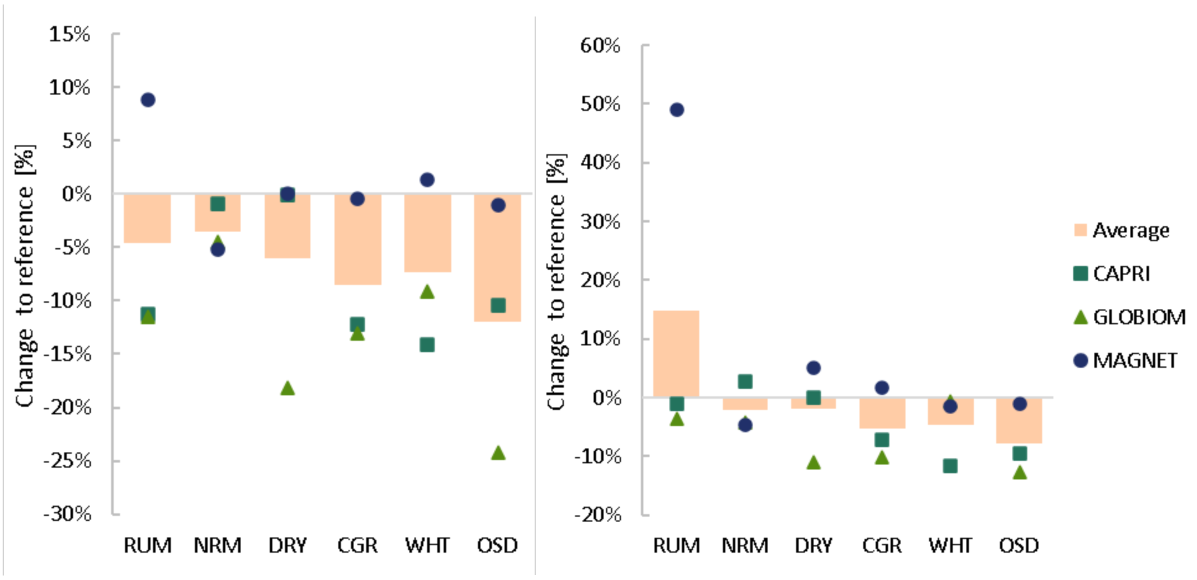

Figure 5. Relative change in EU agricultural production in the 50% buy in scenario (left panel) and full-buy-in scenario (right panel) in 2050 compared to the reference scenario. RUM – ruminant beef, NRM – non ruminants (pig and poultry), DRY – milk, CGR – coarse grains, WHT – wheat, OSD - oilseeds

4.3 Globally coordinated GHG mitigation policies and related impacts

The full buy-in scenario, where the whole world takes 1°5 C compatible mitigation action, delivers on average agricultural non-CO_2 emission savings of 3,200 $MtCO_2eq$/yr (at 245 USD/tCO_2eq) across the models (Figure 6) compared to the reference scenario. While GLOBIOM and MAGNET anticipate similar global mitigation potentials in agriculture between 2,500 – 2,800 $MtCO_2eq$/yr, CAPRI is more optimistic (4,300 $MtCO_2eq$/yr) related to higher emission savings from technical mitigation options such as anaerobic digesters and feed supplements, which is in line with results presented in Frank et al. (2019). Compared to the 00%buy-in scenario, where only the EU takes mitigation action, the full buy-in represents a more than 40-fold increase in GHG abatement at global scale and highlights the importance of global action. Similarly as at EU level, at global scale the ruminant sector is also one of the most important sources for GHG mitigation accounting for more than half of the total global GHG abatement, followed by the crop sector (around 20%)and dairy producers (around 15%). In the crop sector, rice offers in the ROW a substantial potential to reduce CH_4 emission of around 400 MtCO2eq/yr.

