CLIMATE CHANGE IMPACTS ON EUROPEAN AGRICULTURE: A MULTI MODEL PERSPECTIVE

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Abstract

We present and integrated supply and demand side analysis of climate change impacts on the agricultural sector from a European perspective based on a joint application of two European focused global partial equilibrium models. Results show that climate change would considerably affect agricultural supply and demand quantities as well as producer prices. Nevertheless, adaptation mechanism such as reallocation of production or intensification can help to absorb the initial climate shock so that impacts on the demand side are eventually significantly smaller. Differences between the two models applied are negligible when comparing results to the output spectrum from other global partial and general equilibrium models running the same scenarios.

1 Introduction

Climate change impacts on food production, socioeconomic developments such as population and income growth in large parts of the world and biofuel policies are the main challenges for the agricultural sector in the future and have raised scientific, political and public interest in long-term forecasts (Godfray *et al.*, 2010). As the world population is expected to rise to 9 billion people until 2050, agricultural production will have to increase significantly in order to meet human food demand (FAO, 2009) . At the same time, climate change poses a major challenge to the agricultural sector, among other, through its negative effects on agricultural productivity growth (Müller & Robertson, 2013). Many studies assessed quantitatively the impact of climate change on agriculture globally or in a specific regions using climate-, crop- and economic models in stand-alone or combined approaches (Iglesias *et al.*, 2011, Nelson *et al.*, 2013, Rosenzweig *et al.*, 2013). For Europe a variety of analyses quantified impacts of climate change on productivity (Audsley *et al.*, 2006, Hermans *et al.*, 2010, Leclère *et al.*, 2013) and concluded that climate change may only slightly influence the evolution of the European agricultural sector compared to other drivers such as economic growth or technological change. However, most European studies focused so far on supply side effects only whereas impacts and feedbacks from the demand side or through international trade have not been considered.

Despite the variety of impact studies on direct effects of climate change, uncertainty remains (Rosenzweig *et al.*, 2013). Already Adams et al. (1990) showed that the impact of climate change strongly depends on the climate model applied. Recently, the Inter-Sectoral Impact Model Intercomparison Project (Warszawski *et al.*, 2013) and Agricultural Model Intercomparison and Improvement Project (AgMIP) addressed uncertainty implied in analyses of individual models. Besides comparisons among climate and crop models, also ten global economic models have been compared in with each other in AgMIP (Nelson *et al.*, 2013, von Lampe *et al.*, 2013). They conclude that harmonizing model assumptions significantly narrows the spread of scenario outcomes, though principal differences remain, particularly when comparing computable general equilibrium and partial equilibrium models. Results from the global gridded crop models show that uncertainty related to agricultural productivity under climate change mainly depends on the crop model used rather than on the climate model inputs (Müller & Robertson, 2013, Rosenzweig *et al.*, 2013). In the economic models, exogenous yield shocks due to climate change can be, to a certain extent, compensated due to endogenous model responses resulting in a significantly smaller impact on final production and demand quantities compared to the initial shock. With respect to some key variables, economic models generally agree in increasing producer prices under climate change scenarios and overall decreasing production and consumption compared to a Baseline scenario without climate change (Nelson *et al.*, 2013, von Lampe *et al.*, 2013).

Here we want to supplement literature by adding an integrated supply and demand side analysis of climate change impacts on the agricultural sector from a European perspective. Instead of focusing on global developments, but acknowledging that climate change affects crop yields differently across scales and regions (Lobell *et al.*, 2011, Reidsma *et al.*, 2007) and considering the specific political setting given through the Common Agricultural Policy (CAP) in Europe, we present a European focused analysis. We apply and link two European focused global models to quantify the impacts of climate change in terms of food prices and market balances including trade positions up to 2050. The joint analysis is based on the two partial equilibrium models, CAPRI (Common Agricultural Policy Regionalised Impact modelling system, Britz and Witzke (2012)) and GLOBIOM-EU, a European-focused variant of the Global Biosphere Management Model, Havlík et al. (2011)). At the same time we deepen the understanding of system drivers and mechanisms and account for uncertainty as we compare the results of two different models on the same set of scenarios which are based on the new Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs).

2 Models

2.1 CAPRI

CAPRI 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. The core of CAPRI is based on the linkage of a European-focused supply module and a global market module. The supply module consists of independent aggregate non-linear programming models which cover the EU27, Norway, Western Balkans and Turkey. They represent all agricultural production activities and related output generation and input use at regional (280 NUTS2) or farm type level. The programming models are combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers' decisions. The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour. Each programming model optimizes income under restrictions relating to land balances, including a land supply curve, nutrient balances and nutrient requirements of animals and if applicable, to policy obligations. Decision variables are crop areas and total land use, herd sizes, fertilizer application rates and the feed mix. With respect to policy implementation, the different policy instruments of Pillar I and Pillar II of the Common Agricultural Policy (CAP) are depicted in detail for the EU. 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 50 primary and processed agricultural products, covering about 80 countries or country blocks 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. Land is not explicitly allocated to activities when the model is solving. But the land demand elasticities in the system imply certain yield elasticities that may be used to disaggregate the total supply response into contributions from yields and from areas and to estimate the land allocation in scenarios, starting from the baseline land allocation. On the demand side the Armington approach, assumes that the products are differentiated by origin, allowing the simulation of bilateral trade flows and of related bilateral and multilateral trade instruments, including tariff-rate quotas. This sub-module delivers the output prices used in the supply module and allows for market analysis at global, EU and national scale, including a welfare analysis.

