Towards **Ru**ral **S**ynergies and **T**rade-offs between
Economic Development and **E**cosystem Services

D2.1 Global drivers of EU land use

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Deliverable 2.1

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EXECUTIVE SUMMARY

The objective of this deliverable is to identify and assess global drivers of change and to quantify the impact on global and European land use. Therefore, a variety of macro-economic and climate change scenarios has been developed and implemented in a global economic land use model. Different shared socio-economic pathways provide different future assumptions on global drivers of land use change (SSP1 - a sustainability scenario; SSP2 - a middle of the road scenario; SSP3 - opposite tendencies to SSP1).

The highest price increase among the SSPs for agricultural products can be observed in SSP3 which reflects the high scarcity of agricultural commodities due to high population growth and low rates of technical change in the agricultural sector. Under SSP1, low population growth and sustainable diets with less meat on the demand side and high technical growth rates on the supply side lead to the lowest price increases at the global level across the different SSPs. The middle of the road scenario under SSP2 shows the highest crop production quantities. Prices increase more compared to SSP1 because of higher population growth, a less sustainable diet and lower rates of technical change, but less compared to SSP3.

In terms of land use change, SSP2 shows the highest expansion of agricultural land until 2050. In general, it can be observed that under all SSPs forest and other natural land is converted to agricultural land to enable the additional production of crops, livestock products and bioenergy carriers. Different land use change patterns can be observed from a regional perspective. In Europe only small land use change effects are projected while Asia, Latin America, and Africa all are projected to bear large shares of land use changes. The major shares of deforestation are projected to take place in Latin America and in Sub-Saharan Africa.

The climate change impacts show negative average yield effects at the global level for the crop sector. However, grassland productivity increases slightly due to climate change. Consequently, global crop production is projected to decrease and world market prices increase due to climate change effects across SSPs. However, in single regions climate change might have a yield increasing effect on agricultural production and increase regional supply. Overall, climate change drives additional deforestation as more cropland comes into production to buffer the negative climate change impact on crop yields. However, due to increase of grassland productivity and reallocation of livestock production across regions and livestock systems, grassland areas decrease in all SSPs compared to a situation without climate change resulting in less conversion of other natural vegetation.

To conclude, we achieved to successfully identify important drivers of EU land use and implement a consistent set of scenarios taking into account both climate change and socio-economic drivers in GLOBIOM. This is a first important step towards the ultimate goal of work package two of the TRUSTEE project which is to quantify global drivers of land use dynamics and provide prospective scenarios of future land use changes in the EU at different scales.

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1 INTRODUCTION

Socioeconomic developments such as population and income growth in large parts of the world, climate change impacts on food production and biofuel policies are the main challenges for the agricultural sector in the future. They have raised scientific, political and public interest in long-term forecasts to assess the impact of these global drivers of change on the environment (Schmidhuber and Tubiello, 2007; Godfray et al., 2010; Foley et al., 2011). 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; Godfray et al., 2010). At the same time, climate change poses a major challenge to the agricultural sector, among other, through its possibly negative effects on agricultural productivity growth (Wheeler and von Braun, 2013; Müller and Robertson, 2014).

In order to assess the impact of climate change under different potential futures, a new set of scenarios have been developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The scenarios are constructed around a scenario matrix with two basic elements, the socio-economic drivers (shared socio-economic pathways - SSPs (O'Neill et al., 2014)) and the climatic driver (representative concentration pathways – RCPs; (van Vuuren et al., 2011)). The SSPs are assembled along the axis of "challenges for mitigation" and "challenges for adaptation" (Figure 1). They describe plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions. The SSPs consist of a narrative storyline and a set of quantitative drivers (GDP and population growth) (Kriegler et al., 2012).

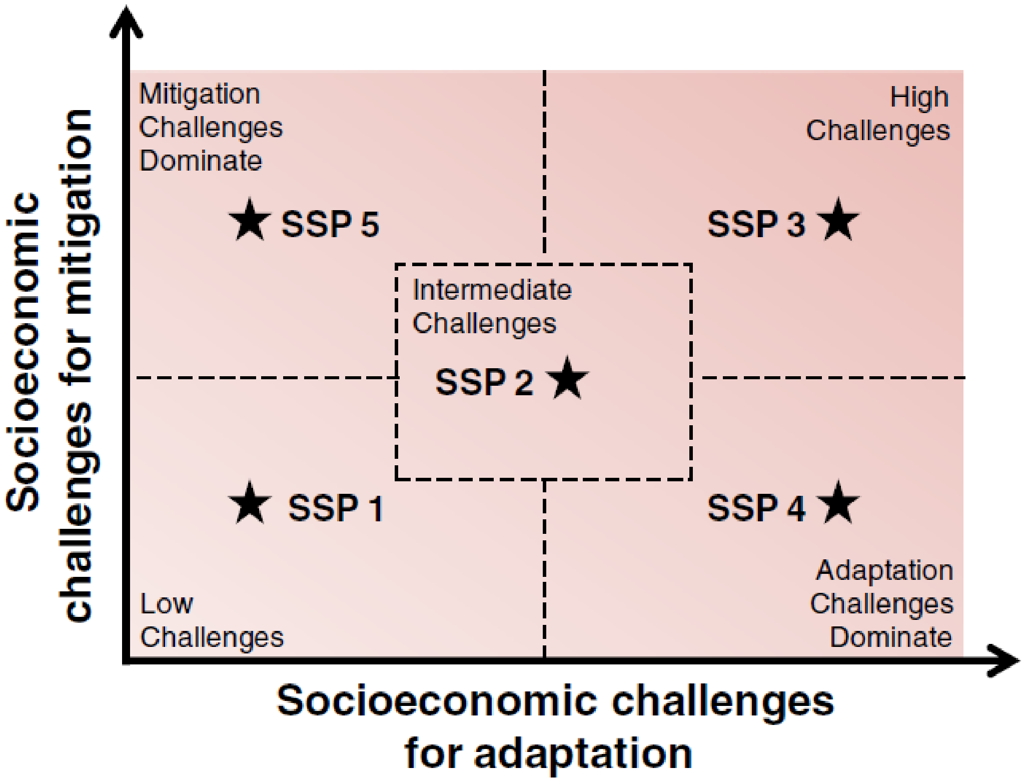

Figure 1. Matrix of the shared socio-economic pathways (O'Neill et al., 2014).

The second axis of the IPCC scenarios is a set of RCPs which were developed to explore the impact of climate change under different radiative forcing levels. In total four RCPs were produced that lead to radiative forcing levels[*] of 8.5, 6.0, 4.5 and 2.6 Watts per square meter (W/m^2), by 2100. Forcing refers to the global average radiative forcing in W/m^2 on the basis of greenhouse gases (GHG) and air pollutants (Van Vuuren et al., 2014). In the Inter-Sectoral Impact Model Intercomparison Project (Warszawski et al., 2014) the different RCPs have been quantified by five global climate models. However, there remain large uncertainties surrounding model projections of future climate for a given level of radiative forcing. Consequently, regional climate projections can differ significantly from the projection from another climate model for the same RCP (Van Vuuren et al., 2014). Nevertheless, the RCPs provide consistent global state-of-the-art climate change projections.

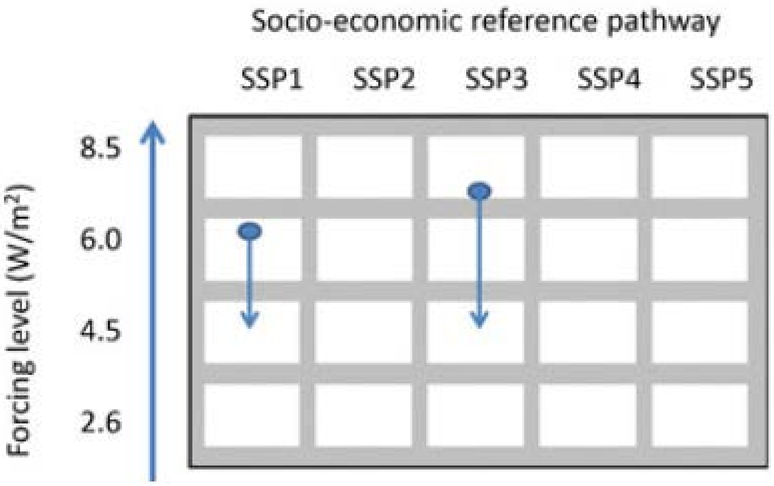

Figure 2. Scenario matrix architecture. Movement along the arrow will require introduction of mitigation policies and changes in the assumed adaptation policies (given the different level of climate change). (Van Vuuren et al., 2014).

SSPs and RCPs are combined in a scenario matrix structure (Figure 2) which allows assessing the impact of socio-economic and climatic drivers. Scenarios can be defined for each cell in Figure 2 where one RCP intersects with one set of SSP assumptions. Scenarios without climate policy (reference scenarios) based on different SSPs may produce different levels of radiative forcing and thus take different positions along the forcing level axis.

In this deliverable we want to identify and assess global drivers of change and quantify the impact on global and European land use. Therefore we will implement a set of consistent scenarios taking into account both climate change and socio-economic drivers in GLOBIOM, a global economic land use model. This deliverable will provide input to Task 2.2 which will quantify prospective scenarios of future land use changes in the EU at more refined scales.

The structure of this deliverable is as follows: In the first part the GLOBIOM model is introduced, followed by a description of global drivers of change and the presentation of the scenarios used. Thereafter, the scenario results with a focus on land use impacts and conclusions are presented.

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[*] Radiative forcing is commonly used in climate science and refers to the change in net irradiance at the tropopause (difference in energy absorbed by the earth and energy radiated back to space).

2 METHODOLOGY

2.1 GLOBIOM model structure

GLOBIOM (Global Biosphere Management Model) is a global economic land use model which has been developed at IIASA since 2007 (Havlík et al., 2011; Havlík et al., 2014). It is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy and forestry sectors. It is a linear programming model based on the spatial equilibrium approach developed by Takayama and Judge (1971). Figure 1 presents the model structure graphically while main model characteristics are presented in Table 1.

