ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

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DELIVERABLE 2.2

Deliverable title: Preliminary scenarios of the developments in agricultural commodity markets, livestock production systems, and land use and land cover

Abstract: This report provides a first version of quantified scenarios for the livestock sector both at the global level and for the project regions. These scenarios are based on storylines presented in the deliverable 2.1 and hence are consistent with the Shared Socio-economic Pathways (SSPs) developed as part of the new scenarios for IPCC AR5. The analysis is carried out using the global agricultural and forestry sector economic model GLOBIOM. Impacts of the different storylines on agricultural markets, livestock production systems, land use and land use change, and greenhouse gas emissions are reported.

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1 Introduction

The livestock sector accounts for 30% of global land area and is a major driver of land use change (Geist and Lambin 2002). Steinfeld et al. (2006) calculated that deforestation due to expansion of pasture and feed crops was responsible for 8% of total anthropogenic CO_2 emissions. In addition, methane emissions from enteric fermentation and manure management accounted for 32% and 7%, respectively, of agricultural sector non-CO_2 emissions (US-EPA 2006). Due to continued population and economic growth, the total demand for calories from animal origin is projected to double by 2050 (Alexandratos et al., 2006). Large-scale forward looking quantitative assessments agree that either consumption has to be reduced or considerable productivity gains must be achieved to ensure sustainability of the agricultural sector in general, and of the livestock sector in particular (Bouwman, 2005; Stehfest et al., 2009; Popp et al., 2010; Wirsenius et al., 2010).

Alternative storylines including assumptions about human diet preferences and technological change in the agricultural sector have been elaborated in deliverable D2.1 earlier in this work package. These AnimalChange storylines have been constructed around the Shared-Socioeconomic Pathways (SSPs, O'Neill et al. 2012) developed themselves as the backbone of the scenario work to be presented in the IPCC 5th Assessment Report (AR5). The SSPs provide quantitative information on future population and gross domestic product (GDP), and semi-quantitative information on technological change and consumer preferences which has been converted in numbers as part of D2.1. Here, we quantify the effects of the different storylines on agricultural markets, land use and land cover, livestock production systems, and greenhouse gas emissions, at the horizon of 2030 and 2050. The analysis is carried out with the global partial equilibrium model GLOBIOM (Havlík et al. 2011). Although the results could be presented for each of the 30 world regions represented in the model individually (EU27 is split in 5 regions), we decided for these preliminary scenarios to present them at the level of four region aggregates – World, Europe, Latin America, and Africa&MidEast[1] which are relevant for the AnimalChange project.

The report is structured as follows: in Section 2, we briefly introduce the modelling tool, in Section 3 we discuss the values of the major scenario drivers, and Section 4 presents the scenario results. Finally, we summarise and discuss the limits of these preliminary results, as well as suggest further developments in Section 5.

2 Modeling tool: GLOBIOM

2.1 General overview

The Global Biosphere Management Model (GLOBIOM) is a partial equilibrium model that covers the agricultural and forestry sectors, including the bioenergy sector. It is used for analyzing medium- to long-term land use change scenarios. In GLOBIOM, the world is divided into 30 economic regions, in which a representative consumer is modeled through a set of isoelastic demand functions. The spatial resolution of the supply side relies on the concept of Simulation Units, which are aggregates of 5 to 30 arcmin pixels belonging to the same altitude, slope, and soil class, and also the same country. For crops, grass, and forest products, Leontief production functions covering alternative

[1] Europe – EU27 + Balkan countries + Iceland, Norway and Switzerland, Latin America – Central and South America incl. Mexico, Africa&MidEast – Sub-Saharan Africa, North Africa, Middle East and Turkey.

production systems are calibrated based on biophysical models like EPIC (Williams et al. 1995). For the present study, the supply side spatial resolution was aggregated to 120 arcmin (about 200 x 200 km at the equator).

Economic optimization is based on the spatial equilibrium modeling approach (Takayama and Judge 1971). The price-quantity equilibrium is computed a la McCarl and Spreen (1980) at the regional level. The model is calibrated to year 2000 FAOSTAT activity levels and is then recursively solved in 10-year time steps.

2.2 Livestock sector

GLOBIOM incorporates a particularly detailed representation of the global livestock sector (Havlík et al. forthcoming). With respect to animal species distinction is made between dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs. Livestock production activities are defined in several alternative production systems adapted from Seré and Steinfeld (1996): for ruminants, grass based (arid, humid, temperate/highlands), mixed crop-livestock (arid, humid, temperate/highlands), and other; for monogastrics, smallholders and industrial. For each species, production system, and region, a set of input-output parameters is calculated based on the approach in Herrero et al. (2008). Feed rations are defined consisting of grass, stovers, feed crops aggregates, and other feedstuffs. Outputs include four meat types, milk, and eggs, and environmental factors (manure production, N-excretion, and GHG emissions). The initial distribution of the production systems is based on Robinson et al. (2011). Switches between production systems allow for feedstuff substitution and for intensification or extensification of livestock production.

2.3 Land use change

Six land cover types are distinguished in GLOBIOM: cropland, grassland, short rotation tree plantations, managed forest, unmanaged forest and other natural vegetation. Depending on the relative profitability of the individual activities and on the inertia constraints, the model can switch from one land cover type to another. Comprehensive greenhouse gas accounting for agriculture and land use change is implemented in the model. Detailed description of these accounts and other additional background information are provided in Havlík et al. (2011) and Mosnier et al. (2012).

3 Drivers of change

AnimalChange scenarios are constructed around the two basic elements constituting the new (AR5) IPCC scenarios – Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs). SSPs provide the socio-economic framework under which different climate scenarios develop. The two parts were separated in the scenario development phase and hence SSPs do not contain any assumptions about climate change and one RCP can be potentially matched with several SSPs. This leads to a matrix of potentially up to 20 scenarios. In this first step, we will focus on quantification of the effects of the storylines developed based on the SSP assumptions in D2.1, and we will leave for a later stage the assessment of the climate scenario effects. Three SSPs out of five are considered: SSP1 - featuring relatively high levels of economic growth, lower levels of demographic growth, high levels of education, international cooperation, fast technological growth, convergence between developed and developing countries, sustainability concerns in consumer behaviour…, SSP2 - representing business as usual development, and SSP3 featuring opposite tendencies to SSP1 – relatively slow economic growth, sustained population growth,… The positioning of these scenarios in the space of challenges to adaptation and mitigation is depicted in Figure 1.

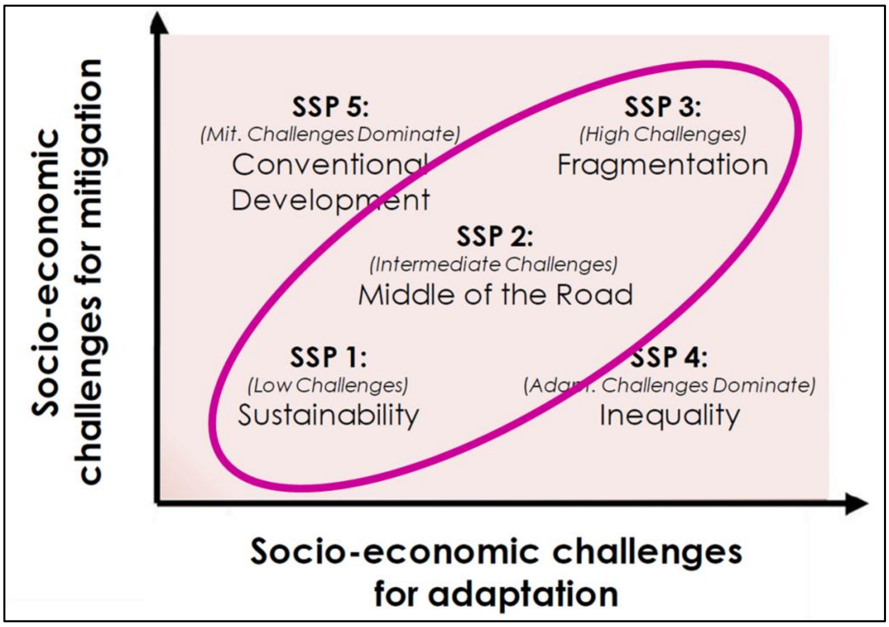

Figure 1: The scenario space to be spanned by Shared SocioEconomic Pathways, contrasting five SSPs differing in challenges for adaptation and for mitigation. Livestock storylines for SSP1 to SSP3 are being developed. (Adapted from O'Neill et al., 2012).

3.1 Macro drivers

SSP process provides quantified projections of major socio-economic drivers – population and GDP. This information is directly used in GLOBIOM. World population is projected to increase from the current 7 billion to 8, 9 and 10 billion for SSP1, SSP2, and SSP3, respectively. In Africa and Latin America, the increase is similar as at the global scale, the most important for SSP3 and the least important for 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 2).

The SSPs differ substantially in the levels of projected economic growth (Figure 3); GDP reaches globally 20 000 USD per capita by 2050 under SSP1, but does not exceed 10 000 USD per capita under SSP3. The differences in the growth rates between the scenarios are higher in developing regions (Africa, Latin America), and lower in industrialized regions (Europe).

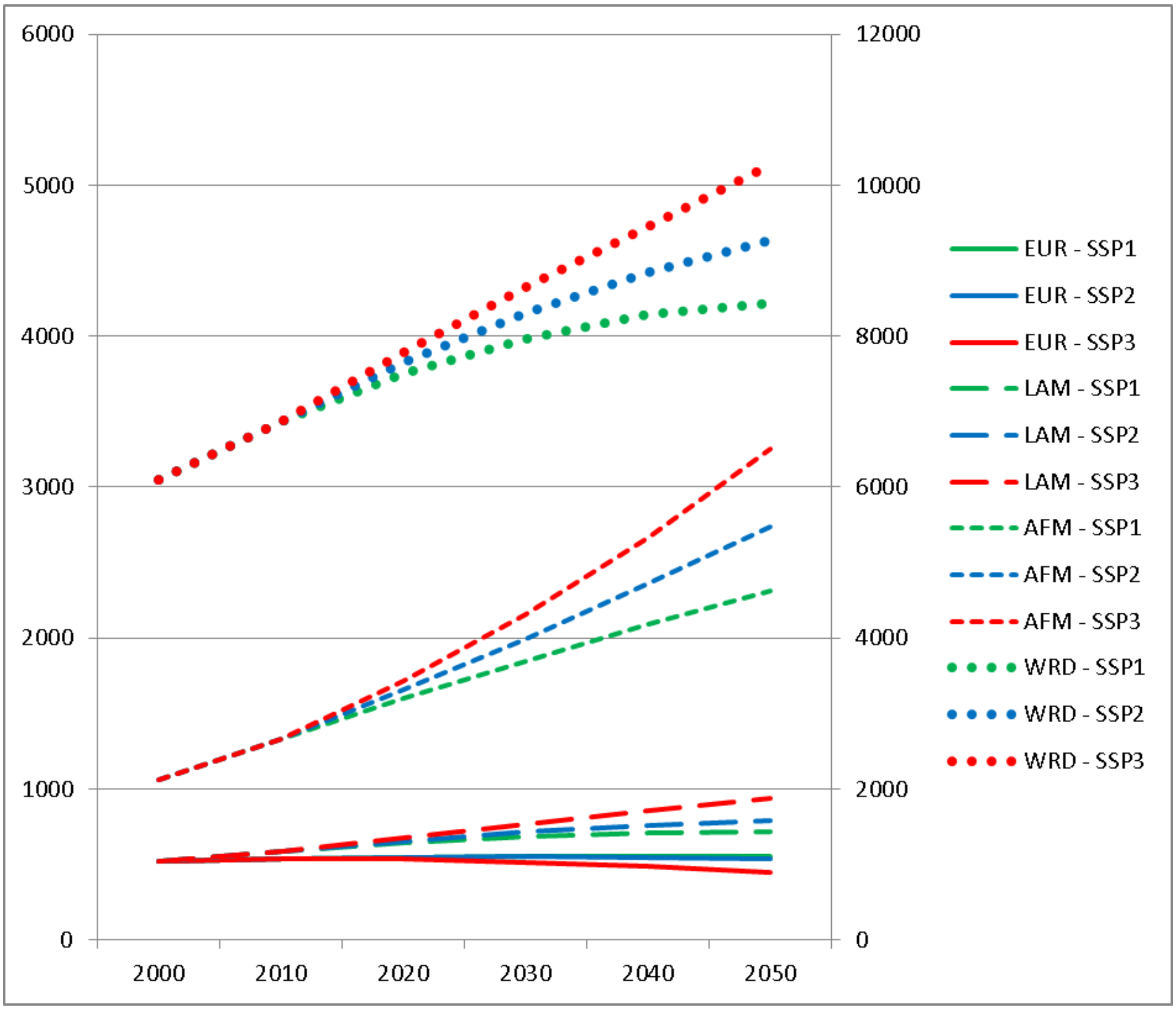

Figure 2: Population projections [Mio]. (World population numbers on the secondary axis.) Source: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=welcome

Both population and GDP growth are important drivers of future demand for agricultural commodities in general and livestock products in particular. 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.

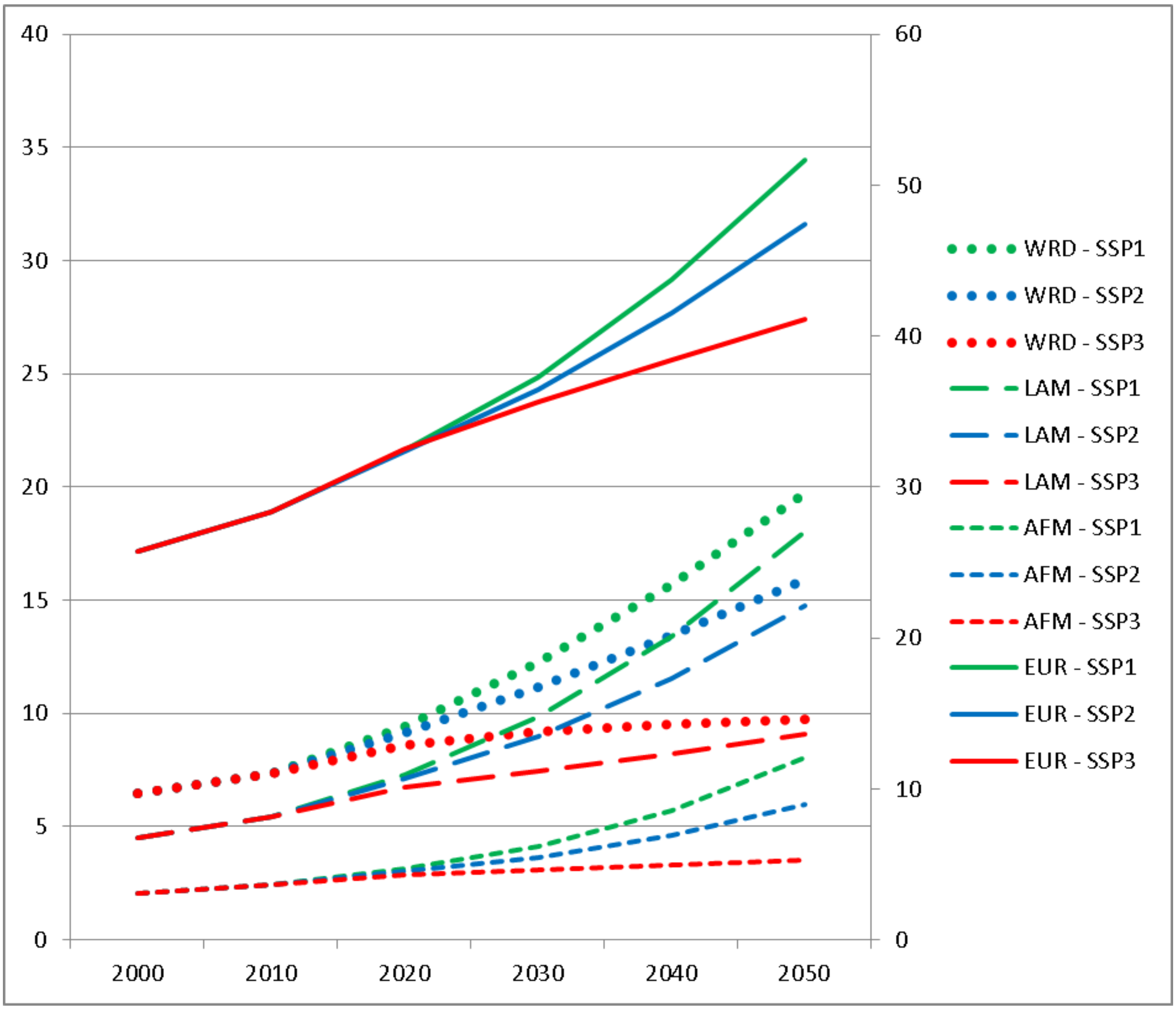

Figure 3: Projected GDP per capita in USD2005 at MER. (EUR values on the secondary axis.) Source: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=welcome

3.2 Agriculture and land use sector drivers

The general SSPs give a semi-quantitative guidance about some agricultural and land use sector related parameters. On the demand side, assumptions are provided about developments of human diet preferences beyond the conventional relationship between diets and income. On the supply side, assumptions about technological progress and its sources are of particular interest. Between the two, there is the issue of losses and wastes, which currently represent some 30% of the agricultural production (FAO, 2011) and hence could play an important role in increasing the efficiency of natural resource use. The methodology adopted to derive most of these parameters has already been exposed in the deliverable D2.1 “Storylines for the livestock sector scenarios in EU, studied SICA regions and global level”. Here, we will just briefly summarize the elements important for the analysis of the scenario results.

