IMPACTS OF LIVESTOCK FEEDING TECHNOLOGIES ON GREENHOUSE GAS EMISSIONS

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Abstract

Until 2050, the global population is projected to reach almost 9 billion people resulting in a rising demand and competition for biomass used as food, feed, raw material and bio-energy, while land and water resources are limited. Moreover, agricultural production will be constrained by the need to mitigate dangerous climate change. The agricultural sector is a major emitter of anthropogenic greenhouse gases (GHG). It is responsible for about 47 % and 58 % of total anthropogenic emissions of methane (CH_4) and nitrous oxide (N_2O) (IPPC, 2007). CH_4 emissions are associated with enteric fermentation of ruminants, rice cultivation and manure storage; N_2O emissions are related to nitrogen fertilizers and manure application to soils, but also to manure storage. Land use changes, pasture degradation and deforestation are the main sources of agricultural CO_2 emissions, where livestock is a major driver of deforestation and climate change, accounting for 18 % of anthropogenic GHG emissions (Steinfeld et al., 2006). In this context, the key role of livestock is to be investigated. According to FAO, livestock uses already about 30% of the Earth's land surface as resource for grazing while demand for livestock products will continue to rise significantly, especially to feed the animals.

For the assessment of future food supply and land-use patterns as well as the environmental impacts of the agricultural sector, there is an urgent need to identify and analyse main characteristics of the livestock sector. Concerning the conversion efficiency of natural resources like land and water to animal products, feeding technologies play a crucial role. They also determine the magnitude of environmental impacts per amount commodity generated.

For ten world regions we define the feeding technology for five livestock subsectors as a set of the following parameters: feed mix, feed energy requirements per unit output, and methane emissions per unit output. We calculate these parameters on the basis of FAO Food Balance Sheets and data from the literature. The resulting regional feed demand of marketable feed is consistent with FAO data.

To assess the impacts of different feeding technologies, we implement this concept in the global land use model MAgPIE that is appropriate to assess future anthropogenic GHG emissions from various agricultural activities and environmental and economic impacts of different pathways of the agricultural sector by combining socio-economic regional information with spatially explicit environmental data. We compare three alternative feeding scenarios in terms of GHG emissions from agricultural activities (CH_4, N_2O). We find that methane emissions rise significantly under a scenario of production extensification (i.e. higher roughage shares in feed mixes). Under an intensification scenario, future methane emissions are even lower than in 1995, but N_2O emissions from nitrogen fertilizers and manure application to soils increase.

1 Introduction

Human use of land and organic materials is a major component of the global biochemical cycles influencing carbon, nitrogen, phosphorous and water flows. Only about one fifth of the terrestrial surface hardly knows any human interferences, while two third serves as resource for the production of biomass (Sanderson et al., 2002; Erb et al., 2007). There are multiple destinies of biomass: satisfying the demand for food and feed, providing raw materials for buildings and industrial processes and supplying energy, especially in developing countries, but increasingly also in high income countries due to ambitious policies for climate change mitigation. Currently, human appropriation of biomass accounts for 16 % of global terrestrial NPP (18.7 PG/yr in 2000). Livestock is a crucial driver of land related human interaction with the Earth System, consuming 58 % of the economically used plant biomass (12.1 Pg/yr) in contrast to 12 % directly serving as human food (Krausmann et al., 2007).

The development of agriculture is imbedded in the context of a rapidly changing world. On-going population growth, increasing incomes and urbanization notably in developing countries and induced rising per capita caloric intake will intensify the pressures on agricultural systems and ecosystems over the whole world, but in particular in Asia, Latin America and Africa. The rising demand for food will be accompanied by a diet shift towards animal products. The realization of this livestock revolution (Delgado et al., 1999) would implicate a huge transformation of agriculture. Recent studies suggest that the consumption of animal products in the developing world will be at least double in comparison to the developed world in 2050 (Rosegrant et al., 2009).

The dominance of the livestock sector within global agriculture is reflected by data on land use. According to FAO, grazing land for ruminants accounts for almost 30 % of Earth's land surface. Furthermore, global livestock production requires additional feedstock like feed crops (currently covering 34 % of global cropland (Steinfeld et al., 2006), various food crop residues and conversion by-products from food processing. Hence, the need to feed the animals is an underlying determinant of the production and processing of vegetal food commodities and competes with all other potential usages of biomass. Since the feed baskets also include food crops, livestock directly vies with humans for the valuable natural resources securing sufficient nutrition. Due to the considerable range of possible - including biomass which cannot be directly metabolized by humans - feed demand of global animal population eminently contends with other socio-economic appropriations of biomass, like manufacturing and industrial processes, and in particular with the use of biomass within the energy sector.

The last remark holds true to the extent that the second generation biofuels gain in importance. In contrast to the so-called “first generation” of biofuels like ethanol, where corn, sugarcane, sugar beet, potatoes and wheat are the common feedstock types and biodiesel is produced from plant oil, the second generation of biofuels are more flexible in respect to the required feedstock. Cellulosic and heterogeneous biomass, crop and conversion by-products and even waste can be used for the generation of energy (Cantrell et al.,2008; Sklar, 2008).

Since plantations generating feedstock for second generation biofuels can be established on marginal land (Tilman et al., 2006; Zomer et al., 2008), there could emerge another hotspot of future trade-offs with regard to livestock production. These trade-offs between the use of biomass within the livestock or the energy sector are of outstanding interest because they touch a crucial aspect of both sectors: the emission of greenhouse gases.