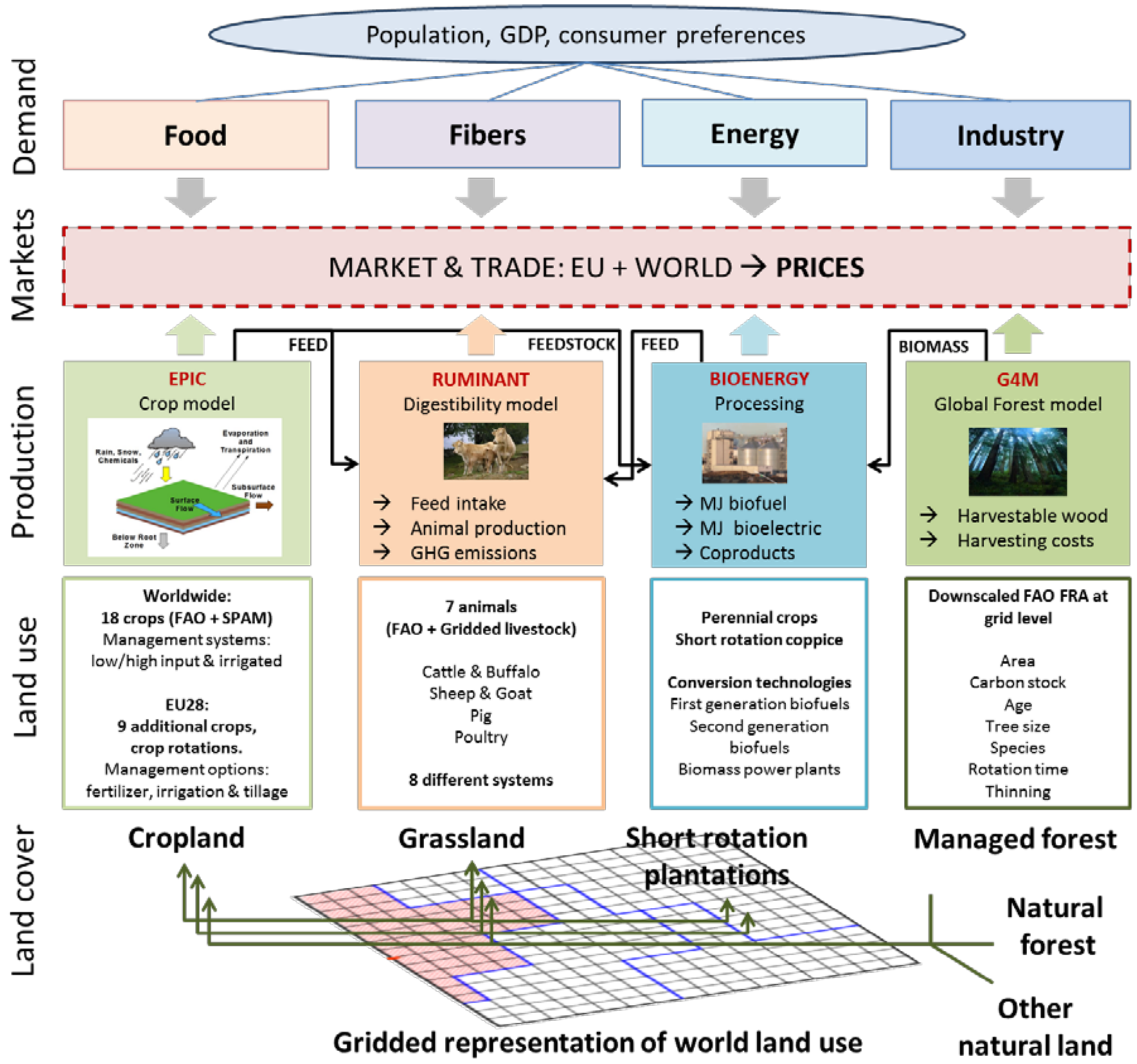

Figure 3. Illustrative GLOBIOM model structure.

In the objective function of the model, a global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize welfare (i.e. the sum of producer and consumer surplus) subject to resource, technological, demand and policy constraints.

The model encompasses all world regions aggregated to 30 regions which either represent single countries or aggregates of countries. GLOBIOM is calibrated to FAOSTAT data for the year 2000 (average 1998 - 2002) and runs recursively dynamic in 10-year time-steps up to 2050. Demand for final products (agricultural, forestry and bioenergy products), prices and international trade are represented at the level of aggregated world regions. Commodity demand is specified as downward sloped iso-elastic function parameterized using FAOSTAT data on prices and quantities, and price elasticities as reported by Muhammad (2011).

Table 1. Main GLOBIOM characteristics

	GLOBIOM
Model framework	Bottom-up, starts from land and technology at grid level
Sector coverage	Detailed focus on agriculture, forestry and bioenergy (partial equilibrium)
Regional coverage	Global (30 regions)
Resolution on production side	Detailed grid-cell level
Time frame	2000-2050 (ten year time step)
Market data source	FAOSTAT
Land use change mechanisms	Geographically explicit. Land conversion possibilities allocated on grid-cells taking into account suitability, protected areas.
Representation of technology	Detailed biophysical models estimates for agriculture and forestry with several management systems
Demand side representation	One representative consumer per region and per good, only reacting to price
GHG accounting	12 sources of GHG emissions covering crop cultivation, livestock, land use change etc.

On the supply side, GLOBIOM uses a bottom-up approach where land resources and their characteristics are the fundamental elements. The model is based on a detailed disaggregation of land into Simulation Units (SimU) – clusters of 5 arcmin pixels belonging to the same country, altitude, slope and soil class and to the same 0.5° x 0.5° pixel (Skalský et al., 2008). SimUs delineation builds on a comprehensive global database, which contains geo-spatial data on soil, climate/weather, topography, land cover/use, and crop management (e.g. fertilization, irrigation). Cropland, grassland, forest and short rotation tree plantation productivity is computed together with related environmental parameters like GHG budgets or fertilizer and water requirements at the SimU level, either by means of process based biophysical models or by means of downscaling from national data sets. Production technologies at the level of SimU, or their aggregates, are specified through Leontief production functions, which imply fixed input – output ratios.

On the crop production side, GLOBIOM represents globally 18 major crops (barley, beans, cassava, chickpeas, corn, cotton, groundnut, millet, palm oil, potato, rapeseed, rice, soybean, sorghum, sugarcane, sunflower, sweet potato, wheat) and 4 different management systems (irrigated – high input, rainfed – high input, rainfed – low input and subsistence) simulated by the biophysical process based crop model EPIC (Williams, 1995; Izaurralde et al., 2006).

The livestock sector component of the model uses the International Livestock Research Institute/FAO production systems classification. We consider four production systems: grassland based, mixed, urban and other. The first two systems are further differentiated by agro-ecological zones. For our classification we retained three zones arid/semi-arid, humid/subhumid and temperate/tropical highlands. Monogastrics are split into Industrial and Smallholder. Eight different animal groups are considered: bovine dairy and meat herds, sheep and goat dairy and meat herds, poultry broilers, poultry laying hens, mixed poultry and pigs. Animal numbers are at the country level consistent with FAOSTAT. The livestock production system parameterization relies on the dataset by Herrero et al. (2013).

For the forest sector, primary forest productivity such as mean annual wood biomass increment, maximum share of saw logs in harvested biomass, and harvesting costs are provided by the G4M model (Kindermann et al., 2006). Five primary forest products are represented in the model (saw logs, pulp logs, other industrial logs, fuel wood and biomass for energy).

Six land use types are dynamically modelled (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 more detailed information on GLOBIOM we refer to Havlik et al.(2014).

2.2 Important model characteristics with respect to land use

In this section we want to give a brief overview of main model characteristics, which make GLOBIOM highly suitable to assess the impact of global change driver on land use and land use change.

2.2.1 Spatially explicit representation of biophysical land characteristics

GLOBIOM relies on a detailed spatially explicit geo-dataset which enables the model to optimize the localization of the production for crop cultivation at high resolution taking into account biophysical soil characteristics, yields and costs in each spatial unit (SimU). Each SimU contains information specific to the productivity of each crop according to the biophysical model EPIC. Land use change is managed directly at the level of SimUs. A land transition matrix defines which land use conversion paths are possible and the costs associated to it depending on the land type to convert i.e. it is usually less costly to expand into natural vegetation than into forest. This approach allows for a good representation of the main drivers of land use change and deforestation observed in the different regions of the world and is therefore highly valuable to quantify global impacts on land use.

2.2.2 Endogenous yield response and marginal yield

In GLOBIOM, yield changes include two different components: Technological change allows yields to increase over time independently from other economic assumptions e.g. due to breeding, introduction of new varieties or technology diffusion. This parameter is model exogenous (see section 2.3.1.3). However, yield responses to prices through e.g. shift in management systems or reallocation of production from less to more productive units are represented endogenously.

In GLOBIOM, crops and livestock have different management systems with their own productivity and cost. The distribution of crops and animals across spatial units and management types determines the average yield at the regional level. Farmers adjust their management systems and the production locations due to price changes, which impact the average yields through different channels:

- Intensification caused by shifts between rain fed management types (subsistence, low input and high input);
- Yield increase following investment in irrigated systems.
- Change in allocation across spatial units with different suitability (climate and soil conditions).

The detailed representation of management systems and land allows GLOBIOM to represent feedbacks in a consistent way e.g. increased prices leading to intensification which again has implication on cropland expansion and land use change.

2.2.3 Detailed set of GHG emission sources

The detailed representation of geographically explicit land use (change) enables to precisely link to these activities to the associated emission accounts and quantify the impacts of land use on GHG emissions. A dozen of different GHG emission sources related to agriculture and land use change are represented in GLOBIOM (Table 2). Agricultural emissions sources are covered at 94% and land use change emissions are consistent with historical observation. All GHG emissions calculations in GLOBIOM are based on IPCC guidelines on GHG accounting.