3.2.1 Food demand

Food demand can be influenced by many different factors in interplay at different levels (society, industrial sector, households and individual). Among the various drivers can be listed: population, income, urbanization, trade regime, agro-food market structure, retailing and marketing practices, consumer preference… (see Kearney, 2010 for overview and discussion).

In GLOBIOM, we focus on the most important factors and our 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 linearly 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.

Income effect in GLOBIOM captures the pure effect of income but also indirectly of some other patterns that reflect structural changes (urbanization, consumer changes with globalization, etc.) and cannot be disentangled for the estimation. Income elasticities used in GLOBIOM rely on two main sources: USDA elasticity dataset (Muhammad et al., 2011) and the Food Balance Sheets (FBS) from FAO. Indeed, although the USDA database provides a convenient ready-to-use set of elasticities, their values have been criticized, in particular in the case of Europe (see Abler, 2010). To complement this dataset with more accurate information, we performed regressions on the FAO FBS versus the change in income per capita on the period 1995-2005. When a robust trend was observed, the corresponding income elasticity was preferred to calibrate the initial year of GLOBIOM. This approach in particular allows for better reflection of recent observed trends (such as decrease of cereals in consumption in several regions such as Europe or China, which are not reflected with the positive elasticity estimates evaluated by USDA).

In order to project food consumption, a last assumption needs to be made on the trend of the income elasticity, to reflect the change in marginal utility associated to food consumption when a country progressively develop. To derive this parameter, we build some scenarios of future diets mainly based on FAO projections (Alexandratos et al., 2006). These scenarios are adapted to the different storylines for each modeling exercise. The general rule for developed countries is that consumption does not exceed 3600 kcal/c/d, which is slightly higher than the level of Western Europe. The only exception is the United States that show already consumption over this level and is projected until a level of 4000 kcal/c/d. It is important to note that these levels are much higher than the nutrient prescriptions (usually around 2,800 kcal/c/day for a strong and active adult, see USDA 2010), because FAO data correspond to food available for final consumer, which therefore includes domestic waste.

The assumptions were adapted to match the diet storylines for the different SSPs as follows:

- For SSP2, these future diets follow the projections from FAO at the horizon 2050.
- For SSP3, as economic growth is much lower in developing region, the income effects alone leads to a significantly lower demand per capita in these regions.
- For 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 (North America for example). Second, animal protein demand is reduced in regions where more than 75 g prot/cap/day are consumed for animal and vegetal products. A minimum consumption of 25 g prot/cap/day of animal calories is ensured but red meat consumption is reduced to 5 g prot/cap/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 at 75 g prot/cap/day and a reduction of root consumption at a level of 100 kcal/cap/day.

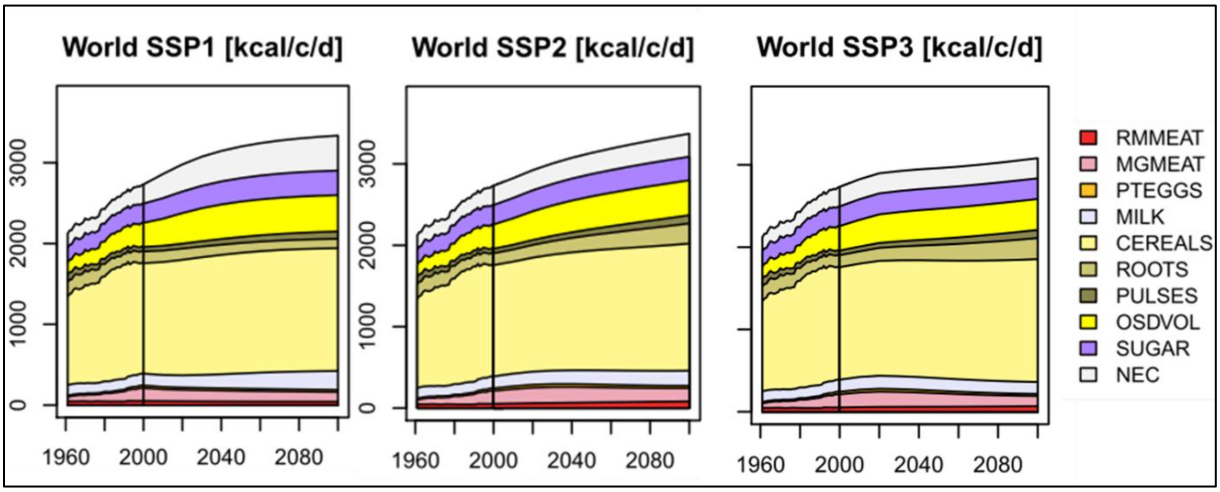

Figure 4: Per capita calorie availability for household consumption at the world level, without consideration of any price effect [kcal/capita/day].

Figure 4 illustrates the differences in future consumption patterns at the world level depending on the different GDP per capita scenarios from the SSPs. Figure 5 shows the different nutrition transitions at the world level for animal products underlying the SSP scenarios, following the IIASA interpretation of the storylines.

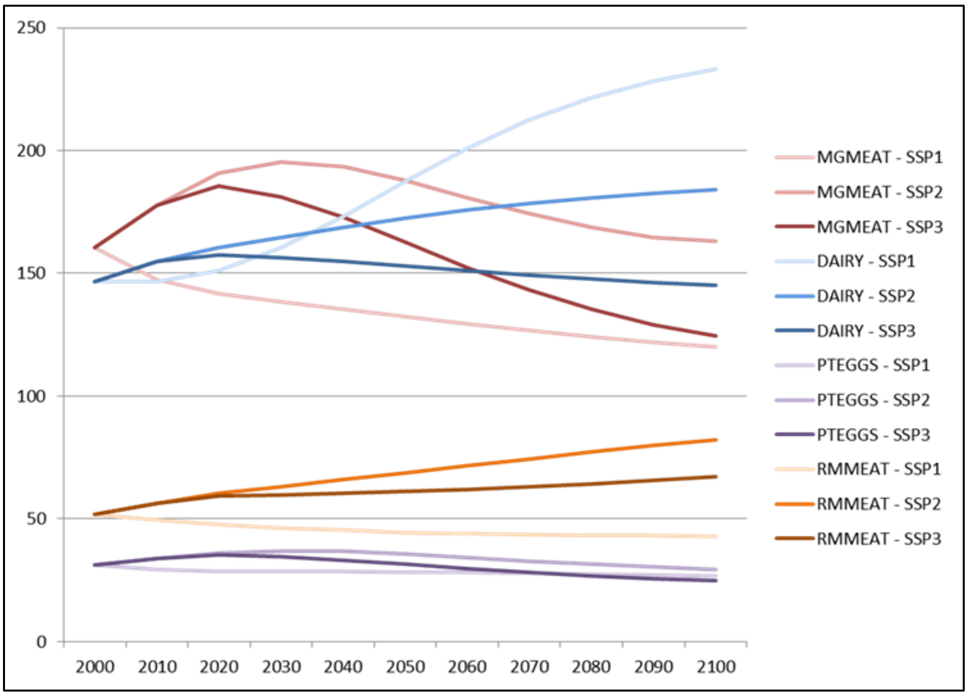

Figure 5: Food availability for household consumption at world level for several animal products across SSPs without price effects [kcal/capita/day].

3.2.2 Technological progress in crop production

Future crop yields were projected based on econometric estimation of the relationship between crop yields and GDP per capita. 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 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. Formally, the fixed effects model can be written as

$$y_{it}^{c} = \sum_{j}^{M} d_{ij}\alpha_i + \sum_{g}^{G} g_{ig}\beta_g^c\, x_{it} + u_{it}\ ,$$

where y_{it}^{c} shows the yield of country i in period t, d_{ij} denote the fixed effects (country) dummy of country i with $d_{ij} = 1\ \forall\ i = j$ and 0 otherwise, fixed effects coefficient α_i captures the countries' individual time-invariant difference, g_{ig} stands for the GDP per capita group dummy with $g_{ig} = 1\ \forall\ i \in g$ (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} denotes the unobserved error term.

The forecast was calculated for each country on the basis of its base year yield in 2005. The base year yield was the five year average yield of 2005. The increment in yield stemming from GDP per capita increase of a given scenario was then added to a country's base year yield. There is no need to account for countries' fixed effects coefficients as it is supposed that individual time-invariant country characteristics are unchanged. The forecast formula then takes the simple form

$$y_{i,FORECASTYEAR}^{C} = y_{BASEYEAR}^{C} + \beta_g^c[(\ln(GDPPC_{FORECASTYEAR}^{C}) - \ln(GDPPC_{BASEYEAR}^{C}\ )]$$

As an example for the wheat yield forecast of the U.S. the coefficient takes the value 1.785 which is the coefficient valid for all countries belonging to the high income group. The U.S. forecast for 2050 and projected GDP per capita in the SSP1 scenario is then calculated as

$$y_{U.S.,2050}^{Wheat} = 2.8(\frac{t}{ha}) + 1.785[\ln(72338) - \ln(42600)](\frac{t}{ha}) \cong 3.21(\frac{t}{ha}).$$

In cases where the estimate was either not significant or the resulting elasticity deviated by more than 25% from the historically observed elasticity at the level of GLOBIOM regions, these estimates were replaced by time series estimates, either at the country or region level. Figure 6 shows the resulting yield projections in an aggregate over all modelled crops in terms of calories produced per hectare. In the initial ranking, the highest yield are observed in Europe, followed by Latin America and Africa&MidEast. This ranking is mostly preserved over the whole simulation period although Latin America catches up with Europe under both the SSP1 and SSP2. Yields in Europe are still projected to grow by 35-50% depending on the SSP. The relative yield growth in Latin America is similar as in Africa&MidEast – 123% under SSP1, 106% under SSP2, and 66% under SSP3. For these preliminary scenarios, a simple assumption of the nitrogen intensity of the future production is been made as reported in deliverable D2.1 – proportional inctrease of nitrogen utilisation to yield growth (elasticity = 1) under SSP2, decreasing nitrogen intensity (elasticity = 0.75), and increasing nitrogen intensity (elasticity = 1.25).

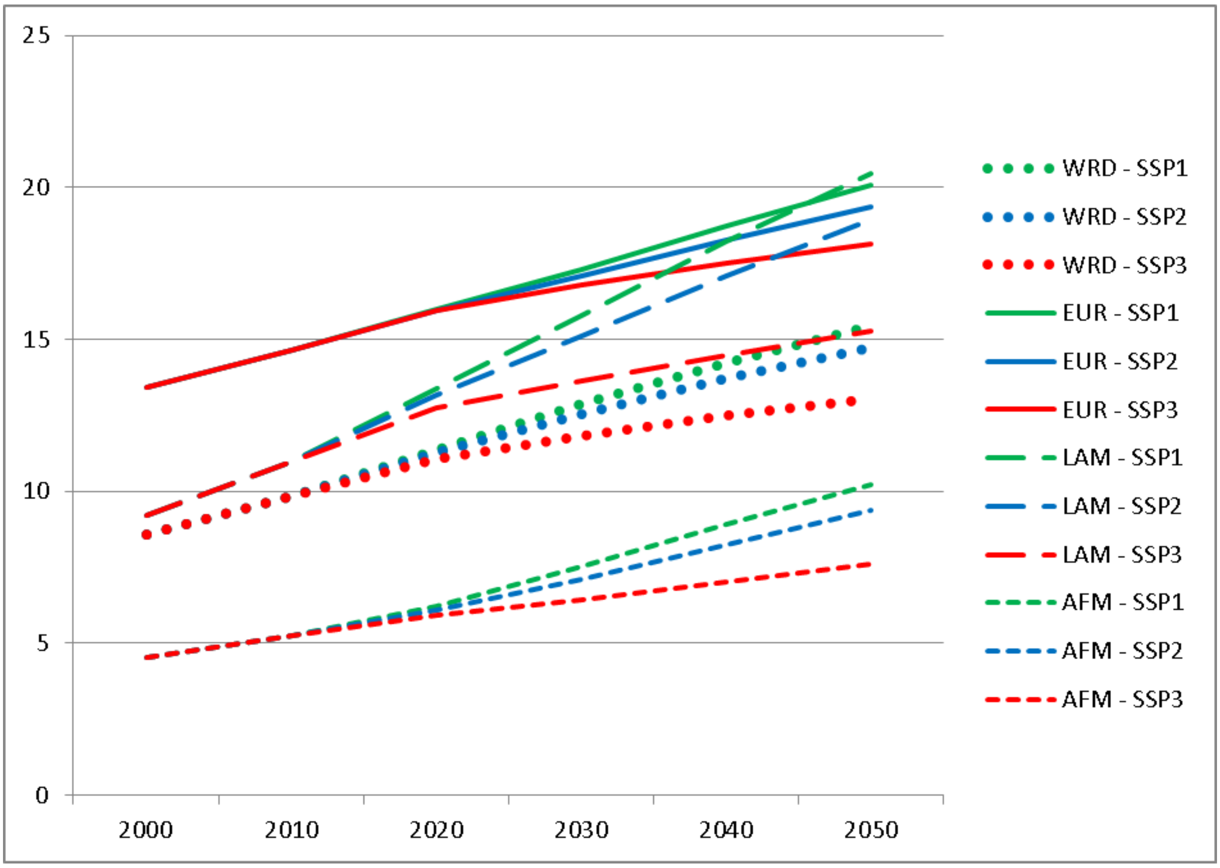

Figure6: Aggregate crop yield projections by SSP [giga calories per ha]

The yield projections were than implemented as exogenous yield shifters in GLOBIOM. However, GLOBIOM has two other sources of potential yield change: *i)* switches between crop management systems (intensive and extensive rainfed systems, and irrigated system), *ii)* re-allocation of individual crops to more or less productive fields. In order to stay as close as possible to the projected yields, which already include both these effects, we have constrained to possibility to switch between the systems for the scenario runs. However, the re-allocation in space was allowed, which will lead to slight differences between the exogenous yield projections and the yields calculated as result of GLOBIOM scenario runs.

3.2.3 Technological progress in livestock production

Productivity in the livestock sector can be specified in multiple ways. Given the data provided by FAOSTAT, the most straightforward indicator would be productivity per head. Unfortunately, this indicator tells us very little about the real resource usage. For our purposes, feed conversion efficiency (unit of product per unit of feed) appears more relevant. However, since FAOSTAT does not split feed use by product or livestock category, and also the feed coverage is not exhaustive, econometric approaches as adopted for the projections of crop yields cannot be used here. Therefore we applied a mixed approach: first, global annual rates of feed conversion efficiency increase were estimated for the livestock products from the AgRIPE fit and from Bouwman et al. (2005) for SSP2, and then regional and SSP specific annual rates of increase were calculated by scaling this central estimate by the rates of change estimated for crop yields as described above. Where necessary, a ceiling was introduced to avoid biologically infeasible values. The estimates of the global annual rates of change were a major output of the deliverable D2.1 and are described in great detail there.