The main databases used in CAPRI are EUROSTAT, FAOSTAT, OECD and extractions from the Farm Accounting Data Network (FADN). The supply response of each NUTS2 or farm type in the European-focused supply module is estimated using time series data on land use and corresponding price and cost developments. The parameters of the global market model are synthetic, i.e. to a large extent taken from the literature and other modelling systems. Typically CAPRI is used for simulations starting from a given baseline. To produce this baseline, trend estimations constrained to account for technology restrictions and external prior information are used, in this study in particular from GLOBIOM-EU. For a more detailed description of CAPRI see Britz and Witzke (2012).

2.2 GLOBIOM-EU

GLOBIOM-EU is a global recursive dynamic partial equilibrium bottom-up model integrating the agricultural, bioenergy and forestry sectors. In the objective function, the global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize the sum of producer and consumer surplus subject to resource, technological and policy constraints. Demand and international trade are represented at the level of 53 aggregated world regions (28 EU member countries, 25 regions outside EU). Commodity demand is specified as downward sloping function with constant elasticities parameterized using FAOSTAT data on prices and quantities, and own price elasticities as reported by Muhammad (2011). Outside Europe the supply side of the model is based on a detailed disaggregation of land into Simulation Units (SimUs) – clusters of 5 arcmin pixels belonging to the same country, altitude, slope and soil class, and to the same 50x50 km pixel. For the EU (except Croatia, Cyprus and Malta) a new EU-SimU architecture (Balkovic *et al.*, 2009) has been incorporated. The concept of the EU-SimUs is identical with the global one however it is based on more detailed datasets (basic spatial unit is a 1x1 km pixel, soil class is decomposed into texture, soil depth, soil stoniness, NUTS2 regions boundaries plus additional dimensions for land cover category, presence of irrigation equipment and river catchments). Information on land cover is based on CORINE land cover map (CLC2000) instead of the product used globally – GLC2000 (Global Land Cover).

Crop, forest and short rotation tree productivity is estimated together with related environmental parameters like GHG budgets or nitrogen leaching, at the level of SimUs, either by means of process based biophysical models or by means of downscaling. On the crop production side outside Europe, the model represents 18 major crops and 4 different management systems (irrigated, high input – rainfed, low input – rainfed and subsistence) simulated with the bio-physical process based model EPIC (Environmental Policy Integrated Climate)(Williams, 1995). For the European crop sector EPIC simulations with detailed representation of management systems (3 tillage systems - conventional, reduced and minimum tillage and 2 fertilizer and irrigation systems), crop rotations and additional crops have been incorporated. Parameters for primary forest production such as mean annual increment, maximum share of saw logs in harvested biomass and harvesting costs are provided by the G4M model. Six land use types are represented in the model (cropland, grassland, short rotation tree plantation, managed forests, natural forests and other natural land) which can be converted into each other depending on the demand on the one side, and profitability of the different land based activities on the other side. For a more detailed description of the global model version see Havlík et al.(2011).

3 Scenarios

3.1 General scenario information

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change distinguishes between two dimensions of scenarios: the RCPs (Moss et al., 2010) and the SSPs (Kriegler et al., 2012). Four RCPs were developed each of which corresponding to a specific radiative forcing pathway. Additionally, five SSPs were developed by the Integrated Assessment Modelling and Impacts, Adaptation and Vulnerability communities. The SSPs have been assembled along the axes of challenges to mitigation and challenges to adaptation to climate change. Besides the narratives, they also contain quantitative (population and gross domestic product (GDP) developments) and semi-quantitative elements. AgMIP uses a subset of IPCC RCPs and SSPs up to 2050. From the full set of AgMIP scenarios (von Lampe et al., 2013), this paper has picked three that appeared particularly illuminating in the context of climate change: A Baseline scenario and two climate change scenarios differing in the climate and crop models applied (Table 2). The Baseline scenario represents present climate and in socioeconomic terms SSP2, associated with the catch phrase “middle of the road” meaning medium challenges to mitigation and adaptation and continuation of current trends. The climate change scenarios analyse SSP2 combined with RCP 8.5. They differ in the General Circulation Models (GCMs) predicting regional temperature and precipitation and the crop models projecting climate change induced changes in average crop yields. While S3 and S6 do not differ uniformly across regions on the global level S6 is clearly more pessimistic for average crop yields. Apart from the scenario characteristics described above, other model assumptions are kept constant.

