Food and Agriculture Organization
of the United Nations

# Global Livestock Environmental Assessment Model

## Version 2.0

Data reference year: 2010

Model description

*Revision 5*
*July 2018*

# Global Livestock Environmental Assessment Model

Model Description

Version 2.0

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# ABBREVIATIONS

| | |
|---|---|
| **$CH_4$** | Methane |
| **$CO_2$** | Carbon dioxide |
| **$CO_2$-eq** | Carbon dioxide equivalents |
| **DM** | Dry Matter |
| **EE** | Eastern Europe |
| **EFA** | Economic Fraction Allocation |
| **ESEA** | East Asia and South-East Asia |
| **FUE** | Feed Use Efficiency |
| **GAEZ** | Global Agro-Ecological Zones |
| **GHG** | Greenhouse gas |
| **GIS** | Geographic Information System |
| **GLEAM** | Global Livestock Environmental Assessment Model |
| **GLW** | Gridded Livestock of the World |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **LAC** | Latin America and the Caribbean |
| **LCA** | Life-Cycle Assessment |
| **LUC** | Land-use change |
| **MFA** | Mass Fraction Allocation |
| **MMS** | Manure management system |
| **$N_2O$** | Nitrous oxide |
| **NA** | North America |
| **NENA** | Near East and North Africa |
| **OCE** | Oceania |
| **OECD** | Organization for Economic Cooperation and Development |
| **RUS** | Russian Federation |
| **SA** | South Asia |
| **SSA** | Sub-Saharan Africa |
| **VS** | Volatile solids |
| **WE** | Western Europe |

# ACKNOWLEDGEMENTS

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The GLEAM development and analysis team is composed of Anne Mottet, Carolyn Opio, Alessandra Falcucci, Giuseppe Tempio, Rubén Martínez Rodríguez, Giuseppina Cinardi, Monica Rulli, Félix Teillard and Aimable Uwizeye.

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# CHAPTER 1 – INTRODUCTION

The Global Livestock Environmental Assessment Model (GLEAM) was developed to address the need for a comprehensive tool to assess interactions between livestock and the environment. GLEAM supports stakeholders in their efforts towards adopting more sustainable practices that ensure higher efficiency, improved livelihoods for farmers and mitigation of environmental impacts.

The present document describes the latest version of the model, GLEAM 2.0. It includes a number of improvements, updates and methodological changes compared to the previous version (GLEAM 1.0, described in FAO, 2013a and FAO, 2013b):

- New animal **distribution maps**. GLEAM 2.0 uses Version 2 of the Gridded Livestock of the World (GLW; Robinson *et al.*, 2014), which is adjusted to 2010 animal numbers from FAOSTAT.
- New production system: with the inclusion of cattle **feedlots**, GLEAM 2.0 accounts for the particularity in feeding and animal management specific to this system.
- New **crop layers**: GLEAM 2.0 incorporates a modified version of the Global Agro-Ecological Zones (GAEZ) maps (FAO, 2016) for crops used as feed, standardized to FAOSTAT data for 2010 and at a spatial resolution of approximately 10 km x 10 km at the equator.
- Inclusion of production and transport of **phosphorus** and **potassium fertilizers,** and production, transport and application of **pesticides** for the estimation of emissions related to feed production.
- Updated methodology to calculate the emissions associated with **land-use change** related to **soy** and **palm kernel cakes**.

## 1.1 – MODEL OVERVIEW

GLEAM is a process-based model based on a Life Cycle Assessment (LCA) framework. It covers 11 main livestock commodities at global scale, namely meat and milk from cattle, sheep, goats and buffalo; meat from pigs; and meat and eggs from chickens. The model runs in a Geographic Information System (GIS) environment and provides spatially disaggregated estimates on greenhouse gas (GHG) emissions and commodity production by production system, thereby enabling the calculation of the emission intensity for any combination of commodity and farming systems at different spatial scales. The highest spatial resolution considered by the model is defined by squared cells of approximately 10 km x 10 km at the equator. Each cell represents a portion of the earth and has an attribute value associated with it, such as crop yields or animal numbers, being the smallest unit of information in the GIS environment.

GLEAM is built on six modules reproducing main steps of livestock supply chain: the herd module, the feed ration and intake module, the animal emissions module, the manure module, the feed emissions module and the allocation module. The overall structure is shown in Figure 1.1. The figure is also a representation of the calculation sequence. Each module is explained in detail in its corresponding chapter.

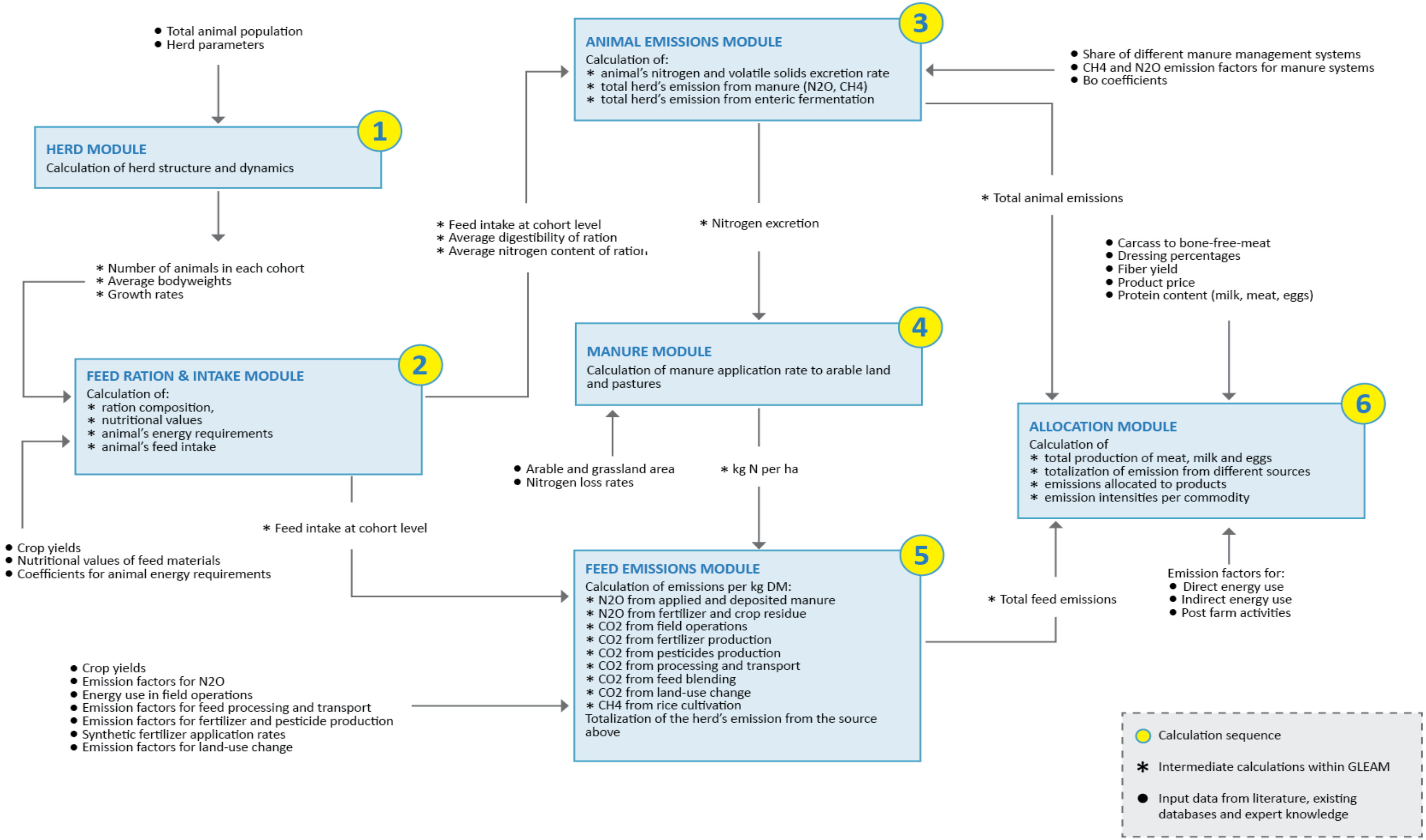
## 1.2 –GLEAM AND THE LCA FRAMEWORK

The LCA framework is defined in ISO standards 14040 and 14044 (ISO, 2006a and ISO, 2006b). It is a method widely accepted in agriculture and other industries to evaluate the environmental impact of products. It is also used to estimate the resource use and identify hotspots of environmental impact within a product's life cycle. The main strength of LCA lies in its ability to provide a holistic assessment of production processes in terms of resource use, pressures, and environmental impacts (ISO, 2006a and ISO, 2006b). LCA also provides a framework to broadly identify effective approaches to reduce environmental burdens and is recognized for its capacity to evaluate the effect of a change within a production process on the overall life-cycle balance of environmental burdens. This approach enables the identification and exclusion of measures that simply shift environmental problems from one phase of the life cycle to another.

### *1.2.1 – Functional unit*

The functional units used to report GHG emissions in GLEAM are expressed as "kg of carbon dioxide equivalents ($CO_2$-eq) per kg of protein in animal product". This choice allows the comparison between different livestock products.

*Figure 1.1 – Overview of GLEAM structure.*

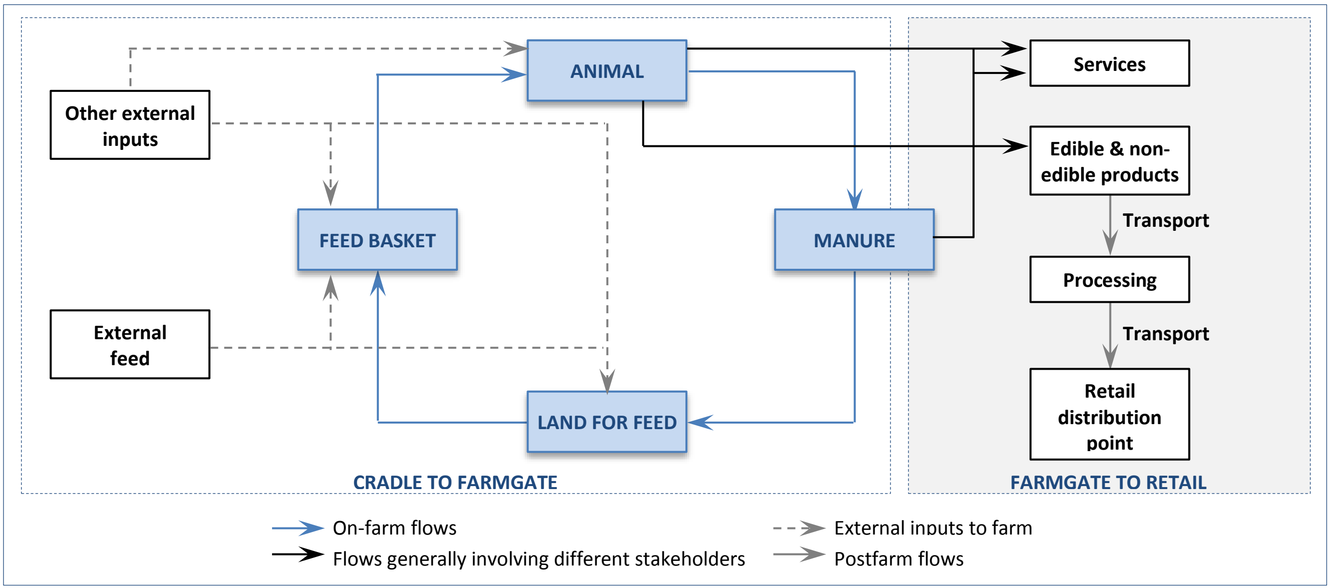


## 1.2.2 – System boundary

GLEAM covers the entire livestock production chain, from feed production to the retail point (Figure 1.2). The system boundary is defined from "Cradle-to-retail of processed animal products." All emissions occurring at the final consumption are outside the defined system boundary, and are thus excluded from this assessment. Livestock supply chains are complex, with a number of interacting unit processes that include crop and pasture production, manure management systems, feed processing and transport, animal breeding and management, etc. The LCA approach models the flow of all products through processes on-farm but also off-farm such as feed imports and exports of animal products or live-animals. The model also covers other external inputs such as energy, fertilizers, pesticides and machinery use.

These connections require the development of specific modules and attribution techniques for the allocation of emissions to different processes and co-products. The processes not only represent different activities in the supply chains, but also define the inter-linkages among production processes such as the link between animal performance, animal feed requirements (energy and protein requirements) and production of outputs such as manure, edible and non-edible products, services and emissions.

***Figure 1.2** – System boundary used in GLEAM.*



## 1.3 – SOURCES OF EMISSIONS

GLEAM estimates emissions of the three major GHGs associated with livestock supply chains, namely methane ($CH_4$), nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$). Table 1.1 shows the emission sources that are included in GLEAM.

**TABLE 1.1.** Emission sources covered in GLEAM

| Source of emissions | | Description |
|---|---|---|
| **Feed $CO_2$** | field operations | $CO_2$ emissions arising from the use of fossil fuels during field operations |
| | fertilizer production | $CO_2$ emissions from the manufacture and transport of synthetic nitrogenous, phosphate and potash fertilizers |
| | pesticide production | $CO_2$ emissions from the manufacture, transport and application of pesticides |
| | processing and transport | $CO_2$ generated during the processing of crops for feed and the transport by land and/or sea |
| | blending and pelleting | $CO_2$ arising from the blending of concentrate feed |
| **Feed land-use change $CO_2$** | soybean cultivation | $CO_2$ emission due to LUC associated with the expansion of soybean |
| | palm kernel cake | $CO_2$ emission due to LUC associated with the expansion of palm oil plantations |
| | pasture expansion | $CO_2$ emission due to LUC associated with the expansion of pastures |
| **Feed $N_2O$** | applied and deposited manure | Direct and indirect $N_2O$ emissions from manure deposited on the fields and used as organic fertilizer |
| | fertilizer and crop residues | Direct and indirect $N_2O$ emissions from applied synthetic nitrogenous fertilizer and crop residues decomposition |
| **Feed $CH_4$** | Rice production | $CH_4$ emissions arising from the cultivation of rice used as feed |
| **Enteric fermentation $CH_4$** | | $CH_4$ emissions caused by enteric fermentation |
| **Manure management $CH_4$** | | $CH_4$ emissions arising from manure storage and management |
| **Manure management $N_2O$** | | $N_2O$ emissions arising from manure storage and management |
| **Direct energy use $CO_2$** | | $CO_2$ emissions arising from energy use on-farm for ventilation, heating, etc. |
| **Embedded energy use $CO_2$** | | $CO_2$ emissions arising from energy use during the construction of farm buildings and equipment |
| **Postfarm $CO_2$** | | $CO_2$ emissions from the processing and transport of livestock products |

## 1.4 – DATA RESOLUTION

Data availability, quality and resolution vary according to parameters and countries considered (Table 1.2). In OECD countries, where farming tends to be more regulated and monitored, there are often comprehensive national or regional datasets, and in some cases sub-national datasets (e.g. manure management in dairy systems in USA). Conversely, in non-OECD countries, data is often unavailable necessitating the use of regional default values (e.g. backyard pig and chicken herd parameters).

Basic input data such as animal numbers, herd parameters, mineral fertilizer application rates, temperature, etc. are taken from the literature and specific surveys. Intermediate calculations generate outputs and are used in subsequent calculations in GLEAM. They include data on growth rates, animal cohort (or groups), feed rations, animal energy requirements, etc.

**TABLE 1.2.** Spatial resolution of the main GLEAM input variables

| Parameters | Cell[1] | Sub-national | National | Regional[2] | Global |
|---|---|---|---|---|---|
| **Herd** | | | | | |
| Animal numbers | X | | | | |
| Live weights | | X | X | X | |
| Mortality, fertility and replacement data | | X | X | X | |
| **Manure** | | | | | |
| Nitrogen losses rates | | | | | X |
| Management system data | | X | X | X | |
| Leaching rates | | | | X | |
| **Feed** | | | | | |
| Crop yields | X | | | | |
| Harvested area | X | | | | |
| N, P and K fertilizer application rate | | | X | | |
| Pesticides application rate | | | X | | |
| Mechanization level | | | X | | |
| Nitrogen crop residues | X | | | | |
| Feed ration | | | X[3] | X | |
| Digestibility and energy content of feedstuffs | | | X | X | X |
| Nitrogen content of feedstuffs | | | | X | X |
| Energy in field operations and transport | | | | | X |
| Transport distances | | | | | X |
| **Land-use change** | | | | | |
| Soybean | | | X | | |
| Palm kernel cake | | | X | | |
| Pasture | | | X | | |
| **Animal productivity** | | | | | |
| Yield (milk, eggs, fibers) | | | X | X | |
| Dressing percentage | | | X | X | |
| Fat and protein content | | | X | X | X |
| Product farmgate prices[4] | | | X | X | |
| **Postfarm** | | | | | |
| Transport distances of animals or products | | | X | | |
| Energy use | | | X | | |
| **Annual average temperature** | X | | | | |
| **Direct and indirect energy** | | X | X | X | |

The spatial resolution varies geographically and depends on the data availability. For each input, the spatial resolution of a given area is defined at the finest level possible.

[1] Approximately 10 km x 10 km at the equator.

[2] Geographic regions or agro-ecological zones.

[3] Ruminants: rations in industrialized countries; monogastrics: share of swill and non-locally produced materials.

[4] Only for allocation in small ruminants.

## 1.5 – LIVESTOCK DISTRIBUTION AND PRODUCTION SYSTEMS

### *1.5.1 – Animal populations and spatial distribution*

National inventory for all major livestock species (cattle, buffaloes, sheep, goats, pigs and chickens) are based on FAOSTAT data for 2010. The geographic distribution is based on the Gridded Livestock of the World (GLW) model. Density maps from GLW are based on observed densities and explanatory variables such as climatic data, land cover and demographic parameters (Robinson *et al.*, 2014).

## *1.5.2 – Livestock production systems*

GLEAM distinguishes between three production systems for cattle (grassland based, mixed farming systems and feedlots), two for buffaloes, sheep and goats (grassland based and mixed farming systems) (Table 1.3). For monogastric species, the model distinguishes three production systems for pigs (backyard, intermediate and industrial) and three for chickens (backyard, layers and broilers; the last two being industrial) (Table 1.4). Livestock production systems are further classified according to the agro-ecological zones as defined in Seré and Steinfeld (1996):

- **Temperate** includes temperate regions, where at least one or two months a year the temperature falls below 5°C; and tropical highlands, where the daily mean temperature in the growing season ranges from 5 to 20 °C.
- **Arid** includes arid and semi-arid tropics and subtropics, with a growing period of less than 75 days and 75-180 days, respectively.
- **Humid** includes humid tropics and sub-humid tropics where the length of the growing period ranges from 181-270 days or exceeds 271 days, respectively.