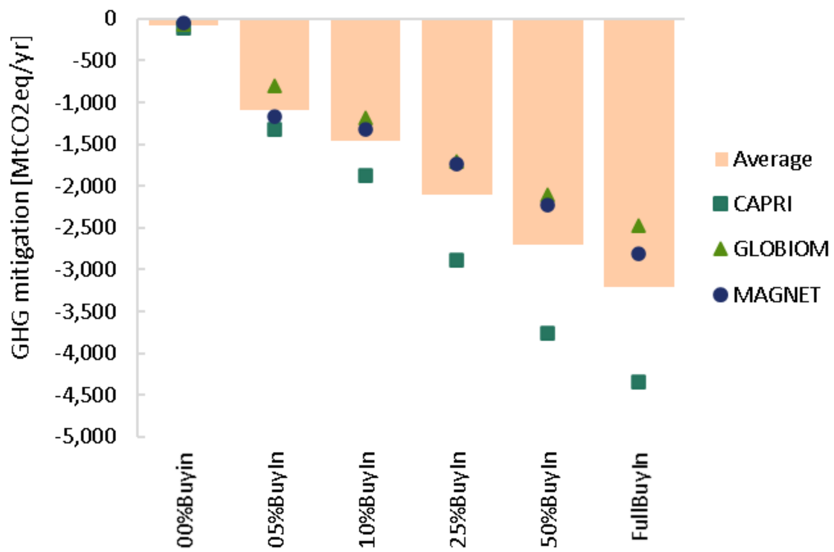

Figure 6. Global GHG mitigation potential from agriculture in MtCO2eq/yr in 2050 across models.

Interestingly, even a low levels of ROW mitigation efforts, substantial GHG reductions can be achieved globally. For example, in the 10%buy-in scenario almost half of the total GHG potential from the full buy-in scenario (and 20 times more mitigation than compared to the 00%buy-in scenario) can be achieved and at 50%buy-in scenario even 85% of the potential (and 36 times more mitigation than compared to the 00%buy-in scenario). This shows that a substantial amount of the total GHG mitigation potential can be realized at already low costs in the ROW.

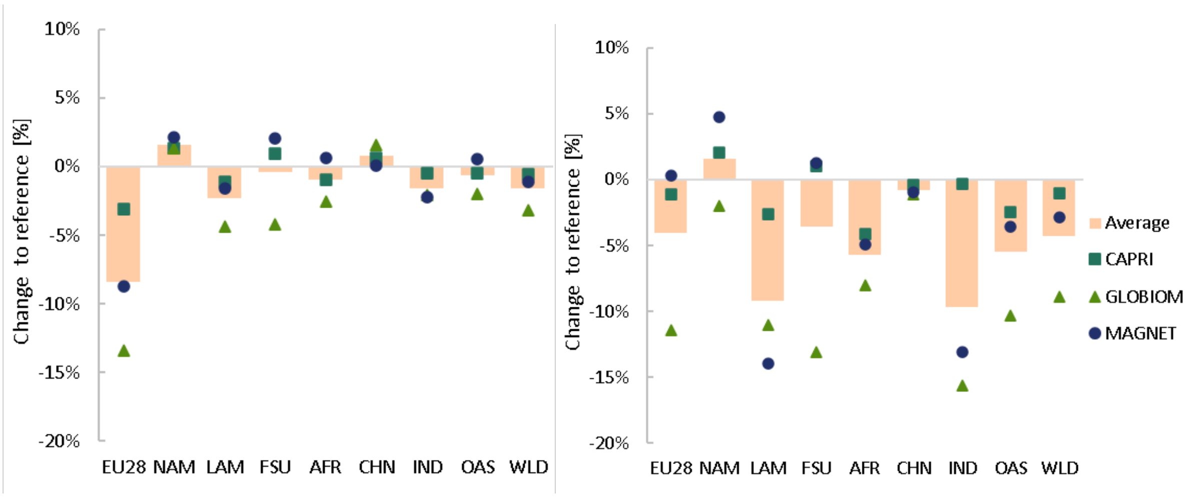

Figure 7. Relative change in livestock production in the 10% (left panel) and 50% (right panel) buy in scenario in 2050 compared to the reference scenario across world regions. EU28 – European Union, NAM – North America, LAM – Central and South America, FSU – Former Soviet Union countries, AFR – Africa and Middle East, CHN – China, IND – India, OAS – Other Asia, WLD – World.

When extending the mitigation policy to the ROW, impacts on EU producers get buffered and distributed more balanced across world regions (Figure 7). With increasing level of ROW ambition, results show that livestock producers in developed regions like EU and North America become less impacted or even benefit as compared to India, or Latin American and African countries that are much more impacted due to their less GHG efficient livestock production systems. This results in significant impacts on regional livestock calorie consumption (Figure 8) as agricultural prices increase more drastically in response to the carbon tax that penalizes in particular GHG intensive producers in the global South. At the same time, consumers in those regions are usually more price sensitive given their lower income levels. Consequently, the full buy-in scenario shows substantial impacts on regional livestock (but also total) calorie consumption levels in those regions that already nowadays face food insecurity. Hence, an ambitious uniform carbon tax for the agricultural sector could further exacerbate those food security issues as shown by Hasegawa et al. (2018). Impacts on calorie consumption (Figure 8) varies across models with GLOBIOM being the most price sensitive while CAPRI rather price inelastic. This behaviour is related to the difference in demand side representation in the models (Table 1), in particular the representation of cross price elasticities and substitution effects. For example, in CAPRI aggregate food consumption stabilizes even under high food/carbon prices due to strong substitution e.g. between ruminant and non-ruminant products, which also buffers impacts on the supply side as shown in Figure 7 where CAPRI has the lowest impact on livestock production levels.