Table 1. Scenarios used in the paper

Scenario code	**RCP**	**GCM**	**Crop model**	**CC impact in 2050**	**GDP growth 2005/2050**	**Population growth 2005/2050**
Baseline	Present climate	-	-	-	WLD 125% EU 73%	WLD 44% EU 2%
S3	RCP 8.5	IPSL-CM5A-LR	LPJmL	-11%		
S6	RCP 8.5	HadGEM 2-ES	DSSAT	-21%		

Baseline assumptions on yield growth without climate change are taken from the IMPACT model (Nelson et al., 2010). Quantitative information on population and GDP developments was taken directly from the SSP database (IIASA/OECD, 2013). For implementation of the climate change impacts we calculated average yield shifters per crop, management system and region from the crop models for the different climate scenarios. The shifters were applied to shift future yields and costs in the different climate scenarios.

3.2 Linking CAPRI and GLOBIOM-EU Baseline

In order to capture the complex interrelations between technological, structural and preference changes for agricultural products world-wide in combination with changes in policies, population and non-agricultural markets, CAPRI relies on several data sources. It is either based on external (“expert”) forecasts, as well as on trend forecasts using the CAPRI database. The purpose of these trend estimates is, on the one hand, to compare expert forecasts with a purely technical extrapolation of time series and, on the other hand, to provide a safeguard in case no information from external sources is available. In order to align the Baseline in the two models, GLOBIOM-EU is run in a first step. Baseline projections on crop and livestock supply and demand quantities as well as global cropping areas and land use balance are then mapped to CAPRI items and regions. GLOBIOM-EU outputs are given "weights" and are used as "expert" data to align CAPRI to GLOBIOM-EU for the Baseline scenario.

4 Results

The results section is split into four parts: First the Baseline scenario is described in detail based on GLOBIOM-EU. This is followed by a section on the endogenous response of the two models to the climate change shock and impacts of climate change on European consumers and producers.

4.1 Baseline scenario

In the Baseline scenario, world population increases to around 9.2 billion until 2050 (+44% globally (WLD), and +2% in EU28 compared to 2005). GDP growth per capita (GDPpCAP) is expected to more than double in globally and rise by around 70% in the EU28 resulting in a significant increase in demand for agricultural products. Table 3 shows aggregated population, GDPpCAP, productivity and price changes in 2050 compared to 2005. Productivity growth represents exogenous technological change based on IMPACT model but does not include model endogenous productivity increases e.g. change in management system or reallocation of production to more productive areas. While macroeconomic drivers (population and GDPpCAP) remain constant across scenarios, prices increase stronger with climate change as crop yields are negatively impacted. In the Baseline global crop prices remain stable until 2050 while they decrease by around 9% inside the EU. Similar pattern can be observed in the livestock sector where global and European prices remain rather constant until 2050. This development is within the price range of other global economic models used in AgMIP (von Lampe *et al.*, 2013).

Table 2: Population, GDPpCAP, price and productivity increases in 2050 compared to 2005 in GLOBIOM-EU in different scenarios.

			Baseline	**S3**	**S6**
Crop sector	WLD	Price	*0.98*	*1.19*	*1.24*
		Productivity	*1.65*	*1.48*	*1.33*
	EU28	Price	*0.91*	*1.13*	*1.20*
		Productivity	*1.49*	*1.33*	*1.27*
Livestock sector	WLD	Price	*1.02*	*1.08*	*1.12*
		Productivity	*1.06*	*1.06*	*1.06*
	EU28	Price	*0.98*	*1.05*	*1.08*
		Productivity	*1.03*	*1.03*	*1.03*
Macroeconomic	WLD	Population	*1.44*	*1.44*	*1.44*
		GDPpCAP	*2.25*	*2.25*	*2.25*
	EU28	Population	*1.02*	*1.02*	*1.02*

	GDPpCAP	1.73	1.73	1.73

Technological change is an important driver of global food prices as it directly affects productivity of land and production costs. Even though demand increases over time due to population and income growth putting pressure on markets and prices, (real) crop prices actually remain stable due to yield growth and adaptations on the supply side. Crop yields are projected to increase by 65% globally and by around 50% inside the EU due to technological change in the Baseline. In the livestock sector productivity increases are smaller compared to the crop sector. Productivity increases only by 6% globally and 3% inside the EU.

Until 2050, global supply increases substantially as demand for crop and livestock products is projected to almost double globally. Table 4 shows crop aggregate demand developments and the relative share of the sources for the additional demand (food, feed and other uses). Worldwide, the most significant demand increases are expected from additional demand for food and livestock feeding followed by demand for other uses (mostly biofuels but also other uses i.e. seeds, waste). Only for wheat (WHT) and paddy rice (RIC) around half of the additional demand is related to human food consumption. For coarse grains (CGR) and oilseeds (OSD) around 60% of additional demand is driven by livestock feeding and increasing demand for biofuels is especially important for sugar crops (SUG) with a share of 48%.

