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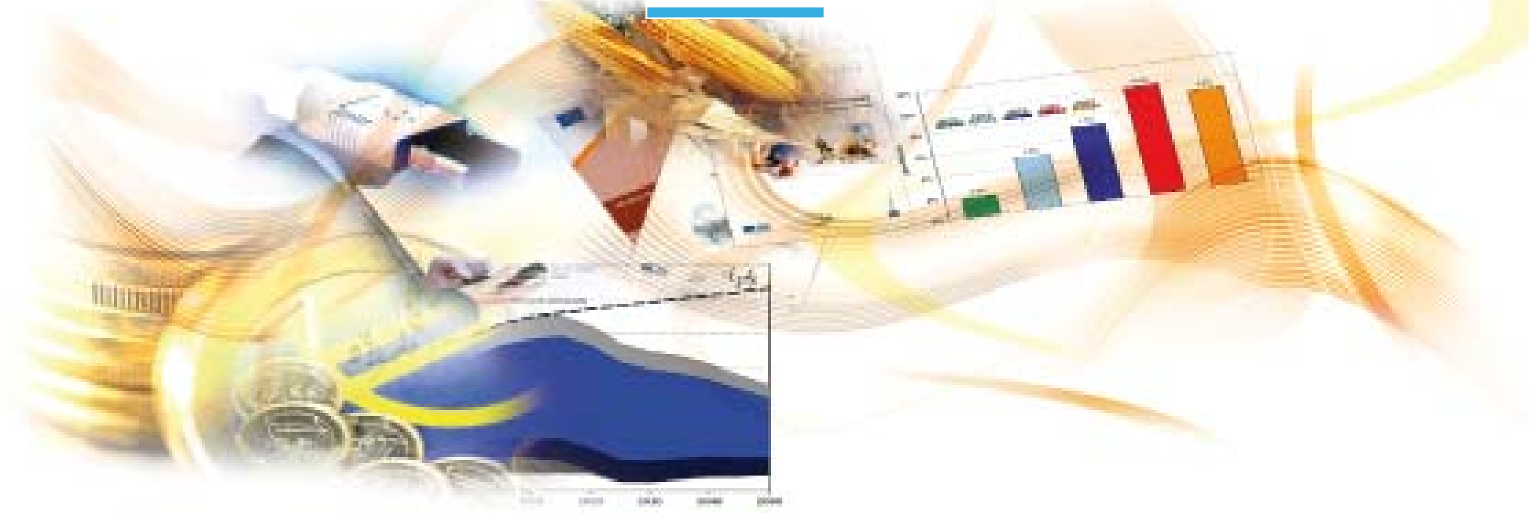

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CAPRI Long-term Climate Change Scenario Analysis: The AgMIP Approach

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1 Introduction

Long-term agricultural market developments have attracted considerable attention recently due to growing food security concerns. Key long-term drivers in agricultural sector are linked to climatic changes and population growth potentially having strong implications for agricultural productivity and food availability. An important driver relates to the recent expansion of the biofuel sector which affects food availability through competition for land resources.

In this paper, we simulate long-term global effects of crops productivity changes under different climate scenarios and the impact of expansion of 2nd generation biofuels using the Common Agricultural Policy Regionalised Impact (CAPRI) model. These analyses are conducted in the framework of the AgMIP project (Agricultural Model Intercomparison and Improvement Project) (Robinson *et al*. 2014; von Lampe *et al*. 2014). The AgMIP project is a major international effort to assess the state of global agricultural modelling and to understand climate impacts on the agricultural sector.[1] The economics modelling component of AgMIP is engaging key global economic modellers in a cross-model scenario comparison exercise.

With a growing concern of changing global weather patterns, an extensive list of studies have been conducted to examine the impact of climate changes on agricultural production and farming sector (e.g. Easterling *et al*. 1993; Chang 2002; Peiris *et al*. 1996; Hakala 1998; Brown and Rosenberg 1999; Rotter and Van de Geijn 1999; Craigon *et al*. 2002; Jones and Thornton 2003). Many studies have concluded that the effects of climate change on crop yields would highly depend upon the geographical location of the crop production with crops in some regions benefited (Cuculeanu *et al*. 1999; Ghaffari *et al*. 2002; Shrestha *et al*. 2013) while crops in other regions showed adverse effect under new climatic conditions (Woodward *et. al*. 1991; Wheeler *et al*. 1996; Batts *et al*. 1997; Morison and Lawlor 1999; Jones and Thornton 2003; Parry *et al*. 2004).

There has been a tremendous increase in the production of transportation fuels derived from biomass (i.e., biofuels) in recent years. The expansion of biofuels and biofuel policies has sparked a lively debate and controversy about the contribution of biofuels to various issues related to developments in agricultural markets. As shown in recent studies (Gardebroek 2010; de Gorter, Drabik and Just 2012; de Gorter and Just 2009; Ciaian and Kancs 2011), biofuels may have far-reaching side-effects on

[1] http://www.agmip.org/

agricultural markets due to price interdependencies between the energy, bioenergy, and agricultural markets. For example, they may directly or indirectly affect food prices (Baier et al. 2009; Ciaian and Kancs 2011, Rahim, Zariyawati and Shahwahid 2009), have environmental implications (Kancs 2007), or induce indirect land use changes (Piroli, Ciaian and Kancs 2012; Searchinger *et al*. 2008).

2 Methodology

We employ the CAPRI model to investigate the economic impacts of climate change in the global agricultural sector. 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. A detailed description of CAPRI is available in Britz and Witzke (2012). The modelling of global agricultural markets (hereafter referred to as "market module") 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. Based on the Armington approach (Armington 1969), products are differentiated by origin, enabling to capture bilateral trade flows. The market module covers all main world regions split in 75 countries or country aggregates and 50 agricultural products.

CAPRI also contains a more detailed modelling of production side of the EU and selected European Countries (hereafter referred to as "supply module"). The supply module is composed of separate, regional and farm-type, non-linear programming interlinked with the market module through prices and quantities. The regional programming models are based on a model template assuming profit-maximizing behaviour under technological constraints, most importantly in animal feeding and fertilizer use, but also constraints on inputs and outputs such as young animals, land balances and policies (e.g. set-aside) (Jansson and Heckelei, 2011). The supply module currently covers all individual Member States of the EU-27 and also Norway, Turkey and the Western Balkans.

Modelling climate change

A number of economic approaches and models are applied for assessing the economic impacts of climate change. They can be classified as either ‘structural’ or ‘spatial-analogue’ approaches. The first approach is interdisciplinary and interlinks models from several disciplines (Schimmelpfennig *et al*. 1996; Adams *et al*. 1998a; Fernández *et al*. 2013). A common method applied to interlink different type of models consists of using biophysical models to predict crop yield effects of climate change scenarios which are then used as an input into the economic model to predict economic impacts (e.g. Adams *et al*. 1998b). The key distinguishing feature of the 'spatial-analogue' approach is that it is more explicit in taking into consideration spatial variation in climate change (e.g. Darwin *et al*. 1995). In this report the first approach is applied. The advantage of this approach is that it provides a more explicit representation of causal effects and adjustments of the agricultural sector to climate change.

The implementation of climate change scenarios in CAPRI was introduced in the form of exogenous productivity shocks. The productivity shock for EU and selected EU countries was introduced in the supply module, whereas the productivity shock for the rest of the world was introduced in the market module. The market module is a partial equilibrium modelling framework. In this module climate change was introduced by adjusting supply function parameters such that at given prices, yields would change according to the productivity shock. In contrast, the supply module contains an explicit representation of the production activities. The climate change was introduced in the supply module directly through an adjustment of their crop yields plus an associated adjustment of input requirements, in particular for crop nutrients.[2]

Modelling biofuels

CAPRI biofuel module includes a global representation of biofuel markets, with endogenous supply, demand and trade flows for biofuels and biofuel feedstocks. CAPRI allows the effects of a shift in biofuel developments to impact on food production and prices, the potential use of by-products in the feed chain, the changes in land use and feedstocks trade. Two biofuel product markets are modelled - ethanol and biodiesel - and three technology pathways are considered in CAPRI - 1st generation biofuels, 2nd generation biofuels, and non-agricultural biofuels. The 1st generation ethanol feedstock are produced for example from wheat, barley, rye, oats, maize, other cereals, sugar and table wine, whereas 1st generation biodiesel is produced from rape oil, sunflower oil, soya oil, and palm oil (Blanco *et al*. 2013).

Two different product aggregates are introduced in the CAPRI to cover feedstock for 2nd generation biofuel processing: (1) a product aggregate for agricultural residues which covers straw from cereals/oil seed production and sugar beet leaves and (2) a product aggregate for new energy crops which cover herbaceous and woody crops like poplar, willow and miscanthus. The use of residues from livestock production, which covers manure and cadavers, is not included explicitly in the second generation

[2] In the final equilibrium prices change in all European and non-European regions, triggering endogenous adjustments of crop yields, such that the final yield changes differ from the exogenous productivity shocks.

processing as this source is assumed to have only a marginal importance for biofuel processing. However, biofuels produced in this processing path will show up under the aggregate on non-agricultural biofuels. Furthermore, the demand shares for the single agricultural residues are provided exogenously in the model meaning that there is no economic draw back that influences crop allocation decisions based on demand for e.g. straw based ethanol. This assumption was based on the observation that the potential of agricultural residues resulting from the activity levels of cereals, oilseeds and sugar beet production is high enough that even a significant expansion of the second generation scenario would only generate a demand lower than the actual potential. The demand share for new energy crops in the second generation production quantities is also provided exogenously in the model. However, as the production of new energy crops require agricultural land, the available agricultural land for the production of other agricultural products is reduced accordingly with the yield information collected for new energy crops (Blanco *et al.* 2013).

3 Scenarios

The CAPRI simulations rely upon scenarios provided by the AgMIP project. The scenarios are summarised in Table 1. The scenarios differ in terms of their assumptions about (von Lampe *et al.* 2014; Willenbockel 2013)

- population and GDP growth (SSP (Shared Socio-Economic Pathway[3]) dimension),
- the evolution of atmospheric greenhouse gas concentration levels (RCP (Representative Concentration Pathway[4]) dimension),
- the impact of a given greenhouse gas concentration path on temperature and precipitation at regional scales as projected by different global circulation models (GCM dimension),
- the impact of the projected climate scenarios on crop yields as projected by different crop model suites (Crop model dimension),
- growth in biofuel demand (Bioenergy demand dimension).

[3] See Kriegler *et al.* (2012).
[4] See Moss *et al.* (2010)

Table 1: Scenario definition

Scenario code	Type of scenario	SSP	RCP	GCM	Crop model
S1	Reference scenario	SSP2	Present climate	none	none
S2	Alternative reference scenario	SSP3	Present climate	None	None
S3	Climate change scenario	SSP2	RCP8p5	IPSL-CM5A-LR	LPJmL
S4	Climate change scenario	SSP2	RCP8p5	HadGEM2-ES	LPJmL
S5	Climate change scenario	SSP2	RCP8p5	IPSL-CM5A-LR	DSSAT
S6	Climate change scenario	SSP2	RCP8p5	HadGEM2-ES	DSSAT
S7	Biofuel reference scenario	SSP2	Present climate	None	None
S8	Biofuel change scenario	SSP2	Present climate	None	None

Source: AgMIP project; von Lampe *et al*. 2014

The *reference scenario* (S1) represents a counterfactual situation with no climate change considered. Under this scenario economic assumptions (population and GDP growth) are based on the Shared Socio-economic Pathway (SSP) 2 (O'Neill *et al*. 2012; van Vuuren *et al*. 2012; Kriegler *et al*. 2012; von Lampe *et al*. 2014) available from the GLOBIOM model (Havlík *et al*. 2011). Apart from the macro variables population and GDP, GLOBIOM also provides external a priori information for the long run evolution of major agricultural outputs for a coordinated reference run (see Section 4.1), including the underlying assumptions on agricultural productivity growth rates. The exogenous component of yield changes in GLOBIOM was harmonised with those from the IMPACT model (Nelson *et al*. 2010) such that the CAPRI reference scenario is also consistent with the standard assumptions on productivity shifts in the AgMIP project. The alternative reference scenario S2 assumes higher population growth and lower per-capita income growth in developing regions.

Four *climate change scenarios* (S3-S6) apply productivity shifters based on an RCP 8.5, which was run through two different General Circulation Models (GCMs): IPSL-CM5A-LR and HadGEM2-ES (Müller and Robertson, 2013). In next step two different crop models (LPJmL and DSSAT) used the changes in regional temperature and precipitation to generate climate change induced changes in average crop yields (Robinson et al. 2014; von Lampe *et al*. 2014; Willenbockel 2013). The crop yield changes are used as exogenous productivity shifters in CAPRI to generate climate change scenarios.

Scenarios S7 and S8 represent the third group of scenarios which analyses the impact of *biofuels* on agricultural markets. The scenario S7 serves as a benchmark for comparison with S8, which considers an increase in second-generation bioenergy demand (Lotze-Campen *et al*. 2014; von Lampe *et al*. 2014; Willenbockel 2013).

4 Scenario Results

In this section scenario results are presented in order to provide inside on the potential effects of climate changes, biofuels and macro developments on the global agricultural sector. Following AgMIP we aggregate results by commodity and world regions. Eight commodity groups are considered – wheat (WHT), coarse grains (CGR), rice (RIC), oilseeds (OSD,) sugar (SUG), ruminant meat (RUM), non-ruminant meat (NRM), and dairy products (DRY) – and an aggregate of the five crop groups (CR5). Additionally, commodity aggregate for all crops covered by CAPRI model (CRP) and an aggregate of the total agricultural sector (AGR) are calculated.

Country aggregates include Canada (CAN), USA, Brazil (BRA), other South and Central America (OSA), Former Soviet Union (FSU), Europe (EUR), Middle-East and North Africa (MEN), Sub-Saharan Africa (SSA), China (CHN), India (IND), South-East Asia (SEA), other Asia (OAS), and Australia and New Zealand (ANZ). A second level of regional aggregation adds up regions to North America (NAM), South and Central America (OAM), Africa and Middle East (AME), Southern Asia (SAS) as well as total World (WLD).

We report scenario projections for 2030 and 2050. Results are presented in relative terms. For the reference scenario, results are reported relative to the base year value 2005. For the alternative reference scenario (S2), climate scenarios (S3-S6), and biofuel scenario (S8), the results are reported as percentage deviation from their respective reference scenario (S1 or S7). We also compare CAPRI results with other AgMIP economic model results. AgMIP includes ten economic models: five are computable general equilibrium models (AIM, ENVISAGE, FARM, GTEM, MAGNET) while the others (GCAM , GLOBIOM, IMPACT, MAgPIE) including CAPRI are partial equilibrium multi-market models (for more details see von Lampe *et al.* 2013; Valin *et al.* 2014; von Lampe *et al.* 2014).