Table 2. GHG emission sources in GLOBIOM

Sector	Source	GHG	Reference	Tier
Crops	Rice methane	CH_4	Average value per ha from FAO	1
Crops	Synthetic fertilizers	N_2O	EPIC runs output/IFA + IPCC EF	1
Crops	Organic fertilizers	N_2O	RUMINANT model + Livestock systems	2
Crops	Carbon from cultivated organic soil (peatlands)	CO_2	FAOSTAT	1
Livestock	Enteric fermentation	CH_4	RUMINANT model	3
Livestock	Manure management	CH_4	RUMINANT model + Literature review	2
Livestock	Manure management	N_2O	RUMINANT model + Literature review	2
Livestock	Manure grassland	N_2O	RUMINANT model + Literature review	2
Land use change	Deforestation	CO_2	IIASA G4M Model emission factors	2
Land use change	Other natural land conversion	CO_2	Ruesch and Gibbs (Ruesch and Gibbs, 2008)	1
Land use change	Soil organic carbon	CO_2	JRC / EPIC	3

2.3 Global drivers of land use

In this section, we identify global drivers of land use and land use change and develop prospective scenarios which are used to quantify land use change impacts. The scenarios developed and quantified are in line with the scenarios used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). In the following section we are going to present the SSPs and RCPs and their quantification in GLOBIOM in more detail.

2.3.1 Shared socio-economic pathways (SSPs)

SSPs provide the socio-economic framework and hence do not contain any assumptions on climate change. They have been assembled along the axes of challenges to mitigation and challenges to adaptation to climate change. Three out of five SSPs have been quantified in the present work:

- **SSP1 – Sustainability:** Relatively high levels of GDP growth, lower levels of population growth, high levels of education, international cooperation, fast technological growth, convergence between developed and developing countries, sustainability concerns in consumer behaviour etc.
- **SSP2 – Middle of the Road:** Representing business as usual development and continuation of currently observed trends.
- **SSP3 – Fragmentation:** Opposite tendencies to SSP1, relatively slow economic growth, sustained population growth etc.

2.3.1.1 Population and GDP growth

The SSPs provide quantified projections of major socio-economic drivers (population and GDP growth) of global change which are directly implemented in GLOBIOM (IIASA/OECD, 2013). World population is projected to increase from the current 7 billion to 8, 9 and 10 billion people for SSP1, SSP2 and SSP3, respectively. In Africa and Latin America, the increase is similar as at the global scale with the highest growth in SSP3 and the lowest in SSP1. In Europe, on the contrary, population is the highest under SSP1, where the slow increase observed over the past decades continues, and it is the lowest under SSP3, where it decreases to levels close to those observed in the middle of the past century.

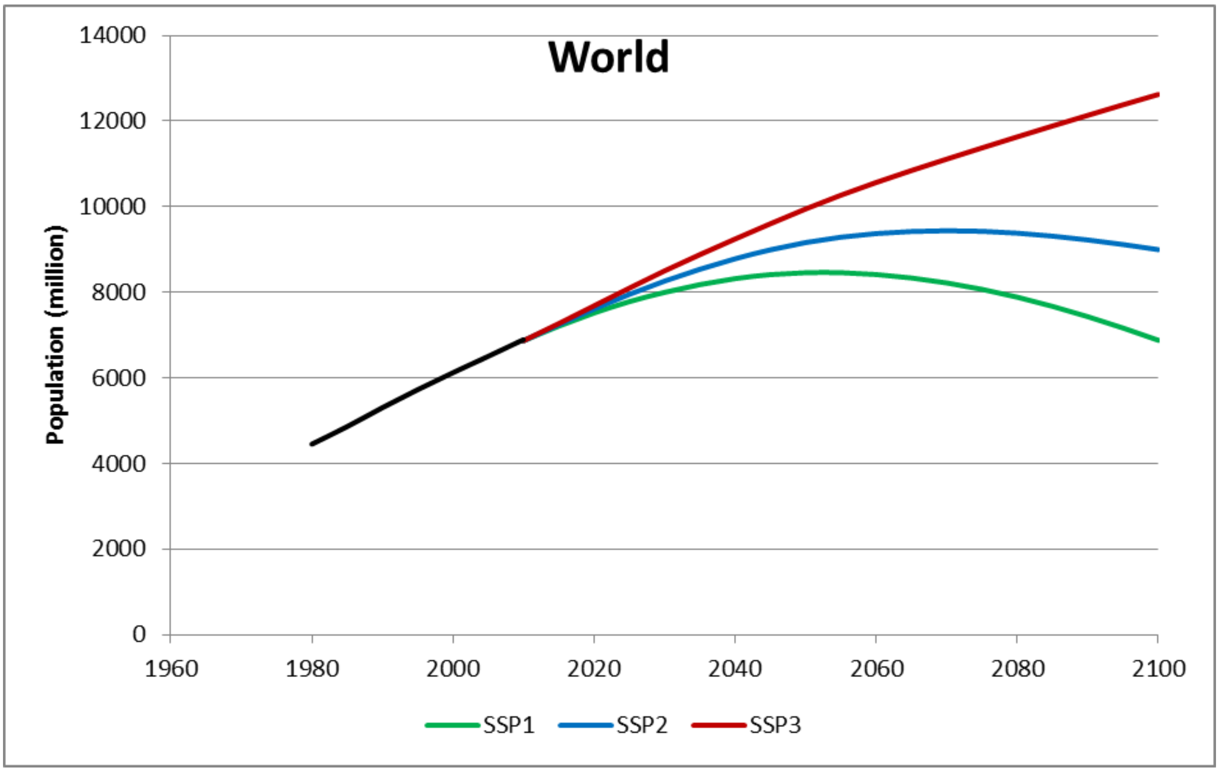

Figure 4. Population growth for different SSPs in million people.

The SSPs differ substantially in the levels of projected economic growth. The differences in the growth rates between the scenarios are higher in developing regions (Africa, Latin America), and lower in industrialized regions (Europe). Both population and real GDP growth are important drivers of future demand for agricultural commodities in general. Since they go in the developing regions in opposite directions – higher GDP growth is accompanied by lower population growth - the overall impact on demand is ambiguous.

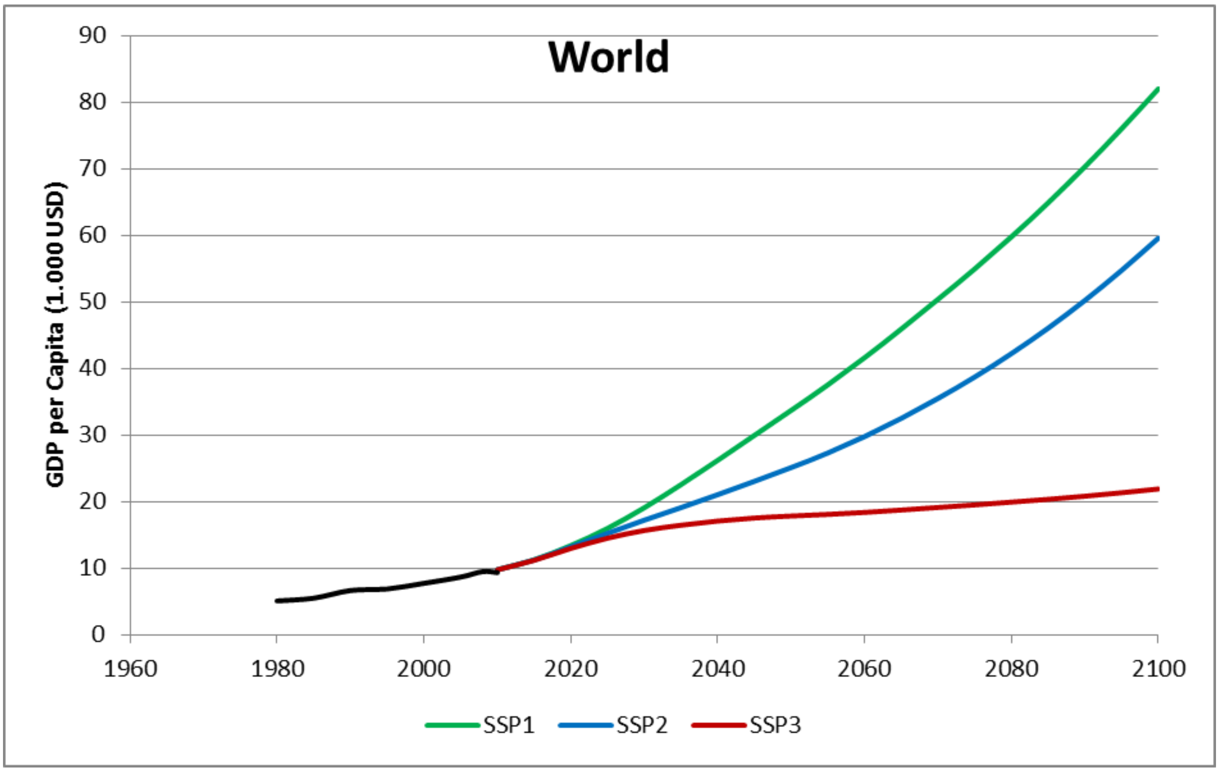

Figure 5. Real GDP per capita growth in 1.000 USD for different SSPs.