Table 3: Relative increase in demand quantities until 2050, percentage share coming from additional food, feed and other uses for wheat (WHT), coarse grains (CGR), paddy rice (RIC), oilseeds (OSD) and sugar crops (SUG).

		Baseline				**AgMIP**
		2005-2050	**% food**	**% feed**	**% other**	**2005-2050**
WLD	WHT	1.4	0.53	0.35	0.12	1.4 - 2.0
	CGR	2.1	0.19	0.64	0.17	1.8 - 2.2
	RIC	1.5	0.48	0.45	0.07	1.3 - 1.9
	OSD	2.3	0.22	0.58	0.20	1.6 - 2.4
	SUG	2.4	0.32	0.20	0.48	1.6 - 2.6
EU28	WHT	1.2	0.17	0.24	0.60	0.9 – 1.3
	CGR	1.3	0.03	0.51	0.46	0.8 – 1.6
	RIC	1.1	0.55	0.25	0.20	1.0 – 1.6
	OSD	1.8	0.01	0.24	0.75	1.0 – 2.3
	SUG	1.5	0.14	0.03	0.83	1.0 – 3.1

The picture looks different inside the EU where increasing demand for crops is largely driven by additional biofuel consumption (% other) and livestock feeding rather than an increase in human food consumption. Around 60% of the additional demand for WHT is driven by additional demand for biofuels inside the EU while for OSD and SUG this goes up to more than 75%. The second biggest driver is the livestock sector contributing with almost 51% of additional CGR and 24% of WHT and OSD demand. Only 17% for WHT and 3% for CGR is related to growth in human food consumption. Globally demand increases are in line with AgMIP even though they are in the upper range for CGR, OSD and SUG and at the lower end for WHT (Table 4). For EU28 the global economic models differ substantially in demand projections. However, the GLOBIOM-EU and CAPRI are in line with most models in predicting a rather modest demand increase.

Productivity increases are not sufficient to meet the doubling demand for agricultural products by 2050 without expansion of agricultural area. Consequently, cropland expands globally by 14% until 2050. Inside Europe cropland continues historic trends and decreases by around 7%. Grasslands increase by 14% (stable in EU) driven by increasing demand for livestock feeding. These trends for crop- and grassland expansion are within ranges of AgMIP (Schmitz *et al.*, 2013). By 2050, 140 Mha of plantation forest are established to meet rising energy demand, 13 Mha of which in the EU while forest area declines by 4% (-169 Mha).

4.2 Endogenous model responses to climate change

Climate change significantly impacts global agricultural markets in the scenarios analysed (S3, S6), as crop yields decrease and prices increase (Table 3). However, impacts depend on the climate and crop models used as well as on the economic model implementing these shocks. In both climate change scenarios, prices rise compared to the Baseline without climate change as productivity decreases. Figure 3 shows the models response to the exogenous climate change impacts on productivity (YEXO). We decompose the exogenous climate signal into responses in terms of total productivity changes (YILD), impacts on cropland (AREA), production (PROD), consumption (CONS) and prices (XPRP). Globally the exogenous yield shock of -11% in S3 and -21% in S6 can be buffered in both models due endogenous adaptation strategies e.g. on the supply in GLOBIOM-EU through reallocation of production within and across regions or a shift in management systems. Consequently, the exogenous climate change shock translates eventually into YILD declines in S3 between 7-8% and 10-15% in S6. Expansion of AREA increases by around 1-4% in both models in S3 and 3-6% in S6 limiting further the impact of YEXO. Eventually, global demand and production decreases by 4-6% in S3 and 7-10% in S6 compared to an initial yield shock of -11% S3 and -21% S6.

At global level, the two models respond similarly to climate change in both scenarios even though some particularities of the models can be observed. In S6, GLOBIOM-EU does not buffer as much of the climate change shock in term of yield but more in AREA growth as CAPRI which nevertheless results in slightly stronger demand and production decreases. In S3, GLOBIOM-EU also shows slightly higher demand and production due to less AREA expansion. Prices increase on average by around 25% in S3 and 31% in S6 in GLOBIOM-EU while in CAPRI projects price increases of around 25% in S3 and 38% in S6. To conclude, our results fit well with the observed patterns in AgMIP where global economic models respond to a YEXO of -18% (across all AgMIP climate change scenarios) with -12% YILD, +10% AREA, and -3% PROD on average (Nelson *et al.*, 2013).

