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Introduction

Grasslands are versatile ecosystems, generating a diverse array of goods and services that are useful to humankind. By maximizing pastures as the primary source of livestock diets, grasslands provide alternatives to concentrate feed. This reduces the inefficient use of arable land and increases the food that is directly available for human consumption from cereals, grains and legumes. Grasslands also provide various ecosystems services that regulate, support and underpin the environment that we live in. These include climate regulation, water storage, nutrient cycling, pollination and biodiversity.

However, the potential role of grasslands in addressing environmental and food security challenges is often poorly understood and under-valued. Within future population and food system modelling scenarios for 2050, projections of food production have focused almost entirely on intensive food crops and an increasing share of animal products reared on intensive feed crop production (cf. Alexandratos and Bruinsma 2012, Steinfeld *et al.* 2006). In contrast, the contribution of grasslands and permanent pastures are largely ignored. This is particularly surprising, given that grasslands and permanent pastures amount to 3.5 billion ha globally – more than twice the total area of croplands.

To better understand the potential of grasslands to contribute to future food security and sustainability demands, this working paper presents modelling scenarios for a food system with grassland-based livestock production[1]. The conventional forecast for 2050 is compared with different scenarios involving a hypothetical shift away from the use of concentrates towards a food system involving greater grassland-based livestock production. This modelling exercise seeks to address four urgent questions relating to the viability of a grassland-based system, while evaluating the potential implications of such a change for the environment, people and economies.

[1] Different scenarios of a 'grassland-based system' are considered in the model. At one end of the continuum, ruminant production is 100% grassland based and monogastrics fed entirely using food byproducts (the '0Conc' scenario). As a baseline comparison the '100Conc' scenario lies at the other end of the continuum, representing the current level of concentrate use extrapolated to 2050.

Q1. Is it possible to produce enough calories and protein to ensure food security in a global food system based on grassland livestock production? The production and availability of calories and protein need to be sufficient to ensure food security. Due to the more efficient use of land area for food crop production, it can be assumed that calorie availability will increase with a shift to greater grassland-based livestock production. On the other hand, protein availability may be more of a challenge, as high-protein food from animal sources is replaced by food crops. Assuring a sufficient supply of protein will require an increase in fish consumption and adequate production of legumes.

Q2. How will human diets need to change for a food system based on grassland livestock production and protein-rich food crop cultivation to meet projected global protein needs? A reduction in concentrate feed implies that less animal products will be available. This reduction will particularly affect the production of pigs, poultry and eggs as monogastrics cannot be fed on grasslands. Livestock protein sources will need to be replaced by an increased share of legumes or fish in human diets. Dietary changes must also be shaped by nutritional and health imperatives.

Q3. How would a shift to greater grassland-based livestock production affect feeding rations, the composition of animal species and varieties, and the productivity of the livestock sector? A wide variety of food by-products (e.g. bran, whey) can be used as a substitute for concentrates to feed monogastrics. However, the nutritional composition of these by-products is less favourable than an optimized concentrate mix. This will likely lead to a reduction in productivity, possibly leading to a shift in species and varieties of livestock reared towards those that can optimally live on a modified composition of feedstuffs.

Q4. What are the environmental impacts of a grassland-based system of livestock production? The intensification of livestock production with increased concentrate use is commonly suggested as the only viable strategy to meet the demands of food system scenarios for 2050, while reducing environmental impacts (e.g. Steinfeld *et al*. 2006). In common scenarios, an estimated 35 percent increase in global population and changes in human diets are predicted (e.g. Alexandratos and Bruinsma 2012). This will lead to a higher demand for livestock products, placing increased pressure on natural resources and the environment (Pelletier and Tyedmers 2010, Thornton 2010). As an alternative, grassland-based livestock production has been advocated as a less intensive strategy with lower environmental impacts (Foley *et al*. 2011, Garnett 2011). However, the performance of a grassland-based global food system has not yet been assessed across a range of environmental and natural resource use indicators and also regarding food supply.

The methods and assumptions behind the modelling results are presented below, followed by the preliminary results. Key questions, data gaps and other challenging issues in the wider context of sustainable grassland management are identified.

Methods

Sustainable and Organic Livestock model

The Sustainable and Organic Livestock model (SOL-m)[2] was used to model scenarios of grassland-based livestock production. SOL-m involves a mass and nutrient balance, based on detailed FAOSTAT-data and additional data sets where necessary. The model is programmed in GAMS (General Algebraic Modelling System), allowing for optimization of the system for food availability, environmental or economic indicators. Some parts of the data preparation for SOL-m are managed in the statistical software package R.

SOL-m operates at country level, covering 230 countries, 185 primary crop and grassland activities and 14 livestock activities. The main livestock activities (cattle, pigs, chickens) are further differentiated into detailed herd structures which are estimated at country level. Products are differentiated by commodity (230 main products) and sub-commodity (700 sub-commodities) to capture the effects of by-products (e.g. brans, oil-cakes, whey).

