SUSTAINABILITY AND ORGANIC LIVE-STOCK MODELLING (SOL-m)

Impacts of a global upscaling of low-input and organic livestock production

Preliminary Results

by
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About this document

The Sustainability and Organic Livestock model (SOL-m) is a project (see Concept Note) of the FAO Natural Resources and Management Department that has been commissioned to the Research Institute of Organic Farming (FiBL) in Frick, Switzerland. This summary report presents the preliminary results of the SOL-model. Currently, plausibility checks are conducted, model parts are refined and further data is gathered for verifying the trends specified thus far. The full project outcomes and a dedicated publication, including quantitative impacts of the scenarios, will be availble in mid June 2013. The outcomes of the current Phase I of SOL-m point to substantial environmental, social and economic potential of a global conversion to grassland-based farming. Thus, FAO has already engaged in Phase II of SOL-m on Sustainable Grasslands.

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Background

Human activities have already reached the edge of the planetary boundaries, and even overcrossed them in some cases . Globally, agricultural systems, and particular livestock systems, are an important source of greenhouse gas emissions, and among the leading causes of biodiversity loss and water pollution . Besides the provision of protein-rich foodstuffs, through the use of grasslands (ruminants) or food waste (monogastrics), livestock systems used to substantially contribute to soil fertility via manure excretion, capital storage and labor substitution. Modern livestock husbandry, however, lost its original ecological and socio-cultural role in a functioning farming system by unilaterally focusing on milk, meat and egg production. On the one hand, modern intensive livestock systems are highly efficient in terms of high per-head productivity of meat, milk and eggs. On the other hand, the intensification of livestock systems during the past few decades has resulted in a number of downsides. With the substitution of grassland with feed concentrates, the pressure on arable land increased and led to severe nutrient imbalances at farm, country and regional levels. Furthermore, intensification of livestock production resulted in a higher incidence of livestock diseases and a decreased longevity of animals.

Despite these problematic developments, economic conditions still favor intensive livestock systems. The projected increase of world population and swelling demand for livestock products, especially higher income populations of developing countries, coupled with a rapidly diminishing natural resource base, call for an urgent reduction of the ecological footprint of livestock production.

There are a number of models on global agricultural land use, livestock production and their future development addressing food security, greenhouse gas emissions and other aspects of the livestock sector challenges. However, there are no models that analyze the impacts of a global conversion of animal husbandry to low-input production systems, such as organic agriculture, on food availability and the main global environmental challenges. With increasing resource scarcity, there is need to understand what options would be feasible in a shock scenario, such as too expensive or unavailable fossil fuel. More importantly, there is an urgent need to model, in a comprehensive and interlinked way, the technical and economic feasibility of alternative food supply scenarios. To this end, SOL-m computes and analyzes the potential impacts of a global conversion of livestock systems to low-input systems and organic management.

Model

SOL-m was developed to shed light on these questions. SOL-m is a global land use and food systems model capable of analyzing the impacts of different production scenarios on land use, food availability, material flow (i.e. N, P, energy, GHG) and other environmental impacts.

SOL-m aims to show impacts of different land use and livestock production scenarios. It also bears the opportunity to relate the environmental impacts to production, as done in agricultural life cycle assessments for products or specific supply chains. The core model consists of a food supply module, a food demand module and a separate module where supply and demand are matched. In the food **supply module**, activities and products are formulated for land use and livestock activities, which are linked via feeding rations to each other. In the **food demand** module, human population and diets are defined for calculating the required food for human nutrition. All food products modeled in the food supply module and food requirements from the demand module are subsumed in the **food balance module**, where the global food surplus or deficiency is quantified.

SOL-m is largely based on, and consistent with, the FAOSTAT data and classification system. Where data gaps occurred (e.g. on the areas and yields of various types of grasslands, feeding rations, herd structures), other datasets were created/used.

Food waste is entered into the model as a variable in the food demand module, increasing the amount of food demanded, and as a variable in the food supply module, reducing the quantity of food supplied into the food balance. In the **environmental impacts module**, the environmental impacts are evaluated according to methods described in Table 1.