Bioenergy production is supposed to decrease GHG emissions of the energy sector and is therefore supported and regulated by numerous policies for climate change mitigation. But there is an active scientific debate, whether this is really the case, if all direct and indirect emissions caused by agricultural production and the induced land use changes are taken into account (Havlík et al., 2010). In addition, many studies highlight the role of agricultural production as major emitter of anthropogenic GHG emissions, accounting for about 47 % and 58 % of total anthropogenic emissions of methane (CH_4) and nitrous oxide (N_2O) (IPPC, 2007). Global assessments for future GHG emissions from agriculture for 2020 range from 6700 Mt CO_2-equ (US-EPA, 2006) to 10150 Mt CO_2-equ (Strengers et al., 2004). Within agriculture, the lion's share of GHG emissions can be traced back to livestock production. Ruminants are the largest anthropogenic source of CH_4 which is produced by enteric fermentation (Crutzen et al., 1986). Due to lower conversion efficiencies from feed to animal products, they generally have an higher impact on ecosystems, requiring more land resources than any other agricultural activity and forcing degradation as well as deforestation (Asner et al., 2004).

Being responsible for 18 % of anthropogenic GHG emissions the whole livestock sector is a substantial driver of climate change (Steinfeld et al., 2006). Several studies investigate the issue of GHG emissions from livestock production, concentration on single world regions (Herrero et al., 2008; Yamaji et al., 2004) or selected GHG emissions and nutrient cycles (Oenema et al., 2005). Recently, the topic of dietary change attracts attention. A number of analyses emphasize the importance of consumption patterns for the mitigation of dangerous climate change (Aiking et al., 2006; McMichael et al., 2007). There is evidence that changes in diets are even more effective than technological mitigation option, in combination providing high GHG emission reduction potentials (Popp et al., 2010). Mitigation costs required to meet the 450 ppm CO_2-equ stabilization target (Meinshausen et al., 2006) could be reduced by about 50 % through a global transition to a low-meat diet recommended for health reasons by the Harvard Medical School for Public Health (Stehfest et al., 2009).

For exploring the impacts of global change on the livestock sector and vice versa, for estimating the extent of the livestock revolution and its transformation pressures on agricultural systems, there is an urgent need to identify and analyse main characteristics of livestock production. A proper assessment of the combined effects of various potential developments within the livestock sector has to analyse the sensitivity of decisive impact variables like deforestation, GHG emissions, land use change and food price indices with respect to variations of the most important parameters describing livestock production systems. In this article, we argue that the magnitude of environmental impacts per amount of animal product generated is highly determined by the conversion efficiency of natural resources like land, water and biomass to the provided commodities. Conversion efficiencies from feed to animal products vary between different animal types and are closely linked to feeding technologies. For ten world regions, we define the feeding technology for five livestock subsectors by feed energy requirements per unit output and the underlying feed mix.

In order to assess the direct and indirect impacts of feeding technologies in a spatially explicit way, we implement this concept in the global land use model MAgPIE (Lotze-Campen et al., 2008). By combining socio-economic regional information with spatially explicit data on potential crop yields, land and water constraints as well as carbon pools and flows from a global process-based vegetation and hydrology model (LPJmL) (Bondeau et al., 2007), MAgPIE is appropriate to assess environmental and economic impacts of different pathways of the agricultural and notably the livestock sector under the pressures of global change. A recent extension of MAgPIE (Popp et al., 2010) associates each spatially explicit agricultural activity with GHG emissions, hence allowing to integrate the issue of GHG emissions into the matrix of potential trade-offs and adverse externalities of agricultural production. In the following, we use MAGPIE to compare three alternative feeding scenarios in terms of their land use impacts and GHG emissions.

The rest of the paper is structured as follows: we first describe our modelling framework, the implementation of GHG emissions and the data and methodology underlying the presented integration of the livestock sector in MAgPIE. The next section is dedicated to the model application, where we define our baseline assumptions and explored scenarios, followed by the presentation and comparison of the scenario and baseline results, also with regard to other studies. We conclude by putting our main results into perspective through discussion in the last section.

2 Methodology and Data

2.1 The MAgPIE modelling framework

The Model of Agricultural Production and its Impact on the Environment (MAgPIE) (see Lotze-Campen et al., 2008 for a detailed description) is a non-linear mathematical programming model. Coupled to a spatially explicit process-based global dynamic vegetation and hydrology model (LPJmL) (Sitch et al., 2003; Bondeau et al., 2007), it simulates land-use and water allocation and other geographic and biochemical information on a spatial resolution of three by three degrees along with macroeconomic parameters on a regional level. This approach provides the opportunity to investigate long-term dynamics of global change driven by regional socio-economic variables as well as spatially diverse and disaggregated developments like climate change impacts on yields, thus integrating many different scales and methods of several disciplines. This transdisciplinary framework allows us to link monetary and physical units and processes in a straightforward way. As the dual solution of the mathematical programming model, we obtain shadow prices for binding constraints offering valuable insights in the scarcity of the respective variables, particular interesting for those where a market is typically not available. The information flow within our modelling system is displayed in Figure 1.

