Supplementary information

Agricultural productivity and greenhouse gas emissions: trade-offs or synergies between mitigation and food security?

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1. The GLOBIOM model

The analysis is carried out using the Global Biosphere Management Model (GLOBIOM, Havlík et al., 2011, 2013). GLOBIOM is a global partial equilibrium model integrating the agriculture and forestry sectors in a bottom-up setting based on detailed grid-cell information. It is used to analyze global issues concerning land use competition between the major land-based production sectors up to 2050. The model is issued from a well-established tradition of linear programming models (Takayama and Judge, 1971; McCarl and Spreen, 1980), and similar in structure to the US-FASOM model (Schneider et al., 2007, Beach et al., 2012). It has been applied already to a large set of topics, such as bioenergy policies (Frank et al., 2012, Mosnier et al., 2013; Kraxner et al., 2013), deforestation (Mosnier et al., 2012), livestock sector (Havlík et al., 2013), irrigation (Sauer et al., 2010) and land prospective issues (Schneider et al., 2011). The consistency of its behavior has been assessed in particular through comparisons with other models (Smith et al., 2010, Schmitz et al., 2013).

1.1. A grid cell approach

All supply side data are implemented in the model at the level of gridcell-based Simulation Units (Skalsky et al., 2008). Simulation Units are delineated at the 5 minute of arc resolution at the intersection of the same altitude, slope, and soil class, 0.5 x 0.5 degrees grid, and the country boundaries. For the present version, in order to ease computation time with livestock modelling, the grid was in fact aggregated at the 2 x 2 degree resolution in the model, but keeping a layer of differentiation across three agroecological zones: humid, temperate or arid, according to Sere and Steinfeld classification of livestock systems. This led to a total of 10,894 different modelling units distributed across the 30 regions.

1.2. Crop production

GLOBIOM incorporates the production of 18 different crops across the world representing around 70% of the total world harvested area and 85% of the vegetal calorie supply. Each crop can be produced under different technologies depending on profitability: subsistence, low input, high input, and irrigated, when water resource is available. Crop yields are generated at the grid cell level on the basis of soil, slope, altitude and climate information, using the EPIC model (see section 2). Within each management, input structure is fixed following a Leontief function. Yields therefore react only through change in management system, spatial reallocation, and an exogenous component representing an input-neutral technical change. However, in order to properly control trends in overall yield change, for this study, we also blocked the switch across management systems. In each cell, the share of subsistence, low and high input and irrigated was fixed for all the scenarios of the paper and the systems dimension therefore aggregated.

1.3. Livestock sector

The model also incorporates a particularly detailed representation of the global livestock sector. 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 in GLOBIOM are defined with a digestion model (RUMINANT, see section 2.2) 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. As for crops, the different systems were for this particular paper aggregated in each simulation units in order to block any endogenous productivity change and control directly the feed conversion efficiency through an exogenous shifter.

The representation of the grass feed intake is an important component of the system representation as grassland productivity is explicitly represented in the model. Therefore, the model can represent a full interdependency between grassland and livestock. In this paper, switches in system being fixed, sparing grassland can only be reached by change in total demand, animal productivity and spatial reallocation of the production to more productive grasslands.

1.4. Forestry

Although not the focus of this paper, the forestry sector is also represented in GLOBIOM, and participates to land use competition with five types of primary products (pulp logs, saw log, biomass for energy, traditional fuel wood, and other industrial logs) which are consumed by industrial energy or cooking fuel demand or processed and sold on the market as final products (pulp and sawn wood). These products are supplied by managed existing forests and short rotation plantations expanding into other land use type. Harvesting costs and yields are sourced from the G4M global forestry model (Kindermann et al., 2006) on the basis of information on species selection, variation of thinning and choice of rotation length.

1.5. Market equilibrium

Economic concepts are based on spatial equilibrium modeling approach. This modeling technique allows to represent good as homogenous products and to track at the same time price absolute levels and quantities. Demand and international trade are represented at the level of 30 economic regions. Final consumption depends on price levels, whereas bilateral trade is determined depending on marginal cost of production in the different regions, and transportation costs. The algorithm determines the optimal land and resource allocation maximizing an objective function of consumer and producer surplus and provides associated prices. The model is run recursive dynamic along a 10 year steps baseline starting in 2000 and solved using linear programming solver through a GAMS interface.

2. Yield scenarios

2.1. Crop yield

2.1.1. Yield extrapolation in scenarios

Our baseline ("TREND") is built around the assumption than future yields will follow the past trend with a linear extrapolation (Fischer et al, 2009). Historical trend is estimated on the period 1980-2010 using FAOSTAT data, except for Eastern Europe and Former Soviet Union countries where we took the 1995-2010 period to take into account the change in farming structure during the 1990s. As illustrated in figure 1 of the article, average crop yield in developed regions keep a slow pace increase (0.4% p.a. on average) to reach a total yield of 4.9 dry matter (DM) tons per ha by 2050 for the bundle of the 17 crops considered. Latin America, starting slightly lower, succeeds to take a leader position in 2050 at 5 t DM / ha. The good performance of this region can be explained by favorable environmental conditions but also different composition of crops with higher yields (such as sugar cane). Emerging Asia catches up even faster at a growth rate of 1% per year and reaching 4.6 t DM / ha in 2050. This contrasts with the situation in Eastern Europe and Former USSR ("REUR") that started from similar level in the 70s but hardly exceeds 3.6 t DM / ha in 2050 if the current trend continues. Last, Africa, starting from a lower level, remains largely behind other continents with only 40% of the average level of Latin America by 2050. In order to provide more insight on how these trends decompose across regions, figure S1 represents the trend for each region in "blue", which can be compared with past record.

Projecting a continuation of such past trends can appear as an optimistic assumption. Some regions currently show for specific crops a slow-down in their growth rate (eg. wheat in Northern Europe or rice in China; see Cassman et al., 2010). At the same time, there is little ground to impose a plateau on a certain number of crops when projecting up to 2050, considering possibility that new varieties may offer potential to further yield improvements (Fischer et al., 2009). Our "SLOW" scenario therefore reflects an intermediate situation where future yields do not materialize as in the past and some stagnation occur in developing regions. However, we did not apply this alternative assumption to developed regions considering the point of focus of this article is developing regions. This case is explored in a separate sensitivity analysis in section 4.3 of the paper. The "SLOW" trend is visible in figure S1 in red.

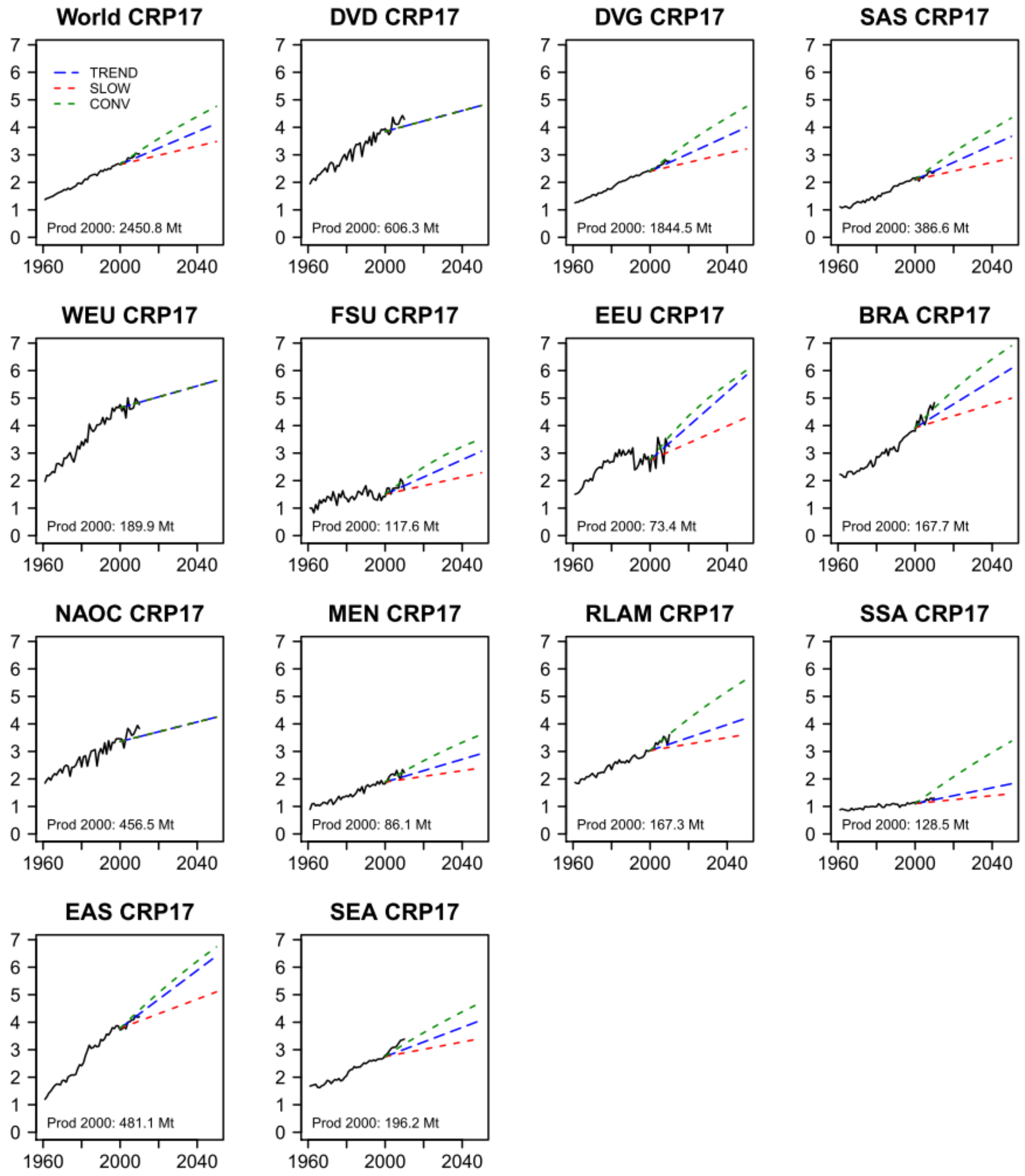

Figure S 1. Historic yield and yield projections according to the TREND, SLOW and CONV scenario for the average of 17 crops in GLOBIOM modeled with EPIC (t DM/ha). DVD= Developed; DVG=Developing. Region codes are the same as in figure 2.

Our last scenario (“CONV”) explores the possibility of exploiting yield gaps that were not closed in the “TREND” scenario. Indeed the yield gap observed in 2000 for some regions can be closing as a business as usual situation if past trends prolong. For example, in the case of China, the yield gap for rice is very limited (see section 2.1.2). With the “TREND” scenario, we therefore assume that additional yield gain will be obtained through other technologies than just intensification under current varieties, in particular through breeding. The “CONV” scenario therefore does not assume additional yield increase due to gap closure, because the historical yield growth is kept as the low bound for yield growth increase for such cases. On the opposite, in Sub-Saharan Africa, extrapolating the past trend let yield potential for most crops largely unexploited under “TREND”. In that case, the additional yield increase following the yield gap closure by 50% in “CONV” makes a significant difference with the baseline.

Obviously, projecting yield towards 2050 remains a very arbitrary exercise. For that reason, we chose the simplest possible baseline with a linear trend to avoid any country or crop specific treatment that would make the process less transparent. Are the future yield projections obtained all biophysically feasible? For developed regions, this remains an opened question, but in a case where the full set of new technologies is used, further yield improvement can be expected. For example, Fischer et al. (2009) list a different track of research to improve potential yield (conventional breeding, increased photosynthetic rates, genetic enhancement through use of wild species, stress tolerance, etc.). Additionally, they reports some potential yield obtained in specific regions much higher than current average farm yield. They also remind that Monsanto has set an objective of doubling corn yield between 2000 and 2030. On the other hand, a caveat of our approach is that we do not take into account possible negative impact of climate change that appears of one of the main challenger of a continuation of past trends. That is why we developed the “SLOW” scenario to explore how such effect could affect the results.

