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Table of contents

1. Introduction	5
2. Methodology.....	6
2.1. Model - GLOBIO	6
2.2 Scenario choice	6
2.3 Model - GLOBIOM.....	8
2.4 Model – MAgPIE	9
3. Results.....	10
3.1 Biodiversity impacts from climate change - GLOBIO.....	10
3.2 Integrated scenarios - GLOBIO	11
3.3 Non-market impacts from climate change – GLOBIOM.....	12
3.3.1 Land cover	13
3.3.2 Fertilizer use	17
3.3.3. Greenhouse gas emissions	20
4. Conclusions	27
5. References	29

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Deliverable Summary

A number of different models are used to assess the direct and indirect impacts of climate change on biodiversity. Currently, results from applications of the GLOBIO, GLOBIOM and MAgPIE models are presented. Whilst the results of GLOBIO identify direct impacts of climate change on indicators of biodiversity, specifically the effects on plants and vertebrates, these effects are expected to be overwhelmingly negative by 2050. GLOBIOM and MAgPIE identify indirect effects of climate change on biodiversity through the analysis of the effects on land cover, fertilizer use, and greenhouse gas emissions from changes in agricultural and forestry production.

Whilst both models report that the results are sensitive to the climate-socio-economic scenario combination analysed, the models agree that land cover changes are more induced due to changes in climatic conditions relative to other regional cultivation areas than to other climatic zones in the world market. For example, GLOBIOM shows that cropland is projected to decrease in parts of Southern Europe but expand in Northern Europe. For both models, this reallocation effect is reflected in matching shifts of fertiliser use that in turn can be expected to affect biodiversity as nitrogen leaches into the local environment. As deforestation is rather limited in Europe, the largest changes in GHG emissions stems from these changes to nitrogen application. The delay in the monetary evaluation is due to the complexity of integrating results from different models and therefore being able to obtain key model input data for the economic assessment. However, the deliverable is expected to be finalized at M25, therefore without any negative impact on the project workflow, that foresees the use of these data at M32.

1. Introduction

World-wide biodiversity has declined significantly during the last 100 years, driven mostly by an increase in agriculture area at the expense of natural habitats (Sala, van Vuuren, and Zaitsev 2005). In the future it is expected that climate change could become an equally important threat to biodiversity (Sala et al. 2000; van Vuuren, Sala, and Pereira 2006). The impact of climate change could in particular be important for sensitive systems (e.g. mountain systems), in the case of rapid climate change and in the case of large-scale disruption of existing climate systems (e.g. drying of Amazon regions). In these cases, it might be difficult for ecosystems to adapt to the new climate.

It should be noted that impacts of climate change may not always be direct. First of all, climate change may lead to lower agricultural yields. This may lead to a situation in which more land is needed to feed the global population. But also some climate policy responses could impact biodiversity. For instance, the use of bioenergy could lead to large claims on land leading by itself to negative impacts on biodiversity. The overall impact in that case would depend on the combined impact of bioenergy on limiting climate change and increased land use. Similarly, also other climate mitigation measures requiring land such as afforestation/reforestation strategies and strategies to prevent deforestation could impact biodiversity, in fact both as conservation measure and as threat depending on the exact implementation.

Integrated biodiversity models such as GLOBIO can help to explore the biodiversity impacts of integrated climate change scenarios. Here, we present an assessment of climate change impacts for the COACCH project. This is done in 2 ways, first we show the underlying relationships in the GLOBIO model based on available information in the literature. This relationship presents the pure relation between climate change and biodiversity loss. Second, we show the integrated evaluation of a number of scenarios. These results capture both climate change and land impacts.

In addition, the Global Biosphere Management Model (GLOBIOM) and the Model of Agricultural Production and its Impact on the Environment (MAGPIE) are used to analyze the competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors. Indicators of climate change studied in the two models are land cover, fertilizer use and greenhouse gas emissions.

2. Methodology

2.1. Model - GLOBIO

GLOBIO is a scenario-based gridded global model for biodiversity (Alkemade et al. 2009). The model is used to assess the impact of various drivers and pressures on local biodiversity, including plants and vertebrates. In GLOBIO, the main variable quantifying biodiversity in an ecosystem is the Mean Species Abundance (MSA), giving a measure of intactness of an ecosystem relative to a natural, undisturbed, state (Alkemade et al. 2009). The MSA index ranges from 0 to 1, where 1 represents a system where the biodiversity is fully intact and 0 means that the original ecosystem is fully destroyed.

In GLOBIO, several pressures, or drivers, reduce the MSA: climate change, land use, roads and fragmentation, atmospheric nitrogen deposition and hunting. For each of these pressures, a relationship is created from databases designed specifically for this purpose, relating MSA to key variables like global mean temperature, type of land use in a grid cell, proximity to a road etc.

Combining the pressure-impact relations and socio-economic and climate future projections, GLOBIO creates estimates of biodiversity loss on a 300m grid resolution. A detailed explanation of the most recent GLOBIO model is available in (Schipper AM 2019).

2.2 Scenario choice

To assess the impact of both socio-economic and climate related variables, various combinations of SSP and RCP scenarios can be used. The socio-economic projections in the model are derived from the SSP scenarios (Riahi et al. 2017), while the RCP scenarios (van Vuuren et al. 2011) are used for climate related variables. An overview of the key properties of each SSP is summarized in Table 1.

Table 1. Characteristics of socio-economic scenarios

	SSP1	SSP2	SSP3	SSP4	SSP5
Storyline	Sustainability: Taking the Green Road	Middle of the Road	Regional Rivalry: A Rocky Road	Inequality: A Road Divided	Fossil-fuelled Development: Taking the Highway
Population from 2050 to 2100	Decline to 7B people	Stabilisation around 9B people	High growth towards 13B people	Stabilisation around 9B people	Decline to 7B people
GDP	Medium-high	Medium-high	Low	Medium-low	High
Land-use	Effective international cooperation	Limited efforts to curb land-use emissions	No possibility to encourage countries to avoid	Limited efforts to curb land-use emissions	Effective international cooperation

			deforestation		
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The scenarios for which GLOBIO was used in this deliverable were originally created for the global assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). As part of the IPBES collaboration a modelling and harmonization protocol was developed: BES-SIM. Three SSP/RCP combinations were chosen in BES-SIM to cover the widest range in climate and socio-economic scenarios possible: SSP1-RCP2.6 for a sustainability-oriented scenario with climate mitigation policy, SSP3-RCP6.0 for a regional rivalry baseline scenario and SSP5-RCP8.5 for a fossil-fueled development baseline scenario.

These three scenarios correspond to the three Tier 1 SSP/RCP combinations selected in CMIP5, the climate model inter-comparison project (with some variation on whether the baseline SSP3 run reaches a radiative forcing of 6.0 or 7.0 W/m²). The COACCH project considers a different set of scenarios, with overlapping SSP1-RCP2.6 and SSP5-RCP8.5 scenarios, as shown in Table 2.

Table 2. Selection of socio-economic scenarios

	SSP1	SSP2	SSP3	SSP4	SSP5
8.5					
7.0					
6.0				*	
4.5		†			
3.4				*	*
2.6		†			
1.9	*				

	CMIP5
	BES-SIM
	COACCH

*: Tier 2 in CMIP5

†: Includes climate signal variations

“We selected work done for the BES-SIM scenario analysis to connect IPBES, which has been an authoritative study on biodiversity impacts. For COACCH, the available results were reinterpreted in order to single out climate change as a driver of biodiversity loss. These results can subsequently be used to estimate economic impacts in the COACCH project (see further Figure 3 and Table 3).

2.3 Model - GLOBIOM

GLOBIOM's analytical process captures the multiple interrelationships between the different systems involved in provision of agricultural and forestry products, for example, population dynamics, ecosystems, technology, and climate.

GLOBIOM is a global, recursively dynamic, and partial equilibrium model (Havlík et al. 2014). It integrates the agricultural, bioenergy, and forestry sectors and draws on comprehensive socioeconomic and geospatial data. It accounts for the 18 most globally important crops, a range of livestock production activities, forestry commodities, first- and second-generation bioenergy, and water. Production is spatially explicit and considers land, management, and weather characteristics.

The market equilibrium is solved by maximizing the sum of producer and consumer surplus subject to resource, technological, and political constraints. Using the year 2000 as the baseline, GLOBIOM simulates demand and supply quantities, bilateral trade flows, and prices for commodities and natural resources at 10-year-step intervals up to 2050. This gives planners a basis for setting future land use and, more importantly, for identifying possible shortfalls in food and biomass supplies.

For the European Union, GLOBIOM has been enhanced to make use of available European datasets (Frank et al. 2015, Frank et al. 2016). A more detailed grid structure is used and the unit of analysis of the model is the NUTS2. Information on land cover is based on CORINE land cover map (CLC2000) and crop sector representation includes alternative tillage systems (conventional, reduced, and minimum tillage), crop rotations, residue management and additional crops i.e. sugar beet, rye, oats, flax, fallow, green fodder and corn silage. The model relies also on a detailed representation of the forest industries including industrial by-products (e.g. black liquor, sawdust, saw chips) (Lauri et al. 2014). In terms of trade and demand, every country of the EU is represented by its own demand and trade flows. All countries in the EU can trade with other countries in the EU or with regions in the rest of the world through a common EU market. Hence, trade flows go towards or away from a single EU country, to an EU-level market, and subsequently to another EU country or a world region outside Europe.