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

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 was derived from literature and expert consultations
Use of fossil energy resources	Cumulative energy use (CED) 1.05-1.08	Based on LCA data (Ecoinvent, Schader , and other literature)
Global warming potential	GWP IPCC100a	Methodology and inventory based on Tier 1 and Tiers 2 approaches, as specified in IPCC-Guidelines . Further data was taken from LCA studies
Nitrogen eutrophication	Nitrogen surplus and losses	Inputs (e.g. fertilizer quantities), outputs (e.g. yields, crop residues, nutrient contents) and losses (i.e. NH_3, N_2O and NO_3) are calculated per land use activity and country
Phosphorus eutrophication	P_2O_5 surplus	The P_2O_5 surplus serves as an indicator for P losses, such as in cases of soil loss. Inputs (e.g. fertilizer quantities), output (e.g. yields, crop residues, nutrient contents) are calculated per crop and country
Toxicity	Average amount of and danger of pesticides used per hectare	Toxicity factors calculated were 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	Linked to land use factor. Assumption: additionally cropland increases pressure on forests and may lead to increased deforestation
Grassland exploitation	Cattle stocking density on grasslands	Average number of cattle heads per hectare of grassland

Biodiversity	Four of the five main drivers of biodiversity loss were covered (all except invasive species, see text for more information)	Based on the 5 main drivers of biodiversity loss suggested by the Millennium Ecosystem Assessment . Biodiversity is integrated as a function of the following indicators: global warming potential, nitrogen eutrophication, phosphorus eutrophication, toxicity, deforestation pressure and grassland exploitation

The model is designed as a linear programming (LP) model from a policy-makers' perspective. This means that it allows for optimization of production with respect to different policy goals (e.g. maximize food production, minimize GHG emissions) under restrictions (e.g. do not allow arable land to be used for concentrate production). The model was programmed using the General Algebraic Modeling System (GAMS). Food utilization and commodity trees of the FAOSTAT working system were calculated with the statistical software R. In the current version, scenario assumptions were incorporated manually into the model due to data constraints.

Principally, the model is working at country level. This means that most data are specified for each country (e.g. land use, livestock numbers, yields) and later aggregated to regional or global level in order to provide comprehensible results. For this preliminary report, we present global level results only, because some data are only available at global level. This fact required an assumption of completely globalized concentrate markets. It is planned to successively specify the model in more details. For example, if high quality data for a certain country is identified, global assumption can be substituted with it.

As this project focused on livestock production, other external drivers such as GMOs, aquaculture, fisheries, food waste, specific technological developments (e.g. cultured meat) and biofuels was set constant (*ceteris paribus*). This allowed a specific treatment of the low-input livestock production impacts.

The calculation of the base year, representing the current situation, was based on data from 2005-2009. The base year served for calibrating the model and for comparing the results of the other scenarios. Using this base year as a reference, five different scenarios were modeled within SOL-m:

- Scenario 1 is the baseline FAO scenario for 2050 , with the corresponding trends for population growth, yield increases, meat consumption, etc.. Livestock type specific feeding rations (e.g. grassland/concentrate shares) were assumed to remain unchanged.
- Scenario 2 assumes a 50% reduction in livestock concentrate feeding (though non-food by-products from food production, such as wheat brans or dredges, are excluded from this reduction). Correspondingly, feeding ratios were adapted according to feed availability and this determines the livestock numbers in this Scenario. A general condition for all scenarios was to provide at least as much calories for human nutrition as the FAO baseline Scenario 1.
- Scenario 3 is similar to Scenario 2 but assumes a complete ban of concentrates instead of a 50% reduction (while non-food by-products from food production are still included in feed).
- Scenario 4 assumes a complete conversion to organic livestock husbandry, including feed production. In this scenario, organically produced concentrates at potentially high shares are allowed. Animal numbers are determined by feed and food availability when the whole livestock husbandry is organic and the overall condition of aggregate calorie supply as in Scenario 1. We assume that all organic production comes from organic farms

that converted all their activities. Correspondingly, not only feed production is organic but the organic share in all agricultural production rises

- Scenario 5 combines Scenario 3 and 4, by assuming both a conversion to organic livestock production and a complete ban of concentrate feeding.

Further details on the scenarios and the assumptions can be found in Table 3 (Annex).

Results

SOL-m calculations revealed that, contrary to the baseline Scenario 1, sufficient calories and protein could be produced in 2050 without compromising environmental impacts through a global conversion to low-input and organic livestock management. In Scenario 2 (i.e. 50% reduction of concentrate feed), and even more so in Scenario 3 (i.e. no concentrate feed), food availability increases while pressure on forest areas decreases. Furthermore, many positive environmental impacts could be achieved, including lower GHG emissions and energy use, lower N and P surpluses and toxicity potentials. It is important to note, however, that it will not be possible to sustain environmental quality in 2050 with the same consumption level trends of livestock products (Table 2).