However, when coming to developing countries, it can be seen that our projections hardly lead to greater yields than the current level observed in developed regions. This ensures that projected yield for these regions are feasible from a crop physiology perspective, although each regions has its own growing environmental conditions. Only two crops appear to have yield notably higher than recorded in developed regions. First, cotton is projected in our best scenario as reaching on average 5t/ha in developing regions in “CONV” by 2050. This would obviously require good irrigation conditions but does not seem biophysically infeasible as some yield greater than 4t/ha are regularly reported in some countries like Turkey or Syria (FAOSTAT). The second case is sunflower that we project to levels at 2.5 t/ha on average in developing regions, also for “CONV”. These also appear biophysically feasible, as average yields over 2.5 t/ha are reported for some regions (eg. Mercau et al., 2001 in Argentina).

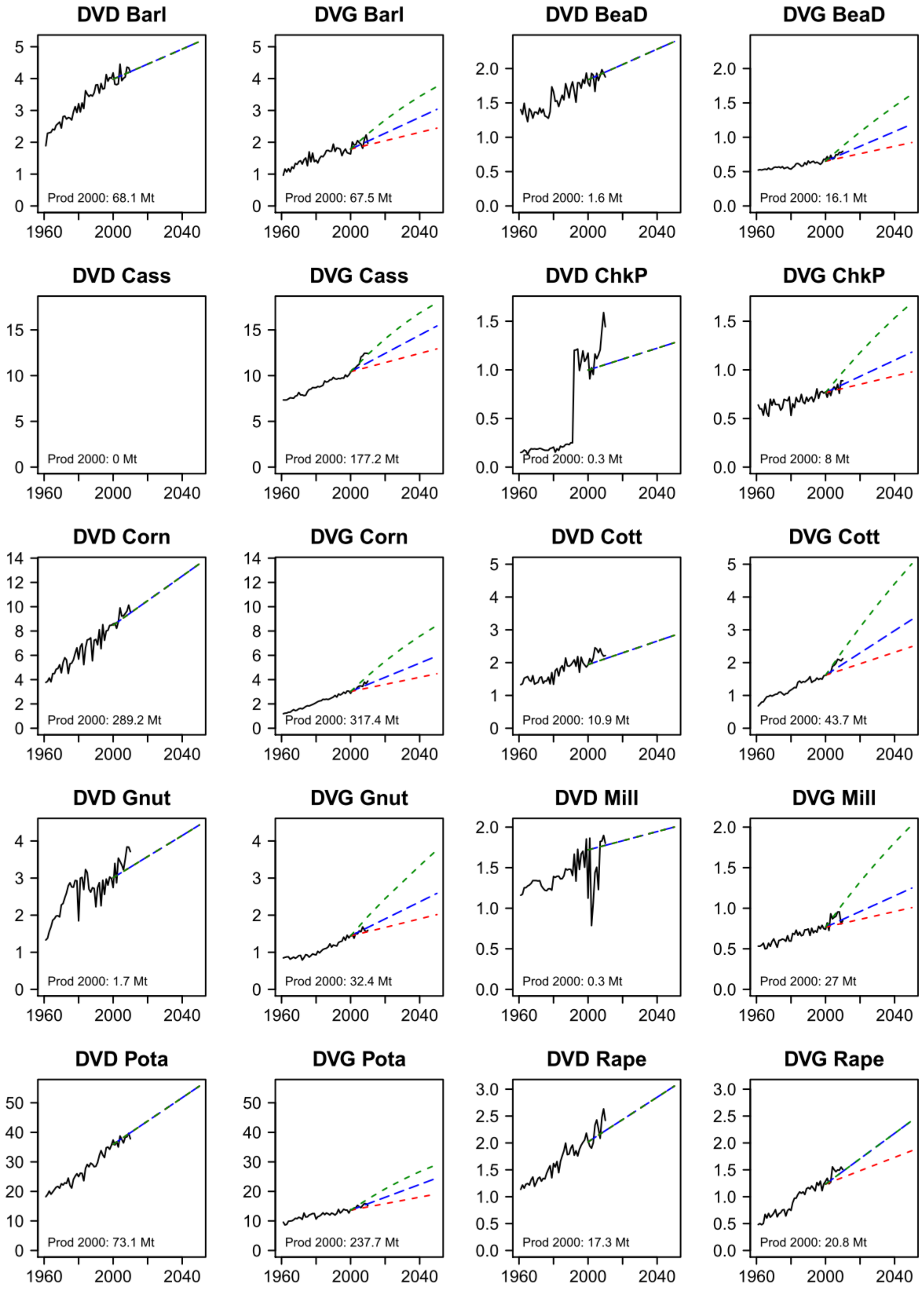

Figure S 2 – Historic yield and yield projections according to the TREND, SLOW and CONV scenario for each of the 17 crops in GLOBIOM modeled with EPIC. DVD= Developed; DVG=Developing. Crops: Barl = barley; BeaD = Dry beans; Cass = Cassava; ChkP = Chick peas; Cott = Cotton; Gnut = Groundnut; Mill = Millet; Pota = Potatoes; Rape = Rapeseed.

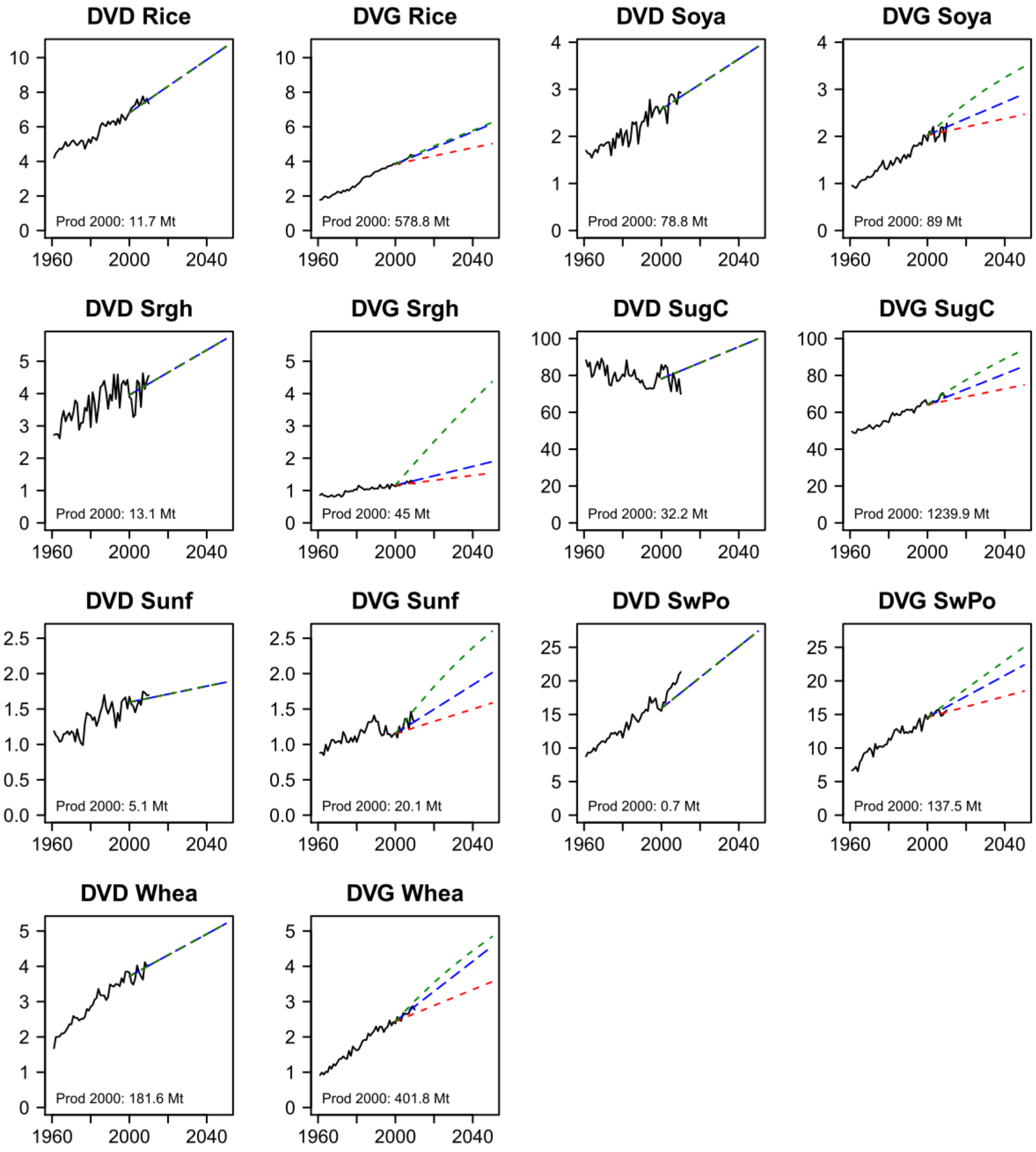

Figure S 2 – (continuation of previous page) Historic yield and yield projections according to the TREND, SLOW and CONV scenario for each of the 17 crops in GLOBIOM modeled with EPIC. DVD= Developed; DVG=Developing. Crops: Soya = Soybeans; Srgh = Sorghum; SugC = Sugar cane; Sunf = Sunflower; SwPo = Sweet potatoes; Whea = Wheat.

2.1.2.Identifying crop yield gaps.

Our crop productivity scenario “CONV” relies on an assumption of closing yield gap by 50% for crops in developing countries. In order to assess yield gaps for crops, we rely on the crop model EPIC which is used to assess for each region potential yield under different management systems: rain-fed cultivation with high level of input (potential water-constrained yield) or irrigated systems with high level of input (pure potential yield). We calculate the average potential yield by applying our high input system to all rain-fed crops and keeping irrigated systems fixed. The gap between this average potential yield at the country level and the FAO reported yield is used as a proxy for yield gap.

The EPIC model is run for the 17 different crops on a world mosaic of homogenous response units (HRUs) defined as the intersection of GIS layers of slope, altitude and soil, at a 5 arcminute resolution, and fit within a grid of 0.5 x 0.5 degree resolution (largest unit area possible; for more information on the concept of HRU, see Skalsky et al., 2008). The high input system (HI) considered is obtained by parameterizing the model with an automatic nitrogen fertilization assumption: N-fertilization rates are automatically applied based on N-stress levels (N-stress free days in 90% of the crop growing period). The upper limit of N application is set at 200 kg/ha/a. For irrigated systems (IR), N and irrigation rates are based on stress levels (N and water stress free days in 90% of the crop growing period. N and irrigation upper limits are 200 kg/ha/a and 300 mm/a. We also run a subsistence farming system for which no fertilizer or irrigation is considered. Information on crop location and management system are source from SPAM (You and Wood, 2008).

We display below the difference in observed FAO yield and attainable yield obtained with the EPIC runs for the three major cereals: wheat, corn and rice. As can be seen on figure S3, our estimated wheat yield gap is at the world level relatively small, with little margin of improvement in Europe or in China that appear close to their potential. Rice is in an even more extreme situation (figure S4), considering that many observed yields are above the values obtained with the crop model. This suggests that no easy improvement can be achieved in those regions for this crop. However, the case of corn (figure S5) shows much more potential with large margin to exploit in Africa, South America or China.