All GLOBIOM scenarios used in this deliverable are a new product of COACCH and novel in three aspects: First, the currently best-available climate data for Europe (Euro-Cordex) has been used to assess the impacts of climate change on the agricultural sector using a suit of biophysical models. Second, these climate impacts on productivity are integrated into the above-mentioned enhanced version of GLOBIOM that is specifically tailored to Europe. Third, the scenarios are set-up in a way that allows for the separate and integrated impact analysis of the agriculture, forestry and fisheries sector (rather than e.g. only the agricultural sector). The results portrayed in D2.5 build upon the modelling exercise conducted in D2.2 of COACCH. For a more detailed description of GLOBIOM's scenario set-up, we refer the reviewer to D2.2 (Boere et al., 2019).

2.4 Model – MAgPIE

MAgPIE 4 is a modular open-source framework for modeling global land systems (Dietrich et al 2019) that combines economic and biophysical approaches to simulate spatially explicit global scenarios of land use within the 21st century and the respective interactions with the environment. MAgPIE 4 provides a holistic framework to explore future transformation pathways of the land system, including multiple trade-offs with ecosystem services and sustainable development.

MAgPIE allocates land use to fulfil competing demands for commodities, feed, carbon storage, land conservation and environmental protection. Land use is broadly categorized in cropland, forest plantation, forest land, pasture land, and other natural land. MAgPIE takes spatially explicit data on potential crop yields, land and water constraints from LPJmL 5 (von Bloh et al 2017) and combines it with information on technological development and production costs. It includes agricultural trade with different levels of regional self-sufficiency constraints. MAgPIE calculates the following AFOLU GHG emissions: CO₂ from land use change (including changes to soil and plant carbon pools), N₂O from fertilizing agricultural soils and manure management, and CH₄ from enteric fermentation, manure management and rice cultivation. It includes a full dynamic and endogenous budget of the agricultural nitrogen cycle.

In the latest submission of April 2020 the MAgPIE results have been integrated. The MAgPIE analysis follows a similar fashion as the GLOBIOM analysis to allow for inter-model comparison. This new version of the deliverable therefore also includes a discussion section on how the results of the two models compare.

To be able to disentangle the differences introduced by global climate research projects, climate models, RCPs, crop models, crop model assumptions such as CO₂ fertilization, SSPs, mitigation efforts and economic models, GLOBIOM and MAgPIE analyse the full matrix of these elements. This matrix of scenarios can be found in Annex I of Deliverable 2.2 of COACCH (Boere et al., 2019).

3. Results

3.1 Biodiversity impacts from climate change - GLOBIO

GLOBIO uses a variety of MSA-impact relations, each corresponding to a biodiversity pressure/driver. For COACCH, the most relevant driver is climate change. GLOBIO uses a pressure-impact relationship relating MSA to global mean temperature. Direct observations of changes in species richness due to climate change are difficult to obtain, especially for more extreme temperature changes. For this reason, GLOBIO uses data from studies on specialised bioclimatic envelope models. Such models estimate the climatic variables in which a species can thrive or survive. Then, as the climatic variables change, the spatial distribution and occurrence of the species is changed accordingly.

In GLOBIO, only climate change effects on global mean temperature increases are considered, ignoring possible impacts from changes in precipitation patterns or regional climate change impact differences. From the different envelope model results, a beta regression analysis is performed to obtain MSA-pressure curves, as shown in Figure 1.

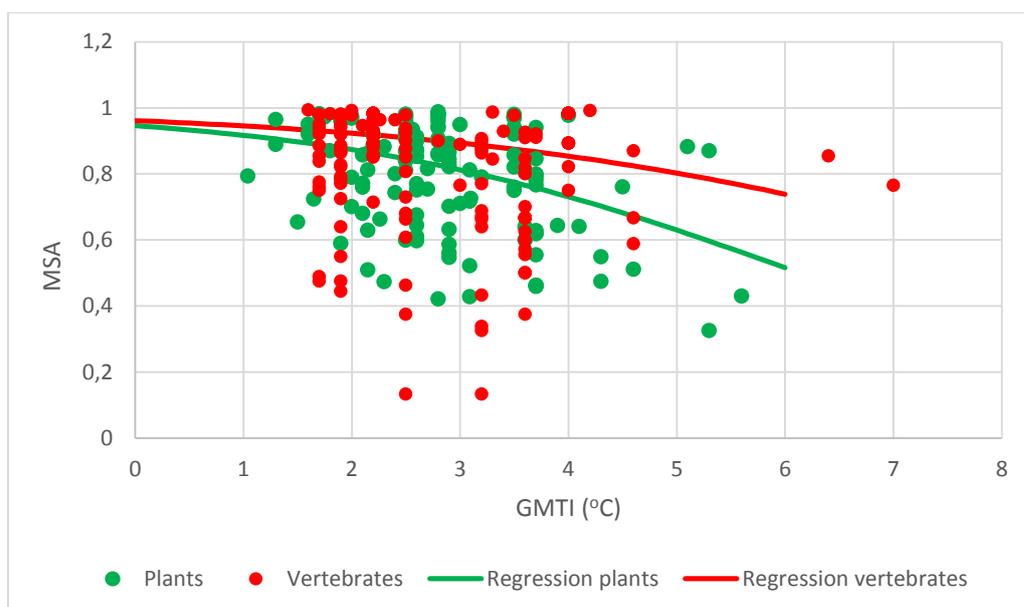


Figure 1 - MSA-pressure curve resulting from envelope model studies for both plants and vertebrates

The results show the negative impact of climate change on biodiversity. Plants are more sensitive to climate change than vertebrates (partly resulting from a lower ability to adapt). The exact relationships are best with uncertainty – with some studies suggesting even strong impacts at 2-3 degrees warming. The “median” regression line suggests 25-30% decline in plant biodiversity for 4 degrees warming and a 10-20% decline in vertebrate biodiversity.

3.2 Integrated scenarios - GLOBIO

Here, we focus on the three BES-SIM scenarios: SSP1-RCP2.6, SSP3-RCP6.0 and SSP5-RCP8.5. The global MSA is calculated for 2015 as a reference, and then compared to the global MSA in 2050 for each of the three scenarios, as shown in Figure 2. The SSP1-RCP2.6 scenario shows little change in MSA compared to 2015, especially when only plants are considered. The regional rivalry and fossil-fuelled development scenarios show a much stronger impact on biodiversity for plants. Interestingly, the effect on vertebrates is more constant throughout the three future scenarios. The SSP3-RCP6.0 shows a stronger effect on vertebrates MSA than the SSP5-RCP8.5 scenario, even though the former uses a smaller climate change scenario (RCP6.0 vs RCP8.5). It should be noted that the difference in global mean temperature between RCP6.0 and RCP8.5 is still relatively small in 2050, and increases further towards the end of the century. The MSA difference as function of GMT increase is shown in Figure 3.

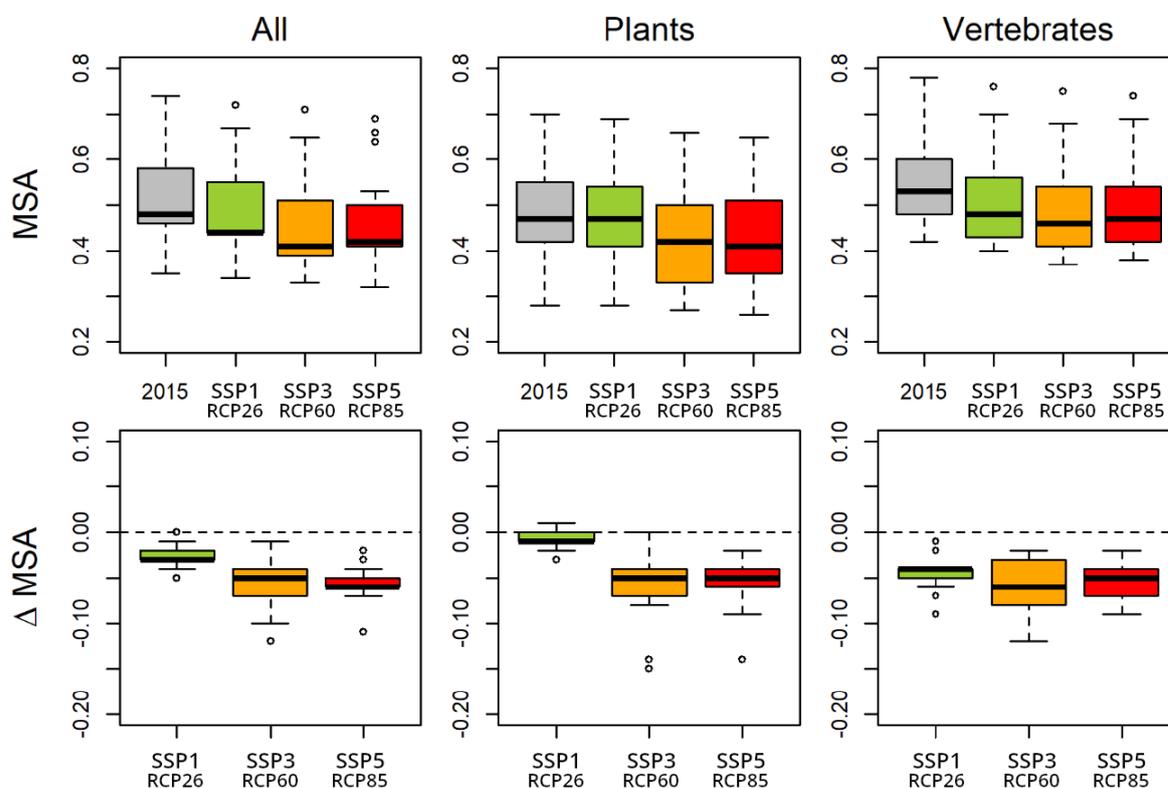


Figure 2 - Global Mean Species Abundance in 2015 compared to the three BES-SIM scenarios: S (Sustainability, SSP1-RCP2.6), RR (Regional rivalry, SSP3-RCP6.0) and FD (Fossil-fuelled development, SSP5-RCP8.5). Bottom row: difference in global MSA compared to 2015 (Schipper AM 2019).