**TABLE 1.3.** Characteristics of livestock production systems for ruminant species used in GLEAM

| Production system | Characteristics |
|---|---|
| **Ruminant species** | |
| Grassland based (or grazing) systems | Livestock production systems found in areas dominated by pastures and rangelands with short growing period (<60 days) or very low human density (<20 people per km$^2$), in which more than 10% of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than 10 livestock units per hectare of agricultural land. |
| Mixed farming systems | Livestock production systems found in areas dominated by cropland or areas with growing period >60 days and human density >20 people per km$^2$, in which more than 10% of the dry matter fed to animals comes from crop by-products and/or stubble or more than 10% of the value of production comes from non-livestock farming activities. |
| Feedlots | Specialized, fully market-oriented operations where animals are fed with a specialized diet that is intended to stimulate weight gain. This period typically lasts for six to nine months, depending on the starting and targeted live weight. Diets are generally composed of highly energetic and protein-rich feedstuffs, such as corn and cakes, respectively. Although it can vary among different operations, animals are kept in fully enclosed areas to facilitate the fattening process. |

**Source:** authors based on Seré and Steinfeld (1996) and Robinson et al. (2011).

**TABLE 1.4.** Characteristics of livestock production systems for monogastric species used in GLEAM

| Production system | Characteristics | Housing |
|---|---|---|
| **Pigs** | | |
| Backyard | Mainly subsistence driven or for local markets; level of capital inputs reduced to the minimum; herd performance lower than commercial systems; feed contains maximum 20% of purchased non-local feed; high shares of swill, scavenging and locally-sourced feeds. | Partially enclosed: no concrete floor, or if any pavement is present, made with local material. Roof and support made of local materials (e.g. mud bricks, thatch or timber). |
| Intermediate | Fully market-oriented; medium capital input requirements; reduced level of overall herd performance (compared with industrial); locally-sourced feed materials constitute 30 to 50% of the ration. | Partially enclosed: no walls (or made of a local material if present), solid concrete floor, steel roof and support. |
| Industrial | Fully market-oriented; high capital input requirements (including infrastructure, buildings, equipment); high level of overall herd performance; purchased non-local feed in diet or on-farm intensively produced feed. | Fully enclosed: slatted concrete floor, steel roof and support, brick, concrete, steel or wood walls. |
| **Chicken** | | |
| Backyard | Animals producing meat and eggs for the owner and local market, living freely. Diet consists of swill and scavenging (20 to 40%) while locally-produced feed constitutes the rest. | Simple housing using local wood, bamboo, clay, leaf material and handmade construction resources for supports plus scarp wire netting walls and scrap iron for roof. |
| Layers | Fully market-oriented; high capital input requirements; high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed. | Layers housed in a variety of cage, barn and free-range systems, with automatic feed and water provision. |
| Broilers | Fully market-oriented; high capital input requirements; high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed. | Broilers assumed to be primarily loosely housed on litter, with automatic feed and water provision. |

**Source:** authors based on Seré and Steinfeld (1996) and Robinson et al. (2011).

#### *1.5.2.1 – Ruminant systems*

The distinction between grazing and mixed systems was based on the methodology developed by Robinson et al. (2011), using the above mentioned predictors: population density, land cover and length of growing period.

The further classification of feedlot systems was based on the existence of such systems in the countries as reported in the literature and in national census. Input data were collected through literature reviews and expert opinion and, depending on the availability, at national or sub-national level. Sources of information include national statistics (USDA, 2012; EUROSTAT, 2010; MLA, 2011), literature research (Agribenchmark, 2013; Scholtz et al., 2008) and direct consultations with national experts.

The location of feedlots was based on the distribution maps from GLW, and aligned with national sources when they exist. For each country with feedlot presence, cells were ranked according to the animal density. Those with the highest density of cattle were classified as potential feedlot areas.

#### *1.5.2.2 – Pigs*

The distinction of production systems for pigs was performed using the methodology described in Gilbert *et al.* (2015). The authors developed a model based on national reported data on the share of 'backyard' pigs and data on gross domestic product (GDP) per capita (in purchase power parity for 2010; $PPP_{2010}$). This model was then used to estimate the proportion of backyard pigs in countries where this proportion was unavailable. Finally, the estimated numbers of backyard animals were spatially distributed according to the distribution of the human rural population, with areas of high rural population corresponding to higher density of backyard pigs. The distinction between 'intermediate' and 'industrial' systems was done on the basis of reported data supplemented by expert opinion.

#### *1.5.2.3 – Chickens*

The same procedure based on Gilbert *et al.* (2015) was followed for chickens to distinguish between 'backyard' and 'industrial' systems. Animals in the industrial systems were further sub-divided into layers and broilers, in three steps combining production data of meat and eggs from FAOSTAT and productivity figures from GLEAM (Box 1). Then, adjustments to the resulting fractions were done so that the proportions of meat and egg protein production in GLEAM correspond as close as possible to those reported by FAOSTAT.

**BOX 1 – DISAGGREGATION OF INDUSTRIAL CHICKENS INTO LAYERS AND BROILER SYSTEMS**

The procedure to disaggregate industrial systems ($CHK_{IND}$) into layers ($CHK_{LYR}$) and broilers ($CHK_{BRL}$) was done in three steps:

**STEP 1.** Average yields for eggs and meat were calculated for all chicken in each country, using the backyard and industrial yields calculated from GLEAM parameters and weighting the averages by the shares of backyard and industrial animals from Gilbert et al (2015).

$$\overline{EGG}yield = (CHK_{BCK} * EGGyield_{BCK} + CHK_{IND} * EGGyield_{LYR})$$
$$\overline{MEAT}yield = (CHK_{BCK} * MEATyield_{BCK} + CHK_{IND} * MEATyield_{BRL})$$

Where:

$\overline{EGG}yield$ = flock's weighted average egg yield, kg eggs·head$^{-1}$
$\overline{MEAT}yield$ = flock's weighted average meat yield, kg CW·head$^{-1}$
$CHK_{BCK}$ = share of backyard systems taken from Gilbert *et al.*, fraction
$CHK_{IND}$ = share of industrial systems taken from Gilbert *et al.*, fraction
$EGGyield_{BCK}$ = egg yield for backyard animals calculated from GLEAM parameters, kg eggs·head$^{-1}$
$EGGyield_{LYR}$ = egg yield for layer animals calculated from GLEAM parameters, kg eggs·hen$^{-1}$
$MEATyield_{BCK}$ = meat yield for backyard animals calculated from GLEAM parameters, kg CW·head$^{-1}$
$MEATyield_{BRL}$ = meat yield for broiler animals calculated from GLEAM parameters, kg CW·head$^{-1}$

**STEP 2.** The average yields were combined with production data from FAOSTAT to calculate the share of animals producing meat in the total flock.

$$MEAT_{share} = \frac{FAOSTAT_{meat}/\overline{MEAT}yield}{(FAOSTAT_{meat}/\overline{MEAT}yield) + (FAOSTAT_{eggs}/\overline{EGG}yield)}$$

Where:

$MEAT_{share}$ = share of animals producing meat in the flock, fraction
$FAOSTAT_{meat}$ = chicken meat production from FAOSTAT, kg CW
$\overline{MEAT}yield$ = flock's weighted average meat yield, kg CW·head$^{-1}$
$FAOSTAT_{eggs}$ = eggs production from FASOTAT, kg eggs
$\overline{EGG}yield$ = flock's weighted average egg yield, kg eggs·head$^{-1}$

**STEP 3.** The share of meat producing animals was applied to the industrial animals to estimate the number of "broilers", while the share of "layers" was calculated as the difference.

$$CHK_{BRL} = CHK_{IND} * MEAT_{share} \qquad CHK_{LYR} = CHK_{IND} - CHK_{BRL}$$

Where:

$CHK_{BRL}$ = share of broiler animals in the flock, fraction
$CHK_{IND}$ = share of industrial systems taken from Gilbert *et al.*, fraction
$MEAT_{share}$ = share of animals producing meat in the flock, fraction
$CHK_{LYR}$ = share of layer animals in the flock, fraction

# CHAPTER 2 – HERD MODULE

The first step towards the estimation of production and impacts of livestock supply chains is the characterization of animal populations, which is the function of the herd module.

In particular, the use of the IPCC (2006) Tier 2 methodology requires animal populations to be categorized into distinct cohorts based on animal type, weight, phase of production and feeding situation. This characterization supports the calculation of country-specific age structure, animal performance, feed intake and related emissions. Table 2.1 summarizes the cohorts used in GLEAM, their definition and the sections of the model description where they are calculated. For the schematic representation of the herd dynamics, see Figures 2.1 to 2.3.

**TABLE 2.1.** Summary of cohorts in GLEAM

| Cohort | Description | Section |
|---|---|---|
| **CATTLE** | | **2.1.2** |
| **AF** | Adult females, producing milk and calves | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **AM** | Adult males, used for reproduction and draught power | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **MF** | Meat female animals not fattened in feedlots | |
| **MM** | Meat male animals not fattened in feedlots | |
| **MFf** | Meat females, surplus animals fattened for meat production in feedlots | |
| **MMf** | Meat males, surplus animals fattened for meat production in feedlots | |
| **BUFFALOES, SHEEP, GOATS** | | **2.1.2, 2.2.2, 2.2.2** |
| **AF** | Adult females, producing milk and calves/lambs/kids | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **AM** | Adult males, used for reproduction and draught power (buffaloes only) | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **MF** | Meat female animals | |
| **MM** | Meat male animals | |
| **PIGS** | | **2.3.2** |
| **AF** | Adult females, producing piglets | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **AM** | Adult males, used for reproduction | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **M2** | Meat animals, female and male fattening animals for meat production | |
| **CHICKENS** | | |
| **BACKYARD SYSTEMS** | | **2.4.2** |
| **AF** | Adult females, used for reproduction | |
| **AM** | Adult males, used for reproduction | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **MF1, MF2** | Growing and adult surplus females | |
| **MM** | Surplus males, sold for meat | |
| **LAYERS** | | **2.4.3** |
| **AF** | Adult females, used for reproduction | |
| **AM** | Adult males, used for reproduction | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **MF1** | Growing laying females | |
| **MF2** | Adult laying females during the first laying period | |
| **MF3** | Adult laying females during the molting period | |
| **MF4** | Adult laying females during the second laying period | |
| **MM** | Surplus males, sold for meat | |
| **BROILERS** | | **2.4.4** |
| **AF** | Adult females, used for reproduction | |
| **AM** | Adult males, used for reproduction | |
| **RF** | Replacement females, to replace culled and dead adult females | |
| **RM** | Replacement males, to replace culled and dead adult males | |
| **M2** | Adult female and male broiler animals | |

*Figure 2.1 – Schematic representation of the herd dynamics for ruminants*

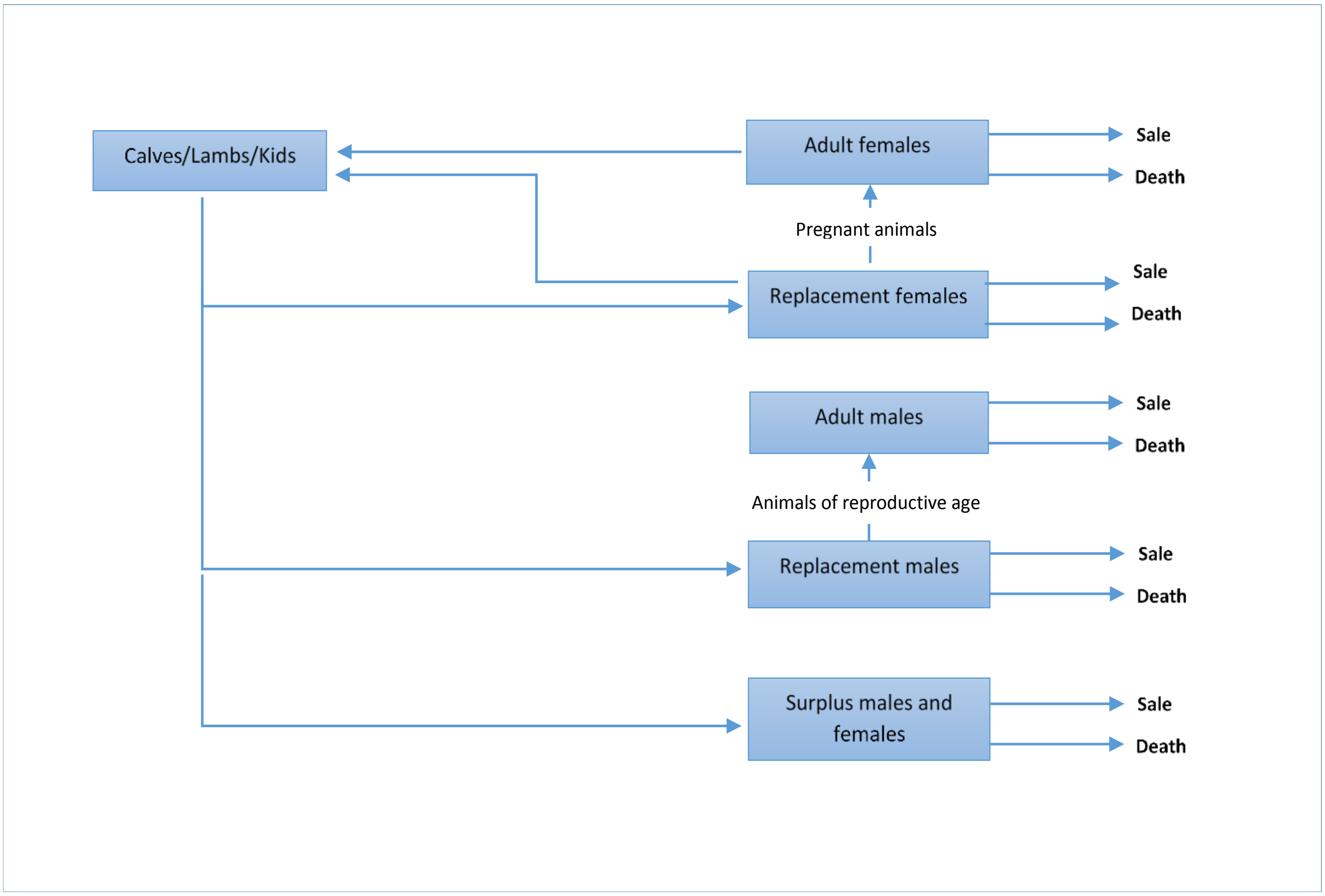



*Figure 2.2 – Schematic representation of the herd dynamics for pigs and broiler chickens*