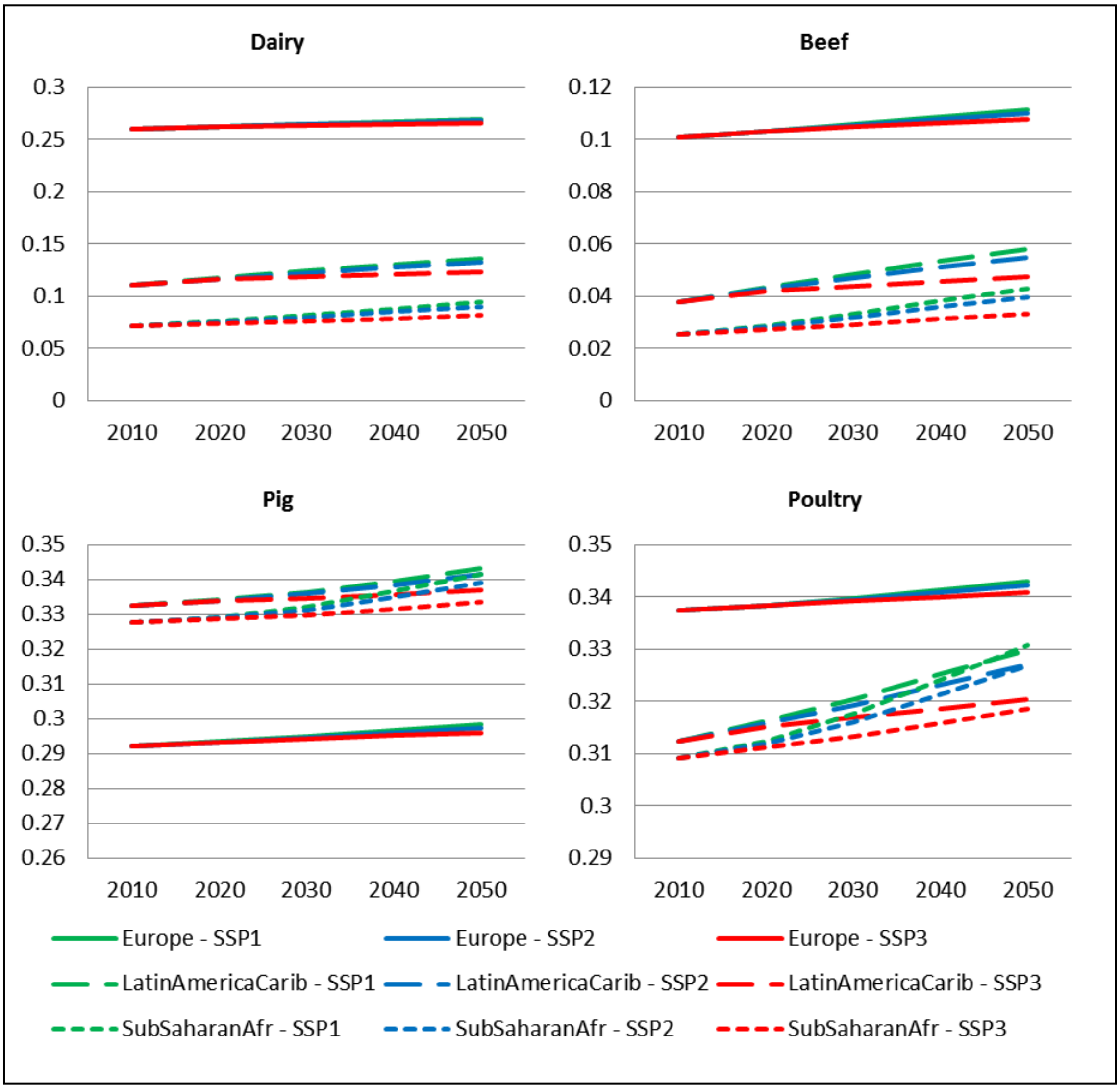

Figure 7: Projected feed conversion efficiencies [kg protein product / kg protein feed].

Feed conversion efficiency change for the period 2010-2050 reaches the highest value, +70%, in SubSaharan Africa under SSP1 (Figure 7). 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 efficincies 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 swtiches 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.

3.2.4 Losses and waste management

Losses and wastes were not explicitly represented in GLOBIOM so far. In order to take into account this important aspect which seems as another relevant AnimalChange storylines element, 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.

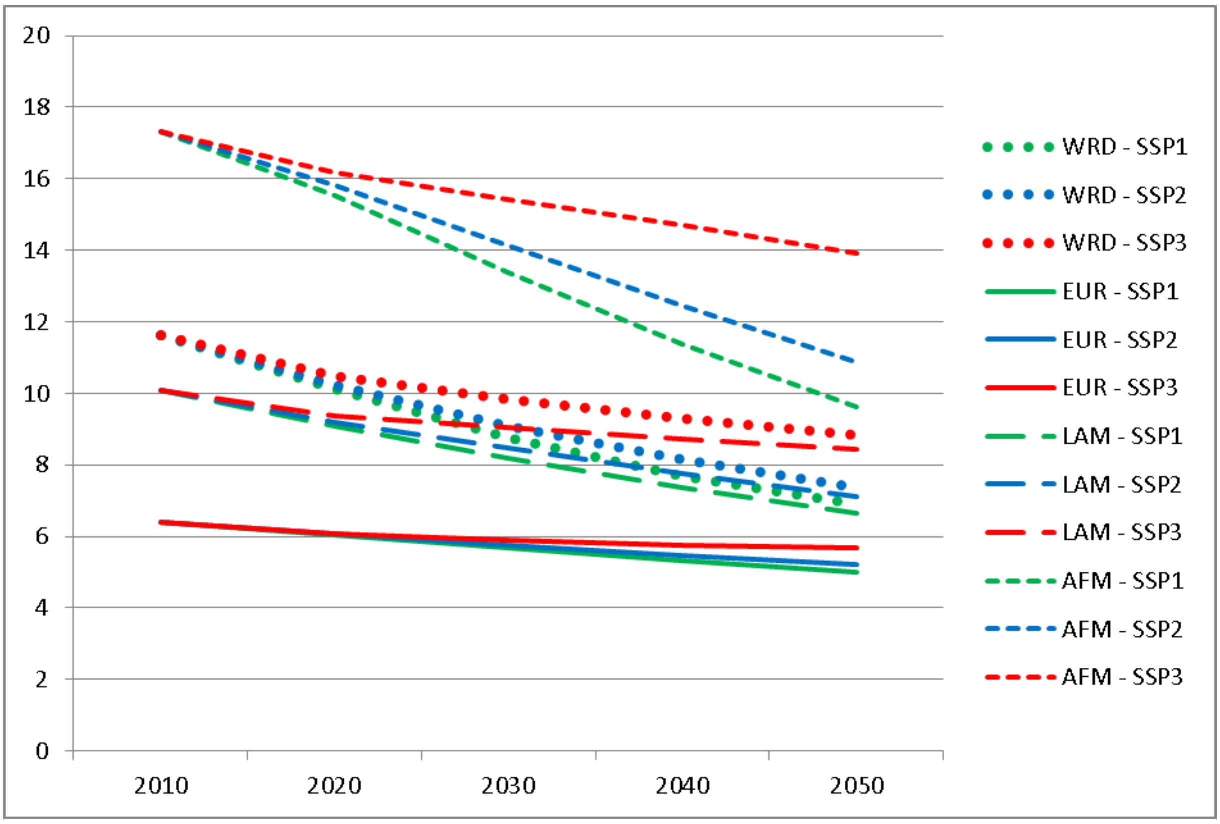

Figure 8: Losses and wastes development in the Oilseeds&Pulses sector [%].

The highest losses and wastes in the Oilseeds&Pulses sector were observed in the Africa&MidEast region, 17%, and the lowest LW were in Europe, 6% (Figure 8). Under SSP1, LW in Africa&MidEast 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&MidEast (Figure 9). 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.

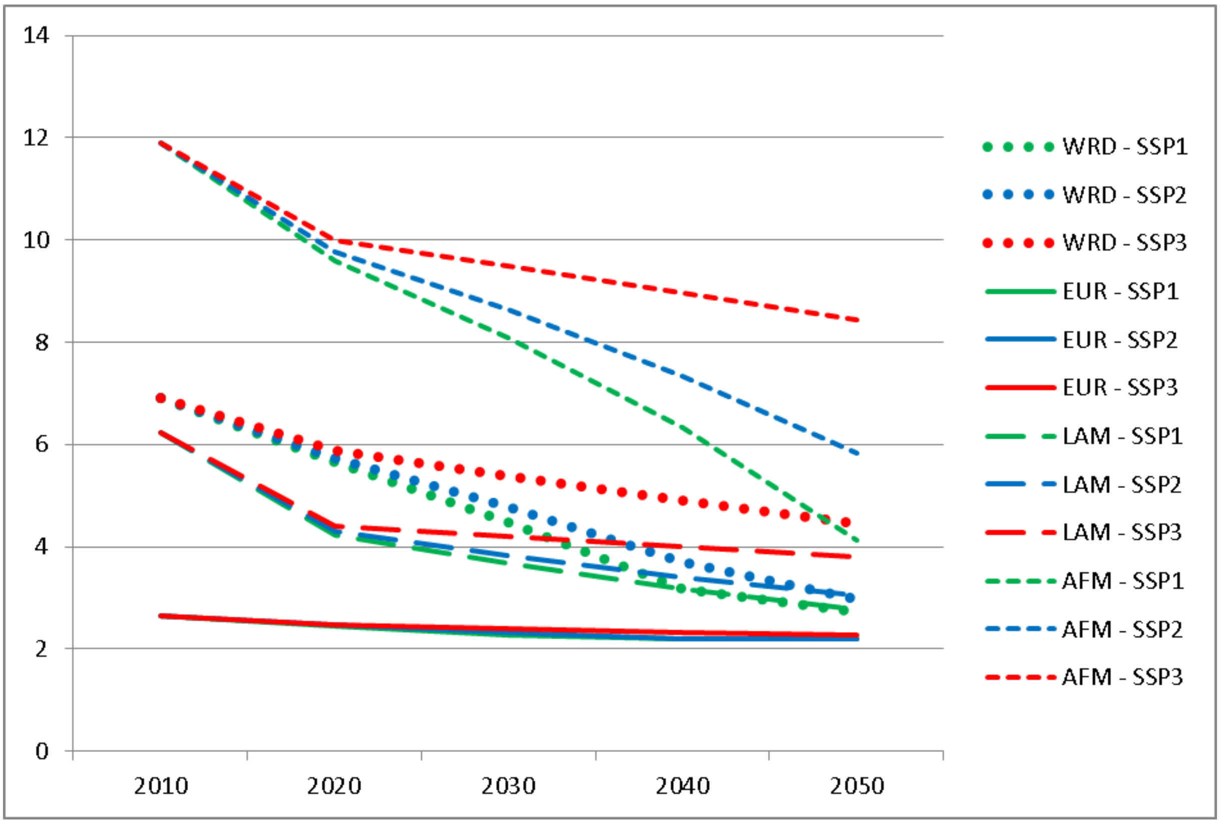

Figure 9: Losses and wastes development in the dairy sector [%].

4 Results

4.1 Agricultural markets

4.1.1 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. Globally, calorie consumption per capita would increase the most under SSP2, where it would be in 2050 by 14% higher than in 2000. Mostly, because of the lower GDP growth and lower technological progress leading to higher production cost, the calorie consumption per capita would increase by 3% only under SSP3. Total calorie consumption per capita under SSP1 would globally reach similar levels as under SSP2 but both the regional and the commodity structure would exhibit significant differences (Figure 10). With respect to the commodity structure, crop product consumption would increase by 10% and livestock product consumption by 37%, under SSP2, whereas it would be 12% and 19% under SSP1. The relative stagnation of per capita livestock product consumption hides a 2% decrease in meat consumption and a 61% increase in milk consumption.

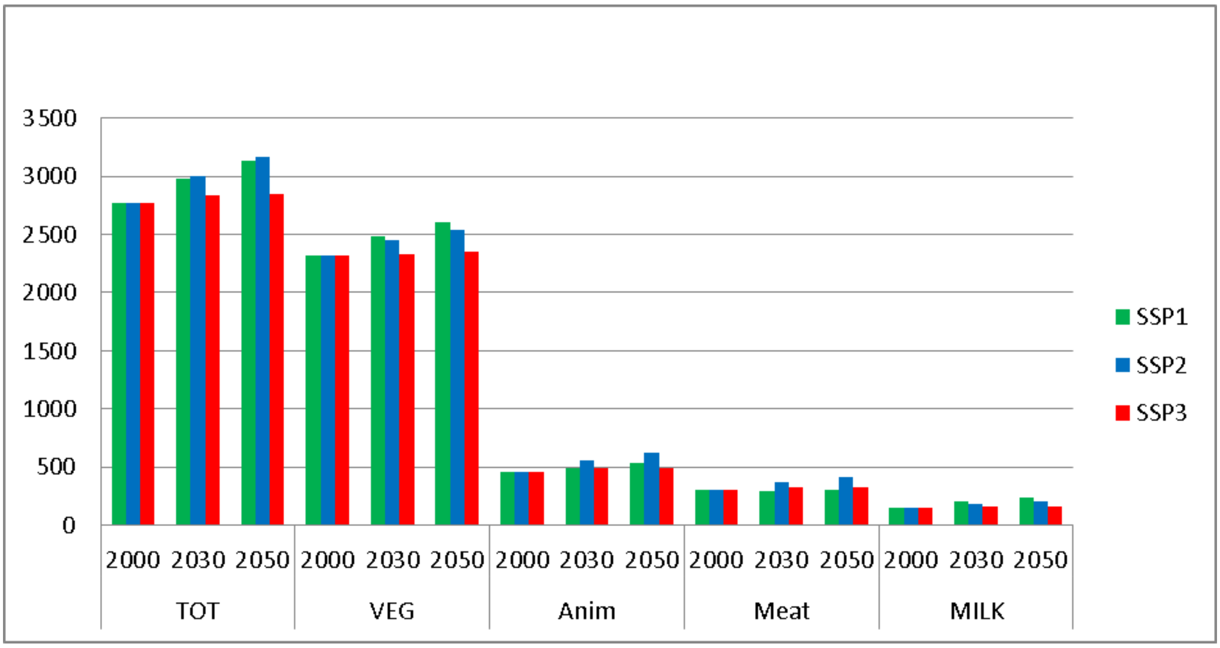

Figure 10: World food consumption per capita [kcal/capita/day].

Regional differences in per capita consumption are striking already in the base year, especially for the livestock products. As Figure 11 shows, the global per capita consumption was about 450 kcal/cap/day, varying from about 200 kcal/cap/day in Africa&MidEast to 1000 kcal/cap/day in Europe. Also in Latin America, the livestock product consumption was above the average. In 2050, the highest per capita consumption would be reached under SSP2. Under SSP3, the low economic growth and technological progress would lead to a relatively small (compared to SSP2) increase in Europe and in LatinAmerica and would result in a quasi-stagnation in Africa&MidEast. Under SSP1, more sustainable diets and better household waste management would lead to a decrease in livestock product consumption in Europe (-2%), and to an increase by 43% in Africa&MidEast due to high economic growth and fast technological progress.