2.3.1.2 Food demand

In GLOBIOM, food demand projections are based on the interaction of three different drivers: i) population growth, ii) income per capita growth, and iii) response to prices. Drivers (i) and (ii) are exogenously introduced in the model baseline. Demand increases proportionally with population in each of the 30 GLOBIOM regions. GDP per capita changes determine demand variation depending on income elasticity values associated to each scenario. Price effect (iii) is endogenously computed, and the final demand in the model is therefore influenced by some other assumptions on technology, natural resources, etc. that shape price patterns. The assumptions for the trend of the income elasticity were adapted to match the diet storylines for the different SSPs as follows:

- **SSP2:** These future diets follow the projections from FAO at the horizon 2050 (Alexandratos and Bruinsma, 2012).
- **SSP3:** As economic growth is much lower in developing region, income effects alone lead to a significantly lower demand per capita in these regions. GDP growth decreases much less in developed regions.
- **SSP1:** Future diets are considered to be more sustainable than in the FAO baseline. Therefore, some alternative assumptions are made on total consumption per capita and demand for some specific products. First, to reflect the better management of domestic waste in developed countries, consumption per capita is in the regions assumed almost constant, whereas it could increase in SSP2 for some developed regions. Second, animal protein demand is reduced in regions where more than 75 g protein/capita/day are consumed for animal and vegetal products. A minimum consumption of 25 g protein/capita/day of animal calories is ensured but red meat consumption is reduced to 5 g protein/capita/day (target remains possible through non ruminant meat, eggs and milk). For developing regions, more nutritious diets are assumed and this materialized through an

increase in protein intake to 75 g protein/capita/day and a reduction of root consumption to a level of 100 kcal/capita/day.

2.3.1.3 Technological progress

For technological change we converted the semi-quantitative information of the SSPs into crop and livestock productivity growth rates. Crop productivities have been estimated using econometric analysis. We follow Tilman et al. (2011) who showed that economic income groups are a significant variable when projecting crop yields. We estimated yield response functions to GDP per capita for 18 crops using a fixed effects model with panel data[†]. Crop yields in levels from FAOSTAT were fitted on countries' logarithmized GDP per capita over the period 1980-2009 by fixed effects panel estimation. The response to GDP per capita was differentiated over four income groups oriented at World Bank's income classification system (<1.500, 1.500-4.000, 4.000-10.000, >10.000 USD GDP per capita). Country level yield data was provided from FAOSTAT while GDP per capita was based on World Bank data (1980-2009). The coefficient for yield response to GDP per capita was informed by observations stemming from countries in the same economic group. Countries were grouped oriented at World Bank's economic groups with slight changes in group thresholds to balance groups and secure enough observations in each group. Estimation was carried out for each of the 18 crops separately. Yields in Europe are projected to grow by 35-50% depending on the SSP until 2050. The relative yield growth in Latin America is similar as in Africa & Middle East – 123% under SSP1, 106% under SSP2, and 66% in SSP3. A simple assumption with respect to the nitrogen intensity of the future production has been made. We assume a decrease of nitrogen utilisation to yield growth under SSP1 (elasticity = 0.5) and SSP2 (elasticity = 0.75) and increasing nitrogen intensity (elasticity = 1.25) under SSP3.

For the livestock sector, efficiency increases for five livestock products (ruminant, pig and poultry meat, milk and eggs) are based on Bouwman et al. (2005). Ruminant meet feed conversion efficiency (unit of product per unit of feed) for the period 2010-2050 is highest in Sub-Saharan Africa under SSP1 (+70%). The efficiency improves there by about 50% also under SSP2, and similar growth is projected for Latin America for both SSP1 and SSP2. Also dairy feed conversion efficiency improves in these two regions by about 20-30% under SSP1 and SSP2. Pigs and poultry feed efficiencies, as well as efficiencies in Europe, usually increase by less than 5% over the whole projection period. Depending on the SSP we allow in GLOBIOM for more or less important switches between the livestock production systems. The production system structure is more or less frozen under SSP3 and fairly flexible under SSP1. This can be justified by the general assumption of better access to credits, public investment in infrastructure, capacity building etc. under SSP1 compared to SSP3. Hence, feed conversion efficiency change will be close to the projected values under SSP3 but it may differ under SSP1.

[†] Formally, the fixed effects model can be written as: $y_{it}^{c} = \sum_{j}^{m} d_{ij} a_i + \sum_{g}^{G} g_{ig} \beta_g^c x_{it} + u_{it}$
where y_{it}^{c} shows the yield of country *i* in period t, d_{ij} denotes the fixed effects (country) dummy of country *i* with $d_{ij} = 1 \; \forall \; i = j$ and 0 otherwise, fixed effects coefficient a_i captures the countries' individual time-invariant difference, g_{ig} stands for the GDP per capita group dummy with $g_{ig} = 1 \; \forall \; g$ (i.e. if country *i* belongs to GDP per capita group *g*), coefficient β_g^c captures the effect of GDP per capita of countries in group *g*, *M* is the number of countries in the sample, *c* is the crop index, and u_{it} is the unobserved error term.

2.3.1.4 Losses and wastes

In order account for food losses and wastes, we used the analysis published by FAO (2011). The study specifies three types of losses (pre-distribution) according to the phase of the production chain in which they happen (Agricultural production, Postharvest handling and storage, Processing) and two types of wastes (Distribution/Retail, Consumption).

With respect to representation of these three categories in GLOBIOM and their projections in the future, we assume that

- “Production” and hence yields as reported by FAOSTAT are net of losses during agricultural production. Hence, their developments are included already in the crop yield projections based on historical FAOSTAT crop yields and do not require particular attention here.
- “Consumption” in FAOSTAT Food Balance Sheets is reported gross (before subtraction of the Consumption wastes). Hence, assumptions about Consumption wastes are implicitly included in the food demand projections.

So for the explicit losses and wastes (LW) analysis we are left with three categories. For projections of future rates of these losses and wastes, we have decided to investigate their relationship between to the GDP per capita in a cross section approach for the region aggregates reported by FAO (2011). Five product categories were considered (Cereals, Oilseeds&Pulses, Roots&Tubers, Meat, Milk). However, only for Oilseeds&Pulses and Milk, the losses and wastes to be covered in GLOBIOM, were both important enough and a clear relationship between the GDP per capita and the LW rates existed. Thus, only for these two product categories the LW storylines were quantified.

The highest losses and wastes in the Oilseeds&Pulses sector were observed in the Africa & Middle East region, 17%, and the lowest LW were in Europe, 6%. Under SSP1, LW in Africa & Middle East would go down 10%. Globally, LW would go down from 12% to 7-9% depending on the SSP. Also in the dairy sector, the highest losses and wastes occurred in Africa & Middle East. They are projected to go down from 12% to 4-9% depending on the scenario. Globally, the production recovered from former losses and wastes could add 3-5% to the milk supply. Overall, the global effects are rather small compared to the crop yield and feed efficiency developments but they can play some role in particular regions.

2.3.2 Representative concentration pathways (RCPs)

Four representative concentration pathways have been developed for the climate modelling community as a basis for long-term and near-term modelling experiments (Van Vuuren et al., 2014). The four RCPs span from 2.6 to 8.5W/m^2 radiative forcing values until 2100 ranging thereby from a <2 degree warming scenario up to a 4 degree scenario (Figure 6). The RCPs are the product of an innovative collaboration between integrated assessment modellers, climate modellers, terrestrial ecosystem modellers and emission inventory experts.

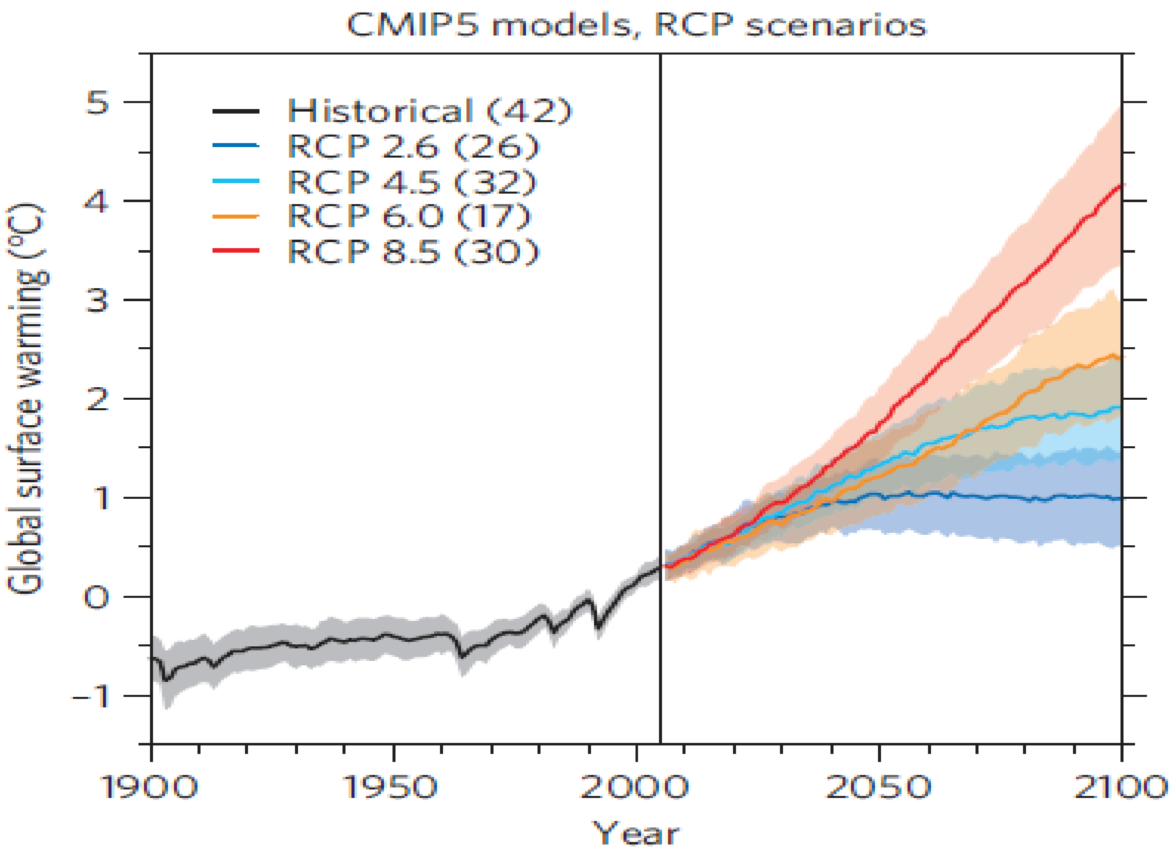

Figure 6. Global surface warming in the different RCPs from the CMIP5 (Coupled Model Intercomparison Project) (IPCC, 2013).

