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APPENDIX A

The Global livestock environmental assessment model (GLEAM)

1. INTRODUCTION

The Global Livestock Environmental Assessment Model (GLEAM) is a process-based static model that simulates the functioning of livestock production systems. The current version of the model (V1.0) focuses primarily on the quantification of GHG emissions, but future versions will include other processes and flows for the assessment of other environmental impacts, such as those related to water, nutrient and land use.

The model differentiates the 11 main livestock commodities, which are: meat and milk from cattle, sheep, goats and buffalo; meat from pigs; and meat and eggs from chickens. It calculates the GHG emissions and production for a given production system within a defined spatial area, thereby enabling the calculation of the emission intensity for combinations of commodities, farming systems and locations.

The main purpose of this appendix is to explain the way in which GLEAM calculates the emission intensity of livestock products. The input data used in GLEAM (and associated issues of data quality and management) are addressed in Appendix B. The focus of this appendix is on:

- providing an overview of the main stages of the calculations;
- outlining the formulae used; and
- explaining some of the key assumptions and methodological choices made.

2. MODEL OVERVIEW

The model is GIS-based and consists of:

- input data layers;
- routines written in Python (http://www.python.org/) that calculate intermediate and output parameters; and
- procedures for running the model, checking calculations and extracting output.

The basic spatial unit used in the GIS is a cell of 3 arc minutes. The emissions and production are calculated for each cell using input data of varying levels of spatial resolution (see Appendix B). The overall structure of GLEAM is shown in Figure A1, and the purpose of each module summarized below.

- The **herd module** starts with the total number of animals of a given species and system within a cell (see Appendix B for a brief description of the way in which the total animal numbers are determined). The module also determines the herd structure (i.e. the number of animals in each cohort group, and the rate at which animals move between cohort groups) and the characteristics of the average animal in each cohort (e.g. weight and growth rate).
- The **manure module** calculates the rate at which excreted N is applied to pasture and crops.

- The **feed module** calculates key feed parameters, i.e. the nutritional content and emissions per kg of the feed ration.
- The **system module** calculates each animal's energy requirement, and the total amount of animal product (milk, meat and fibre) produced in the cell each year. It also calculates the total annual emissions arising from manure management, enteric fermentation and feed production.
- The **allocation** module combines the emissions from the system module with the emissions calculated outside GLEAM, i.e. emissions arising from (a) direct on-farm energy use; (b) the construction of farm buildings and manufacture of equipment; and (c) post-farm transport and processing. The total emissions are then allocated to output in the form of products and services (milk, meat and eggs, fibre and draught power) and the emission intensity per unit of commodity calculated. Each of the stages in the model is described in more detail below.

3 HERD MODULE

The functions of the herd module are to:

- Determinate the herd structure, i.e. the proportion of animals in each cohort, and the rate at which animals move between cohorts; and
- Calculate the characteristics of the animals in each cohort, i.e. the average weight and growth rate of adult females and adult males.

Emissions from livestock vary depending on animal type, weight, phase of production (e.g. whether lactating or pregnant) and feeding situation. Accounting for these variations in a population is important if emissions are to be accurately characterized. The use of the IPCC (2006) Tier 2 methodology requires the animal population to be categorized into distinct cohorts. Data on animal herd structure are generally not available at the national level. Consequently, a specific herd module was developed to decompose the herd into cohorts. The herd module characterizes the livestock population by cohort, defining the herd structure, dynamics and production.

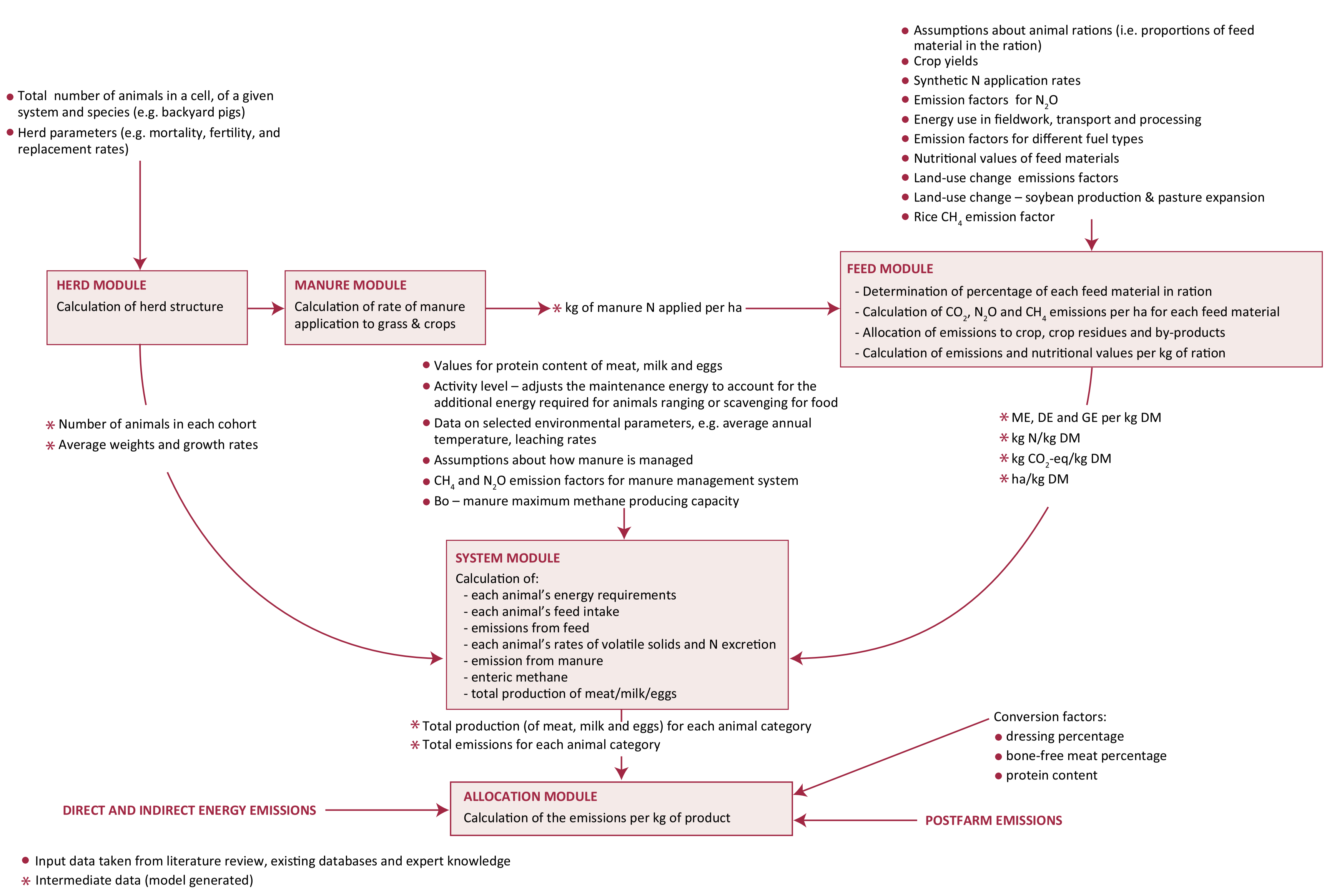
Herd structure. The national herd is disaggregated into six cohorts of distinct animal classes: adult female and adult male, replacement female and replacement male, and male and female surplus or fattening animals which are not required for maintaining the herd. Figure A2 provides an example of a herd structure (in this case for cattle). In this assessment it is assumed that all surplus calves are fattened for meat.[12]

The key production parameters required for herd modeling include data on *mortality, fertility, growth and replacement rates,* also known as "rate parameters". In addition, other parameters are used to define the herd structure. They include:

- the age or weight at which animals transfer between categories e.g. the age at first parturition for replacement females or the weight at slaughter for fattening animals;
- duration of key periods i.e. gestation, lactation, time between servicing; and
- the ratio of breeding females to males.

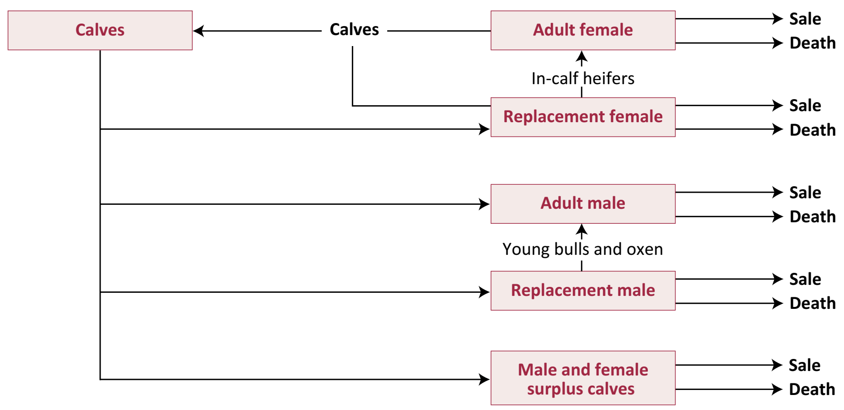
[12] In some intensive dairy systems, surplus calves may be slaughtered within a few days after birth.