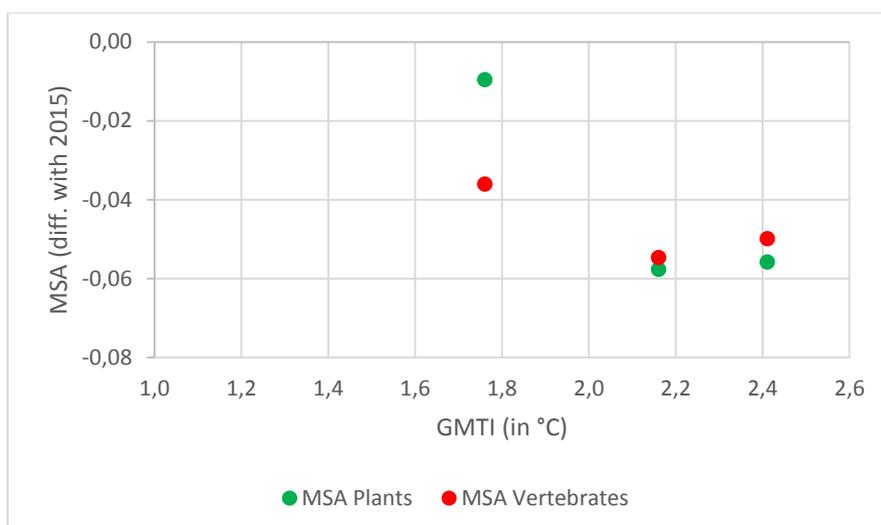


Figure 3 - MSA loss in 2050 for the three different scenarios, as function of Global Mean Temperature increase in 2050.

The results shown in Figure 3 capture both the climate and land use impacts of the scenarios (as function of climate change). The impact of climate alone can be isolated as indicated in the Table 3 that reports for the MSA indicator (globally and referring to both plants and vertebrates) the climate change impacts only (assuming the other drivers to be constant). The loss of MSA can also be expressed in terms of a equivalent amount of loss of pristine natural area (last column of Table 3).

Table 3: Summary of biodiversity loss (both plants and vertebrates) based on MSA calculations for climate change only (assuming other drivers to be constant)

	Scenario	Temperature (°C)	MSA	Eq. Loss (Gha)
2015		0.99	0.480	--
2050	SSP2_2.6	1.77	0.467	-0.17
	SSP2_3.4	1.92	0.464	-0.21
	SSP2_4.5	2.04	0.462	-0.24
2100	SSP2_6.0	2.10	0.460	-0.25
	SSP2_2.6	1.76	0.467	-0.16
	SSP2_3.4	2.17	0.459	-0.27
	SSP2_4.5	2.70	0.446	-0.44
	SSP2_6.0	3.32	0.429	-0.66

3.3 Non-market impacts from climate change – GLOBIOM

We present in this section the impacts of different climate change scenarios on non-market indicators related to land use and agricultural markets impacts in the GLOBIOM and MAgPIE models. These impacts are indirect impacts, in the sense that they result from the adaptation response of agriculture and forestry to the climate change through shifts in management practices, production reallocation and land use change.

Three different indicators are scrutinized, reflecting different ecosystem services and hidden costs to the environment: land cover change, fertilizer use, and greenhouse gas emissions.

3.3.1 Land cover

Climate change is expected to impact crop yield and affect cropland needs, as change in harvested area is part of the adaptation response that farmers adopt in response to yield changes. Two effects can be expected: as yields decrease, farmers can expand their harvested area to compensate for a part of their losses, in particular if prices on the markets increase. But in case some substitution across crops is possible, farmers may also adopt alternative crops providing them more profit opportunities or abandon the land to grow crops in other regions with more favorable conditions. Non-market impacts on the other hand receive no price or no complete price in the optimization algorithm. In the case of land expansion, the optimization only considers the land-expansion costs but not for the environmental damage of removing the natural vegetation.

GLOBIOM

The way the different effects counterbalance can be observed in Figure 4 below. For instance, the figure shows that areas like the South of Spain respond to climate change with significant decrease of cropland, whereas others expand in the North of the same country. This is a reallocation effect due to the relatively more favourable conditions for crop cultivation in the North, compared to the South of Spain, something that is shown in **Figure 5**. Here, yields of winter wheat somewhat increase in the North-West of Spain but largely decrease in the South of Spain. However, the most general trend due to climate change remains a decrease in cropland in the EU, due to the yield increase associated with CO₂ fertilisation, in particular for crops like wheat that are already benefitting from the climate change. By 2050, for three out of the four GCMs, EU cropland decreases by 2 to 5 Mha, and in 2070, the decrease of cropland area can reach 6.5 Mha (HadGEM-ES RCP4.5). Change in pasture area is less significant in our scenarios (less than 0.5 Mha increase to compensate for concentrate feed higher prices), also because we ignore the effect of CO₂ fertilisation on grass productivity. As a consequence, land area devoted to nature significantly increases, in a range of 2.5-5 Mha by 2050, except for the GFDL-ESM2M scenario where EU cropland remains relatively stable (see Figure 4 and Figure 6).

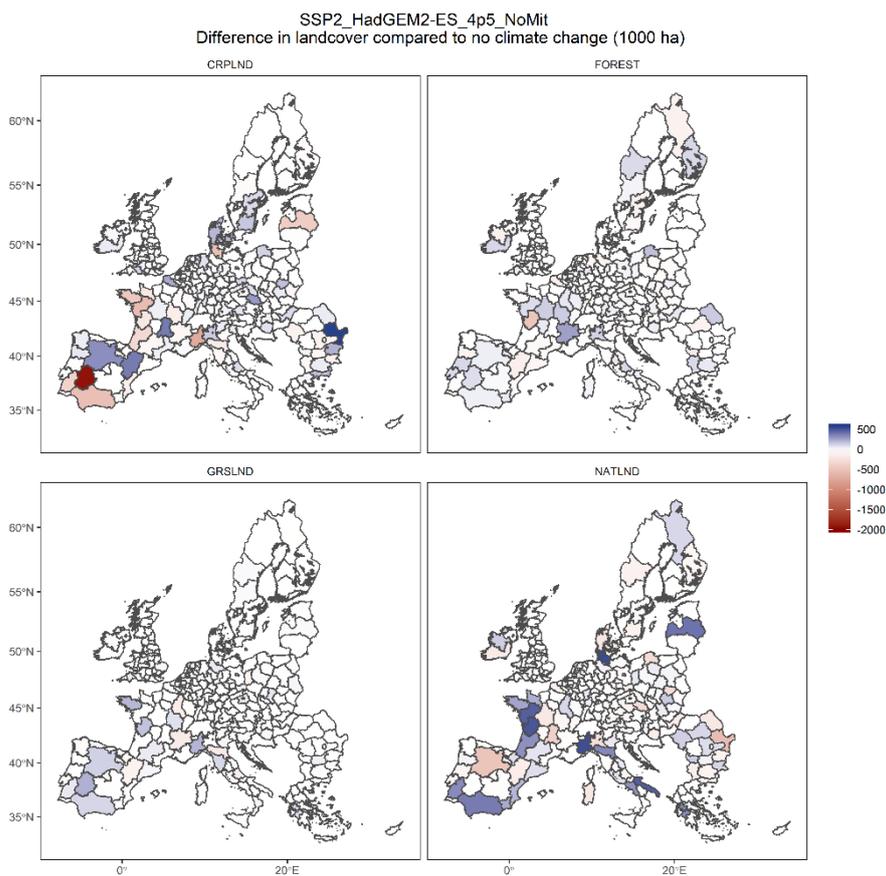


Figure 4: Impacts of RCP4.5, HadGEM2-ES, in 2050 on land cover change.