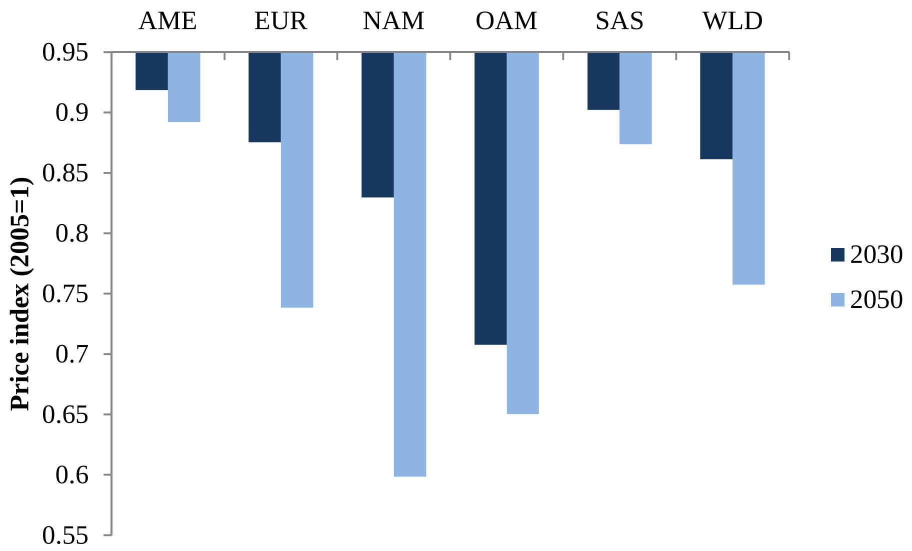
4.1 Reference scenario

The evaluation of the CAPRI reference scenario projections for 2030 and 2050 in terms of prices, yields, production and land use attempts to reflect agricultural market developments and the response to macro drivers as defined in SSP2. The construction of CAPRI reference scenario builds on a combination of four information sources: (1) medium-term projections (up to 2020) from the Aglink-COSIMO reference scenario, (2) long-term projections from the GLOBIOM model and biofuel related projections from the

PRIMES energy model, (3) analysis of historical trends and (3) where available also more specific expert information (for a detailed description, see Britz and Witzke 2012).

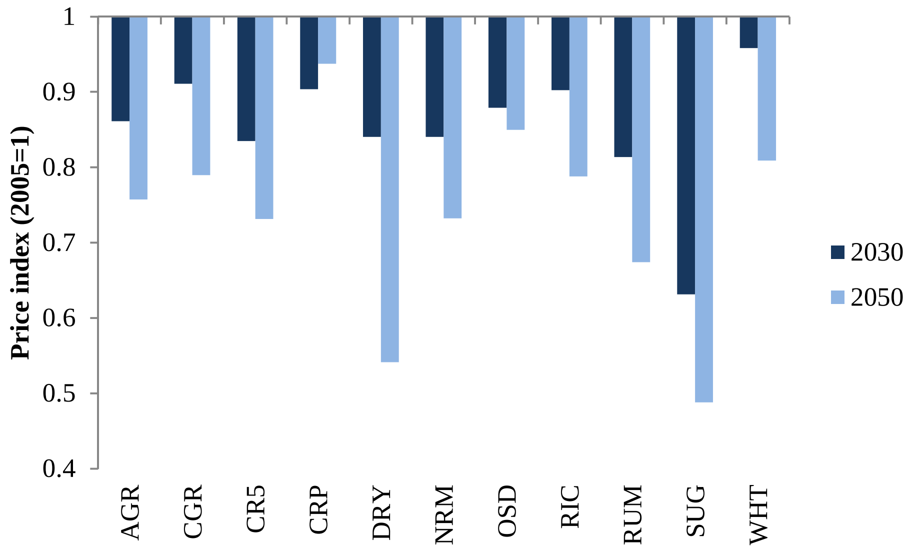
Table 2 reports real price projections by commodity aggregate and by region.[5] Real prices for major crop and animal commodities are projected to decrease in the long time horizon. On average for agricultural aggregate (AGR) , world prices decrease by 14% in 2030 and by 24% in 2050 relative to base year 2005 level. Across regions the price drop varies between 10% and 40% (Figure 1). There is also observed heterogeneity in the price response across commodity groups, between 5% and 50% with stronger changes observed in 2050. In general, the world prices of sugar (SUG) and to some extent also diary price (DRY) show a higher rate of decrease than prices of other commodities. Excluding these two commodity groups, the rest of world prices drop by 35% or less (Figure 2). Compared to other AgMIP models, CAPRI projects the strongest global average price decline among all models for the AGR and CR5 aggregates as well as for SGR, OSD, RUM, and is together with MAGNET among the two models with the strongest average price reductions for WHT, CGR and RIC (Willenbockel 2013; von Lampe *et al.* 2014).

Figure 1: Average producer price index by region for the reference scenario, 2030 and 2050 (2005=1)



[5] CAPRI assumes 1.9% inflation rate.

Figure 2: Average global producer price index by sector for the reference scenario, 2030 and 2050 (2005=1)



Total global agricultural land is projected to stay fairly constant in most world regions over the projection period. The exception is southern Asia (SAS) and some south America (OAM) (Table 3, Figure 3). At world level, the total area expands by 3% in 2030 and by 5% in 2050 relative to base year. However, stronger changes are observed at commodity group level. In particular sugar area expands strongly followed by oilseeds, whereas wheat area drops in 2050 (Figure 4). In comparison to other AgMIP models, the projected expansion in global cropland area in CAPRI less than 10% under the reference scenario – a similar order of magnitude as projected by GCAM, GLOBIOM and IMPACT. The crop area expansion for this group of models is significantly lower than for the other sub-group of models projecting area increases near 20% or more (AIM, ENVISAGE, MAGNET, MAgPIE) (Willenbockel 2013; Schmitz *et al.* 2014).

Figure 3: Land use projections by region for the reference scenario, 2030 and 2050 (2005=1)

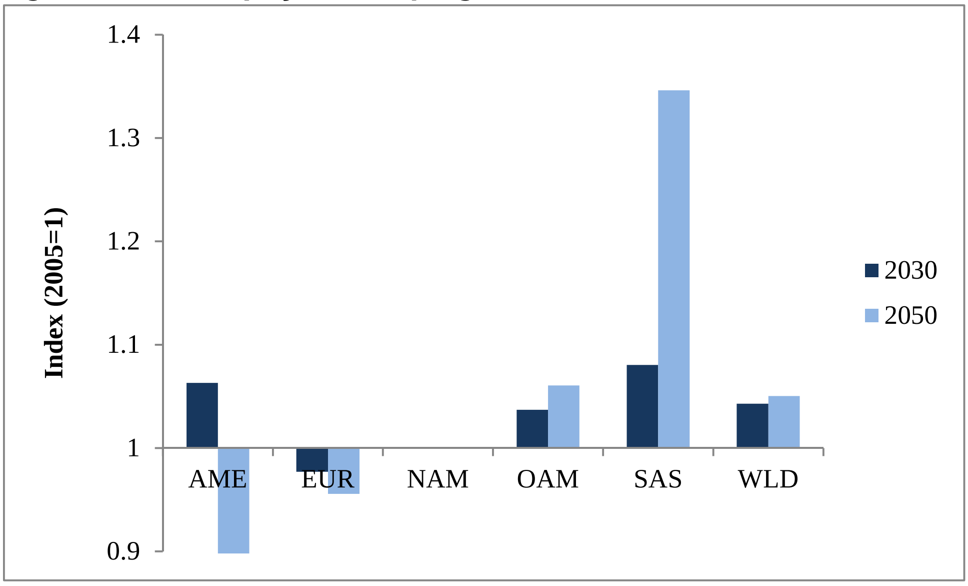
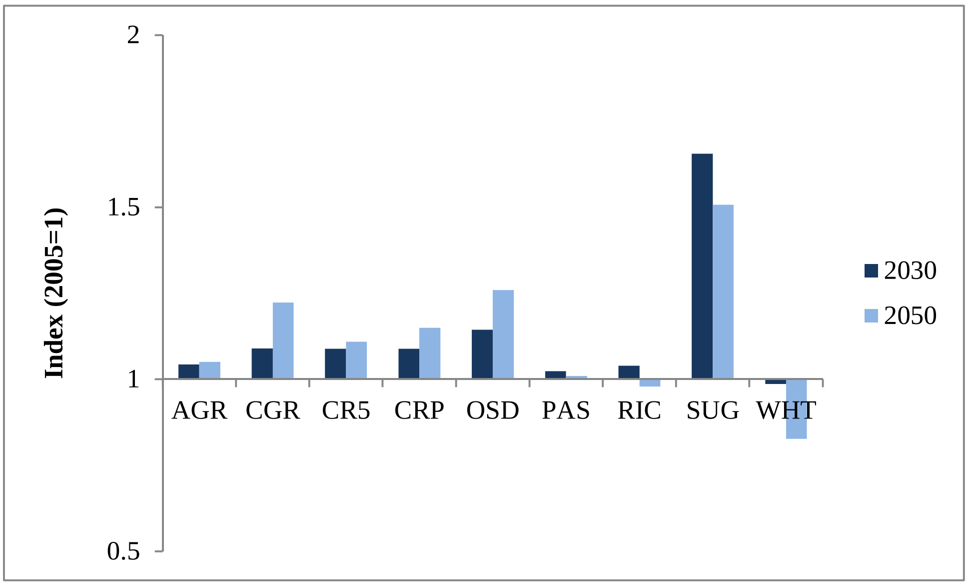


Figure 4: World land use projections by sector for the reference scenario, 2030 and 2050 (2005=1)



Robust productivity changes are projected to occur over the time horizon considered. They reflect development of agricultural productivity growth as provided by GLOBIOM as well as endogenous CAPRI model adjustments (see section 4.1). Relative to the base year level, global yields for the five main crop aggregate groups are projected to expand between 13% and 25% in 2030 and between 27% and 73% in 2050. The strongest yield effect is observed for wheat and rice (Figure 5). Particularly high productivity gains are projected to occur in Africa and Asia (Table 4). Yield improvements drive production expansion leading to an increase of the world main aggregate commodity groups between 20% and 65% in 2030 and between 33% and 93% in 2050 relative to 2005. A particularly high global production expansion is observed for sugar driven by land use increase in Brazil. Most other commodity groups increase at global level between 25% and 30% in 2030 and between 50% and 65% in 2050 (Figure 6). At region level, the variation in production is somehow larger; in several regions production for some commodity groups more than doubles in 2050. (Table 5, Figure 7). Compared with other AgMIP models, CAPRI projects the smallest global production increase of all reporting models for WHT and RUM. For the other commodity groups the CAPRI projections for 2050 are close to the mid-range of the spectrum (Willenbockel 2013).

Figure 5: Global projections for yields by sector for the reference scenario, 2030 and 2050 (2005=1)

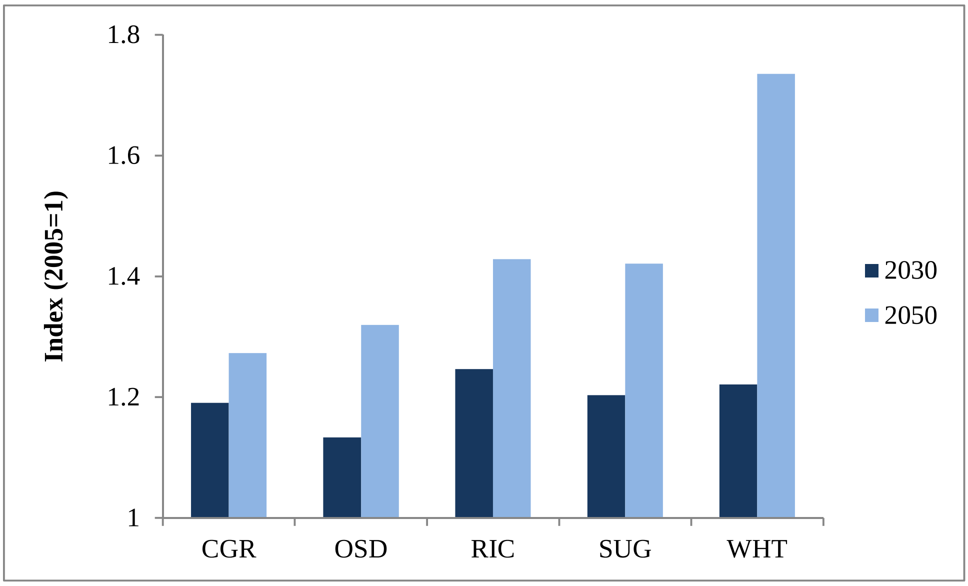
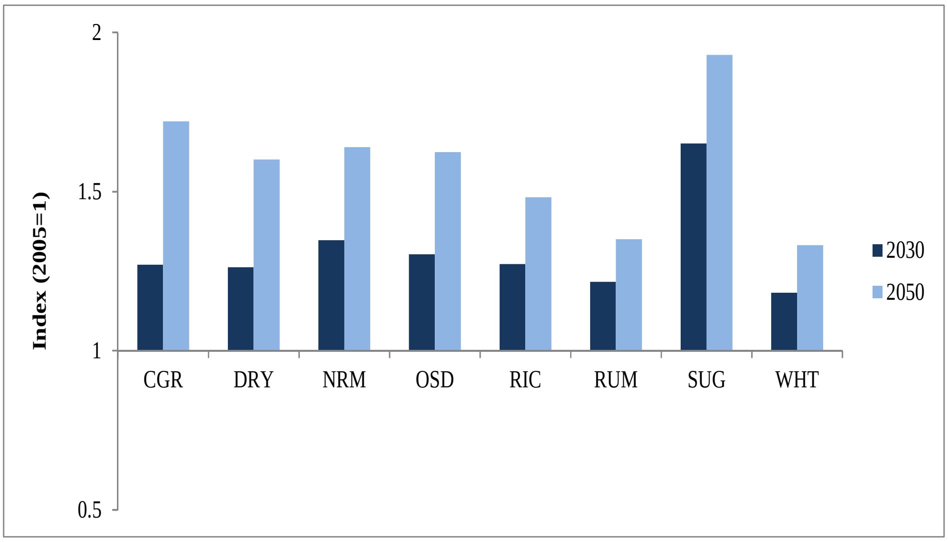


Figure 6: Global production projections by sector for the reference scenario, 2030 and 2050 (2005=1)

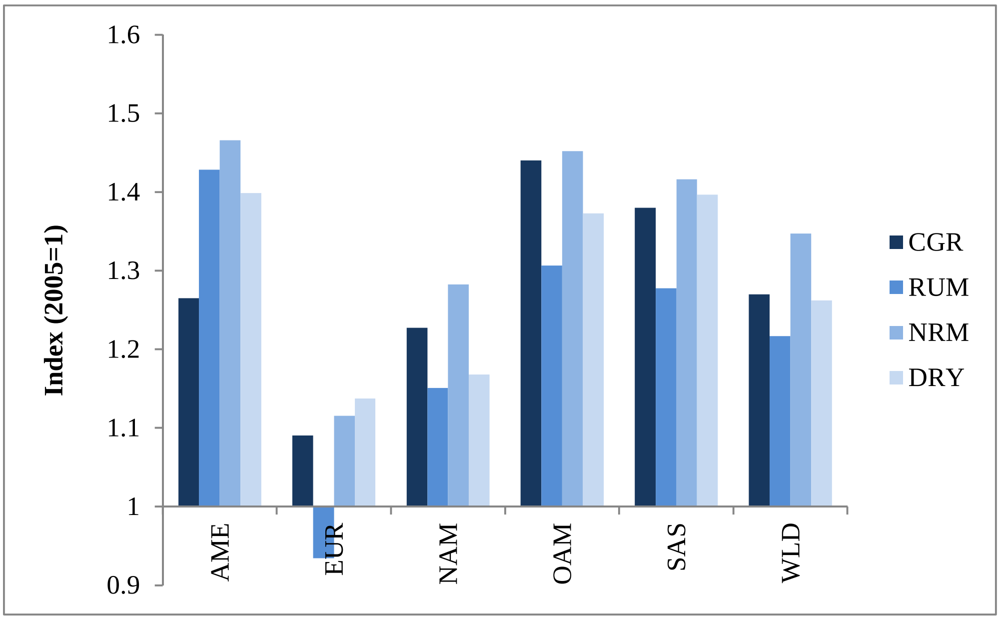


Long run global food consumption pattern show a significant growth driven by population and GDP expansion.[6] Relative to the base year level, global consumption expands between 17% and 65% in 2030 and between 33% and 93% in 2050 relative to 2005. The largest global consumption increase is observed for sugar and coarse grains whereas wheat expands the least (Figure 8). Developing countries drive the consumption expansion (AME, SAS, OAM), whereas developed courtiers show a much more moderate increases (EUR, NAM). (Table 6, Figure 9).