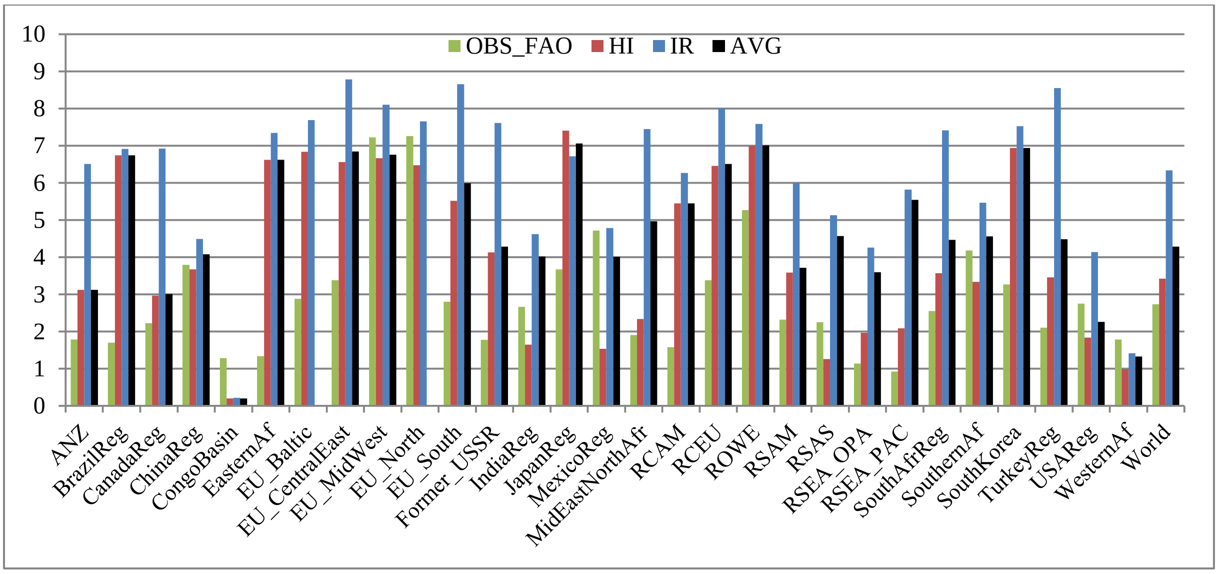

Figure S 3 FAO average wheat yield in 2000 (OBS_FAO), and attainable wheat yield through high input (HI), irrigated (IR) and combined (AVG) systems on the base of current crop location.

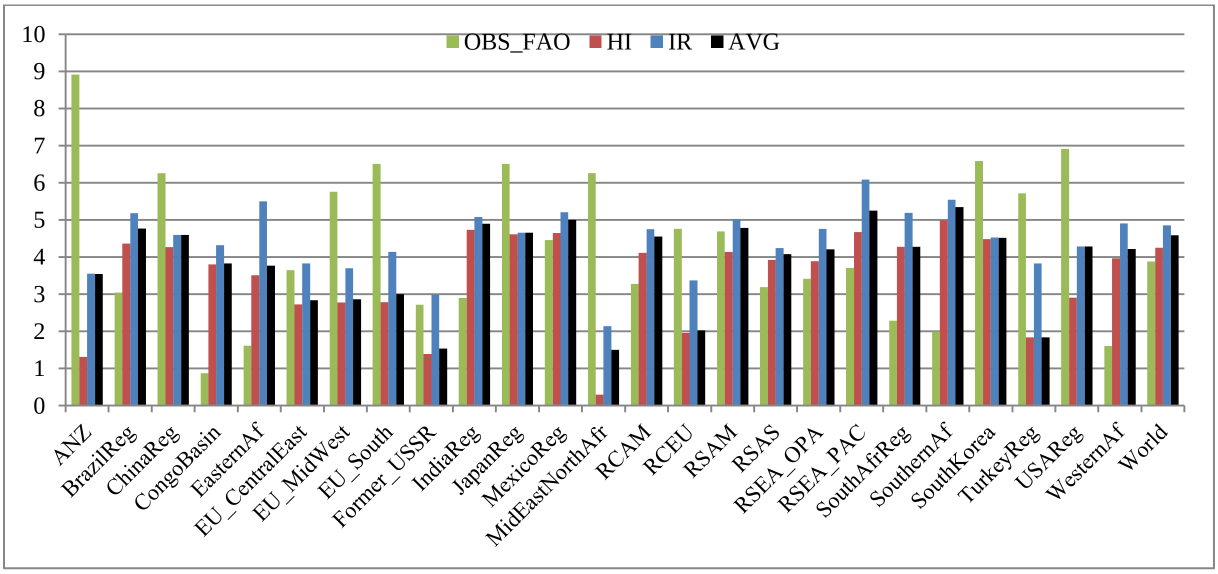

Figure S 4 FAO average rice yield in 2000 (OBS_FAO), and attainable rice yield through high input (HI), irrigated (IR) and combined (AVG) systems on the base of current crop location.

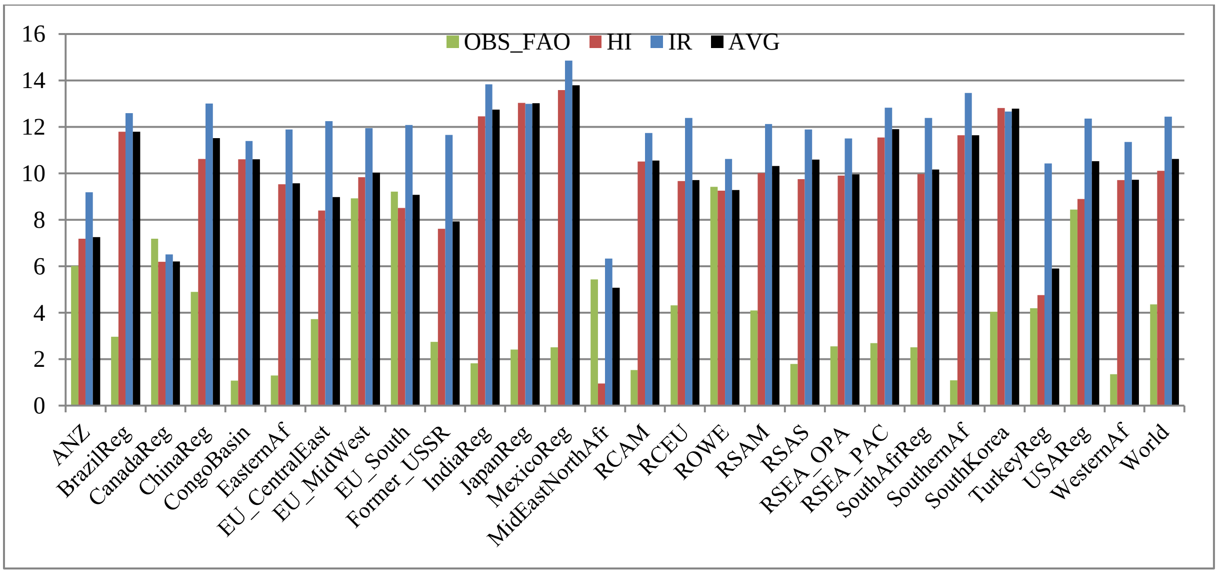

Figure S 5 FAO average corn yield in 2000 (OBS_FAO), and attainable corn yield through high input (HI), irrigated (IR) and combined (AVG) systems on the base of current crop location.

2.1.3. Comparison of our crop yield gap estimates with the literature

In order to assess the relevance of our CONV scenario, we compare our yield gap assessment with some other findings from the literature. The results are presented below in table S1. Two other studies have been used to compare our estimates. Mueller et al. (2012) provide estimates of attainable yield gap under available technologies in different regions of the world. The results presented here are sourced from the figure 2 of their paper, and we reaggregated our results using their regional nomenclature (similar code to this study except for ANZ, Australia-New Zealand, aggregated to South-East Asia, and NAM, North America, separated). These authors in particular calculate what would be the production in different parts of the world if 100% of attainable yield was reached. The other paper used for the comparison is Licker et al. (2010), which provide some maps of yield gaps identified by different colored pixel. As no summary statistics were provided in this paper, we derived from map visual interpretation the range of values for reported yield gaps.

Table S 1. Crop yield gaps in our model and a selection of studies for three major cereals and underlying causes (production in Mt)

		Mueller et al., 2012			GLOBIOM/EPIC			Licker et al., 2010	Main limiting factor[b]	
Region	**Crop**	**Prod 2000**	**Prod att**	**Yield gap**	**Pot. Yield gap**	**Yield gap 50%**	**Prod att 50%**	**Yield gap**	**Muller et al., 2012**	**Neumann et al., 2010**
NAM	Corn	260	300	13%	19%	10%	290	0%-25%	None	Na
NAM	Wheat	80	130	38%	0%	0%	80	12%-62%	N + W	A + I
NAM	Rice	10	10	0%	0%	0%	10	na	None	Na
LAM	Corn	75	140	46%	75%	60%	189	0%-75%[a]	N	I + M[c]
LAM	Wheat	20	35	43%	43%	27%	28	25%-50%	N	Na
LAM	Rice	20	32	38%	24%	14%	23	na	N + W	Na
WEU	Corn	45	60	25%	6%	3%	46	37%-62%	None	Na
WEU	Wheat	95	120	21%	0%	0%	95	0%-25%	None	Na
WEU	Rice	2	2	0%	0%	0%	2			
EEU+FSU	Corn	25	70	64%	60%	42%	43	25%-62%	N + W	Na
EEU+FSU	Wheat	95	205	54%	56%	39%	155	25%-75%	N	A + L
EEU+FSU	Rice	0	0		0%	0%	0			
MENA	Corn	1	5	80%	3%	2%	1	na	na	Na
MENA	Wheat	30	70	57%	59%	41%	51	na	N + W	M + A
MENA	Rice	0	0		0%	0%	0			
SSA	Corn	25	100	75%	86%	75%	102	25%-100%	N + W	M + A
SSA	Wheat	2	5	60%	64%	47%	4	na	N + W	Na
SSA	Rice	10	30	67%	63%	46%	18	na	N	I
SAS	Corn	15	35	57%	85%	74%	58	0%-62%	N + W	M + I
SAS	Wheat	90	170	47%	39%	24%	118	12%-75%	N + W	Na
SAS	Rice	175	280	38%	37%	22%	226	12%-50%	Variable	Na
EAS	Corn	120	225	47%	58%	40%	201	25%-50%	N	Na
EAS	Wheat	100	140	29%	8%	4%	104	0%-75%	None	S + I
EAS	Rice	195	245	20%	0%	0%	195	0-37%	None	Na
SEA+ANZ	Corn	15	20	25%	75%	59%	37	0-25%	None	Na
SEA+ANZ	Wheat	20	45	56%	45%	29%	28	12%-50%	N + W	Na
SEA+ANZ	Rice	140	205	32%	21%	12%	159	25%-50%	Variable	I + L[d]
WORLD	Corn	581	955	39%	57%	40%	968			
WORLD	Wheat	532	920	42%	33%	20%	663			
WORLD	Rice	552	804	31%	23%	13%	633			
NAM+WEU	Corn	305	360	15%	17%	9%	337			
NAM+WEU	Wheat	175	250	30%	0%	0%	175			
NAM+WEU	Rice	12	12	0%	0%	0%	12			
ROW	Corn	276	595	54%	72%	56%	632			
ROW	Wheat	357	670	47%	42%	27%	488			
ROW	Rice	540	792	32%	23%	13%	621			

[a] 0%-37% in South America; 37%-75% in Central America

[b] Limiting factors codes: N = Nutrient; W = Water; M = Market Influence; S = Slope; I = Irrigation; L = Labor; A = Accessibility;

[c] For Central America

[d] Specific information for Indonesia: M + A + L

EPIC estimate are reported in Table S1 for the potential average yield gap, water constrained for rain-fed agriculture location (see previous section), and for the yield gap corresponding to the closure of half this potential gap, which is the gap used for the CONV scenario in the paper. Looking first at the potential estimated yield gaps, we can see some differences between the EPIC potential yield and the attainable yield from Mueller et al., but these differences are usually kept within the range of the value reported by Licker et al.