SOL-m was calibrated to reproduce the FAO 2050 projections on calorie and protein availability, animal numbers and land use (Alexandratos and Bruinsma, 2012). We assumed the same changes in shares of livestock and plant products, population and yield increases as this FAO forecast. Figure 1 provides an overview of the SOL-m structure.

For each livestock and plant production activity, relevant inputs, outputs and losses[3,4] were characterized for each country. Feed, fertilizer and food balances were calculated for each country, along with environmental impacts/flows covering fresh matter, dry matter, nitrogen and phosphorus, metabolizable and gross energy, raw protein, cumulative energy demand and global warming potential. Table 1 gives an overview of the environmental indicators used in SOL-m.

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[2] SOL-m was developed by FiBL for the FAO. For further details see FAO 2012.

[3] Inputs for plant production activities cover mineral and organic fertilizers, manure and crop residues, nitrogen fixation, seeds, herbicides, fungicides, insecticides, buildings, agricultural machinery, and processes including tillage, seeding, fertilization, spraying of pesticides, harvesting, transports, irrigation, flooding and drying. Outputs are crop yields and crop residues. Losses are specified in terms of NH_3, NO_3 and N_2O, due to fertilizer application.

[4] Inputs for livestock production cover buildings, grass, forage crops, concentrates, fences, diesel, electricity and milking as a process. Outputs are differentiated by yield type (milk, meat, eggs and hides) and manure. The losses encompass NH_3, NO_3, N_2O and CH_4 lost during manure management, as well as due to enteric fermentation.