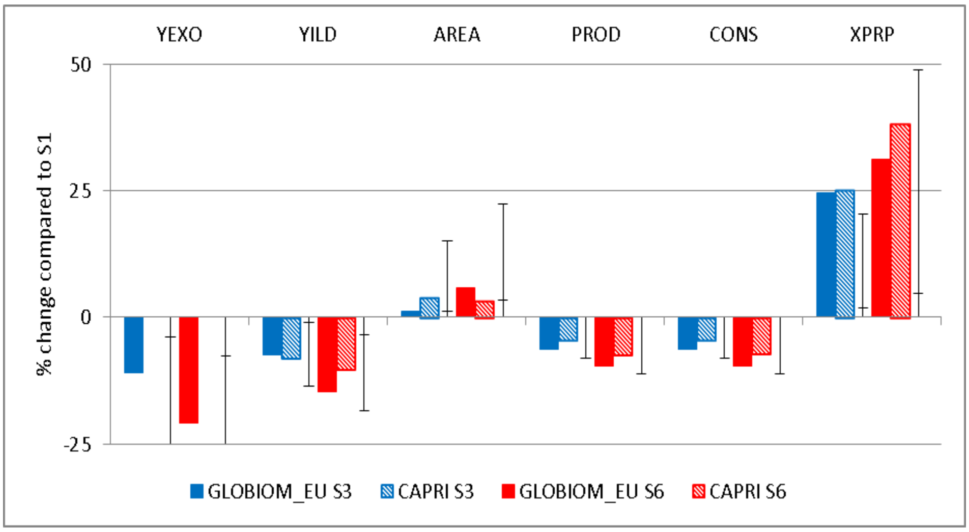

Figure 1: % change of climate change scenarios compared to the Baseline on prices (XPRP), areas (AREA), supply (PROD), demand (CONS), yields (YILD) and exogenous yield shock (YEXO) of total crop production globally. Upper and lower dashes represent minimum and maximum values from all models in the AgMIP exercise.

Compared to responses on the supply and demand side prices are the most sensitive parameter impacted by climate change in the models. In GLOBIOM-EU the biggest price shocks across commodity groups at global level can be observed for CGR (26 % S3 - 65% S6) and OSD (37% S6 - 43% S3) while impacts are smaller for WHT (24% S3 - 28% S6) and RIC (15% S6 - 21% S3). CAPRI projects similar price ranges for CGR (27% S3 - 51% S6), however the two models differ in magnitude of price shocks for the remaining commodities where CAPRI reports higher prices for WHT (32% S3 - 57% S6), RIC (37% S6 - 38% S3) and a lower price increase for OSD (24% S3 - 28% S6). In general, CAPRI tends to predict stronger price increases related to the climate change shocks compared to GLOBIOM-EU across products and regions.

Looking at EU28, a slightly different response to climate change can be observed compared to the global level (Figure 4). In GLOBIOM-EU, impacts of climate change can only be slightly buffered through intensification due to limited adaptation capacity through management shifts and reallocation of production especially in S3. Consequently, climate change impacts are mostly compensated through expansion of cropland which affects total productivity as less suitable areas enter production. In EU28, YILD decreases on average by around 7-11% in S3 and 9-14% in S6 (YEXO of 11% in S3 and 16% in S6). In S3, AREA expands by 4-9% and 6-9% in S6 with GLOBIOM-EU projecting the upper range in both scenarios. PROD declines in S3 by 3-4% and 4-7% in S6 and CONS decreases by 3-4% in S3 and 3-5% in S6 with CAPRI predicting a smaller impact on the demand side.

Compared to the AgMIP results, GLOBIOM-EU is at the lower range of endogenous yield adaptation to climate change while both models are well in line for AREA expansion. Impacts on the production side are stronger compared to other models where some report increasing PROD under climate change (especially for OSD) in Europe. Consequently, also price increases are at the upper end compared to other models. However, given the big range of projections in AgMIP for Europe, CAPRI and GLOBIOM-EU seem to project consistently the impacts of climate change on European producer and consumers and help narrowing down the potential spectrum of impacts on agriculture. The models agree on general response patterns with other models as adaptations on the supply side (YILD, AREA and PROD) are bigger compared to rather inelastic behaviour for CONS which is consistent with Nelson et al. (2013).

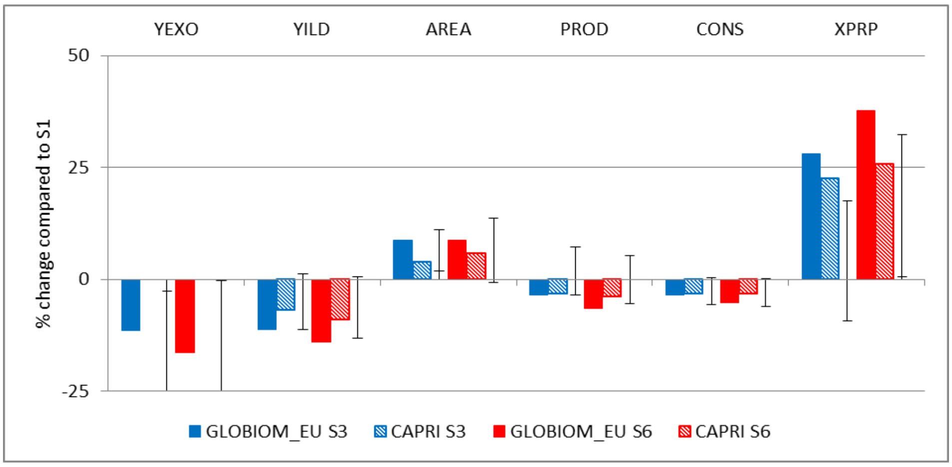

Figure 2: % change of climate change scenarios compared to the Baseline on prices (XPRP), areas (AREA), supply (PROD), demand (CONS), yields (YILD) and exogenous yield shock (YEXO) of total crop production in Europe. Upper and lower dashes represent minimum and maximum values from all models in the AgMIP exercise.