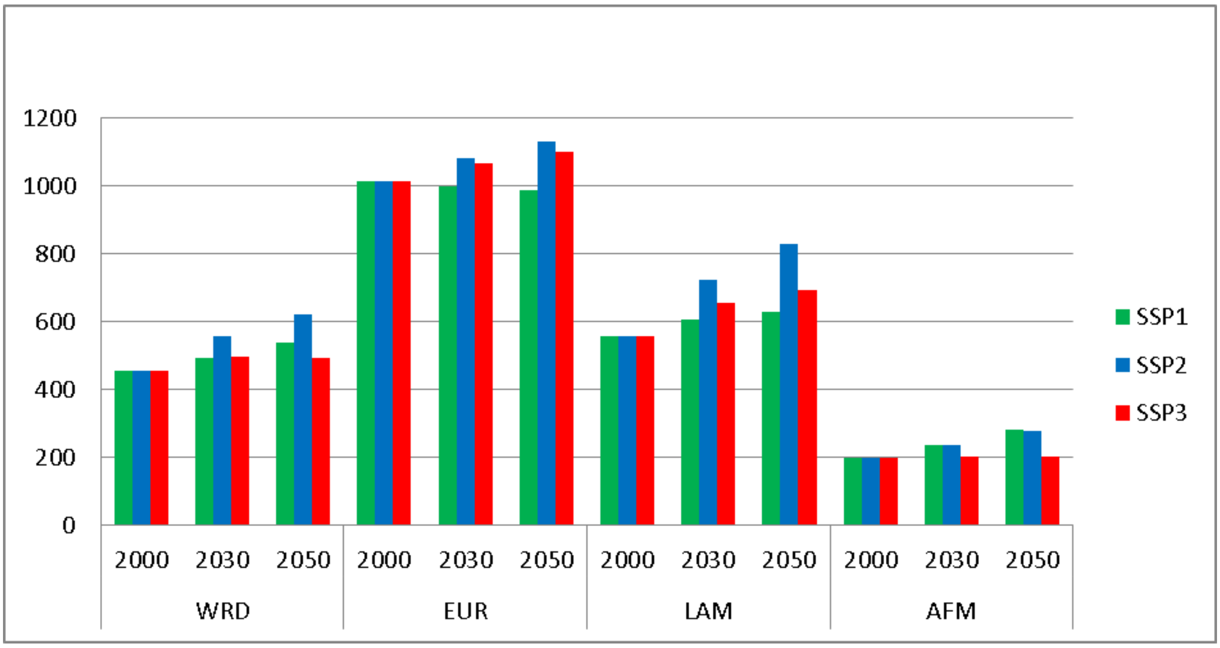

Figure 11: Livestock product consumption per capita [kcal/capita/day].

These per capita food consumption changes would translate globally in 73% increase in total calorie consumption under SSP2 by 2050, corresponding to 66% increase in crop products consumption and 106% increase in livestock product consumption, Figure 12.

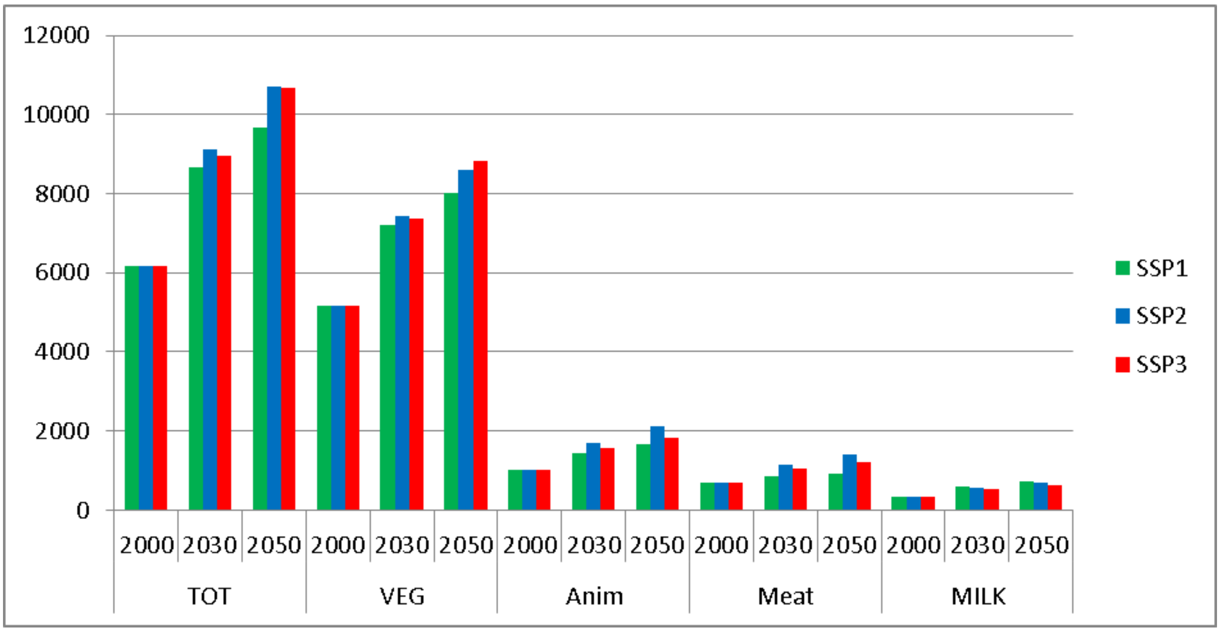

Figure 12: World food consumption - total [peta calories].

In 2000, about 20% of global livestock consumption happened in Europe (Figure 13). Latin America consumed about half and Africa&MidEast about 40% of livestock calories compared to Europe. In 2050 under SSP2, the order of the biggest consumers is completely reversed wit the highest consumption in Africa&MidEast and the lowest consumption in Europe. The share of Europe in total consumption would hence fall to 10%.

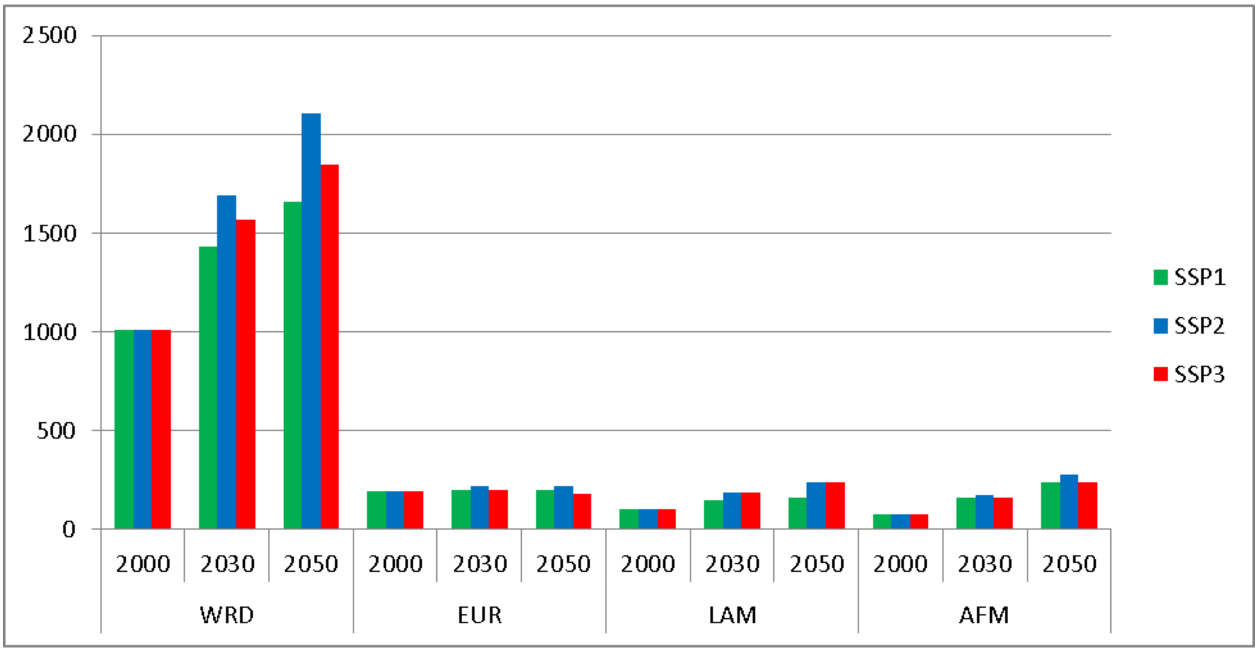

Figure 13: Livestock product consumption - total [peta calories].

Human consumption, is in GLOBIOM the only explicitly represented demand for livestock products. However, for crop products we represent also other demands; in particular "Feed demand" and "Process demand", the latter being equivalent to demand by the biofuels sector.

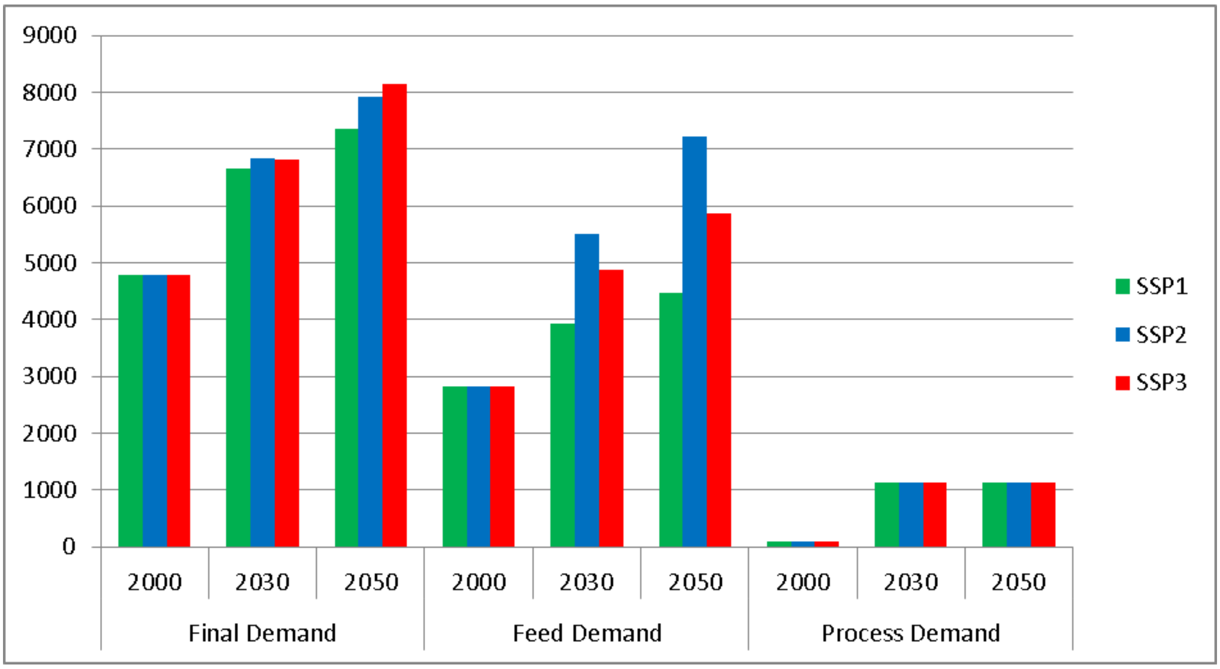

Figure 14: World demands for crops in primary commodity equivalent [peta calories].

Feed is the second largest item after food in the total crop demand, it would peak at 44% of total demand under SSP2 (Figure 14). Process demand / demand of crops for biofuels of first generation, would in 2050 reach the largest share under SSP1 – 9% of all crop production in terms of calories.

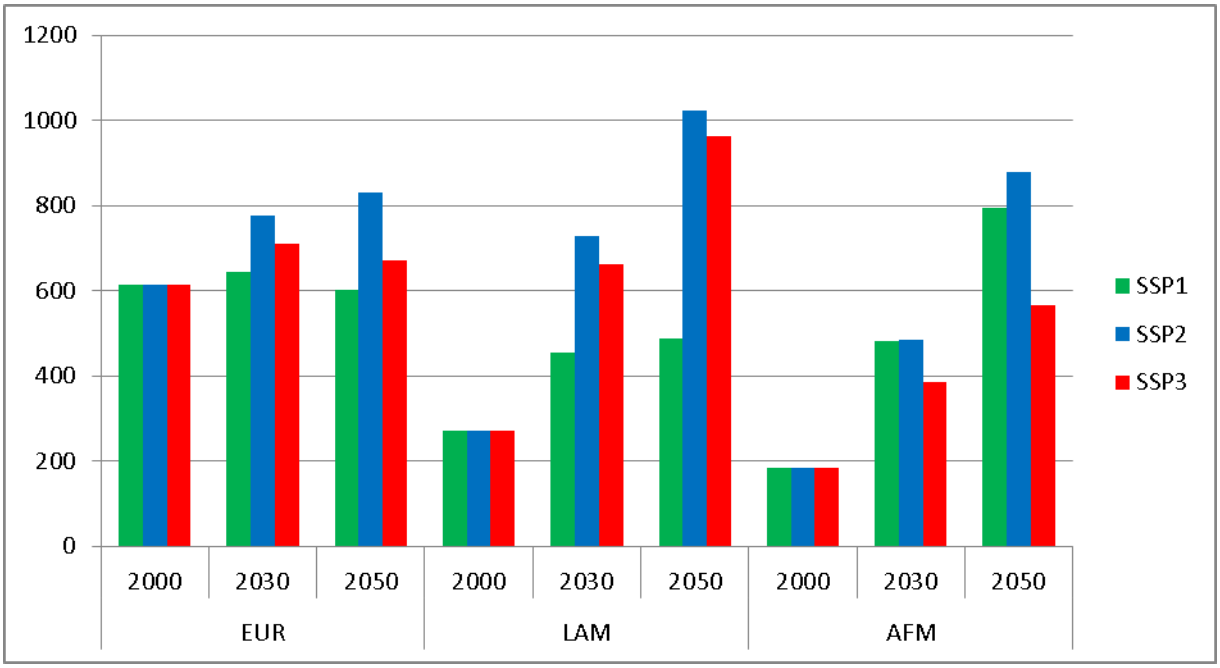

Figure 15: Demand for feed crops by region [peta calories].

Crop feed demand distribution across the regions mimics the livestock production in 2000. In 2050, the feed crops demand is the highest under SSP2 for all project regions. Under SSP1 and SSP3, it is stagnating in Europe (Figure 15). Under SSP3, the feed demand is the highest in Latin America, under SSP1, it is the highest in Africa&MidEast.

4.1.2 Production

To satisfy the different demands for crop products, the crop production would increase between 2000 and 2050 globally by 109% under the SSP2. The increase would be similar under SSP3, +95%, and only under SSP1, it would be substantially lower, +66%. Different regions are projected to contribute differently to this growth, Figure 16. While in Europe, the crop production is projected to increase by 63% under SSP2, it is projected to increase by almost 200% in Latin Amerca, and by 250% in Africa&MidEast. Under SSP3, the suply develops similarly in Europe and Latin America, but the lack of technological change reduces substantially the growth in supply in Africa&MidEast, +180%.

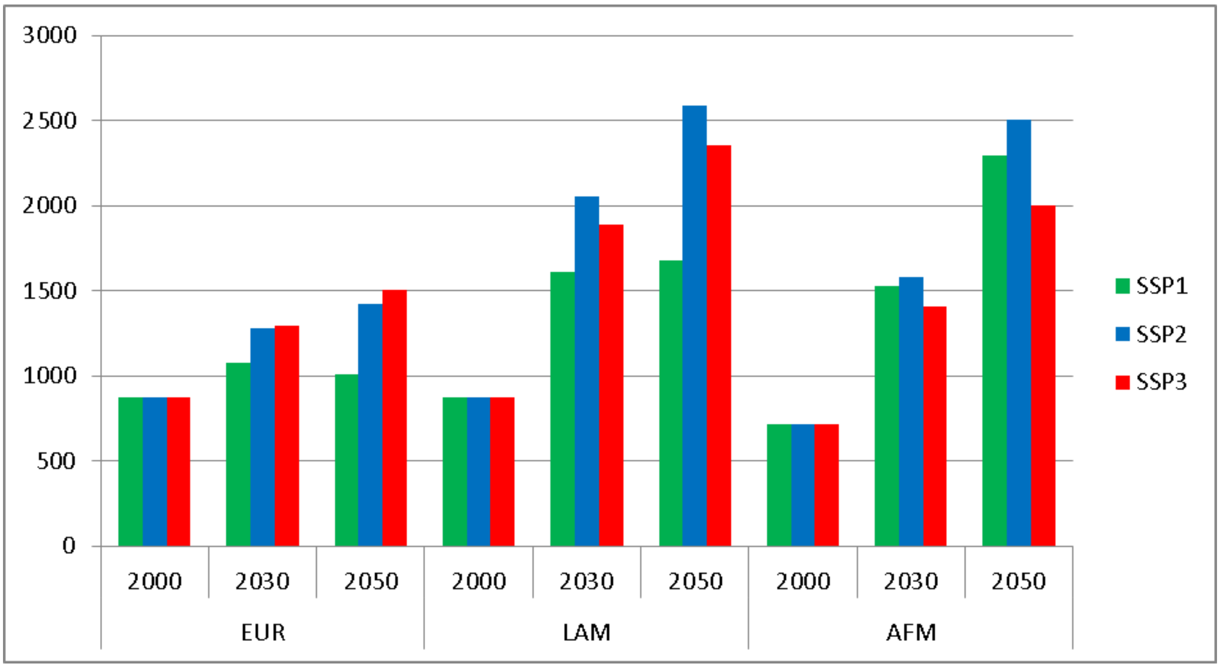

Figure 16: Supply of vegetal calories by region [peta calories].