[6] Note that CAPRI assumes a shift of consumption pattern over time linked to composition of processed versus non-processed goods. More precisely, CAPRI assume shat with GDP growth consumption shifts towards more processed goods. This is implemented by correlating GDP level with processing margins.

Figure 7: Aggregate production projections by region for the reference scenario, 2030 and 2050 (2005=1)

a) 2030



b)2050

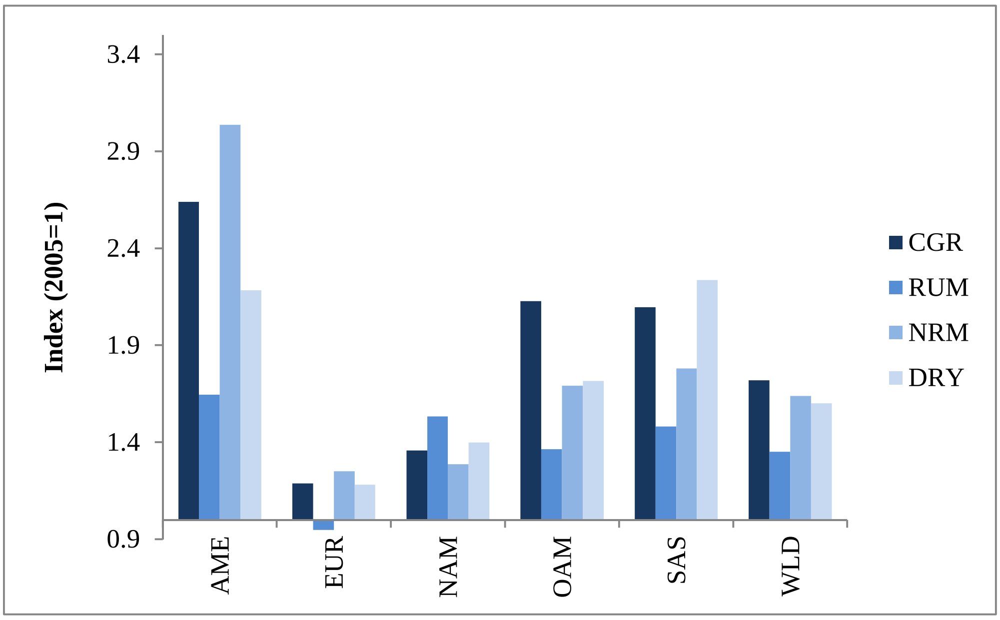


Figure 8: Global consumption projections by sector for the reference scenario, 2030 and 2050 (2005=1)

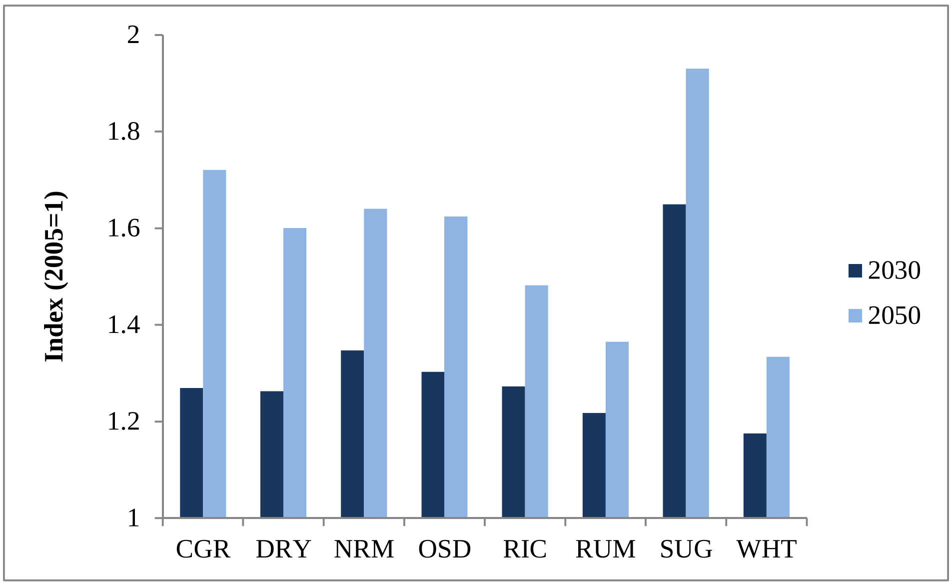
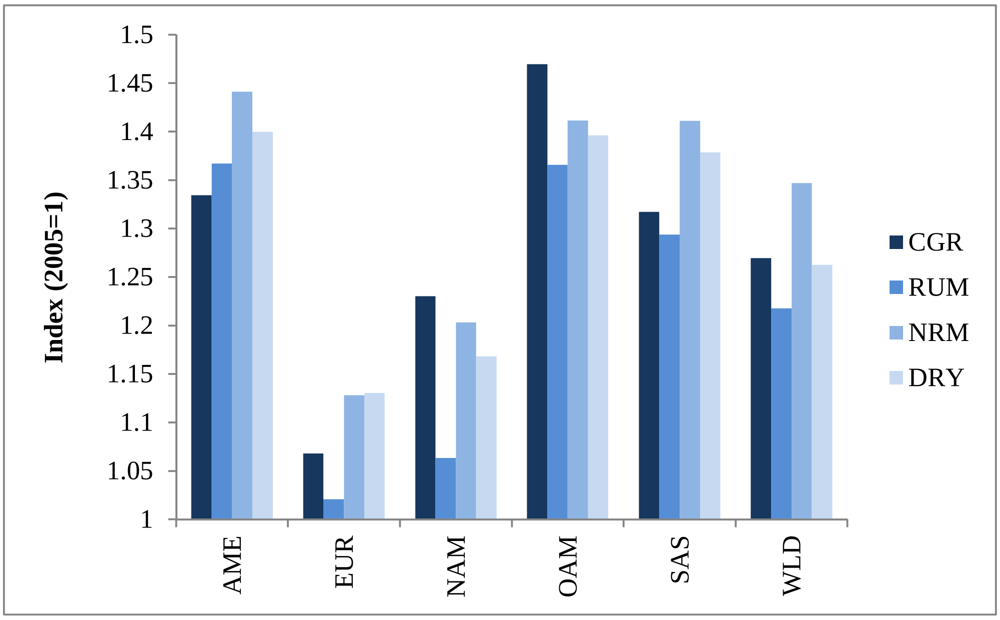
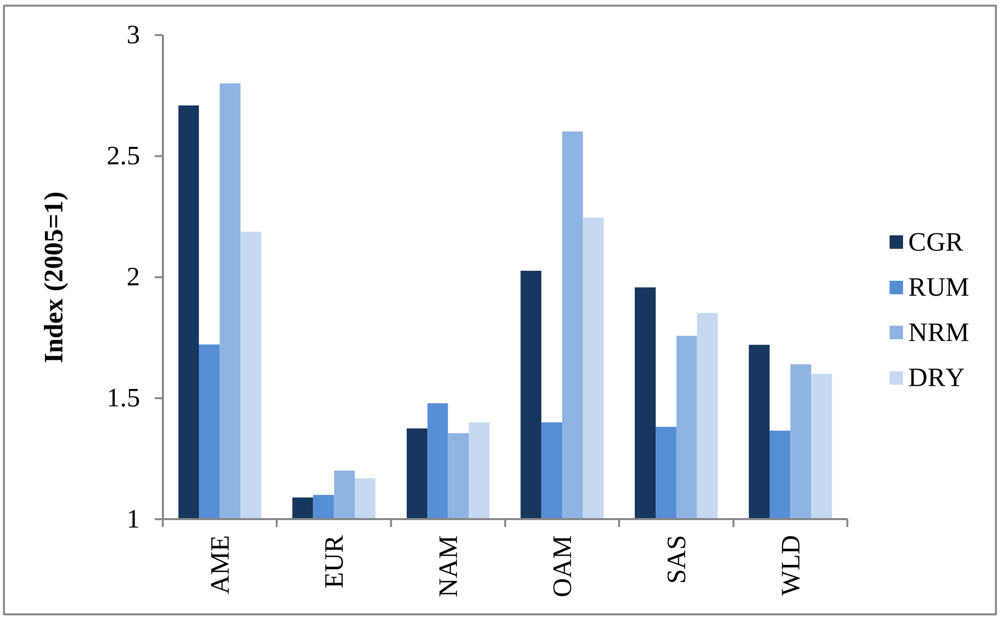


Figure 9: Consumption projections by region for the reference scenario, 2030 and 2050 (2005=1)

a) 2030



b) 2050



4.2 Alternative socio-economic assumptions

Compared to the reference scenario S1 under which global population rises to 9.3 billion in 2050, the alternative S2 assumes higher population growth globally (11%) and in developing countries (EUR, NAM) but lower population growth in the developed world (AME, OAM, SAS) (Figure 10). At the same time, economic output would be lower than under S1 virtually everywhere, with global GDP lower by around 13% and 30% relative to the reference level in 2030 and 2050, respectively. Consequently, the global per capita GDP is 17% and 36% below S1, with reductions by more than 50 percent in Sub-Saharan Africa and parts of Asia, whereas in the developed countries the drop is lower than 15% (Figure 11).

Figure 10: Population growth by region in S2, 2030 and 2050 (index, reference scenario=1)

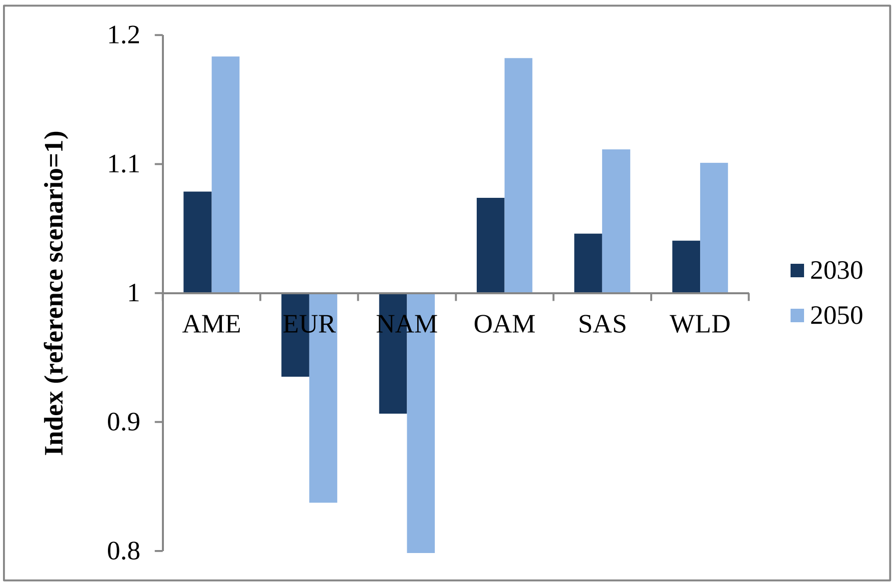
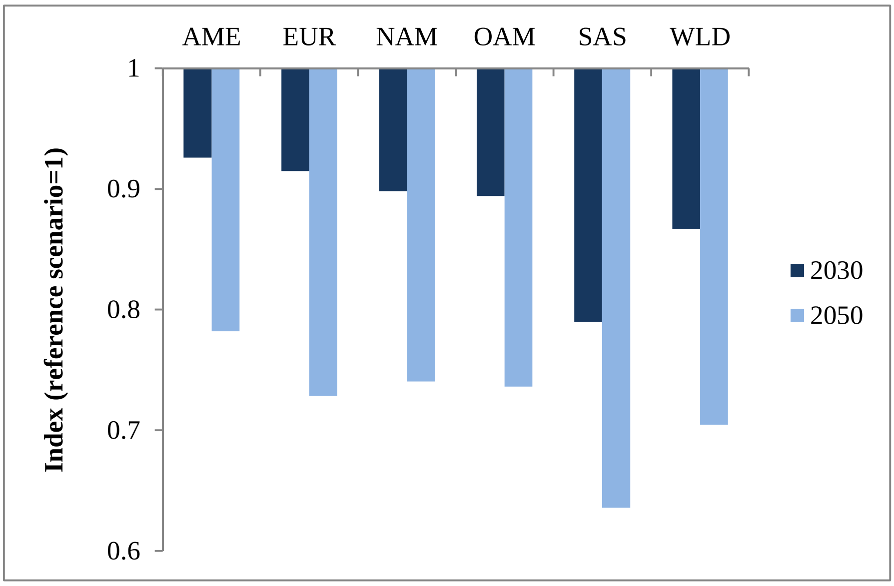
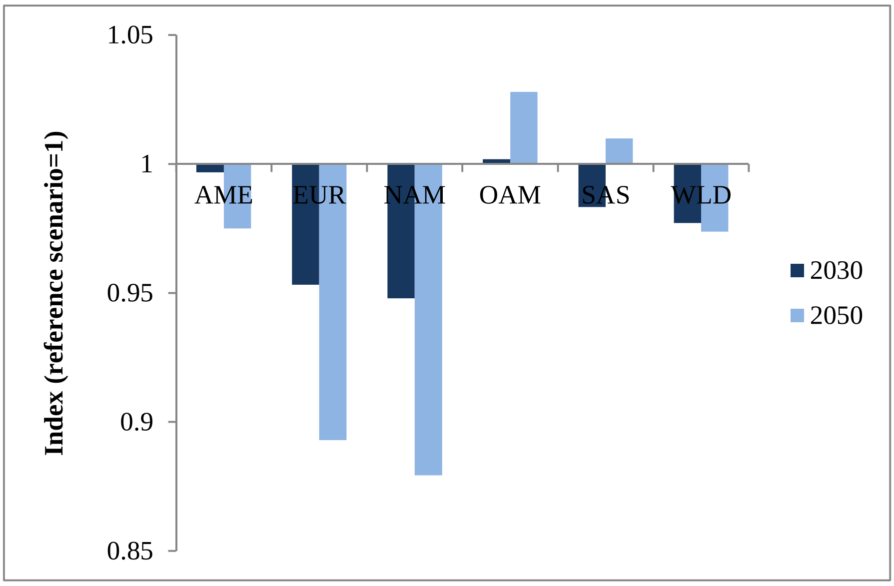