For corn, we find more important yield gap that in Mueller (57% versus 39%). At the same time, the values for North America appear conservative (13%) and yield increases after a decade are already over this level of attainable yield. Indeed yield gap analysis usually does not represent yield enhancement related to improvement of varieties as it assesses potential yield under current technologies. Considering that only 50% of the gaps are closed leads however to more comparable yield gap (40%) at the world level.

Wheat yield gap assessment is found relatively lower than in Mueller et al. (33% vs 42%). This is mainly due to a very different estimation of yield gaps for North America and Western Europe. As illustrated in the previous section, our EPIC simulations for wheat provide for these regions yield levels slightly lower than the levels currently reached. Therefore, we consider that the yield gap is closed already. In the case of other regions of the world (ROW), our yield gap estimate is however much closer to Mueller et al. (42% vs 47%). Considering only 50% of yield gap can be closed is equivalent to representing for wheat a yield gap of 27%.

With respect to rice, we also find a lower yield gap estimate (23% vs 32% for Mueller et al.) mainly because of different assessment of the yield in Eastern Asia, where we consider there that yield are already closed. For South Asia and South-East Asia, our assessments are more in agreement. As a consequence, and considering our assumption of closing 50% of yield gap, only limited yield boost on rice can be considered for the CONV scenario, and it can only occur in South Asia and South-East Asia.

2.2. Livestock productivity

2.2.1.Feed conversion efficiency calculation

In this study, we look at the improvement of livestock productivity measured as feed conversion efficiency, i.e. feed requirements (in total DM t) by animal product output. All livestock productivity data in GLOBIOM are based on a validated dynamic digestion and metabolism model (RUMINANT, Herrero et al 2002), as described in Herrero et al (2008, 2013) and Thornton and Herrero (2010). The model estimated productivity (milk, meat), methane emissions and manure and N excretion.

In order to reconcile process-based model and national accounts in a consistent framework, bovine and small ruminants’ productivities estimation follows a three steps process which consists of first, specifying a plausible feed ration, second, calculating in RUMINANT the corresponding yield, and finally confronting at the region level with FAOSTAT (Supply Utilization Accounts) data on production. These three steps are repeated in a loop until a match with the statistical data in FAOSTAT was obtained (see details in Herrero et al., 2013 & Havlík et al, 2013a). For monogastrics, information on feed quality is used to estimate feed intake, productivity and feed use efficiency using standard nutrient requirements guidelines from the National Research Council.

The heterogeneity in ruminant productivity across regions seems wider for livestock products than for crops (see from figure S6 to S8) and this is an inherent function of the quality of the diet for ruminants in different regions (Herrero et al, 2013). We compare our base year figures sourced from Herrero et al with some other estimates from the literature (Wirsenius, 2010, and Bouwman, 2005).

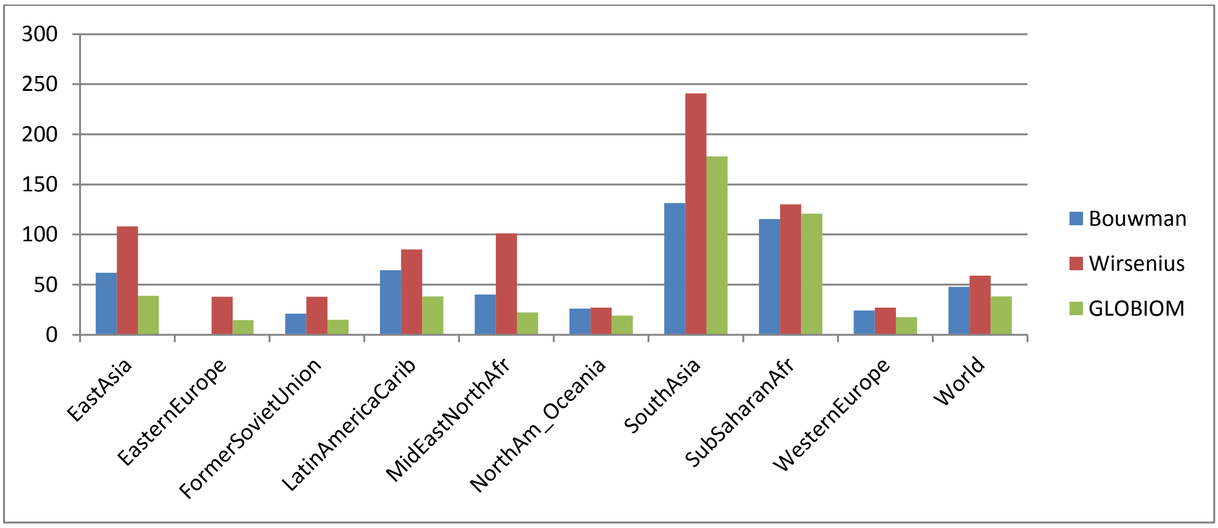

Figure S 6 Feed use per unit of cattle beef according to different sources (kg dry matter feed per kg output). Source: Bouwman (2005), base year: 1995; Wirsenius (2010), base year:1992/94; base year for this paper: 2000.

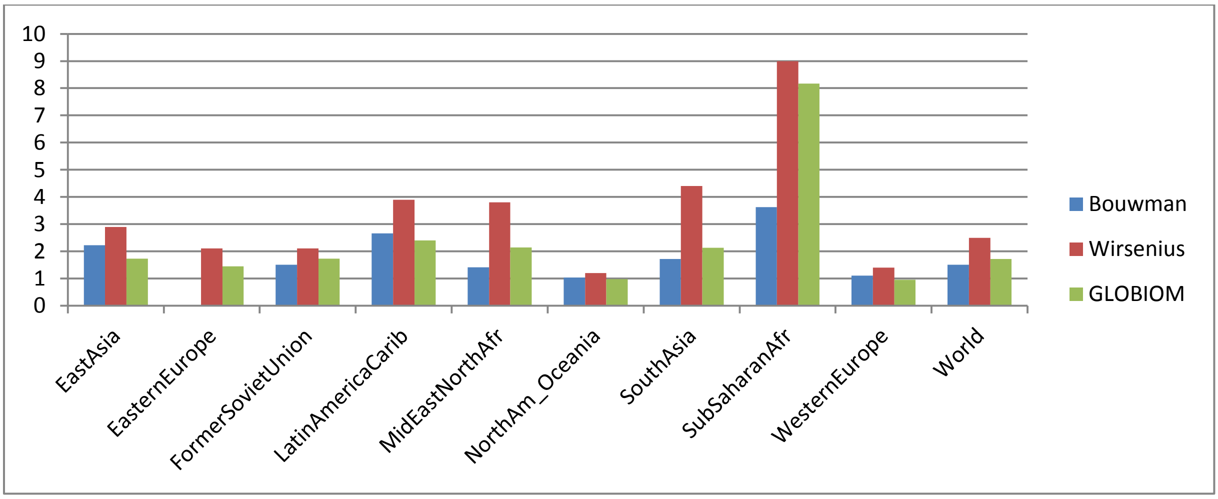

Figure S 7 Feed use per unit of cattle milk according to different sources (kg dry matter feed per kg output). Source: Bouwman (2005), base year: 1995; Wirsenius (2010), base year:1992/94; base year for this paper: 2000.

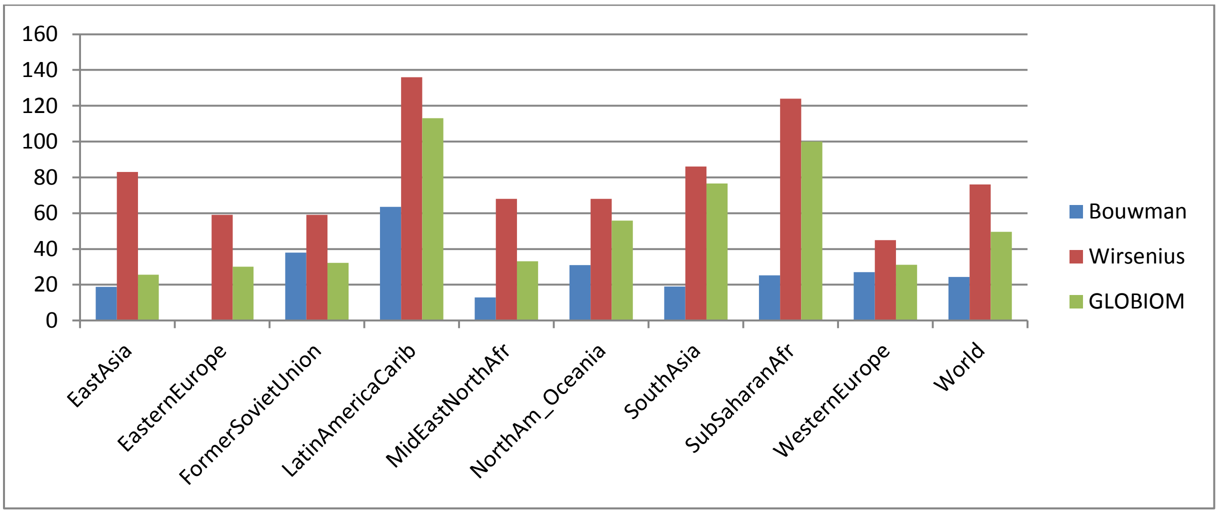

Figure S 8 Feed use per unit of small ruminant meat according to different sources (kg dry matter feed per kg output). Source: Bouwman (2005), base year: 1995; Wirsenius (2010), base year:1992/94; base year for this paper: 2000.

Our estimates appear fully consistent with other sources, however, they also vary for some specific regions, which illustrates the difficulty to precisely characterize the average livestock productivity with the current data available on feed consumption. As can be clearly observed on the different figures, we sometimes tend to agree with Wirsenius (2010) for some regions and for some others with Bouwman (2005). What these figures however illustrate whatever the source chosen is the gap between the production efficiency during developing and developed regions. It is the influenced of reducing this gap that will be at the basis of our scenario on livestock productivity.

For monogastrics, the contrast between developing and developed regions is however much less clear (see figure S9 and S10). According to Bouwman (2005), most regions are already at the efficiency frontier for pigs, whereas Wirsenius shows more disparity, but also sometimes much higher efficiency (ie lower feed use per unit of output). Our data are also inconclusive on a pattern (see Herrero et al. for more details).