Also livestock production is projected to nearly double under the SSP2, +92% globally. The relative changes in production across the projected regions are similar as for the crop production, with the exception of Europe, where the livestock production is almost stagnating, with the highest growth being +20% under SSP2.

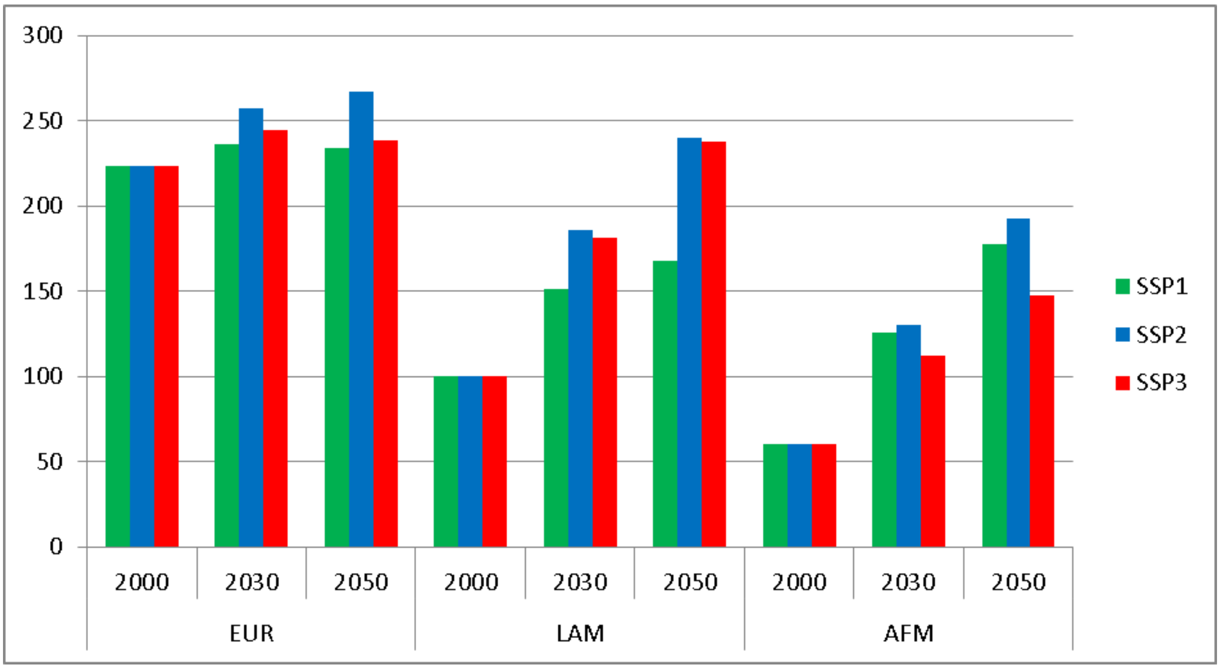

Figure 17: Supply of animal calories by region [peta calories].

4.1.3 Prices

Overall, we project relatively stable agricultural commodities prices. Crop price index is projected to remain between 1.01 and 1.04 compared to 2000 at the world level under SSP2, being slightly lower in Europe and Latin America, and higher in Africa&MidEast (Figure 18). Livestock product price index is projected to reach about 1.06 under SSP2 both by 2030 and 2050, with again the lowest price increase in Europe, slightly higher increase in Latin America and substantial increases, going over 50%, in Africa&MidEast (Figure 19).

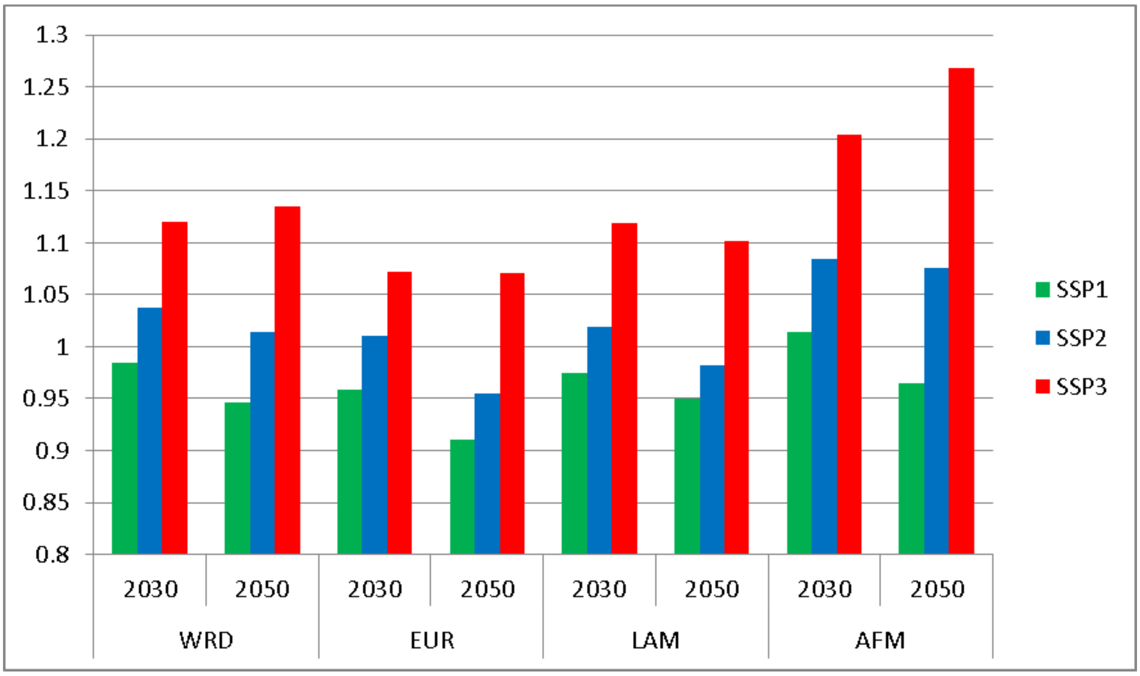

Figure 18: Crop price index compared (2000 = 1).

Both the crop price index as well as the livestock product price index calculated with respect to 2000 price levels, take the highest values under SSP3, and the lowest values under SSP1 although the production tends to be the highest under SSP2. This points to the differences in the major drivers of these scenarios. Under SSP3, the relatively high population growth and relatively low technological progress, lead to high producer prices. Under SSP1, relatively low population growth, sustainability considerations in western diets, and fast technological progress lead to low prices.

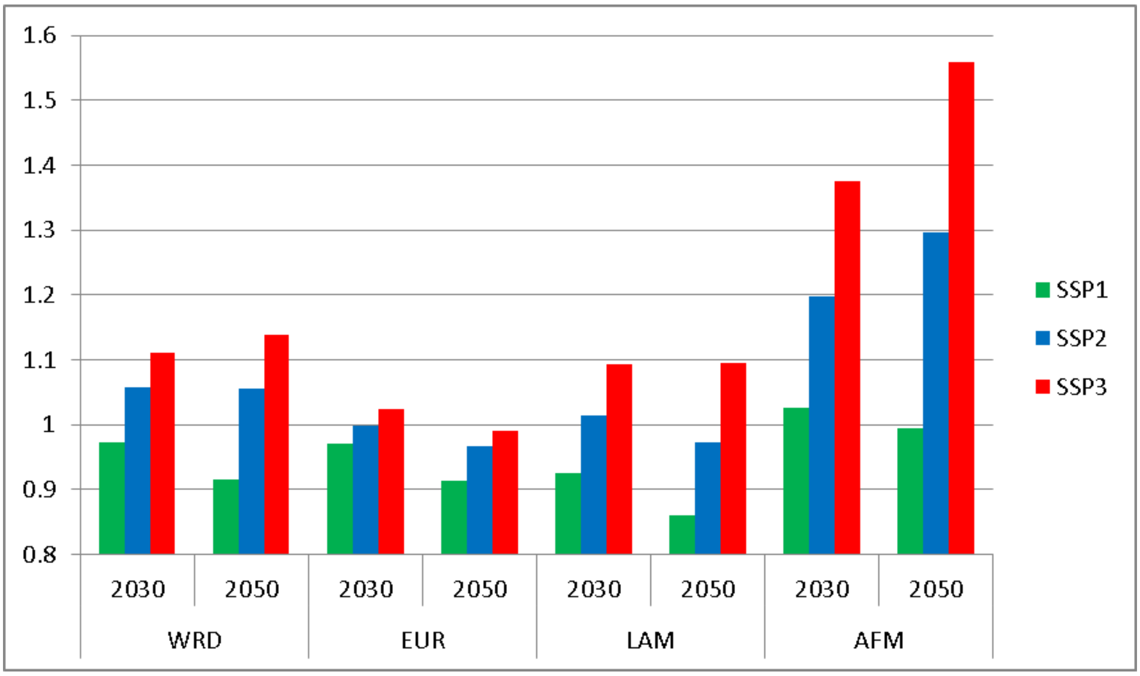

Figure 19: Livestock product price index compared (2000 = 1).

4.2 Land use and land use change

4.2.1 Land cover

The increased production will come to some extent from intensification of production on the current agricultural land but will also require expansion of agricultural activities in other land cover types. We estimate that under SSP2, 175 Mio ha of additional cropland and 300 Mio ha of additional grassland would enter production by 2050 compared to 2000 (Figure20). These numbers compare fairly well with the FAOSTAT land use statistics which report that between 1961 and 2009, the area of Arable land & Permanent crops increased by 162 Mio ha and the area of Permanent meadows and pastures increased by 269 Mio ha. Additional demand for about 150 Mio ha of land comes in our model from short rotation tree plantations providing feedstock for bioenergy. The total expansion would hence reach 625 Mio ha covered from 35% by expansion in forests and 65% would come from expansion in Other Natural Land. This would mean in absolute numbers an average rate of deforestation of about 4.4 Mio ha per year. The recent rates of deforestation as reported by FRA2010 were 8.3, 4.4 and 5.6 Mio ha per year over the periods 1990-2000, 2000-2005, and 2005-2010, respectively.

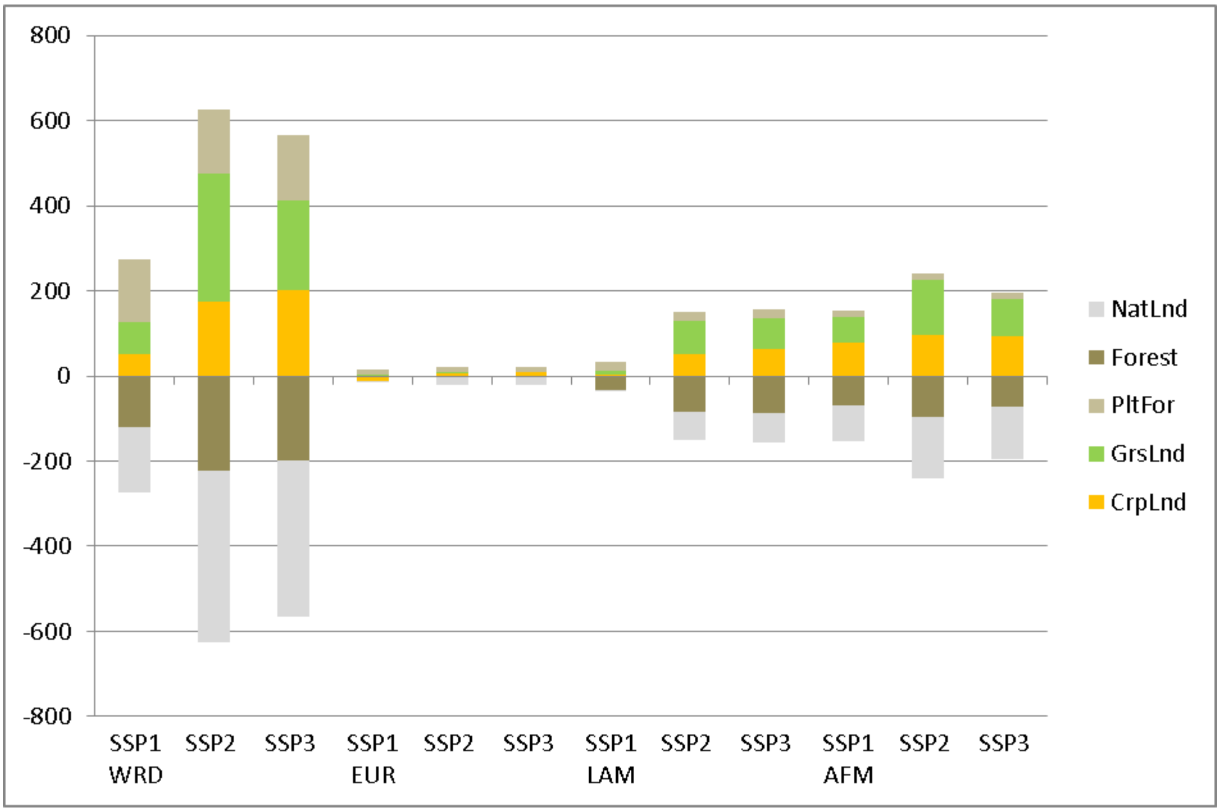

Figure 20: Cumulative land cover change over 2000-2050 [Mio ha].

The land cover change is not equally distributed across all the project regions. More than half, 55%, of the global cropland expansion is projected to occur in Africa&MidEast, about 30% in Latin America, and only 4% in Europe. Similarly for grassland, 43% of the expansion is projected to happen in Africa&MidEast, 27% in Latin America, and not even 1% in Europe. About 44% of the total deforestation is projected to happen in Africa&MidEast, and 37% in Latin America, thus the project regions represent more than 80% of the overall deforestation.

The SSP2 is the scenario with the highest demand for additional agricultural land because of the mix of sustained demand and moderate yield increases. Under SSP3, lower meat demand caused by lower economic growth and higher production prices leads to grassland expansion lower by 30% than under SSP2, and this causes the total agricultural land expansion being lower, albeit the slightly higher cropland expansion. Under SSP1, both cropland and grassland expansion represent less than 30% of the expansion necessary under SSP2, leading to conversion of just 44% of the Forest and Other Natural Land.

4.2.2 Cropland management

Exogenous crop yield increases as presented in Section 3.2.2 are systematically the highest under SSP1 and the lowest under SSP3 (IntsEf in Figure 21). However, this is only one source of yield change in GLOBIOM. The other one appears at higher spatial aggregates and is due to re-allocation of the production across the individual Simulation Units, "pixels". This effect is systematically negative under SSP1 and mostly positive under SSP3. One interpretation could be that since the technological progress is assumed to be low and the total demand relatively high because of the large population, which together lead to high agricultural prices, crop production seeks to on the one hand use the best available resources, and on the other hand is competitive in acquiring them. Another potential reason for this phenomenon could be that the technological progress allows to develop crop production also in regions which start from very low yields but improve rapidly. From this latter perspective the positive aggregation effect would suggest that with low crop yield growth production will seek the most productive regions. The sum of the two effects leads to highest overall yield increase under SSP2 and not SSP1 as could be expected. The aggregate crop yield increase over 2000-2050 reaches about 70% globally under SSP2. It reaches some 40% in Europe, and 90 to 115% in Latin America and Africa%MidEast.