Figure A1.
Schematic representation of GLEAM



Source: Authors.

Figure A2.
Structure of herd dynamics for cattle



Source: Authors.

4. MANURE MODULE

The function of the manure module is to calculate the rate at which excreted N is applied to feed crops.

The manure module calculates the amount of manure N collected and applied to grass and cropland in each cell by:

- calculating the amount of N excreted in each cell by multiplying the number of each animal type in the cell by the average N excretion rates;
- calculating the proportion of the excreted N that is lost during manure management and subtracting it from the total N, to arrive at the net N available for application to land; and
- dividing the net N by the area of (arable and grass) land in the cell to determine the rate of N application per ha.

5. FEED MODULE

The functions of the feed module are to:

- Calculate the composition of the ration for each species, system and location;
- Calculate the nutritional values of the ration per kg of feed DM; and
- Calculate of GHG emissions and land use per kg of DM of ration.

The feed module determines the diet of the animal, i.e. the percentage of each feed material in the ration, and calculates the emissions (N_2O, CO_2 and CH_4) arising from the production, processing and transport of the feed. It allocates the emissions to crop co-products such as crop residues or meals) and calculates the emission intensity per kg of feed. It also calculates the nutritional value of the ration, in terms of its energy and N content.

5.1 Determination of the ration

Animal rations are generally a combination of different feed ingredients. For ruminants, three broad categories of feed are considered: roughages, by-products and concentrates. Typically, major feed ingredients include:

- Grass: ranges from natural pasture and roadsides to improved and cultivated grasslands and leys.
- Feed crops: crops specially grown to feed livestock, e.g. maize silage or grains.
- Tree leaves: browsed in forests or collected and carried to livestock.
- Crop residues: plant material left over from food or other crops, such as straw or stover, left over after harvesting.
- Agro-industrial by-products and wastes: by-products from the processing of non-feed crops such as oilseeds, cereals, sugarcane, and fruit. Examples include cottonseed cakes, rapeseed cakes and brans.
- Concentrates: high quality mixtures of by-products and feed that are processed at specialized feed mills into compound feed.

In all livestock production systems, the composition of the feed ration depends on the availability of pasture and fodder, the crops grown and their respective yields. The fraction of concentrates in the ration varies widely, according to the need to complement locally available feed, the purchasing power of farmers, and access to markets. While actual diets will vary depending on what crops are grown locally and the price of feed crops, the balance of forage, crops and by-products must be reasonable in order to match animal performance. The proportion of each feed component is determined differently for industrialized and developing country regions:

- for the industrialized regions, the composition (i.e. feed materials) and relative portions of the feed ration materials are taken from country national inventory reports, literature and targeted surveys.
- for developing countries, due to scanty information, a feed allocation scheme was devised based on literature and expert knowledge. This allocation scheme assumes that in developing regions there is a close relationship between land use and the feed ration.

Feed allocation scheme for developing countries. The feed allocation scheme is based on the availability of feed resources (crops and forage) and animal requirements. The determination of the feed ration is outlined stepwise below:

1. Define the proportion of by-products and concentrates in the ration (based on surveys, literature and expert knowledge) and the difference is considered roughages.
2. Calculate the total roughage availability in each pixel based on the dry matter yields per hectare of pasture, fodder and crop residues and the land area of the respective feeds. Data for this calculation was obtained from a number of sources: FAOSTAT for specific crops (e.g. fodder beet, soybean, rapeseed, cottonseed, sugar beet and palm fruit); You *et al.* (2010) from the Spatial Production Allocation Model (SPAM) for 20 crops; and Haberl *et al.* (2007) to estimate the above-ground net primary productivity for pasture.
3. Feed requirements for all ruminant species were then assessed. This was done by expressing the different ruminant species and categories of animals in cattle equivalent, to take into account the fact that these animals are competing for the same feed resource.
4. To assess the feed availability, a ratio between the total roughage availability (calculated in 2 above) and ruminant species biomass (in cow equivalent calculated in 3 above) was obtained.

5. Total ruminant annual feed requirements are then calculated for the total cow equivalent based on the assumption that an animal consumes about 2 to 3 percent of its bodyweight on a daily basis and hence, on an annual basis, DMI will range between 7.3 and 14 kg DM.
6. The total amount of roughage feed available is then compared with the animal feed requirements within each cell. Comparing the total feed availability with the animal requirements provides an indication of feed adequacy in terms of sufficiency, deficiency or surplus for any given location. An area can be classified based on the dry matter availability and generally a dry matter availability of less than 2 percent of the bodyweight can be considered as a deficit, dry matter availability between 2 and 3 percent can be considered as adequate, and above 3 percent can be considered as surplus. In situations where ample feed is not available to meet the requirements of the animals (i.e. less than 2 percent), the feed ration is supplemented with leaves and hay.
7. The proportion of each roughage material within the feed ration is then obtained by dividing the quantity available of each roughage material by the total available roughage.
8. The proportions of the roughage materials (calculated in 7 above) plus the by-products and concentrate proportions (defined in 1 above) form the total feed ration which sums to 100.

Tables B7 to B12 in Appendix B present the average feed rations and the proportions of the different feed materials within the feed ration for the world's main regions and species.

5.2 Determination of the ration's nutritional values

Nutritional values such as the digestibility and N-content of each individual feed material are used to calculate the nutritional value of animal feed rations. These nutritional values are multiplied by the percentage of each feed material in the ration to arrive at the average energy and N content per kg of DM for the ration as a whole. Table B13 in Appendix B compares regional variation in digestibility of feed rations for ruminant species.

5.3 Determination of the ration's GHG emissions and land use per kg of DM from feed

The categories of GHG emission included in the assessment of each feed material's emissions are:

- direct and indirect N_2O from grass and crop cultivation;
- CO_2 arising from loss of above and below ground carbon brought by land-use change;
- CO_2 from the on-farm energy use associated with field operations (tillage, manure application, etc.) and crop drying and storage;
- CO_2 arising from the manufacture of fertilizer;
- CO_2 arising from crop transport; and
- CO_2 arising from off-farm crop processing.

A brief outline of how the emissions were calculated is provided below.

Determination of feed emissions: N_2O from pasture and crop cultivation. Nitrous oxide emissions from cropping include direct N_2O, and indirect N_2O from leaching and volatilization of ammonia. It was calculated using the IPCC (2006) Tier 1 methodology. Synthetic N application rates were defined for each crop at a national level, based on existing data sets (primarily FAO's fertilizer use statistics, http://www.fao.org/ag/agp/fertistat/index_en.htm) and adjusted down where yields were below certain thresholds. Manure N application rates were calculated in the manure module. Crop residue N was calculated using the crop yields and the IPCC (2006, Volume 4, Chapter 11, p. 11.17) crop residue formulae.

Determination of pasture and crop emissions: CO_2 from land-use change. The approach for estimating emissions from land-use change is presented in Appendix C.

Determination of feed emissions: CO_2 from fertilizer manufacture. The manufacture of synthetic fertilizer is an energy-intensive process, which can produce significant amounts of GHG emissions, primarily via the use of fossil fuels, or through electricity generated using fossil fuels. The emissions per kg of fertilizer N will vary depending on the factors such as the type of fertilizer, the efficiency of the production process, the way in which the electricity is generated, and the distance the fertilizer is transported. Due to the lack of reliable data on these parameters, and on fertilizer trade flow, the average European fertilizer emissions factor of 6.8 kg CO_2-eq per kg of ammonium nitrate N in all regions was used (Jenssen and Kongshaug, 2003), which includes N_2O emissions arising during manufacture.

Determination of feed emissions: CO_2 from field operations. Energy is used on-farm for a variety of field operations required for crop cultivation, such as tillage, preparation of the seed bed, sowing and application of synthetic and organic fertilizers, crop protection and harvesting. The type and amount of energy required per ha, or kg, of each feed material parent crop was estimated. In some countries, field operations are undertaken using non-mechanized power sources, i.e. human or animal labour. The energy consumption rates were adjusted to reflect the proportion of the field operations undertaken using non-mechanized power sources. Table A1 gives an indication of the average level of mechanization per region. From the level of mechanization, we also inferred reliance on animal draught power in the country, and therefore the bull to cow ratio in the herd. The emissions arising from fieldwork per ha of each crop were calculated by multiplying the amount of each energy type consumed per ha, by the emissions factor for that energy source.