4.3 Climate change impacts on food consumption

Having analysed endogenous model responses to an exogenous climate change signal, we want to focus now on demand side effects in more detail. Climate change has a significant impact on human consumption for livestock and crop products as demand quantities decrease compared to the Baseline as prices increase. Both models agree that human food consumption declines stronger in S6 due to the higher climate change shock and the resulting price increases (Figure 5). Despite this common trend in the two models across products, CAPRI demand reacts less sensitive to the climate shocks. In CAPRI price changes are overall higher and consumption decreases smaller pointing towards a rather inelastic demand while GLOBIOM-EU shows a more elastic demand behaviour. Across all products GLOBIOM-EU projects stronger food demand decreases. Total calorie consumption per capita drops by 5% in S3 and 7% in S6 globally compared to the Baseline. Impacts on consumption quantities for crop products are higher compared to the livestock sector as the crop sector is directly impacted through climate change, while the livestock sector only indirectly through higher feed costs (grassland productivity is assumed to remain constant across scenarios).

In Europe consumers are less impacted from climate change in terms of calorie consumption. Demand quantities decrease significantly less compared to the ROW where people suffer more from higher food prices induced by climate change. Average calorie consumption per capita decreases in both scenarios by around 3% compared to the Baseline in GLOBIOM-EU. Similarly as at global level, also inside Europe CAPRI shows a smaller decrease in demand quantities compared to GLOBIOM-EU (Figure 6). For some products in Europe even a small increase in demand quantities can be observed in CAPRI even though prices rise. This is due to cross price effects, in the case of wheat, for example with vegetables and meats that are increasing even stronger than cereals. Another reason is the so-called Armington correction that converts the change in aggregate consumption (domestic + imported) from utility points into tons. If price changes are small, but the domestic-imported composition changes markedly, the Armington correction may change the sigh of the overall effect from negative into positive which applies to maize in the case of the EU under the “S3” scenario, for example.

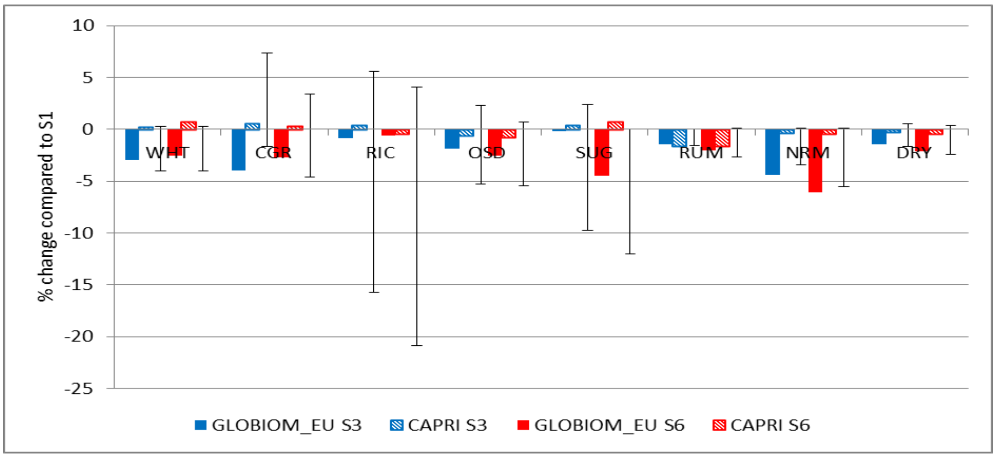

Figure 3: % impact of climate change scenarios on food consumption in 2050 in EU28 for wheat (WHT), coarse grains (CGR), paddy rice (RIC), oilseeds (OSD), sugar crops (SUG),

ruminant meat (RUM), non-ruminant meat (NRM) and dairy products (DRY). Error bars show min/max values from AgMIP models.

4.4 *Climate change impacts on the European agricultural sector*

Looking at impacts of climate change on the supply side inside EU28, both models project climate change impacts on crop aggregates (WHT, CGR, OSD and SUG) consistently despite some differences especially in price developments as explained already above. Figure 7 plots model responses across products and scenarios for CAPRI and GLOBIOM-EU in EU28. To conclude, overall endogenous behaviour to climate change inside Europe is well in line across the two models at aggregated EU level. Especially YILD responses to climate change but also AREA, XPRP and PROD responses are reasonably well correlated in CAPRI and GLOBIOM-EU. On the demand side, CAPRI is more sensitive to climate change as it even shows for some products positive feedbacks on CONS parameter due to cross price effects.