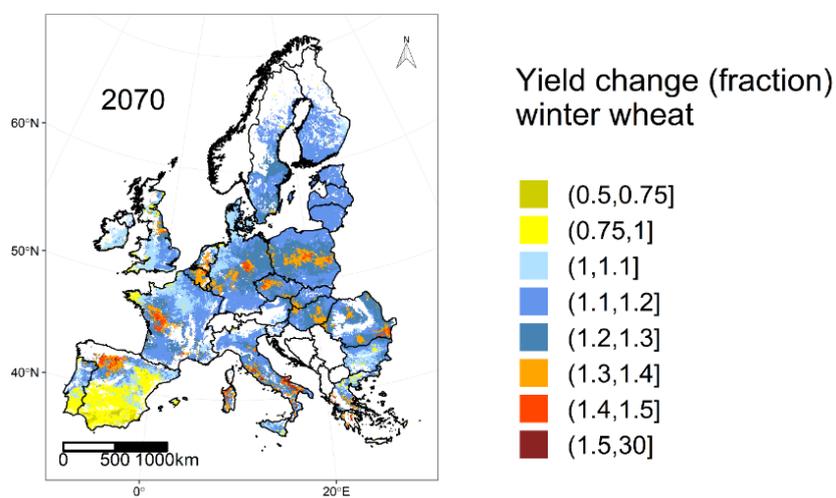


Figure 5: Impact of climate change on winter wheat yield by 2070 in Europe for HadGEM-ES2 under RCP4.5

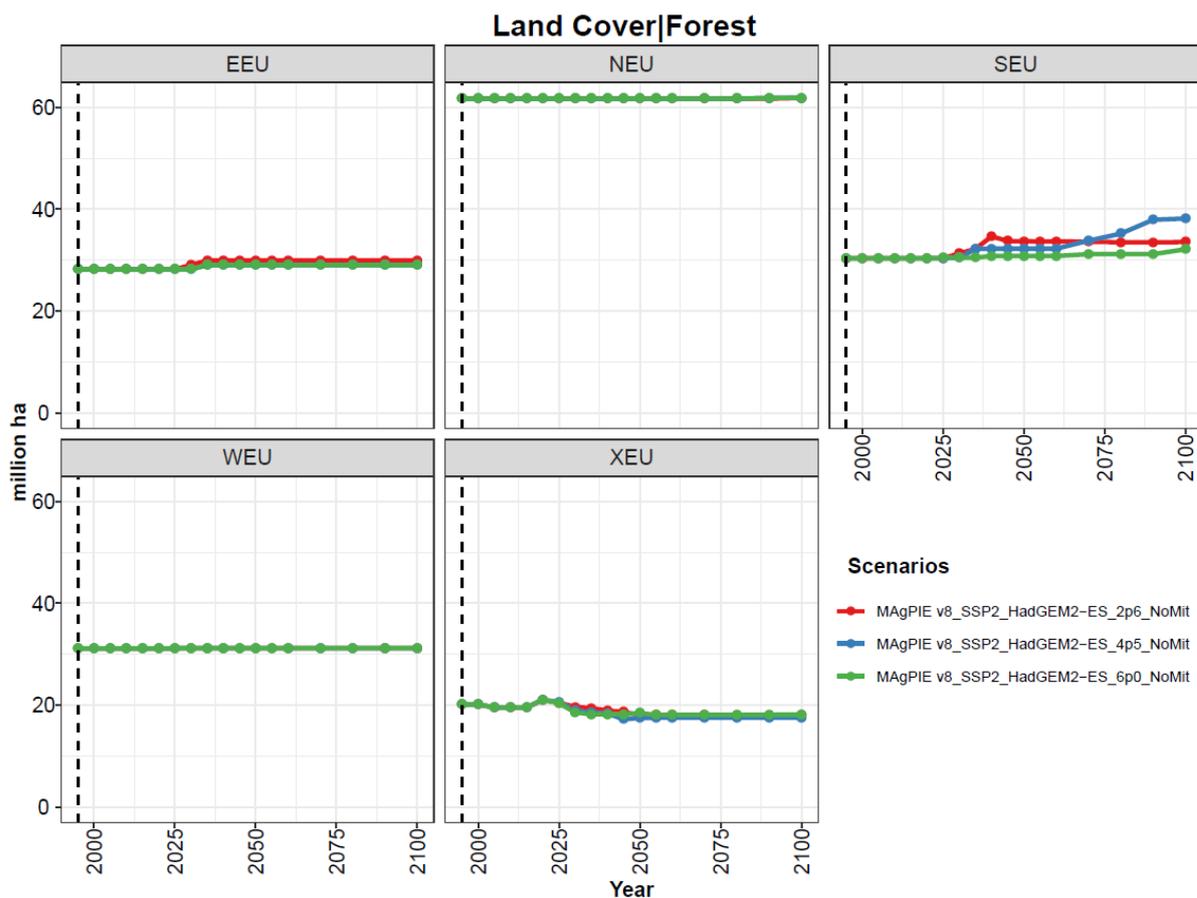


Figure 7: Change in forest land cover (including forestry) for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

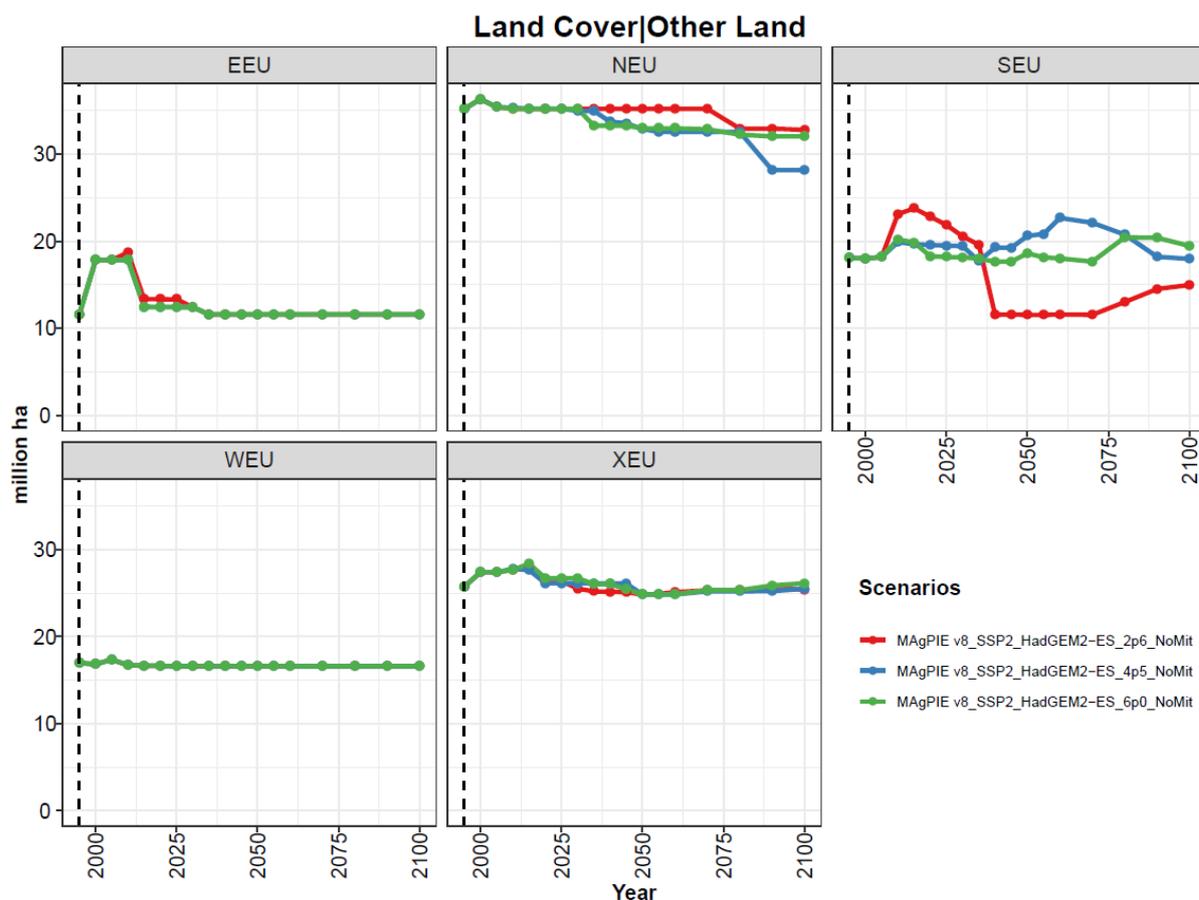


Figure 8: Change in “other land” (land cover which neither classifies as agricultural land, nor as forest, nor as built-up area) for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

3.3.2 Fertilizer use

Fertilizer application generates greenhouse emissions through N_2O but also generates adverse impacts in case of leaching and run-off in river streams, including eutrophication in water pools. Nitrogen pollution thereby includes most importantly nitrate leaching to groundwater and surface waters, air pollution by ammonia and nitrous oxide as greenhouse gas (the latter will be discussed in the section on climate change). As climate change affects crop productivity, farmers will need to adapt their practices to accommodate or compensate for the effects on yields.

GLOBIOM

The analysis from GLOBIOM reveals that the impact on fertilizer use will likely follow the direction of crop yield changes, as farmers provide the nutrient requested by crops for the growth in their new environmental conditions.

Figure 9 below illustrates the extent of variation of nitrogen fertilizer in the face of different climate change scenarios, and at different time periods. Results are strongly influenced by the climate model chosen. When changes are expected to be positive to crop growth, like in the GFDL-ESM2M or the NorESM1-M case, fertilizer consumption increases, and the level of extra use can exceed 500,000 tonnes for Europe after 2050 in the case of GFDL (all RCPs). But for the HadGEM scenario, the prospect is the reverse, as crop yield losses lead farmers to decrease their application. The strongest impacts are however observed in RCP2.6 and RCP4.5 as CO₂ fertilization tend to compensate for the yield losses for RCP6.0.