Table A1. Estimated average level of mechanization by region

Continent	Estimated rate of mechanisation *(percentage)*
Africa	16
Asia	78
Central and South America	96
Europe	100
North America	100
Oceania	100

Source: FAOSTAT (2009).

Determination of feed emissions: CO_2 from transport and processing. Pasture and crop residues, by definition, are transported minimal distances and are allocated zero emissions for transport. Non-local feeds are assumed to be transported between 100 km and 700 km by road to their place of processing. In countries where more of the feed is consumed than is produced (i.e. net importers), feed that are known to be transported globally (e.g. soybean meal) also receive emissions that reflect typical sea transport distances. Emissions from processing arise from the energy consumed in activities such as milling, crushing and heating, which are used to process whole crop materials into specific products. Therefore, this category of emissions applies primarily to feeds in the by-product category.

Determination of feed emissions: CO_2 from blending and transport of compound feed. Energy is used in feed mills for blending non-local feed materials to produce compound feed and to transport it to its point of sale. It was assumed that 186 MJ of electricity and 188 MJ of gas were required to blend 1 000 kg of DM, and that the average transport distance was 200 km.

5.4 Allocation of emissions between crop and its by-products

In order to calculate the emission intensity of the feed materials, emissions need to be allocated between the crop and its by-products, i.e. the crop residue or by-products of crop processing used as feed. The general expression used is:

$$GHGkgDM = GHGha/(DMYGcrop \cdot FUEcrop + DMYGby \cdot FUEby) \cdot EFA/MFA$$

where:

GHGkgDM	=	emissions (of CO_2, N_2O, or CH_4) per kg of dry matter
GHGha	=	emissions per ha
DMYGcrop	=	gross crop yield (kgDM/ha)
DMYGby	=	gross crop residue or by-product yield (kgDM/ha)
FUEcrop	=	feed use efficiency, i.e. fraction of crop gross yield harvested
FUEby	=	feed use efficiency, i.e. fraction of crop residue or by-product gross yield harvested
EFA	=	economic fraction, crop or co-product value as a fraction of the total value (of the crop and co-product)
MFA	=	mass fraction, crop or co-product mass as a fraction of the total mass (of the crop and co-product)

Dry matter yields and estimated harvest fractions were used to determine the mass fractions. Where crop residues were not used for feed or bedding, they were assumed to have a value of zero, i.e. 100 percent of the emissions were allocated to the crop.

Allocation techniques of feed emissions is summarized in Table A2. Emissions from post-processing blending and transport are allocated entirely to feed. It should be highlighted that emissions that are not allocated to feed do not cease to exist. Rather, they are allocated to other commodities. Failure to follow this approach may lead to incorrect policy conclusions.

Table A2. Summary of the allocation techniques used in the calculation of plant-based feed emissions

Products	Source of emissions	Allocation technique
All feed crops and their by-products	N_2O from manure application N_2O from synthetic fertilizer CO_2 from fertilizer manufacture CO_2 from fieldwork	Allocation between the crop and co-product is based on the mass harvested, and the relative economic values (using digest-ibility as a proxy)
By-products only	CO_2 from processing CO_2 from LUC (for soybean)	Allocated to the processing by-products based on mass and economic value
Feed produced off-farm	CO_2 from transportation and blending	100 percent to feed material

Source: Authors.

6. SYSTEM MODULE

The functions of the system module are to:

- Calculate the average energy requirement (MJ) and feed intake (kg DM) of each animal cohort;
- Calculate the total feed emissions and land use arising from the production, processing and transport of the feed;
- Calculate the CH_4 and emissions arising during the management of manure;
- Calculate enteric CH_4 emissions.

6.1 Calculation of animal energy requirement

The system module calculates the energy requirements of each animal, which is then used to determine the feed intake (in kg of DM). The model uses the IPCC Tier 2 algorithms (IPCC, 2006 Volume 4, Chapter 10, Equations 10.3 to 10.13) to calculate energy requirements for each animal sub-category. The gross energy requirement is the sum of the requirements for maintenance, lactation and pregnancy, animal activity, weight gain and production.[13] The method estimates a maintenance requirement (as a function of live-weight and energy expended in feeding); a production energy requirement influenced by the level of productivity (e.g. milk yield, live-weight gain, wool production); physiological state (pregnancy and lactation); and the stage of maturity of the animal. Based on production and management practices, the net energy and feed requirements of all animals are first calculated, taking into account the following parameters:

- *Weight*. Larger animals need more energy for maintenance than smaller ones.
- *Production*. The output from animals can be milk and meat, but also non-edible products and services. Data on production of edible and non-edible products is taken from literature and statistical databases. In general terms, a higher production or more labour per day requires more energy and thus more feed per day.

[13] Total production is computed on the basis of herd parameters (reproduction, mortality, etc.) and productivity parameters (such as milk yield and weight gain) used in the analysis. Consequently, total production may not be consistent with total production in the FAOSTAT database.

- *Production/feeding environment (Grazing or stall feeding).* Animals in ranging systems that have to search for their feed (often over long distances) have higher energy requirements than those in grazing systems or stall-fed systems.

6.2 Calculating feed intake, total feed emissions and land use

The feed intake of each animal category (in kg DM/day) is calculated by dividing the animal's energy requirement by the average energy content of the ration from the feed module:

Feed intake (kgDM/animal/day) = total energy requirements (MJ/animal/day)/feed energy content (MJ/kgDM)

where: feed energy content = 18.45 (MJ/kgDM)

The feed intake of each cohort is multiplied by the number of animals in each group to obtain the total daily feed intake for the entire herd. The feed emissions and land use associated with the feed production are then calculated by multiplying the total feed intake for the herd by the emissions or land use per kg of DM taken from the feed module.

6.3 Calculation of CH_4 emissions arising enteric fermentation

Emissions from enteric fermentation (kg CH_4/head) are a function of feed digestibility (DE), i.e. the percentage of gross energy intake that is metabolized. An enteric methane conversion factor, Y_m (percentage of gross energy converted to methane) is used to calculate the methane emissions from enteric fermentation. A Tier 2 approach is applied for the calculation of enteric CH_4 emissions due to the sensitivity of emissions to diet composition and the relative importance of enteric CH_4 to the overall GHG emissions profile in ruminant production. The IPCC (2006) defines the CH_4 conversion factor (Y_m) as 6.5±1 percent, indicating that Y_m is at the high end of the range when digestibility of feed is low and vice versa. The Y_m value of 6.5 is realized at a digestibility of 65 percent. To better reflect the wide-ranging diet quality and feeding characteristics globally, this assessment developed specific Y_m values based on the following formula:

$$Y_{m\ Cattle} = 9.75 - 0.05 \cdot DE$$
$$Y_{m\ mature\ sheep} = 9.75 - 0.05 \cdot DE$$
$$Y_{m\ lamb<1\ year} = 9.75 - 0.05 \cdot DE$$

Y_m is subsequently used in the following formula to estimate the CH_4 emission factor

$$EFCH_4 = (365 \cdot GE \cdot (Y_m / 100) / 55.65)$$

where: $EFCH_4$ is the CH_4 emission factor (kg CH_4 head $^{-1}$ yr $^{-1}$); Y_m corresponds to CH_4 conversion factor; GE is the gross energy intake (MJ head^{-1} day^{-1}) and the factor 55.65 (MJ kg CH_4) represents the energy content of CH_4.

6.4 Calculation of CH_4 emissions arising during manure management

Calculating the CH_4 per head from manure using a Tier 2 approach requires (a) estimation of the rate of excretion of volatile solids per animal, and (b) estimation of the proportion of the volatile solids that are converted to CH_4. The volatile solids excretion rates are calculated using Equation 10.24 from IPCC (2006). Once the volatile solids excretion rate is known, the proportion of the volatile solids converted to CH_4 during manure management per animal per year can be calculated using Equation 10.23 from IPCC (2006).

The CH_4 conversion factor depends on how the manure is managed. In this study, the manure management categories and emission factors in IPCC (2006, Volume 4, Chapter 10, Table 10A-7) were used. The proportion of manure managed in each system is based on official statistics (such as the Annex I countries' National Inventory Reports to the UNFCCC), other literature sources and expert judgement.

6.5 Calculation of N_2O emissions arising during manure management

Calculating the N_2O per head from manure using a Tier 2 approach requires (a) estimation of the rate of N excretion per animal, and (b) estimation of the proportion of the excreted N that is converted to N_2O.