In the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al., 2014), five global climate models (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M) quantified the four RCPs with and without CO_2 fertilization effect. Climate effects have then been passed on to seven global gridded crop models (EPIC, GEPIC,GAEZ-IMAGE, LPJmL, LPJ-GUESS, pDSSAT and PEGASUS) which in turn simulated crop- and grassland specific productivity shifters (Rosenzweig et al., 2014). Figure 5 presents the information flow from the climate to the economic models.

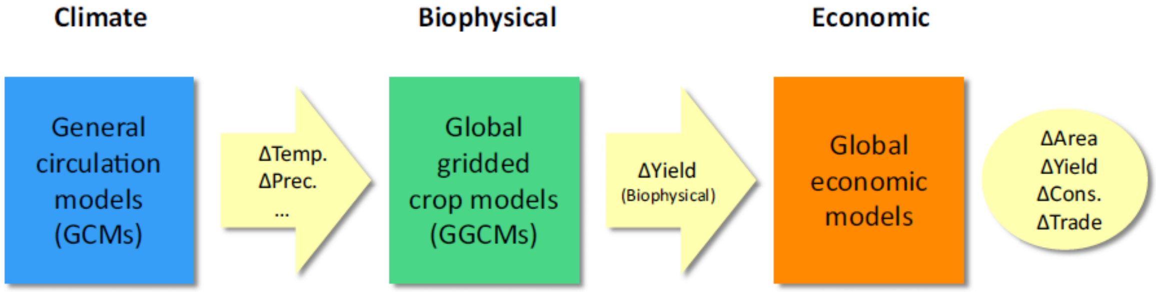

Figure 7. The impact modelling chain from climate through to crop and economic effects (Nelson et al., 2014).

For implementation of these climate change impacts on crop- and grasslands in GLOBIOM, 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. As a trade-off between computing requirements and inclusion of major uncertainties in the biophysical impact of climate change, we decided to focus on a limited set of scenarios to quantify the impact of climate change on future land use. We chose RCP 8.5 quantified by HadGEM2-ES and EPIC crop model with CO_2 fertilization effect. However, results are available for the full ISI-MIP dataset. Figure 6 presents average temperature and annual rainfall changes for the climate RCP 8.5 in HadGEM2-ES.

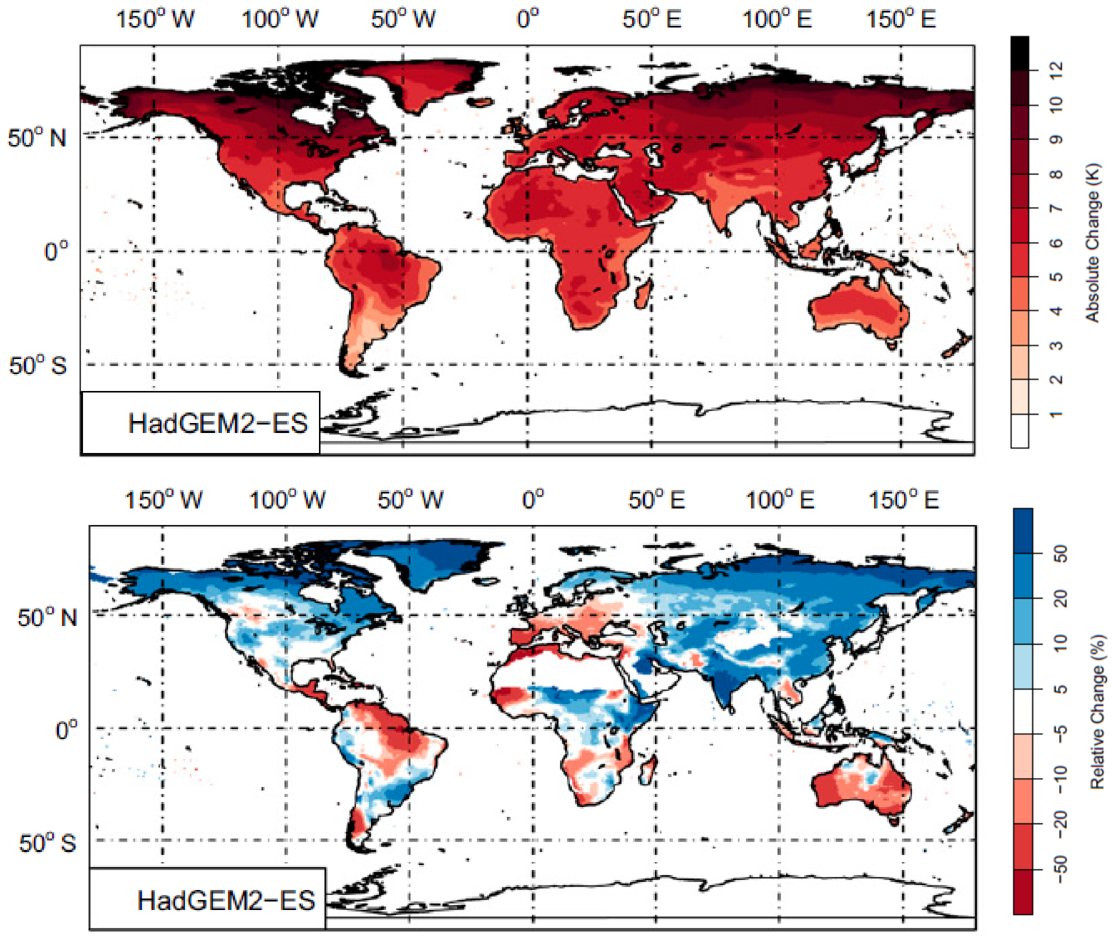

Figure 8. Difference in average surface air temperature (absolute change in Kelvin) and relative difference in average annual rainfall of the century (2070–2099) and present-day (1980–2010) under RCP8.5 in HadGEM2-ES (Warszawski et al., 2014).

2.3.3 Quantified scenarios – global drivers of EU land use

To quantify the impact of global drivers of change on global and European land use, we quantify a set of macro-economic and climatic drivers. We chose three macro-economic scenarios (SSP1, SSP2 and SSP3) and one climate scenario (RCP 8.5 from the HadGEM2-ES circulation model) described above. The climatic effects from HadGEM2-ES - RCP 8.5 were handed over to EPIC (a global gridded crop model) which in turn delivered crop specific yield projections and impacts on grasslands to GLOBIOM. To quantify drivers of EU land use, six scenarios have been quantified in GLOBIOM which are presented in Table 3.

Table 3. Prospective scenarios used for the quantification of global drivers of EU land use in GLOBIOM.

Scenario code	SSP	RCP	GCM	Crop model	Crop productivity growth 2000/2050	GDP growth 2000/2050	Population growth 2000/2050
S1	*SSP1*	*None*	*None*	*None*	79%	330%	38%
S2	*SSP2*				70%	221%	52%
S3	*SSP3*				51%	128%	68%
S4	*SSP1*	*RCP 8.5*	*HadGEM2-ES*	*EPIC*	60%	330%	38%
S5	*SSP2*				53%	221%	52%
S6	*SSP3*				35%	128%	68%

3 RESULTS AND DISCUSSION

In this chapter, GLOBIOM results until 2050 are presented and discussed for the scenarios presented above. First, we start with the analysis of the macro-economic drivers in section 3.1 before climate change impacts are discussed in more detail in section 3.2.

3.1 Impact of macro-economic drivers

3.1.1 Consumption

Total change in human consumption of agricultural commodities is the result of change in consumption per capita and in the size of the population. Global average daily calorie intake per capita (animal and vegetal) is projected to increase the most under SSP2 (Figure 9). Average calorie intake would be 13% higher in 2050 compared to 2000 mainly driven by real GDP growth. In contrast, under SSP3 global consumption of calories per capita is projected to increase only slightly by 2% compared to 2000. This is related to lower GDP growth rates and at the same time higher commodity prices caused by slower rates of technical progress in the agricultural sector. In SSP1, calorie intake per capita is slightly below SSP2 as a shift to more sustainable diets decreases calorie intake in developed countries.

Consumption levels differ substantially across regions. While average consumption levels are already high in Europe (EUR) in 2000, they are substantially lower in Africa and the Middle East (AFM). In SPP1, calorie intake is lowest in Europe due to dietary changes compared to SSP2 and SSP3. For the AFM region the opposite is projected: calorie intake would be the highest under SSP1 since GDP growth and high technical progress rates make food more affordable for larger shares of the population, while low GDP growth and low technical progress rates under SSP3 keep average calorie consumption almost at 2000 levels.

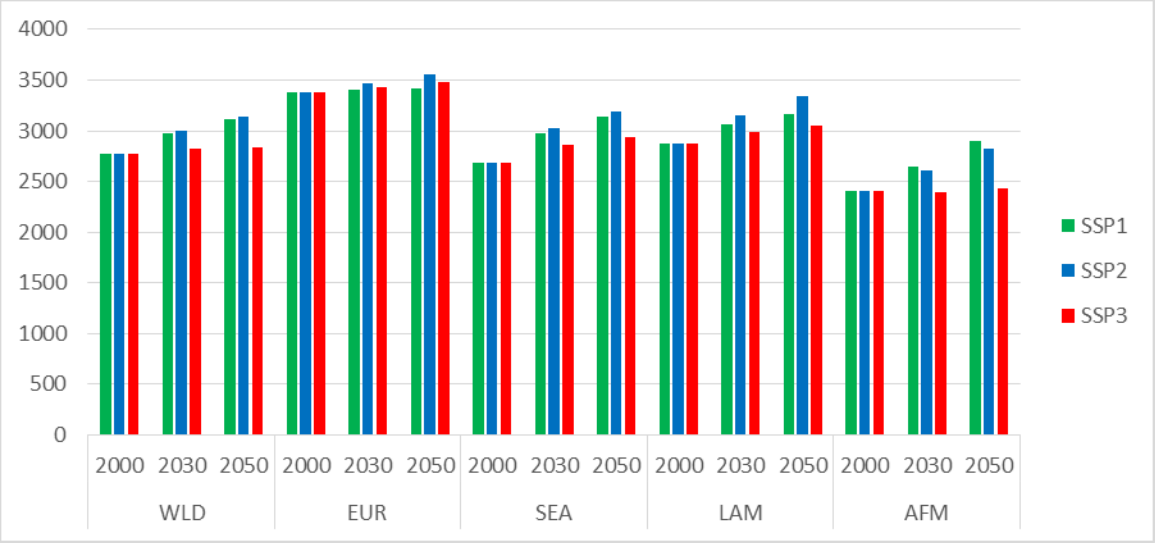

Figure 9. Food consumption per capita (kcal/capita/day). WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

Total food consumption values are presented in Figure 10. Overall, lower per capita growth rates observed under SSP3 are overcompensated by population growth effects. Thus, total consumed calories are similar between SSP2 and SSP3 in 2050. However, under SSP3 the total has to be shared by a larger world population.