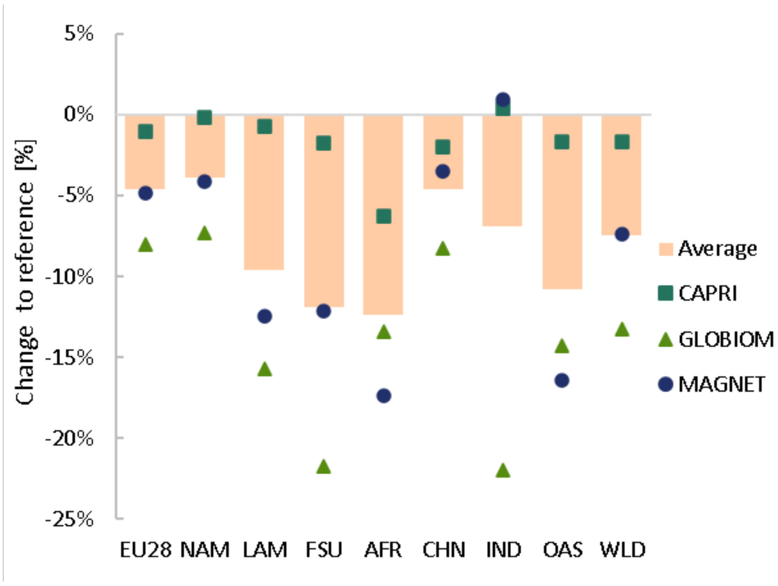

Figure 8. Relative change in livestock calorie intake in the full buy-in scenario in 2050 compared to the reference scenario across world regions. EU28 – European Union, NAM – North America, LAM – Central and South America, FSU – Former Soviet Union countries, AFR – Africa and Middle East, CHN – China, IND – India, OAS – Other Asia, WLD – World.

5 Conclusions and recommendations

We applied three global economic agriculture sector models with detailed representation of the EU to identify the impact of an ambitious unilateral EU mitigation policy on European farmers and GHG emissions. In addition, we quantified several global mitigation scenarios where in addition to the EU, also regions outside Europe take action to reduce GHG emissions in agriculture ranging from very modest efforts up to 1.5°C compatible mitigation action. We find that:

- An ambitious unilateral EU mitigation policy in line with efforts needed to achieve the 1.5 C target globally results in domestic GHG emission savings from agriculture of around 145 $MtCO_2eq/yr$ on average across the three models (100 – 170 $MtCO_2eq/yr$ at 245 USD/tCO_2eq)
- However, at global scale agricultural emission savings are reduced to only 75 $MtCO_2eq/yr$ (50 – 110 $MtCO_2eq/yr$) due to large leakage effects (-48%) that decrease the efficiency of a unilateral mitigation policy. As part of the EU production is reallocated to the ROW in

response to the unilateral mitigation policy, agricultural emissions increase in the ROW and domestic EU emission savings are partly offset.