The N excretion rates are calculated using Equation 10.31 from IPCC (2006) as the difference between intake and retention. N-intake depends on the feed dry matter intake and the N content per kg of feed. The feed dry matter intake depends, in turn, on the animal's energy requirement (which is calculated in the system module, and varies depending on weight, growth rate, milk yield, pregnancy, weight gain and lactation rate and level of activity) and the feed energy content (calculated in the feed module). N retention is the amount of N retained in, either as growth, pregnancy live weight gain or milk.

The rate of conversion of excreted N to N_2O depends on the extent to which the conditions required for nitrification, denitrification, leaching and volatilization are present during manure management. The IPCC (2006) default emission factors for direct N_2O (IPCC, 2006 Volume 4, Chapter 10, Table 10.21) and indirect via volatilization (IPCC, 2006 Volume 4, Chapter 10, Table 10.22) are used in this study, along with variable leaching rates, depending on the AEZ.

7. ALLOCATION MODULE

The functions of allocation module are to:

- Sum up the total emissions for each animal cohort;
- Calculate the amount of each commodity (meat, milk, eggs, wool) produced;
- Allocate emissions to each commodity (meat and meat), non-edible outputs (fibre and manure used for fuel), draught and services; and
- Calculate total emissions and emission intensity of each commodity.

7.1 Calculation of the total emissions for each animal cohort

The system module calculates the total emissions arising from feed production, manure management and enteric fermentation. Post farmgate emissions (Appendix D) and direct and indirect on-farm energy use (Appendix E) are calculated separately and incorporated in the allocation module.

7.2 Calculation of the amount of each commodity (meat, milk, fibre) produced

Milk. Total milk production was calculated based on average milk production per animal and number of milking animals. Total milk is then converted to fat and protein milk. Using FPCM as the basis for comparison ensures a comparison between milk produced by different breeds and feeding regimes. All milk was converted to FPCM using the following equations:

Milk yield from cattle was corrected at 4.0 percent fat and 3.3 percent protein using the equation: FPCM (kg) = milk production, kg • [0.337+ 0.116 • fat, (percent) + 0.06 • protein, (percent)]

Milk yield from small ruminants was corrected at 6.5 percent fat and 5.8 percent protein according to Pulina, Macciotta and Nuda (2004) using the equation: FPCM (kg) = milk production, kg • [0.25+ 0.085 • fat, (percent) + 0.035 • protein, (percent)]

Buffalo milk production was expressed was corrected at 4 percent fat and 3.1 percent protein using the following equation (Di Palo, 1992): FPCM (kg) = milk production, kg • [1+ 0.011 • {(fat, (percent) • 10-40) + (10 • protein, (percent)-31)}]

Meat. Total meat production is calculated from the number of live animals (per cohort group) that leave the farm for slaughter and the live weight at which they are sold. Dressing percentages for the conversion of live weight to carcass weight are given in Appendix B, Tables B20 and B21. Conversion of carcass to bone-free meat is obtained by multiplying by 0.75 and 0.70 for large and small ruminants, respectively. The conversion of bone-free meat (BFM) to protein is based on the assumption that BFM is 18 percent protein by weight.

Natural fibre. Total fibre (wool, mohair and cashmere) is estimated by multiplying kg of fibre produced per animal by the number of fibre producing animals in the herd.

7.3 Allocation to co-products and calculation of emission intensity

For ruminant species, emissions are allocated between the edible commodities, i.e. meat and milk. In reality, there are usually significant amounts of other commodities produced during processing, such as skin, feathers and offal. However, the values of these can vary markedly between countries, depending on the market conditions, which, in turn, depend on factors such as food safety regulations and consumer preferences. Allocating no emissions to these can lead to an over-allocation to meat. The potential effect of this assumption is explored in Appendix F. Allocation techniques applied in this assessment are discussed below:

Meat and milk. Emissions related to goods and services other than meat and milk (e.g. fibre, manure used for fuel, draught power) were first calculated separately and deducted from the overall system emissions, before emissions were attributed to meat and milk.

Within the dairy herd, some animals only produce meat (fattened surplus calves), while others contribute to the combined production of meat and dairy products (milked cows, adult reproduction male animals and replacement stock). For the latter group, we chose to allocate GHG emissions on the basis of their protein con-

Table A3. Example of allocation between edible products from dairy production

	Part of herd producing milk and meat *(milking cows, adult male, replacement stock)*	**Part of herd producing meat only** *(surplus males and females)*
Total emissions *(kg CO_2-eq)*	1 700 000	350 000
Total protein *(kg)*	Milk: 18 000 Meat: 1 500	Meat: 2 500
Fraction of milk protein	0.92	NA
Fraction of meat protein	0.08	1
Emission intensity of milk	= (1 700 000 · 0.92)/18 000 **= 87 kg CO_2-eq/kg protein**	
Emission intensity of meat	= [(1 700 000 · 0.08) + 350 000]/(1 500+2 500) **122 kg CO_2-eq/kg protein**	

NA: Not Applicable.
Source: Authors' calculations.

tent. Table A3 provides an illustration of how the technique is applied. This method reflects the fact that a primary function of the livestock sector is to provide humans with edible protein. The advantages of using protein content are that it enables direct comparison with other food products and is also relatively stable in time (as opposed, for example, to the relative prices of meat and milk) and that it can be applied in situations where markets are absent or where they are highly localized and not comparable across regions. However, a disadvantage is that other nutritional properties, such as minerals, vitamins and energy, and essential fatty acids are not captured.

Emissions related to surplus calves fattened for meat production were entirely attributed to meat production. However, the emissions related to the production of calves, i.e. the pregnancy of the dairy cows and female replacement stocks, were allocated to milk because they are an essential input for milk production. No emissions were allocated to the other parts of the slaughtered animal (e.g. skin, horns), although these are utilized and represent an economic yield. This may result in a slight overestimation of the emissions per kg of carcass weight. In beef herds, all emissions were allocated to meat after the deduction of emissions related to draught power (in the case of cattle) and fibre (wool, cashmere and mohair) from small ruminants.

Manure. Manure is another by-product of livestock production. The emissions related to manure were allocated through the subdivision of the production processes:

- *Emissions related to manure storage* were fully allocated to the livestock system.
- *Emission from manure applied on the land used for feed, food and cash crop production* were allocated to livestock in situations where the crop as a whole or in part (e.g. silage, grain, oilseeds) was used for animal nutrition. In situations where manure was entirely deposited on grassland and feed crops, no allocation was required because the manure remained within the livestock system. On the other hand, where parts of the crop (e.g. crop residues) were used for feed, emissions were allocated according to the relative weight of harvested products used as feed, corrected for digestibility. Due to

the absence of an economic value for crop residues, digestibility was used as a proxy for economic value. In cases where the crop was not used for animal nutrition, emissions were not allocated to livestock.

- *Emissions from manure used for fuel at the household level* leave the livestock system and therefore emissions from burning were not allocated to the livestock system.
- *Emissions from manure discharged into the environment* were solely attributed to livestock activities.

Fibre (wool, cashmere and mohair). Fibre is a by-product of sheep and goat production; however in some countries these products can be considered as main products of production due to their price leverage and market value. In this study, the allocation of the carbon footprint to fibre was performed based on the market value of all system outputs – meat, milk, and fibre products. The fractions of the economic value of the co-product within the total economic value of all products produced by a given species were utilized as an allocation factor to partition GHG emissions between fibre and the edible products. This fraction was determined as:

$$F_w = (Wool_{kg} \cdot Price_{wool})/(Meat_{kg} \cdot Price_{meat} + Milk_{kg} \cdot Price_{milk} + Wool_{kg} \cdot Price_{wool})$$

where: F_w is the ratio of economic value of wool to the total economic value of all products produced. Similar calculations were performed for countries producing cashmere and mohair. Wool, meat and milk represent the mass of the product in kg. Table A4 provides an illustration of how the technique is applied. To implement the total economic value, producers prices averaged over five years were taken from the FAOSTAT price domain, reflecting prices that farmers receive at the farmgate. Subsequent to the deduction of emissions for fibre production from the overall emissions, protein content was then used to allocate emissions between meat and milk.

Table A4. Example of allocation between non-edible (wool) and edible products from sheep dairy production

	Part of herd producing milk, meat and wool		Part of herd producing meat and wool only
Total emissions *(kg CO_2-eq)*	80 000		20,000
Total protein *(kg)*	Milk: 500	Meat: 50	Meat: 200
Total economic value *($)*	Milk: 4 000	Meat: 9 000	Wool: 700
Fraction of milk protein	0.9		NA
Fraction of meat protein	0.1		1
Total emission allocated to wool	=80 000 · [700/(4 000+9 000+700)] **= 4 088 kg CO_2-eq**		=20 000 · [700/(4 000+9 000+700)] **= 1 022 kg CO_2-eq**
Total emissions allocated to milk and meat	= 80 000 – 4 088 **= 75 912 kg CO_2-eq**		= 20 000 – 1 022 **= 18 978 kg CO_2-eq**
Emission intensity of milk		= (75 912 · 0.9)/500 **= 138 kg CO_2-eq/kg protein**	
Emission intensity of meat		= [(75 912 · 0.1) + 18 978]/(50+200) **= 104 kg CO_2-eq/kg protein**	

NA: Not Applicable.
Source: Authors' calculations.