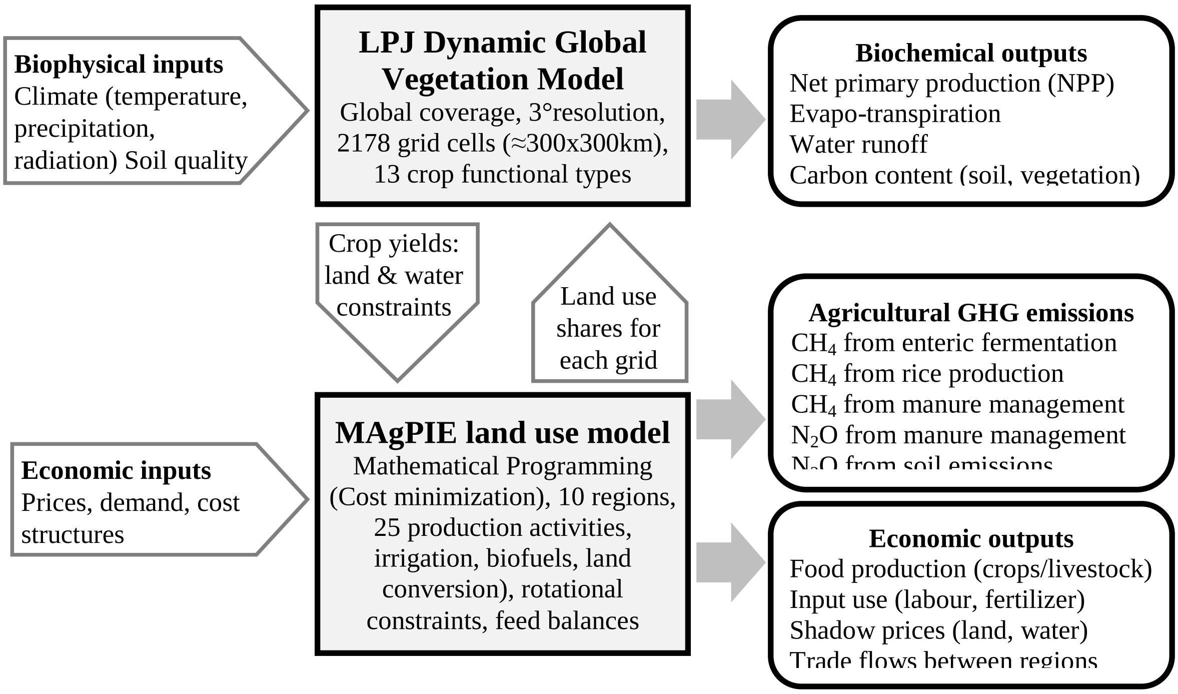

Figure 1: Information flow within the modelling system

The non-linear objective function of the land-use model is to minimize total costs of production for a given amount of agricultural demand. Regional food energy demand is defined for an exogenously given population and income growth in 15 vegetal and 5 animal food categories (temperate cereals, maize, tropical cereals, rice, five oil crops, pulses, potatoes, cassava, sugar beets, sugar cane, other food crops, ruminant meat, pig meat, poultry meat, eggs and milk), based on regional diets (FAOSTAT, 2010). Demand for bioenergy has to be fulfilled by two bioenergy crops. Feed for livestock is produced as a mixture of food crops, crop and conversion by-products, fodder and pasture. Fibre demand is currently satisfied with one cropping activity (cotton). Cropland, pasture and irrigation water are fixed inputs in limited supply in each grid cell, measured in physical units of hectares (ha) and cubic meters (m^3). Variable inputs of production are labour, chemicals, and other capital (all measured in USD), which are assumed to be in unlimited supply to the agricultural sector at a given price. Moreover, the model can endogenously decide to acquire yield-increasing technological change at additional costs. For future projections the model works on a time step of 10 years in a recursive dynamic mode. The link between two consecutive periods is established through the land-use pattern. For the base year 1995, total agricultural land is constrained to the area currently used within each grid cell, according to Ramankutty and Foley (1999). The optimized land-use pattern from one period is taken as the initial land constraint in the next. Optionally, additional land from the non-agricultural area can be converted into cropland at additional costs. Trade in food products between regions is constraint by minimum self-sufficiency ratios and export shares for each region.

Potential crop yields for each grid cell are supplied by the Lund-Potsdam-Jena dynamic global vegetation model with managed Lands (LPJmL) (Sitch et al., 2003; Bondeau et al., 2007). LPJmL endogenously models the dynamic processes linking climate and soil conditions, water availability and plant growth, and takes the impacts of CO_2, temperature and radiation on yield directly into account. LPJmL also covers the full hydrological cycle on a global scale, which is especially useful as carbon and water-related processes are closely linked in plant physiology (Gerten et al., 2004; Rost et al., 2008). Potential crop yields for MAgPIE are computed as a weighted average of irrigated and non-irrigated production, if part of the grid cell is equipped for irrigation according to the global map of irrigated areas (Döll and Siebert, 2000). In case of pure rain-fed production, no additional water is required, but yields are generally lower than under irrigation. If a certain area share is irrigated, additional water for agriculture is taken from available water discharge in the grid cell. Water discharge is computed as the runoff generated under natural vegetation within the grid cells and its downstream movement according to the river routing scheme implemented in LPJmL.

Spatially explicit data on yield levels and freshwater availability for irrigation is provided to MAgPIE on a regular geographic grid, with a resolution of three by three degrees, dividing the terrestrial land area into 2178 discrete grid cells of an approximate size of 300 km by 300 km at the equator. Towards higher latitudes the grid cells become smaller. Each cell of the geographic grid is assigned to one of ten economic world regions (Figure 2): Sub-Saharan Africa (AFR), Centrally-planned Asia including China (CPA), Europe including Turkey (EUR), the Newly Independent States of the Former Soviet Union (FSU), Latin America

(LAM), Middle East/North Africa (MEA), North America (NAM), Pacific OECD including Japan, Australia, New Zealand (PAO), Pacific (or Southeast) Asia (PAS), and South Asia including India (SAS). The regions are initially characterized by data for the year 1995 on population (CIESIN et al., 2000), gross domestic product (GDP) (World Bank, 2001), food energy demand (FAOSTAT, 2010), average production costs for different production activities (McDougall, 1998), and current self-sufficiency ratios for food (FAOSTAT, 2010). While all supply-side activities in the model are grid-cell specific, the demand side is aggregated at the regional level. Regional demand defined by total population, average income and net trade, is being met by the sum of production from all grid cells within the region.