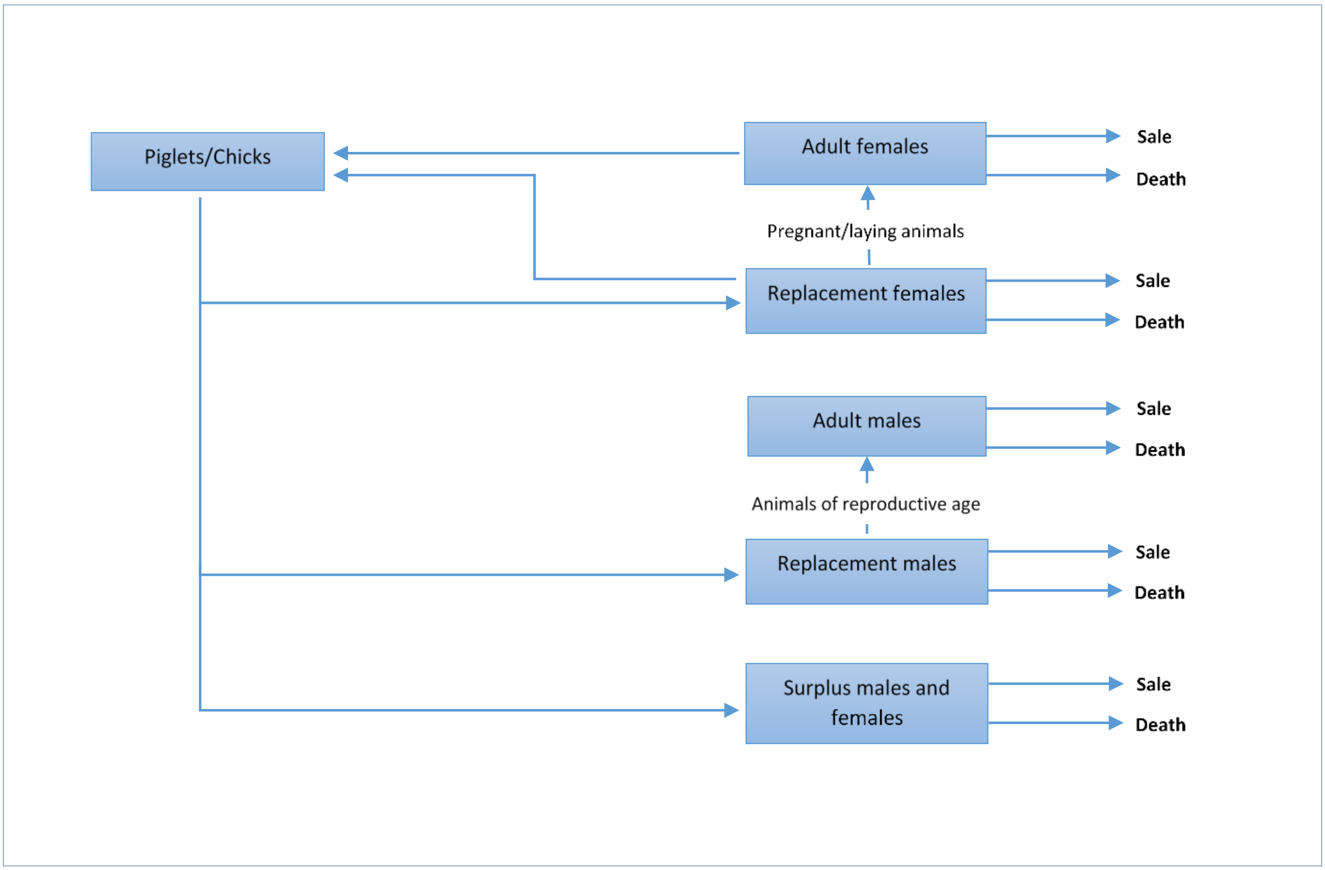
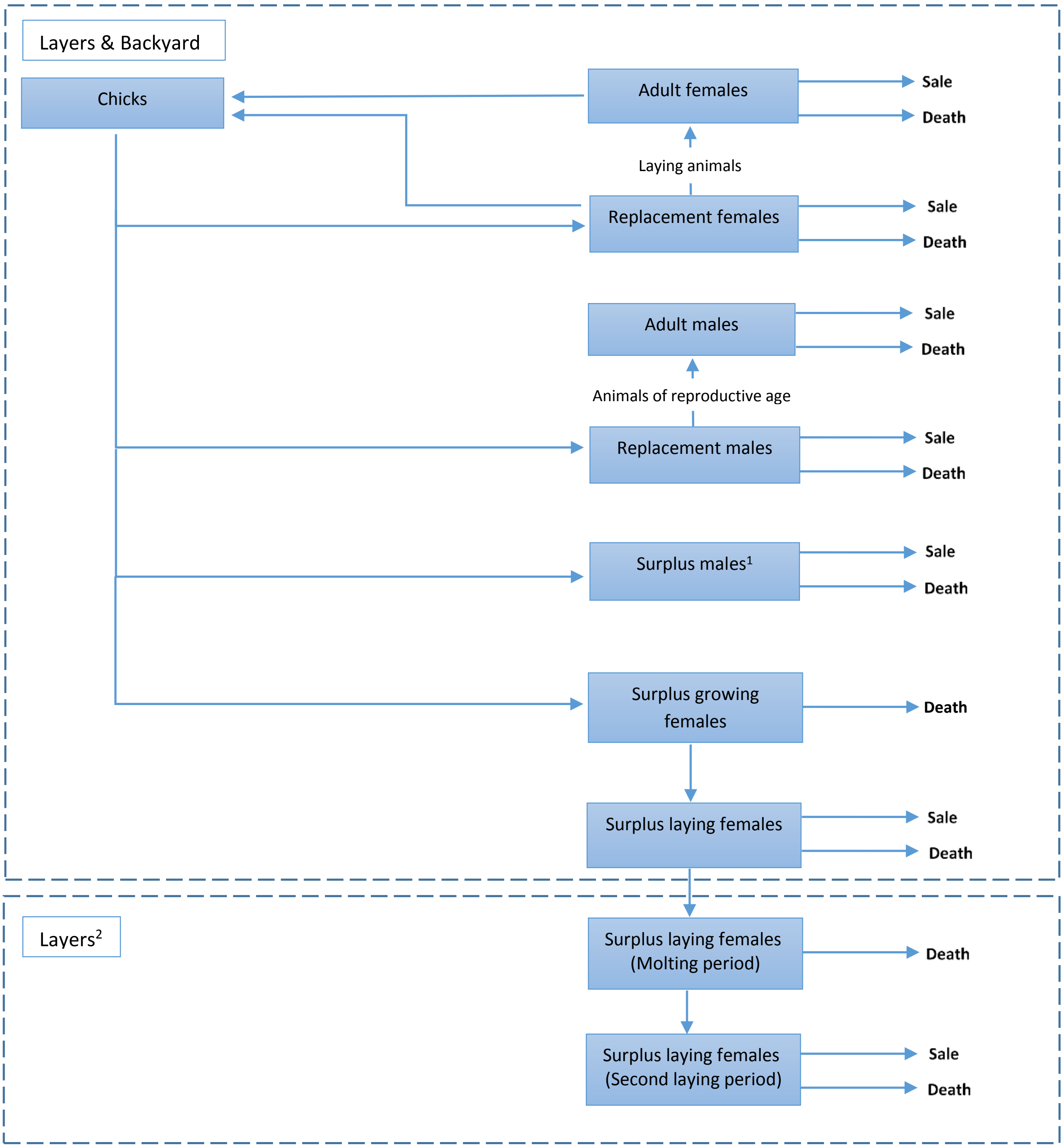


*__Figure 2.3__ – Schematic representation of the herd dynamics for backyard and layer chickens*




[1] In some countries, the surplus males of the Layers system are slaughtered immediately. Where this is the case, all values for this cohort

[1] In some countries, the laying females of the Layers system are kept for a second laying period after a molting phase. Where this is not the case, they are sold after the first laying period and all values for this section are null.

# 2.1 – HERD MODULE: LARGE RUMINANTS

This section provides the description of parameters and equations for cattle and buffaloes. Input data and parameters are described in section 2.1.1. Equations are provided in section 2.1.2.

## *2.1.1 – Input and output data and variables*

Tables 2.2 and 2.3 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.4 to 2.7 (Supplement S1).

**TABLE 2.2.** Cattle and buffaloes input data and parameters

| Variable | Description | Unit |
|---|---|---|
| **INITIAL AGGREGATED ANIMAL NUMBERS** | | |
| **NCOWS** | Total number of cattle per cell from GLW | heads |
| **NBUFF** | Total number of buffaloes per cell from GLW | heads |
| **FNUM** | National animal numbers that go into feedlots in a year | heads |
| **LIVE WEIGHTS** | | |
| **Ckg** | Live weight of calves at birth | kg |
| **AFkg** | Live weight of adult cows | kg |
| **AMkg** | Live weight of bulls | kg |
| **MFSkg** | Live weight of female fattening animals at slaughter | kg |
| **MMSkg** | Live weight of male fattening animals at slaughter | kg |
| **LWSTARTF, LWENDF** | Live weight of feedlot female fattening animals at the beginning and at the end of the fattening period, respectively | kg |
| **LWSTARTM, LWENDM** | Live weight of feedlot male fattening animals at the beginning and at the end of the fattening period, respectively | kg |
| **DEATH, FERTILITY AND REPLACEMENT RATES** | | |
| **DR1** | Death rate female calves | percentage |
| **DR1M** | Death rate male calves | percentage |
| **DR2** | Death rate other animals than calves | percentage |
| **FR** | Fertility rate of adult female animals | percentage |
| **FRRF** | Rate of fertile replacement females. **Note**: a default value of 0.95 is used in all situation | fraction |
| **RRF** | Replacement of adult cows | percentage |
| **OTHER INPUT VARIABLES** | | |
| **AFC** | Age at first calving | year |
| **FATTDAY** | Length of fattening period in feedlot operations | days |
| **DCR** | Dairy cow to total stock of population ratio | fraction |
| **MFR** | Bull to cow ratio | fraction |

**TABLE 2.3.** Cattle and buffaloes output variables

| Variable | Description | Unit |
|---|---|---|
| **COHORTS IN ALL SYSTEMS** | | |
| **AF** | Adult females, producing milk and calves | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction and draught power | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **MF** | Meat female animals not fattened in feedlots (cattle) or meat female animals (buffaloes) | heads·year$^{-1}$ |
| **MM** | Meat male animals not fattened in feedlots (cattle) or meat male animals (buffaloes) | heads·year$^{-1}$ |
| **CF** | Female calves | heads·year$^{-1}$ |
| **CM** | Male calves | heads·year$^{-1}$ |
| **COHORTS SPECIFIC TO FEEDLOTS** | | |
| **MFt** | Total meat female animals, both feedlot and non-feedlot (only cattle) | heads·year$^{-1}$ |
| **MFf** | Meat females, surplus animals fattened for meat production in feedlots (only cattle) | heads·year$^{-1}$ |
| **MMt** | Total meat male animals, both feedlot and non-feedlot (only cattle) | heads·year$^{-1}$ |
| **MMf** | Meat males, surplus animals fattened for meat production in feedlots (only cattle) | heads·year$^{-1}$ |
| **COHORT SPECIFIC DATA** | | |
| ***c*exit** | Number of sold animals for meat production from cohort *c* | heads·year$^{-1}$ |
| ***c*in** | Number of animals entering cohort *c* | heads·year$^{-1}$ |
| ***c*x** | Number of dead animals in cohort *c* | heads·year$^{-1}$ |
| ***c*kg** | Live weight of cohort *c* | kg·head$^{-1}$ |
| **ANIMAL NUMBERS SUBTOTALS** | | |
| **DCATTLE** | Total animal numbers in the cattle dairy herd | heads·year$^{-1}$ |
| **DBUFFALO** | Total animal numbers in the buffalo dairy herd | heads·year$^{-1}$ |
| **M_HERD** | Total fattening animals from dairy and beef herds | heads·year$^{-1}$ |
| **DAILY WEIGHT GAINS** | | |
| **DWGF** | Average daily weight gain of female animals from calf to adult weight | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM** | Average daily weight gain of male animals from calf to adult weight | kg·head$^{-1}$·day$^{-1}$ |
| **DWGFF** | Average daily weight gainof female animals in feedlots (only cattle) | kg·head$^{-1}$·day$^{-1}$ |
| **DWGMF** | Average daily weight gainof male animals in feedlots (only cattle) | kg·head$^{-1}$·day$^{-1}$ |
| **OTHER VARIABLES** | | |
| **ASF** | Age at slaughter of non-feedlot female animals | year |
| **ASM** | Age at slaughter of non-feedlot male animals | year |
| **AFD** | Adult female animals from dairy herd | heads·year$^{-1}$ |

## *2.1.2 – Herd equations – Large ruminants*

### *2.1.2.1 – Dairy herd - Female section*

AF = DCR * NCOWS or DCR * NBUFF[a]

AFin = AF * (RRF / 100)

AFx = AF * (DR2 / 100)

AFexit = AF * (RRF / 100) – AFx

CFin = AF * ((1 – (DR2 / 100)) * (FR / 100) + (RRF / 100)) * 0.5 * (1 – (DR1 / 100))

CMin = AF * ((1 – (DR2 / 100)) * (FR / 100) + (RRF / 100)) * 0.5 * (1 – (DR1M / 100))

RFin = ((AF * (RRF / 100)) / FRRF) / $(1 – (DR2 / 100))^{AFC}$

RFexit = ((AF * (RRF / 100)) / FRRF) – AFin

RFx = RFin – (AFin + RFexit)

RF = (RFin + AFin) / 2 * AFC

MFin = CFin – Rfin

Unit: *heads·year$^{-1}$*

ASF = AFC * (MFSkg – Ckg) / (AFkg – Ckg)

Unit: *year*

[a] Use NCOWS or NBUFF accordingly to the species.

**Equations for cattle**

$$MFtexit = MFin * (1 - (DR2 / 100))^{ASF}$$
$$MFtx = MFin - MFtexit$$
$$MFt = (MFin + MFtexit) / 2 * (AFC * (MFSkg - Ckg) / (AFkg - Ckg))$$
$$MFtd = MFt$$

Unit: *heads·year⁻¹*

**Equations for buffaloes**

$$MFexit = MFin * (1 - (DR2 / 100))^{ASF}$$
$$MFx = MFin - MFexit$$
$$MF = (MFin + MFexit) / 2 * (AFC * (MFSkg - Ckg) / (AFkg - Ckg))$$

Unit: *heads·year⁻¹*

### *2.1.2.2 – Dairy herd - Male section*

$$AM = AF * MFR$$
$$AMx = AM * (DR2 / 100)$$
$$AMexit = AM / AFC - AMx$$
$$AMin = AM / AFC$$ [b]
$$RMin = AMin / (1 - (DR2 / 100))^{AFC}$$
$$RMx = RMin - AMin$$
$$RM = (RMin + AMin) / 2 * AFC$$
$$MMin = CMin - RMin$$

Unit: *heads·year⁻¹*

$$ASM = AFC * (MMSkg - Ckg) / (AMkg - Ckg)$$

Unit: *year*

**Equations for cattle**

$$MMtexit = MMin * (1 - (DR2 / 100))^{ASM}$$
$$MMtx = MMin - MMtexit$$
$$MMt = (MMin + MMtexit) / 2 * (AFC * (MMSkg - Ckg) / (AMkg - Ckg))$$
$$MMtd = MMt$$
$$DCATTLE = AF + RF + MFt + AM + RM + MMt$$
$$AFD = AF$$

Unit: *heads·year⁻¹*

**Equations for buffaloes**

$$MMexit = MMin * (1 - (DR2 / 100))^{ASM}$$
$$MMx = MMin - MMexit$$
$$MM = (MMin + MMexit) / 2 * (AFC * (MMSkg - Ckg) / (AMkg - Ckg))$$
$$DBUFFALO = AF + RF + MF + AM + RM + MM$$
$$AFD = AF$$

Unit: *heads·year⁻¹*

[b] For cattle and buffalos, bulls are replaced in relation to the age at first calving. This is done to prevent inbreeding, that is, bulls serving their own daughters.

### *2.1.2.3 – Beef herd*

**Equations for cattle**

BCATTLE = NCOWS – DCATTLE

IF DCATTLE = 0

AF = NCOWS * (1 – MFR)

ELSE

AF = (AFD / DCATTLE) * BCATTLE

Unit: *heads·year$^{-1}$*

**Equations for buffaloes**

BBUFFALO = NBUFF – DBUFFALO

IF DBUFFALO = 0

AF = NBUFF * (1 – MFR)

ELSE

AF = (AFD / DBUFFALO) * BBUFFALO

Unit: *heads·year$^{-1}$*

Once AF in non-dairy herd is estimated, the model follows the same equations shown in Sections 2.1.2.1 and 2.1.2.2.

### *2.1.2.4 – Feedlot animals*

MFtd = Female fattening animals from dairy herd

MFtb = Female fattening animals from beef herd

MMtd = Male fattening animals from dairy herd

MMtb = Male fattening animals from beef herd

M_HERD = MFtd + MMtd + MFtb + MFtb

Unit: *animals·year$^{-1}$*

DMFfrac = MFtd / M_HERD

BMFfrac = MFtb / M_HERD

DMMfrac = MMtd / M_HERD

BMMfrac = MMtb / M_HERD

Unit: *fraction*

MFfd = FNUM * DMFfrac

MFfb = FNUM * BMFfrac

MMfd = FNUM * DMMfrac

MMfb = FNUM * BMMfrac

Unit: *animals·year$^{-1}$*

For clarity purposes, the suffixes ...d and ...b are omitted in all the steps in Female and Male sections below, as the equations for animals from dairy and beef herds are the same.

**Female section**

MFfexit = MFtexit * (MFf / MFt)

Unit: *animals·year$^{-1}$*

AFF = (LWSTARTF – Ckg) / (AFkg – Ckg) * AFC

ASFF = AFF + FATTDAY / 365

Unit: *year*

MF = MFt –MFf

MFexit = MFtexit * (MF / MFt)

Unit: *animals·year$^{-1}$*

**Male section**

MMfexit = MMtexit * (MMf / MMt)

Unit: *animals·year*$^{-1}$

AFM = (LWSTARTM – Ckg) / (AMkg – Ckg) * AFC

ASFM = AFM + FATTDAY / 365

Unit: *year*

MM = MMt – MMf

MMexit = MMtexit * (MM / MMt)

Unit: *animals·year*$^{-1}$

### *2.1.2.5 – Average weights and growth rates*

RFkg = (AFkg – Ckg) / 2 + Ckg

RMkg = (AMkg – Ckg) / 2 + Ckg

MFkg = (MFSkg – Ckg) / 2 + Ckg

MMkg = (MMSkg – Ckg) / 2 + Ckg

MFfkg = (((LWSTARTF – Ckg) / 2 + Ckg) * AFF + ((LWENDF – LWSTARTF) / 2 + LWSTARTF) * (FATTDAY / 365)) / ASFF

MMfkg = (((LWSTARTM – Ckg) / 2 + Ckg) * AFM + ((LWENDM – LWSTARTM) / 2 + LWSTARTM) * (FATTDAY / 365)) / ASFM

Unit: *kg·head*$^{-1}$

DWGF = (AFkg – Ckg) / (365 * AFC)

DWGM = (AMkg – Ckg) / (365 * AFC)

DWGFF = (DWGF * AFF + ((LWENDF – LWSTARTF) / FATTDAY) * (FATTDAY / 365)) / ASFF

DWGFM = (DWGM * AFM + ((LWENDM – LWSTARTM) / FATTDAY) * (FATTDAY / 365)) / ASFM

Unit: *kg·animal*$^{-1}$*·day*$^{-1}$

## 2.2 – HERD MODULE: SMALL RUMINANTS

This section provides the description of parameters and equations for sheep and goats. Input data and parameters are described in section 2.2.1. Equations are provided in section 2.2.2.

### *2.2.1 – Input and output data and variables*

Tables 2.8 and 2.9 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.10 and 2.11 (Supplement S1).