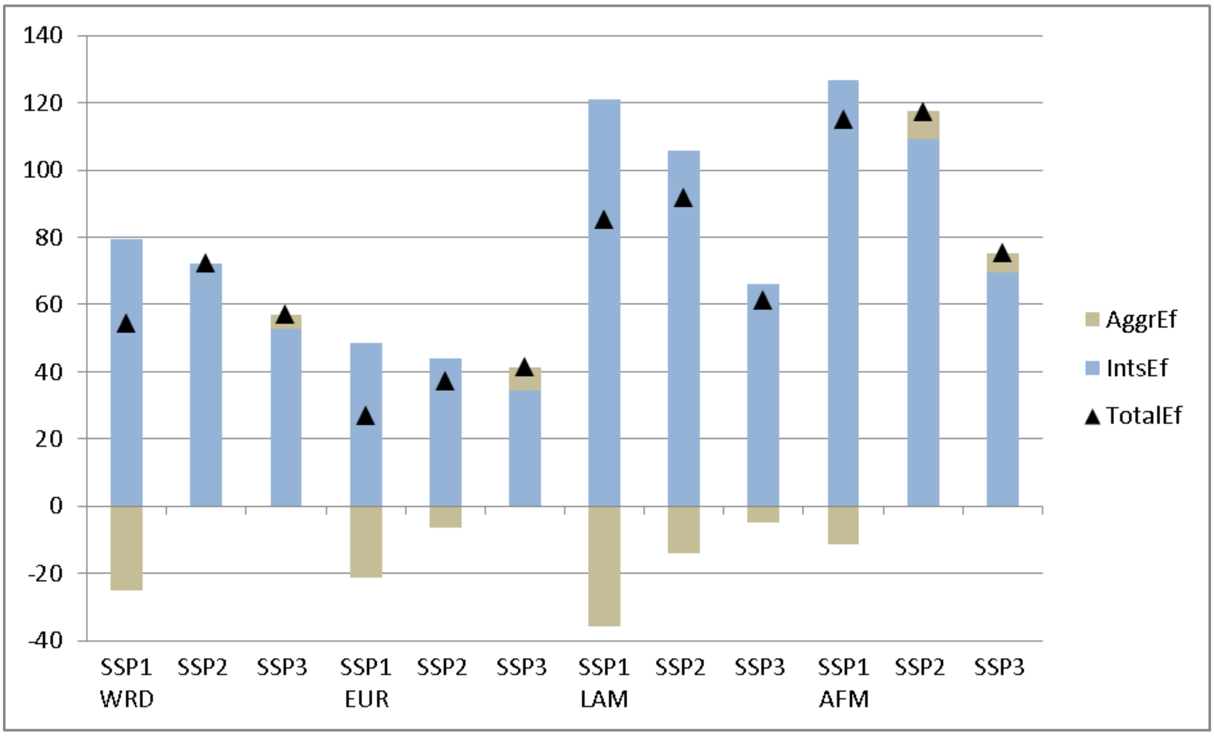

Figure 21: Total crop yield change in terms of calories over 2000-2050 decomposed between intensification/exogenous and aggregation effects [%].

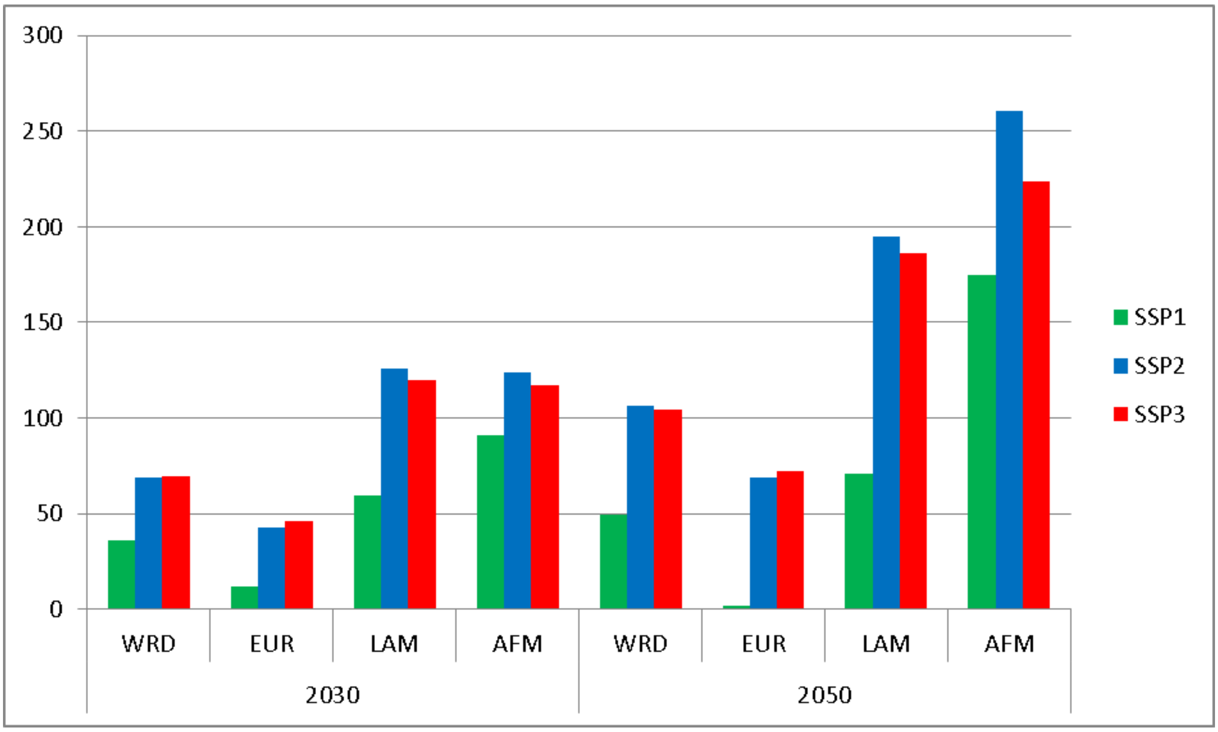

Figure 22: Additional nitrogen consumption compared to 2000 [%].

The increased yields would require additional inputs. We estimate that globally the use of nitrogen fertilizer would need to double under SSP2 by 2050 (Figure 22), and also 15% more irrigation water would be required (Figure 23).

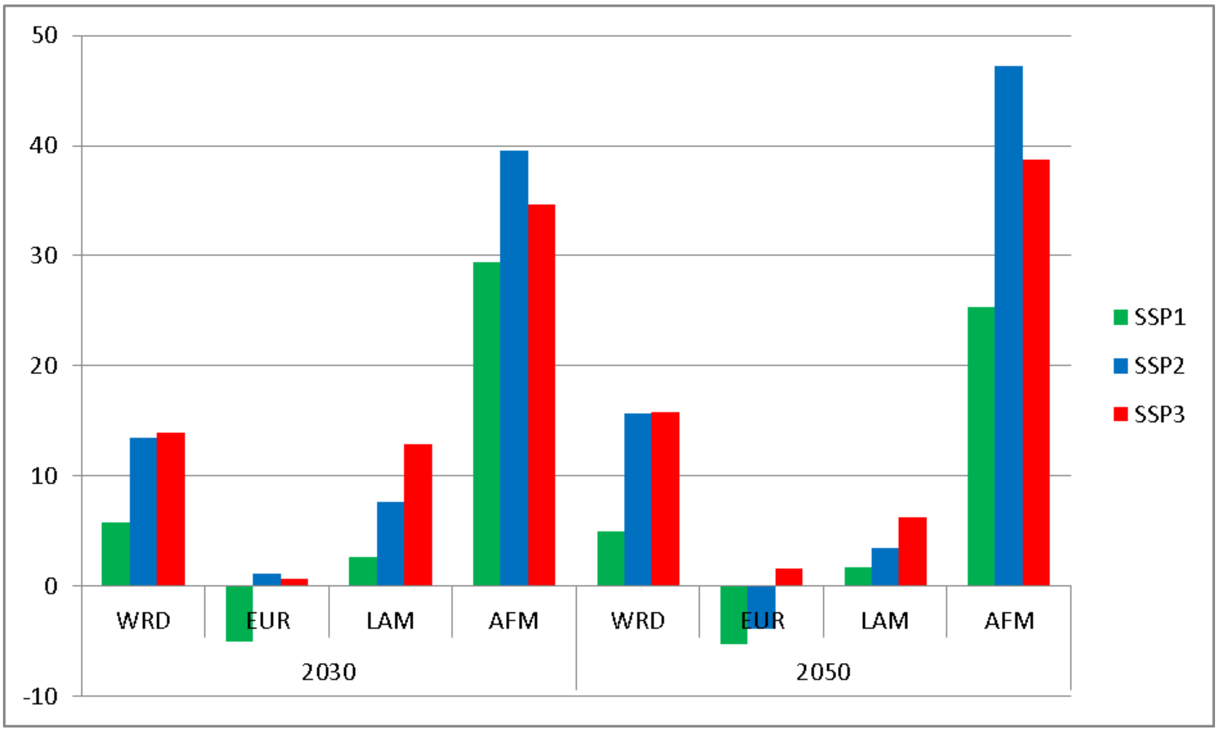

Figure 23: Additional irrigation water consumption compared to 2000 [%].

4.3 Livestock sector

4.3.1 Livestock production by product

We have seen before that the total livestock production is projected to increase by about 92% (expressed in calories). Under SSP2, the growth in production of the different commodity aggregates is relatively equally distributed: +106% for monogastric meat and eggs, +88% for ruminant meat, and +85% for milk. The model results reflect well our assumptions about the sustainable diets under SSP1, where the share of ruminant meat decreases substantially, whereas milk production is less restricted, and overall the per capita food consumption is limited. This results in ruminant meat production increasing by 22% only between 2000-2050, monogastrics product supply increasing by 45%, about half of the growth under SSP2, and milk production growing even more than under SSP2, by +91% (Figure 24).

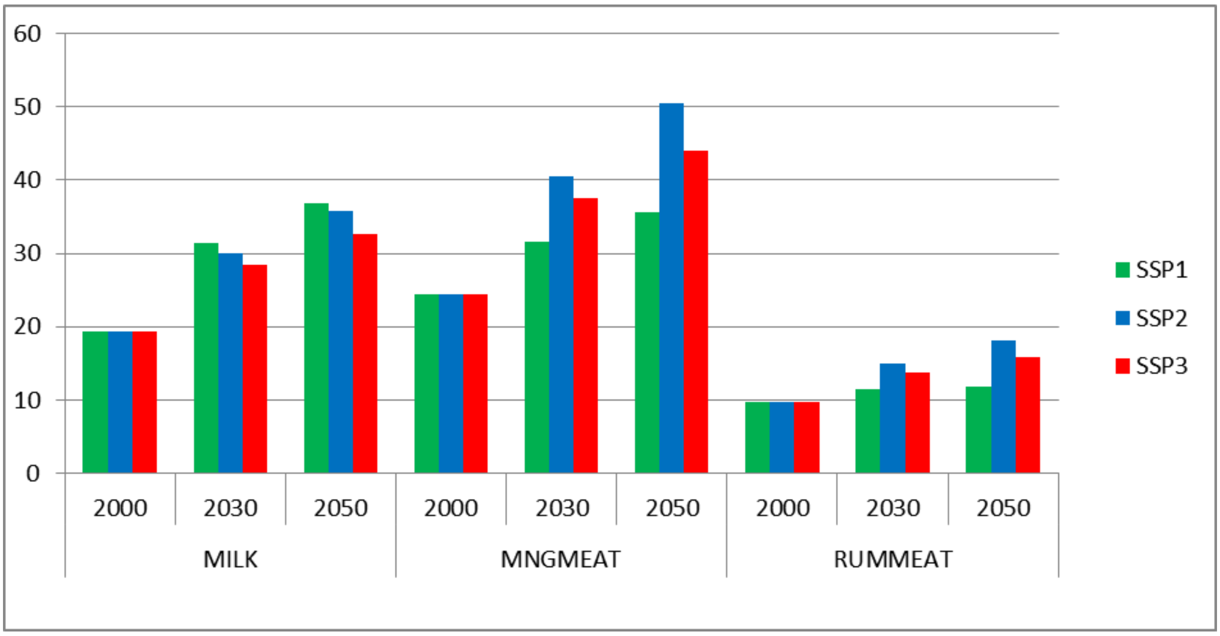

Figure 24: Global livestock production by product [Mio tonnes protein].

Monogastrics production is still projected to grow in Europe under SSP2, +33% by 2050. However, this growth looks like stagnation when compared with projected developments in the other regions. In Latin America, monogastrics production is projected to increase by 170%, and it would be almost multiplied by six in Africa&MidEast (Figure 25).

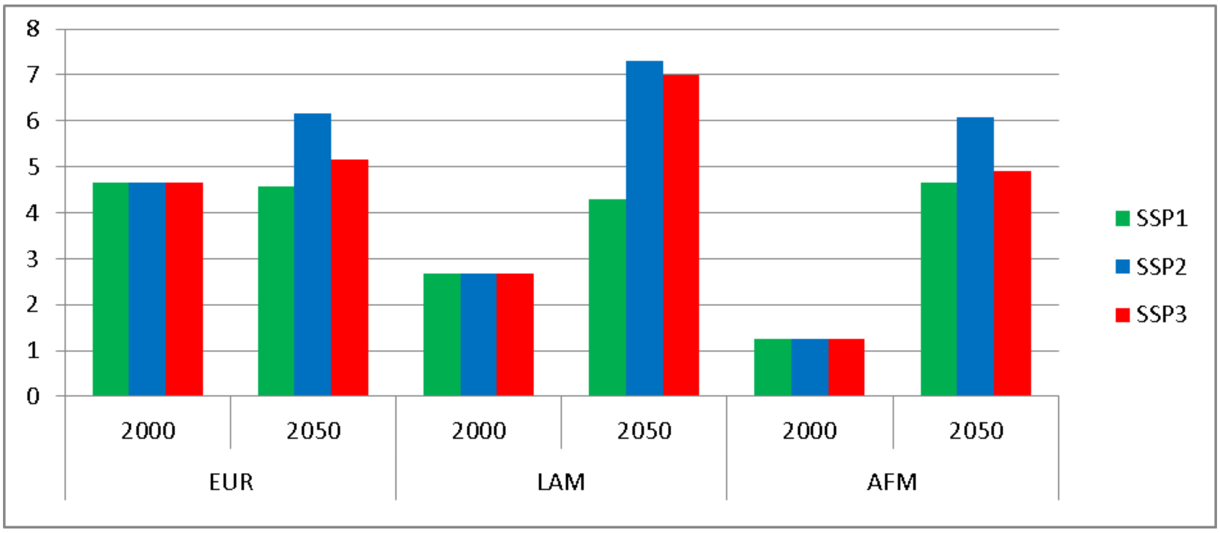

Figure 25: Global monogastrics production by region [Mio tonnes protein].

European ruminant meat production is projected to increase by 15% only by 2050 under SSP2 (Figure 26). Ruminant meat production in Latin America and Africa&MidEast is projected to grow by 125% and 160%, respectively, but the different scenarios would have very different effects in these two regions. Under SSP3, the low economic and technological growth in Africa&MidEast would lead to a growth by 70% only, while the production would be similar as under SSP2 in Latin America. On the other hand, under SSP1, the lower world demand would push down production in Latin America (+21% only), but the sustained demand in Africa&MidEast together with their improved competitiveness would still lead to a growth by 112% compared to 2000.