The version of MAgPIE presented here incorporates a representation of the dominant greenhouse gas emissions (GHG) from different agricultural activities. We focus on N_2O-emissions from the soil and manure storage as well as CH_4-emissions from rice cultivation, enteric fermentation and manure storage that add up to 87 % of total agricultural (land use) emissions in the year 2000 (US-EPA 2006). As agricultural emissions arise from multiple causes, they depend on the type of agricultural activity. Their extent is heavily influenced by crop or animal type, fertilizer input, climate, soil quality or farm management. In the following we give an overview of the simulated agricultural emissions (see Popp et al., 2010 for more details).

2.2 GHG emissions from agricultural production

We calculate anthropogenic *N_2O emissions from agricultural soils* by including direct as well as indirect emissions. In our approach, direct N_2O emissions are affected by nitrogen input due to synthetic fertilizers, crop residues, N-fixing crops, and manure application. Indirect N_2O emissions enter the atmosphere by one of two pathways: 1) atmospheric deposition of NO_x and NH_3 (originating from fertilizer use and livestock excretion of nitrogen), and 2) leaching and runoff of nitrogen from fertilizer applied to agricultural fields and from livestock excretion. Anthropogenic N_2O *from animal waste management systems (AWMS)* is produced by the nitrification and denitrification of the organic nitrogen content in livestock manure and urine. In our modeling approach N_2O emissions from AWMS are affected by the amount of livestock products, livestock product specific nitrogen excretion and specific AWMS for animal products. Anthropogenic *CH_4 emissions from AWMSs* are produced during the anaerobic decomposition of manure. In our model, CH_4 emissions from AWMS are influenced by livestock species and temperature. We furthermore differentiate between developed and developing countries. The anaerobic decomposition of organic matter in flooded rice fields also produces CH_4. We model anthropogenic *CH_4 emissions from rice cultivation* to depend on water management practices and regional specific emission factors.
Anthropogenic CH_4 *emissions from enteric fermentation* occur when microbes in an animal's digestive system ferment food. CH_4 is produced as a byproduct and is exhaled by the animal. The amount of enteric CH_4 is mainly determined by the composition and digestibility of feed, but also on the rumen passage rate, and is calculated as a factor of the GE content of the feed intake. The feedstock specific CH_4 emission factors expressed as GE content of the amount of

CH_4 generated as share of the GE content of the feed were taken from Wirsenius (2000) and are in correspondence with the CH_4 emission factors suggested by the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997).

All emission factors are consistent with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) and the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). All IPCC national parameters, livestock and crop types are aggregated to the MAgPIE regions, animal and crop production types. In line with international greenhouse accounting practice (IPCC 2007), emission factors are expressed as carbon dioxide equivalents. CO_2, N_2O and CH_4 emissions were converted and summed together to CO_2 equivalents (CO_2-e) using the ‘global warming potential’ (GWP), which determines the relative contribution of a gas to the greenhouse effect. The GWP (with a time span of 100 years) of CO_2, CH_4 and N_2O is 1, 25 and 298, respectively (IPCC 2007).

2.3 Livestock production

The description of the livestock sector is based on FAO data (FAOSTAT, 2010) for the period 1994-1996 on production, utilization and trade of agricultural commodities as well as on feed use in view of the total animal population. For the production of fodder crops, we refer to an earlier release of the FAO statistical database (FAOSTAT, 2004), since the following versions do not enclose this information anymore. Data from the FAOSTAT Food Balance Sheets (FBS) allow calculating the demand for livestock products of the reference period and are a profound statistical basis to project the demand in the future. Given the required supply of livestock commodities to satisfy this demand, we have to identify the induced land use and biomass production for feed. The supply of animal food commodities is realized by five livestock production activities (ruminant meat, pig meat, poultry meat, eggs and milk). The realization of each of the livestock production activities is based on the distinction of animal functions (reproducers, producers and replacing animals) and the specification of the energy content of each feedstuff in gross energy (GE), digestible energy (DE), metabolizable energy (ME), and in the case of ruminants, also net energy (NE) for maintenance (NE.m), growth (NE.g) and lactation (NE.l). We use specific feed energy requirements per commodity unit generated for each animal function and livestock activity from Wirsenius (2000), which include the minimum requirements for maintenance, growth, lactation, reproduction and other basic biological functions of the animals. In addition, they comprise a general allowance for basic activity and temperature effects and are complemented by extra energy expenditures for grazing. The specific feed energy requirements per unit output are consistent with available FAOSTAT data on animal productivity and reflect the conversion efficiency of feedstock to animal products. The resulting regional feed energy demand has to be fully satisfied by the specific energy content of the feed mix to obtain a complete feed energy balance.

The next step in the calculation procedure consists in computing the corresponding total feed use in dry matter as well as the feed mix for each animal function and livestock activity. For this purpose, we have to supplement the feed use data from the FBS covering most food crops and the production data for fodder crops with three other important feed categories: crop by-products, conversion by-products and pasture. Estimates of feed use of by-products were based on harvest indices of food crops, extraction rates of food processing, recovery rates and assignment rates for feed use (Wirsenius, 2000; Krausmann, 2008; FAOSTAT, 2010), whereas the latter parameter type was used as point of departure to complement the regional picture of total feed use within a reasonable range for each feedstock, while simultaneously fitting the regional feed use data to the corresponding livestock production and feed requirements. The distribution of the described expanded data base on regional feed use of the whole livestock sector to single livestock activities and animal functions was obtained by an optimization model. The penalty function to be minimized includes balancing feedstock for the feed energy balances like additional fodder crops and grazed biomass and the deviation of