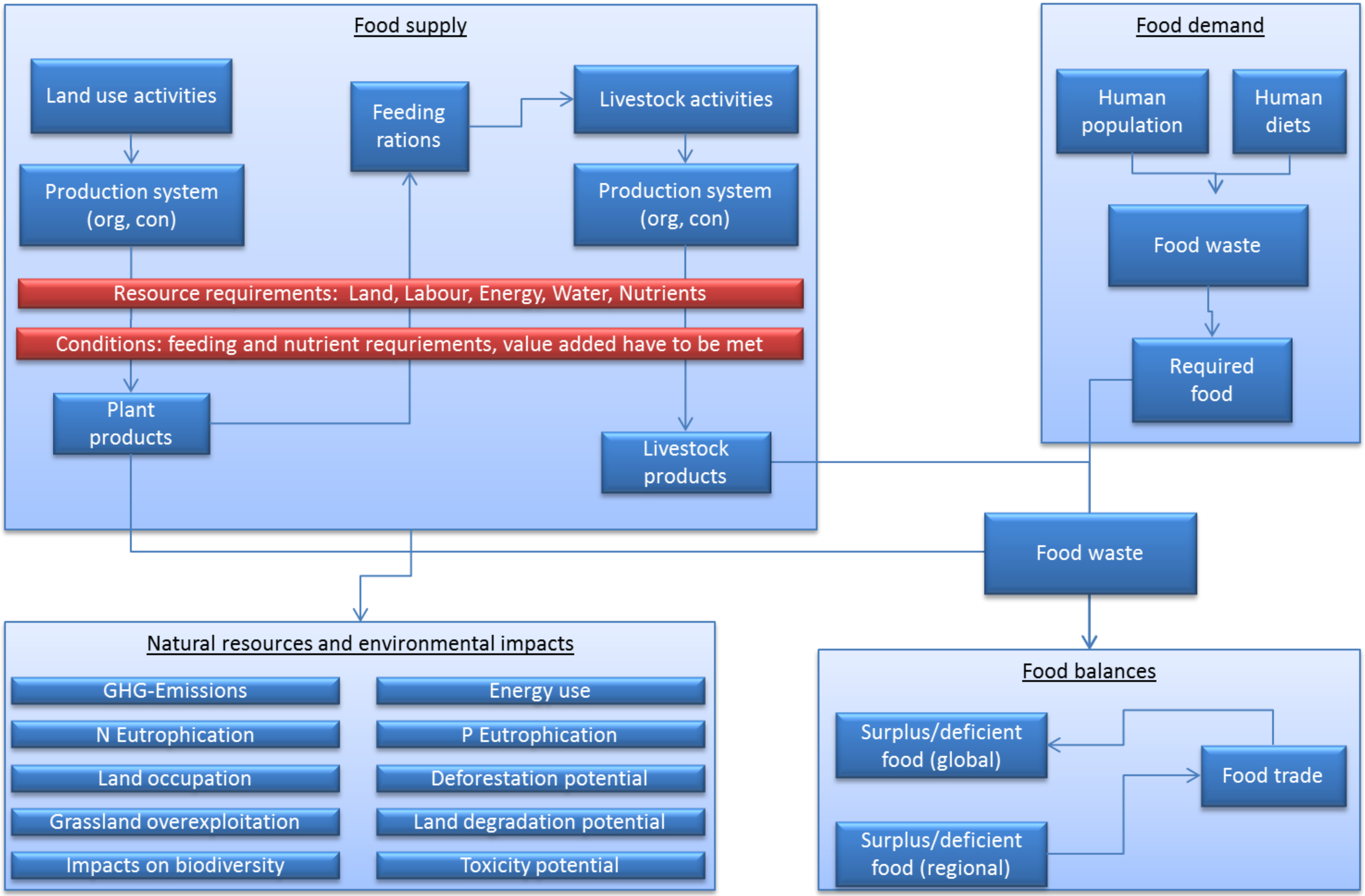

Figure 1: Overview of the SOL-m structure

Table 1: Overview of environmental indicators used in the SOL-m

Environmental impact	Indicator	Description
Land occupation	Land occupation in terms of arable, permanent crops and grassland	Data on land use based on FAOSTAT. This indicator is linked to the indicators “deforestation pressure” (see below)
Land degradation	Crop-specific factor covering the erosion susceptibility of crops	Erosion susceptibility was modeled as a function of different crop types. Therefore, the length of period during crop growth was taken as an indicator. Data from literature and expert consultations.
Use of fossil energy resources	Cumulative energy use (CED) 1.05-1.08	Based on LCA data (Ecoinvent, Schader (2009), and other literature).
Global warming potential	GWP IPCC100a	Methodology and inventory based on Tier 1 and 2 approaches, as specified in IPCC-Guidelines (2006). Further data taken from LCA studies.
Nitrogen eutrophication	Nitrogen surplus and losses	Inputs (e.g. fertilizer quantities), outputs (yields, crop residues, nutrient contents, etc.) and losses (NH_3, N_2O and NO_3) are calculated per land use activity and country
Phosphorus eutrophication	P_2O_5 surplus	The P2O5 surplus serves as an indicator for P losses, e.g. in cases of soil loss. Inputs (e.g. fertilizer quantities), output (yields, crop residues, nutrient contents, etc.) are calculated per crop and country. Only countries with a phosphorus surplus are added up.
Toxicity	Average amount of and danger of pesticides used per ha	Toxicity factors calculated based on expert assessments of crop-specific pesticide applications. Three factors were taken into account: a) intensity of application, b) country specific pesticide legislation, and c) economic and physical access to pesticides by farmers
Deforestation pressure	Additionally required crop land per annum	Linked to land occupation. Basic assumption: If agricultural production increases, additional cropland increases pressure on forests and may lead to increased deforestation. For the base year increases of land occupation in countries expanding agricultural land use was taken.
Grassland exploitation	Cattle stocking density on grasslands	Relation between grass feed demand by livestock and available grass
Biodiversity	Four of the five main drivers of biodiversity loss will be covered (all except invasive species, see text for more information)	Based on the framework suggested by the Millennium Ecosystem Assessment (5 main drivers of biodiversity loss) (MEA, 2005), biodiversity is integrated as a function of the following indicators: Global warming potential, nitrogen eutrophication, phosphorus eutrophication, toxicity, deforestation pressure, grassland exploitation

Modelling scenarios of concentrate reduction for 2050

Various scenarios were calculated with different shares of concentrate use in relation to the current baseline level of concentrate use (100%, 95%, 90%, 85%, 80%, 75%, 70%, 65%, 60%, 55%, 50%, 0%). In the different scenarios ruminant feeding rations contain an increasing share of grass. In parallel, the production of feed and forage crops and the feed utilization of food crops was reduced, with food by-products[5] remaining as the only source of animal feed besides grass. Monogastrics were assumed to be feeding on an increasing share of by-products, up to 100% in the situation where ruminants are fed entirely on grass. The areas released from feed production were assumed to be used for food production. To account for the less favourable nutritional quality of such a by-product mix, we assumed a yield decrease of 20% in monogastrics for a diet fully based on by-products.

Each different concentrate use scenario was also calculated for the yield forecasts as used in the FAO 2050 forecasts (Alexandratos and Bruinsma 2012) and an alternative yield forecast including climate change impacts and CO_2-fertilization from Müller *et al*. (2010)[6]. Finally, all scenarios were calculated according to one of two conditions: keeping *per capita* protein supply constant in the first instance, and keeping *per capita* energy supply constant in the second. In total 48 Scenarios were calculated. For this paper, only the scenarios with constant protein supply and yield forecasts used in the FAO 2050 projections are shown. This is because protein supply is more of a limiting factor than energy supply in the context of a reduction of concentrates.

Data sources and assumptions

Data on crop production and grassland areas are from the FAO 2050 forecasts (Alexandratos and Bruinsma 2012), supplemented by nutritional value and fertilizer demand data from the Swiss Agricultural Research Institutes Agroscope, International Fertilizer Industry Association IFA and a range of other sources. The utilization shares reported in FAOSTAT were used to calculate how much of these crops are available for feed also in the FAO 2050 projections.