Figure 11: GDP growth by region in S2, 2030 and 2050 (index, reference scenario=1)



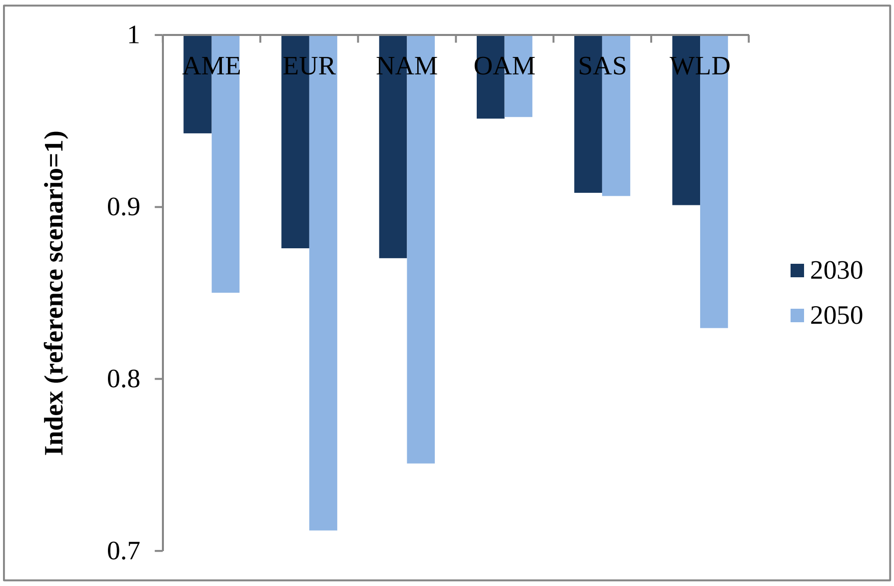
Global consumption of agricultural products is predicted to fall relative to S1 by 2% and 3% in 2030 and 2050, respectively. This effect is largely driven by lower GDP drop which is more than offset by population increase. However, in Southern Asia and South and Central America which are projected to have substantial population expansion, consumption increases (Figure 12). Most AgMIP models report similar magnitude in the global consumption decrease in scenario S2 relative to the reference scenario S1. The exceptions are EPPA, ENVISAGE which project a drop in consumption by more than 10% (Willenbockel 2013).

Figure 12: Global consumption changes by region in S2, 2030 and 2050 (index, reference scenario=1)



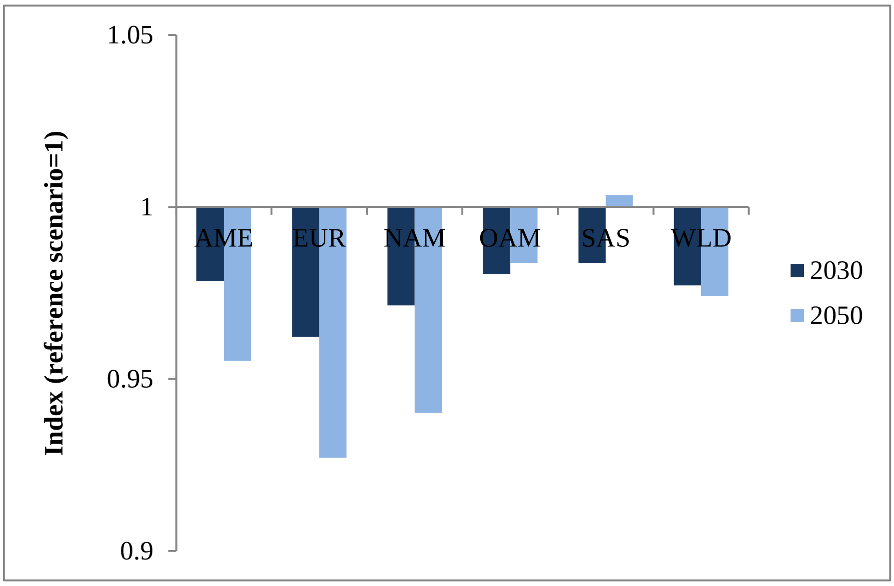
The drop in consumption in S2 relative to S1 translates into substantial decrease of global prices (Figure 13). Global prices decrease by around 10% and 17% in scenario S2 relative to the reference scenario in 2030 and 2050, respectively. In those regions with stronger consumption reductions (Europe and North America) generally also show higher price decrease relative to the reference scenario. CAPRI projects similar global price responses to IFPRI's IMPACT model. The rest of models show either a smaller price decrease (ENVISAGE, EPPA, GCAM, GLOBIOM), price increase (FARM, GTEM, MAGNET) or mixed price effects (MAgPIE) (Willenbockel 2013; von Lampe *et al.* 2014).

Figure 13: Global price changes by region in S2, 2030 and 2050 (index, reference scenario=1)



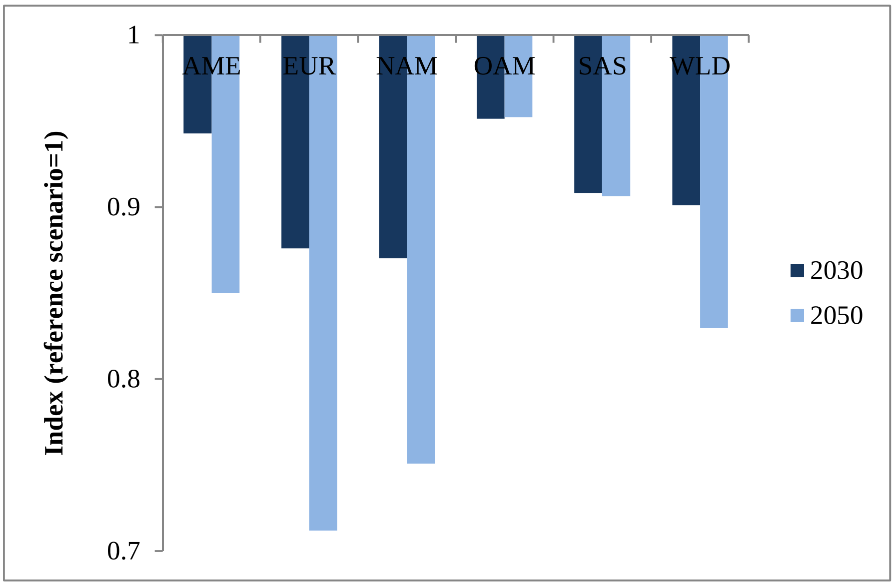
Similar to consumption changes, global agricultural production falls relative to S1 by around 2.5% in 2030 and 2050. Same hold for most world regions, with exception of Southern Asia (SAS) where production increases slightly in 2050 (Figure 14). Most AgMIP models report global production decrease between 1.5% and 5% in scenario S2 relative to the reference scenario S1. Only EPPA and ENVISAGE report significantly higher production drops (more than 10%) than CAPRI (Willenbockel 2013).

Figure 14: Global production changes by region in S2, 2030 and 2050 (index, reference scenario=1)



Lower production leads to decrease in global land use by around 1% with largest drop being observed in Europe and North America (Figure 15). Other AgMIP models predict the same order of magnitude in global land use change (between -0.8% and -3) with exception of AIM and ENVISAGE which report a larger area drop, between 7% and 10% (Willenbockel 2013; Schmitz *et al.* 2014).

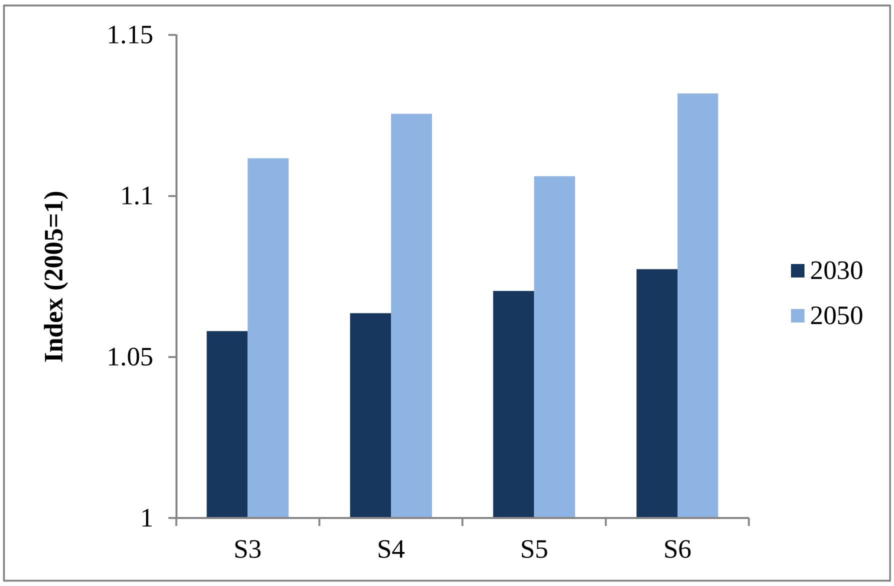
Figure 15: Global land use changes by region in S2, 2030 and 2050 (index, reference scenario=1)



4.3 Climate change effects

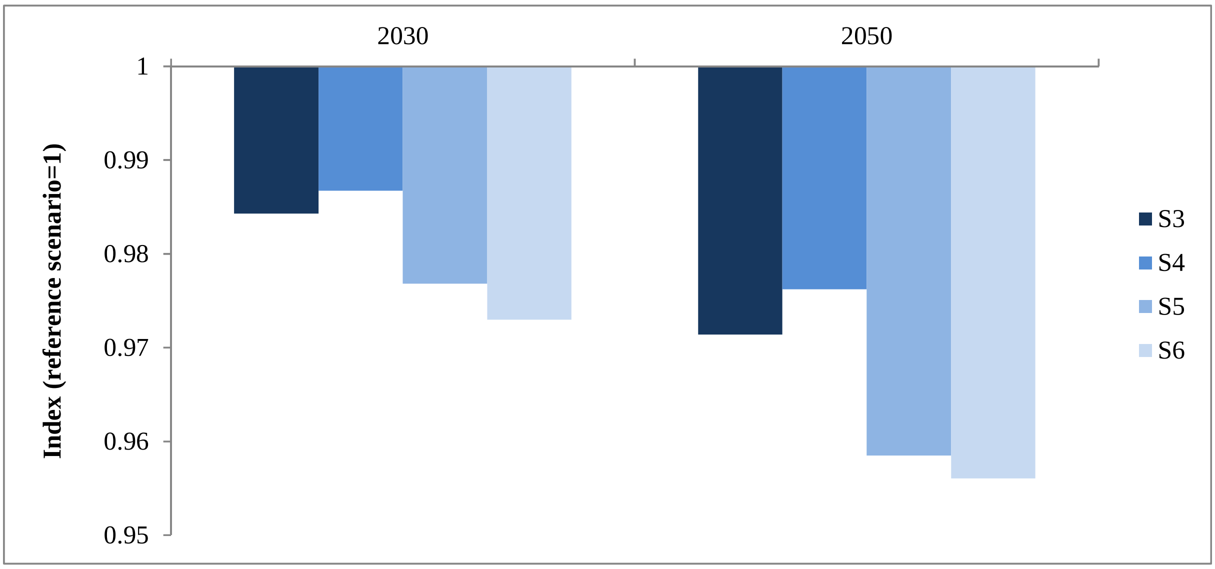
The simulation results indicate a moderate impact on the world agricultural markets at aggregated level. However, there is strong variation across regions. At world level, Global agricultural prices increase between 6% and 13% relative to the reference scenario. The S6 scenario generally shows stronger price increases than the other scenarios. Also stronger price increase occurs in 2050 relative to 2030 (Table 7, Figure 16). The variation of price changes across commodity aggregates and regions is larger and varies in most cases between 3% and 50%. The strongest price effect is observed for wheat, coarse grains and rice, whereas the smallest for sugar (Table 7, Table 8). In line with all other AgMIP models, CAPRI projects rises in the global producer prices in response to the predominantly adverse impacts of climate change on crop yields. The magnitude of the effects as well as the pattern across the four different impact scenarios is similar to GLOBIOM, IMPACT, MAGNET and AIM, while another cluster of models (ENVISAGE, GCAM, FARM and GTEM) generates noticeably lower global price impacts and MAgPIE projects significantly stronger price impacts for S4 and S6 (Willenbockel 2013; von Lampe *et al*. 2014).