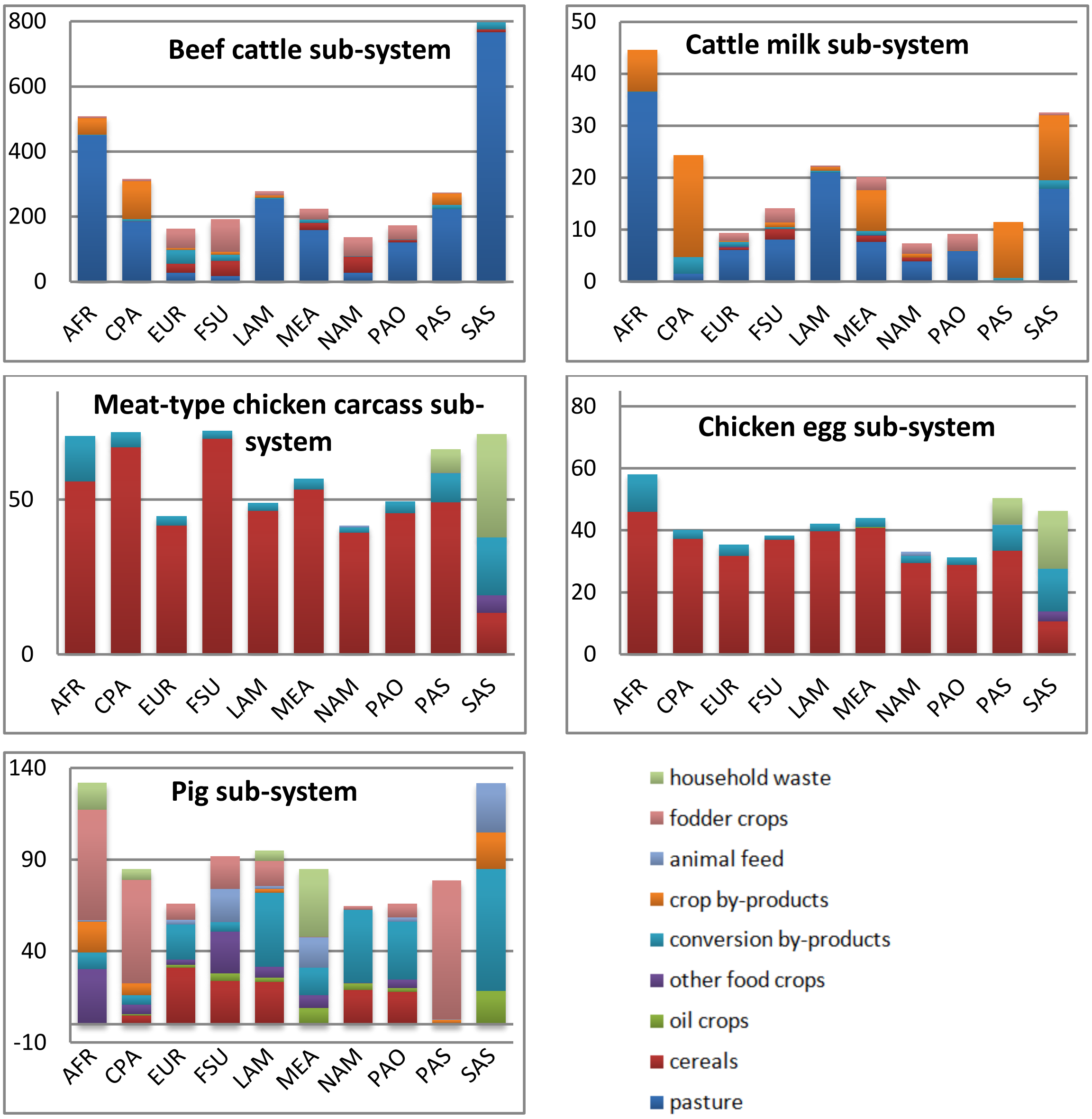

Figure 2: Regional specific feed energy requirements per unit animal product generated (GJ/t FM) and the share of different feedstock categories in the feed mix

the nutrient density of the resulting feed mixes from regional nutrient density recommendations. For developed countries, the nutrient density guidelines are based on NRC data (NRC 1989, NRC 1996), whereas for developing countries they are estimated by Wirsenius (2000). Since animals have only a limited capacity of eating and digesting biomass per unit time, feed rations must offer a certain nutrient density to meet a certain animal productivity target. The nutrient density guidelines - that depend on the intended animal productivity - ensure that the feed mix and the feed use of fodder, pasture and various crop and conversion by-products, i.e. all feedstock types where no consistent global database exists, are in line with the specific feed energy requirements also depending to a high extent on the productivity parameters.

Figure 2 illustrates regional specific feed energy requirements per unit animal product generated (in GJ per ton fresh matter) and the share of different feedstock categories in the feed mix. Figure 3 gives an overview on data sources and information flow of our representation of the livestock sector.