**TABLE 2.8.** Sheep and goats input data and parameters

| Variable | Description | Unit |
|---|---|---|
| **INITIAL AGGREGATED ANIMAL NUMBERS** | | |
| **NSHEEP** | Total number of sheep, per cell from GLW | heads |
| **NGOAT** | Total number of goats, per cell from GLW | heads |
| **LIVE WEIGHTS** | | |
| **Ckg** | Live weight of lambs or kids at birth | kg |
| **AFkg** | Live weight of adult female animals | kg |
| **AMkg** | Live weight of adult male animals | kg |
| **MFSkg** | Live weight of female fattening animals at slaughter | kg |
| **MMSkg** | Live weight of male fattening animals at slaughter | kg |
| **DEATH, FERTILITY AND REPLACEMENT RATES** | | |
| **DR1** | Death rate of lambs or kids | percentage |
| **DR2** | Death rate other animals than lambs or kids | percentage |
| **FR** | Fertility rate of adult female animals | percentage |
| **FRRF** | Rate of fertile replacement females. **Note**: a default value of 0.95 is used in all situation | fraction |
| **RRF** | Replacement rate female animals | percentage |
| **OTHER INPUT VARIABLES** | | |
| **AFC** | Age at first lambing/kidding | year |
| **DSR** | Dairy sheep or goats ratio, fraction of dairy sheep or goats of the total population | fraction |
| **MFR** | Ram to ewe (sheep) or does to bucks (goats) ratio | fraction |
| **LINT** | Lambing or kidding interval, period between two parturitions | days |
| **LITSIZE** | Litter size, number of lambs or kids per parturition | heads |

**TABLE 2.9.** Sheep and goats output variables

| Variable | Description | Unit |
|---|---|---|
| **COHORTS** | | |
| **AF** | Adult females, producing milk and lambs or kids | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **MF** | Meat females <1 year, surplus animals fattened for meat production | heads·year$^{-1}$ |
| **MM** | Meat males <1 year, surplus animals fattened for meat production | heads·year$^{-1}$ |
| **C** | Lambs or kids | heads·year$^{-1}$ |
| **RF1** | Replacement females at the end of first year | heads·year$^{-1}$ |
| **RFA** | Replacement females in the midst of first year | heads·year$^{-1}$ |
| **RFB** | Replacement females in the midst of the second year | heads·year$^{-1}$ |
| **RM1** | Replacement males at the end of first year | heads·year$^{-1}$ |
| **RMA** | Replacement males in the midst of first year | heads·year$^{-1}$ |
| **RMB** | Replacement males in the midst of the second year | heads·year$^{-1}$ |
| **COHORT SPECIFIC DATA** | | |
| ***c*exit** | Number of sold animals for meat production from cohort *c* | heads·year$^{-1}$ |
| ***c*in** | Number of animals entering cohort *c* | heads·year$^{-1}$ |
| ***c*x** | Number of dead animals in cohort *c* | heads·year$^{-1}$ |
| ***c*kg** | Live weight of cohort *c* | kg·head$^{-1}$ |
| **ANIMAL NUMBERS SUBTOTALS** | | |
| **DSHEEP** | Total animal numbers in the sheep dairy herd | heads·year$^{-1}$ |
| **DGOAT** | Total animal numbers in the goats dairy herd | heads·year$^{-1}$ |
| **DAILY WEIGHT GAINS** | | |
| **DWGF** | Average daily weight gain of female animals from lamb or kid to adult weight | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM** | Average daily weight gain of male animals from lamb or kid to adult weight | kg·head$^{-1}$·day$^{-1}$ |
| **OTHER VARIABLES** | | |
| **ASF** | Age at slaughter of non-feedlot female animals | year |
| **ASM** | Age at slaughter of non-feedlot male animals | year |
| **AFD** | Adult female animals from dairy herd | heads·year$^{-1}$ |

## 2.2.2 – Herd equations – Small ruminants

### 2.2.2.1 – Dairy herd - Female section

AF = DSR * NSHEEP or DSR * NGOAT
AFin = AF * (RRF / 100)
AFx = AF * (DR2 / 100)
AFexit = AF * (RRF / 100) – AFx
Cin = AF * ((1 – (DR2 / 100)) * (((365 * FR) / LINT) / 100) * LITSIZE + (RRF / 100))
RFin = ((AF * (RRF / 100)) / FRRF) / ((1 – (DR1 / 100)) * (1 – (DR2 / 100))$^{(AFC-1)}$)
RFexit = ((AF * (RRF / 100)) / FRRF) – AFin
RFx = RFin – (AFin + RFexit)
RF1 = RFin * (1 – (DR1 / 100))
RFA = (RFin + RF1) / 2
RFB = ((RF1 + AFin) / 2) * (AFC – 1)
RF = ((RFin + RF1) / 2) + (((RF1 + AFin) / 2) * (AFC – 1))
MFin = Cin / 2 – Rfin
Unit: *heads·year*$^{-1}$

ASF = AFC * (MFSkg – Ckg) / (AFkg – Ckg)
Unit: *year*

MFexit = MFin * (1 – (DR1 / 100))$^{ASF}$
MFx = MFin – MFexit
MF = (MFin + MFexit) / 2 * ASF
Unit: *heads·year*$^{-1}$

### 2.2.2.2 – Dairy herd - Male section

AM = AF * MFR
AMx = AM * (DR2 / 100)
AMexit = AM / (3 * AFC[c]) – AMx
AMin = AM / (3 * AFC)
RMin = AMin / ((1 – (DR1 / 100)) * (1 – (DR2 / 100))$^{(AFC-1)}$)
RM1 = RMin * (1 – (DR1 / 100))
RMA = (RMin + RM1) / 2
RMB = ((RM1 + AMin) / 2) * (AFC – 1)
RMx = RMin – AMin
RM = ((RMin + RM1) / 2) + ((RM1 + AMin) / 2) * (AFC – 1)
MMin = Cin / 2 – RMin
Unit: *heads·year*$^{-1}$

ASM = AFC * (MMSkg – Ckg) / (AMkg – Ckg)
Unit: *year*

MMexit = MMin * (1 – (DR1 / 100))$^{ASM}$
MMx = MMin – MMexit
MM = (MMin + MMexit) / 2 * ASM
Unit: *heads·year*$^{-1}$

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[c] For cattle, bulls are replaced in relation to the age of first calving. This is done to prevent inbreeding, bulls serving their own daughters. In the case of sheep, farmers tend to exchange rams. It is assumed that a ram is exchanged twice, which means that he can serve for three periods, so the replacement rate is only one third of what it would be on the basis of the AFC.

**Equations for sheep**

DSHEEP = AF + RF + MF + AM + RM + MM

AFD = AF

Unit: *heads·year*$^{-1}$

**Equations for goats**

DGOAT = AF + RF + MF + AM + RM + MM

AFD = AF

Unit: *heads·year*$^{-1}$

### 2.2.2.3 – Non-dairy herd

**Equations for sheep**

BSHEEP = NSHEEP – DSHEEP

IF DSHEEP = 0

AF = NSHEEP * (1 – MFR)

ELSE

AF = (AFD / DSHEEP) * BSHEEP

Unit: *heads·year*$^{-1}$

**Equations for goats**

BGOAT = NGOAT – DGOAT

IF DGOAT = 0

AF = NGOAT * (1 – MFR)

ELSE

AF = (AFD / DGOAT) * BGOAT

Unit: *heads·year*$^{-1}$

Once AF in non-dairy herd is estimated, the model follows the same equations shown in Sections 2.2.2.1 and 2.2.2.2.

### 2.2.2.4 – Average weights and growth rates

RFkg = (AFkg + Ckg) / 2

RF1kg = Ckg + ((AFkg – Ckg) / AFC)

RFAkg = (Ckg + RF1kg) / 2

RFBkg = (RF1kg + AFkg) / 2

RMkg = (AMkg + Ckg) / 2

RM1kg = Ckg + ((AMkg – Ckg) / AFC)

RMAkg = (Ckg + RM1kg) / 2

RMBkg = (RM1kg + AMkg) / 2

MFkg = (MFSkg - Ckg) / 2 + Ckg

MMkg = (MMSkg - Ckg) / 2 + Ckg

Unit: *kg·head*$^{-1}$

DWGF = (AFkg – Ckg) / (365 * AFC)

DWGM = (AMkg – Ckg) / (365 * AFC)

Unit: *kg·head*$^{-1}$*·day*$^{-1}$

# 2.3 – HERD MODULE: PIGS

This section provides the description of parameters and equations for pigs. Input and output data and parameters are described in section 2.3.1. Equations are provided in section 2.3.2.

## 2.3.1 – Input and output data and variables

Tables 2.12 and 2.13 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.14 to 2.16 (Supplement S1).

**TABLE 2.12.** Pigs input data and parameters

| Variable | Description | Unit |
|---|---|---|
| **INITIAL AGGREGATED ANIMAL NUMBERS** | | |
| **NPIGS** | Total animal number, per cell and production system | heads·year$^{-1}$ |
| **LIVE WEIGHTS** | | |
| **Ckg** | Live weight of piglets at birth | kg |
| **Wkg** | Live weight of piglets at weaning age | kg |
| **AFkg** | Live weight of adult female animals | kg |
| **AMkg** | Live weight of adult male animals | kg |
| **M2Skg** | Live weight of fattening animals at slaughter | kg |
| **DEATH, FERTILITY AND REPLACEMENT RATES** | | |
| **DR1** | Death rate of piglets before weaning age | percentage |
| **DRR2A** | Death rate of replacement animals between weaning and adult ages | percentage |
| **DRR2B** | Death rate of adult animals | percentage |
| **DRF2** | Death rate of fattening animals | percentage |
| **FR** | Annual parturitions per sow | parturition·year$^{-1}$ |
| **FRRF** | Rate of fertile replacement females. **Note**: a default value of 0.95 is used in all situation | fraction |
| **RRF** | Replacement rate female animals | percentage |
| **RRM** | Replacement rate male animals | percentage |
| **OTHER INPUT VARIABLES** | | |
| **WA** | Weaning age | days |
| **LITSIZE** | Litter size, number of piglets per parturition | heads·parturition$^{-1}$ |
| **MFR** | Boar to sow ratio | fraction |
| **DWG2** | Average daily weight gain of fattening animals | kg·head$^{-1}$·day$^{-1}$ |

**TABLE 2.13.** Pigs output variables

| Variable | Description | Unit |
|---|---|---|
| **PRINCIPAL COHORTS** | | |
| **AF** | Adult females, producing piglets | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **M2** | Meat animals, female and male fattening animals for meat production | heads·year$^{-1}$ |
| **C** | Piglets | heads·year$^{-1}$ |
| **COHORT SPECIFIC DATA** | | |
| ***c*exit** | Number of sold animals for meat production from cohort *c* | heads·year$^{-1}$ |
| ***c*in** | Number of animals entering cohort *c* | heads·year$^{-1}$ |
| ***c*x** | Number of dead animals in cohort *c* | heads·year$^{-1}$ |
| ***c*kg** | Live weight of cohort *c* | kg·head$^{-1}$ |
| **DAILY WEIGHT GAINS** | | |
| **DWGF** | Average daily weight gain of female young replacement animals | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM** | Average daily weight gain of male young replacement animals | kg·head$^{-1}$·day$^{-1}$ |
| **OTHER VARIABLES** | | |
| **AFCF** | Age at first parturition calculated in basis of the daily weight gain | year |
| **AFCM** | Age at which boars are considered adults in the basis of the daily weight gain | year |
| **A2S** | Length of fattening period for meat animals | year |

## 2.3.2 – Herd equations – Pigs

### 2.3.2.1 – Female section

AF = NPIGS / 10
AFin = AF * (RRF / 100)
AFx = AF * (DRR2B / 100)
AFexit = AF * (RRF / 100) – AFx
Cin = AF * ((1 – (DRRB2 / 100)) * FR * LITSIZE + (RRF / 100) * LITSIZE) * (1 – (DR1 / 100))
Unit: *heads·year*$^{-1}$

DWGF = AFkg / ((AFkg + AMkg) / 2) * DWG2
Unit: *kg·head*$^{-1}$*·year*$^{-1}$

AFCF = (AFkg – Wkg) / (365 * DWGF) + (WA / 365)
Unit: *year*

RFin = ((AF * (RRF / 100)) / FRRF) / (1 – (DRR2A / 100))$^{AFCF}$
RFexit = ((AF * (RRF / 100)) / FRRF) – AFin
RFx = RFin – (AFin + RFexit)
RF = (RFin + AFin) / 2 * ((AFkg – Wkg) / (365 * DWGF) + (WA / 365))
MFin = Cin / 2 – RFin
Unit: *heads·year*$^{-1}$

### 2.3.2.2 – Male section

AM = AF * MFR
AMx = AM * (DRR2B / 100)
Unit: *heads·year*$^{-1}$

DWGM = AMkg / ((AFkg + AMkg) / 2) * DWG2
Unit: *kg·head*$^{-1}$*·year*$^{-1}$

AFCM = (AMkg – Wkg) / (365 * DWGM) + (WA / 365)
Unit: *year*
AMexit = AM * RRM / 100 – AMx
AMin = AM * RRM / 100
RMin = AMin / (1 – (DRR2A / 100))$^{AFCM}$
RMx = RMin – AMin
RM = (RMin + AMin) / 2 * ((AMkg – Wkg) / (365 * DWGM) + (WA / 365))
MMin = Cin / 2 – RMin
Unit: *heads·year*$^{-1}$

### 2.3.2.3 – Fattening section

M2in = MFin + MMin
Unit: *heads·year*$^{-1}$

A2S = (M2Skg – Wkg) / (365 * DWG2)
Unit: *year*

M2exit = M2in * (1 – (DRF2 / 100))$^{A2S}$
M2x = M2in – M2exit
M2 = (M2in + M2exit) / 2 * ((M2Skg – Wkg) / (365 * DWG2))
Unit: *heads·year*$^{-1}$

### *2.3.2.4 – Average weights*

| | | |
|---|---|---|
| RFkg | = | (AFkg – Wkg) / 2 + Wkg |
| RMkg | = | (AMkg – Wkg) / 2 + Wkg |
| M2kg | = | (M2Skg – Wkg) /2 + Wkg |

Unit: $kg \cdot head^{-1}$

## 2.4 – HERD MODULE: CHICKENS

This section provides the description of parameters and equations for chicken. Input and output data and parameters are described in section 2.4.1. Equations are provided in section 2.4.2 to 2.4.4.

### *2.4.1 – Input and output data and variables*

Tables 2.17 and 2.18 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.19 to 2.21 (Supplement S1).

**TABLE 2.17.** Chickens input data and parameters

| Variable | Description | Unit |
|---|---|---|
| **INITIAL AGGREGATED ANIMAL NUMBERS** | | |
| **AFC** | Age at first laying (hens) or reproduction (roosters) | days |
| **NCHK** | Total number of chickens per cell | heads |
| **LIVE WEIGHTS** | | |
| **ALL SYSTEMS** | | |
| **Ckg** | Live weight of chicks at birth | kg |
| **BACKYARD SYSTEMS** | | |
| **AF2kg** | Live weight of females at the end of the laying period | kg |
| **AM2kg** | Live weight of males at the end of the laying period | kg |
| **M2Skg** | Live weight of surplus animals at slaughter | kg |
| **LAYERS AND BROILERS** | | |
| **AF1kg** | Live weight of female reproductive animals at the start of the laying period | kg |
| **AF2kg** | Live weight of female reproductive animals at the end of the laying period | kg |
| **BROILERS** | | |
| **M2Skg** | Live weight at slaughter of female and male broiler animals | kg |
| **DEATH, FERTILITY AND REPLACEMENT RATES** | | |
| **ALL SYSTEMS** | | |
| **DR1** | Chick mortality rate during the first 16-17 weeks. Not an annual rate | percentage |
| **FRRF** | Fertility rate of replacement female animals. **Note**: a default value of 0.95 is used in all situation | fraction |
| **BACKYARD SYSTEMS** | | |
| **DR2** | Death rate adult females and males | percentage |
| **LAYERS** | | |
| **DRL2** | Death rate for the laying period | percentage |
| **DRM** | Death rate during the molting period. **Note**: a default value of 15 is used in all situation | percentage |
| **BROILERS** | | |
| **DRB2** | Death rate for broiler animals laying period | percentage |
| **DRL2** | Death rate for the laying period | percentage |
| **OTHER INPUT VARIABLES** | | |
| **ALL SYSTEMS** | | |
| **MFR** | Rooster to hen ratio per production system | fraction |
| **EGGSyear** | Annual laid eggs per hen per production system | $eggs \cdot year^{-1}$ |
| **EGGwght** | Average egg weight | $gr \cdot egg^{-1}$ |
| **HATCH** | Hatchability, fraction of laid eggs that actually give a chick | fraction |
| **BACKYARD SYSTEMS** | | |
| **AFS** | Age at which adult surplus females are slaughtered | days |
| **CYCLE** | Number of reproductive laying cycles | # cycles |
| **CLTSIZE** | Laid eggs per cycle per reproductive hen | $eggs \cdot cycle^{-1}$ |
| **LAYERS** | | |
| **LAY1weeks** | Length of the first laying period | weeks |
| **LAY2weeks** | Length of the second laying period. **Note**: a default value of 30 is used in all situation | weeks |
| **MOLTweeks** | Length of the molting period. **Note**: a default value of 6 is used in all situation | weeks |
| **BROILERS** | | |
| **A2S** | Age at slaughter for meat animals | days |
| **BIDLE** | Idle days between two production cycles. **Note**: a default value of 14 is used in all situation | days |
| **LAYweeks** | Length of the laying period | weeks |

**TABLE 2.18**. Chickens output variables

| Variable | Description | Unit |
|---|---|---|
| **Principal cohorts** | | |
| **Backyard systems** | | |
| **AF** | Adult females, used for reproduction | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **MF1, MF2** | Growing and adult surplus females | heads·year$^{-1}$ |
| **MM** | Surplus males, sold for meat | heads·year$^{-1}$ |
| **C** | Chicks | heads·year$^{-1}$ |
| **Layers** | | |
| **AF** | Adult females, used for reproduction | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **MF1** | Growing laying females | heads·year$^{-1}$ |
| **MF2** | Adult laying females during the first laying period | heads·year$^{-1}$ |
| **MF3** | Adult laying females during the molting period | heads·year$^{-1}$ |
| **MF4** | Adult laying females during the second laying period | heads·year$^{-1}$ |
| **MM** | Surplus males, sold for meat | heads·year$^{-1}$ |
| **C** | Chicks | heads·year$^{-1}$ |
| **Broilers** | | |
| **AF** | Adult females, used for reproduction | heads·year$^{-1}$ |
| **RF** | Replacement females, to replace culled and dead adult females | heads·year$^{-1}$ |
| **AM** | Adult males, used for reproduction | heads·year$^{-1}$ |
| **RM** | Replacement males, to replace culled and dead adult males | heads·year$^{-1}$ |
| **M2** | Adult female and male broiler animals | heads·year$^{-1}$ |
| **C** | Chicks | heads·year$^{-1}$ |
| **Cohort specific data** | | |
| ***c*exit** | Number of sold animals for meat production from cohort *c* | heads·year$^{-1}$ |
| ***c*in** | Number of animals entering cohort *c* | heads·year$^{-1}$ |
| ***c*x** | Number of dead animals in cohort *c* | heads·year$^{-1}$ |
| ***c*kg** | Live weight of cohort *c* | kg·head$^{-1}$ |
| **Daily Weight Gains** | | |
| **Backyard systems** | | |
| **DWGF1** | Average daily weight gain of all hens in their youth period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGF2** | Average daily weight gain of reproductive and surplus hens in their laying and fattening period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM1** | Average daily weight gain of all male chickens in their youth period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM2** | Average daily weight gain of reproductive roosters in their reproductive period | kg·head$^{-1}$·day$^{-1}$ |
| **Layers** | | |
| **DWGF1** | Average daily weight gain of all hens in their youth period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGF2** | Average daily weight gain of layers and reproductive hens in their laying period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM1** | Average daily weight gain of all male chickens in their youth period | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM2** | Average daily weight gain of reproductive roosters in their reproductive period | kg·head$^{-1}$·day$^{-1}$ |
| **Broilers** | | |
| **DWGF0** | Average daily weight gain of reproductive female animals | kg·head$^{-1}$·day$^{-1}$ |
| **DWGM0** | Average daily weight gain of reproductive male animals | kg·head$^{-1}$·day$^{-1}$ |
| **DWGB** | Average daily weight gain of broiler animals | kg·head$^{-1}$·day$^{-1}$ |
| **Other variables** | | |
| **Backyard systems** | | |
| **AF1kg, AM1kg** | Live weight of female and male reproductive animals at the start of the laying period | kg·head$^{-1}$ |
| **AFkg, AMkg** | Average live weight of adult females and males, respectively | kg·head$^{-1}$ |
| **MMSkg** | Live weight of male surplus animals at slaughter | kg·head$^{-1}$ |
| **EGGconsAF** | Number of eggs used for human consumption by reproductive hen | egg·head$^{-1}$·year$^{-1}$ |
| **Layers** | | |
| **AF1kg, AM1kg** | Live weight of female and male reproductive animals at the start of the laying period | kg·head$^{-1}$ |
| **AF2kg, AM2kg** | Live weight of female and male reproductive animals at the end of the laying period | kg·head$^{-1}$ |
| **AFkg, AMkg** | Average live weight of adult females and males, respectively | kg·head$^{-1}$ |
| **MF11kg, MF22kg** | Average live weight of laying hens during their growing and laying period, respectively | kg·head$^{-1}$ |
| **MMkg** | Average live weight of surplus male animals | kg·head$^{-1}$ |
| **Broilers** | | |
| **AM1kg, AM2kg** | Live weight of male reproductive at the start and the end of the reproductive period | kg·head$^{-1}$ |