Animal numbers for each scenario were derived from feed supply, taking into account the feeding rations in different countries (the share of grass, concentrates and forage crops used to feed cattle). Concentrate feed composition and its nutritional value was based on the food and by-products that are available as feed in each country and assumed to be the same for all animal types. The same relationship between feed supply and demand as in the FAO

[5] These are food by-products that partly could be used for human consumption (e.g. wheat brans or whey), but currently are not used for that (as e.g. most wheat flour used is “white” flour, thus discarding brans as by-products). We thus assumed the same dietary patterns regarding food crop processing and by-product use as today.

[6] Forecasts on yield increases till 2050 including climate change and CO_2-fertilization are approximately a third of the FAO 2050 forecasts, on average.

2050 projections[7] was used for the scenarios to ensure better comparability between results.[8]

Because of these assumptions, the results of the different scenarios are closely tied to feed supply, which differed as the share of concentrates decreased, and demand balances, based on metabolizable energy.[9]

For fish and seafood production, the forecasts from OECD-FAO (2012) were linearly expanded to 2050. We also assumed reduced concentrate availability for fed aquaculture, which reduces the share of fish and seafood in the scenarios.

Nutrient balances for N and P were calculated based on the fertilizer quantities reported in FERTISTAT, combined with quantities of crop residues, crop yields and crop nutrient contents, N-fixation, animal production, manure excretion and manure nutrient contents. This data is taken from FAOSTAT and additional data sources such as IPCC guidelines for national GHG inventories.

Environmental impacts were calculated by multiplying emissions factors by area harvested and tons of products produced, differentiated by country and crop or animal activity.

Fertilization of crop activities was calculated based on nutrient availability from the various fertilizer sources, applied to crops in relation to their relative nutrient demand. Nitrogen was calculated for all fertilizer types. Phosphorus supply was calculated from the quantities of organic fertilizers, with the available mineral P fertilizer applied to different crops in relation to the remaining P demand.

Grassland yields were differentiated by country, using an average of the yields reported in Erb *et al*. (2009) for his two best grassland classes.[10] Grassland areas were taken from FAOSTAT. Global parameters were used for all other grassland characteristics. Nitrogen fixation in grasslands was assumed to be 20kg N per ton dry matter yield. Yield increases were assumed to be 0.0008% per year, reflecting a moderate increase to 2050. The effects of climate change on grassland were dealt with in the same way as crops by including the same average yield reductions.

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[7] Feed supply and demand in FAOSTAT is based on animal numbers, feed quantities (based on utilization shares of total crop quantities), nutritional value of the feed and nutrient requirements of animals.
[8] These ratios reflect an over-supply of grass and undersupply of concentrates. Keeping the same ratios to derive animal numbers from feed supply allows for a better comparability of results between the FAO 2050 forecast and the other scenarios.
[9] No differentiation has been made between animal types, assuming the same metabolizable energy content per unit product.
[10] These classes were chosen because they correspond to the grassland data in FAOSTAT.

Preliminary Results and Discussion

The preliminary results of the 2050 grasslands' model are structured around the four questions outlined in the introduction.

Q1. Is it possible to produce enough calories and protein to ensure food security in a global food system based on grassland livestock production?

Yes, enough calorie provision with grassland-based livestock production is indeed feasible; in fact, global average *per capita* calorie availability increases by over 30% with respect to the FAO 2050 forecasts in Alexandratos and Bruinsma (2012). This is due to the much more efficient calorie production of crops for direct human consumption, rather than via crops fed to animals. While total calorie availability from croplands can be achieved, proteins are more challenging as a reduction in animal products disproportionally reduces protein availability. Using the same cropping areas as in the FAO 2050 forecasts[11], protein availability increases by more than 10%. To provide the same *per capita* protein supply for each country as in the official forecast, 6% less cropland area is needed globally.

At country level, results need to be further differentiated. Countries with a large share of animal products in the human diet can only provide the same amount of protein with increased land use. However, to ensure an adequate protein supply for human nutrition only, in contrast to the current oversupply in these countries, grassland-based scenarios also assure food security regarding protein. It should be emphasized that proteins are the most important limiting factor. To illustrate this point, meeting the condition of a constant supply of calories can still result in an undersupply of protein for some countries, whereas the condition of a constant protein supply will also ensure a sufficient supply of calories.

The FAO 2050 forecast supplies a global average of 3,070 kcal *per capita* per day (Alexandratos and Bruinsma 2012). However, the current global average is approximately 2,800 kcal per capita per day. Food wastage in the supply chain has already been accounted for in these figures.[12] Therefore, the projected average daily calorie requirements are relatively high compared to average daily requirements of humans today. It is conceivable that some share of calorie production could be allocated to protein-rich food production.