Figure 16: Climate change impact on world prices for the agricultural aggregate (AGR), 2030 and 2050 (index, reference scenario=1)



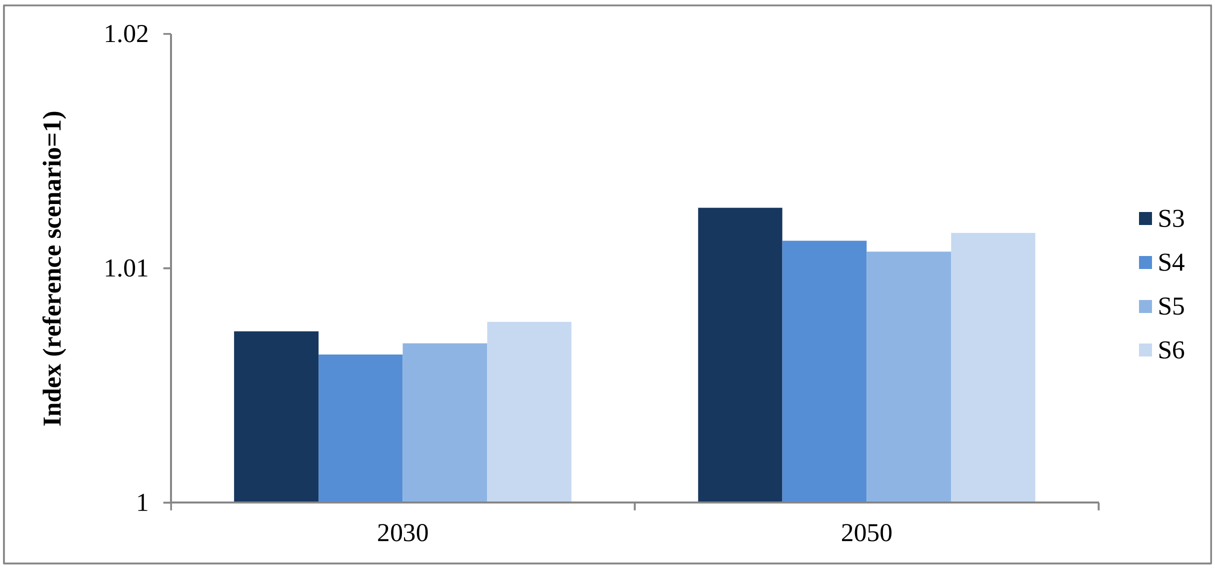
The positive price effects are driven by the drop in global agricultural supply. At global level, the aggregate production drops between 1% and 4%. The S5 and S6 scenarios show stronger production decreases than the other two scenarios (S3 and S4) as well as stronger production increase occurs in 2050 relative to 2030 (Figure 17). Looking at the regionally disaggregated level we find stronger adjustments in the aggregate production, varying between -30% and 5% relative to the reference scenario (Table 9). In line with most AgMIP models, CAPRI projects negative-signed global agricultural production responses across all four climate change scenarios. FARM, EPPA, MAGNET and MAgPIE report lower magnitudes of global production changes than CAPRI. The rest of models report comparable magnitudes as CAPRI for the global production changes (Willenbockel 2013).

Figure 17: Climate change impact on production, 2030 and 2050 (index, reference scenario=1)



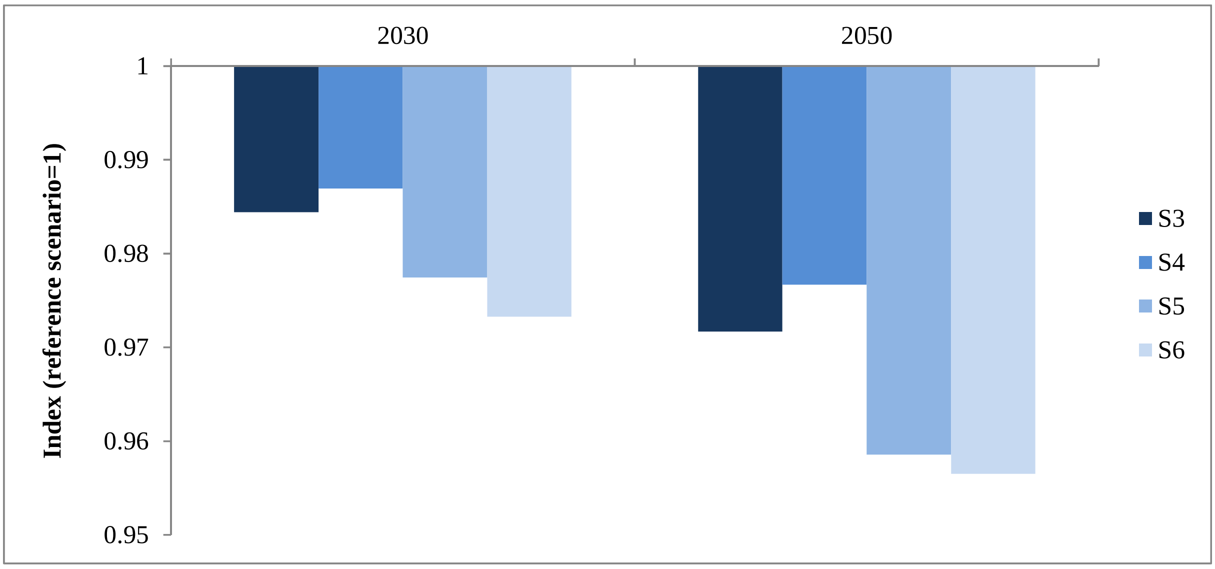
Aggregate land use changes induced by climate change are relatively small. Total global agricultural area increases between 0.5% and 2% in 2030/2050 relative to the reference scenario (Figure 18). More important are land relocation effects between different commodity aggregates (between -8% and 8%). Land use of sugar decreases, whereas land area of other crops tends to increase (Table 11). At the regional level, climate change leads to an increase in total agricultural across all regions with highest expansion occurring in Africa and South America (Table 12). The CAPRI projections are close to the median across all AgMIP models in all four climate scenarios (Willenbockel 2013).

Figure 18: Climate change impact on the total world agricultural area, 2030 and 2050 (index, reference scenario=1)



The reduced availability of agricultural commodities due to climate changes is reflected in lower consumption levels dropping between 1.3% and 4% at aggregate global level (Figure 19). The strongest affected are observed for coarse grains and rice (Figure 19, Table 13, Table 14).

Figure 19 Climate change impact on global consumption, 2030 and 2050 (index, reference scenario=1)



4.4 Second generation bioenergy effects

A final set of scenarios simulates the implications of substantially increased biomass use for 2nd generation biofuel considered in scenario S8. The simulation of scenario S8 are reported relative to the reference scenario S7 which assumes no 2nd generation biofuel production from new energy crops. CAPRI assumes all additional biomass from new energy crops to come from agricultural land in scenario S8. While much of the biomass would come from forest activities, some agricultural land is converted either directly to forest land or used for annual or perennial biomass production, thus reducing land available for crop production. In addition, the biomass production would compete for other resources otherwise used in the production of food and feed commodities.

The primary impact of the 2nd generation biofuels is on land use. Land is shifted away from agricultural commodity production to new energy crops which should be reflected in lower production levels of agricultural commodities and higher agricultural prices. Figure 20 displays the projected average global land use changes due to the increase of the 2nd generation biofuel demand. Global land use expands due to the 2nd generation biofuel at around 2% relative to the reference scenario (Figure 20). The most land increase is coming from North America followed by Southern Asia and Europe (Figure 21). The total land expansion is driven by land use of new energy crops used for production of 2nd generation biofuels which expands by up to 21 times relative to the reference scenario (Figure 22). The expanded cultivation of new energy crops is at the expense of commodity crops the area of which reduces between 1% and 6% (Figure 23). Other AgMIP models that consider S8 scenario report an increase of global land use between -1.4% and 2.2% relative to S7 in 2050 (Willenbockel 2013; Lotze-Campen *et al*. 2014).

Figure 20 Impact of 2nd generation biofuels on global land use, 2030 and 2050 (index, reference scenario=1)

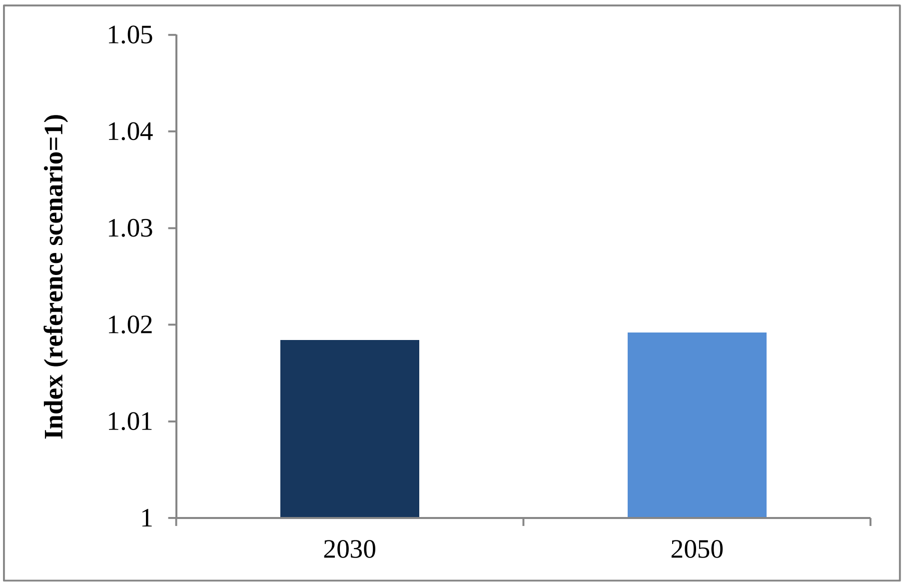


Figure 21 Impact of 2nd generation biofuels on land use by region, 2030 and 2050 (index, reference scenario=1)

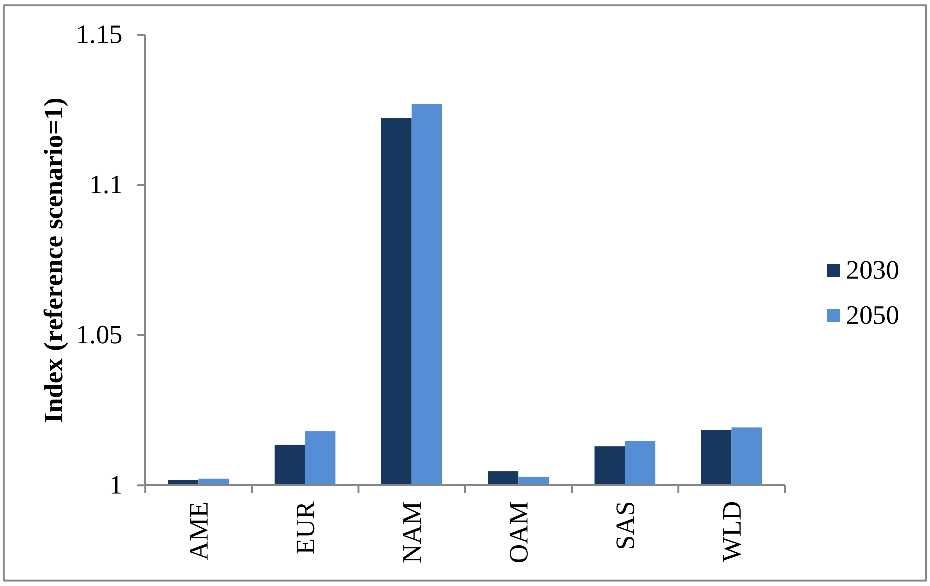


Figure 22 Impact on global 2nd generation land use, 2030 and 2050 (index, reference scenario=1)

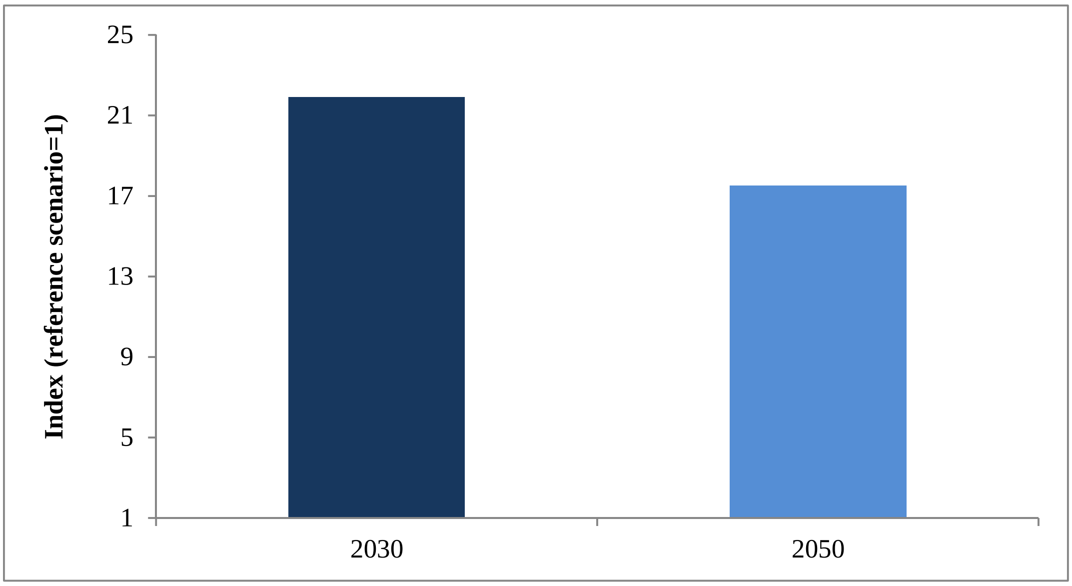
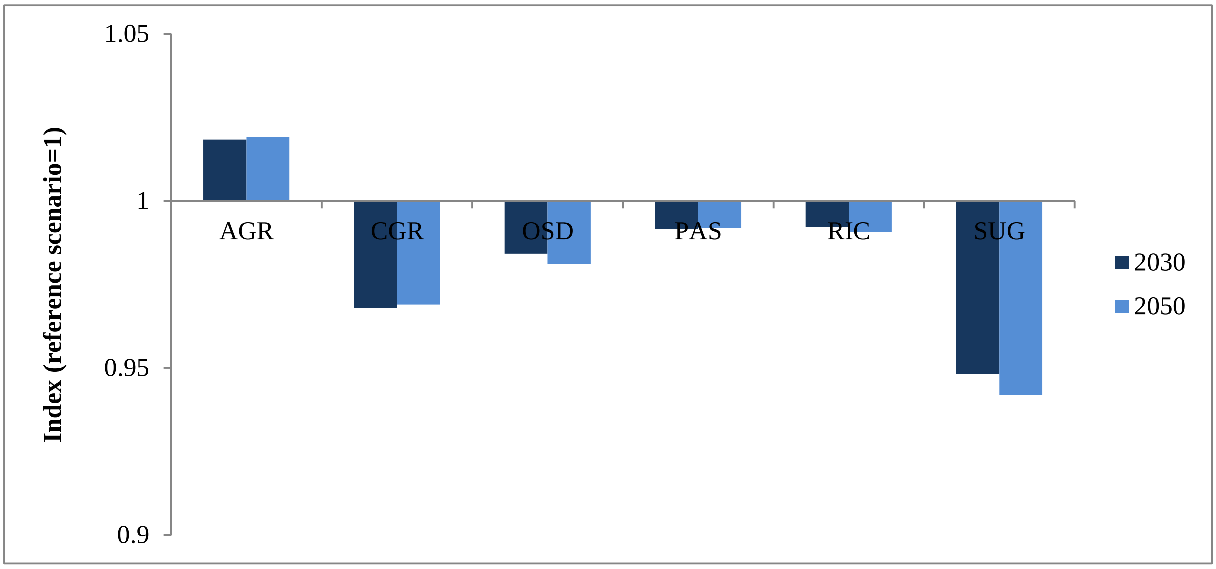


Figure 23 Impact of 2nd generation biofuels on global land use by sector, 2030 and 2050 (index, reference scenario=1)



The land use shift to new energy crops cultivation reduces the area available for commodity crops leading to lower global production levels by around 1.8% relative to the reference scenario (Figure 24). At regional level, production changes mirror the land use changes with highest production drop being observed in North America followed by Southern Asia and Europe (Figure 25). Although overall production contracts, oilseeds and rice show production expansion (Figure 26). Farmers adapt to higher crop prices (see further) by increasing variable inputs and hence increasing yields (Figure 27). The area reduction is more than offset by yield improvement for oilseeds and rice hence we observe higher production level for these crops.