## 2.4.2 – Herd equations – Backyard chickens

### 2.4.2.1 – Reproductive female section

| | | |
|---|---|---|
| AF | = | NCHK / 100 |

Unit: *heads·year⁻¹*

| | | |
|---|---|---|
| RRF | = | 365 / (AFS – AFC)[d] |

Unit: *year*

| | | |
|---|---|---|
| AFin | = | AF * RRF |
| AFx | = | AF * (DR2 / 100) |
| AFexit | = | AF * RRF – AFx |

Unit: *heads·year⁻¹*

| | | |
|---|---|---|
| EGGSrepro | = | CYCLE * CLTSIZE |

Unit: *eggs·year⁻¹*

| | | | |
|---|---|---|---|
| IF | EGGSrepro | > | EGGSyear |
| | EGGSrepro | = | EGGSyear |

| | | |
|---|---|---|
| EGGconsAF | = | EGGSyear – EGGSrepro |

Unit: *eggs·year⁻¹*

| | | |
|---|---|---|
| Cin | = | (AF * (1 – (DR2 / 100)) * EGGSrepro) * HATCH |
| RFin | = | ((AF * RRF) / FRRF) / (1 – (DR1 / 100)) |
| RFexit | = | ((AF * RRF) / FRRF) – AFin |
| RFx | = | RFin – (AFin + RFexit) |
| RF | = | (RFin + AFin) / 2 * (AFC / 365) |
| MF1in | = | Cin / 2 – RFin |

Unit: *heads·year⁻¹*

### 2.4.2.2 – Reproductive male section

| | | |
|---|---|---|
| AM | = | AF * MFR |

Unit: *heads·year⁻¹*

| | | |
|---|---|---|
| RRM | = | RRF |

Unit: *year*

| | | |
|---|---|---|
| AMx | = | AM * (DR2 / 100) |
| AMexit | = | AM * RRM – AMx |
| AMin | = | AM * RRM |
| RMin | = | AMin / (1 – (DR1 / 100)) |
| RMx | = | RMin – AMin |
| RM | = | (RMin + AMin) / 2 * (AFC / 365) |
| MMin | = | Cin / 2 – RMin |

Unit: *heads·year⁻¹*

---

[d] The replacement rate is defined as the inverse of the productive lifespan expressed in years. The productive lifespan is the period that goes from the age at which animals are reproductive (AFC) to the age at which they are slaughtered (AFS). It is assumed that replacement rate for roosters (RRM) is the same as for hens (RRF).

### 2.4.2.3 – Male fattening section

MMexit = MMin * (1 – (DR1 / 100))
MMx = MMin – MMexit
MM = ((MMin + MMexit) / 2) * (AFC / 365)
Unit: *heads·year*$^{-1}$

### 2.4.2.4 – Female fattening and egg production section

**Growing period**

MF1x = MF1in * (DR1 / 100)
MF1exit = (MF1in – MF1x) * (1 – FRRF)
MF2in = (MF1in – MF1x) * FRRF
MF1 = ((MF1in + MF2in) / 2) * (AFC / 365)
Unit: *heads·year*$^{-1}$

**Laying period**

MF2exit = MF2in * $(1 – (DR2 / 100))^{(AFS – AFC) / 365}$
MF2x = MF2in – MF2exit
MF2 = ((MF2in + MF2exit) / 2) * ((AFS – AFC) / 365)
Unit: *heads·year*$^{-1}$

EGGconsMF = EGGSyear
Unit: *eggs·year*$^{-1}$

### 2.4.2.5 – Average characteristics

AF1kg = M2Skg * (AF2kg / ((AF2kg + AM2kg) / 2))
AM1kg = M2Skg * (AM2kg / ((AF2kg + AM2kg) / 2))
MF1Skg = AF1kg
MF2Skg = AF2kg
MMSkg = M2Skg * (AM2kg / ((AF2kg + AM2kg) / 2))
RFkg = (AF1kg – Ckg) / 2 + Ckg
RMkg = (AM1kg – Ckg) / 2 + Ckg
AFkg = (AF2kg – AF1kg) / 2 + AF1kg
AMkg = (AM2kg – AM1kg) /2 + AM1kg
MF1kg = RFkg
MF2kg = AFkg
MMkg = (MMSkg – Ckg) / 2 + Ckg
Unit: *kg·head*$^{-1}$

DWGF1 = (AF1kg – Ckg) / AFC
DWGF2 = (AF2kg – AF1kg) / (AFS – AFC)
DWGM1 = (AM1kg – Ckg) / AFC
DWGM2 = (AM2kg – AM1kg) / (AFS – AFC)
Unit: *kg·head*$^{-1}$*·day*$^{-1}$

## 2.4.3 – Herd equations – Layers

### 2.4.3.1 – Lay time

IF molting is not done

LAYtime = LAY1weeks / 52

IF molting is done

LAYtime = (LAY1weeks + LAY2weeks + MOLTweeks) / 52

Unit: *year*

### 2.4.3.2 – Reproductive female section

AF = NCHK / 100

AFin = AF / LAY1time

AFx = AF * ((52 * DRL2 / LAY1weeks) / 100)

AFexit = AF / LAYtime – AFx

Cin = AF * (1 – (DRL2 / 100)) * EGGSyear * HATCH

RFin = ((AF / LAYtime) / FRRF) / (1 – (DR1 / 100))

RFexit = ((AF / LAYtime) / FRRF) – AFin

RFx = RFin – (AFin + RFexit)

RF = (RFin + AFin) / 2 * (AFC / 365)

MF1in = Cin / 2 – RFin

Unit: *heads·year*$^{-1}$

### 2.4.3.3 – Male reproduction section

AM = AF * MFR

AMx = AM * ((52 * DRL2 / LAY1weeks) / 100)

AMexit = AM / LAYtime – AMx

AMin = AM / LAYtime

RMin = AMin / (1 – (DR1 / 100))

RMx = RMin – AMin

RM = (RMin + AMin) / 2 * (AFC / 365)

MMin = Cin / 2 – RMin

Unit: *heads·year*$^{-1}$

### 2.4.3.4 – Laying section

**Growing period**

MF2in = MF1in * (1 – (DR1 / 100))

MF1x = MF1in – MF2in

MF1 = ((MF1in + MF2in) / 2) * (AFC / 365)

Unit: *heads·year*$^{-1}$

**Laying period**

MF2exit = MF2in * (1 – (DRL2 / 100))

MF2x = MF2in – MF2exit

MF2 = ((MF2in + MF2exit) / 2) * (LAY1weeks / 52)

IF molting is not done

MF4exit = MF2exit

MF3 = 0

MF4 = 0

Unit: *heads·year*$^{-1}$

IF molting is done

MF3exit[e] = MF2exit * (1 – (DRM / 100))

---

[e] If molting is done, the only variable accounting for the number of adult laying females sold for meat production is MF4exit. In these cases, MF2exit and MF3exit represent the number of laying females moving, in one year, from cohort MF2 to MF3 and from cohort M3 to MF4, respectively.

| | | |
|---|---|---|
| MF3x | = | MF2exit – MF3exit |
| MF3 | = | ((MF2exit + MF3exit) / 2) * (MOLTweeks / 52) |
| MF4exit | = | MF3exit * (1 – (DRL2 / 100)) |
| MF4x | = | MF3exit – MF4exit |
| MF4 | = | ((MF3exit + MF4exit) / 2)) * (LAY2weeks / 52) |

Unit: *heads·year*$^{-1}$

### 2.4.3.5 – Male meat production section

| | | |
|---|---|---|
| IF | | Country is OECD |
| MMexit | = | 0 |
| MMx | = | 0 |
| MM | = | 0 |

Unit: *heads·year*$^{-1}$

| | | |
|---|---|---|
| IF | | Country is not OECD |
| MMexit | = | MMin * (1 – (DR1 / 100)) |
| MMx | = | MMin – MMexit |
| MM | = | ((MMin + MMexit) / 2) * (AFC / 52) |

Unit: *heads·year*$^{-1}$

### 2.4.3.6 – Average weight and growth rates

| | | |
|---|---|---|
| AF1kg | = | MF1kg |
| AF2kg | = | MF2kg |
| AM1kg | = | 1.3 * MF1kg |
| AM2kg | = | 1.3 * MF2kg |
| MM1kg | = | 1.3 * MF1kg |
| MF11kg | = | (MF1kg – Ckg) / 2 + Ckg |
| RFkg | = | MF11kg |
| MF22kg | = | (MF2kg – MF1kg) / 2 + MF1kg |
| AFkg | = | MF22kg |
| AMkg | = | (AM2kg – AM1kg) / 2 + AM1kg |
| RMkg | = | (AM1kg – Ckg) / 2 + Ckg |
| MMkg | = | (MM1kg – Ckg) / 2 + Ckg |

Unit: *kg·head*$^{-1}$

| | | |
|---|---|---|
| DWGF1 | = | (MF1kg – Ckg) / (365 * AFC) |
| DWGF2 | = | (MF2kg – MF1kg) / (7 * LAY1weeks) |
| DWGF3 | = | 0 |
| DWGF4 | = | 0 |
| DWGM1 | = | (AM1kg – Ckg) / (365 * AFC) |
| DWGM2 | = | (AM2kg – AM1kg) / (365 * (LAY1weeks / 52)) |

Unit: *kg·head*$^{-1}$*·day*$^{-1}$

## 2.4.4 – Herd equations – Broilers

### 2.4.4.1 – Reproductive female section

| | | |
|---|---|---|
| AF | = | NCHK / 100 |
| AFin | = | AF / (LAYweeks / 52) |
| AFx | = | AF * (((52 * DRL2 / LAYweeks)) / 100) |
| AFexit | = | AF * RRF – AFx |
| Cin | = | AF * (1 – (DRL2 / 100)) * EGGSyear * HATCH |
| RFin | = | ((AF / (LAYweeks / 52)) / FRRF) / (1 – (DR1 / 100)) |
| RFexit | = | ((AF / (LAYweeks / 52)) / FRRF) – AFin |
| RFx | = | RFin – (AFin + RFexit) |
| RF | = | ((RFin + AFin) / 2) * (AFC / 365) |
| MFin | = | Cin / 2 – RFin |

Unit: *heads·year*$^{-1}$

### 2.4.4.2 – Male reproduction section

| | | |
|---|---|---|
| AM | = | AF * MFR |
| AMx | = | AM * ((52 * DRL2 / LAYweeks) / 100) |
| AMexit | = | AM / (LAYweeks / 52) – AMx |
| AMin | = | AM / (LAYweeks / 52) |
| RMin | = | AMin / (1 – (DR1 / 100)) |
| RMx | = | RMin – AMin |
| RM | = | ((RMin + AMin) / 2) * (AFC / 365) |
| MMin | = | Cin / 2 – RMin |

Unit: *heads·year*$^{-1}$

### 2.4.4.3 – Broilers section

| | | |
|---|---|---|
| M2in | = | MFin + MMin |
| M2exit | = | M2in * (1 – (DRB2 / 100)) |
| M2x | = | M2in – M2exit |
| M2 | = | ((M2in + M2exit) / 2) * (A2S + (BIDLE / 365)) |

Unit: *heads·year*$^{-1}$

### 2.4.4.4 – Average weight and growth rates

| | | |
|---|---|---|
| AFkg | = | (AF2kg + AF1kg) / 2 |
| RFkg | = | (AF1kg – Ckg) / 2 + Ckg |
| AM1kg | = | 1.3 * AF1kg |
| AM2kg | = | 1.3 * AF2kg |
| AMkg | = | 1.3 * AFkg |
| RMkg | = | (AM1kg – Ckg) / 2 + Ckg |
| M2kg | = | (M2Skg – Ckg) / 2 + Ckg |

Unit: *kg·head*$^{-1}$

| | | |
|---|---|---|
| DWGF0 | = | (AF1kg – Ckg) / (365 * AFC) |
| DWGM0 | = | (AM1kg – Ckg) / (365 * AFC) |

Unit: *kg·head*$^{-1}$*·day*$^{-1}$

| | | |
|---|---|---|
| DWG2B | = | (M2Skg - Ckg) / (365 * A2S) |

Unit: kg·*head*$^{-1}$*·day*$^{-1}$

# CHAPTER 3 – FEED RATION AND INTAKE MODULE

Animal diets are one of the most important aspects of livestock production. They largely determine animal productivity, land use and emissions from enteric fermentation, manure and feed production. Feed intake (kg of dry matter per animal) depends on the energy requirement of animals. Feed intake is calculated for each species and cohort based on the feed ration, its nutritional value and energy requirement of animals.

The functions of the 'Feed ration and intake' module are to:

- Define the **composition** of the ration for each species and production system;
- Calculate the **nutritional values** of the ration per kilogram of dry matter, and;
- Calculate the average **energy requirement** and the related **feed intake** of each animal.

The schematic representation of this chapter is composed of different figures, for ruminants refer to Figures 3.1 to 3.3 for the composition of the ration and Figure 3.6 for the energy requirement and feed intake calculation; and for the monogastrics Figures 3.4 to 3.5 and Figure 3.7 respectively.

## 3.1 – CROP YIELDS AND PASTURE PRODUCTIVITY

Crops are used as animal feed in three main forms: 1) as the main crop (e.g. grains or whole crops such as grass or silage); 2) as crop residues (such as straw) or 3) as agro-industrial by-products (e.g. brans and cakes). Data on fresh matter yields per hectare of main crops and their respective land area were taken from a modified version of Global Agro-Ecological Zones (GAEZ 3.0) and Haberl *et al.* (2007) to estimate the above-ground net primary productivity for pasture. These data are used for two main purposes: 1) estimating the local availability of feed for livestock (see Sections 3.2 and 3.3) and 2) allocating the emissions associated with feed production between the crop and the crop co-products (crop residues and by-products) according to the kind of feed materials used by the animals (see Chapter 6, Section 6.5).

To this scope, a first step is the conversion of the fresh matter of each crop to dry matter, to allow for comparability between different materials in terms of mass and emission intensity. To do so, default dry matter (DM) contents for each crop are used from existing database, literature review and expert opinion, following Equation 3.1:

**Equation 3.1 (Crops)**

$$DMYG_{crop} = FMYG_{crop} * DM_{crop} / 100$$

Where:

$DMYG_{crop}$ = gross dry matter yield of each crop, kg $DM \cdot ha^{-1}$

$FMYG_{crop}$ = fresh matter yield of each crop, kg $DM \cdot ha^{-1}$. Input spatial grids from Haberl et al. (2007) or modified from GAEZ 3.0.

$DM_{crop}$ = dry matter content of each crop, percentage. Values are given in Table 3.1 (Supplement S1).

In those cases where the crop residues are needed, either as feed material or for allocation purposes, the yield is calculated, in a second step, using the IPCC formulae (IPCC 2006, Chapter 11, Table 11.2), as shown in Equation 3.2:

**Equation 3.2 (Crop residues)**

$$DMYG_{cr} = DMYG_{crop} * Slope_{-crop} + Intercept_{-crop}$$

Where:

$DMYG_{cr}$ = gross dry matter yield of the crop residues of each crop, kg $DM \cdot ha^{-1}$

$DMYG_{crop}$ = gross dry matter yield of each crop, kg $DM \cdot ha^{-1}$

$Slope_{-crop}$ = slope from IPCC equation for each crop. Values are given in Table 3.1 (Supplement S1).

$Intercept_{-crop}$ = intercept from IPCC equation for each crop. Values are given in Table 3.1 (Supplement S1).

## 3.2 –RUMINANTS' FEED RATIONS

Typically, for ruminant species, the 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 the crop.

- Agro-industrial by-products and wastes: by-products from the processing of crops such as oilseeds, cereals, sugarcane, and fruit. Examples include cottonseed cakes, rapeseed cakes and brans.

- Concentrates: Any feed containing relatively low fibre (< 20%) and high total digestible nutrients (> 60%). These are feed materials used with other components, to improve the nutritive balance of the complete feed, and intended to be further diluted and mixed to produce a supplement or a complete feed[f].

The feed ingredients above are grouped in four broad categories of feed are considered: roughages, cereals, by-products and concentrates. The complete list of feed materials considered in GLEAM is shown in Table 3.2.

In all livestock production systems, the feed materials, present in the ration, depend on the presence 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. The balance of forage, crops and by-products must be reasonable in order to match animal performance. The proportion of each feed material is determined differently for industrialized and developing regions, for 2 main reasons. First, while in the industrialized countries, on the basis of literature review and expert consultation, it was possible to completely define the feed ration composition, in terms of the proportions of each feed material, this was not the case for the rest of the world. Second, we assume that the feed ration composition, at least the forage part, is strictly related to what is available on the ground. For further details see Sections 3.2.2 and 3.2.3.

For ruminant species, three feeding groups of animals are defined due to their distinctive feeding necessities: adult females (AF), replacement animals and adult males (AM, RF, RM) and surplus males and female animals (MF, MM). A specific group is also defined for animals raised in feedlot (Table 3.3).

To help the reader in understanding the GLEAM methodology for estimating the feed ration composition, a schematic representation with hypothetical figures has been drawn for ruminant species in Figures 3.1 to 3.3.