Animal draught power. Herd structure, and thus the emissions profile, is affected by the use of animals, usually oxen, for labour. The use of animals for draught power has an influence on the herd's sex and age structure which skews towards higher ratios of male and older animals. Oxen must grow to maturity before they can be used for traction, and this usually takes four years, and therefore they compete with other stock for feed and other resources. The animals are then generally used for a decade before they are slaughtered. The adult male to female ratio is substantially higher than normal when animals are used for draught power because males are slaughtered at a later age.

To allocate emissions to draught power services, we first calculated total emissions and meat output from draught animals alone. In a subsequent calculation step, emissions related to the meat produced from these animals were estimated as being identical to those of meat produced from non-draught animals, slaughtered at an earlier age. The difference (accruing from the extra lifetime and the energy requirements for the labour of draught animals) was then attributed to draught power services.

Capital functions of cattle. In any cattle production system, animals constitute a form of capital, and can be sold or bought according to investment and cash flow requirements. In many pastoral systems, the capital functions of cattle are a particularly important, because they enable the accrual of savings to manage cash needs, insure against risk, and manage crises in the absence of adequate financial institutions. Therefore, low replacement rates are often a feature in these systems, because cattle are often kept even after their productivity drops. While the provision of these capital functions affects the herd structure and emission profiles of these systems, no emissions were allocated to capital services, due to difficulties in obtaining relevant information.

Slaughter by-products. In addition to the production of carcasses, slaughtering processes also produce a whole package of by-products, organs, hide, blood, etc. that are utilized for other purposes, often outside the livestock food chain. Thus, the allocation of emissions to by-products produced at the slaughterhouse can have a major impact on the GHG emission intensity for meat products. This study did not explicitly take into account by-products from slaughter due to the lack of reliable information and data. However, we explored the impact of their inclusion on emission intensity of beef in a selected case study (see Appendix F).

In terms of edible product, ruminants produce both milk and meat. The emissions were allocated between these two commodities, using the following method:

- Quantify the total emissions from animals required for milk and meat production (adult female and adult male, replacement stock and surplus animals).
- Deduct emissions related to draft power (for large ruminants), and manure used for fuel based on the approaches outlines above.
- For the dairy sector, which produces both milk and meat, emissions are allocated on a protein basis (see Tables A3 and A4). For small ruminants, allocation is first performed between the edible and non-edible products based on economic value and subsequently protein content is used to allocate between milk and meat.

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APPENDIX B

Data and data sources

This appendix presents the main data utilized in this assessment. The data can be classified into *basic input data* and *intermediate data*. Basic input data can be defined as primary data such as animal numbers, herd parameters, mineral fertilizer application rates, temperature, crop yields, etc. and are data taken from other sources such as literature, databases, and surveys. Intermediate data are an output of the modelling procedure required in further calculation in GLEAM and may include data on growth rates, animal cohort groups, feed rations, animal energy requirements, feed intake, etc.

1. DATA RESOLUTION AND DISAGGREGATION

Data availability, quality and resolution vary according to the parameter and the country in question. In OECD countries, where farming tends to be more regulated, there are often comprehensive national or regional data sets, and in some cases sub-national data (e.g. for manure management in U.S. dairy). Conversely, in many non-OECD countries, data are unavailable, necessitating the use of regional default values (e.g. herd parameters). Examples of the spatial resolution of some key parameters are given in Table B1.

2. HERD

Livestock distributions. Maps of the spatial distribution of each animal species and production systems are one of the key inputs into the GLEAM model. Total ruminant numbers at a national level are reported in FAOSTAT. The spatial distributions used in this study were based on maps developed in the context of FAO's Gridded Livestock of the World (FAO, 2007).

Herd parameters. The national herd is disaggregated into cohorts according to six animal classes: adult female and male, replacement female and male, and male and female surplus or fattening animals that are not required for maintaining the herd and are kept for meat production only. The key biological parameters required for herd modelling incorporate data on mortality, fertility and growth rate, also known as "rate parameters".

- *Fertility parameters:* data on fertility are usually incorporated in the form of parturition rates (e.g. calving, kidding, lambing rates), and are normally defined as the number of births occurring in a specified female population in a year. For cattle, the number of births per year is assumed to be one. However, in the case of small ruminants, litter size is taken into account. The model utilizes age-specific fertility rates for adult and young replacement females. The proportion of breeding females that fail to conceive is also included.
- *Mortality rates:* data on mortality are incorporated in the form of death rates. In the modelling process, age specific death rates are used; mortality rate in calves and mortality rate in other animal categories. The death rate of

Table B1. Spatial resolution of the main input variables

Parameters	Cell[1]	Subnational	National	Regional[2]	Global
Herd					
Animal numbers	X				
Weights		X →	→	X	
Mortality, fertility and replacement data		X →	→	X	
Manure					
N losses rates					X
Management system		X →	→	X	
Leaching rates				X	
Feed					
Crop yields	X				
Harvested area	X				
Synthetic N fertilizer rate			X		
N residues	X[3]			X[4]	
Feed ration			X[5] →	X	
Digestibility and energy content			X →	→	X
N content				X →	X
Energy use in fieldwork, transport and processing					X
Transport distances					X
Land-use change					
Soybean (area and trade)			X		
Pasture (area and deforestation rate)			X		
Animal productivity					
Yield (milk, eggs, and fibers)			X →	X	
Dressing percentage			X →	X	
Fat and protein content			X →	→	X
Product farmgate prices[6]			X →	X	
Postfarm					
Transport distances of animals or products			X		
Energy (processing, cooling, packaging)			X		
Mean annual temperature	X				
Direct and indirect energy			X →	X	

→ The spatial resolution of the variable varies geographically and depends on the data availability. For each input variable, the spatial resolution of a given area is defined as the finest available.

[1] Animal numbers and mean annual temperature: ~ 5 km x 5 km at the equator; crop yields, harvested area and N residues: ~ 10 km x 10 km at the equator.

[2] Geographical regions or agro-ecological zones.

[3] For monogastrics.

[4] For ruminants.

[5] Ruminants: rations in the industrialized countries; Monogastrics: rations of swill and concentrates.

[6] Only for allocation in small ruminants.

calves reflects the percentage of pregnancies that end with a dead calf. This may occur by abortion, still birth or death in the first 30 days after birth.

- *Growth rates:* the growth rate of animals is based on the age at which they attain adult weight. For females, this depends on the age at first parturition, although some growth takes place after this. The age at which animals are sold for slaughter is based on the defined slaughter weight and the calculated growth rate.
- *Replacement rates:* these represent the number of adult animals replaced by younger adult animals per year. The replacement rate of female animals is taken from the literature. Literature reviews did not reveal any data on the replacement rate of male animals, so the replacement rate was defined as the reciprocal value of the age at first parturition, on the assumption that farmers will prevent in-breeding by applying this rule. For small ruminants, adult males are usually exchanged twice by farmers and therefore have three service periods.

Tables B2-B6 present input herd parameter data used in this analysis.

Table B2. Herd parameters for dairy cattle, regional averages

Parameters	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	Weights *(kg)*									
Adult cow	747	500	593	518	371	486	463	346	551	325
Adult bull	892	653	771	673	477	326	601	502	717	454
Calves at birth	41	33	38	36	20	28	31	23	38	20
Slaughter female	564	530	534	530	329	256	410	87	540	274
Slaughter male	605	530	540	530	367	243	410	141	540	278
	Rate *(percentage)*									
Replacement adult cow	35	31	31	27	15	28	22	21	21	10
Fertility	77	83	83	84	73	80	80	75	80	72
Death rate female calves	8	8	8	8	20	15	10	22	9	20
Death rate male calves	8	8	8	8	20	15	10	50	9	20
Death rate other animals	3	4	4	4	6	6	4	8	9	6
Age at first calving (years)	2.1	2.3	2.3	2.2	3.4	2.5	2.1	3.1	2.6	4.0

Source: Input data based on literature, surveys and expert knowledge.