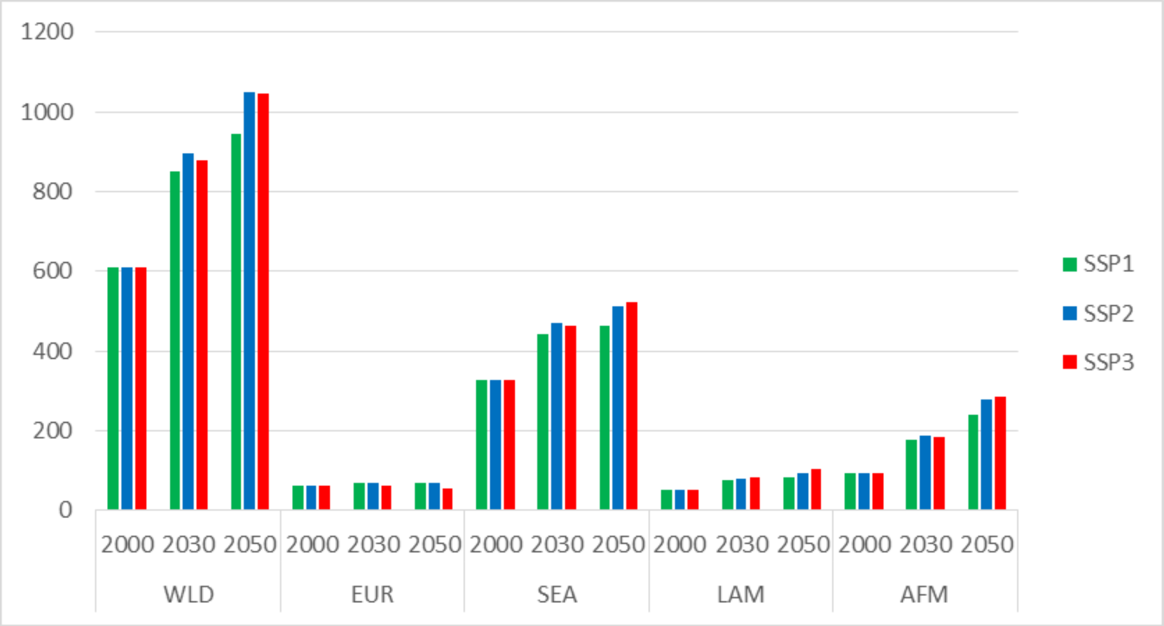

Figure 10. Total food consumption (petacalories). WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

3.1.2 Prices

The strongest price increases at the global level for both crops and livestock products can be observed for SSP3 (Figure 11, Figure 12). This reflects that under SSP3 the highest scarcity of agricultural commodities appears, caused by strong demand effects due to high population growth in combination with only moderate productivity changes. In SSP2, GDP growth rates also boost demand until 2050. However, world market prices increase to a much lesser extent compared to SSP3 related to higher productivity increases. In SSP1, average prices even decline at global level until 2050. Low population growth rates and sustainability considerations in Western diets on the demand side as well as high technical progress on the supply side relax the situation on agricultural markets. Across world regions the highest price increases can be observed in Africa where productivity gains are overcompensated by rising demand through significant population and GDP growth.

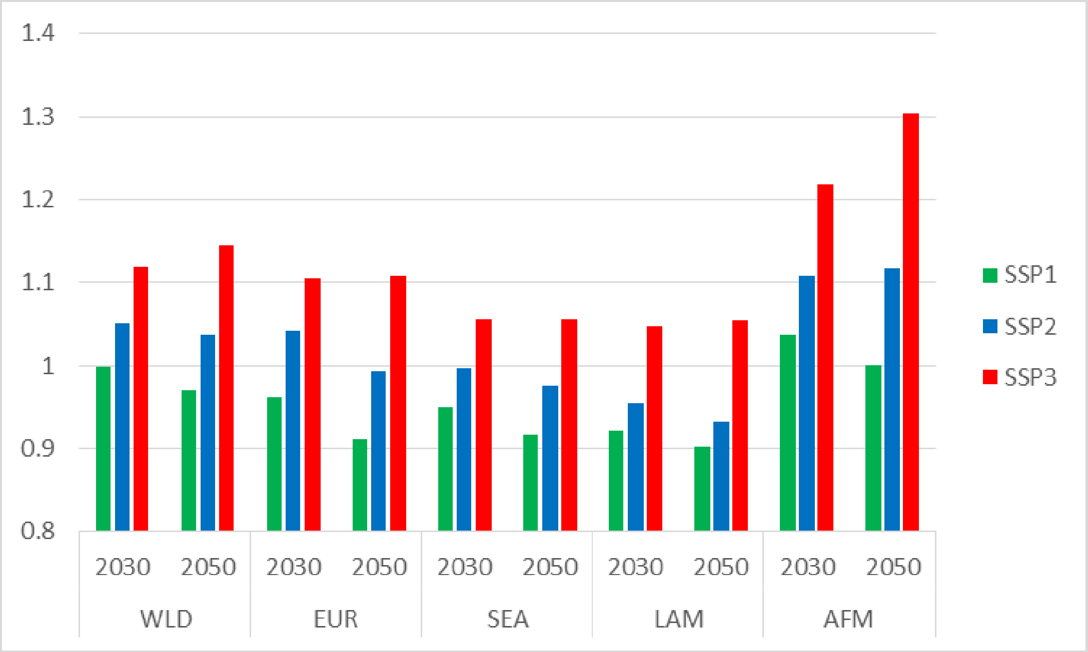

Figure 11. Crop price index (2000 = 1); Real prices. WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

In general, price effects on livestock product markets are projected to be stronger than price effects for crops. From a regional perspective, the highest price increases can be observed in Africa and the Middle East for all SSPs for both livestock and crop products.

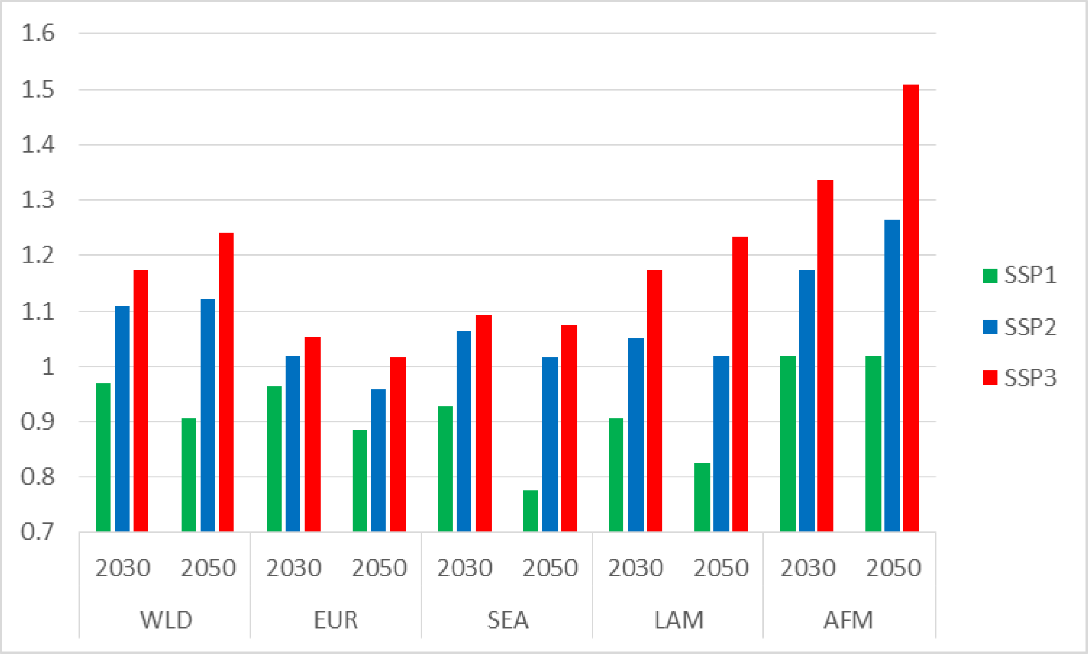

Figure 12. Livestock product price index (2000 = 1); Real prices. WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

3.1.3 Land use and land use change

Additional demand for agricultural commodities can be met by increasing production via two channels: 1) intensification of production on land already under agricultural use or 2) expansion of agricultural production area into other land cover types.

Figure 13 depicts land use changes on a global level and for selected regions. In general, it can be observed that in all presented regions mainly forest and other natural land (NatLnd) is converted to agricultural land to enable the additional production of crops, livestock products and bioenergy feedstocks. At the global level, the highest expansion of agricultural land until 2050 can be observed under SSP2. Almost 600 million hectares (Mha) of agricultural land are additionally taken into production compared to 2000. Almost half of this additional area is converted to grassland (276 Mha GrsLnd), while additional cropland (CrpLnd) amounts to 160 Mha and 150 Mha are reallocated to the production of short-rotation tree plantations (PltFor) providing biomass for bioenergy production.