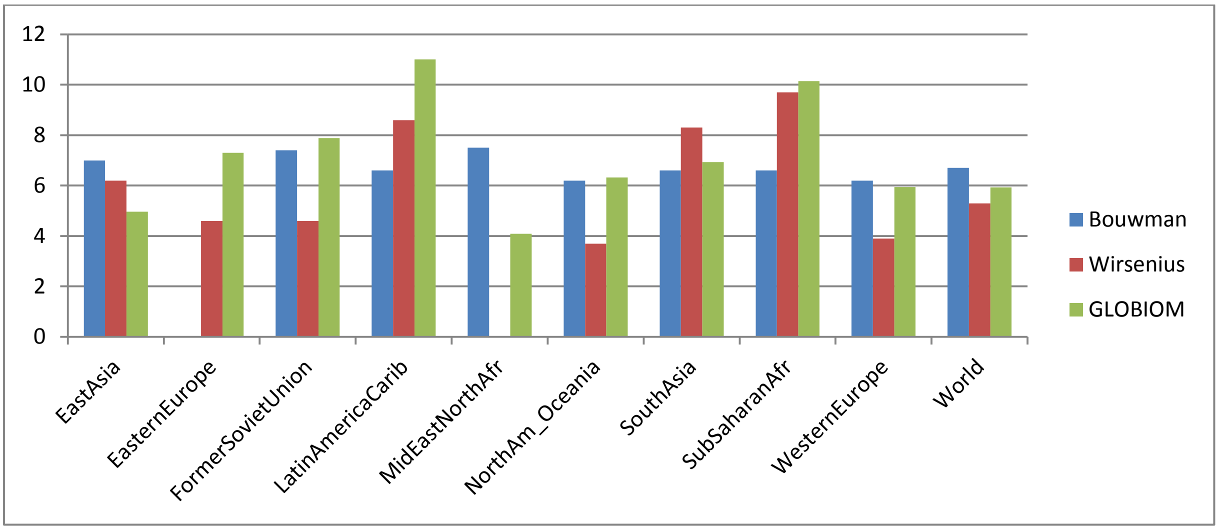

Figure S 9 Feed use per unit of pig meat according to different sources (kg dry matter feed per kg output). Source: Bouwman (2005), base year: 1995; Wirsenius (2010), base year:1992/94; base year for this paper: 2000.

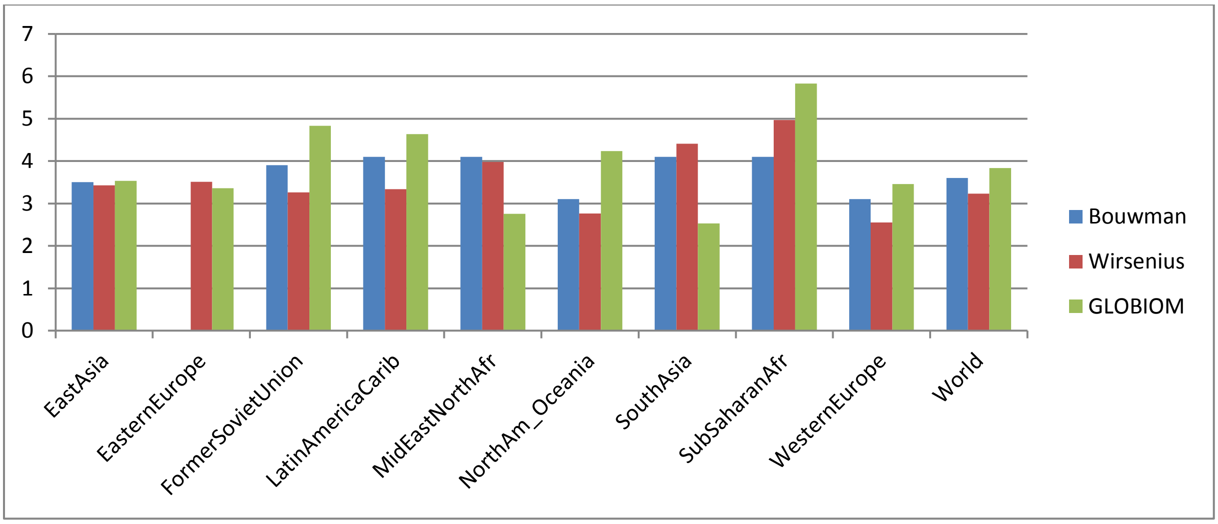

Figure S 10 Feed use per unit of poultry meat and eggs according to different sources (kg dry matter feed per kg output). Source: Bouwman (2005), base year: 1995; Wirsenius (2010), base year:1992/94; base year for this paper: 2000.

Following these observations, in the absence of reliable data on non-ruminant productivity, we decided not to consider any yield gap scenarios in this paper for pigs. This should not affect the conclusions of the paper for two reasons. First livestock direct emissions are emitted for 91% by ruminant (Herrero et al., 2013). Second, non ruminant are not directly link to land, only indirectly through grain feed whose land requirement are at global level evaluated to 320 Mha, ie ten times less than the grassland occupation (3.5 Gha of grassland according to FAO, which about 2 Gha are grazed in GLOBIOM).

2.2.2.Baseline and convergence scenario for feed efficiency

We take in our baseline as our default assumption the livestock productivity trends from Bouwman et al. (2005). In their paper, they propose a trend for livestock productivity until 2030, defined per system and we also implement and these trends for our livestock systems, by animal and category (mixed or grassfed), and prolong them up to 2050.

An overview of the productivity trend obtained for ruminant meat is provided in the figure 1 of the article (panel b). We observe that these productivity trends prolong a satisfactory manner the historical trends (also sourced from Bouwman et al.). Feed conversion efficiency is less than half the efficiency from OECD and Eastern Europe countries and sometimes much lower (almost 10 times lower for Asia in the years 1970).[1] However, some regions have been catching up at considerable pace, such as Asia that reaches half of the level of Latin America today. Following Bouwman et al. trends, we assume in our baseline that Asia gets very close to current Latin America yield by 2050. The catching up patterns are similar in the case of milk products (see figure S11).

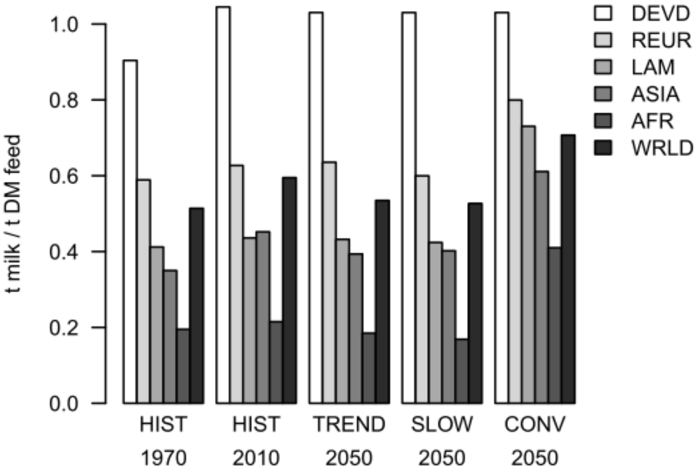

Figure S 11 Average productivity in historical record and for GLOBIOM baseline for ruminant dairy, including replacement animals. Years 1970, 1990, and 2010 are sourced from FAO PRODSTAT database (5-year average for 1970 and 1990 and 3-year average for 2010). Region definition: OECD = OECD members except Eastern European countries; REUR = Eastern Europe and Former USSR; ASIA = South-East and East Asia; LAM= Latin America; WRLD = World.

For the catching up scenario, we assume that 25% of the gap between the present yield and the yield of OECD regions is bridged. For this, we compute a feed conversion efficiency level of reference for

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[1] There is significant uncertainty in characterizing average feed efficiency at the world level at the different period of time. Here, we backcast present productivities such as computed in GLOBIOM from FAOSTAT using the trends of Bouwman et al. (2005).

each of the animals, and follow the convergence path, except if the baseline scenario is higher; in this latter case, we remain on the baseline path, so that the convergence scenario is always higher or equal in trend than the baseline.

3. GHG emissions

Greenhouse gas emissions are at the core of the article analysis. We provide in this section more details on GHG accounts in GLOBIOM and the underlying emission factors and compare with other sources in the literature.

As explained in the table 3 of the article, GLOBIOM accounts for a wide range of sources, in the crop and in the livestock sectors, but also emissions related to land use changes.

3.1. Livestock emissions

In GLOBIOM, we assign the following emission accounts to livestock directly: CH_4 from enteric fermentation, CH_4 and N_2O from manure management, and N_2O from excreta on pasture (N_2O from manure applied on cropland is reported in a separate account linked to crop production). The estimation of these emissions follows an IPCC tier 3 approach for enteric fermentation thanks to the use of the RUMINANT model (section 2.2) to compute emissions for each species and system by region. For other livestock sources, we use a tier 2 approach. Detailed description of how these coefficients are calculated is provided in Herrero et al. (2013). In brief, CH_4 from enteric fermentation is a simultaneous output of the feed-yield calculations in the RUMINANT model, as well as nitrogen content of excreta and the amount of volatile solids. The assumptions about proportions of different manure management systems, manure uses, and emission coefficients are based on detailed literature review.

3.2. Crop sector emissions

Crop emissions sources accounted in the paper are N_2O fertilization emissions, from synthetic fertilizer and from organic fertilizers, as well as CH_4 methane emissions from rice cultivation.

Synthetic fertilizers are calculated on a Tier 1 approach, using the information provided by EPIC on the fertilizer use for each management system at the simulation unit level and applying the emission factor from IPCC AFOLU guidelines. Synthetic fertilizer use is therefore built in a bottom up approach, but upscaled to the International Fertilizer Association statics on total fertilizer use per crop at the national level for the case where calculated fertilizers are found too low at the aggregated level. This correction allows to ensure a full consistency with observed fertilizer purchases.

Organic fertilizer emissions are calculated with RUMINANT, following a methodology similar to what was applied for livestock allocated emissions.

In the case of rice, we only apply a Tier 1 approach, with a simple formula where emissions are proportional to the area of rice cultivated. Emission factor is taken from FAO.

3.3. Land use change emissions

Land use change emissions are computed based on the difference between initial and final land cover carbon stock. For forest, above and below-ground living biomass carbon data are sourced from Kindermann et al. (2008), who provide geographically explicit allocation of the carbon stocks. The carbon stocks are consistent with the Forest Assessment Report (FRA 2010). Therefore, our emission factors for deforestation are in line with those of FAO.

Additionally, carbon stock from grasslands and other natural vegetation is also taken into account using the above and below ground carbon from the biomass map of Ruesch and Gibbs (2008).

When forest or natural vegetation is converted into some agricultural use or short rotation plantation, we consider in our approach that all below and above ground biomass is released in the atmosphere. However, we do not account for litter, dead wood and soil organic carbon.

3.4. Comparison with the literature

GLOBIOM incorporates main sources of GHG emissions for agricultural and land use change. These sources are all listed in Table 3 of the paper. In this section, we compare our emission estimates with those of some other inventories and observations.

3.4.1.Agriculture

For emissions from agriculture, we compare our base year emissions with those of three sources: FAOSTAT (Tubiello et al., 2013), EPA non CO_2 emission database (2012), and EDGAR v4.2 from JRC & PBL (2009). As can be observed in Table S2 below, organized following the 1996 UNFCCC reporting guidelines, these different databases report varying range of sources and emission values.

In terms of source coverage, we cover 94.1% of emissions sources reported by FAOSTAT (only missing non CO_2 emissions from soil and burning from agricultural residues and drained organic soil). Because they are not classified by UNFCCC as agricultural source, emissions from fertilizer production are not accounted by these different inventories and not reported in GLOBIOM. However, another important source of emissions missing in FAOSTAT is Savannah burning (5.9% of agricultural emissions according to EDGAR v4.2. and up to 19.2% of emissions in EPA database - aggregated with agricultural residues and other agricultural soil emissions). Overall, Tubiello et al. (2013) estimate that the FAOSTAT GHG database represents 80-85% of all agricultural emissions.

Total emissions allocated to agriculture vary across databases not only because of the number of sources covered but also because of the level of emission reported for each source. However, because the intervals of confidence associated to each source are large, this does not reflect inconsistencies. Overall, emissions in GLOBIOM are 9% lower than FAOSTAT estimates for the same sources, 18% lower than EPA and 27% lower than EDGAR v4.2. A part of this difference is attributable to the way livestock emissions are computed. Herrero et al (2013) use a tier 3 approach for enteric fermentation and also disaggregated them into 9 types of production systems for 28 regions. A large proportion of animals in the developed world are in systems of low productivity, which drive gross emissions downwards in comparison to other estimates based on Tier 1 methods, which use aggregated data. Our tier 3 method also provides more realistic estimates of feed intake for low quality diets, which is a crucial factor driving the lower gross emissions of these large numbers of animals.