Table B3. Herd parameters for beef cattle, regional averages

Parameters	N. America	Russian Fed.[1]	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	Weights *(kg)*									
Adult cow	649	0	529	530	431	501	403	350	419	271
Adult bull	843	0	688	689	563	542	524	505	545	347
Calves at birth	40	0	35	35	29	33	27	23	28	20
Slaughter female	606	0	529	530	445	223	403	73	392	349
Slaughter male	565	0	529	530	478	218	403	68	400	288
	Rate *(percentage)*									
Replacement adult cow	14	0	15	15	21	16	22	21	14	11
Fertility	93	0	93	93	75	90	93	75	73	59
Death rate female calves	11	0	10	10	18	15	10	22	14	19
Death rate male calves	11	0	10	10	18	15	10	50	14	19
Death rate other animals	4	0	3	3	7	7	3	8	6	7
Age at first calving (years)	2.0	0	2.3	2.3	2.8	2.5	2.1	3.1	3.4	3.9

[1] Based on our estimates, the Russian Federation has no specialized beef herd.

Source: Input data based on literature, surveys and expert knowledge.

Table B4. Herd parameters for goats, regional averages

Parameters	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	Weights *(kg)*									
Adult female	64	55	59(61)	50	37(40)	44(34)	50	32(31)	35(37)	29(31)
Adult male	83	100	88(91)	100	53(56)	60(43)	81	42(39)	50(60)	36(40)
Kids at birth	6.4	2.2	4.0(4.6)	5.0	2.7(3.2)	3.9(2.1)	3.6	2.7(2.4)	3.5(3.7)	2.2(2.3)
Slaughter female	36	30	26	30	32	27	38	25	27	19
Slaughter male	36	30	26	30	32	27	38	25	28	19
	Rate *(percentage)*									
Replacement female	30	18	17	18	19	24	21	19	24	16
Fertility	85	90	87	90	87	88	87	81	80	87
Death rate kids	18	5	4	5	31	37	12	15	14	27
Death rate other	9	2	2	2	7	16	6	5	5	7
Age at first kidding (years)	1.4	1.3	1.3	1.3	1.6	1.1	1.4	1.8	1.5	2.0

Note: Numbers in brackets refer to parameters for meat animals.

Source: Input data based on literature, surveys and expert knowledge.

Table B5. Herd parameters for sheep, regional averages

Parameters	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	Weights *(kg)*									
Adult female	80	49	62	44	41	47	70	35	59	38
Adult male	108	101	82	85	55	65	98	45	81	51
Lambs at birth	4	3	4	3	3	4	4	3	3	3
Slaughter female	27	21	29	21	26	26	35	24	29	24
Slaughter male	27	21	29	21	26	26	35	24	29	24
	Rate *(percentage)*									
Replacement female	21	23	29	22	21	16	24	18	20	17
Fertility	92	95	91	90	83	77	100	81	91	76
Death rate lambs	19	17	18	18	25	31	9	24	18	33
Death rate other	8	2	3	5	12	14	4	12	12	13
Age at first lambing (years)	2.1	1.9	1.6	1.8	1.4	1.6	1.8	1.6	2.0	1.5

Source: Input data based on literature, surveys and expert knowledge.

Table B6. Herd parameters for buffalo, regional averages

Parameters	LAC	E & SE Asia	E. Europe	N. America	Russian Fed.	South Asia	NENA	W. Europe
	Weights *(kg)*							
Adult female	650	380	559	650	650	485	500	648
Adult male	900	398	700	800	800	532	610	800
Calves at birth	38	24	38	38	38	31	32	38
Slaughter female	400	190	481	350	440	215	310	352
Slaughter male	475	190	380	350	440	135	309	352
	Rate *(percentage)*							
Replacement female	10	20	20	10	20	20	16	10
Fertility	75	57	68	76	68	53	69	76
Death rate female calves	7	29	8	8	8	24	18	8
Death rate male calves	7	28	8	8	8	44	18	8
Death rate others	2	6	4	4	4	9	6	4
Age at first calving (years)	3.0	4.0	3.2	2.5	3.6	4.0	3.1	2.5

Note: Based on this analysis, SSA and Oceania have no buffalo herd.
Source: Input data based on literature, surveys and expert knowledge.

3. FEED

Animal rations are generally a combination of different feed ingredients. For ruminants, three broad categories of feed are considered: roughages, by-products and concentrates. Feed is defined by a feed ration which differs among animal categories as defined in the herd module. Three separate feed rations are formulated for the following categories: adult females; replacement males and females and adult males; and surplus (meat) animals for fattening. Tables B7 to B12 present the average feed rations and proportions of different feed materials within the feed basket by region and ruminant species.

In this assessment, all plant-based feed materials are identified by three key parameters: dry-matter yield per hectare; net energy content (or digestibility); and nitrogen content. These three parameters are data input in the calculation of the feed ration and its nutritive value. The dry matter yield determines the type of feed ingredients that make up the feed ration as well as the potentially available feed in a region. The digestibility and N-content of feed define the quality properties of feed and determine the efficiency with which feed is digested and eventual GHG emissions. Table B13 presents regional average feed ration digestibility values.

Emission factors for key data inputs into feed production. Emissions of fossil CO_2 from feed production, transport and processing are dependent on the amounts and types of fuels used. Table B14 presents emission factor data used in the calculation of the feed emission intensity.

Emissions of CO_2 and N_2O occurring during the production of nitrogenous fertilizers. The most commonly occurring mineral fertilizer, ammonium nitrate, which consists of equal parts of ammonium- and nitrate-nitrogen, currently releases ~6.8 kg CO_2-equivalents in production (Jenssen and Kongshaug , 2003). Due to the lack of reliable data on these parameters, and on fertilizer trade flow, the average European fertilizer emissions factor of 6.8 kg CO_2-eq per kg of ammonium nitrate N in all regions was used.

4. MANURE

There are considerable differences in emissions from MMS. Data requirements for the estimation of GHG emissions from MMS include: information on how manure is managed, the types of MMS, and the proportion of manure managed in these systems. Additionally, climatic information (e.g. temperature) is important because emission factors are climate dependent. It was thus necessary to consider the climate under which livestock is managed in each country.

On a global scale, there is limited data available on how manure is managed and the proportion of the manure managed in each system. Consequently, this study relied on various data sources such as national inventory reports, literature and expert knowledge to define the proportions of manure management systems. It uses the IPCC (2006) classification of MMSs (definition in Table 10.18, IPPC guidelines). Regional variations manure management practices are presented in Tables B15 to B19.

Table B7. Dairy cattle feed ration, regional averages

	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	percentage									
Roughage										
Fresh grass	14.4	23.8	33.2	22.5	41.4	22.4	68.3	10.7	54.9	56.8
Hay	17.0	23.8	16.6	22.8	17.8	19.2	5.6	14.2	15.4	18.1
Legumes and silage	30.6	34.3	22.6	33.2	0.3	2.7	10.4	-	-	-
Crop residues	-	1.8	2.5	1.8	31.7	38.4	-	60.1	8.7	17.0
Sugarcane tops	-	-	-	-	1.6	0.6	-	3.5	2.6	1.9
Leaves	-	-	-	-	3.6	2.3	-	6.1	6.5	3.0
By-products and concentrates										
Bran	4.4	2.9	2.0	3.0	0.6	0.5	2.5	0.2	0.4	0.1
Oilseed meals	6.4	4.6	8.5	5.7	2.3	6.7	1.3	5.2	6.4	3.1
Wet distillers grain	4.3	-	-	-	-	-	-	-	-	-
Grains	22.8	7.2	13.2	9.1	0.2	7.2	11.8	-	4.9	0.1
Molasses	-	-	0.1	-	0.5	-	-	-	0.1	0.1
Pulp	-	1.8	1.3	1.8	-	-	-	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B8. Beef cattle feed ration, regional averages

	N. America	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	percentage								
Roughage									
Fresh grass	35.2	36.0	21.0	24.9	23.6	63.5	8.0	65.1	61.1
Hay	39.4	14.8	21.9	36.7	18.7	6.8	12.5	9.4	12.6
Legumes and silage	7.8	23.1	32.3	2.1	0.7	10.7	-	-	-
Crop residues	-	3.8	2.1	24.2	46.2	-	68.0	10.2	19.4
Sugarcane tops	-	-	-	0.1	0.8	-	3.6	2.5	3.7
Leaves	-	-	-	9.2	2.8	-	5.9	4.1	1.6
By-products and concentrates									
Bran	0.9	1.7	3.5	0.3	0.2	3.8	0.1	0.1	-
Oilseed meals	0.6	7.6	6.6	1.9	2.7	1.5	1.9	3.9	1.4
Wet distillers grain	1.0	-	-	0.0	-	-	-	-	-
Grains	15.1	10.6	10.5	0.6	4.2	13.7	-	4.7	0.1
Molasses	-	0.7	-	-	-	-	-	-	-
Pulp	-	1.7	2.1	-	-	-	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B9. Dairy buffalo feed ration, regional averages