Moreover, Tables 3.7 to 3.13 (Supplement S1) present average composition of feed rations for ruminant species at regional level.

[f] A complete feed is a nutritionally adequate feed for animals, compounded by a specific formula to be fed as the sole ration and capable of maintaining life and/or promoting production without any additional substance being consumed except water.

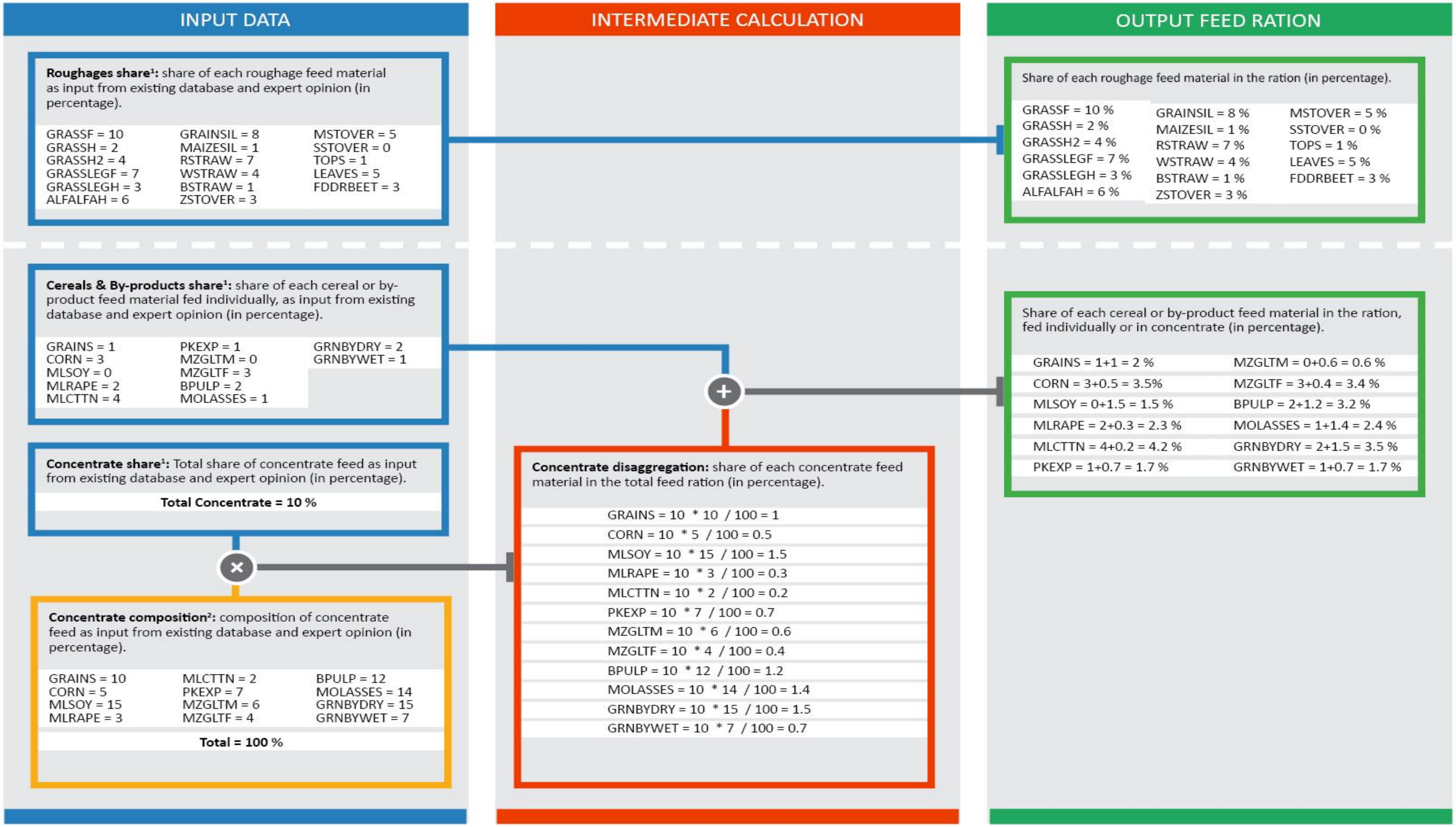
**TABLE 3.2.** List of feed materials for ruminant species

| Number | Material | Description |
|---|---|---|
| **Roughages** | | |
| **1** | GRASSF | Any type of natural or cultivated fresh grass grazed or fed to the animals. |
| **2** | GRASSH | Hay (grass is cut, dried and stored) or silage (grass is cut and fermented) from any natural or cultivated grass. |
| **3** | GRASSH2 | Hay from adjacent areas. |
| **4** | GRASSLEGF | Fresh mixture of any type of grass and leguminous plants that is fed to the animals. |
| **5** | GRASSLEGH | Hay or silage produced from a mixture of any type of grass and leguminous plants. |
| **6** | ALFALFAH | Hay or silage from alfalfa (*Medicago sativa*) |
| **7** | GRAINSIL | Silage from whole barley (*Hordeum vulgare*), oat (*Avena sativa*), buckwheat (*Fagopyrum esculentum*) and fonio (*Digitaria spp.*) plants. |
| **8** | MAIZESIL | Silage from whole maize (*Zea mays*) plants. |
| **9** | RSTRAW | Fibrous residual plant material such as straw, brans, leaves, etc. from rice (*Oryza spp.*) cultivation. |
| **10** | WSTRAW | Fibrous residual plant material such as straw, brans, leaves, etc. from wheat (*Triticum spp*.) cultivation. |
| **11** | BSTRAW | Fibrous residual plant material such as straw, brans, leaves, etc. from barley (*Hordeum vulgare*), rye (*Secale cereale*) or oat (*Avena sativa*) cultivation. |
| **12** | ZSTOVER | Fibrous residual plant material such as straw, brans, leaves, etc. from maize (*Zea mays*) cultivation. |
| **13** | MSTOVER | Fibrous residual plant material such as straw, brans, leaves, etc. from millet (*Pennisetum glaucum, Eleusine coracana, Panicum miliaceum, etc*) cultivation. |
| **14** | SSTOVER | Fibrous residual plant material such as straw, brans, leaves, etc. from sorghum (*Sorghum spp.*) cultivation. |
| **15** | TOPS | Top portion of sugarcane (*Saccharum spp.*) plants, consisting of green leaves, bundle sheath and variable proportions of immature cane. |
| **16** | LEAVES | Leaves from natural, uncultivated vegetation found in trees, forest, lanes etc. |
| **17** | FDDRBEET | Fodder beet (*Beta vulgaris*), also known as mangel beet or field beet, used as animal feed. |
| **Cereals** | | |
| **18** | GRAINS | Grains from barley (*Hordeum vulgare*), oat (*Avena sativa*), buckwheat (*Fagopyrum esculentum*) and fonio (*Digitaria spp.*). |
| **19** | CORN | Grains from maize (*Zea* mays) plant. |
| **By-products** | | |
| **20** | MLSOY | By-product from soy (*Glycine max*) oil production, commonly referred to as 'soy cakes' or 'soybean meal'. |
| **21** | MLRAPE | By-product from rape (*Brassica napus*) oil production, commonly referred to as 'rape cakes' or 'rapeseed meal'. |
| **22** | MLCTTN | By-product from cottonseed (*Gossypium spp.*) oil production, commonly referred to as 'cottonseed meal'. |
| **23** | PKEXP | By-products from the production of kernel palm oil (*Elaeis guineensis*), commonly referred to as 'kernel cake'. |
| **24** | MZGLTM | By-product from maize processing. It is a protein-rich feed, with about 65% crude protein content. |
| **25** | MZGLTF | By-product from maize processing. Unlike the gluten meal, its protein content is lower, of about 25% crude protein content. |
| **26** | BPULP | Also known as 'beet pulp', is the remaining material after the juice extraction for sugar production from the sugar beet (*Beta vulgaris*). |
| **27** | MOLASSES | By-product from the sugarcane sugar extraction. |
| **28** | GRNBYDRY | 'Dry' by-products of grain industries such as brans, middlings, etc. |
| **29** | GRNBYWET | 'Wet' by-products of grain industries such as biofuels, distilleries, breweries, etc. |
| **Concentrates** | | |
| **30** | CONC | Concentrate feed from feed mills. |

**TABLE 3.3.** Feeding groups for ruminant species

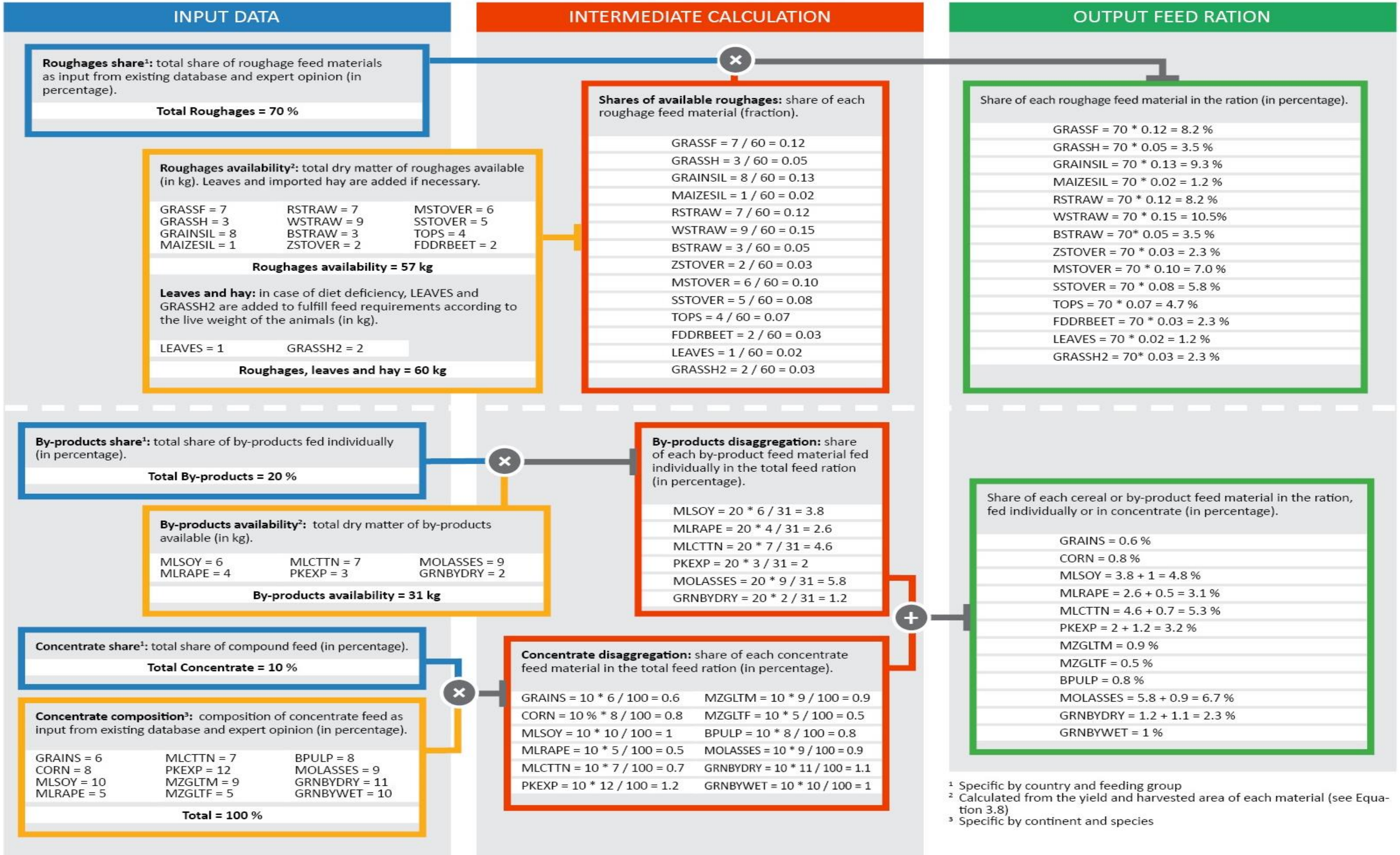
| Animal category | GLEAM cohorts |
|---|---|
| **Cattle and Buffaloes** | |
| Group 1 | AF |
| Group 2 | AM, RF, RM |
| Group 3 | MF, MM |
| Group f | MFf, MMf (applies to feedlot animals only) |
| **Small ruminants** | |
| Group 1 | AF |
| Group 2 | AM, RF, RM |
| Group 3 | MF, MM |

***Figure 3.1*** *Representation of a hypothetical example of feed ration estimation for ruminant species in industrialized countries*



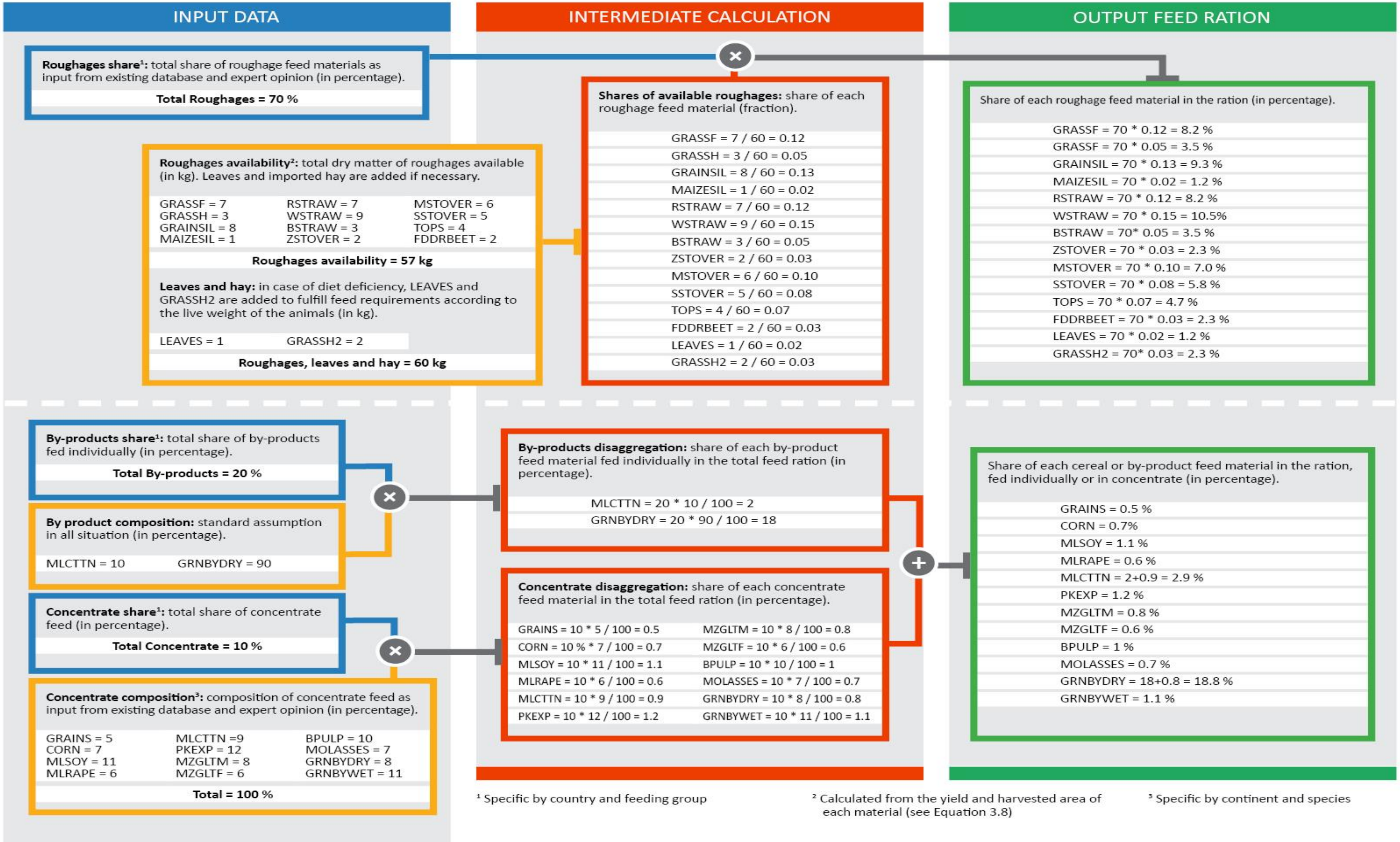

¹ Specific by country and feeding group
² Specific by continent and species

***Figure 3.2*** *Representation of a hypothetical example of feed ration estimation for cattle in developing countries*




¹ Specific by country and feeding group
² Calculated from the yield and harvested area of each material (see Equation 3.8)
³ Specific by continent and species

***Figure 3.3** Representation of a hypothetical example of feed ration estimation for buffaloes and small ruminants in developing countries*



### *3.2.1 – Calculation of the net dry matter yields*

The net dry matter yield of each feed material in a given area defines the yield that is available as feed for the animals. For the purpose of estimating the animal ration it is used as a main input in those cases where the calculation of the local availability of feed is required, that is in the developing regions and, therefore, it is calculated only for the roughages and by-products (see Section 3.2.2).

In general, the gross dry matter yield (of the crop or crop residues, depending on the feed material; Equation 3.2) is corrected by the Feed Use Efficiency (FUE), which is the fraction of the yield that is effectively ingested and used as feed by the animals. For silages produced by cereals, it is assumed that the total above-ground biomass production is used, so both the crop and crop residues yields must be considered. Moreover, for some feed materials, the yield of the respective parental crop is also multiplied by the Mass Fraction Allocation (MFA) factor of the material. The latter is a default factor accounting for the feed material mass as a fraction of the total mass of the crop.

Calculation are shown in Equation 3.3. Table 3.4 summarizes the specific equation and input used for each feed material for the calculation of the net dry matter yield.