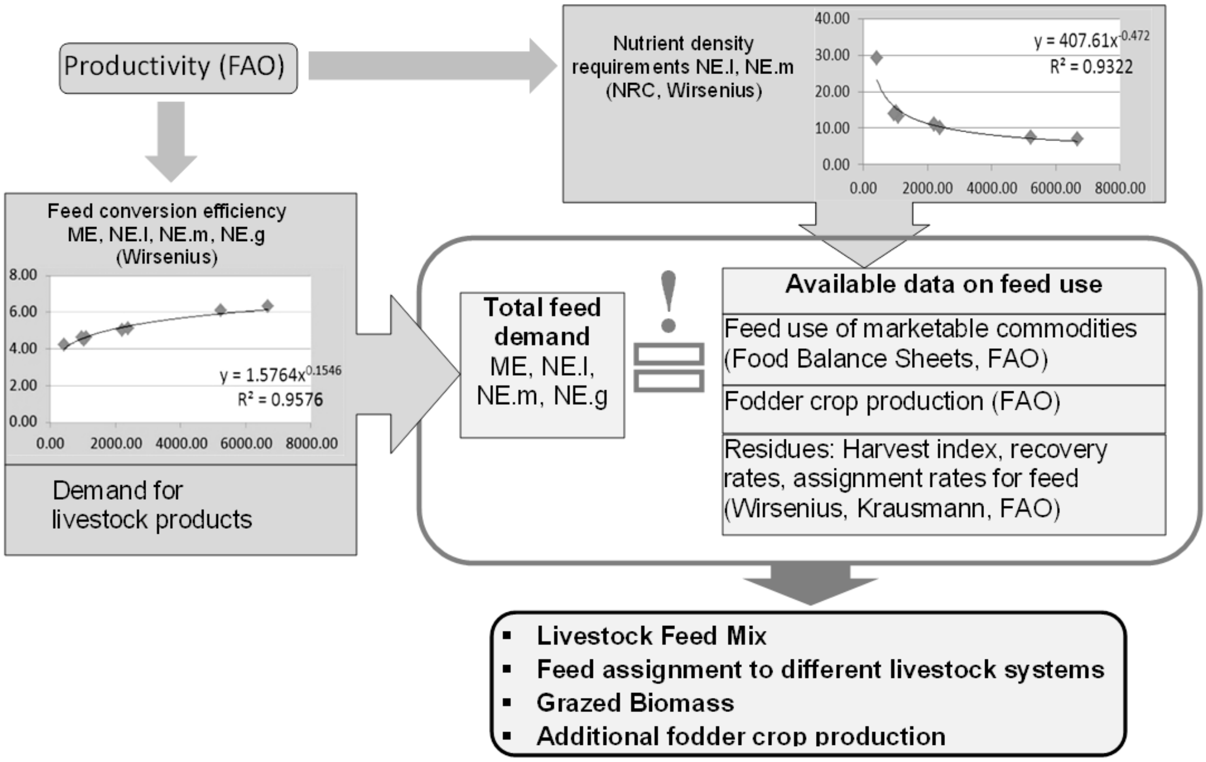

Figure 3: Data sources and information flow within the livestock sector

3 Model application

3.1 Scenario analysis

The development of global agriculture takes place in a rapidly changing world. In order to assess future anthropogenic GHG emissions from various agricultural activities and environmental and economic impacts of different pathways of the agricultural sector, we have to identify and implement the principal drivers of global change. Within this framework and context of change, we may analyse the effects of different feeding technologies.

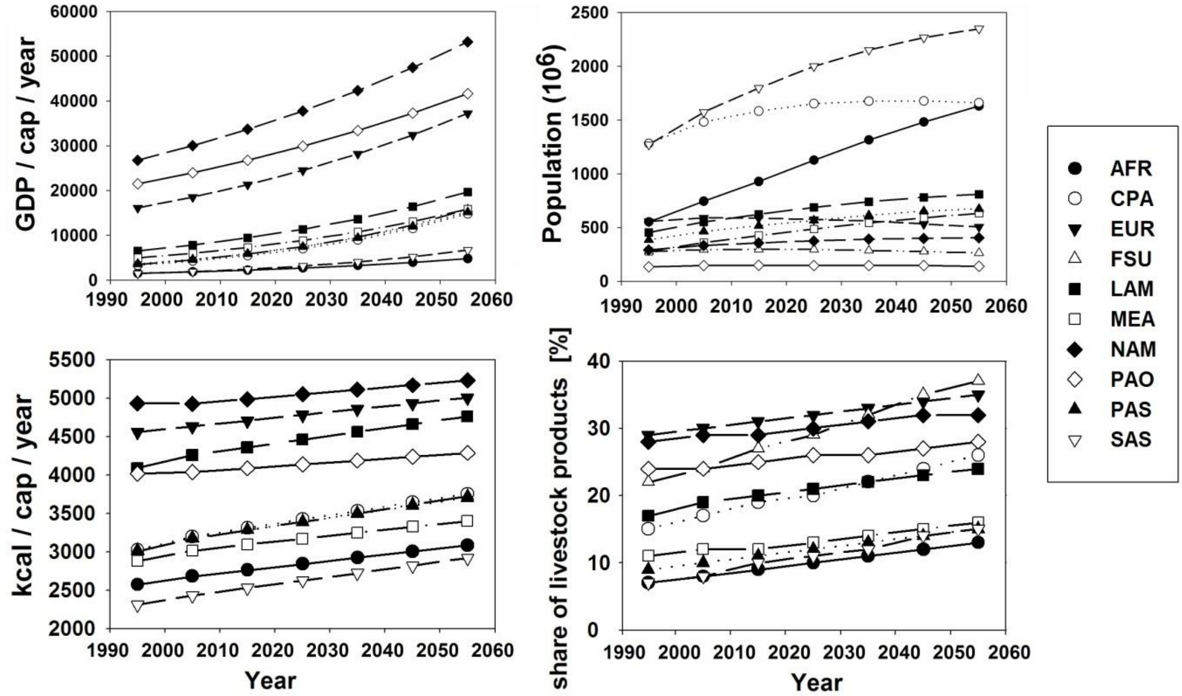

Figure 4: Exogenous scenario inputs on regional population and GDP growth, calorie intake per person per day and share of livestock products for all model regions

For the baseline scenario, we run the MAgPIE model in six 10-year time steps from 1995 until 2055 in a recursive dynamic manner. The model is driven by external scenarios on population growth and GDP growth taken from the SRES A2 scenario (IPCC, 2000). Global population increases up to about 9 billion in the year 2055, and average world income per capita reaches about 15,000 US$ (in 1995 purchasing power parity terms). There are no climate impacts on future yields, i.e. relative yield variability between grid cells is constant at 1995 levels. The link between GDP and food energy demand as well as the income induced shift in dietary preferences towards meat are given by regression equations as described by Lotze-Campen et al. (2008) and Popp et al. (2010) respectively. Figure 4 displays the setting of global change as result of the mentioned exogenous scenario inputs which forms the basis of the baseline scenario as well as of the feeding scenarios.