The FAO 2050 projections from Alexandratos and Bruinsma (2012) assume that yields will increase over time for all crops, up to 75% for some crops, and around 35% for most crops. However, these projected increases do not consider the effects of climate change on crop yields. Depending on crops and modelling assumptions, the impacts of climate change could cause a drastic reduction in crop yields, in some cases to 0% (Müller *et al.* 2010). For a model family that includes the highly uncertain effects of increased CO_2-levels on yields, average

[11] A moderate increase by 70 million ha (Alexandratos and Bruinsma 2012).

[12] FAOSTAT figures already account for food wastage in the supply chain, although this is not included at the consumer level.

yield increases are about 10% to 2050, with a large range of uncertainty. According to the yield forecasts that include climate change impacts, it will not be possible to provide the supply of protein calculated in the FAO 2050 forecast.

Q2. How will human diets need to change for a food system based on grassland livestock production and protein-rich food crop cultivation to meet projected global protein needs?

The changes in livestock production associated with the 100% grassland-based livestock production have substantial impacts on animal product supply. Milk and meat supply from ruminants decreases by almost 50%, while meat from monogastrics and poultry eggs are reduced by up to 90%. The overall reduction in animal products is compensated for by an increase in protein provision from plants (optimally from legumes) and fish.

Such changes would have a dramatic effect on nutritional habits, especially in industrialised countries, where the share of animal products in diets is high. In particular, countries where animal products are mainly sourced from monogastrics would be most affected, as the reduction in monograstric products is greater than for ruminants in relative terms. Figure 2 presents an overview of changes in human nutrition parameters following concentrate-feed reduction in livestock production.

Q3. How would a shift to greater grassland-based livestock production affect feeding rations, the composition of animal species and varieties, and the productivity of the livestock sector?

In the 100% grassland-based livestock production scenario, ruminants are entirely fed on grass and monogastrics on by-products of human food production. To account for the less favourable nutritional quality of such a by-product mix, a yield decrease of 20% in monogastrics was assumed for a diet fully based on by-products. As a consequence, species composition changes towards significantly lower shares of monogastric products. Currently, the model cannot capture more detailed changes in animal varieties or livestock production systems, for example, a potential trend towards double purpose breeds. Furthermore, open questions remain about the productivity of purely grassland-fed ruminants in various countries and monogastrics on a modified diet. Figure 3 presents an overview of changes in the agricultural sector following concentrate-feed reduction in livestock production.

Q4. What are the environmental impacts of a grassland-based system of livestock production?

Under the 100% grassland-based livestock production scenario most negative environmental impacts are reduced. This is due to two main factors. Firstly, food production for human consumption is more efficient via crops compared to via feedstuffs for animals. Consequently, the area of land required for crops is reduced along with related impacts such as pesticide use. Secondly, the negative environmental impacts associated with nutrient surpluses are considerably reduced due to the decrease in animal numbers and manure quantities excreted. Grassland overexploitation increases for small reductions in concentrate use. However, greater reductions in concentrate feed results in an easing of pressure on grasslands as the additional cropland that is released can deliver a sufficient supply of proteins. Figure 4 gives an overview of the changes in environmental impacts for different scenarios.