	N. America	W. Europe	E. Europe	NENA	E & SE Asia	South Asia	LAC
	percentage						
Roughage							
Fresh grass	-	1.7	38.9	3.4	35.7	5.2	65.3
Hay	15.6	16.1	25.9	10.7	13.7	20.1	12.2
Legumes and silage	34.4	33.7	17.3	-	-	-	-
Crop residues	5.2	5.0	-	72.8	39.5	54.8	8.4
Sugarcane tops	-	-	-	5.8	2.2	4.7	2.2
Leaves	-	-	-	4.0	2.3	8.1	5.2
By-products and concentrates							
Bran	4.7	0.8	4.6	1.6	3.3	3.6	3.4
Oilseed meals	10.9	11.5	5.2	1.6	3.3	3.6	3.4
Wet distillers grain	7.3	7.0	-	-	-	-	-
Grains	15.6	18.2	8.1	-	-	-	-
Molasses	-	-	-	-	-	-	-
Pulp	6.2	6.0	-	-	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B10. Buffalo meat feed ration, regional averages

	Russian Fed.	NENA	E & SE Asia	South Asia	LAC
	percentage				
Roughage					
Fresh grass	41.1	38.9	37.8	5.9	68.0
Hay	27.4	27.7	12.0	19.8	13.2
Legumes and silage	18.3	-	-	-	-
Crop residues	-	29.8	43.5	60.1	8.9
Sugarcane tops	-	-	2.1	4.7	2.3
Leaves	-	2.2	2.5	7.5	5.3
By-products and concentrates					
Bran	4.7	0.7	1.1	1.0	1.1
Oilseed meals	3.3	0.7	1.1	1.0	1.1
Wet distillers grain	-	-	-	-	-
Grains	5.2	-	-	-	-
Molasses	-	-	-	-	-
Pulp	-	-	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B11. Small ruminant milk feed ration, regional averages

	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	percentage									
Roughage										
Fresh grass	29.7	32.0	24.9	32.5	46.4	23.0	62.2	23.9	74.9	58.8
Hay	37.5	24.6	19.3	25.0	7.0	33.8	6.9	6.3	11.9	4.9
Legumes and silage	2.6	9.8	6.6	10.0	0.7	-	7.8	-	-	-
Crop residues	-	11.5	16.4	11.8	38.4	26.9	1.1	53.9	8.7	31.1
Sugarcane tops	-	-	-	-	2.2	0.3	-	2.3	2.1	3.9
Leaves	-	-	-	-	0.9	2.1	-	1.6	0.3	0.2
By-products and concentrates										
Bran	5.8	8.6	11.3	8.2	2.1	6.9	9.8	6.0	1.0	0.6
Oilseed meals	2.1	2.3	4.3	2.1	1.7	6.9	0.6	6.0	1.0	0.6
Wet distillers grain	-	-	-	-	-	-	-	-	-	-
Grains	17.2	3.6	5.4	3.3	0.2	-	5.5	-	-	-
Molasses	0.2	-	0.7	-	-	-	-	-	-	-
Pulp	4.9	7.6	11.1	7.2	0.3	-	6.1	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B12. Small ruminant meat feed ration, regional averages

	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
	percentage									
Roughage										
Fresh grass	34.8	38.2	45.4	37.0	34.9	19.7	75.4	25.7	68.9	57.9
Hay	44.0	29.4	21.6	29.0	22.2	32.6	7.5	6.6	18.8	8.8
Legumes and silage	3.0	11.8	9.7	12.0	0.6	-	9.3	-	-	-
Crop residues	-	13.7	13.0	13.9	37.4	39.2	1.2	55.9	9.9	27.9
Sugarcane tops	-	-	-	-	1.8	0.3	-	4.2	1.4	5.2
Leaves	-	-	-	-	2.2	1.5	-	1.7	0.2	0.2
By-products and concentrates										
Bran	0.2	3.6	2.8	4.3	0.5	3.3	4.7	3.0	0.4	-
Oilseed meals	0.5	0.2	2.2	0.3	0.3	3.3	0.1	3.0	0.4	-
Wet distillers grain	-	-	-	-	-	-	-	-	-	-
Grains	17.3	0.4	0.7	0.5	-	-	0.9	-	-	-
Molasses	0.2	-	1.3	-	-	-	-	-	-	-
Pulp	-	2.6	3.4	3.1	-	-	1.0	-	-	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B13. Calculated feed digestibility, regional averages

Region	Dairy	Beef	Small Ruminants	Buffalo
	percentage			
N. America	71.8	68.3	66.2	73.4
Russian Fed.	72.6	-	65.4	70.7
W. Europe	77.0	76.1	69.7	75.5
E. Europe	73.5	73.8	67.4	72.8
NENA	56.1	57.7	55.5	52.0
E & SE Asia	59.0	57.4	56.3	56.0
Oceania	72.9	72.9	69.8	-
South Asia	52.6	50.7	54.1	52.1
LAC	62.2	62.7	58.9	60.5
SSA	57.3	57.2	55.5	-

Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (SPAM, FAOSTAT).

Table B14. Emissions factors for fuel consumption

Fuel	Emission factor	Source
Diesel	3.2 kg CO_2-eq/litre diesel	Berglund *et al.* (2009)
Oil	5.7 kg CO_2-eq/kg oil	de Boer (2009)
Coal	17.8 kg CO_2-eq/kg coal	de Boer (2009)
Gas	7.6 kg CO_2-eq/m^3 gas	de Boer (2009)

Table B15. Dairy cattle manure management systems, regional averages

MMS	Burned for fuel	Daily spread	Drylot	Uncovered anaerobic Lagoon	Liquid slurry	Pasture, range, paddock	Solid storage
	percentage						
N. America	-	9.5	-	27.2	26.3	11.8	25.2
Russian Fed.	-	-	-	-	-	22.5	77.5
W. Europe	-	2.3	-	0.1	41.6	26.6	29.5
E. Europe	-	1.4	-	-	10.2	17.0	71.3
NENA	3.6	-	39.4	-	-	46.1	10.9
E & SE Asia	1.5	-	29.1	-	3.1	30.7	35.7
Oceania	-	1.2	-	4.6	0.1	94.2	-
South Asia	20.0	-	54.4	-	-	23.5	2.0
LAC	0.4	-	41.5	-	-	53.5	4.7
SSA	6.9	-	34.8	-	-	39.7	18.5

Source: Input data from literature, national inventory reports and expert knowledge.

Table B16. Beef cattle manure management systems, regional averages

MMS	Burned for fuel	Daily spread	Drylot	Uncovered anaerobic Lagoon	Liquid slurry	Pasture, range, paddock	Solid storage
	percentage						
N. America	-	-	12.8	-	0.7	43.4	43.2
Russian Fed.	-	-	-	-	-	-	-
W. Europe	-	4.2	0.1	-	22.1	47.6	25.9
E. Europe	-	-	-	-	65.0	33.0	2.0
NENA	9.3	-	34.9	-	-	42.8	12.9
E & SE Asia	0.6	-	33.9	-	-	27.7	37.8
Oceania	-	-	-	-	-	100.0	-
South Asia	20.0	-	58.2	-	-	20.3	1.4
LAC	0.2	-	4.8	-	-	91.8	3.2
SSA	6.2	-	34.3	-	-	46.5	13.0

Source: Input data from literature, national inventory reports and expert knowledge.

Table B17. Buffalo milk production manure management systems, regional averages

MMS	Burned for fuel	Daily spread	Drylot	Liquid slurry	Pasture, range, paddock	Solid storage
	percentage					
N. America	17.4	40.2	42.4	-	-	-
W. Europe	3.4	61.9	34.7	-	-	-
E. Europe	13.0	67.8	18.2	-	1.0	-
NENA	50.8	9.2	-	38.9	-	1.1
E & SE Asia	31.0	13.3	-	53.6	-	2.0
South Asia	37.8	1.3	-	40.4	-	19.9
LAC	50.7	1.2	-	48.0	-	-

Source: Input data from literature, national inventory reports and expert knowledge.

Table B18. Buffalo meat production manure management systems, regional averages

MMS	Burned for fuel	Daily spread	Drylot	Liquid slurry	Solid storage
	percentage				
Russian Fed.	27.8	66.6	5.6	-	-
NENA	48.7	22.9	-	13.4	14.5
E & SE Asia	28.6	9.1	-	61.2	0.8
South Asia	38.6	1.5	-	39.7	2-
LAC	93.8	1.2	-	4.9	-

Source: Input data from literature, national inventory reports and expert knowledge.