While land use changes are similar in SSP2 and SSP3, they are significantly smaller under SSP1. This can be explained by higher rates of technical change and a lower total demand due to low population growth and a switch to more sustainable diets until 2050. Consistently, global deforestation is lowest in SSP1 (131 Mha) in absolute levels, compared to 259 Mha in SSP2 and 252 Mha in SSP3. However, under SSP1 60% of the area additionally taken into agricultural production formerly was forest area, while in the other SSPs the share is only 44%.

Strong differences can be observed from a regional perspective. In Europe only very small land use change effects are projected. The largest amount of land additionally taken into agricultural production is used for production of short-rotation tree plantations for bioenergy production at the expense of other natural vegetation (around +13 Mha across SSPs until 2050). While in SSP1, expansion of short rotation tree plantations takes place on spared cropland (-14 Mha) due to high productivity growth in the agricultural sector which allows the preservation of other natural vegetation, in SSP2 and SSP3 other natural vegetation decreases by around 15 Mha. Forest area and managed grassland area (+3 Mha in SSP1 and SSP2, -1 Mha in SSP3) remains more or less stable across scenarios until 2050.

In contrast to Europe, major land use changes take place in Asia, Latin America, and Africa. Under SSP1, 54% of global deforestation is projected to take place in Sub-Saharan Africa, while under SSP2 and SSP3 the share is 37% and 28%, respectively. The total amount of deforested area is relatively stable in Sub-Sahara Africa across the SSPs. A different picture appears for Latin America: deforestation roughly triples in SSP2 and SSP3, compared to SSP1. While in SSP1 only 28% of the deforested area is located in Latin America, the share increases to 45% under SSP2 and 54% under SSP3.

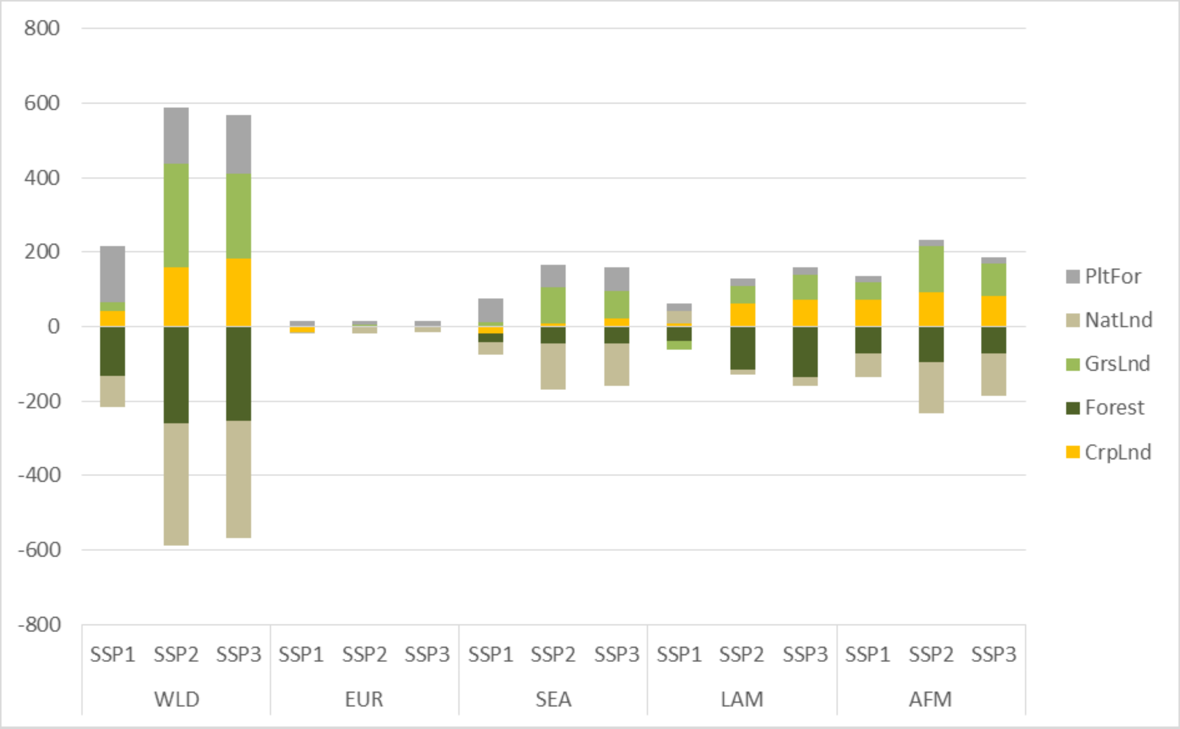

Figure 13. Cumulative land use change 2000 – 2050 (in million hectares). WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

Intensification effects can also be observed until 2050. Overall, it can be differentiated between exogenously implemented productivity changes (Table 3 and section 2.3.1.3) and model endogenous yield responses due to reallocation of production across individual simulation units and shift in management system. In SSP1, exogenous yield growth rates are usually higher than total yield, which implies negative endogenous crop yield changes while in SSP2 and SSP3 endogenous effects are mostly positive. This may be explained by the fact that due to high agricultural prices and demand (SSP2 and SSP3) best available resources are allocated to agricultural production. Furthermore, higher technological progress rates (as under SSP1) may increase the possibilities to produce on former marginal land.

3.1.4 GHG emissions

At global level, net GHG emissions (crop- and livestock production, land use change and fossil fuel substitution from bioenergy production) are clearly the lowest in SSP1 (Figure 14) while the highest net GHG emissions are projected in SSP2. This is consistent with the observed land use change effects presented in Figure 13. In all SSPs, the largest share of GHG emission can be traced back to the production of crops, followed by emissions caused by livestock production. However, until 2050 emissions from land use change increase the strongest.

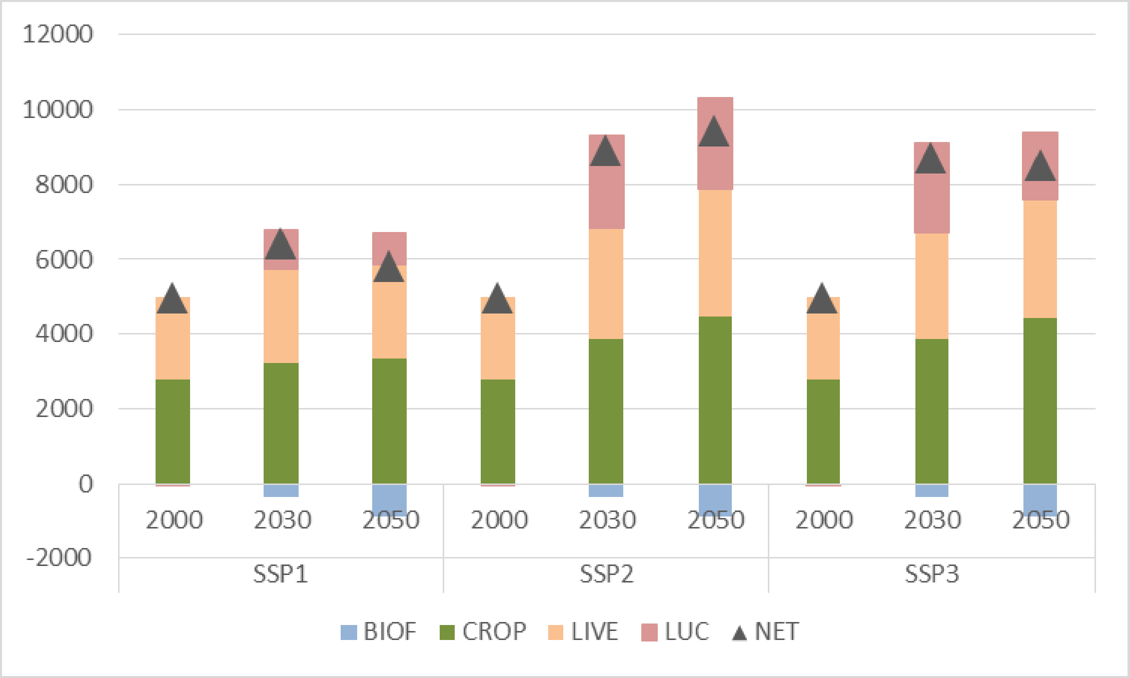

Figure 14. Global GHG emissions (in million tons CO_2 eq). BIOF- fossil fuel substitution from bioenergy production, CROP – crop sector emissions, LIVE – livestock sector emissions, LUC – land use change emissions, NET – total emissions.

In Europe, net emissions appear to be relatively constant over time in all SSPs. Nevertheless, in SSP1 there is a slight tendency towards decreasing emissions while in the other two SSPs emissions are projected to slightly increase until 2050 as emissions from crop production increase related to lower efficiency gains.

3.2 Climate change impacts

In this section, impacts of climate change on agricultural markets and on land use will be discussed for the three SSPs. At the global level, climate change is projected to have on average negative impacts on yields (Table 3). As a result, costs of agricultural production increase, global production decreases and world market prices increase (Figure 15). However, in single regions climate change may positively impact yields resulting in an increase in agricultural production and decreasing prices. These effects can be observed for example in Europe under SSP1 and SSP2 (Figure 17).