In order to assess the impact of future changes in feeding technologies, we compare the reference scenario with an *extensive* and an *intensive* feeding scenario characterized by the respective feed baskets and feed energy requirements per unit output. In the *extensive* scenario, we exogenously define for each region a linear transformation of the initial feed energy requirements for 1995 to the feed energy requirements of the region with the lowest conversion efficiency from feed to animal food. Since the feed energy requirements are closely interrelated to the feed baskets, we also linearly transform the feed shares of the main categories *cereals*, *oil crops*, *other food crops*, *conversion by-products*, *crop by-products*, *animal feed*, *fodder crops*, *household waste* and *pasture*. On average, AFR and SAS feature the lowest conversion efficiencies. Since the livestock sector in SAS has a set of exceptional characteristics like huge recovery and feed assignment rates and even a market for various crop by-products as well as the importance of occasional feeds like roadside grazing, household waste and weeds within the feed mix, we choose the parameterization of AFR as prototype for an extensive livestock sector. Analogously, we determine the *intensive* scenario and assign NAM as model region for an intensive livestock sector with the best feed to food conversion efficiency, followed by EUR.

3.2 Results

3.2.1 Reference scenario

First, we intend to explore the impact of the exogenous input scenarios representing aspects of future changes like population and income growth and the related shifts in lifestyles on agricultural non-CO_2 emissions (CO_2-e). Under the baseline assumption of a time-invariant parameterization of the livestock sector, MAgPIE projects global agricultural non-CO_2emissions (CO_2-e) to increase (compared by 1995) by 254% until 2055 (Figure 5).

The contribution of different sources and emissions vary widely between regions. Global CH_4 emissions will increase by 257 % and global N_2O emissions by 251 %. Global CH_4 emissions from enteric fermentation will increase by 322 %, N_2O emissions from soils by 252 % and total emissions from manure management by 249 % (CH_4: 255%; N_2O: 234 %). CH_4 emissions from rice production are far less affected (30 %).

Less developed regions like MEA (1502 %), FSU (665 %), AFR (587 %), SAS (376 %), LAM (264 %), and PAS (236 %), and CPA (177 %), where population numbers and incomes are projected to rise most, show the highest increase in total Non-CO_2 emissions until 2055. In contrast, developed regions like EUR (85 %), PAO (111 %) and NAM (164 %) with least projected population growth rates show lowest increase in total Non-CO_2 emissions until 2055 (see Figure 6). Increases in GHG emissions are mainly associated with world population increases from currently 6.5 billion to 9 billion by 2050 (UN, 2005), but the small gap between the increase of NAM and CPA displays that there is also another determinant for the projected developments of the agricultural non-CO_2emissions (CO_2-e), namely the export shares. For 1995, MAgPIE simulates global non-CO_2emissions to be 4504 Mt (CO_2-e).

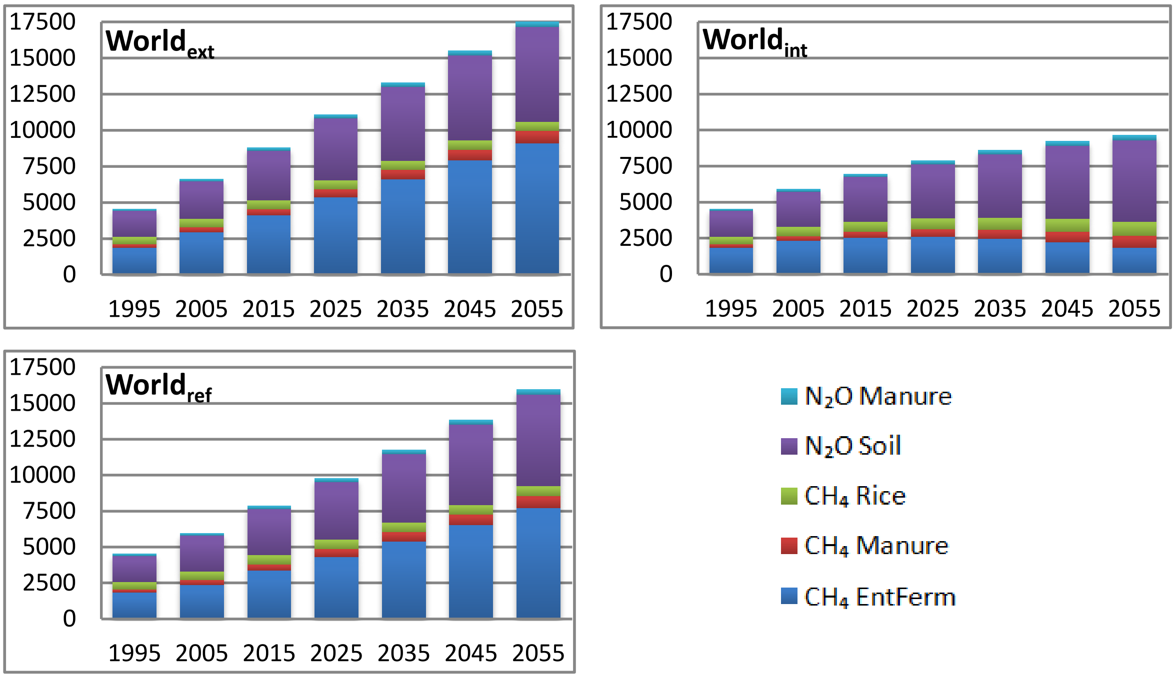

Figure 5: Global agricultural non-CO_2emissions (CO_2-e) for all scenarios

3.2.2 Scenario analysis

Our ‘baseline scenario’, i.e. constant parameterization of the livestock sector, reveals that global agricultural non-CO_2 emissions will increase from 4504 CO_2-e in 1995 to 15963 CO_2-e until 2055. The extensive scenario shows that a transformation of regional livestock systems to low efficient production conditions leads to a ratio of global agricultural greenhouse gases by 10 % until 2055 compared to the baseline scenario. Global CH_4 emissions from enteric fermentation rise by 389 %, CH_4 emissions from manure management by 256 %, N_2O soil emissions by 263 % and N_2O from manure management by 230 %. In contrast, CH_4 emissions from rice cultivation and N_2O soil emissions increase 20 %.