Table S 2. Global GHG emissions from agriculture in 2000 under UNFCCC framework in GLOBIOM and different databases ($MtCO_2$-eq/yr)

UNFCCC 1996 CRF code		GLOBIOM	FAOSTAT[1]	EPA 2012	EDGAR v4.2
4A	**Enteric fermentation**	**1,502**	**1,863**	**1,811**	**2,283**
4B	**Manure Management**	**457**	**323**	**390**	**363**
	CH_4	251	168	216	271
	N_2O	207	155	174	92
4C	**Rice cultivation**	**487**	**490**	**495**	**839**
4D	**Agricultural soil**	**1,009**	**1,530**	**1,684**	**1,584**
	Synthetic fertilizer N_2O	522	521	na[2]	713
	Manure left on pasture	403	675	na[2]	528
	Manure applied on cropland	83	105	na[2]	236
	Other Soil emissions (CO_2)	na	na	na[2]	107
	Crop residues N_2O	na	132	na[2]	na
	Drained organic soils N_2O	na	97	na[2]	na
4E	**Prescribed burning of Savannas**				**306**
	CH_4	na	na	na	154
	N_2O	na	na	na	152
4F	**Field Burning of Agricultural Residues**		**19**		**44**
	CH_4	na	14	na	34
	N_2O	na	5	na	10
ND	**Other Agricultural emissions (EPA)[3]**			**1,043**	
	CH_4	nd	nd	344	nd
	N_2O	nd	nd	699	nd
TOTAL GLOBIOM sources		**3,455**	**4,206**	**4,380**	**4,962**
TOTAL Agriculture		**3,455**	**4,225**	**5,423**	**5,312**
	GLOBIOM Sources coverage		*94.1%*	*80.8%*	*93.4%*

1 Accessed 14/05/2013

2 Detailed not provided. For comparison of GLOBIOM source coverage, we assume the full aggregate covers GLOBIOM sources.

3 EPA only reports an aggregate for Savanna burning, agricultural residues burning, and other agricultural soils

nd= not defined; na=not available

3.4.2.Land use change emissions

Land use change dynamics traced in the model also cover only a part of afforestation, land use and land use change emissions sources (AFOLU). Because the model does not monitor geographic reallocation at a finer scale that its grid cell resolution (in this study 2 x 2 degrees), deforestation measured is only net deforestation, calculated in each pixel as the difference between final and initial forest cover. Afforestation in developed regions is not modeled and supposed unaffected by agricultural expansion. Therefore, our deforestation figures need to be compared to net tropical deforestation statistics, which report lower deforestation and emission numbers than gross deforestation. Table S3 presents the level of GHG emissions reported by a few assessments for land use change emissions. As can be seen looking at the EDGAR database, land use change emissions from forest biomass only account for a share of 32% of total emissions attributable to land use change. However, EDGAR assumes a low figure for biomass land use change emissions. If this figure was replaced by the FAOSTAT estimate, the share of emissions represented in GLOBIOM would be higher at 51%.

Table S 3. Global CO_2 emissions for land use change according to different sources and in GLOBIOM ($MtCO_2$/yr)

	EDGAR v4.2	**FAOSTAT**			**Pan et al. (2011)**		**GLOBIOM**	
							TREND	**SLOW**
Land use change sources	**2000**	**1995-2000**	**2001-2005**	**2006-2010**	**1990-2000**	**2000-2007**	**2000-2030**	**2000-2030**
Net forest conversion (living biomass)[1]	**1,622**	**3,599**	**2,634**	**2,616**	**na[3]**	**na[3]**	**1,306**	**1,588**
Net tropical deforestation[2]	1,622	4,021	3,181	2,984			1,306	1,588
Forest cover rest of the world	na	-422	-546	-368			na	na
Other vegetation conversion	na	na	na	na	na	na	591	703
Decay of wetlands/peatlands	2,345	na	na	na	na	na	na	na
Forest fires-post burn decay incl. decomposition of peatlands due to drainage	1,172	na	na	na	na[3]	na[3]	na	na
TOTAL GLOBIOM sources	**1,622**	**3,599**	**2,634**	**2,616**	**na**	**Na**	**1,897**	**2,291**
TOTAL reported	**5,139**	**3,599**	**2,634**	**2,616**	**5,353**	**4,033**	**1,897**	**2,291**

[1] differently labelled depending on database: EDGAR: Forest fires inc. Peat fires - attributed by authors of this paper to tropical areas mainly; FAOSTAT: Converted forest - living biomass emissions; Pan et al.: Tropical land use change emissions account account for living biomass and loss in forest dead wood, litter and soil carbon.

[2] For a consistent match with tropical forest basin accounted for deforestation in GLOBIOM, the following regional aggregates were allocated in FAOSTAT to net tropical deforestation : Africa+, South America+, Central America+, South-Eastern Asia+;

[3] Pan et al. (2011) provide details on the different stock in living and dead carbon stock for various regions; however, this also includes the forest regrowth effect, therefore we only reported the total emissions associated to net tropical deforestation, including carbon decay.

Emissions presented in the main scenario of this paper correspond to the release of living biomass carbon in forest and other natural land. Two important sources are therefore omitted:

- Carbon decay emissions, released from dead wood, litter and forest soil are not accounted, because, apart from forest, this information is not implemented in the model for other land use type – Ruesch and Gibbs (2008) maps only provide living biomass carbon stock. Additionally, soil carbon stocks in different biomes significantly depend on soil management practices that we do not explicitly represent here. Because the importance of soil carbon emissions following forest conversion is widely acknowledged, we perform a sensitivity analysis on the forest emission factor, assuming that all the carbon from dead wood, litter and soil is also emitted.
- Peatland emissions are also not accounted in this paper. This is mainly due to the difficulty of precisely allocating the share of agricultural expansion going into peatland and to limited information about peat land management. Due to the high uncertainty around the magnitude of peatland emissions (Murdiyarso et al., 2010), we decided for this paper not to consider this source.

Net tropical deforestation emissions trend for the period 2000-2030 is estimated in GLOBIOM around 1,300 $MtCO_2$/year (scenario TREND). This represents 44% of the total net tropical deforestation emissions attributed by FAO to the period 2006-2010. Three different reasons explain why we assume a lower level of deforestation emissions in our baseline:

i) We only represent in the model agricultural drivers of deforestation. These drivers represent around 80% of deforestation causes worldwide (Geist and Lambin, 2002; Hosonuma et al., 2012). Figure S12 illustrate how our deforestation emission estimates would be affected if we could account for other deforestation drivers and 30% of deforestation is due to subsistence agriculture, whose dynamics is difficult to trace in an economic equilibrium model, because disconnected from market evolutions.

ii) The second cause of difference is the assumption that future agricultural expansion will occur more largely than before in non-forested area. Historically, it was estimated that 80% of agricultural expansion would take place in forest (Gibbs et al., 2010). In our projections, only 50% of agriculture expansion is at the expense of forest on the period 2000-2030 and this share falls to 30% on the period 2030-2050. This decrease of deforestation is in line with current statistical reporting (see Fig S12) and policy evolution in regions such as Brazil where change in governance and enforcement have recently diminished pressure on the Amazon (Nepstad et al., 2009; Macedo et al., 2012; Nolte et al., 2013).

iii) The third cause is related to our baseline assumptions that yield and feed efficiency will follow their historical patterns over the next 50 years. The sensitivity to this factor is well illustrated by the paper. When we assume in the “SLOW” scenario that yield growth is lower, emissions increase by 22%. An even more pessimistic scenario is explored with the same model in Havlík et al. (2013), where yield are maintained at their current level of 2000 when projecting in the future (scenario S0). Under such an assumption, deforestation is doubled when compared to the baseline. Land use change emissions in our baseline are therefore to be interpreted in light of our baseline underlying assumption.

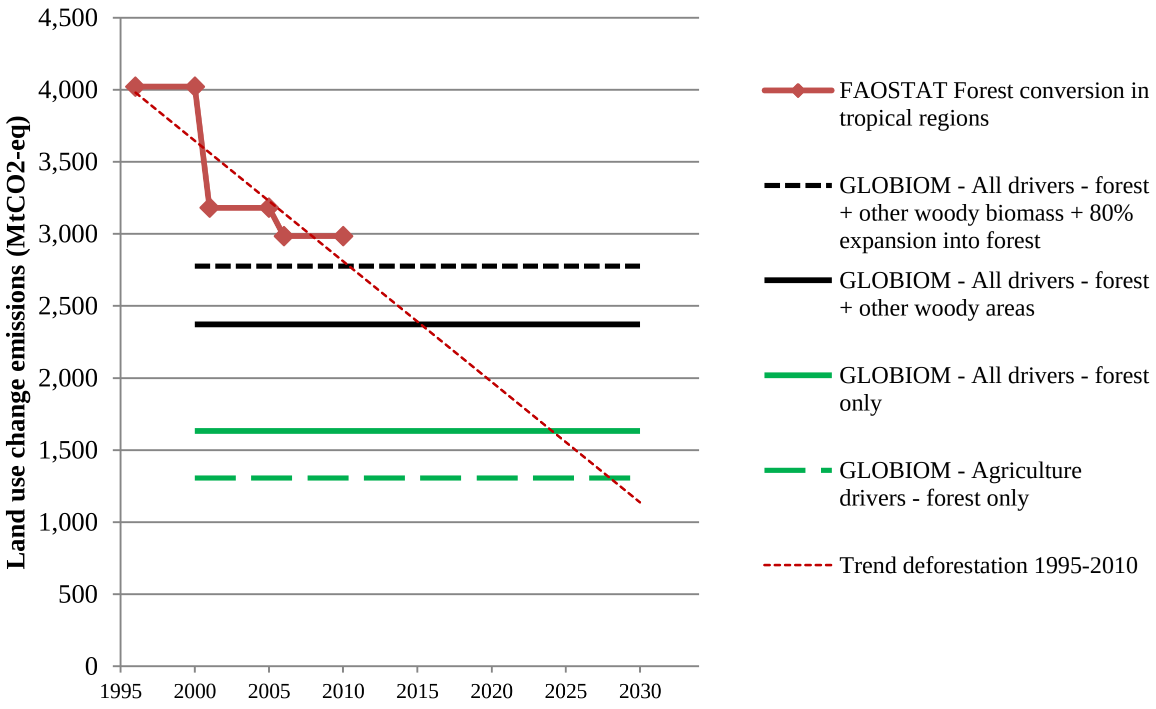

Figure S 12. Land use change related biomass emissions reported in FAOSTAT on the period 1995-2000, 2000-2005 and 2005-2010 for tropical forest, and GLOBIOM average projection for 2000-2030, under different accounting assumptions. FAO figures come from table S1.

FAOSTAT trend and GLOBIOM projected values are compared in Fig S12. It can be seen that if all drivers are taken into account for deforestation, the FAO trend would reach GLOBIOM estimate between 2020 and 2025. If emissions from woody biomass are added, the level of emissions is much higher and reached around 2015. Last, if we assume that 80% of new agricultural land expands into forest, the level of emissions reaches almost the level observed on the period 2005-2010 by FAO.