Table B19. Small ruminant manure management systems, regional averages

MMS	Drylot	Pasture, range, paddock	Solid storage
		percentage	
N. America	-	47.4	53.0
Russian Fed.	-	18.0	82.0
W. Europe	-	83.8	16.2
E. Europe	-	64.6	35.2
NENA	37.5	57.2	5.2
E & SE Asia	0.8	56.7	42.3
Oceania	-	100.0	-
South Asia	12.8	85.0	2.0
LAC	3.7	83.3	12.7
SSA	9.3	84.4	6.2

Source: Input data from literature, national inventory reports and expert knowledge.

Table B20. Dressing percentages for large ruminants

	N. America	Russian Fed.	W. Europe	E. Europe	NENA	E & SE Asia	Oceania	South Asia	LAC	SSA
					percentage					
Dairy cattle										
Adult and replacement females	50	50	50	50	48	50	50	50	50	47
Adult and replacement male	50	50	50	50	48	50	50	50	50	47
Surplus female and male	52	52	52	52	50	55	52	55	52	47
Beef cattle										
Adult and replacement females	55	55	55	55	50	50	50	50	50	47
Adult and replacement male	55	55	55	55	50	50	50	50	50	47
Surplus female and male	60	60	60	60	55	55	55	55	55	47
Buffalo										
Adult and replacement females	49	49	49	49	49	49	49	49	49	49
Adult and replacement male	50	50	50	50	50	50	50	50	50	50
Surplus female and male	55	55	55	55	55	55	55	55	55	55

Source: Input data from literature, surveys and expert knowledge.

Table B21. Dressing percentages for small ruminants

Region	Goats	Sheep
	percentage	
N. America	52	52
Russian Fed.	43	45
W. Europe	43	48
E. Europe	43	45
NENA	44	45
E & SE Asia	48	49
Oceania	45	50
South Asia	43	48
LAC	44	49
SSA	48	45

Source: Input data from literature, surveys and expert knowledge.

5. PRODUCTION AND ALLOCATION

Dressing percentage. Dressing percentage can be defined as the percent of the live animal that ends up in the carcass. The LW:CW ratio varies substantially depending on a range of factor including breed, gender, diet, age, diet, cold versus warm carcass weight, and distance trucked. Tables B20 and B21 present the dressing percentages used for large and small ruminants.

Emission allocation factors. Table B22 presents a comparison of dairy and beef herds in total cattle population across world regions, their contribution to total beef production and the allocation factors used in this assessment for the allocation of emissions between milk and meat from the dairy herd. Emission allocation factor for wool, yield and total economic value (for meat, milk and wool produced by sheep) are presented in Table B23. See Appendix A for more details on allocation techniques applied.

Table B22. Percentage of dairy and beef herds, ratio of beef production from cattle herds and emission allocation factor for milk and meat from the dairy herd

	Percentage of cattle		Ratio of beef production from dairy and specialized beef herd		Allocation factor between milk and meat from the dairy herd
Region	Dairy herd	Beef herd	Dairy herd	Beef herd	Fraction
LAC	24.8	75.2	0.31	0.69	0.92
E & SE Asia	20.9	79.1	0.23	0.77	0.93
E. Europe	99.2	0.80	0.99	0.01	0.94
N. America	23.8	76.2	0.24	0.76	0.94
Oceania	38.1	61.9	0.38	0.62	0.96
Russian Federation	100.0	-	1.00	-	0.91
South Asia	56.9	43.1	0.60	0.40	0.90
SSA	57.5	42.5	0.59	0.41	0.90
NENA	98.9	1.1	0.98	0.02	0.92
W. Europe	70.5	29.5	0.70	0.30	0.95

Source: GLEAM.

Table B23. Emission allocation factors for sheep

Country*	Total economic value (*'000 US$*)	Wool allocation factor	Wool (*kg/animal)*
Afghanistan	78 513	0.14	2.6
Albania	169 530	0.03	3.1
Algeria	519 567	0.08	2.4
Argentina	980 205	0.28	6.2
Armenia	18 138	0.09	2.1
Australia	4 967 220	0.38	6.4
Austria	31 346	0.02	3.5
Azerbaijan	79 042	0.13	2.1
Bangladesh	16 262	0.16	2.6
Belarus	1 797	0.06	5.0
Belgium	8 128	0.21	3.5
Bhutan	292	0.50	2.6
Bolivia	137 832	0.32	5.3
Bosnia and Herzegovina	41 272	0.09	3.1
Brazil	278 548	0.30	6.1
Bulgaria	44 497	0.09	5.0
Canada	24 881	0.11	5.5
Chile	88 762	0.26	6.0
China	1 797 202	0.17	2.1
Colombia	38 411	0.80	6.0
Croatia	91 675	0.01	3.1
Cyprus	26 049	0.01	2.1
Czech Republic	10 792	0.23	5.0
Denmark	9 372	0.26	5.0
Ecuador	45 468	0.51	4.3
Egypt	190 515	0.08	2.4
Eritrea	53 231	0.05	2.0
Estonia	1 554	0.08	2.8
Ethiopia	62 025	0.42	2.0
Finland	3 064	0.15	2.8
France	792 773	0.04	3.5
Georgia	28 259	0.20	2.1
Germany	144 509	0.04	3.5
Greece	1 368 750	0.01	3.1
Hungary	84 145	0.04	5.0
India	875 770	0.16	2.6
Indonesia	181 290	0.11	1.0
Iran (Islamic Republic of)	1 099 145	0.05	2.6
Iraq	149 159	0.19	2.1
Ireland	243 544	0.20	2.0
Israel	31 197	0.02	2.1

(Continued)

Table B23. *(Continued)*

Country*	Total economic value *('000 US$)*	Wool allocation factor	Wool *(kg/animal)*
Italy	1 022 570	0.02	3.1
Jordan	83 719	0.03	2.1
Kazakhstan	149 923	0.09	2.1
Kenya	103 366	0.11	2.0
Kuwait	24 814	0.21	2.1
Kyrgyzstan	46 492	0.06	2.1
Latvia	914	0.15	2.8
Lebanon	18 130	0.12	2.1
Lesotho	20 706	0.49	3.8
Lithuania	863	0.08	2.8
Luxembourg	911	0.09	3.5
Macedonia	62 263	0.02	3.1
Malaysia	1 475	0.15	1.0
Mali	158 637	0.13	2.0
Malta	1 382	0.04	3.1
Mexico	342 445	0.02	2.0
Moldova, Republic of	15 252	0.10	5.0
Mongolia	79 706	0.06	2.1
Montenegro	8 935	0.02	3.1
Morocco	674 549	0.12	2.4
Myanmar	14 162	0.03	1.0
Namibia	36 361	0.07	3.8
Nepal	15 740	0.12	2.6
Netherlands	74 491	0.03	3.5
New Zealand	1 699 390	0.23	5.5
Norway	143 600	0.18	2.8
Pakistan	250 607	0.14	2.6
Paraguay	12 046	0.29	5.3
Peru	305 378	0.26	6.0
Poland	13 963	0.07	5.0
Portugal	315 014	0.02	3.1
Republic of Serbia	58 074	0.02	3.1
Romania	370 170	0.05	5.0
Russian Federation	321 514	0.18	5.0
Saudi Arabia	412 672	0.13	2.1
Slovakia	9 059	0.09	5.0
Slovenia	8 112	0.02	3.1
South Africa	1 048 040	0.23	3.8
Spain	1 659 448	0.02	4.5
State of Libya	196 954	0.09	2.4
Sudan	1 310 660	0.03	2.4

(Continued)

Table B23. *(Continued)*

Country*	Total economic value *('000 US$)*	Wool allocation factor	Wool *(kg/animal)*
Sweden	20 060	0.09	2.8
Switzerland	42 600	0.02	3.5
Syrian Arab Republic	2 711 860	0.02	2.1
Tajikistan	26 784	0.24	2.1
Tunisia	277 587	0.11	2.4
Turkey	1 792 952	0.04	2.1
Turkmenistan	171 606	0.77	2.1
Ukraine	24 660	0.10	5.0
United Arab Emirates	28 401	0.13	2.1
U.K. of Great Britain and Northern Ireland	1 110 150	0.05	2.8
United Republic of Tanzania	49 968	0.09	2.0
United States of America	174 326	0.22	4.8
Uruguay	258 626	0.41	6.2
Uzbekistan	130 762	0.51	2.1
Yemen	268 873	0.09	2.1

* Represents 95 percent of the global sheep population.
Source: GLEAM based on input data from literature, national inventory reports, expert knowledge and databases (FAOSTAT).

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