The intensive scenario, i.e. the linear transformation of regional parameterizations to an intensive model system, decreases global non-CO_2 emissions in 2055 by 97 % compared to our baseline model. Even under the assumptions of a massive increase of animal products, global CH_4 emissions from enteric fermentation decrease by 8 %. CH_4 emissions from manure management rise by 248 % and N_2O from manure management by 227 %. CH_4 emissions from rice cultivation increase by 88 % and N_2O soil emissions increase by 213 %.

Figure 6: Regional agricultural non-CO_2emissions (CO_2-e) for all scenarios

4 Discussion

The main objective of this paper was to emphasize the importance of the stage of development of the livestock sector with respect to global GHG emissions. We presented the implementation of the livestock sector in MAgPIE which allows us to assess various linkages between animal food production and socio-economic determinants in line with biochemical and geographical information. In order to highlight the impact of different livestock parameterizations, we applied this modeling approach for testing the sensitivity of global GHG emissions concerning feeding technologies. Our stylized scenarios span the action space for possible future developments although the borders of this space may be regarded as unlikely pathways. The effects of the extensive and intensive feeding scenarios are to be considered as upper and lower bounds for GHG emissions and are therefore capable of illustrating the range and extent of mitigation options within the livestock sector. These options are an essential supplement of the mitigation efforts in the energy system and by reforestation. Further strategies to reduce the impact of livestock production on the environment, particularly the climate system, consist in diet shifts towards a more vegetal based diet and the reduction and substitution of ruminant meat by poultry or pig meat. Targeting the livestock sector within a climate protection framework would not only make it more feasible to reach the 2°-target, it would also reduce the mitigation costs (Stehfest, 2009). Besides emission reductions, a more intensive livestock system consumes fewer natural resources and spares land for other purposes and natural ecosystems.

On the other hand, livestock rearing offers a variety of social benefits in terms of nutrient rich food and fertilizer, livelihoods and employment, provision of insurance and draft work. These values cannot be easily replaced. Livestock directly supports the livelihoods of 600 million poor smallholder farmers in the developing world (Thornton et al., 2006; Perry et al., 2007), predominantly living in mixed systems where manure from animals is used to enhance the fertility of soils, animals provide tractation and agricultural activities are imbedded in closed nutrient cycles. Hence, the productivity of the food crop production is closely interrelated with livestock. At this point, it has to be stressed that the issue of reducing the adverse impacts of livestock production on the demand side always has to consider the specific local circumstances and different levels of animal food consumption. The trade-offs between livestock rearing, livelihood, ecosystems and climate change mitigation appear in a different light in places where the excessive consumption of animal food already exceeds dietary recommendations from public health institutions (Willett, 2001) or the adverse effects on ecosystems are notably severe like at hotspots of nutrient overloads. At places where people suffer from undernourishment and protein deficiencies, the development and expansion of livestock production is an essential step towards food security and better livelihoods and has top priority, thus resolving the trade-off conflict in favor of livestock. It has to be pointed out that the biggest part of the livestock revolution, i.e. the substantial increase of the demand for animal products through population and income growth, takes place under these circumstances.

Accordingly, there is an urgent need not only to consider the demand side but simultaneously investigate how livestock production systems could evolve to satisfy this demand. According to Herrero et al. (2009), the relationship of livestock, livelihoods and the environment is not exclusively affected by contrary orientations. In particular in smallholder mixed crop-livestock systems, there is scope for an increasing animal productivity without using more inputs and depleting natural resources (Herrero et al., 2010). Such a sustainable intensification could improve the environmental performance of livestock production by applying management methods for pastures which enhance carbon sequestration and water productivity, and by introducing better feeding techniques in combination with breeding programs for animal feed and dual-purpose crops. For example, by using residues of dual-purpose varieties of sorghum and millet which achieve the same yield as conventional breeds but with a better quality of the crop by-products, Indian small-holders could improve the milk production of cows and buffalos by up to 50% (Blümmel et al., 2006). Consequently, a better quality of the feed baskets that positively affect CH_4 emissions from enteric fermentation is possible without necessarily tightening the competition for food crops.

In this article, we explored the contribution of agriculture to global non-CO_2 GHG emissions as a function of different feed to food conversion efficiencies and feed baskets. The parameterization of the livestock sector turned out to be of crucial importance for the magnitude of environmental impacts per amount of animal product generated and for the range of expected future GHG emissions from agriculture. Based on this insight on the sensitivity of decisive impact parameters like deforestation, GHG emissions and land use change with respect to transformations within the livestock sector, it is of great importance to better understand the drivers of changes in the livestock sector and to be able to project probable future developments. A proper assessment of the combined effects of various potential developments within the livestock sector, should integrate the issue of GHG emissions into a wider matrix of potential trade-offs and adverse externalities of agricultural production including socio-economic variables like food security and the protection of livelihoods. The environmental and social sustainability of the future use of biomass depends to a high extent on the way in which the main trade-offs involving livestock production are resolved.

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