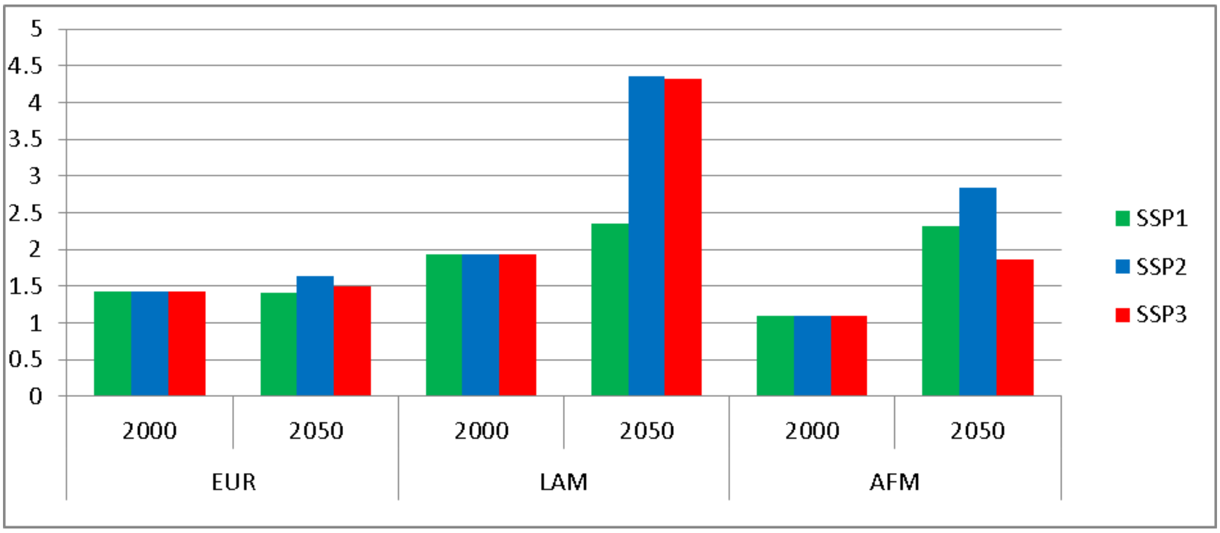

Figure 26: Global ruminant meat production by region [Mio tonnes protein].

European milk production is again projected to grow only slowly, +13% at most. Unlike the ruminant meat production, milk production is not negatively affected under SSP1, it is almost as high as under SSP2 in Latin America, and it is even the highest from the three scenarios for Africa&MidEast (Figure 27).

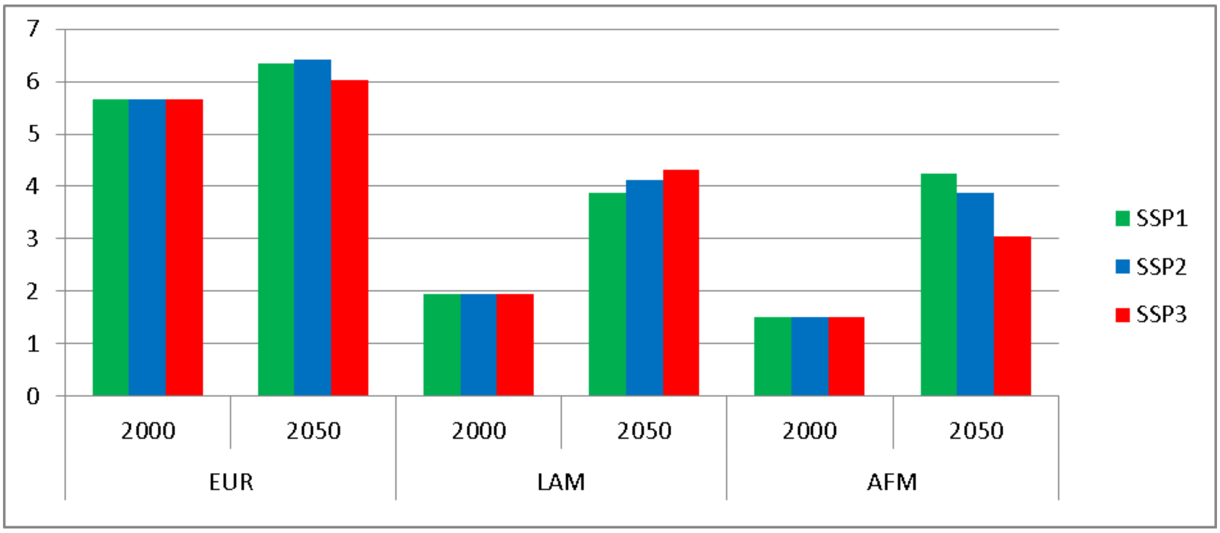

Figure 27: Global raw milk production by region [Mio tonnes protein].

4.3.2 Livestock production by system

Livestock production will have very different impacts on greenhouse gas emissions and other environmental parameters depending on the production systems, and through them the productivity and feedstuff basis. In 2000, 88% of the global monogastrics production came from the industrial systems (Figure 28). While these systems where supplying 94 and 92% of the production in Europe and Latin America, majority (67%) of the production in Africa&MidEast still came from smallholder systems. We do not expect further substantial increases in industrialization in Europe and in Latin America, however in Africa&MidEast, their share is projected to increase from the 33% to about 80% by 2050, independently on the scenario chosen.

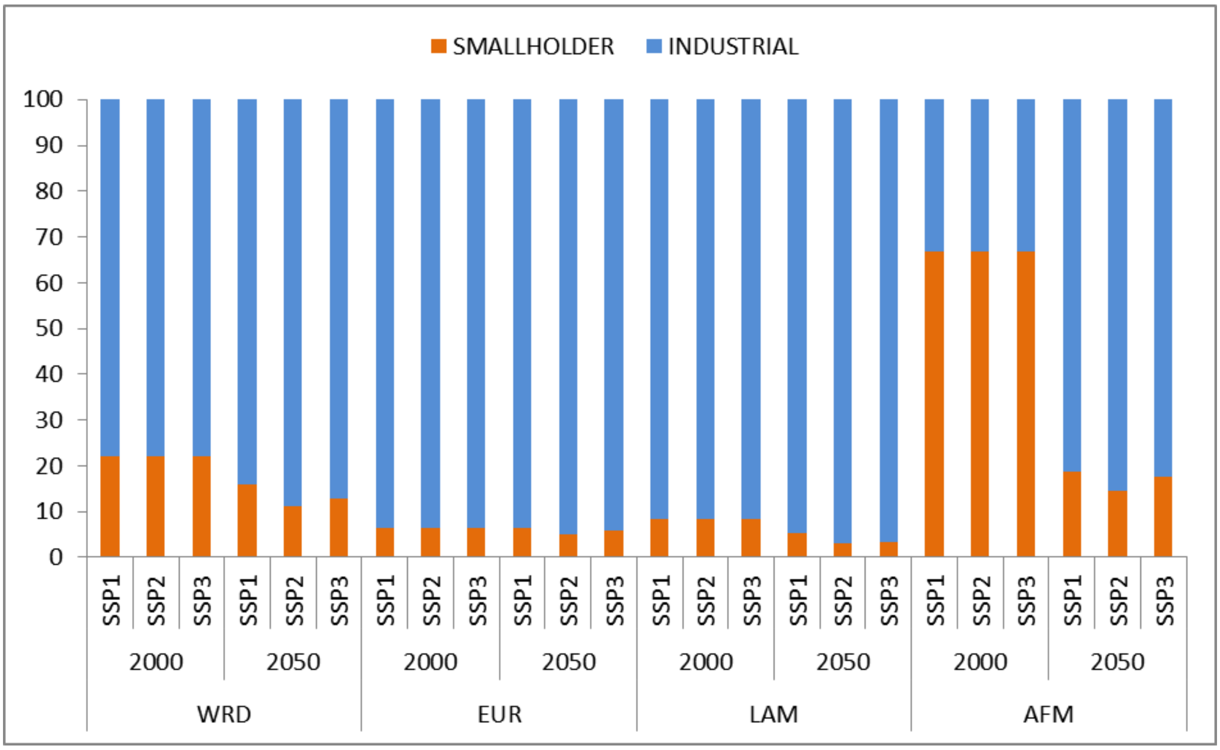

Figure 28: Monogastrics production by system [%].

For ruminants we distinguish 8 production systems: Grassland based – Arid (LGA), Humid (LGH), Temperate/Highlands (LGT), Mixed crop-livestock systems – Arid (MRA), Humid (MRH), Temperate/Highlands (MRT), Urban, and Other. 31% of ruminant meat in 2000 was produced in mixed temperate systems followed by mixed humid (17%), other (16%), and mixed arid (14%) systems (Figure 29). Most of the production in Europe came from the mixed temperate systems (42%), in Latin America from mixed humid systems (48%), and in Africa&MidEast from mixed arid systems (38%). Under SSP2, the major change would be an increase in the share of production coming from grassland based humid systems. Under SSP3, also according to the scenarios assumptions, the production distribution across the systems would remain similar to that one observed in 2000.

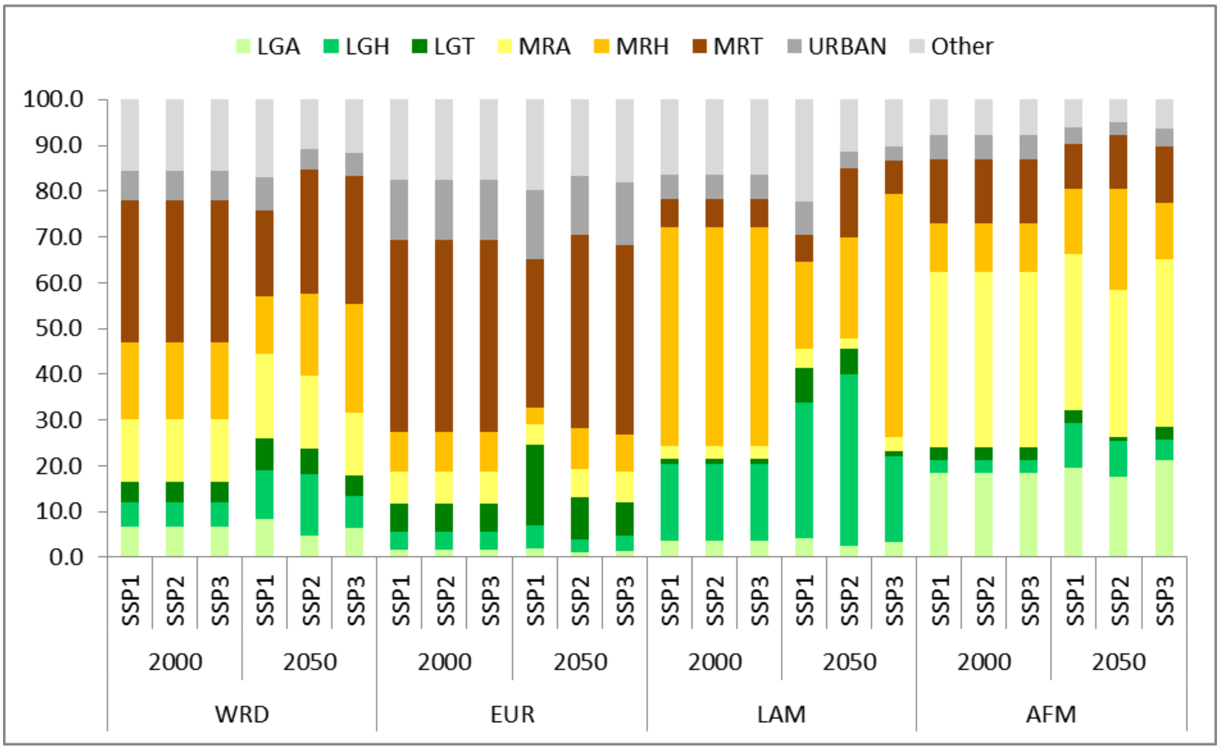

Figure 29: Ruminant meat production by system [%].

Most of the milk production in 2000 was coming from the mixed temperate systems (35%), followed by mixed arid (20%), other (17%), and mixed humid (14%). In Europe and Latin America, up to 56% and 52% of the total production was coming from the mixed temerate and humid systems, respectively. In Africa, mixed arid systems were delivering 42% of the milk production. Globally, the most robust change in the production structure relates to the increase in the share of production coming from mixed arid systems going from 20% in 2000 to up to 34% in 2050. This is mostly due to the developments in Africa&MidEast (Figure 30).

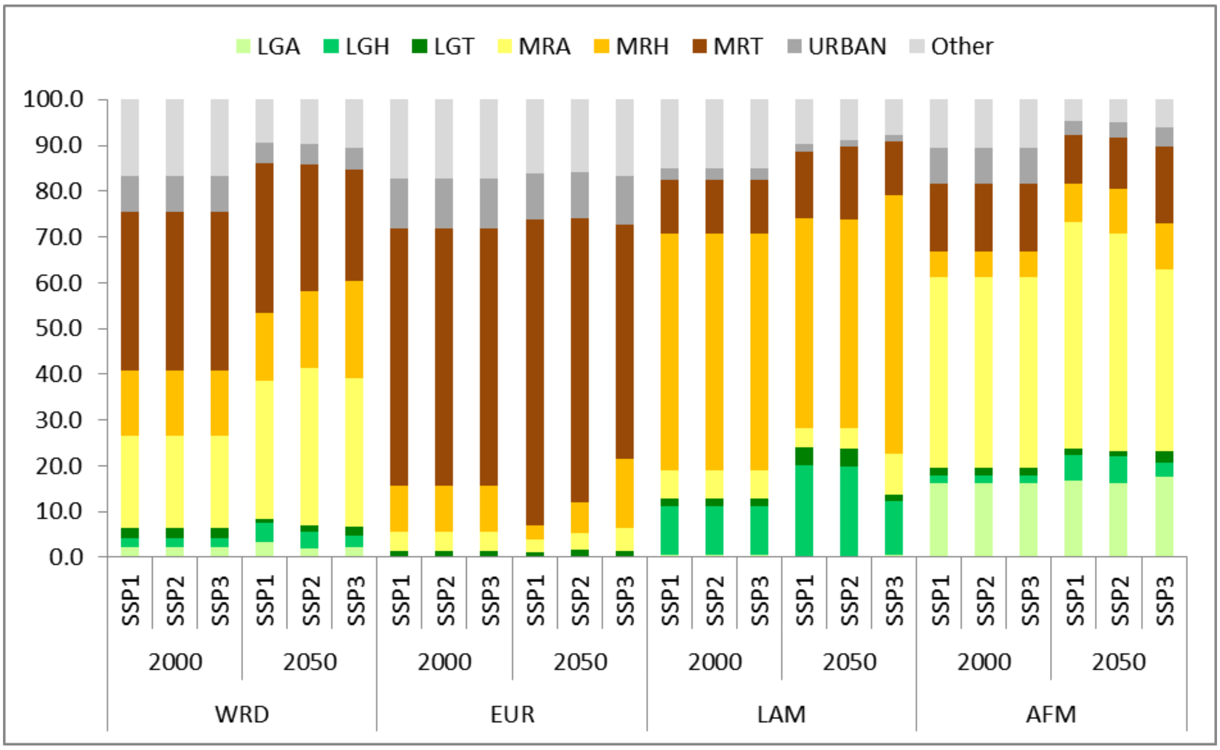

Figure 30: Raw milk production by system [%].

4.4 Greenhouse gas emissions

The three most important sources of greenhouse gas emissions in agricultural and land use sectors were according to our numbers soil N_2O, CH_4 from enteric fermentation, and CO_2 from deforestation[2], all the other emissions accounted together for 15% only. In terms of regional distribution, the project regions were responsible for 57% of the global emissions. Latin America emitted 32% of the total emissions, Africa&MidEast 24%, and Europe only 1%. Total agricultural emissions were with 542, 776, and 818 $MtCO_2eq$ for Europe, Africa&MidEast and Latin America fairly comparable, and the major difference came from the land use change emissions. These emissions were negative in Europe, and almost cancelled out the positive emissions from agriculture there, but with 845 and 1312 $MtCO_2eq$ in Africa&MidEast and in Latin America, they more than doubled the agricultural emissions in these regions (Figure 31).

The amount of future emissions depends substantially on the scenario assumptions. Our projections result in an increase by 34% in 2050 under SSP2, and a decrease by 14% under SSP1. While agricultural emissions would increase by 13% and the land use change emissions by 29% under SSP2, they would decrease by 14 and 49% respectively, under SSP1.