**Equation 3.3**

| | | |
|---|---|---|
| $DMYN_i$ | = | $DMYG_i * FUE_i * MFA_i$<br>for i = 1, 7 to 15, 17, 20 to 23, 27, 28 |

Where:

| | | |
|---|---|---|
| $DMYN_i$ | = | net dry matter yield of feed material *i*, kg $DM \cdot ha^{-1}$ |
| $DMYG_i$ | = | crop gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$. It can either be the yield of the crop, crop residues or, for feed materials 7 and 8, the sum of both. See table 3.4 |
| $FUE_i$ | = | feed use efficiency for feed material *i*, i.e. fraction of the gross yield that is effectively used as feed, fraction |
| $MFA_i$ | = | mass fraction allocation of feed material *i*, i.e. feed material mass as a fraction of the total mass of the crop, fraction. Values are given in Table 3. 4. It is not used for feed materials 9 to 15. |

TABLE 3.4. Net yield equations, gross yields, FUE and MFA for each feed material for ruminant species

| Number | Material | Gross dry matter yields | Net yield equation | FUE | MFA |
|---|---|---|---|---|---|
| **Roughages** | | | | | |
| **1** | GRASSF | Grass | Equation 3.3 | Table 3.5 (Supplement S1)[a] | 1 |
| **2** | GRASSH | Grass | Same as GRASSF | Table 3.5 (Supplement S1)[a] | 1 |
| **3** | GRASSH2 | Grass | Same as GRASSF | Table 3.5 (Supplement S1)[a] | 1 |
| **4** | GRASSLEGF | Grass | Same as GRASSF | Table 3.5 (Supplement S1)[a] | 1 |
| **5** | GRASSLEGH | Grass | Same as GRASSF | Table 3.5 (Supplement S1)[a] | 1 |
| **6** | ALFALFAH | Grass | Same as GRASSF | Table 3.5 (Supplement S1)[a] | 1 |
| **7** | GRAINSIL | Barley and other cereals[b] (crop + crop residues) | Equation 3.3 | 1 | 1 |
| **8** | MAIZESIL | Maize (crop + crop residues) | Equation 3.3 | 1 | 1 |
| **9** | RSTRAW | Rice (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **10** | WSTRAW | Wheat (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **11** | BSTRAW | Barley (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **12** | ZSTOVER | Maize (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **13** | MSTOVER | Millet (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **14** | SSTOVER | Sorghum (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **15** | TOPS | Sugarcane (crop residues) – Equation 3.2 | Equation 3.3 | Table 3.5 (Supplement S1)[a] | Equation 6.10a[c] |
| **16** | LEAVES | NA | NA | 1 | 1 |
| **17** | FDDRBEET | Sugar beet | Equation 3.3 | 1 | 1 |
| **Cereals** | | | | | |
| **18** | GRAINS | Barley and other cereals[b] | NA | 1 | 1 |
| **19** | CORN | Maize | NA | 1 | 1 |
| **By-products** | | | | | |
| **20** | MLSOY | Soybean[c] | Equation 3.3 | 1 | 0.80 |
| **21** | MLRAPE | Rapeseed | Equation 3.3 | 1 | 0.58 |
| **22** | MLCTTN | Cotton | Equation 3.3 | 1 | 0.45 |
| **23** | PKEXP | Oil palm fruit[c] | Equation 3.3 | 1 | 0.03 |
| **24** | MZGLTM | Maize | NA | 1 | 0.05 |
| **25** | MZGLTF | Maize | NA | 1 | 0.21 |
| **26** | BPULP | Sugar beet | NA | 1 | 0.19 |
| **27** | MOLASSES | Sugarcane | Equation 3.3 | 1 | 0.13 |
| **28** | GRNBYDRY | Grains average yield[d] | Equation 3.3 | 1 | 0.17 |
| **29** | GRNBYWET | Barley | NA | 1 | 1 |

[a] For these feed materials the FUE is spatially explicit.
[b] Average yield weighed by the hectares of harvested area of barley and other cereals, excluding wheat, maize, millet, sorghum and rice.
[c] For these feed materials, the MFA is only used for the allocation of the emissions from feed production (see Chapter 6, Section 6.5) and is calculated with a specific equation.
[c] To account for the high level of international trade of these feed materials, average country specific yields were calculated as follows: the average national yield was used for net exporters; for all other countries, a global mean of the yields of all net exporters, weighted by the net export, was calculated and, in a second step, an average between this global yield and each national yield was calculated, weighted by the amount of imported and locally produced product in each country.
[d] Average yield weighed by the hectares of harvested area of wheat, maize, barley, millet, sorghum, rice and other cereals.

## *3.2.2 – Feed rations in industrialized countries*

The feed ration in industrialized countries are taken from country national inventory reports, literature and targeted surveys. The share of each individual feed material is calculated using Equation 3.4.

**Equation 3.4**

$$FEED_{i,fg,T} = FEEDIND_{i,fg,T} \quad \text{for } i = 1 \text{ to } 17$$

$$FEED_{i,fg,T} = FEEDIND_{i,fg,T} + CONC_{fg,T} * CF_{i,T} \quad \text{for } i = 18 \text{ to } 29$$

Where:

| | | |
|---|---|---|
| $FEED_{i,fg,T}$ | = | fraction of feed material *i* in the ration for feeding group *fg*, species and system *T*, fraction |
| $FEEDIND_{i,fg,T}$ | = | share of a feed material *i* fed as a separate product in the ration of feeding group *fg* of species and system *T*, fraction |
| $CONC_{fg,T}$ | = | fraction of concentrates in the diet for the feeding group *fg*, species and system *T*, fraction |
| $CF_{i,T}$ | = | fraction of feed material *i* in the composition of concentrate feed for species and system *T*, fraction |

## *3.2.3– Feed rations in developing countries*

The ration in developing countries is based on the proportion of by-products and concentrates in the ration, which are defined through surveys, literature and expert knowledge, and the availability of roughages in a given cell.

### *3.2.3.1 – Proportion and availability of roughages*

First, the total proportion of roughages in the diet for all ruminant species in a given area (Equation 3.5) is calculated based on the average 'by-products' and 'concentrate' fractions (Equations 3.6 and 3.7, respectively).

**Equation 3.5**

$$RFRAC_{avg,T} = 1 - (BY_{avg,T} + CONC_{avg,T})$$

Where:

| | | |
|---|---|---|
| $RFRAC_{avg,T}$ | = | weighted average fraction of roughages in the diet for ruminant species *T*, fraction |
| $BY_{avg,T}$ | = | weighted average fraction of by-products in the diet for species *T*, fraction. $BY_{avg}$ is calculated in Equation 3.6. |
| $CONC_{avg,T}$ | = | weighted average fraction of concentrates in the diet for species *T*, fraction. $CONC_{avg}$ is calculated in Equation 3.7. |

**Equation 3.6**

$$\begin{aligned} BY_{avg,T} = {} & (BY_{1,T} * (AF_T * AFkg_T) \\ & + BY_{2,T} * (RF_T * RFkg_T + RM_T * RMkg_T + AM_T * AMkg_T) \\ & + BY_{3,T} * (MF_T * MFkg_T + MM_T * MMkg_T)) \\ & / (AF_T * AFkg_T + RF_T * RFkg_T + MF_T * MFkg_T + AM_T * AMkg_T + RM_T * RMkg_T + MM_T * MMkg_T) \end{aligned}$$

Where:

| | | |
|---|---|---|
| $BY_{avg,T}$ | = | weighted average fraction of by-products in the diet for species *T*, fraction |
| $BY_{1,T}$ | = | fraction of by-products in the diet for the feeding group *1,* species and system *T*, fraction |
| $BY_{2,T}$ | = | fraction of by-products in the diet for the feeding group *2,*species and system *T*, fraction |
| $BY_{3,T}$ | = | fraction of by-products in the diet for the feeding group *3,*species and system *T*, fraction |
| $AF_T$, $RF_T$,… | = | animal numbers from the different cohorts as calculated in the herd module for species and system *T*, heads·year$^{-1}$ |
| $AFkg_T$, $RFkg_T$,… | = | average live weights for animals within each cohort as calculated in the herd module for species and system *T*, kg·head$^{-1}$ |

The fraction of by-products for each feeding group ($BY_1$, $BY_2$ and $BY_3$) are defined for each species and system based on literature reviews, expert opinion and surveys.

**Equation 3.7**

$$\begin{aligned} CONC_{avg,T} = {} & (CONC_{1,T} * (AF_T * AFkg_T) \\ & + CONC_{2,T} * (RF_T * RFkg_T + RM_T * RMkg_T + AM_T * AMkg_T) \\ & + CONC_{3,T} * (MF_T * MFkg_T + MM_T * MMkg_T)) \\ & / (AF_T * AFkg_T + RF_T * RFkg_T + MF_T * MFkg_T + AM_T * AMkg_T + RM_T * RMkg_T + MM_T * MMkg_T) \end{aligned}$$

Where:

| | | |
|---|---|---|
| $CONC_{avg,T}$ | = | weighted average fraction of concentrates in the diet for ruminant species *T*, fraction |
| $CONC_{1,T}$ | = | fraction of concentrates in the diet for the feeding group *1,* species and system *T*, fraction |

$CONC_{2,T}$ = fraction of concentrates in the diet for the feeding group *2,* species and system *T*, fraction
$CONC_{3,T}$ = fraction of concentrates in the diet for the feeding group *3,* species and system *T*, fraction
$AF_T$, $RF_T$, … = animal numbers from the different cohorts as calculated in the herd module for species and system *T*, heads·year$^{-1}$
$AFkg_T$, $RFkg_T$, … = average live weights for animals within each cohort as calculated in the herd module for species and system *T*, kg·head$^{-1}$

The fraction of concentrate for each feeding group ($CONC_1$, $CONC_2$ and $CONC_3$) is defined for each species and system based on literature reviews, expert opinion and surveys.

Once the total proportion of roughages in the diet for a given cell is calculated, GLEAM estimates the total available dry matter of roughages from the total dry matter yields and harvested areas of pasture, fodder and crop residues (Equation 3.8).

**Equation 3.8**

$$RFEEDKG = \sum_i (DMYN_i * Area_i)$$
for i = 1, 7 to 15, 17

Where:
RFEEDKG = total dry matter of roughages available per cell, kg
$DMYN_i$ = net dry matter yield of feed material *i*, kg·ha$^{-1}$
$Area_i$ = harvested area of feed material *i*, ha
i = feed material *i* from Table 3.2

In a following step, the available amount of roughages per cell is compared with the animal requirements in that same cell, in order to add leaves and hay in case of feed deficiency. Following IPCC guidelines, GLEAM assumes that daily feed intake, expressed in terms of dry matter, must be between 2 and 3% of live weight. Two conditions are defined based on this criterion and the fraction of roughages in the diet calculated in Equation 3.4: sufficient (when roughages are sufficient to sustain a ratio of daily feed intake to bodyweight equal or higher than 2%) and deficiency conditions (when roughages are only sufficient to sustain a ratio of daily feed intake to bodyweight below 2%).

**Sufficiency conditions**

$$RFEEDKG / LWTOT \geq (0.02 * 365) * RFRAC_{avg,T}$$

**Deficiency conditions**

$$RFEEDKG / LWTOT < (0.02 * 365) * RFRAC_{avg,T}$$

Where:
RFEEDKG = total dry matter of roughages available per cell, kg
LWTOT = total live weight of ruminant species, kg. Calculated in Equation 3.9.
$RFRAC_{avg,T}$ = weighted average fraction of roughages in the diet for ruminant species *T*, fraction
0.02 = daily intake as fraction of body weight.

**Equation 3.9**

$$LWTOT = \sum_T [\sum_c (N_{T,c} * LW_{T,c})]$$

Where:
LWTOT = total live weight of ruminant species, kg
$N_{T,c}$ = number of animals of species *T* and cohort *c*, heads
$LW_{T,c}$ = average live weights of animals of species *T* and cohort *c*, kg·heads$^{-1}$

In situations of deficiency, leaves and hay from adjacent areas are included in the ration in two subsequent steps (Equation 3.10). First, leaves are added to an equivalent of 0.3% of daily intake. Second, hay from adjacent areas is added until reaching the 2% bodyweight equivalent defined previously.

**Equation 3.10**

$LEAVES_T$ = $(0.003 * 365) * LWTOT$

IF $(RFEEDKG + LEAVES_T) / LWTOT > (0.02 * 365) * RFRAC_{avg,T}$

No extra material is needed and the ration is completed following step 5.

IF $(RFEEDKG + LEAVES_T) / LWTOT < (0.02 * 365) * RFRAC_{avg,T}$

Hay from adjacent areas is added as:

$GRASSH2_T$ = $LWTOT * ((0.02 * 365) * RFRAC_{avg,T} – ((RFEEDKG + LEAVES) / LWTOT))$

Where:

$LEAVES_T$ = total dry matter of 'leaves' available for species and system *T*, kg

$GRASSH2_T$ = total dry matter of 'hay from adjacent areas' available for species and system *T*, kg

The final amount of available roughages is calculated as:

**Equation 3.11**

$RFEEDKGFINAL_T$ = $RFEEDKG + LEAVES_T + GRASSH2_T$

Where:

$RFEEDKGFINAL_T$ = total dry matter of roughages available per cell for species and system *T*, kg

RFEEDKG = total dry matter available from roughages per cell, kg

$LEAVES_T$ = total dry matter of 'leaves' available for species and system *T*, kg

$GRASSH2_T$ = total dry matter of 'hay from adjacent areas' available for species and system *T*, kg

### *3.2.3.2 – Share of individual roughage feed materials*

The estimation of individual shares of roughages in animal diets is accomplished in two steps. The first one (Equations 3.12 to 3.14) calculates the share of each roughage material in the total dry matter of roughages available for each species. The second step (Equation 3.15) determines the share of each material in relation to the overall diet.

The share of grass and the distinction between fresh grass and hay is done as follows:

**Equation 3.12**

$GRASSfrac_T$ = $DMYN_1 * Area_1 / RFEEDKGFINAL_T$

Where:

$GRASSfrac_T$ = fraction of grass (both fresh and hay) in the total dry matter of roughages available per cell for species and system *T*, fraction

$DMYN_1$ = net dry matter yield of 'grass', $kg{\cdot}ha^{-1}$

$Area_1$ = grazed or harvested area of 'grass', ha

$RFEEDKGFINAL_T$ = total dry matter of roughages available per cell for species and system *T*, kg

The fraction of grass is then divided between fresh and hay depending on the agro-ecological zone and the grazing time of animals as shown in Table 3.6. The share of 'Pasture' manure management system is used as proxy for the grazing time.

**TABLE 3.6** Partitioning of grass fraction

| Agro-ecological zone | Partitioning of grass |
|---|---|
| **Arid and hyper-arid** | Fresh grass: $FEEDfrac_{1,T}$[a] = $GRASSfrac_T$<br>Grass hay: $FEEDfrac_{2,T}$[b] = 0 |
| **Temperate and tropical highlands** | Fresh grass: $FEEDfrac_{1,T} = GRASSfrac_T * MMS_{pasture,T} / 100$<br>Grass hay: $FEEDfrac_{2,T} = GRASSfrac_T * (100 – MMS_{pasture,T}) / 100$ |
| **Humid** | Fresh grass: $FEEDfrac_{1,T} = GRASSfrac_T$<br>Grass hay: $FEEDfrac_{2,T} = 0$ |

[a]$FEEDfrac_{1,T}$ = fraction of fresh grass in the total dry matter of roughages available per cell for species and system *T*, fraction

[b]$FEEDfrac_{2,T}$ = fraction of hay grass in the total dry matter of roughages available per cell for species and system *T*, fraction

The share of imported hay and leaves is calculated in Equation 3.13 below:

**Equation 3.13**

$FEEDfrac_{3,T}$ = $GRASSH2_T$ / $RFEEDKGFINAL_T$

$FEEDfrac_{16,T}$ = $LEAVES_T$ / $RFEEDKGFINAL_T$

Where:

$FEEDfrac_{3,T}$ = fraction of hay imported from adjacent areas in the total dry matter of roughages available per cell for species and system *T*, fraction

$FEEDfrac_{16,T}$ = fraction of leaves in the total dry matter of roughages available per cell for species and system *T*, fraction

$GRASSH2_T$ = total dry matter of 'hay from adjacent areas' available for species and system *T*, kg

$LEAVES_T$ = total dry matter of 'leaves' available for species and system *T*, kg

$RFEEDKGFINAL_T$ = total dry matter of roughages available per cell for species and system *T*, kg

For the rest of "Roughages", the fraction is calculated as shown in Equation 3.14.

**Equation 3.14**

$FEEDfrac_{i,T}$ = $DMYN_i$ * $Area_i$ / $RFEEDKGFINAL_T$
for i = 7 to 15, 17

Where:

$FEEDfrac_{i,T}$ = fraction of feed material *i* in the total dry matter of roughages available per cell for species and system *T*, fraction

$DMYN_i$ = net dry matter yield of feed material *i*, $kg{\cdot}ha^{-1}$

$Area_i$ = grazed and/or harvested area of feed material *i*, ha

$RFEEDKGFINAL_T$ = total dry matter of roughages available per cell for species and system *T*, kg

i = feed material *i* from Table 3.2

The final step is to estimate the individual shares of roughage materials in the overall animal diet for each feeding group following Equation 3.15.

**Equation 3.15**

$FEED_{i,fg,T}$ = $FEEDfrac_{i,T}$ * (1 – ($BY_{fg,T}$ + $CONC_{fg,T}$))
for i = 1 to 17

Where:

$FEED_{i,fg,T}$ = fraction of feed material *i* in the ration for feeding group *fg*, species and system *T*, fraction

$FEEDfrac_{i,T}$ = fraction of feed material *i* in the total dry matter of roughages available per cell for species and system *T*, fraction

$BY_{fg,T}$ = fraction of by-products in the diet for the feeding group *fg,* species and system *T*, fraction

$CONC_{fg,T}$ = fraction of concentrates in the diet for the feeding group *fg,* species and system *T*, fraction

i = feed material *i* from Table 3.2

### *3.2.3.3 – Share of individual by-product feed materials*

The estimation of individual share of by-products is done by combining the available yields of feed materials and the data on the share of 'by-products' feed category.

**Equation 3.16 – Cattle**

BYFEEDKG = $\sum_i(DMYN_i * Area_i)$
for i = 20, 21, 22, 23, 27, 28

$FEED_{BY,i,fg,T}$ = $BY_{fg,T}$ * $DMYN_i$ * $Area_i$ / BYFEEDKG
for i = 20, 21, 22, 23, 27, 28

Where:

| | | |
|---|---|---|
| BYFEEDKG | = | total dry matter of by-products available per cell, kg |
| $DMYN_i$ | = | net dry matter yield of 'by-product' feed material *i*, $kg \cdot ha^{-1}$ |
| $Area_i$ | = | harvested area of feed material *i*, ha |
| $FEED_{BY,i,fg,T}$ | = | fraction of 'by-product' feed material *i* for feeding group *fg*, species and system *T*, fraction |
| $BY_{fg,T}$ | = | fraction of 'by-products' in the diet for the feeding group *fg,* species and system *T*, fraction |
| i | = | feed material *i* from Table 3.2 |

**Equation 3.17 – Buffaloes and small ruminants**

$$FEED_{BY,22,fg,T} = BY_{fg,T} * 0.1$$

$$FEED_{BY,28,fg,T} = BY_{fg,T} * 0.9$$

Where:

| | | |
|---|---|---|
| $FEED_{BY,22,fg,T}$ | = | fraction 'cottonseed meal' for feeding group *fg*, species and system *T*, fraction |
| $FEED_{BY,28,fg,T}$ | = | fraction 'dry by-products of grain industries' for feeding group *fg*, species and system *T*, fraction |
| $BY_{fg,T}$ | = | fraction of by-products in the diet for the feeding group *fg,* species and system *T*, fraction |

### *3.2.3.4 – Share of individual concentrate feed materials*

Concentrate feed consists of a number of by-products that can be fed as a separate product and as part of a mixed compound feed. The final step, in the estimation of animal diets, is the distribution of that concentrate among individual feed materials.