3.5. GHG emissions uncertainties

Emissions uncertainty can be related to two main factors: i) uncertainty in activity level, ii) uncertainty in emission factor (Tubiello et al., 2013). In the paper, we chose to address activity level uncertainty through sensitivity analyses around the model results. Error bars on graphs reflect uncertainty in emission factors, with a 95% confidence interval, as provided by IPCC 2006 guidelines. The only exception was made for enteric fermentation calculated from Herrero et al. (2013) and based on a Tier 3 approach. The uncertainty estimate for this source was evaluated at +/- 20%. For emissions from land use change, we directly used the uncertainty estimates from Pan et al. (2011) who report their results with an overall +/-66% confidence interval. Uncertainty confidence intervals were applied at the level of the 10 regional aggregates and propagation of errors formula were applied when aggregating across sources. However, we did not apply propagation of errors across regions and simply summed uncertainty intervals to obtain the world level uncertainty.

Table S 4. Uncertainty intervals considered for the uncertainty analysis.

Sector	Source	GHG	Uncertainty
Crops	Rice methane	CH_4	+/-15%
Crops	Synthetic fertilizers	N_2O	+200%/-66%
Crops	Organic fertilizers	N_2O	+200%/-66%
Livestock	Enteric fermentation	CH_4	+/- 20%
Livestock	Manure management	CH_4	+/- 30%
Livestock	Manure management	N_2O	+/- 50%
Livestock	Manure grassland	N_2O	+200%/-66%
Forest	Land use conversion	CO_2	+/-66%
Other vegetation	Land use conversion	CO_2	+/-66%

4. Complementary results on baseline developments and scenarios

4.1. Food demand

4.1.1.Representation of food demand in the model

In GLOBIOM, users of agricultural and wood products are households, livestock for intermediate consumption of feed, sawn wood and wood pulp demand, and bioenergy demand. Each of the 30 economic regions in the model is calibrated on the data from FAOSTAT (food Supply Utilization Account). Final demand and demand for wood products are represented through isoelastic functions for each region and markets. Price elasticities for food are specific to each region and product group (see table S5), and sourced from estimates of USDA (Muhammad et al., 2011). A sensitivity analysis on the values of these elasticities is performed to test the sensitivity of results to these values.

Because we rely on FAOSTAT, it is important to note that our representation of "Food" use corresponds to final demand of households (Food supply to households or Food availability), ie it includes effective food consumption by households but also domestic waste. Therefore, an increase or decrease in food demand does not only inform on change in food ingestion by individuals, but also on change in consumer habit with respect to food handling.

Table S 5. Demand elasticities applied for a selection of most important food products

	Wheat	Corn	Rice	Soya	Cassava	Bovine meat	Pig meat	Poultry meat	Diary
WRLD	-0.27	-0.28	-0.35	-0.24	-0.45	-0.44	-0.47	-0.44	-0.46
NAOC	-0.05	-0.05	-0.05	-0.05	-0.22	-0.26	-0.27	-0.26	-0.28
WEU	-0.05	-0.05	-0.05	-0.06	-0.23	-0.36	-0.36	-0.36	-0.37
EEU	-0.17	-0.17	-0.16	-0.21	-0.34	-0.47	-0.46	-0.46	-0.48
FSU	-0.22	-0.22	-0.22	-0.25	-0.36	-0.5	-0.5	-0.5	-0.52
BRA	-0.27	-0.27	-0.27	-0.29	-0.38	-0.51	-0.51	-0.51	-0.53
RLAM	-0.23	-0.19	-0.27	-0.25	-0.39	-0.5	-0.5	-0.5	-0.53
EAS	-0.36	-0.35	-0.36	-0.35	-0.43	-0.51	-0.55	-0.53	-0.49
SAS	-0.38	-0.38	-0.38	-0.4	-0.46	-0.57	-0.57	-0.57	-0.59
SEA	-0.32	-0.33	-0.33	-0.34	-0.41	-0.55	-0.55	-0.54	-0.56
MENA	-0.28	-0.28	-0.29	-0.3	-0.39	-0.52	-0.52	-0.52	-0.53
SSA	-0.39	-0.4	-0.41	-0.4	-0.49	-0.57	-0.58	-0.55	-0.59

4.1.2.Food demand development towards 2050

Our baseline is based on the Shared Socio-Economic Pathway “Middle of the Road” (SSP2; see O’Neill, 2011). Under this scenario, the world population reaches 9.2 billion people by 2050, whereas the average world GDP per capita increases from 6,700 USD in 2005 to 16,000 USD in 2050. The food demand projections in GLOBIOM are based on income elasticities calibrated on FAO trends (Alexandratos and Bruisma, 2012) and the world food consumption grow in our model by 68% in kcal terms between 2000 and 2050 and reaches 3,045 kcal/cap/day at that horizon (see table S6). The share of animal products in diet only slightly increases, from 16% in 2000 to 17.3% in 2050 (table S7).

Table S 6. Food demand per capita for each region and for the world under the “High-Input” and “Sust-Int” pathways (kcal/cap/day).

	2000	**2030**	**2050**	**2050**			
		TREND		**SLOW**	**CONV**	**CONV-C**	**CONV-L**
NAOC	3,650	3,644	3,665	3,650	3,677	3,671	3,671
WEU	3,488	3,459	3,472	3,450	3,509	3,484	3,498
EEU	3,136	3,324	3,401	3,355	3,466	3,421	3,443
FSU	2,796	3,068	3,208	3,131	3,296	3,245	3,268
BRA	2,881	3,019	3,165	3,110	3,355	3,184	3,335
RLAM	2,752	3,011	3,179	3,141	3,270	3,195	3,253
EAS	2,898	3,230	3,361	3,330	3,381	3,363	3,380
SAS	2,324	2,617	2,800	2,748	2,958	2,907	2,840
SEA	2,402	2,690	2,898	2,838	2,902	2,886	2,922
MENA	3,134	3,201	3,270	3,249	3,317	3,300	3,291
SSA	2,177	2,501	2,742	2,649	3,123	3,070	2,780
WRLD	**2,731**	**2,921**	**3,045**	**2,993**	**3,189**	**3,147**	**3,082**

Table S 7 Share of livestock products in diet for different scenarios under the “High-Input” and “Sust-Int” pathways.

	2000	2030	2050	2050			
		TREND		SLOW	CONV	CONV-C	CONV-L
NAOC	27.4%	27.2%	27.2%	27.0%	27.3%	27.2%	27.3%
EEU	27.6%	29.7%	29.8%	29.2%	30.7%	29.8%	30.5%
WEU	33.9%	33.2%	33.2%	32.8%	33.7%	33.2%	33.6%
FSU	23.8%	27.9%	28.8%	28.3%	29.8%	28.8%	29.8%
BRA	21.7%	25.3%	26.3%	26.0%	30.2%	26.5%	30.1%
RLAM	2,752	3,011	3,179	3,141	3,270	3,195	3,253
EAS	18.1%	24.6%	27.0%	26.6%	27.4%	27.0%	27.4%
SAS	8.4%	10.5%	13.2%	13.1%	14.0%	12.9%	14.3%
SEA	7.4%	11.5%	15.2%	14.7%	15.8%	15.5%	15.6%
MENA	10.4%	11.6%	12.8%	12.6%	13.2%	12.8%	13.2%
SSA	5.9%	5.3%	5.6%	5.5%	5.9%	5.1%	6.6%
WRLD	16.0%	17.0%	17.3%	17.2%	17.7%	16.9%	18.2%

4.2. Production and market prices

The evolution of production, trade and feed versus food use are reported in table S8. Trade and agricultural policies are supposed unchanged and but other competitive use of agricultural products are increasing with bioenergy demand. First generation biofuels extend to the current commitments levels until 2030 and are later stabilized. Bioenergy and biomass use for heating and cooking are fixed exogenously following scenarios from the POLES model (Russ et al., 2007). Price evolution remain relatively moderate thanks to the productivity increase assumptions (see table S9).

Table S 8. Production, demand and trade for main product aggregates for scenarios TREND, SLOW and CONV and for each pathway, in 2000 and 2050 (million tons).

	2000	**2050**				
	TREND	**TREND**	**SLOW**		**CONV**	
	HI	**HI**	**HI/SI**	**FT**	**HI/SI**	**FT**
Cereals						
Supply	1,998	3,436	3,385	3,268	3,536	3,703
Trade	148	362	437	711	340	325
Feed Demand	712	1,383	1,368	1,305	1,390	1,478
Final Demand	1,270	1,875	1,838	1,784	1,967	2,046
Oilseeds						
Supply	394	897	887	854	932	966
Trade	153	326	401	429	310	337
Feed Demand	155	304	299	281	308	332
Final Demand	237	549	543	528	579	589
Other crops						
Supply	1,918	4,979	4,909	4,642	5,016	5,360
Trade	148	246	247	409	215	328
Feed Demand	281	1,104	1,050	908	1,152	1,333
Final Demand	1,484	2,727	2,712	2,587	2,717	2,880
Ruminant meat						
Supply	70	107	98	98	130	132
Trade	3	10	11	11	7	7
Final Demand	70	107	98	98	130	132
Pig and poultry meat						
Supply	215	454	450	430	459	484
Trade	7	10	11	14	10	9
Final Demand	215	454	450	430	459	484
Milk						
Supply	585	943	910	907	1,055	1,049
Trade	24	184	177	176	168	174
Final Demand	585	943	910	907	1,055	1,049

Table S 9. Price index for crops and livestock products by regions and scenario in 2050 (Index 2000 = 1)

	TREND	SLOW		CONV		CONV-C		CONV-L	
	HI	HI/SI	FT	HI/SI	FT	HI/SI	FT	HI/SI	FT
Crops									
BRA	0.98	1.02	1.18	0.97	0.85	0.97	0.85	0.98	0.98
EAS	0.98	1	1.19	0.98	0.93	0.98	0.93	0.98	0.98
EEU	0.96	1	1.18	0.94	0.89	0.94	0.89	0.96	0.96
FSU	0.97	1.02	1.17	0.93	0.72	0.94	0.72	0.97	0.97
MENA	1	1.02	1.15	0.97	0.87	0.97	0.88	1	1
NAOC	0.99	1.03	1.19	0.98	0.94	0.98	0.94	0.99	0.99
RLAM	1.01	1.03	1.18	1	0.79	1	0.79	1.01	1.01
SAS	1.08	1.13	1.29	1.03	0.89	1.04	0.89	1.07	1.08
SEA	1.03	1.07	1.28	1.03	0.9	1.03	0.9	1.03	1.03
SSA	1.08	1.15	1.25	0.95	0.74	0.96	0.74	1.07	1.08
WEU	0.96	1.02	1.18	0.93	0.87	0.93	0.87	0.96	0.96
WRLD	**1.02**	**1.06**	**1.21**	**0.98**	**0.85**	**0.98**	**0.85**	**1.01**	**1.02**
Livestock									
BRA	1.44	1.64	1.74	0.84	0.79	1.4	1.31	0.87	0.88
EAS	1.04	1.14	1.22	0.97	0.94	1.03	1	0.98	0.98
EEU	1.05	1.14	1.2	0.93	0.91	1.02	0.99	0.95	0.97
FSU	1.12	1.22	1.26	1	0.93	1.1	1	1.03	1.03
MENA	1.71	1.82	1.84	1.53	1.51	1.71	1.69	1.56	1.53
NAOC	1.08	1.14	1.23	1.02	1	1.06	1.04	1.04	1.03
RLAM	1.15	1.25	1.3	0.93	0.88	1.11	1.05	0.96	0.96
SAS	1.81	1.93	1.99	1.43	1.34	1.77	1.7	1.46	1.45
SEA	1.11	1.27	1.4	0.93	0.8	1.09	0.94	0.95	0.94
SSA	1.61	1.77	1.85	1.16	0.99	1.53	1.36	1.2	1.19
WEU	1.39	1.48	1.54	1.22	1.18	1.36	1.32	1.25	1.24
WRLD	**1.27**	**1.37**	**1.44**	**1.09**	**1.04**	**1.24**	**1.18**	**1.12**	**1.11**

4.3. Land use change for baseline and scenarios

Changes in yield directly affect the demand for land and generates additional GHG emissions through agricultural land expansion. Table S10 below indicates the magnitude of land use change in the baseline and the different yield scenarios and pathways.