Figure 24 Impact of 2nd generation biofuels on global agricultural production, 2030 and 2050 (index, reference scenario=1)

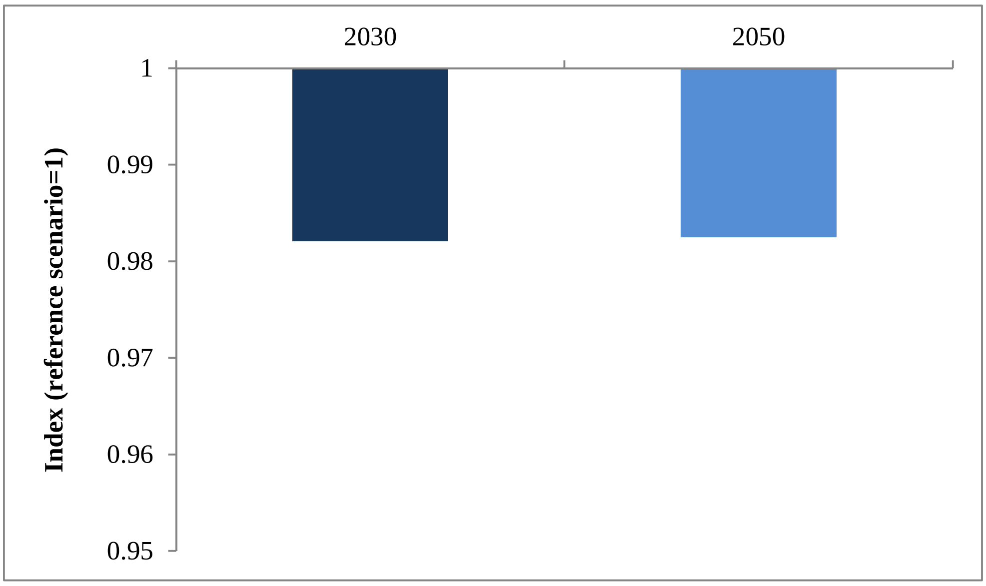


Figure 25 Impact of 2nd generation biofuels on global production by region, 2030 and 2050 (index, reference scenario=1)

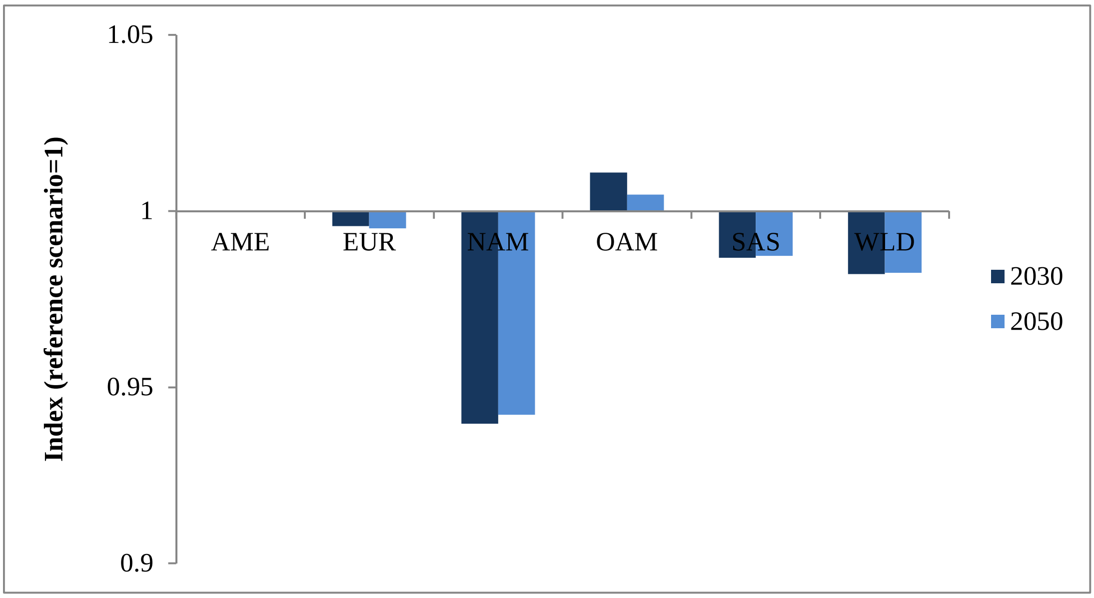


Figure 26 Impact of 2nd generation biofuels on global production by sector, 2030 and 2050 (index, reference scenario=1)

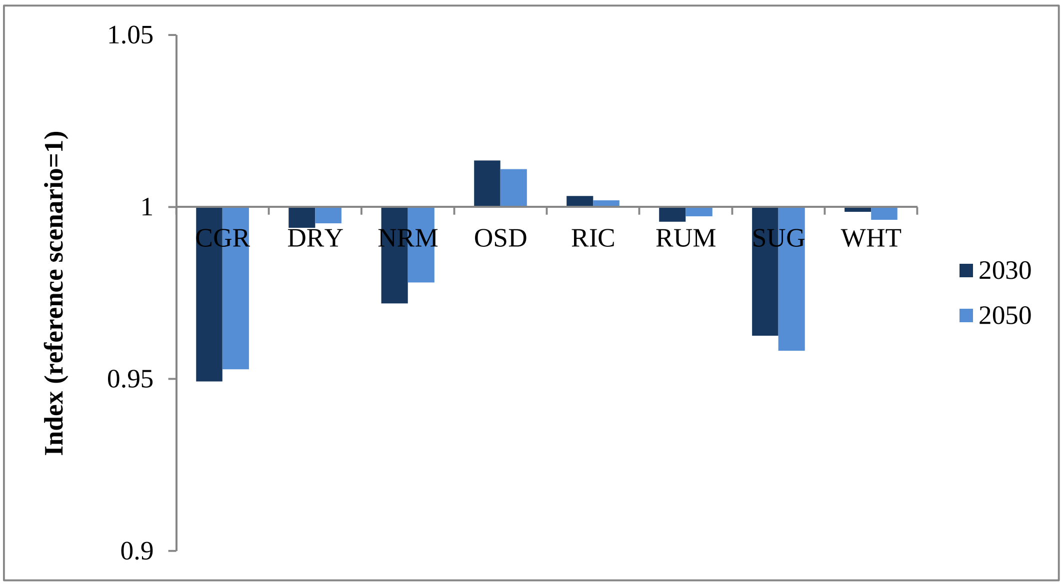


Figure 27 Impact of 2nd generation biofuels on yield changes, 2030 and 2050 (index, reference scenario=1)

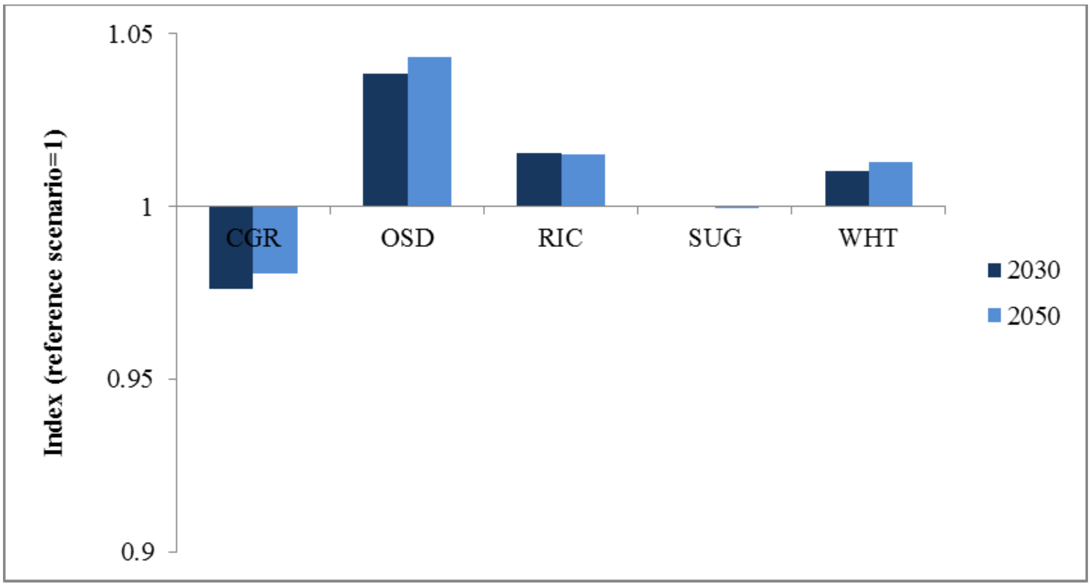


Figure 28 displays the projected average global producer price effects. As expected, the expansion of the 2nd generation biofuels suggest increases in global agricultural price at around 4% relative to the reference scenario. The much stronger price increase is observed for oilseeds and non-ruminant animal prices. In contrast, prices of coarse grains and sugar decrease (Figure 29). In terms of regional variation of price impacts, South Asia (SAS) experiences the highest price increase. The rest of regions show comparable price changes (Figure 30). The CAPRI projections are in line with four of the five AgMIP models which consider S8 scenario and which suggest increases in the reported price indices well below 5 percent relative to the scenario S7. The MAgPIE price increases are much stronger which can partly be explained by the fact that the model treats the demand for agricultural products as exogenous, thus limiting adjustments to the demand shock (Willenbockel 2013; von Lampe *et al*. 2014; Lotze-Campen *et al*. 2014).

Figure 28 Impact of 2nd generation biofuels on global prices, 2030 and 2050 (index, reference scenario=1)

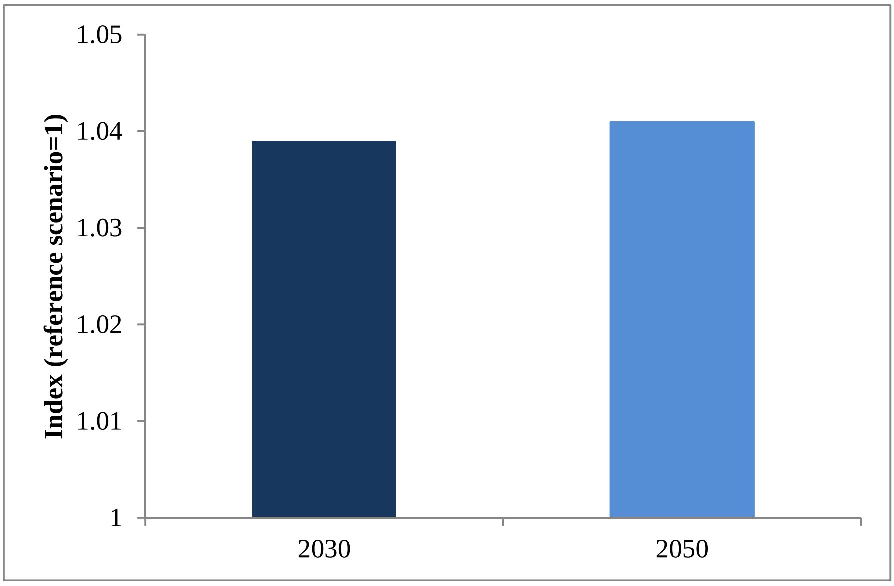


Figure 29 Impact of 2nd generation biofuels on global prices by sector, 2030 and 2050 (index, reference scenario=1)

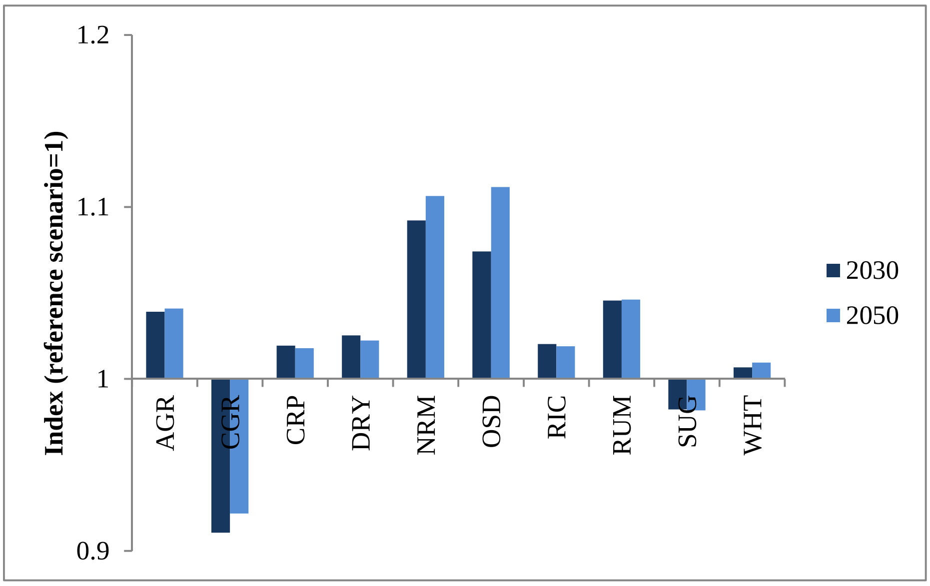
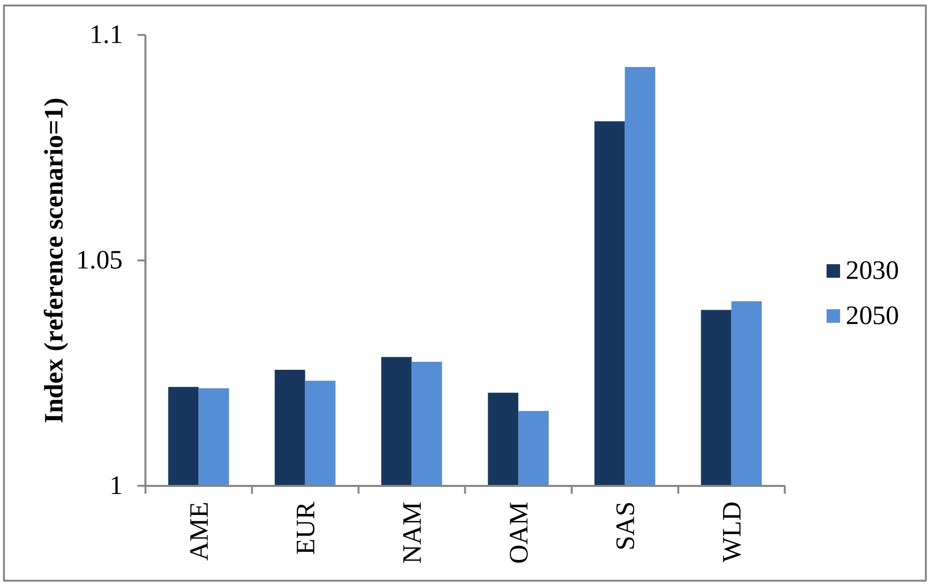


Figure 30 Impact of 2nd generation biofuels on global prices by region, 2030 and 2050 (index, reference scenario=1)



5 Conclusions

The current paper investigates the medium and long-term impacts of climate changes on global agriculture following the AgMIP approach. We employ the CAPRI modelling framework to identify the aggregate effects. We compile one reference scenario which serves as a counterfactual situation of climate change. This scenario reflects economic assumptions as defined under the Shared Socio-economic Pathway (SSP) 2. We simulate one alternative reference scenario, four climate change scenarios and one biofuel scenarios all available from the AgMIP project. All scenarios are run for 2030 and 2050.