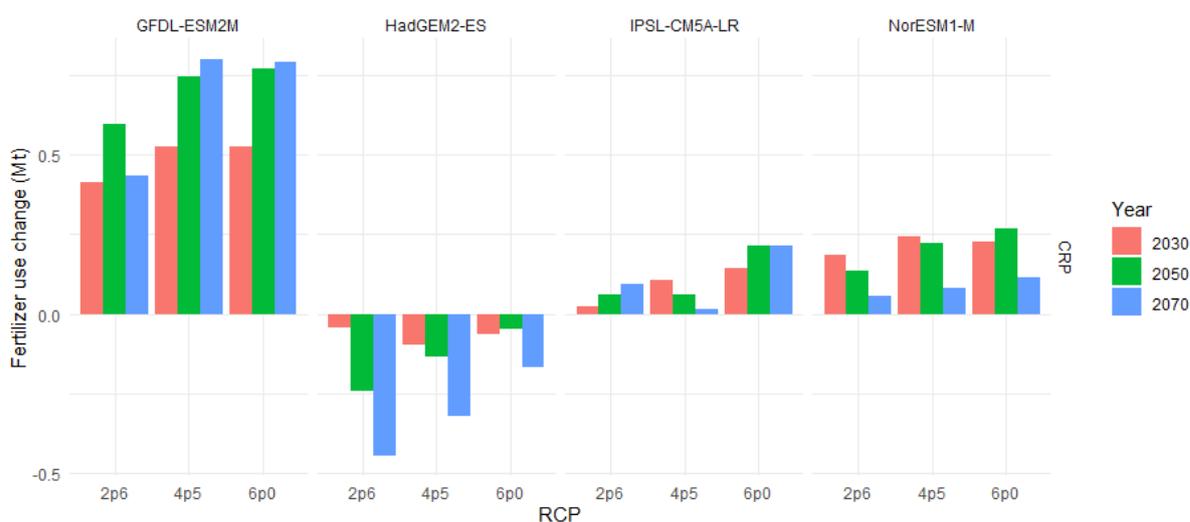


Figure 9: Change in nitrogen fertilizer consumption in the European Union for different RCPs (x-axis) and different time periods (color of the bars), compared to the baseline without climate change.

MAGPIE

As a proxy for nitrogen pollution, MAGPIE includes the inorganic fertilizer usage (Figure 10) and the nitrogen surplus (Figure 11). The latter is defined as the difference between all nitrogen inputs (fertilizer, manure, crop residues, atmospheric deposition etc) and all nitrogen harvest (harvested grains and crop residues). The surplus is a more precise indicator than nitrogen fertilizer application, as it also incorporates the organic nutrients and the beneficial impacts of high nitrogen use efficiency.

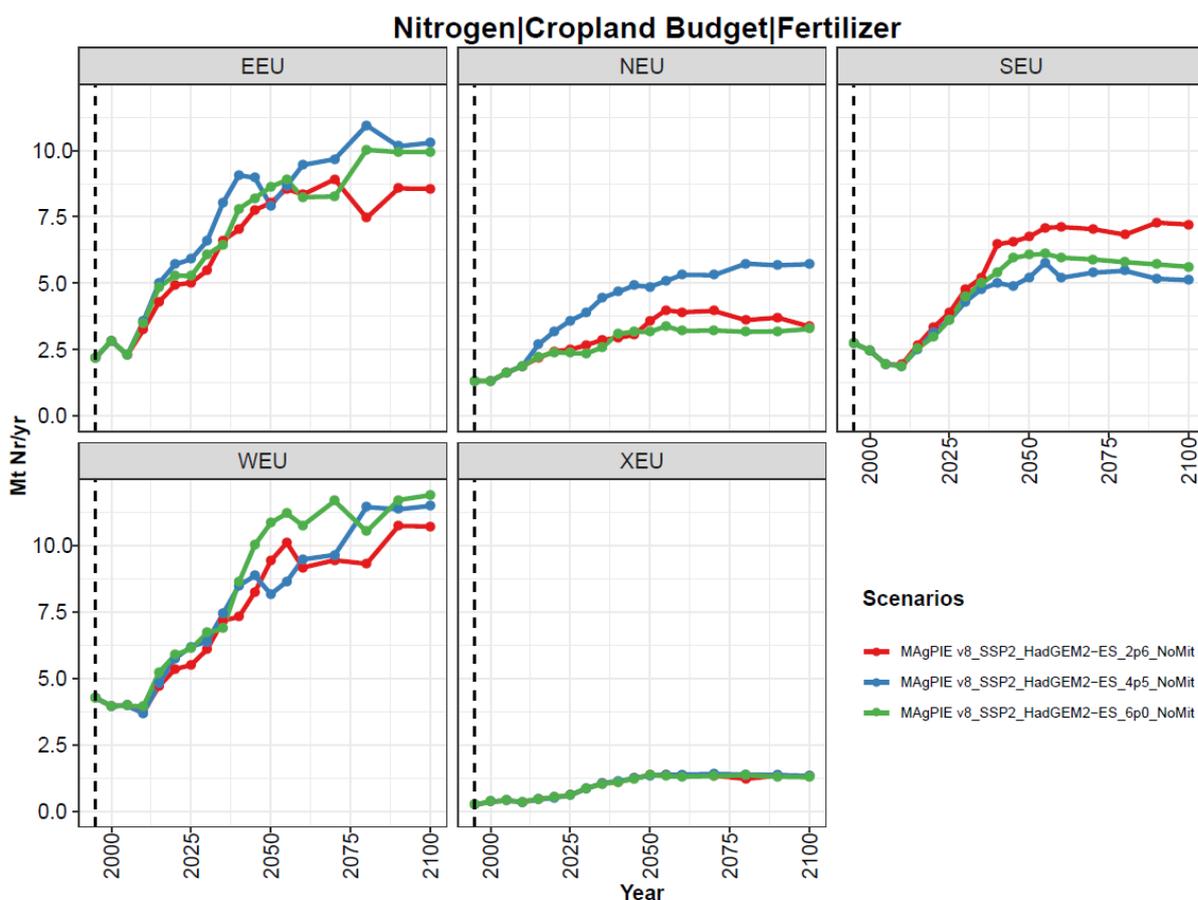


Figure 10: Change in inorganic fertilizer application for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

In general our SSP2 scenarios see a trend of increasing nitrogen fertilizer application, as production further increases and nitrogen use efficiency does not improve substantially.

The impact of climate change on nitrogen pollution in MAgPIE 4 stems mainly from changing production quantities and crop yields. The impact of changing precipitation on the leaching fraction, or the impact of rising temperature on ammonia emissions are not considered in this analysis. The change in nitrogen pollution therefore mostly follows the change in production quantities, yet affected by the nitrogen content of the particular crops. For example, oilcrops like rapeseed have a higher impact on nitrogen pollution than cereals, and their spatial relocation has a higher impact on nitrogen budgets. Nitrogen fertilizer application and nitrogen surplus show similar, yet not identical patterns. The reason for this is that in our simulations, climate change had a much stronger impact on the location of crops than on the location of livestock production systems (also due to the limitation that MAgPIE 4 does not include climate change impacts on livestock systems such as heat stress). A shift in livestock production systems would have also led to a relocation of organic nutrients and to differing patterns between fertilizer application and nitrogen surplus.