Table S 10. Land use change at world level on the periods 2000-2030 and 2000-2050 for the different scenarios and pathways (Mha)

	2000-2030					2000-2050				
	CrpLnd	**GrsLnd**	**Forest**	**NatLnd**	**PltFor**	**CrpLnd**	**GrsLnd**	**Forest**	**NatLnd**	**PltFor**
TREND										
HI	126	61	-131	-116	61	204	150	-216	-283	145
CONV										
HI/SI	59	-36	-91	8	61	118	16	-164	-114	145
diff	*-66*	*-97*	*40*	*124*	*0*	*-87*	*-133*	*51*	*169*	*0*
FT	83	44	-116	-72	62	133	110	-193	-196	146
diff	*-43*	*-17*	*14*	*44*	*1*	*-72*	*-39*	*23*	*87*	*1*
CONV-C										
HI/SI	56	77	-116	-77	61	108	172	-200	-225	145
diff	*-69*	*16*	*14*	*39*	*0*	*-96*	*22*	*16*	*58*	*0*
FT	83	88	-128	-105	62	130	185	-214	-247	146
diff	*-43*	*27*	*3*	*11*	*1*	*-74*	*35*	*2*	*36*	*1*
CONV-L										
HI/SI	130	-47	-109	-34	61	212	3	-179	-181	145
diff	*4*	*-108*	*22*	*82*	*0*	*8*	*-146*	*36*	*102*	*0*
FT	127	24	-121	-91	61	208	83	-197	-238	145
diff	*2*	*-36*	*9*	*25*	*0*	*4*	*-67*	*18*	*45*	*0*
SLOW										
HI/SI	175	93	-151	-176	60	267	172	-243	-341	144
diff	*49*	*32*	*-20*	*-60*	*-1*	*63*	*23*	*-27*	*-58*	*0*
FT	153	61	-139	-134	60	231	148	-228	-296	145
diff	*27*	*0*	*-8*	*-18*	*0*	*27*	*-2*	*-12*	*-13*	*1*

Note: *diff* is the calculation of the difference to the reference scenario (TREND HI).

HI = High-Input; SI = Sust-Intens; FT = Free-Tech.

4.4. GHG emissions by region for the three convergence pathway

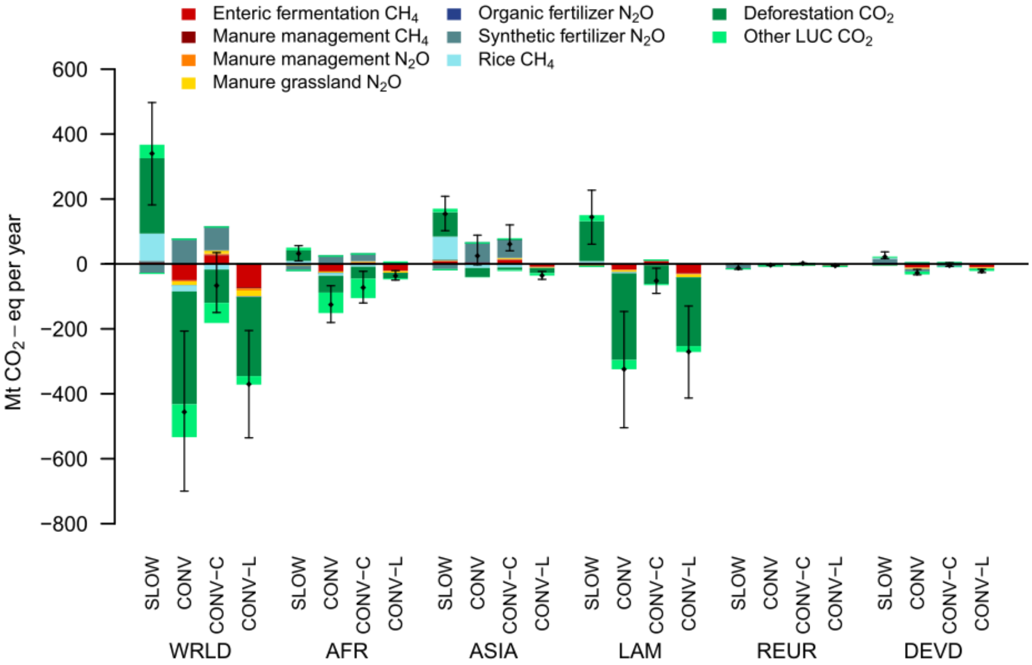

Figure S 13 Difference in emissions per region for scenario “CONV” and High-Input pathway

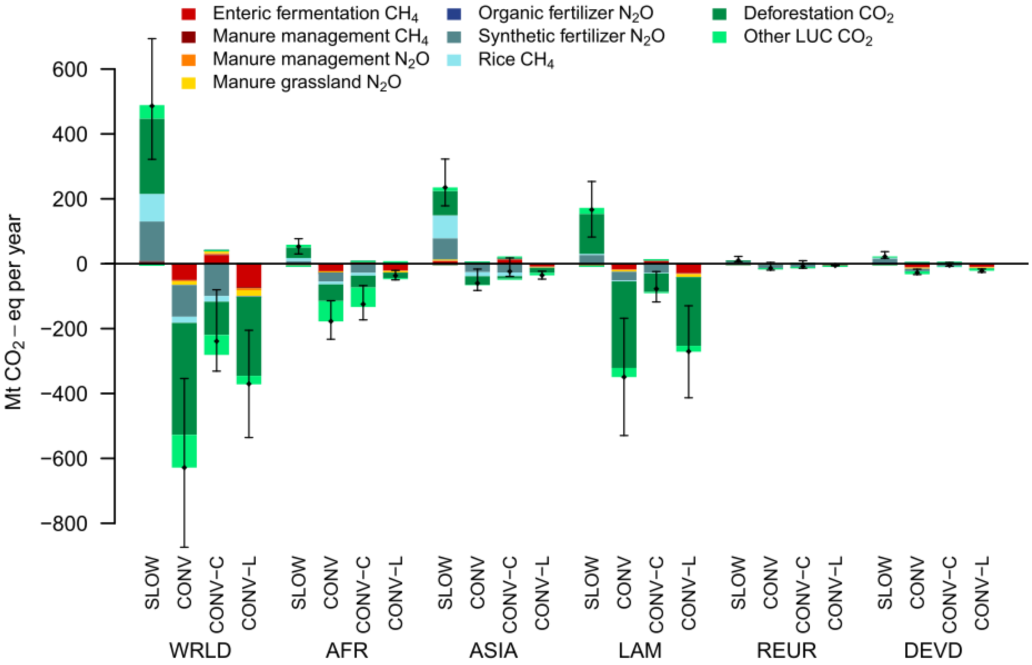

Figure S 14 Difference in emissions per region for scenario “CONV” and Sust-Int pathway

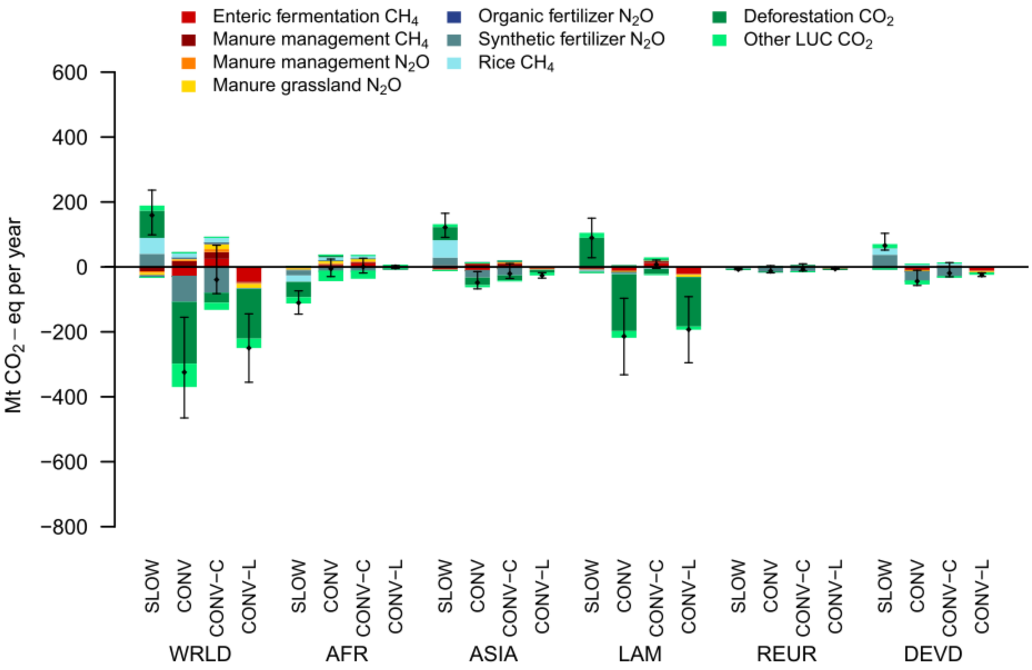

Figure S 15 Difference in emissions per region for scenario "CONV" and Free-Tech pathway

4.5. Additional results from sensitivity analysis

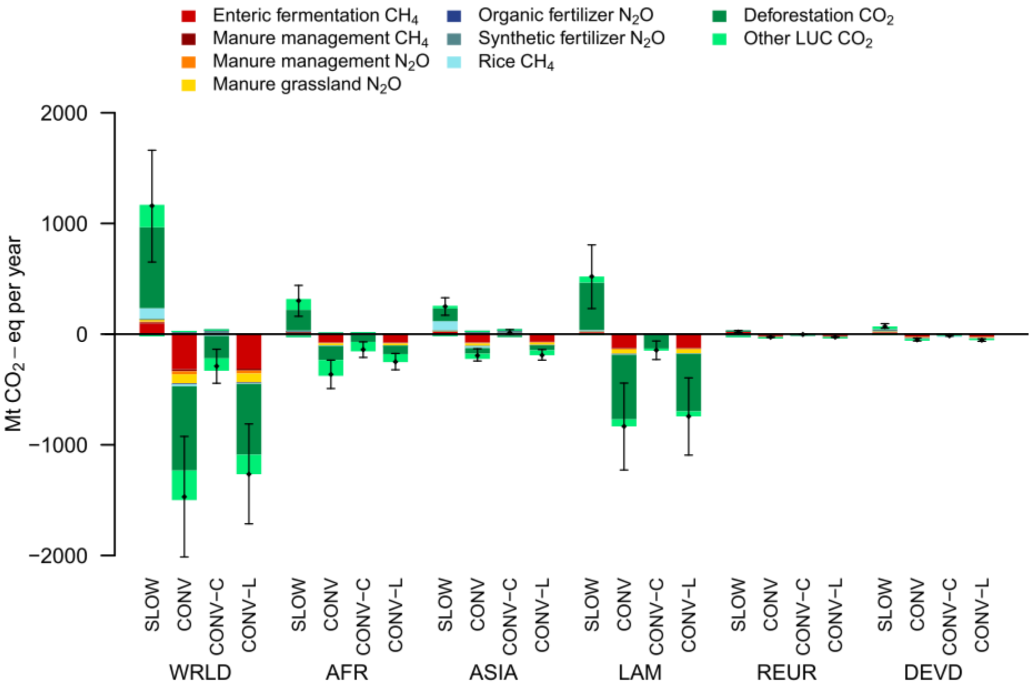

Figure S 16 Difference in emissions per region for scenario of fixed demand (no rebound effect) with the Conventional pathway

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