The results indicate that globally there will be both winners and losers, with some regions benefitting from agricultural production adjustment as a result of climate change whilst most regions suffering losses in production and consumption. In general, there are relatively moderate effects at the global aggregate. For example, the global agricultural production, consumption and land use for agriculture aggregate change by approximately between -4% and 2% in 2030/2050 relative to a reference situation with no climate change. Prices respond stronger to reduced agricultural supply due to climate change, between 6% and 13%. However, there is a stronger impact at regional level and for different agricultural commodities. Regional impacts of climate change may increase by a factor higher than 5 or more relative to the aggregate global impacts. In general, the S5 and S6 scenarios show stronger impacts than the other two scenarios (S3 and S4). As may be expected the climate change effects would be stronger in 2050 compared to 2030.

The primary impact of the 2nd generation biofuels is on land use and agricultural commodity prices. Land is shifted away from agricultural commodity production to new energy crops which is reflected in lower production levels of agricultural commodities and higher agricultural prices. Global land use expands by around 2% relative to the reference scenario, whereas the commodity crops area and production reduce between 1% and 6%. Global agricultural prices increase at around 4% due to the expansion of the 2nd generation biofuels.

An issue that may require further consideration is the responsiveness of fodder production to climate variations. In this first assessment yields of fodder crops including grassland have not been varied in the climate change scenarios, mainly because fodder crops are not explicitly included in the product list of the IMPACT model that served to compile the standardised productivity shocks. Yet it may be expected that fodder crops would be just as vulnerable to climate impacts as other crops. Including assumptions on such effects would considerably reinforce the global market effects via the animal sector.

The results in this paper must be analyzed in the context of limitations imposed on the paper. In particular 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. The use of stylized template supply modules in CAPRI which are structurally identical and express differences between regions solely by parameters alone might fall short of capturing the full regional diversity of farming systems in the EU and globally and their response to climate change and biofuel expansion. In particular, this is the case for the evaluation of climate change impact on cropping systems, technology adaptation, such as fertilization, manure handling, feeding practices and sectoral demand behaviour. The relatively simple representation of agricultural technology in the CAPRI model compared to approaches parameterized based on biophysical models understates the farm response to natural and local constraints. While some of the key drivers of the analysis of agriculture and climate change require a local perspective and modelling, the analysis of impacts will have to be context-specific and should not be estimated via analyses at a high level of abstraction. However, the current structure of the approach gives a good balance between increased detail of represented regions and robustness of the model results for global and long term horizon economic analysis of climate changes and biofuel expansion.

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Table 2: Average producer price index for the reference scenario, 2030 and 2050 (2005=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
AGR																		
2030	0.92	0.91	0.63	0.88	0.91	0.88	0.87	0.89	0.92	0.83	0.71	0.90	0.77	0.90	0.90	0.91	0.82	0.86
2050	0.89	0.71	0.55	0.59	0.92	0.74	0.69	0.83	0.86	0.60	0.65	0.84	0.73	0.87	0.82	0.94	0.60	0.76
CGR																		
2030	0.98	0.99	0.63	0.96	0.96	0.94	0.85	0.98	0.93	0.95	0.75	0.70	0.94	0.94	0.98	1.01	0.95	0.91
2050	0.85	0.85	0.55	0.84	0.84	0.81	0.67	0.86	0.86	0.83	0.65	0.62	0.82	0.82	0.86	0.85	0.83	0.79
CR5																		
2030	0.93	1.00	0.73	0.76	0.96	0.70	0.63	0.88	0.95	0.91	0.79	0.90	0.87	0.91	0.88	0.91	0.94	0.84
2050	0.78	0.85	0.59	0.85	0.85	0.54	0.63	0.77	0.78	0.98	0.70	0.79	0.84	0.80	0.78	0.77	1.01	0.73
CRP																		
2030	0.93	0.92	0.88	0.88	0.90	0.93	0.83	0.91	0.96	0.91	0.85	0.91	0.83	0.90	0.90	0.91	0.92	0.90
2050	1.01	0.97	0.84	0.89	0.95	0.89	0.87	0.93	1.00	0.96	0.86	0.93	0.87	0.94	0.94	1.03	0.97	0.94
DRY																		
2030	0.82	0.91	0.85	0.87	0.81	0.83	0.86	0.82	0.80	0.85	0.85	0.82	0.85	0.83	0.87	0.89	0.85	0.84
2050	0.53	0.59	0.48	0.51	0.54	0.60	0.50	0.50	0.52	0.49	0.52	0.54	0.54	0.51	0.50	0.55	0.49	0.54
NRM																		
2030	0.93	0.91	0.56	0.91	0.96	0.90	0.91	0.91	0.93	0.67	0.71	0.91	0.93	0.93	0.90	0.92	0.66	0.84
2050	0.81	0.80	0.43	0.80	0.84	0.82	0.80	0.80	0.81	0.54	0.59	0.81	0.85	0.82	0.79	0.82	0.53	0.73
OSD																		
2030	0.92	1.16	0.90	0.66	1.08	0.94	0.47	0.93	0.89	0.87	0.86	0.94	0.84	0.96	0.82	0.95	0.97	0.88
2050	0.74	0.88	0.85	0.86	0.96	0.73	0.55	0.93	0.64	1.31	0.92	0.83	0.97	0.87	0.75	0.84	1.53	0.85
RIC																		
2030	0.92	0.91	0.91		0.90	0.92	0.90	0.91	0.95	0.78	0.92	0.91	0.92	0.90	0.90	0.91	0.78	0.90
2050	0.80	0.80	0.80		0.78	0.81	0.80	0.78	0.80	0.71	0.80	0.80	0.81	0.79	0.79	0.80	0.71	0.79
RUM																		
2030	0.92	0.89	0.37	0.91	0.91	0.90	0.91	0.95	0.91	0.84	0.45	0.93	0.54	0.91	0.89	0.92	0.84	0.81
2050	0.78	0.66	0.32	0.64	0.81	0.79	0.66	0.84	0.78	0.61	0.38	0.73	0.44	0.75	0.66	0.79	0.61	0.67
SUG																		
2030	0.77	0.91	0.65	0.91	0.91	0.42	0.91	0.70	0.82	0.91	0.72	0.91	0.85	0.83	0.91	0.72	0.91	0.63
2050	0.62	0.80	0.45	0.80	0.80	0.29	0.80	0.49	0.70	0.80	0.54	0.79	0.71	0.68	0.80	0.54	0.80	0.49
WHT																		
2030	1.00	0.97	0.97	0.95	0.91	1.02	0.85	0.92	1.01	0.96	0.95	0.92	0.95	0.91	0.91	0.92	0.97	0.96
2050	0.82	0.86	0.85	0.84	0.80	0.80	0.74	0.81	0.82	0.85	0.84	0.81	0.83	0.80	0.80	0.79	0.86	0.81

Table 3: Land use projections for the reference scenario, 2030 and 2050 (2005=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
AGR																		
2030	1.06	1.00	1.06	1.00	1.02	0.98	1.00	1.15	1.17	1.00	1.04	1.15	1.02	1.08	1.03	1.00	1.00	1.04
2050	0.89	1.00	1.10	1.00	0.99	0.96	1.00	1.04	0.64	1.00	1.06	1.32	1.04	1.35	4.39	1.04	1.00	1.05
CGR																		
2030	1.14	0.87	1.16	0.92	1.33	0.89	1.10	1.00	0.92	0.96	1.21	0.96	1.24	1.15	1.25	1.18	0.96	1.09
2050	1.47	0.83	1.18	0.98	1.35	0.88	0.80	1.05	0.66	1.31	1.20	1.20	1.22	1.23	1.53	1.61	1.37	1.22
CRS																		
2030	1.09	1.21	1.26	1.11	1.03	0.94	1.08	1.09	0.86	1.00	1.27	1.10	1.28	1.08	1.15	1.20	0.97	1.09
2050	1.36	1.17	1.43	1.21	0.94	0.90	0.82	1.08	0.89	1.11	1.36	1.00	1.28	1.03	1.12	1.56	1.09	1.11
CRP																		
2030	1.10	1.15	1.20	1.11	1.07	0.92	1.07	1.16	0.98	1.00	1.19	1.09	1.18	1.10	1.09	1.16	0.97	1.09
2050	1.36	1.18	1.32	1.11	1.12	0.89	0.87	1.04	1.00	1.07	1.29	1.06	1.25	1.13	1.47	1.52	1.06	1.15
OSD																		
2030	1.14	1.33	1.07	1.25	0.98	1.23	1.17	1.14	1.36	1.11	1.20	0.99	1.35	1.09	1.31	1.09	1.08	1.14
2050	1.26	0.90	1.20	1.66	0.78	1.01	1.07	2.21	0.81	1.22	1.29	1.16	1.39	1.37	1.13	1.34	1.12	1.26
PAS																		
2030	1.06	0.99	0.99	0.91	0.96	0.94	0.98	1.00	1.19	1.00	0.99	1.17	0.98	1.06	0.77	0.97	1.01	1.02
2050	0.80	0.99	1.00	0.91	0.85	0.92	1.04	1.00	0.58	0.97	0.99	1.41	0.98	1.58	16.21	0.94	0.97	1.01
RIC																		
2030	1.34	1.64	0.50		0.91	0.98	1.34	1.03	0.95	0.94	0.81	1.11	1.24	1.03	1.08	1.41	0.94	1.04
2050	1.14	0.14	0.93		0.96	0.78	0.96	0.93	1.04	1.01	0.94	0.97	0.97	0.97	1.04	1.15	1.01	0.98
SUG																		
2030	1.23	0.88	2.46	0.62	1.41	0.63	0.82	1.68	0.88	0.73	2.20	1.63	1.38	1.53	1.20	1.43	0.73	1.66
2050	1.22	1.15	2.69	0.99	1.02	0.62	0.21	0.89	0.96	0.83	2.30	1.07	1.04	1.00	1.13	1.38	0.83	1.51
WHT																		
2030	0.83	1.41	0.89	1.11	0.80	0.94	1.04	1.15	0.80	0.90	1.03	1.15	1.08	1.01	0.86	1.12	0.81	0.99
2050	1.09	1.44	1.87	0.98	0.53	0.90	0.77	0.51	1.01	0.69	1.42	0.88	1.25	0.58	1.35	1.82	0.56	0.83

Table 4: Yield projections for the reference scenario, 2030 and 2050 (2005=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
CGR																		
2030	1.21	1.15	1.25	1.06	1.02	1.18	1.16	1.33	1.15	1.27	1.17	1.23	1.10	1.05	1.12	1.31	1.28	1.19
2050	1.47	1.24	1.68	1.37	1.51	1.35	1.46	1.86	1.10	0.97	1.75	1.57	1.82	1.53	1.53	2.06	0.96	1.27
OSD																		
2030	1.08	0.99	1.17	1.00	1.19	1.22	1.05	1.14	0.98	1.12	1.10	1.15	1.03	1.15	1.12	1.18	1.14	1.13
2050	1.76	2.79	1.30	1.02	1.27	1.38	1.33	1.39	1.03	1.23	1.27	1.45	1.22	1.35	1.38	2.48	1.27	1.32
RIC																		
2030	1.13	1.04	1.89		1.22	1.17	1.04	1.32	1.20	1.23	1.50	1.26	1.20	1.24	1.22	0.99	1.23	1.25
2050	2.33	0.82	1.20		1.32	1.26	1.15	1.77	1.99	1.21	1.42	1.60	1.59	1.40	1.25	3.01	1.21	1.43
SUG																		
2030	1.32	1.33	0.98	1.27	1.08	1.19	1.13	1.02	1.34	1.71	1.04	1.26	1.12	1.17	1.37	1.30	1.72	1.20
2050	2.55	1.64	0.79	1.08	1.22	1.28	0.70	2.26	2.02	1.78	1.22	2.67	1.81	2.10	2.11	3.09	1.79	1.42
WHT																		
2030	1.27	1.00	1.42	1.14	1.31	1.15	1.25	1.23	1.28	1.21	1.39	1.15	1.38	1.27	1.19	1.11	1.24	1.22
2050	1.45	1.33	1.01	1.16	2.16	1.27	1.44	2.81	1.43	1.96	1.49	2.30	1.58	2.35	0.79	1.81	2.28	1.74