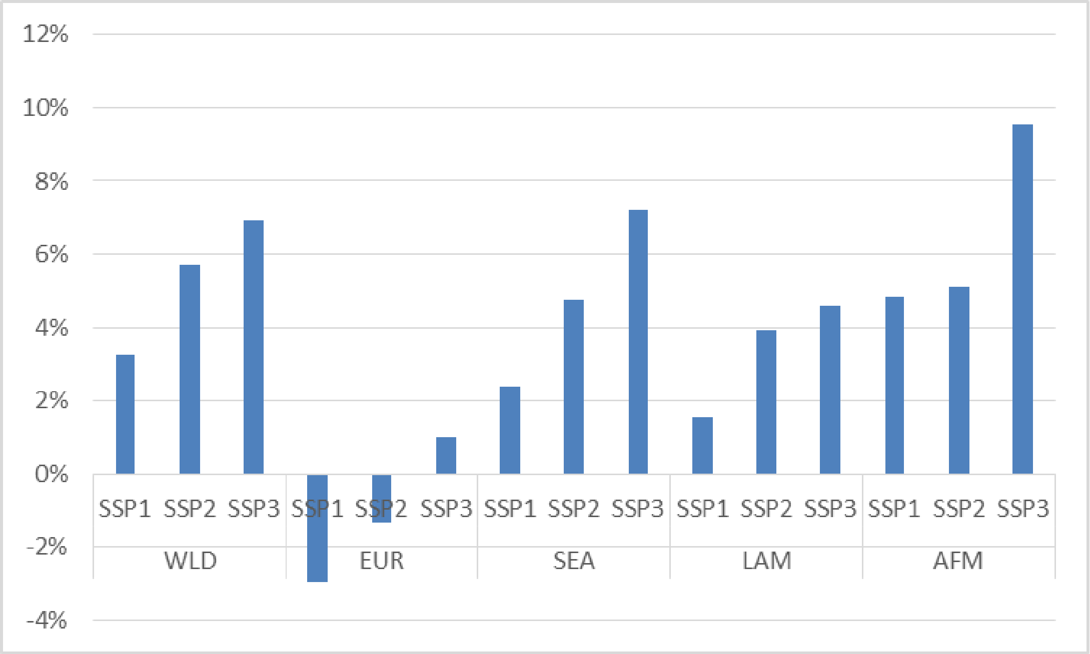

Figure 15. Real crop price changes (in %) of the climate change scenarios in 2050, compared to projections without climate change in 2050 for SSPs and selected regions. WLD – World; EUR – Europe; SEA – South, East and South East Asia; LAM – Latin America; AFM – Africa and Middle East.

Climate change drives production costs up and world market prices increase, resulting in a decrease in global consumption levels. At global level, crop production (and consumption) decrease by around 1.8% in SSP1 and 2.7% in SSP2 and SSP3.

Effects on global land cover change are presented in Figure 16. In general, a relatively stable pattern appears regarding impacts of climate change on global land cover in SSP2 and SSP3. Due to climate change more cropland is taken into production compared to a situation without climate change until 2050 (SSP2: 19 Mha additional cropland due to climate change; SSP3: 35 Mha) to compensate for production losses due to yield decreases. Grassland area declines compared to a situation without climate change (SSP1: 109 Mha less grassland due to climate change; SSP2: 72 Mha; SSP3: 177 Mha less) due to productivity increases and reallocation of livestock productions across regions and livestock systems. Climate change drives additional deforestation across SSPs (SSP1: 58 Mha; SSP2: 31 Mha; SSP3: 24 Mha) while at the same time loss of other natural vegetation decreases as grassland expansion is limited.

In Europe, land cover change effects are comparably low under all SSPs. The strongest climate change impacts can be observed in SSP3, where 2.4 Mha less grassland are taken in production and cropland area is expanded by 1.5 Mha due to climate change. With a rather stable area for short rotation tree plantations (-0.4 Mha) and forest, other natural land increases by 1.4 Mha.

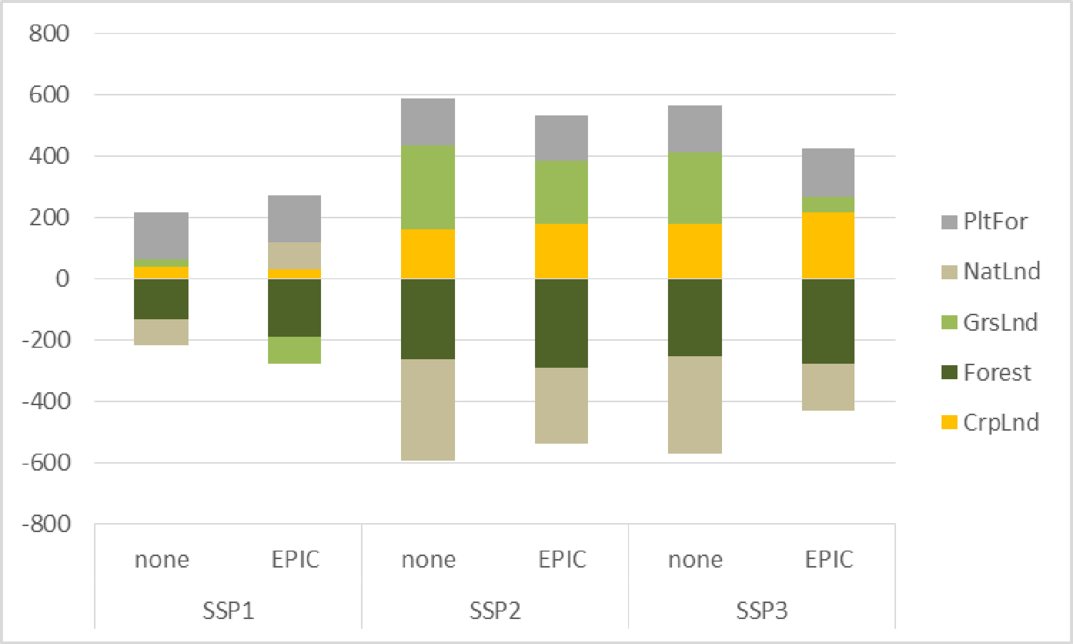

Figure 16. Global cumulative land cover changes 2000 – 2050 (in million hectares) with and without climate change effects.

4 CONCLUSIONS

In our report we identified global drivers of land use and land use change and presented prospective scenarios which have been developed to quantify these drivers. A quantitative assessment of the drivers was undertaken by application of the GLOBIOM model. Furthermore, climate change impacts on crop- and grassland yields as projected by the EPIC crop model were assessed. GLOBIOM is a global economic land use model and has been extensively compared with other global agricultural sector models in AgMIP (Agricultural Model Intercomparison and Improvement Project) (Nelson et al., 2014; Schmitz et al., 2014; Valin et al., 2014; von Lampe et al., 2014).

Different shared socio-economic pathways provide different future assumptions on global drivers of land use change. Under SSP1 a sustainability scenario is provided with relatively high levels of GDP growth, lower levels of population growth, fast technological growth, convergence between developed and developing countries, and sustainability concerns in consumer behaviour. Under SSP2 a middle of the road scenario is presented with an assumed business as usual development and continuation of current trends. Under SSP3 opposite tendencies to SSP1 (such as relatively slow economic growth, sustained population growth) are assumed.

The highest price increase among the SSPs for agricultural products can be observed in SSP3 which reflects the high scarcity of agricultural commodities due to high population growth and low rates of technical change in the agricultural sector. Under SSP1, low population growth and sustainable diets with less meat on the demand side and high technical growth rates on the supply side lead to the lowest price increases at the global level across the different SSPs. The middle of the road scenario under SSP2 shows the highest crop production quantities. Prices increase more compared to SSP1 because of higher population growth, a less sustainable diet and lower rates of technical change, but less compared to SSP3.

In terms of land use change, SSP2 shows the highest expansion of agricultural land until 2050. In general, it can be observed that under all SSPs forest and other natural land is converted to agricultural land to enable the additional production of crops, livestock products and bioenergy carriers. Different land use change patterns can be observed from a regional perspective. In Europe only small land use change effects are projected while Asia, Latin America, and Africa all are projected to bear large shares of land use changes. The major shares of deforestation are projected to take place in Latin America and in Sub-Saharan Africa.

The climate change impacts taken into account are derived by the crop model EPIC and show negative average yield effects at the global level for the crop sector. However, grassland productivity increases slightly due to climate change. Consequently, global crop production is projected to decrease and world market prices increase due to climate change effects across SSPs. However, in single regions climate change might have a yield increasing effect on agricultural production and increase regional supply. Overall, climate change drives additional deforestation as more cropland comes into production to buffer the negative climate change impact on crop yields. However, due to increase of grassland productivity and reallocation of livestock production across regions and livestock systems, grassland areas decrease in all SSPs compared to a situation without climate change resulting in less conversion of other natural vegetation.

To conclude, we achieved to successfully identify important drivers of EU land use and implement a consistent set of scenarios taking into account both climate change and socio-economic drivers in GLOBIOM. This is a first important step towards the ultimate goal of work package two of the TRUSTEE project which is to quantify global drivers of land use dynamics and provide prospective scenarios of future land use changes in the EU at different scales.

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TRUSTEE

Towards **Ru**ral **S**ynergies and **T**rade-offs between
Economic Development and **E**cosystem Services

The TRUSTEE project in a nutshell

Title	Towards Rural Synergies and Trade-offs between Economic Development and Ecosystem Services
Project coordinator	Cécile Détang-Dessendre, INRA UMR Cesaer (Dijon, France)
Grant Agreement	235175 RURAGRI (ANR- 13-RURA-0001-01)
Funding Scheme	RURAGRI ERA-NET, European Commission 7th Framework Programme
Total cost	2,6 M€
Duration	2013 – 2016 (36 months)
Short description	The trade-off/synergy dilemma between economic development and ecosystem services is one of the major issues of sustainable rural development. The main research objective of TRUSTEE is to disentangle the complex relationships between economic development and ecosystem services at different spatial scales using an interdisciplinary approach that involve scientists, experts, and stakeholders. The sub-objectives are: - Analyse the multi-scaled determinants of economic development and ecosystem services on a large European gradient of rural and rural/urban areas. - Increase our understanding of how to achieve mutual benefits for economic development in rural areas and ecosystem services. - Identify and assess the governance mechanisms and policy instruments that enhance sustainable rural vitality in very diverse contexts. - Produce synergies among international researchers of varied disciplines and between researchers and various stakeholders at different governance scales.
Consortium	16 partners from 8 European countries
Read more	http://www.trustee-project.eu/

RURAGRI ERA-NET

SEVENTH FRAMEWORK PROGRAMME

AGENCE NATIONALE DE LA RECHERCHE ANR