- EU emission savings are mainly related to the ruminant sector which contributes 80% of the total mitigation potential while crops and non-ruminants play a minor role. Emission leakage is mostly related to the reallocation of beef production and related emissions while EU milk emission savings are not compensated by increasing emissions outside the EU.
- While EU livestock production is heavily affected by the carbon tax, regions outside the EU benefit and can increase production related to increasing competitiveness. A unilateral EU mitigation policy is projected to substantially impact ruminant production (-22%), rice (-17%), oilseeds (-16%) whereas the impact on milk (-9%), coarse grains (-12%), wheat (-11%) and non-ruminants (-6%) is much more modest across models.
- If the ROW however pursues mitigation efforts in parallel to the ambitious EU mitigation efforts, impacts on EU farmers are much less pronounced as also farmers outside the EU are included in the carbon pricing scheme. Since EU farmers rank among the most GHG efficient producers at global scale, with increasing mitigation efforts in the ROW, EU farmers remain competitive even under an ambitious domestic mitigation policy. For example, in the 50% buy-in scenario, the impact on domestic EU production could be limited to less than -10% on average across models which is substantially less than in the 00% buy-in scenario.
- If globally mitigation efforts in line with the 1.5°C target were adopted for the agricultural sector (full buy-in scenario), impacts on EU farmers would be very modest and beef producers could potentially benefit and even increase domestic production due to their relative GHG efficiency which would further increase their competitiveness under a global carbon tax. Similarly, also other developed regions like North America with highly GHG efficient livestock production systems would benefit while livestock producers especially in Latin America, India and Africa would lose competitiveness and market shares.
- With respect to global emission savings, already adopting modest mitigation efforts in the ROW could lead to significant global emissions savings in agriculture mainly from ruminants and rice production. The 10% buy-in scenario is shown to achieve already half of the total GHG mitigation potential as compared to the full buy-in scenario (and 20 times more mitigation as compared to a unilateral EU mitigation policy) and the 50%buy-in scenario even 85% of the potential (and 36 times more mitigation as compared to a unilateral EU mitigation policy). This highlights that a substantial part of the agricultural mitigation potential in the ROW can be achieved already at low carbon prices.
- Results highlight the importance of global mitigation action to achieve substantial contributions from agriculture. A unilateral EU mitigation policy is found to deliver only small emission savings at the global scale due to reduced efficiency related to emission leakage. However, already modest efforts in the ROW are found to prevent emission leakage and deliver substantial global emission savings. Therefore, sensible mitigation policy design in agriculture e.g. different effort levels across regions, is important to avoid significant impacts on livestock producers in regions in the global South that could further acerbate food security issues in that regions. Likewise, steering efforts towards GHG intensive commodities may help to achieve already substantial emission savings.
- Having analysed in detail the effect of a unilateral EU mitigation policy conditional on a stylized set of ROW mitigation effort levels, future work could focus on developing and quantifying more heterogenous ROW mitigation scenarios. Since the willingness and capability to adopt stringent mitigation efforts in agriculture differs substantially across countries as does the impact of climate change, a more diverse set of ROW mitigation policies and effort levels would further improve the plausibility of these scenarios.

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Appendix

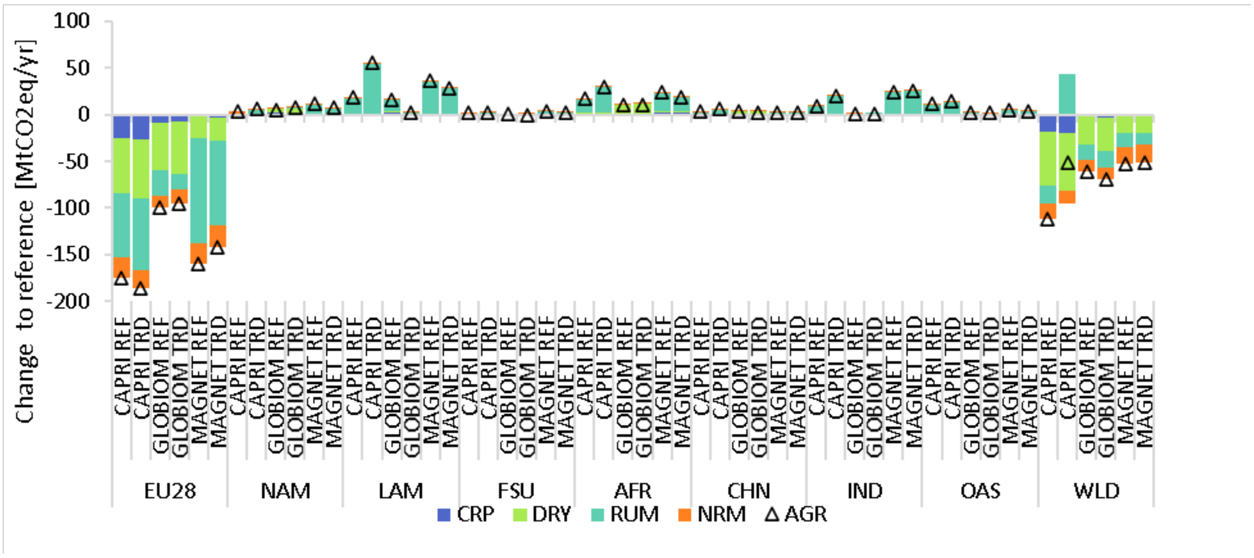

Figure S1. Change in agricultural GHG emissions in the 00%buy-in scenario in 2050 as compared to the corresponding reference across regions for GLOBIOM and MAGNET in the default (REF) scenario and for the trade- sensitivity analysis (TRD) with phased out tariffs.

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