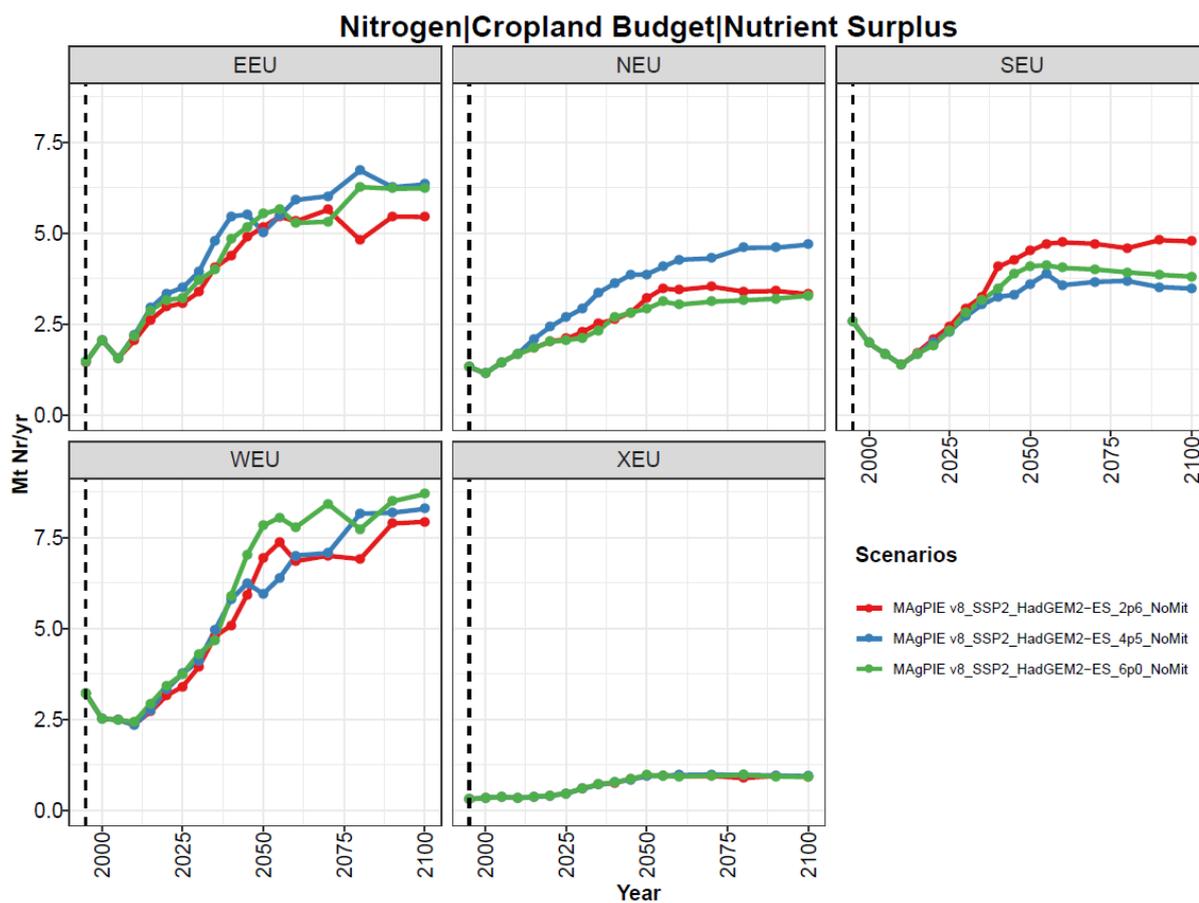


Figure 11: Change in Nitrogen surpluses on croplands for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

3.3.3. Greenhouse gas emissions

Change in the land use system in response to climate change will impact in return greenhouse gases emissions through different channels. Some of these channels are direct, for instance, forest fires or melting of the permafrost can release GHG emissions into the atmosphere. Some other effects are indirect, such as those related to emissions from land cover changes or management response to climate following adaptation in the agriculture or forestry activities.

Agriculture causes direct emissions of the non- CO₂ greenhouse gases N₂O and CH₄, as well as indirect CO₂ emissions from land-use change. These emissions sources are included in GLOBIOM and MAgPIE 4 as far as they are allocated to the agricultural sector according to IPCC accounting. For example, emissions connected to agricultural transport and storage are usually accounted for in the transport sector, while emissions by the chemical industry to produce fertilizers and pesticides are accounted for in the industry sector.

GLOBIOM

The first important indirect response in the agricultural sector is adaptation by farmers through change in nitrogen application to reflect their newly attainable crop yields and intensify their production where possible. **Figure 12** shows how this effect (green bar) represent the largest source of GHG emission variation in the EU. The magnitude and direction of these emissions is however highly dependent on the GCM used and the climate scenario, as previously observed for the fertilizer application case. GFDL is the model for which the response is the highest and most positive, because farmers apply more fertilizers in that scenario, and this degrades the GHG balance of the EU. This comes in contrast with the HadGEM results, where production and fertilizer application tend to decrease. Other adjustments also occur in the EU through the livestock sector, and changes in land cover (mostly conversion of grassland and other natural areas, as deforestation is considered restricted). These latter sources play however a much minor role in the final emission variation for the EU.

Overall, EU emissions vary by a relatively small amount, less than 5 MtCO₂/year for all the scenarios. This corresponds to less than 1% of the AFOLU emissions of the EU. However, as observed in the case of yields and related land use impacts, the impacts are very uneven throughout the EU. Some Member States see their agricultural emissions increase by up to 12% in the case of the HadGEM scenario RCP4.5, whereas some other see a decline of up to 8% (Figure 13). Emissions generally follow the same pattern as land cover change, with especially the areas in the South of Europe decreasing their emissions.

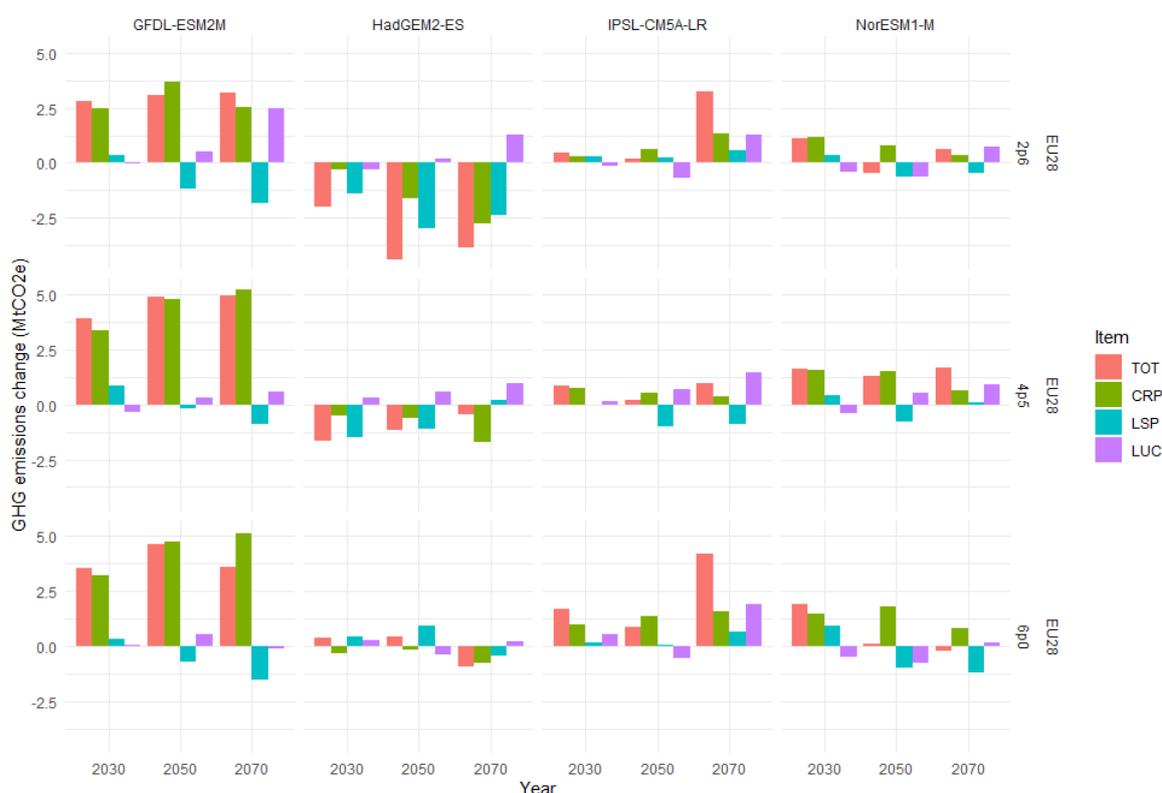


Figure 12: Impact of climate change in emission flows in the EU compared to the baseline. (TOT= total emissions, CRP = crop emissions, LSP = livestock emissions, LUC = land use change emissions).

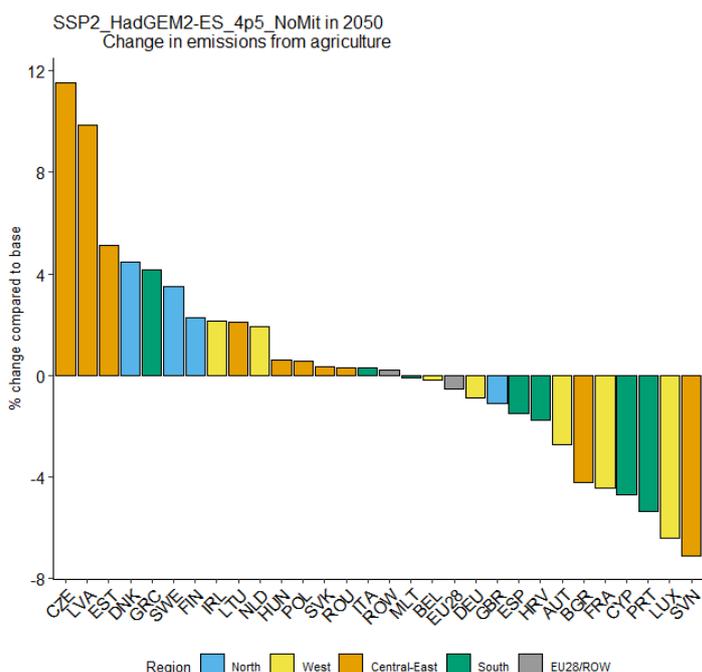


Figure 13: Change in emissions from agriculture under HadGEM2-ES, RCP4.5, in 2050

When looking at global level, the impacts from climate change on GHG emissions is much higher, although also significantly varying across scenarios (Figure 14). Like the variations observed at the EU level, the role of fertilizer emissions, strongly responding to crop yield and related management changes play a crucial role, in particular in the case of NorESM1-M scenario by 2070 under RCP2.6. Livestock still plays a relatively secondary role in the emission fluctuations, but the indirect impacts from climate change are also characterised by a strong variation in land use change emissions. This is driven by the adjustment of cropland described above. As crop yields decrease in some regions, harvested area increases, and cropland expansion leads to further natural land conversion and deforestation emissions. This effect plays a predominant role in several climate scenarios, in particular in the HadGEM case, where emissions are found to decrease. Overall, GHG emission fluctuations can reach in magnitude 100 MtCO₂-eq, which represents about 0.2% of global current GHG anthropogenic emissions. The direction of the emission variation is however highly dependent on the scenario considered.