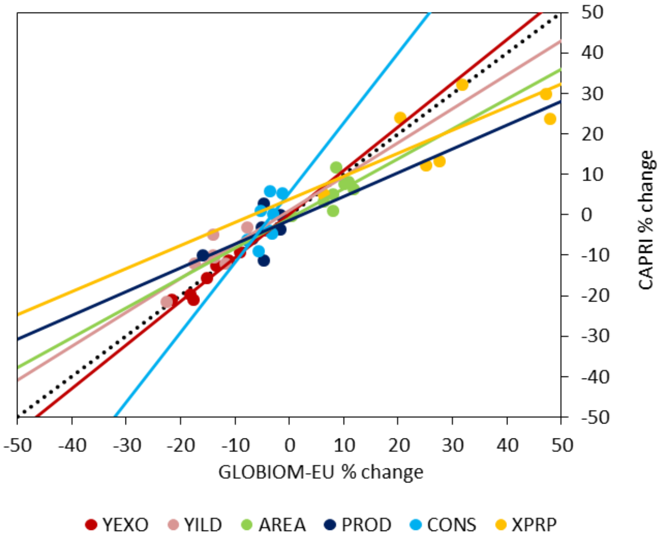

Figure 4: Model responses to a climate change shock across scenarios (S3, S6) and products (WHT, CGR, OSD, SUG) for EU28 in % change compared to Baseline. Each dot corresponds to the EU28 model result for a product and scenario. The dashed line indicates identical (1:1) model responses.

Looking at the crop aggregates separately, the models react different to the climate change shocks for WHT. While in CAPRI the shocks can be buffered through significant intensification related to YILD growth, GLOBIOM-EU compensates through wheat area expansion. In GLOBIOM-EU both climate change scenarios have eventually a similar impact on AREA and CONS while in CAPRI CONS increases even slightly under S6 due to high intensification and AREA expansion. For the PROD both models project a stronger decrease under S3 compared to S6 even though absolute magnitudes are slightly different. With climate change, net exports decrease in GLOBIOM-EU while European farmer remain competitive at the world market and net exports even increase in CAPRI. At country level Central European countries are most severely impacted by climate change in both scenarios in terms of YILD and PROD decreases. In S3, YEXO and YILD in France, Belgium and Luxembourg are most significantly impacted with decreases up to 50%. In S6 YILD is more than halved in the Netherlands and drop by around 50% in Belgium and Luxembourg. These developments cannot be compensates by AREA increases and consequently PROD drop significantly in those countries across the two models. Interestingly, Baltic countries show positive climate change effects on YEXO (28%) and YILD (+25 – 40%) in S6 which triggers AREA expansion and PROD increases as well as Northern countries which report production growth.

Table 4: % change compared to Baseline in 2050 for EU28 in CAPRI and GLOBIOM-EU. Exogenous climate change impact (YEXO), yield (YILD), crop area (AREA), production (PROD), consumption (CONS) and price (XPRP)

			YEXO	YILD	AREA	PROD	CONS	XPRP
WHT	GLOBIOM_EU	S3	-18.1	-17.3	12.0	-7.4	-5.5	47.4
		S6	-15.1	-14.0	11.0	-4.6	-5.1	31.9
	CAPRI	S3	-20.0	-12.1	6.2	-6.6	-9.2	29.8
	_	S6	-15.8	-5.0	8.0	2.6	0.9	32.0
CGR	GLOBIOM_EU	S3	-9.0	-7.6	6.5	-1.6	-2.9	20.5
		S6	-17.5	-13.7	8.1	-6.7	-7.7	50.4
	CAPRI	S3	-9.4	-3.3	3.2	-0.1	0.1	23.8
	_	S6	-21.1	-10.6	4.9	-6.1	-6.3	38.0
OSD	GLOBIOM_EU	S3	-11.1	-13.9	10.3	-5.0	-3.7	27.8
		S6	-21.6	-22.5	8.6	-15.8	-3.0	48.1
	CAPRI	S3	-11.5	-10.1	7.4	-3.1	-3.9	13.1
	_	S6	-21.1	-21.7	11.7	-10.3	-4.8	23.6
SUG	GLOBIOM_EU	S3	-4.1	-2.0	0.5	-1.5	-1.2	6.4
		S6	-13.4	-11.7	8.1	-4.5	-3.4	25.2
	CAPRI	S3	-4.0	-3.4	-0.3	-3.8	5.1	4.8
	_	S6	-12.8	-12.2	0.8	-11.5	5.7	12.1

For CGR the two models react almost identical to the climate change shocks as the exogenous yield shocks trigger consistent behaviour on the supply and demand side. In S3 climate change has only a small impact on PROD and CONS (0- -2%) while in S6 CONS drops by around 6-7% in the models. European net exports are projected to remain at constant levels in both models across scenarios. At country level all member states except the Netherlands show more or less significant negative yield changes induced by climate change in the two scenarios. However, Baltic countries are least affected in both scenarios and Northern countries even experience a positive climate signal in S6 (YEXO +9%, YILD +11%) while production in Central and Eastern European countries decreases substantially.