Table 5: Production projections for the reference scenario, 2030 and 2050 (2005=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
CGR																		
2030	1.27	1.00	1.47	1.10	1.40	1.09	1.37	1.34	1.07	1.23	1.44	1.21	1.42	1.38	1.40	1.34	1.24	1.27
2050	2.64	1.06	1.97	1.38	2.08	1.19	1.29	2.10	0.77	1.36	2.13	1.93	2.24	2.10	2.32	3.34	1.36	1.72
DRY																		
2030	1.40	1.21	1.37	1.00	1.38	1.14	1.02	1.43	1.39	1.17	1.37	1.40	1.37	1.38	0.96	1.41	1.19	1.26
2050	2.18	1.92	1.56	1.32	0.90	1.18	1.11	2.08	1.98	1.40	1.72	2.24	1.81	1.85	1.39	2.41	1.41	1.60
NRM																		
2030	1.47	1.29	1.52	1.13	1.44	1.12	1.39	1.38	1.48	1.28	1.45	1.39	1.39	1.42	1.30	1.44	1.30	1.35
2050	3.04	1.48	1.51	1.24	1.70	1.25	1.08	2.37	2.87	1.29	1.69	2.61	1.84	1.78	1.77	3.36	1.29	1.64
OSD																		
2030	1.30	1.32	1.27	1.25	1.17	1.49	1.25	1.30	1.22	1.24	1.33	1.20	1.39	1.29	1.48	1.35	1.24	1.30
2050	2.46	2.35	1.61	1.73	1.18	1.38	1.44	3.20	0.96	1.48	1.66	1.79	1.70	1.76	1.64	3.35	1.45	1.62
RIC																		
2030	1.31	1.70	0.94		1.10	1.11	1.40	1.36	1.17	1.16	1.21	1.40	1.47	1.28	1.33	1.40	1.16	1.27
2050	2.82	0.11	1.11		1.27	0.99	1.09	1.65	1.89	1.22	1.33	1.61	1.54	1.44	1.35	3.43	1.22	1.48
RUM																		
2030	1.43	1.08	1.37	0.91	1.22	0.93	1.16	1.41	1.46	1.15	1.31	1.36	1.24	1.28	1.23	1.41	1.18	1.22
2050	1.65	1.00	1.57	1.27	1.17	0.95	0.75	1.93	1.55	1.53	1.36	1.84	1.15	1.48	1.70	1.70	1.57	1.35
SUG																		
2030	1.45	1.18	2.42	0.79	1.52	0.76	1.00	1.71	1.17	1.25	2.18	1.69	1.65	1.67	1.70	1.67	1.26	1.65
2050	3.53	1.89	2.12	1.07	1.24	0.80	0.14	2.02	2.07	1.48	2.05	2.94	1.90	2.21	2.74	4.65	1.48	1.93
WHT																		
2030	1.05	1.41	1.26	1.27	1.04	1.14	1.28	1.42	1.04	1.08	1.44	1.33	1.50	1.22	1.02	1.09	1.01	1.18
2050	1.43	1.93	1.90	1.13	1.15	1.21	1.08	1.44	1.31	1.24	2.06	2.00	2.10	1.36	1.09	2.82	1.28	1.33

Table 6: Consumption projections for the reference scenario, 2030 and 2050 (2005=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
CGR																		
2030	1.33	0.94	1.51	0.95	1.38	1.07	1.37	1.28	1.28	1.23	1.47	1.40	1.45	1.32	1.14	1.37	1.25	1.27
2050	2.71	1.57	2.00	1.68	2.06	1.09	1.14	2.03	1.61	1.37	2.03	2.20	2.04	1.96	1.55	3.42	1.35	1.72
DRY																		
2030	1.40	1.22	1.37	1.01	1.38	1.13	1.02	1.43	1.39	1.17	1.37	1.40	1.37	1.38	0.98	1.41	1.18	1.26
2050	2.19	1.93	1.57	1.35	0.91	1.17	1.11	2.08	1.99	1.40	1.72	2.25	1.81	1.85	1.40	2.40	1.40	1.60
NRM																		
2030	1.44	1.36	1.60	1.12	1.45	1.13	1.43	1.42	1.44	1.20	1.49	1.41	1.43	1.41	1.27	1.44	1.21	1.35
2050	2.80	1.39	1.77	1.48	1.70	1.20	1.10	2.43	2.60	1.36	1.74	2.60	1.73	1.76	1.63	3.16	1.34	1.64
OSD																		
2030	1.42	1.44	1.51	1.18	1.09	1.33	1.18	1.32	1.45	1.24	1.48	1.28	1.46	1.19	1.36	1.39	1.25	1.30
2050	2.03	2.39	1.81	1.71	1.15	1.33	1.15	3.08	1.66	1.45	1.82	2.17	1.83	1.70	1.87	2.50	1.42	1.62
RIC																		
2030	1.39	1.32	0.94	1.38	1.10	1.23	1.48	1.34	1.35	1.24	1.18	1.41	1.41	1.27	1.32	1.42	1.23	1.27
2050	2.32	1.83	1.15	1.21	1.27	1.28	0.92	1.57	1.57	1.22	1.29	1.65	1.41	1.44	1.38	2.75	1.22	1.48
RUM																		
2030	1.37	1.05	1.41	1.04	1.23	1.02	1.07	1.38	1.38	1.06	1.37	1.39	1.33	1.29	1.30	1.36	1.07	1.22
2050	1.72	1.03	1.61	1.61	1.16	1.10	0.67	1.93	1.63	1.48	1.40	1.78	1.21	1.38	1.14	1.79	1.47	1.37
SUG																		
2030	1.39	0.99	2.62	1.27	1.53	0.86	0.90	1.67	1.28	1.30	2.36	1.62	1.73	1.59	1.49	1.52	1.30	1.65
2050	2.84	2.79	2.42	1.28	2.12	0.89	0.79	1.58	1.47	1.24	2.34	2.97	2.15	2.04	2.06	4.47	1.24	1.93
WHT																		
2030	1.36	1.29	1.22	1.11	1.04	0.94	1.10	1.43	1.35	1.15	1.32	1.46	1.37	1.24	1.17	1.40	1.16	1.18
2050	1.84	1.91	1.12	2.03	1.15	0.93	0.98	1.44	1.71	1.59	1.41	2.17	1.54	1.36	0.94	2.32	1.48	1.33

Table 7: Climate change impact on prices for the agricultural aggregate (AGR) by region, 2030 and 2050 (index, reference scenario=1)

	AME	ANZ	BRA	CAN	CHN	EUR	FSU	IND	MEN	NAM	OAM	OAS	OSA	SAS	SEA	SSA	USA	WLD
2030																		
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	1.07	1.06	1.06	1.05	1.03	1.06	1.04	1.09	1.06	1.06	1.06	1.07	1.06	1.05	1.07	1.09	1.06	1.06
S4	1.08	1.06	1.06	1.03	1.03	1.07	1.04	1.11	1.08	1.05	1.06	1.08	1.06	1.06	1.07	1.09	1.05	1.06
S5	1.08	1.08	1.07	1.09	1.03	1.05	1.03	1.13	1.07	1.10	1.07	1.12	1.07	1.06	1.07	1.08	1.10	1.07
S6	1.08	1.07	1.08	1.08	1.03	1.07	1.06	1.12	1.08	1.11	1.07	1.10	1.07	1.06	1.08	1.07	1.12	1.08
2050																		
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	1.14	1.11	1.12	1.09	1.05	1.11	1.08	1.16	1.13	1.13	1.12	1.12	1.12	1.09	1.12	1.16	1.13	1.11
S4	1.17	1.12	1.10	1.06	1.06	1.15	1.08	1.22	1.16	1.10	1.11	1.15	1.11	1.11	1.13	1.18	1.11	1.13
S5	1.13	1.09	1.12	1.11	1.05	1.08	1.04	1.22	1.12	1.15	1.11	1.19	1.11	1.10	1.10	1.14	1.15	1.11
S6	1.14	1.11	1.14	1.13	1.05	1.13	1.09	1.20	1.14	1.20	1.12	1.18	1.11	1.10	1.13	1.14	1.21	1.13

Table 8: Climate change impact on world prices by commodity aggregate, 2030 and 2050 (index, reference scenario=1)

	AGR	CGR	CR5	CRP	DRY	NRM	OSD	RIC	RUM	SUG	WHT
2030											
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	1.06	1.14	1.12	1.06	1.04	1.05	1.12	1.18	1.08	1.02	1.15
S4	1.06	1.13	1.13	1.08	1.03	1.05	1.12	1.21	1.08	1.02	1.16
S5	1.07	1.23	1.15	1.05	1.07	1.07	1.10	1.19	1.11	1.04	1.27
S6	1.08	1.27	1.16	1.06	1.06	1.08	1.13	1.19	1.12	1.04	1.26
2050											
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	1.11	1.28	1.25	1.12	1.07	1.09	1.25	1.35	1.14	1.03	1.32
S4	1.13	1.26	1.26	1.15	1.06	1.09	1.23	1.40	1.14	1.03	1.34
S5	1.11	1.42	1.29	1.09	1.08	1.10	1.20	1.37	1.17	1.03	1.56
S6	1.13	1.49	1.32	1.12	1.11	1.13	1.27	1.35	1.20	1.04	1.53

Table 9: Climate change impact on production for the agricultural aggregate (AGR) by region, 2030 and 2050 (index, reference scenario=1)

a) Wheat

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.96	0.97	1.00	0.98	0.98
S4	0.94	1.01	1.03	0.98	0.98
S5	1.01	0.96	0.97	0.91	0.97
S6	1.00	0.97	1.00	0.93	0.98
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.93	0.93	1.02	0.96	0.96
S4	0.89	1.01	1.07	0.95	0.97
S5	1.04	0.93	0.97	0.85	0.96
S6	1.02	0.94	1.03	0.89	0.97

b) Rice

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.95	0.98	0.99	0.96	0.97
S4	0.89	1.01	1.00	0.96	0.96
S5	1.02	1.03	1.03	0.96	0.96
S6	0.96	1.00	1.03	0.96	0.97
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.93	0.96	0.99	0.94	0.94
S4	0.83	1.01	1.01	0.93	0.94
S5	1.06	1.04	1.04	0.93	0.94
S6	0.96	0.97	1.05	0.94	0.95

c) Ruminants

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.99	0.98	0.99	1.00	0.99
S4	0.98	0.99	1.00	0.99	0.99
S5	0.99	0.97	0.98	0.98	0.98
S6	0.98	0.95	0.99	0.98	0.98
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.97	0.98	0.99	0.99	0.98
S4	0.97	0.99	1.00	0.98	0.99
S5	0.98	0.97	0.98	0.96	0.97
S6	0.97	0.96	0.99	0.96	0.98

Table 10: Climate change impact on global production by commodity aggregate, 2030 and 2050 (index, reference scenario=1)

	CGR	DRY	NRM	OSD	RIC	RUM	SUG	WHT
2030								
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	0.97	1.00	1.00	0.99	0.97	0.99	1.00	0.98
S4	0.98	1.00	1.00	0.99	0.96	0.99	1.00	0.98
S5	0.94	1.01	0.99	1.00	0.96	0.98	1.02	0.97
S6	0.92	1.00	0.99	0.99	0.97	0.98	1.01	0.98
2050								
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	0.95	1.00	0.99	0.98	0.94	0.98	1.00	0.96
S4	0.97	1.00	0.99	0.98	0.94	0.99	0.99	0.97
S5	0.90	1.00	0.99	1.00	0.94	0.97	1.00	0.96
S6	0.88	1.00	0.99	0.99	0.95	0.98	1.00	0.97

Table 11: Climate change impact on the total agricultural area by commodity aggregate, 2030 and 2050 (index, reference scenario=1)

	AGR	CGR	CR5	CRP	OSD	PAS	RIC	SUG	WHT
2030									
S1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
S3	1.007	1.007	1.026	1.019	1.078	1.003	1.017	0.979	1.017
S4	1.006	1.006	1.021	1.017	1.054	1.002	1.021	0.982	1.017
S5	1.007	1.034	1.022	1.011	1.013	1.005	1.009	0.976	1.033
S6	1.008	1.038	1.025	1.015	1.026	1.005	1.009	0.977	1.028
2050									
S1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
S3	1.013	1.012	1.059	1.039	1.174	1.002	1.040	0.936	1.044
S4	1.011	1.008	1.046	1.034	1.121	1.002	1.045	0.949	1.043
S5	1.011	1.072	1.048	1.023	1.017	1.006	1.033	0.922	1.085
S6	1.012	1.078	1.054	1.030	1.049	1.004	1.028	0.926	1.068

Table 12: Climate change impact on land use by region, 2030 and 2050 (index, reference scenario=1)

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.95	0.98	0.99	0.96	0.97
S4	0.89	1.01	1.00	0.96	0.96
S5	1.02	1.03	1.03	0.96	0.96
S6	0.96	1.00	1.03	0.96	0.97
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.93	0.96	0.99	0.94	0.94
S4	0.83	1.01	1.01	0.93	0.94
S5	1.06	1.04	1.04	0.93	0.94
S6	0.96	0.97	1.05	0.94	0.95

Table 13: Climate change impact on consumption by region, 2030 and 2050 (index, reference scenario=1)

a) Wheat

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.95	0.99	0.99	0.99	0.98
S4	0.96	0.98	0.99	0.99	0.98
S5	0.98	1.03	0.99	0.94	0.97
S6	1.00	1.05	0.98	0.95	0.98
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.90	1.00	0.98	0.97	0.96
S4	0.92	0.99	0.98	0.97	0.97
S5	0.91	1.05	0.98	0.93	0.96
S6	0.97	1.12	0.97	0.94	0.97

b) Rice

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	1.02	0.94	0.97	0.97	0.97
S4	1.03	0.94	0.97	0.96	0.96
S5	1.01	0.93	0.98	0.97	0.96
S6	1.03	0.92	0.98	0.97	0.97
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.99	0.93	0.96	0.94	0.94
S4	1.01	0.93	0.96	0.94	0.94
S5	0.98	0.92	0.97	0.94	0.94
S6	0.99	0.91	0.97	0.95	0.95

b) Ruminants

	EUR	NAM	OAM	SAS	WLD
2030					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.99	0.99	0.99	0.99	0.99
S4	0.99	0.99	1.00	0.99	0.99
S5	0.99	0.99	0.98	0.98	0.98
S6	0.99	0.99	0.98	0.98	0.98
2050					
S1	1.00	1.00	1.00	1.00	1.00
S3	0.99	0.99	0.98	0.99	0.98
S4	0.99	1.00	0.99	0.98	0.99
S5	0.99	0.99	0.98	0.97	0.97
S6	0.98	0.99	0.98	0.97	0.98

Table 14: Climate change impact on global consumption by commodity groups, 2030 and 2050 (index, reference scenario=1)

	CGR	DRY	NRM	OSD	RIC	RUM	SUG	WHT
2030								
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	0.97	1.00	1.00	0.99	0.97	0.99	1.01	0.98
S4	0.98	1.00	1.00	0.99	0.96	0.99	1.00	0.98
S5	0.94	1.01	0.99	1.00	0.96	0.98	1.02	0.97
S6	0.92	1.00	0.99	0.99	0.97	0.98	1.01	0.98
2050								
S1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S3	0.95	1.00	0.99	0.98	0.94	0.98	1.00	0.96
S4	0.97	1.00	0.99	0.98	0.94	0.99	1.00	0.97
S5	0.90	1.00	0.99	1.00	0.94	0.97	1.00	0.96
S6	0.88	1.00	0.99	0.99	0.95	0.98	1.00	0.97

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Abstract
The current paper investigates the long-term global effects of crops productivity changes under different climate scenarios and the impact of biofuels expansion using the Common Agricultural Policy Regionalised Impact (CAPRI) model. These analyses are conducted in the framework of the AgMIP project (Agricultural Model Intercomparison and Improvement Project). The results indicate that globally there will be both winners and losers, with some regions benefitting from agricultural production adjustment as a result of climate change whilst most regions suffering losses in production and consumption. Biofuel expansion leads to land relocation away from crop agricultural commodity production to new energy crops which is reflected in lower production levels of agricultural commodities and higher agricultural prices.

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