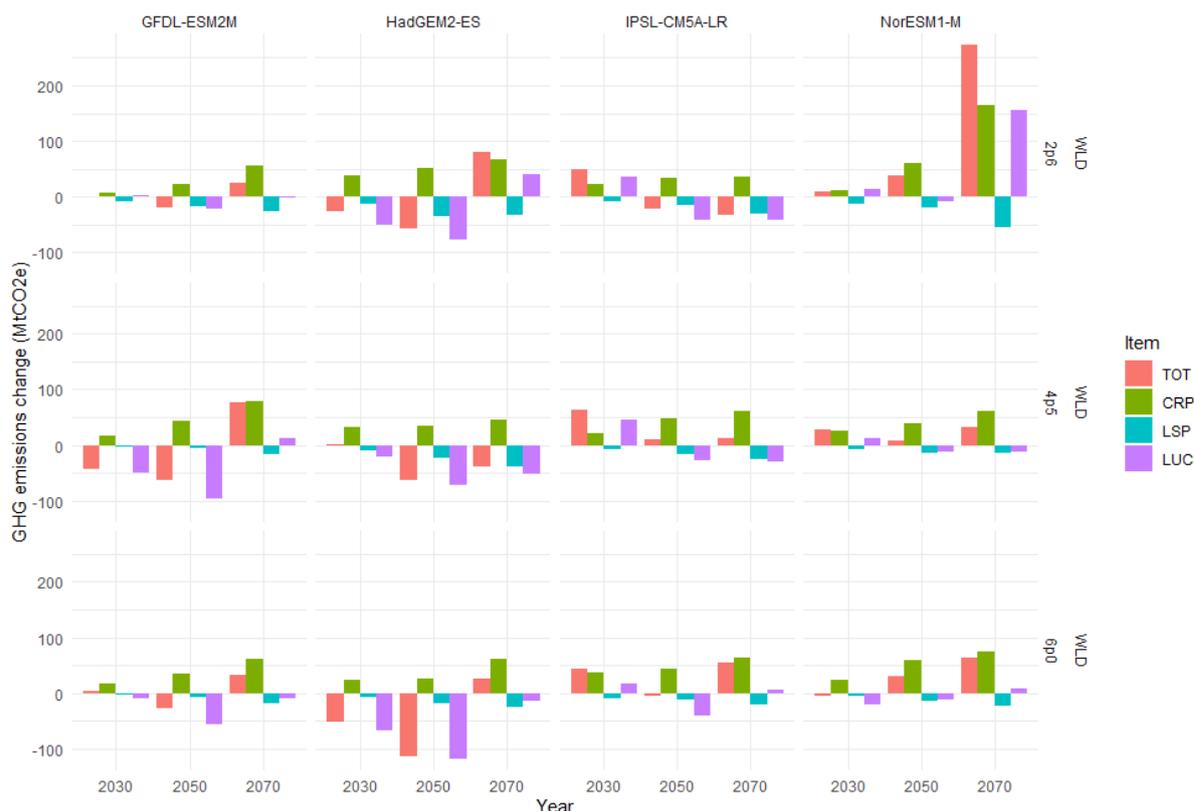


Figure 14: Impact of climate change in emission flows at global level compared to the baseline. (TOT= total emissions, CRP = crop emissions, LSP = livestock emissions, LUC = land use change emissions).

MAGPIE

For this European analysis, CH₄ emissions (see Figure 15) are mainly caused by the enteric fermentation of ruminants and to a lesser degree by manure management. Rice cultivation plays only a minor role in Europe. In our simulations, CH₄ emissions are therefore mostly dependent on the endogenous production quantity of livestock products and on the exogenous scenario-dependent feed mix. We do not cover the impact of temperature on emission factors, which are of some importance in the case of manure management, and we also do not account for a potential adaptation of livestock feed mixes. Our model therefore shows very little impact of climate change on CH₄ emissions, mostly because livestock production is not significantly reallocated in our scenarios.

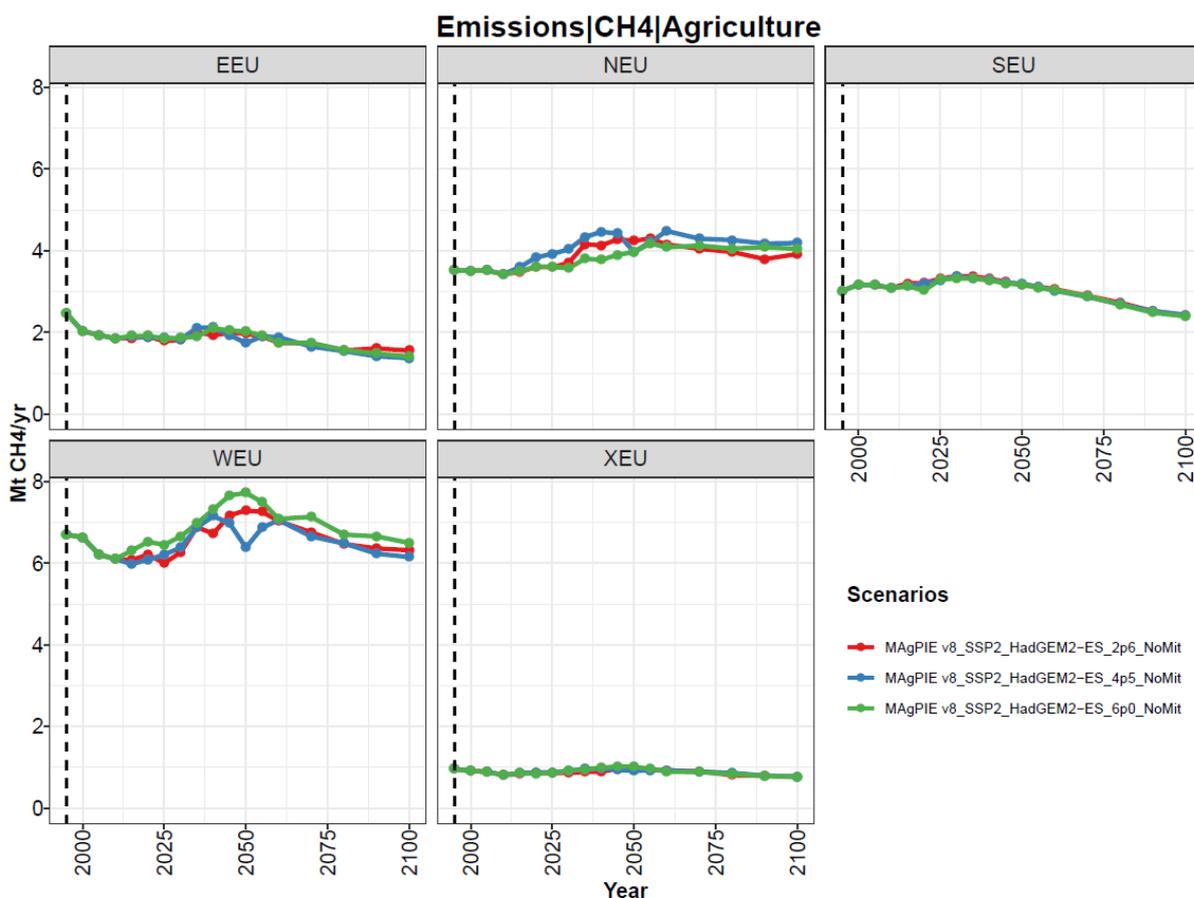


Figure 15: Change in methane emissions (CH₄) caused by agricultural adaptation to climate change, simulated for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

N₂O emissions (Figure 16) in turn are dependent on the fertilization with organic and inorganic fertilizers, and to a lower degree caused also by manure management. Here, climate change has an impact on emissions, which go strongly in line with the change in nitrogen surplus described in the last section. Again, they follow the re-allocation of nitrogen-rich crop production.