The organic Scenario 4 promises to yield many environmental benefits, such as reduced toxicity potentials, N and P surpluses and GHG emissions. However, organic livestock production as practiced today (i.e. utilizing organically produced concentrate feed) will most likely need more land in order to satisfy food demand, especially if the current trends of meat, milk and egg consumption levels per person continue in 2050. According to SOL-m preliminary calculations, about 334 million additional hectares of arable land would be needed globally for an organically-produced supply, even if demand for animal products would halve - while according to the base year, only 70 million additional hectares would be needed. The organic option, however, becomes a win-win if it refrained from using concentrate feeds. Although to different extent, what is certain is that none of the scenarios, including the base year, could ever be sustainable without a global shift to sustainable diets (i.e. decreased consumption of livestock products).

Therefore, if consumption shares of livestock products will go down to a third or fourth of the base year levels, organic livestock production can be combined perfectly with low-concentrate livestock production. In such a combined Scenario 5, almost all environmental indicators react positively, especially deforestation pressure, and food availability becomes more than sufficient for the 2050 population, as land freed from concentrate feed production would be used for plant-based food.

It is also important to note that efforts to achieve efficiency gains in terms of an ecological intensification, that is producing more output with less input, would further decrease pressure on land and other resources. However, while efficiency gains can reduce the demand for natural resources per kg of output, it might also lead to rebound effects , as a reduced resource demand may lead to lower prices and eventually, cause demand increase.

Table 2: Overview of SOL-m impacts of scenarios on food availability and the environment

Indicator	Base year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	2005-2009; current situation	2050; baseline according to official FAO forecast	2050; 50% reduction of concentrate use	2050; 100% reduction of concentrate use	2050; full conversion of livestock to organic management	2050; Scenario 3 and 4 combined
Agricultural land	→ (yellow)	↗ (yellow)	↘ (yellow)	↘ (yellow)	↑ (red)	↘ (yellow)
Human population	→ (yellow)	↑ (green)	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Available food energy for human consumption	→ (yellow)	↑ (green)	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Available food protein for human consumption	→ (yellow)	↑ (green)	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Share of livestock products	→ (yellow)	↑ (green)	↓ (red)	↓ (red)	↓ (red)	↓ (red)
Share of plant products	→ (yellow)	↘ (yellow)	↑ (green)	↑ (green)	↑ (green)	↑ (green)
Nitrogen surplus	→ (yellow)	↑ (red)	↗ (yellow)	↓ (green)	↓ (green)	↓ (green)
Phosphorus surplus	→ (yellow)	↓ (green)	↑ (red)	↗ (yellow)	↓ (green)	↓ (green)
Energy use	→ (yellow)	↑ (red)	↘ (yellow)	↓ (green)	↗ (yellow)	↓ (green)
Global Warming Potential (GWP)	→ (yellow)	↑ (red)	↑ (red)	↓ (green)	↓ (green)	↓ (green)
Land degradation potential	→ (yellow)	↑ (red)	↘ (yellow)	↘ (yellow)	↑ (red)	↘ (yellow)
Deforestation pressure	→ (yellow)	↑ (red)	↓ (green)	↓ (green)	↑ (red)	↓ (green)
Toxicity potential	→ (yellow)	↑ (red)	↘ (yellow)	↘ (yellow)	↓ (green)	↘ (yellow)
Grassland overexploitation	→ (yellow)	↑ (red)	↑ (red)	↗ (yellow)	↑ (red)	↗ (yellow)
Biodiversity	→ (yellow)	↓ (red)	↗ (yellow)	↑ (green)	↑ (green)	↑ (green)

- The direction of the arrows specifies whether the paramer will increase in a scenario.
- Green arrows indicate a development that is considers beneficial from a societal perspective.
- Red arrows indicate a development which is considered detrimental (or challenging in the case of „share of livestock products") from a societal perspective.
- Yellow arrows indicate constant trends or minor changes (less then 5%) according to the preliminary SOL-m calculations.