[2] These numbers are taken from FRA2010 since GLOBIOM starts from equilibrium in 2000, and hence cannot report emissions from land use change from the preceding period.

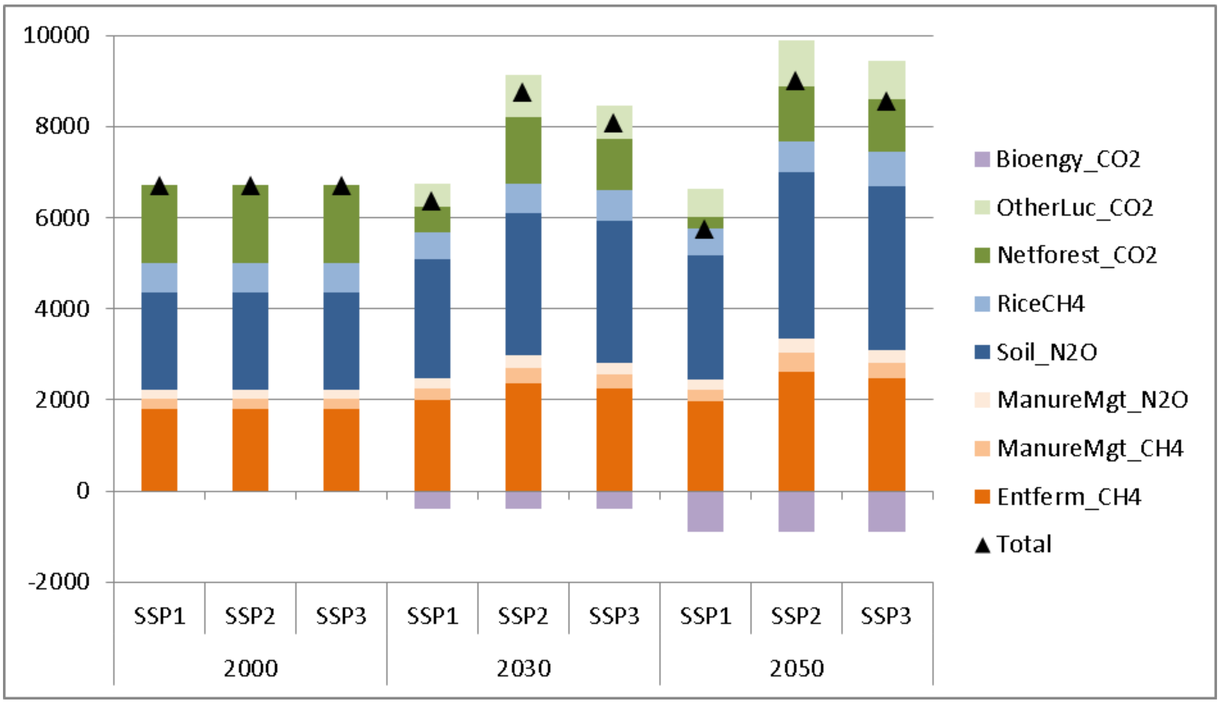

Figure 31: Greenhouse gas emissions - World [Mio tonnes CO_2eq].

In Europe, the most important contributor to agricultural emissions are enteric fermentation with 177 MtCO_2eq and soil N_2O emissions with 251 MtCO_2eq (Figure 32). The emissions from enteric fermentation are increasing by at most 7% by 2050 under SSP2, but the emissions from soil N_2O are projected to still increase by about 40% both under SSP2 and SSP3.[3]

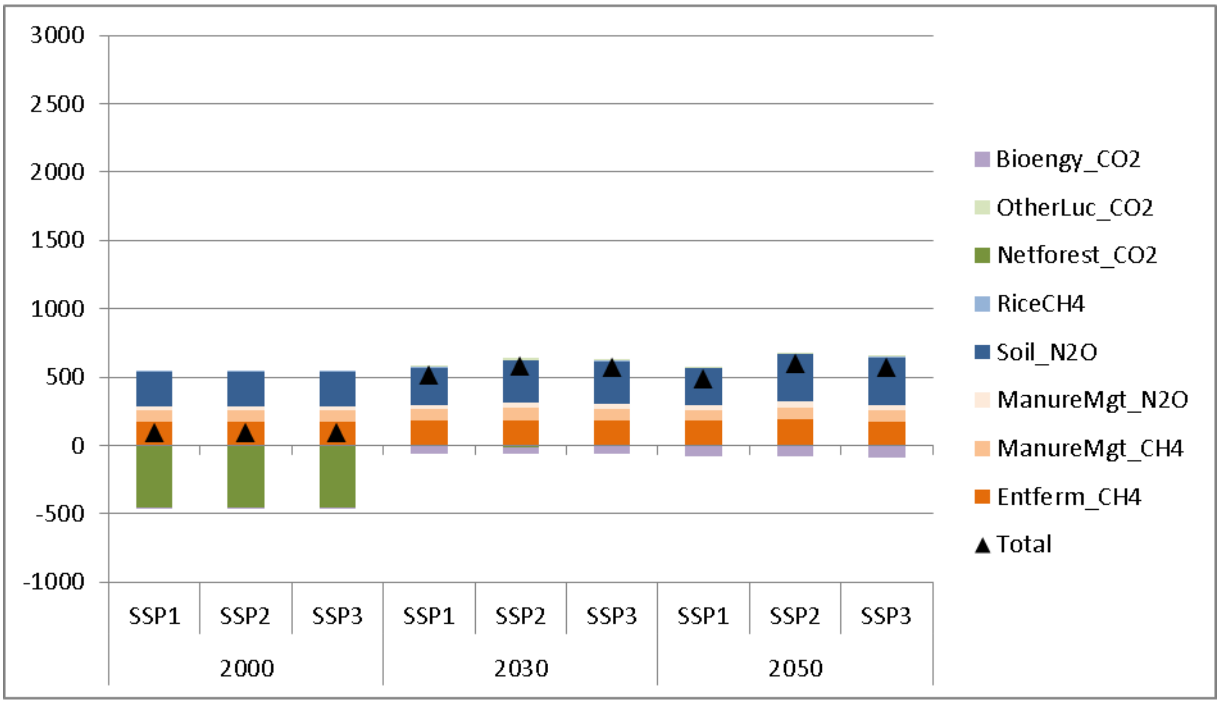

Figure 32: Greenhouse gas emissions - Europe [Mio tonnes CO_2eq].

[3] In this version of the model, net afforestation with traditional forests is not taken into account, therefore it does not appear in the results after 2000. This is a potential limitation of our results for regions with substantial net afforestation, which is the case of Europe.

In Latin America, 62% of 2000 emissions came from land use change, followed by enteric fermentation and soil N_2O. Under SSP1, the total emissions in 2050 could be 36% of those in 2000, and also under SSP2 and SSP3, they would not exceed the 2000 levels. This positive development comes from the reduction of emissions from land use change, -46% under SSP2, and -90% under SSP1. This allows buffering the non-negligible increases in agricultural emissions – e.g. 41% for enteric fermentation and 85% for soil N_2O under SSP2 (Figure 33).

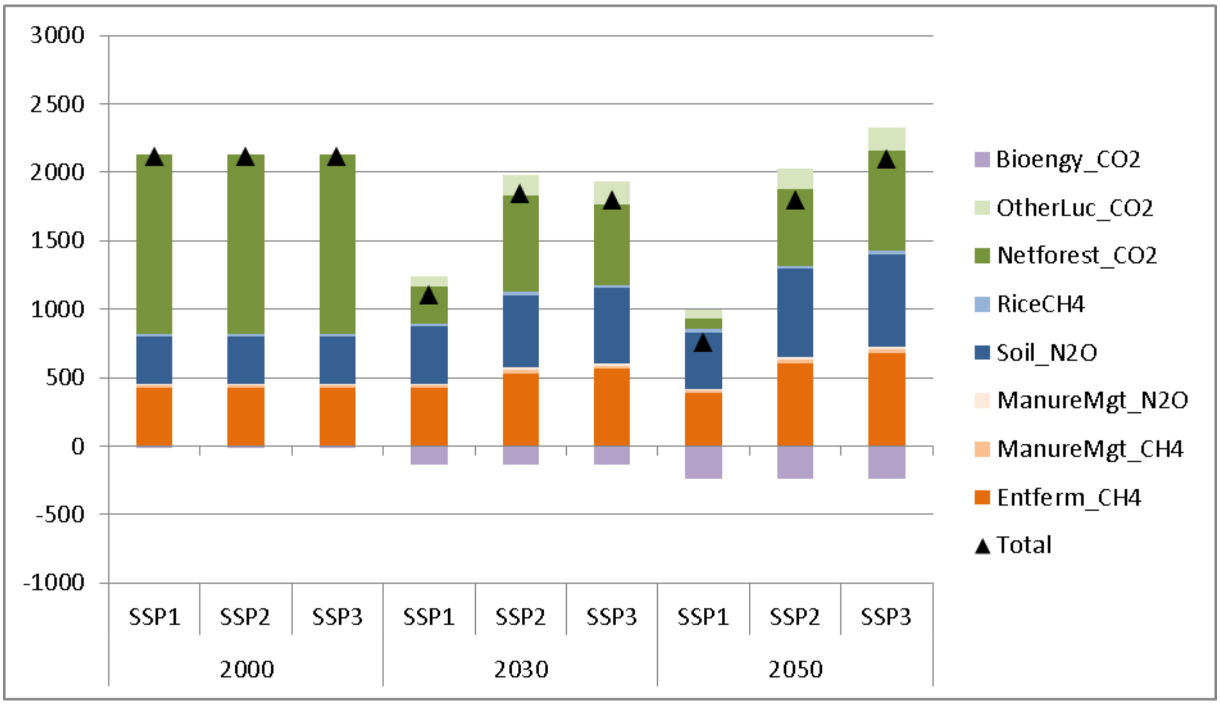

Figure 33: Greenhouse gas emissions – Latin America [Mio tonnes CO_2eq].

Potentially the highest increase in emissions from agriculture and land use change would occur in Africa&MidEast, +50% by 2050 under SSP2. In this region, about half of the 2000 emissions came from land use change and half from agriculture. Soil N_2O and enteric fermentation are the most important sources of agricultural emissions. Soil N_2O is projected to more than double by 2050 under SSP2, and also emissions from enteric fermentation would increase by 42%. SSP1 and SSP3 would lead to lower emissions but still 12 and 18% above the 2000 level (Figure 34).

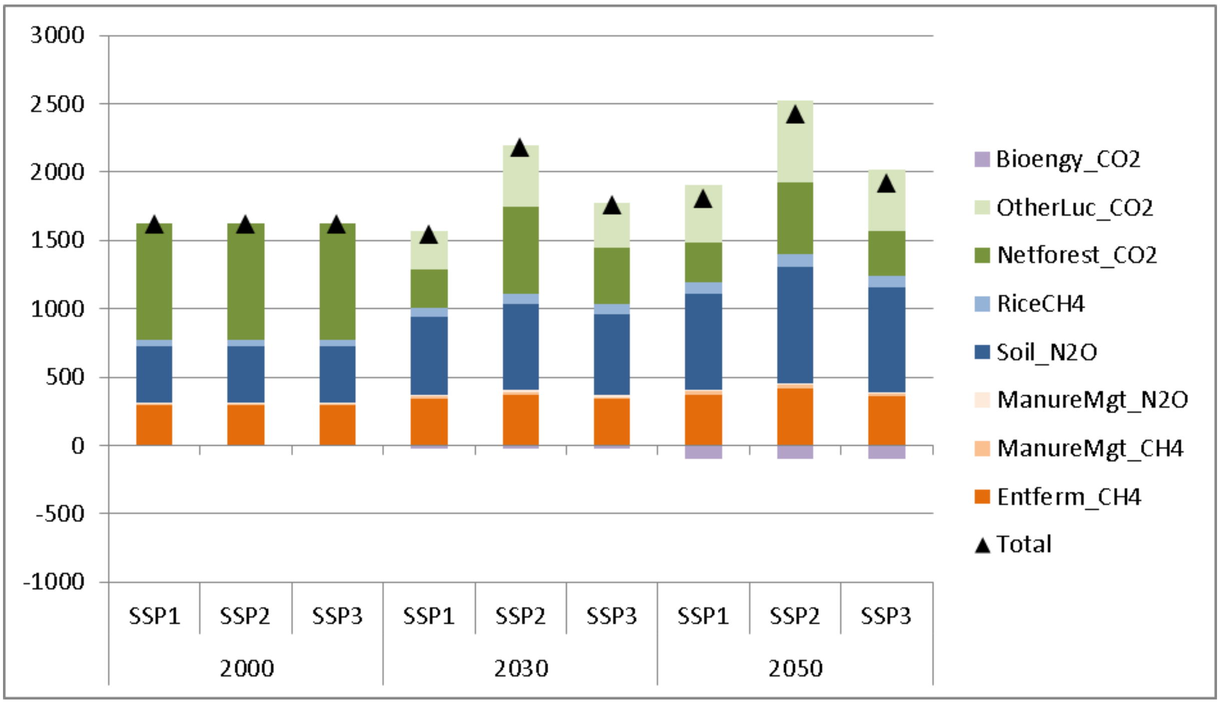

Figure 34: Greenhouse gas emissions – Africa&MidEast [Mio tonnes CO_2eq].

5 Conclusion

The objective of this study was to quantify the impacts of contrasted storylines developed in deliverable D2.1 on agricultural markets, livestock production systems, land use and greenhouse gas emissions. The work has been carried out by means of the GLOBIOM model, and results have been presented for World as whole, and the project regions – Europe, Latin America, and Africa&MidEast. These scenario results should be considered preliminary, as compared to the final scenarios supposed to be delivered in month 42 of the project. The fast track approach has been adopted to provide quick input to other project tasks, and to create a basis for discussions which would allow refinement of the modeling tool and the storylines assumptions before delivering the final scenarios.

In general, the scenario results show that the choice and parameterization of the storylines have been rather successful. On the one hand, the scenario SSP2, supposed to be the "Middle of the Road", or "business as usual", scenario, indeed allows to expand the past observed trends on many of the modeled variables. On the other hand, the two alternative scenarios, SSP1 and SSP3, seem to cover a large part of the possible futures. So under the SSP2, the total demand for livestock product calories is projected to double by 2050 compared to 2000, but because of the technological change both in the crop sector and the livestock sector, the prices are projected to stay close to the 2000 level. These productivity increases would require doubling of the nitrogen use, and also a 15% increase in irrigation water use. In addition, cropland and grassland are projected to expand by additional 175 and 300 Mio ha. As a result of these developments, greenhouse gas emissions from agriculture and land use change would increase by 34%. GHG emissions would however increase by 28% only under SSP3 and they would even decrease compared to 2000 by 14% under SSP1. The global numbers hide huge regional differences, where Europe appears as the more stable region both across the time horizon and across the different scenarios, and Latin America and Africa&MidEast are at the same time very dynamic in time, and very sensitive to the differences between the scenarios. E.g. the ruminant meat production in Africa&MidEast is projected to increase between 2000 and 2050 by 160% under SSP2, but the growth would be only 70% under SSP3; or, the total greenhouse gas emissions in Latin America would stay at the very high 2000 levels under SSP3, but would go down to less than a half under SSP1.

To conclude, although these preliminary results appear consistent, there is still a long way to go to the final scenarios. On the modeling side, we need to accomplish the linkage between AROPAj, CAPRI and GLOBIOM to refine the results for Europe; the representation of the other project regions in GLOBIOM needs to be improved too. On the storylines development side, the climate change impacts need to be added. This has not been done so far since the new logic of the IPCC scenarios does not provide unique couples of socio-economic storylines linked with climate change scenarios but rather a matrix from which the appropriate couples are to be picked up. The appropriate couples can be selected only once the SSP scenarios have been modeled by the Integrated Assessment Models (results expected by mid-2013). However, the lack of climate change impacts in this first round of AnimalChange scenarios can be seen also as an advantage because it allows to better understand the effects of already complex socio-economic scenarios.

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