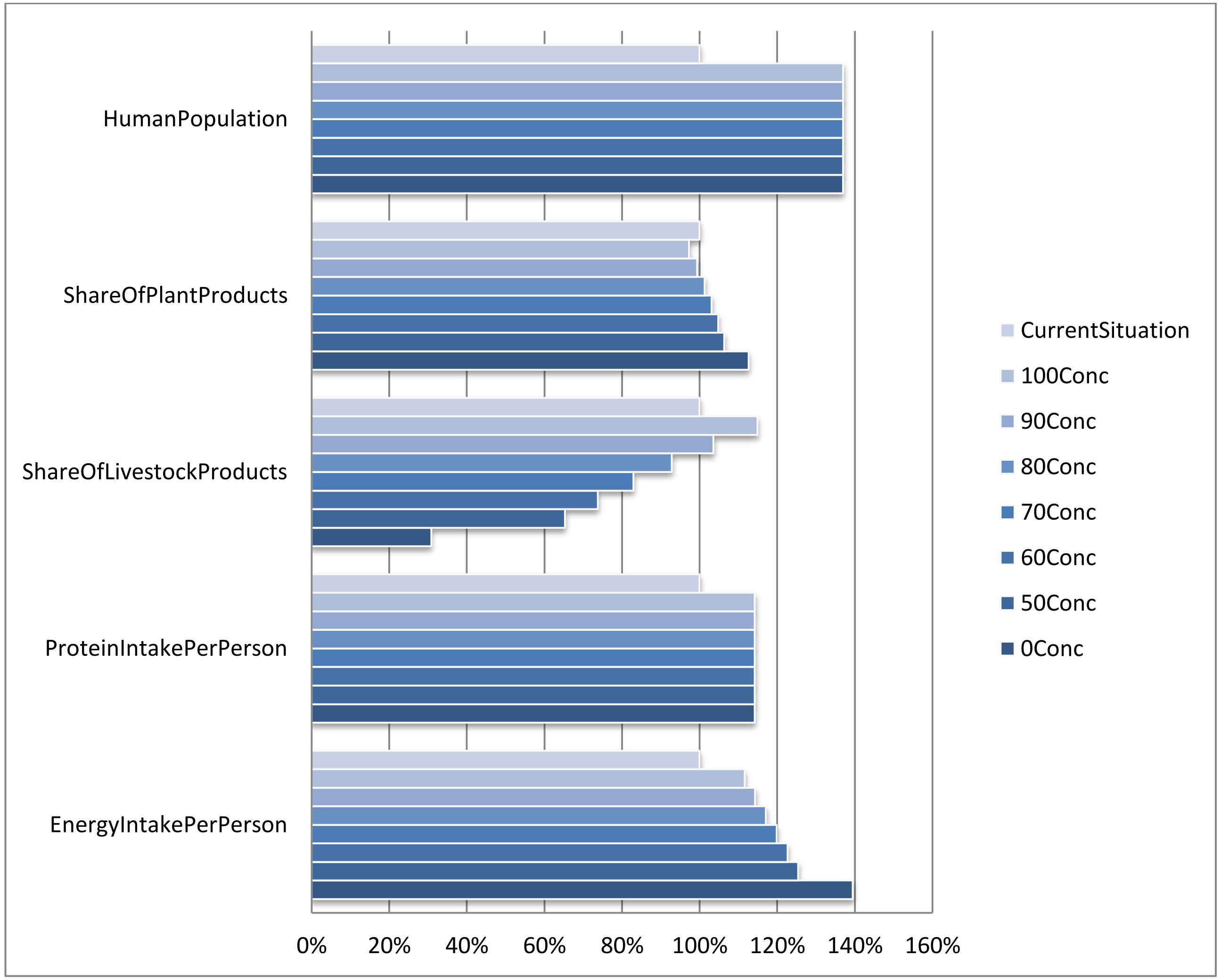

Figure 2: Overview of changes in human nutrition parameters following concentrate-feed reduction in livestock production. Per capita protein supply is held constant between scenarios. The share of plant and animal products refers the *change* in those shares with respect to the current situation. Scenario names refer to the percentage of concentrates used ('XXConc'), in relation to the official FAO forecast, labelled '100Conc'.