Conclusions

SOL-m results suggest that a continued trend of current livestock husbandry practices will most likely lead to problematic trends for most environmental indicators, undermining the very base of food production. On the other hand, a conversion to low concentrate feed livestock production will generate great synergies between food availability and environmental health.

About 60% of the agricultural land worldwide is covered by grasslands. Within the agricultural sector, grasslands play a major role in maintaining food production and fulfill crucial ecological functions such as soil carbon sequestration, maintaining soil fertility, biodiversity and other ecosystem services. Improving grassland management constitutes a powerful lever for boosting food production without jeopardizing natural resources. An increasing number of consumers acknowledge these functions and are willing to pay higher prices for foodstuffs produced in grass-based systems. This development may enhance the economic viability of grassland-based milk and meat production systems compared to concentrate feeding.

Global environmental impacts can be mitigated if livestock production was grassland-based. However, livestock extensification strategies would be feasible only if human diets in developed countries become much less meat intensive and if diets in developing countries, with currently low shares of meat, do not become less meat intensive than anticipated by Alexandratos and Bruinsma . An organic livestock scenario becomes feasible only if concentrate feed use and meat demand were reduced globally. In all environmentally favorable scenarios, meat, milk and egg consumption needs to be reduced and possibilities for alternative protein sources (e.g. legumes, fish) need to be explored.

Therefore, particularly in industrialized countries with a high share of meat, milk and egg consumption, policy measures for steering food demand in a more sustainable direction need to be found. This would set a positive model for more sustainable diets for developing countries' populations with rising income.

References

Annex

Table 3: Overview of scenario assumptions

PARAMETER	Base year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Scenario name	Today	Baseline	50% concentrates	Feed no Food	Organic livestock conversion	Organic livestock conversion fed with no food
Year	2009	2050	2050	2050	2050	2050
Human population	According to FAOSTAT	According to FAOSTAT	According to FAOSTAT	According to FAOSTAT	According to FAOSTAT	According to FAOSTAT
Crop yield increase	No	FAO projection data	FAO projection data	FAO projection data	FAO projection data	FAO projection data
Feeding rations	Feeding rations defined for all major livestock types and linked to country-specific production data	Feeding rations defined for all major livestock types and linked to country-specific production data	Based on rations for base year but if concentrate supply drops to 50%	Based on rations for base year but if concentrate supply drops to 0% (only by- products of food production are used as concentrates)	Feeding rations defined for all major livestock types and linked to country-specific production data	Based on rations for base year but if concentrate supply drops to 0% (only by- products of food production are used as concentrates)
Ruminant meat and milk production	According to FAOSTAT	According to FAO/OECD Agricultural Outlook 2030/2050 (Cattle and buffalo numbers +32%, Sheep and goat numbers +53%)	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability

Non-ruminant meat and egg production	According to FAOSTAT	according to FAO/OECD Agricultural Outlook 2030/2050 (poultry numbers +93%, pigs +24%)	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability	According to model endogenous feedstuff availability
Calorie and protein intake per person	According to FAOSTAT	According to FAO/OECD Agricultural Outlook 2030/2050	Must not fall below Scenario 1	Must not fall below Scenario 1	Must not fall below Scenario 1	Must not fall below Scenario 1
Deforestation	According to FAOSTAT	According to FAO/OECD Agricultural Outlook 2030/2050	If more/less land is needed to satisfy food availability, pressure on forests increases/decreases	If more/less land is needed to satisfy food availability, pressure on forests increases/decreases	If more/less land is needed to satisfy food availability, pressure on forests increases/decreases	If more/less land is needed to satisfy food availability, pressure on forests increases/decreases
Ratio arable land / grassland	According to FAOSTAT	Net grassland stays constant, arable land increases	Net grassland stays constant, arable land increases	Net grassland stays constant, arable land increases	Net grassland stays constant, arable land increases	Net grassland stays constant, arable land increases
Livestock yields	According to FAOSTAT	According to FAO/OECD Agricultural Outlook 2030/2050, livestock yields increase additional 5% as rather intensive scenario is assumed	Based on Scenario 1 but yields decrease by 10% due to changed concentrate composition	Based on Scenario 1 but yields decrease by 20% due to changed concentrate composition	Based on Scenario 1 but yields decrease by 20% due to suboptimal concentrate changed and low livestock production intensity	Based on Scenario 1 but yields decrease by 20% due to changed concentrate composition and low livestock production intensity