For OSD the models project again similar response patterns in terms of YILD, AREA, PROD and CONS while prices are significantly higher in GLOBIOM-EU. As for CGR, also for OSD European farmers decrease their production stronger under S6 compared to S3. In both models, the EU28 decreases net imports in S3 as European producers remain more competitive compared to the ROW while in S6 net imports increase slightly. At country level PROD decreases in most countries related to the YILD declines. While in S3 Northern and Baltic countries are most affected in terms of PROD decreases, the opposite is true in S6 where Northern countries again slightly increase their PROD due to modest YILD decreases and AREA increases.

A consistent behaviour for YILD, AREA (except for S6) and PROD can be observed for SUG. However, while GLOBIOM-EU projects decreasing CONS related to climate change in both scenarios with increasing prices, demand increases in CAPRI by around 5% with climate change. Southern countries are amongst the most heavily impacted countries in both scenarios with YEXO and YILD decreases around 10% and PROD around 2-5%. Like for the other crops, Northern countries are least impacted in S6 and can increase their production due to a modest exogenous climate change shock and AREA increases. To conclude, these results also highlight the regional and crop specific variation of climate change impacts on productivities as e.g. S6 shows on average a higher impact on productivities compared to S3, yet impact for WHT is higher in S3 and when looking at regional variation Northern countries are less impacted by climate change under S6.

5 Conclusions

This study provides a joint analysis of climate change impacts on global agricultural systems from a European perspective, using two European focused partial equilibrium models. We implemented a Baseline scenario by linking CAPRI and GLOBIOM-EU upon which we run two climate change scenarios. Climate change induced productivity shocks compared to the no climate change Baseline, lead to a global reduction of crop supply and related price increases. Through feeding costs, the livestock sector is affected indirectly as well from the changes in crop supply leading to higher prices.

In Europe exogenous climate change yield shocks of -11% in S3 and -16% in S6 result eventually in yield decreases by around 7-11% in S3 and 9-14% in S6 in CAPRI and GLOBIOM-EU. Besides model endogenous intensification, cropland expands by 4-9% in S3 and 6-9% in S6 in order to diminish effects on the supply side. Eventually, production declines only by 3-4% in S3 and 4-7% in S6 and demand decreases by 3-4% in S3 and 3-5% in S6 compared to the significantly higher exogenous climate change shock. In Europe consumers are less impacted from climate change in terms of decreasing calorie consumption compared to the rest of the world where people suffer from higher food prices induced by climate change. Average calorie consumption per capita decreases in both scenarios by around 3% inside Europe and globally by around 5-7%. Compared to other models where some report even increasing production at aggregated European level with climate change, CAPRI and GLOBIOM-EU project consistently a negative impact on the supply side. Moreover, both models agree on an average negative impact of climate change on the demand side. To conclude, CAPRI and GLOBIOM-EU project consistently the impacts of climate change on European producer and consumers and projections help narrowing down the magnitude of impacts given the big spectrum of results from global models for Europe running the same scenarios. Nevertheless, the models reflect general response patterns observed in the global models as adaptations on the supply side are stronger compared to rather inelastic behaviour on the demand side, and prices are the most sensitive parameter affected by climate change (Nelson *et al.*, 2013). With respect to model differences, CAPRI generally tends to predict stronger price effects and less impact on the demand side than GLOBIOM-EU related to lower price elasticities. However, putting differences in context to the larger model comparison exercise (von Lampe et al., 2013), differences between CAPRI and GLOBIOM-EU become negligible against the full spectrum of model results.

Nevertheless, results in this paper must be analysed in the context of limitations underlying the modelling framework and scenario design. An issue that requires further consideration is the responsiveness of grassland yields and animal productivity to climate change which has not been taken into account in this paper. Yet it may be expected that fodder crops and animal activity would be just as vulnerable to climate impacts as other crops. Including such impacts would considerably reinforce the global market effects via the animal sector. In addition, we do not take into account full adaptation of the agricultural sector to climate changes. We consider only partial market induced adaptation (e.g. price, land and variable input adjustments). We do not take into account economic adaptation such as changes in technology, management practices and farm structure.

Despite these shortcomings, our results enable us to conclude that European producers and consumers will be negatively affected by climate change through decreasing productivity and increasing prices. Nevertheless, Europe may still be better off compared to other parts of the world which will be even more impacted by climate change. Even though it may be possible to buffer part of the negative climate signal through adaptation measures on the supply side, especially poor people could be affected by rising food prices induced by climate change.

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