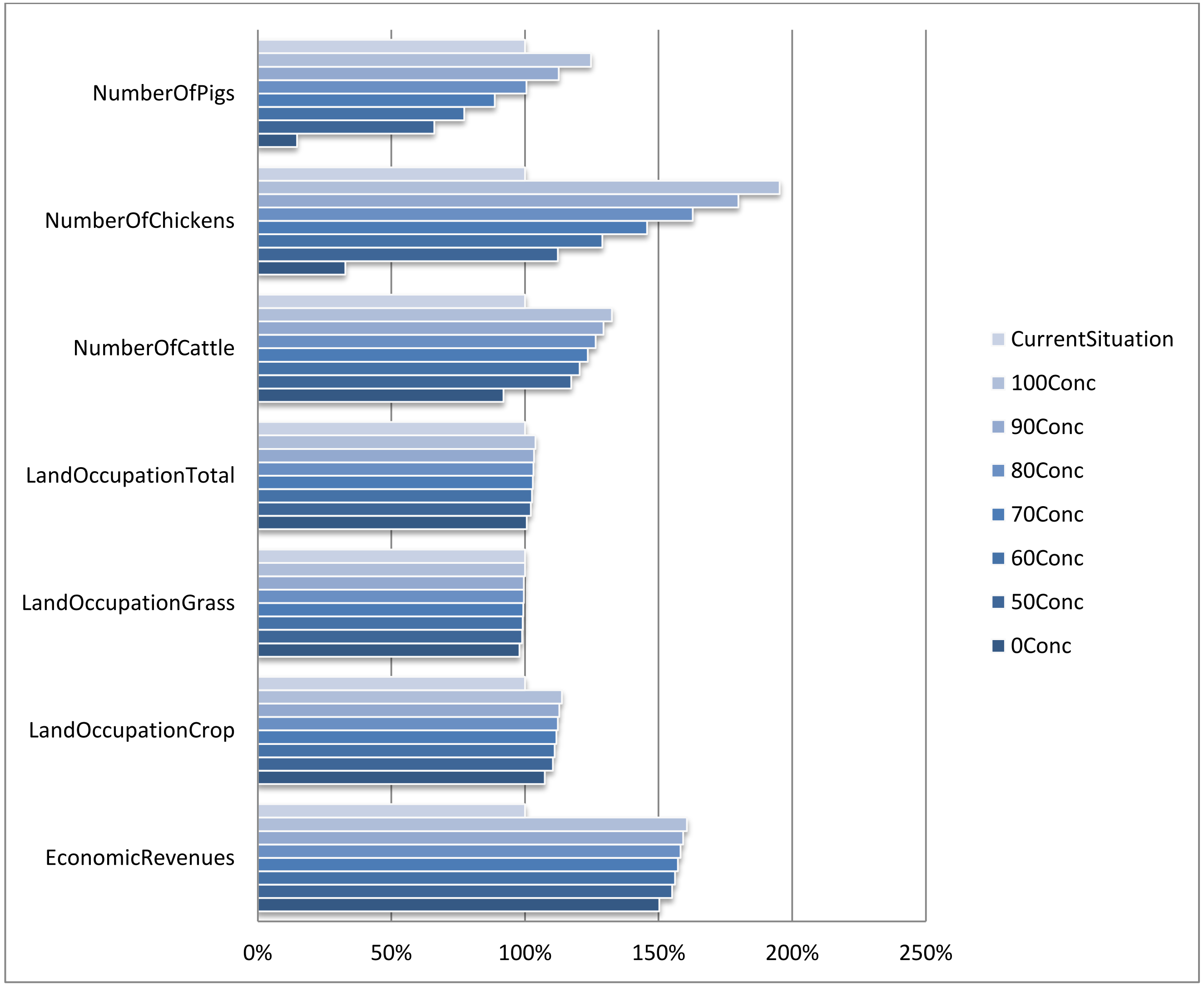

Figure 3: Overview of changes in the agricultural sector following concentrate-feed reduction in livestock production (under the condition of constant per capita protein supply).