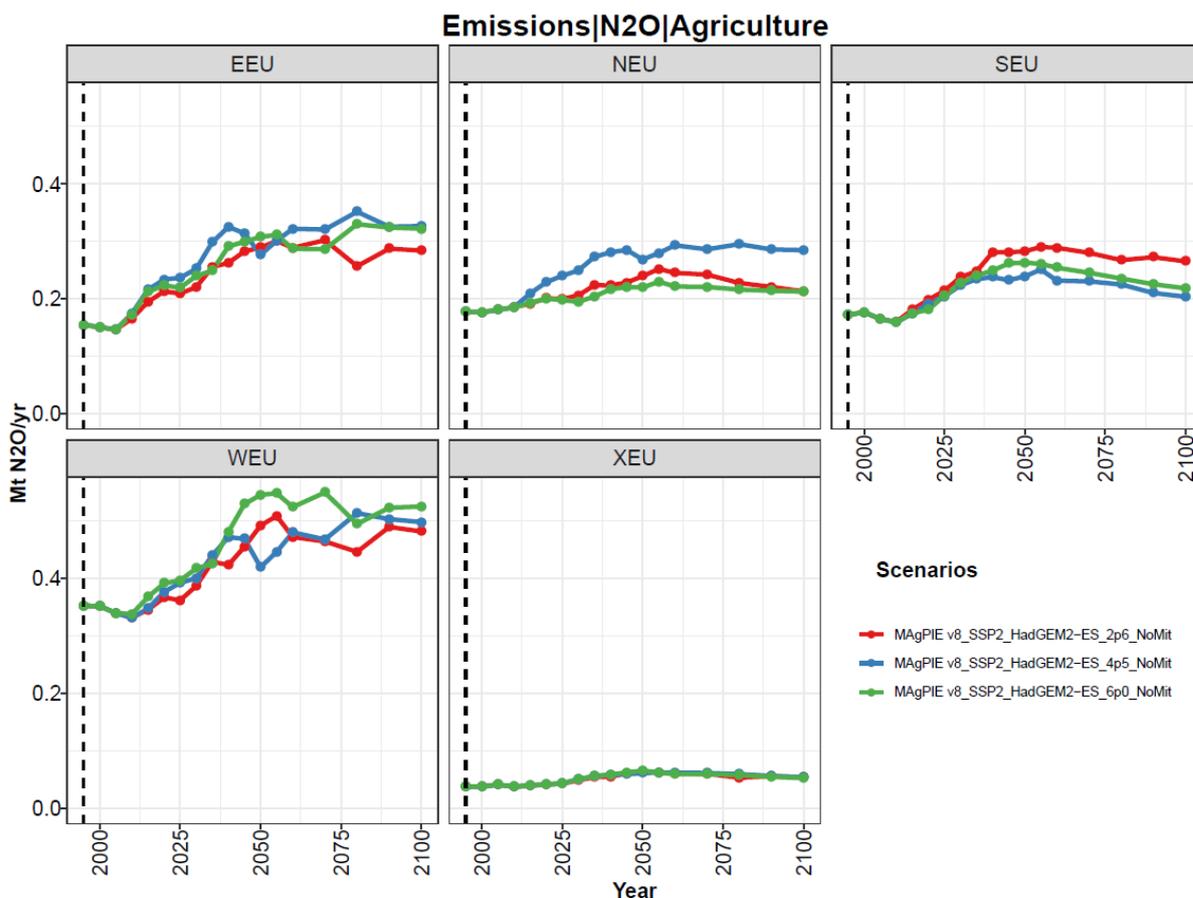


Figure 16: Change in nitrous oxide (N₂O) emissions caused by agricultural adaptation to climate change, for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

The indirect cumulative CO₂ emissions (Figure 17) are in our scenarios mostly negative and reflect the growth of biomass on non-agricultural land and the regrowth of biomass on abandoned land. This growth is to a certain degree enhanced by CO₂ fertilization and nitrogen deposition. Only in the Western EU, we see net-positive emissions towards the end of the century, which are actually directly climate-induced and have to be interpreted as declining carbon intensity of forests, as cropland and pasture areas in this region stay constant.

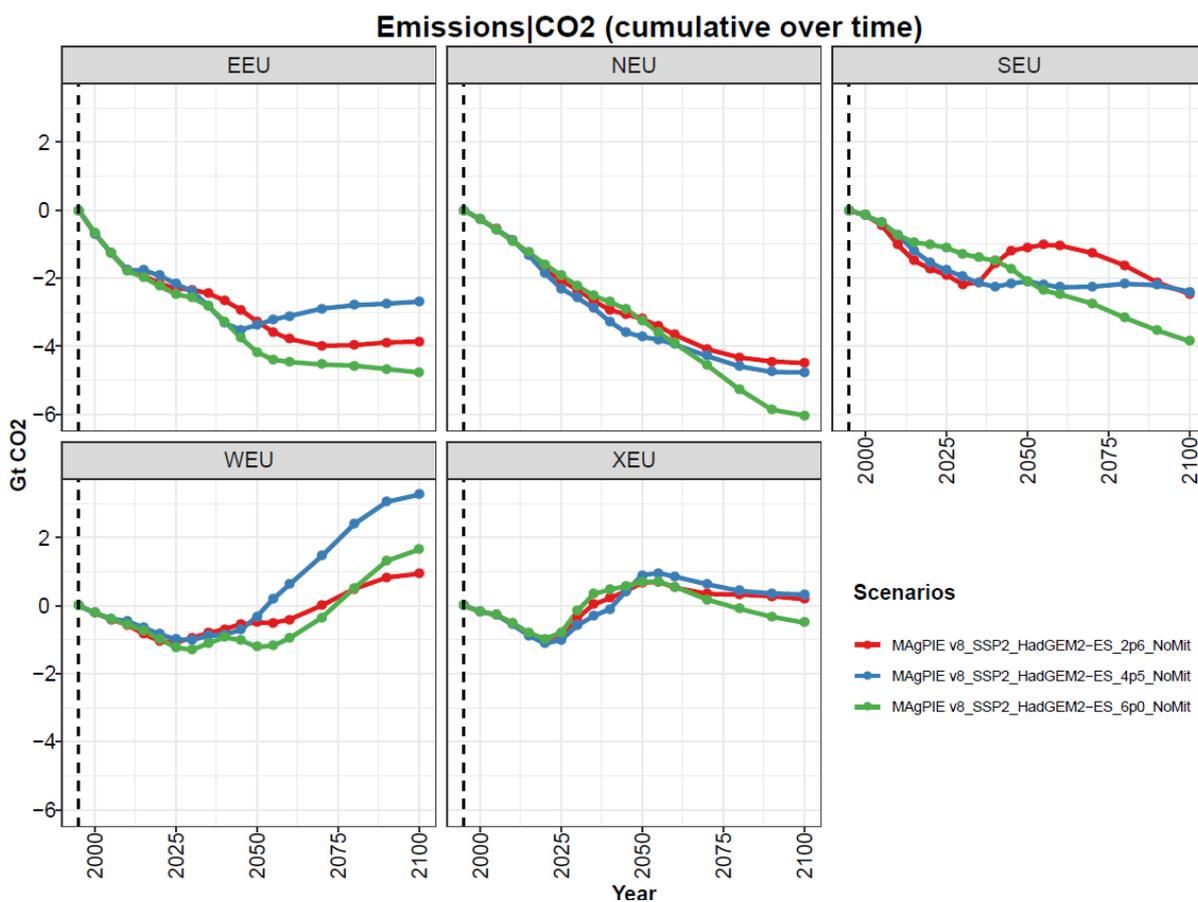


Figure 17: Cumulative CO₂ emissions since 1995 driven by climate impacts and agricultural adaptation, simulated for three scenarios with climate impacts from LPJmL, driven by simulations with HadGEM2-ES for three different degrees of climate forcing (RCPs 2p6, 4p5 and 6p0). The regions are Eastern EU (EEU), Northern EU (NEU), Southern EU (SEU), Western EU (WEU), and non-EU Europe (XEU).

4. Conclusions

GLOBIO

The GLOBIO model has been used to identify the effects of climate change on Mean Species Abundance as an indicator of biodiversity. Specifically, GLOBIO uses a pressure-impact relationship relating MSA to global mean temperature. The impacts of climate change on both vertebrates and plants are found to be negative – though the negative effect is more pronounced for plants who are less able to move location in the face of temperature change. More specifically, regression analysis suggests a 25-30% decline in plant biodiversity for 4 degrees warming and a 10-20% decline in vertebrate biodiversity.

GLOBIOM and MAgPIE

We utilised the GLOBIOM and MAgPIE models to identify and quantify the impacts on land use, fertiliser use and greenhouse gases as a consequence of adaptation in agriculture and forestry management. The impacts of these models reflect indirect impacts, in the sense that they result from the adaptation response of agriculture and forestry to climate change through shifts in management practices, production reallocation and land use change. Non-market impacts on the other hand receive no price in the optimization algorithm. For example, agricultural production costs do not include the external costs of N₂O, CH₄ or CO₂ emissions or the damages of nitrogen pollution. In the case of land expansion, the optimization only considers the land-expansion costs but not for the environmental damage of removing natural vegetation. Also, in the case of fertilizer, only the costs for the nutrients have to be paid but not the environmental externality. The consequence is a market-failure, in which agricultural activity is higher and more resource-intensive than in the welfare optimum. The externalities are practically invisible to the optimization algorithm. The adaptation behaviour of farmers to climate change in the model therefore does not consider these non-market impacts.

Against this background, GLOBIOM and MAgPIE draw some common conclusions on implications of climate change on land cover use, fertilizer use and GHG emissions. Both GLOBIOM and MAgPIE notice a change in land cover due to a change in the relative competitiveness in different regions. Whilst both models report that the results are sensitive to the climate-socio-economic scenario combination analysed, both models find that land cover changes are more induced due to changes in climatic conditions relative to other regional cultivation areas and other climatic zones in the world market. For example, GLOBIOM finds that areas at the latitude of South of Spain respond to climate change with significant decrease of cropland, whereas there is an increase in cropland further North.

For both models, this reallocation effect is reflected in matching shifts of fertiliser use that in turn can be expected to affect biodiversity as nitrogen leaches into the local

environment. Hence, both models show that nitrogen fertilizer application increases with productivity and production growth. Furthermore, MAgPIE shows that nitrogen use efficiency does not really improve.

Parallel associated shifts in GHG emissions are also expected though their size is not significant compared to global changes. As deforestation is rather limited in Europe, the largest changes in GHG emissions stem from changes to nitrogen application, which go strongly in line with the change in nitrogen surplus following the re-allocation of nitrogen-rich crop production.

Overall, the model results indicate strongly that the effects of climate change on biodiversity are likely to be non-negligible by 2050, particularly under the high emission scenarios. They therefore provide an early signalling as to the value of advanced planning for biodiversity conservation that adequately accounts for these projected changes.

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