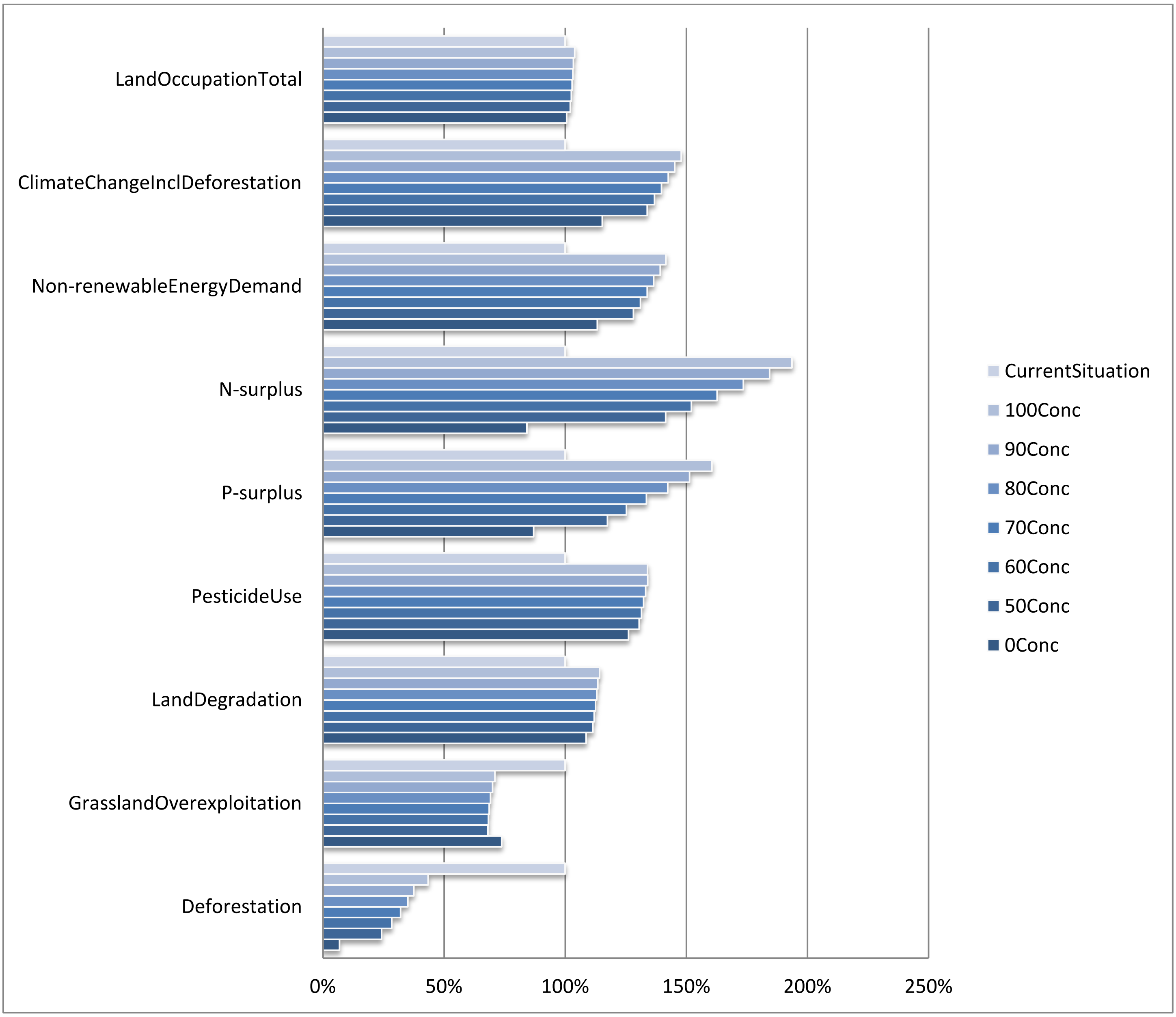

Figure 4: Overview of environmental indicators in the scenarios (for grassland exploitation, lower values indicate higher exploitation).

Conclusions

The preliminary modelling results suggest that in broad terms, a grassland-based system of livestock production is indeed a viable proposition. At a global level, calorie and protein supplies would be sufficient to meet the requirements of the official FAO 2050 projections. Furthermore, the modelling scenarios indicate that many negative environmental impacts would be reduced following a shift away from concentrate feeding to a grassland-based system. These results support the notion of grassland-based system of livestock production that is capable of meeting food security demands while imposing a lighter footprint on the environment – positive outcomes for both the human and environmental pillars of sustainability.

Due to the nature of global food systems models such as SOL-m, these results must be considered as a broad overview that relies on a number of assumptions. As grasslands play a crucial role in this model, the assumptions on grasslands need to be refined by closing some of the data-gaps. Improvements are primarily needed for the following aspects of the model:

- How does the species composition of grass/pastures affect the nutritional value of livestock feed and the productivity of grasslands?
- What is the nutritional value of different types of grasslands as livestock feed, in different regions and for different ruminant species?
- How will climate change affect the nutritional value of grasslands as livestock feed and the productivity of grasslands?
- Which species and varieties of livestock are best suited to different grassland types? What is the productivity (i.e. meat/milk yields) of various species and varieties of livestock?
- What is the carrying capacity of grasslands? What are the current, optimal (in terms of output) and sustainable stocking densities under different management systems?
- How much nutrients from manure remain on grasslands under various management systems and for different animal species?
- What is the nutrient demand of various types of grasslands, including N-fixation?

Currently, the SOL model provides the basis for a comprehensive analysis of grasslands in relation to the food system. A further step to extend the modelling scenarios is to adopt a more encompassing view of sustainable grasslands management by incorporating the multiple ecological functions of grasslands. These include the provision of various ecosystems services and non-productive values such as animal health and welfare. A key step forward would be to collect data to cover at least some of those aspects.

References

Alexandratos, N. and Bruinsma, J. (2012). World Agriculture Towards 2030/2050. The 2012 Revision. in Division, A.D.E. (ed.), *ESA Working Paper*, No. 12-03, Rome, FAO.

Erb, K.H., Krausmann, F., Lucht, W. and Haberl, H. (2009). Embodied HANPP: Mapping the spatial disconnect between global biomass production and consumption. *Ecological Economics*, 69(2): 328-334.

FAO (2012). Sustainability and Organic Livestock model SOLm, Concept note, FAO. http://www.fao.org/nr/sustainability/sustainability-and-livestock/en/

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. and Zaks, D.P.M. (2011). Solutions for a cultivated planet. *Nature*, 478: 337-342.

Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy*, 36: S23-S32.

MEA (2005). 'Ecosystems and Human Well-being: Biodiversity Synthesis', Washington DC, Millenium Ecosystem Assessment (MEA), World Resources Institute.

Müller, C., Bondeau, A., Popp, A., Waha, K. and Fader, M. (2010). Climate change impacts on agricultural yields. *Background note to the World Development Report 2010*, Potsdam Institute for Climate Impact Research (PIK), Germany.

OECD/FAO (2012). Fish and Seafood. *OECD-FAO Agricultural Outlook 2012*. OECD Publishing: http://dx.doi.org/10.1787/agr_outlook-2012-11-en.

Pelletier, N. and Tyedmers, P. (2010). Forecasting potential global environmental costs of livestock production 2000–2050. *Proceedings of the National Academy of Sciences*, 107: 18371-18374.

Schader, C. (2009). 'Cost-effectiveness of organic farming for achieving environmental policy targets in Switzerland'. Ph.D. thesis. Institute of Biological, Environmental

Steinfeld, H., Gerber, P., Wassenhaar, T., Castel, V., Rosales, M. and de Haan, C. (2006). *Livestock's long shadow: environmental issues and options*. Food and Agriculture Organization of the United Nations.

Thornton, P.K. (2010). Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365 (1554): 2853-2867.