**Equation 3.18**

$$FEED_{i,fg,T} = FEED_{i,fg,T}$$

for i = 1 to 17

$$FEED_{i,fg,T} = FEED_{BY,i,fg,T} + CONC_{fg,T} * CF_{i,T}$$

for i = 18 to 29

Where:

| | | |
|---|---|---|
| $FEED_{i,fg,T}$ | = | fraction of feed material *i* in the ration for feeding group *fg*, species and system *T*, fraction |
| $CONC_{fg,T}$ | = | fraction of concentrates in the diet for the feeding group *fg*, species and system *T*, fraction |
| $CF_{i,T}$ | = | fraction of feed material *i* in the composition of concentrate feed for species and system *T*, fraction |
| $FEED_{BY,i,fg,T}$ | = | fraction of 'by-product' feed material *i* for feeding group *fg*, species and system *T*, fraction |
| i | = | feed material *i* from Table 3.2 |

## 3.3 –MONOGASTRICS' FEED RATION

Feed materials for monogastric species are divided into three main categories:

- Swill and feed from scavenging: domestic (and commercial) food waste and feed from scavenging, used in backyard pig and chicken systems and, to a lesser extent, in some intermediate pig systems.
- Non-local feed materials: these are concentrate feed materials that are blended at a feed mill. The materials are sourced from various locations, and there is little link between the location where the feed material is produced and where it is utilized by the animal.
- Locally-produced feed materials: feed that are produced locally and used extensively in intermediate and backyard systems.

Non-local feed materials fall into four categories: **whole feed crops**, where there are no harvested crop residues; **by-products** from brewing, grain milling, processing of oilseeds and sugar production; **grains**, which have harvested crop-residues; and other **non-crop derived feed materials**.

The locally produced feed materials are more varied and, in addition to containing some of the crops, grains and by-products that are part of the non-local feeds, also include: **second-grade crops** deemed unfit for human consumption or use in concentrate feed; **crop residues**; and **forage** in the form of grass and leaves.

A complete list of the feed materials considered is shown in Table 3.14.

The proportions of swill, non-local feed and local feeds in the rations for each system and country are based on reported data and expert judgment.

One of the major differences between the local feeds and the non-local feeds is that the proportions of the individual local feed materials are not defined, but are based on what is available in the country/agro-ecological zone where the animals are located. The percentage of each feed material is determined by calculating the total yield of each of the crops within the country/AEZ, then assessing the fraction of that yield that is likely to be available as animal feed. The percentage of each feed material in the ration is then assumed to be equal to the proportion of the total available feed.

Finally, the total amount of local feed available is compared with the estimated local feed requirement within the cell. If the availability is below a defined threshold, small amounts of grass and leaves are added to supplement the ration.

For a schematic representation of the feed ration estimation for monogastric species see Figures 3.4 and 3.5.

**TABLE 3.14.** List of feed materials for monogastrics

| Number | Material | Description |
|---|---|---|
| **Swill and scavenging** | | |
| **1** | SWILL | Household food waste and other organic material used as feed. |
| **Locally-produced feed materials**[a] | | |
| **2** | GRASSF | Any type of natural or cultivated fresh grass grazed or fed to the animals. |
| **3** | PULSES | Leguminous beans. |
| **4** | PSTRAW | Fibrous residual plant material such as straw, from leguminous plants cultivation. |
| **5** | CASSAVA | Pellets from cassava (*Manihot esculenta*) roots. |
| **6** | WHEAT | Grains from wheat (*Triticum aestivum*). |
| **7** | MAIZE | Grains from maize (*Zea mays*). |
| **8** | BARLEY | Grains from barley (*Hordeum vulgare*). |
| **9** | MILLET | Grains from millet (*P. glaucum, E. coracana, P. miliaceum…*). |
| **10** | RICE | Grains from rice (*Oryza sp.*). |
| **11** | SORGHUM | Grains from sorghum (*Sorghum sp.*). |
| **12** | SOY | Beans from soy (*Glicyne max*). |
| **13** | TOPS | Fibrous residual plant material from sugarcane (*Saccharum spp.*) cultivation. |
| **14** | LEAVES | Leaves from natural, uncultivated vegetation found in trees, forest, lanes etc. |
| **15** | BNFRUIT | Fruit from banana trees (*Musa sp.*) |
| **16** | BNSTEM | Residual plant material such as stems from banana (*Musa sp.*) cultivation. |
| **17** | MLSOY | By-product from soy (*Glycine max*) oil production, commonly referred to as 'soy cakes' or 'soybean meal'. |
| **18** | MLCTTN | By-product from cottonseeds (*Gossypium sp*) oil production, commonly referred to as 'cottonseeds cakes'. |
| **19** | MLOILSDS | By-product (cakes, meals) from oil production other than soy, cottonseed or palm oil. |
| **20** | GRNBYDRY | 'Dry' by-products of grain industries such as brans, middlings, etc. |
| **Non-local feed materials**[b] | | |
| **21** | PULSES | Leguminous beans. |
| **22** | CASSAVA | Pellets from cassava (*Manihot esculenta*) roots. |
| **23** | WHEAT | Grains from wheat (*Triticum aestivum*). |
| **24** | MAIZE | Grains from maize (*Zea mays*). |
| **25** | BARLEY | Grains from barley (*Hordeum vulgare*). |
| **26** | MILLET | Grains from millet (*P. glaucum, E. coracana, P. miliaceum…*). |
| **27** | RICE | Grains from rice (*Oryza sp.*). |
| **28** | SORGHUM | Grains from sorghum (*Sorghum sp.*). |
| **29** | SOY | Beans from soy (*Glicyne max*). |
| **30** | RAPESEED | Seeds from rape (*B. napus*). |
| **31** | SOYOIL | Oil extracted from soybeans (*Glicyne max*). |
| **32** | MLSOY | By-product from soy (*Glycine max*) oil production, commonly referred to as 'soy cakes' or 'soybean meal'. |
| **33** | MLCTTN | By-product from cottonseeds (*Gossypium sp*) oil production, commonly referred to as 'cottonseeds cakes'. |
| **34** | MLRAPE | By-products from rape oil production, commonly referred to as 'canola cakes'. |
| **35** | PKEXP | By-products from the production of kernel palm oil (*Elaeis guineensis*), commonly referred to as 'kernel cake'. |
| **36** | MLOILSDS | By-product (cakes, meals) from oil production other than soy, cottonseed, rapeseed or palm oil. |
| **37** | FISHMEAL | By-products from the fish industries. |
| **38** | MOLASSES | By-product from the sugarcane sugar extraction. |
| **39** | GRNBYDRY | 'Dry' by-products of grain industries such as brans, middlings, etc. |
| **40** | GRNBYWET | 'Wet' by-products of grain industries such as biofuels, distilleries, breweries, etc. |
| **41** | SYNTHETIC | Synthetic additives such as amino-acids or minerals. |
| **42** | LIMESTONE | Used as source of calcium, is given to laying hens to favor the formation of the egg shell. |

[a] Feeds that are produced locally and used extensively in intermediate and backyard systems. It is a more varied and complex group of feed materials, including grains, by-products, crop residues or forages.

[b] Feed materials that are blended at a feed mill to produce concentrate feed. The materials are sourced from various locations and there is little link between the production site and location where are consumed by the animals.

***Figure 3.4*** *Representation of a hypothetical example of feed ration estimation for pigs*

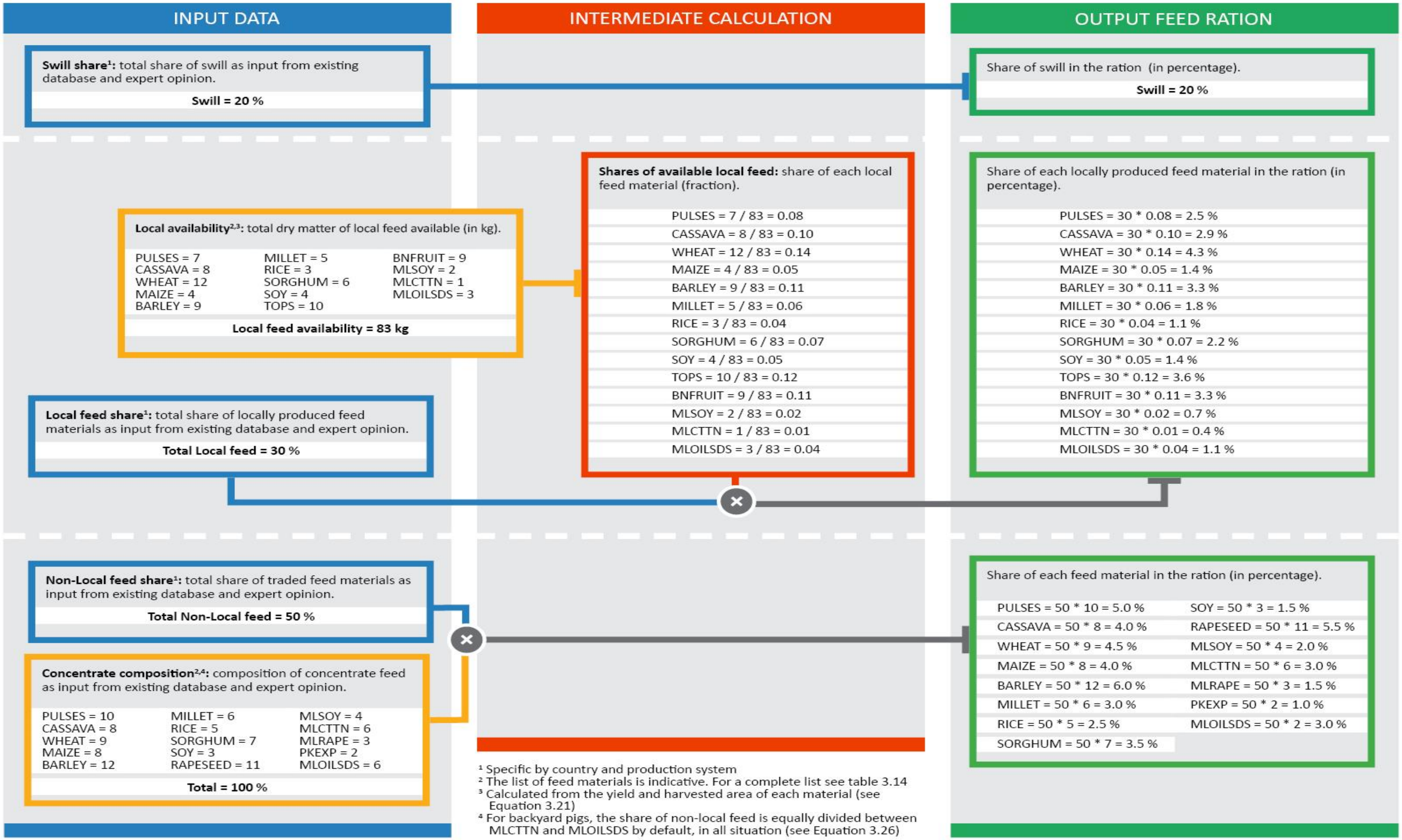
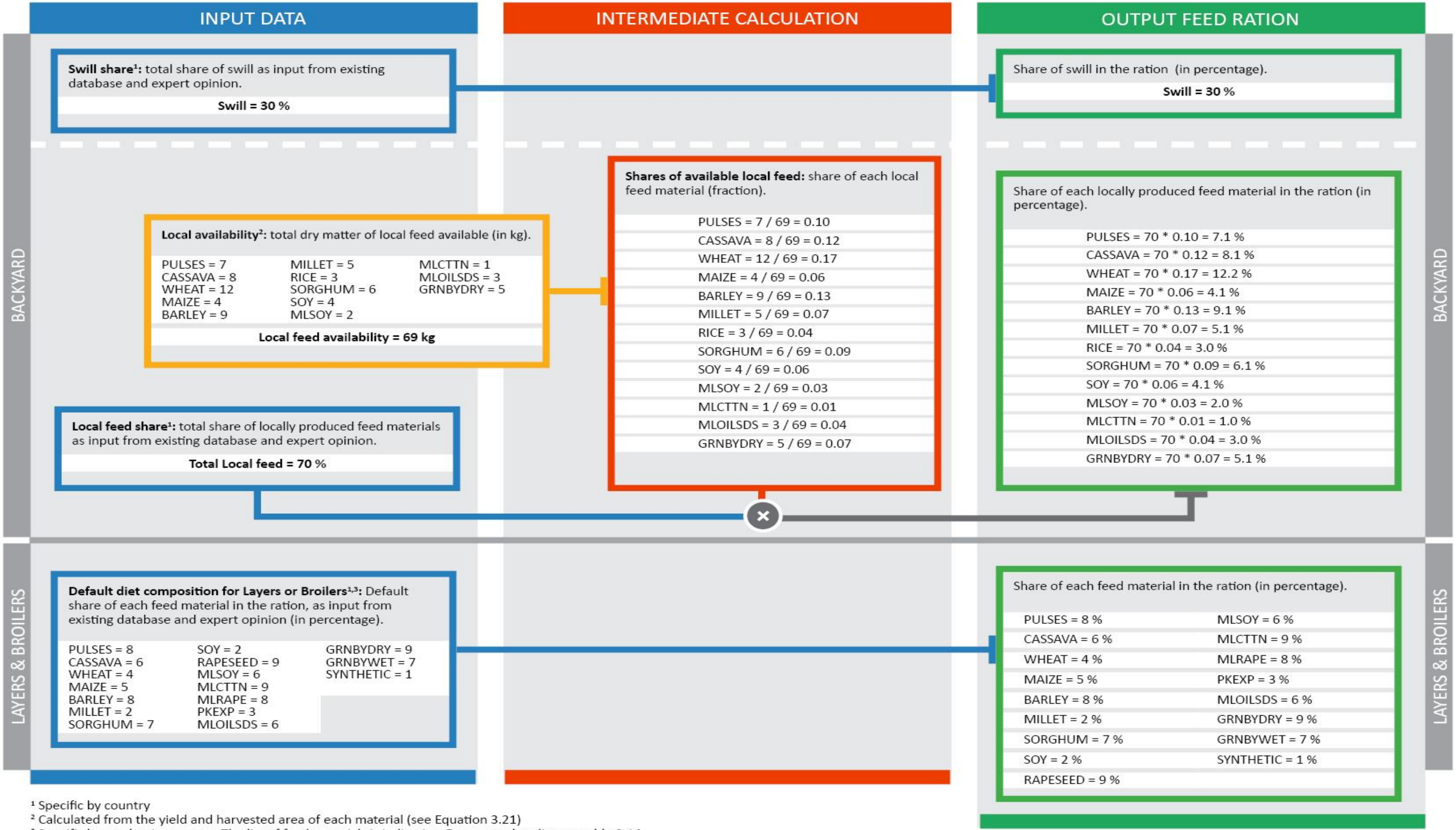


***Figure 3.5*** *Representation of a hypothetical example of feed ration estimation for chickens*




[1] Specific by country
[2] Calculated from the yield and harvested area of each material (see Equation 3.21)
[3] Specific by production system. The list of feed materials is indicative. For a complete list see table 3.14

### *3.3.1 – Calculation of the net dry matter yields*

The net dry matter yield of each feed material in a given area defines the yield that is available as feed for the animals. For the purpose of estimating the animal ration it is used as a main input in those cases where the calculation of the local availability of feed is required (see Sections 3.3.2 and 3.3.4), therefore it is calculated only for the local feed materials. The calculation of the net dry matter yield depends on the type of material considered. In general, the gross dry matter yield (of the crop or crop residues, depending on the feed material; Equation 3.2) is corrected by the FUE, which is the fraction of the yield that is effectively ingested and used as feed by the animals. Moreover, for some feed materials the yield of the respective parental crop is also multiplied by the MFA factor of the material. The latter is a default factor accounting for the feed material mass as a fraction of the total mass of the crop.

Calculation are shown in Equation 3.19. Table 3.15 summarizes the input used for each feed material, for the calculation of the net dry matter yield.

**Equation 3.19**

| | | |
|---|---|---|
| $DMYN_i$ | = | $DMYG_{,i} * FUE_i * MFA_i$<br>for i = 3 to 13, 15 to 20 |

Where:

| | | |
|---|---|---|
| $DMYN_i$ | = | net dry matter yield of feed material *i*, kg DM·ha$^{-1}$ |
| $DMYG_{,i}$ | = | gross dry matter yield for feed material *i*, kg DM·ha$^{-1}$. It can either be the yield of the crop or crop residues. See table 3.15. |
| $FUE_i$ | = | feed use efficiency for feed material *i*, i.e. fraction of the gross yield that is effectively used as feed, fraction |
| $MFA_i$ | = | mass fraction allocation of feed material *i*, i.e. feed material mass as a fraction of the total mass of the crop, fraction. Values are given in Table 3.15. It is not used for feed materials 3, 4, 6 to 11, 13, 15, 16. |

TABLE 3.15. Net yield equations, gross yields, FUE and MFA for each feed material for monogastric species

| Number | Material | Gross dry matter yields | Net yield equation | FUE | MFA |
|---|---|---|---|---|---|
| **Swill and scavenging** | | | | | |
| **1** | SWILL | NA[a] | NA | 1 | 1 |
| **Locally-produced feed materials** | | | | | |
| **2** | GRASSF | Grass | NA | 0.95 | 1 |
| **3** | PULSES | Pulses | Equation 3.19 | 1 | Equation 6.10b[b] |
| **4** | PSTRAW | Pulses (crop residues) – Equation 3.2 | Equation 3.19 | 0.90 | Equation 6.10a[b] |
| **5** | CASSAVA | Cassava | Equation 3.19 | 1 | 1 |
| **6** | WHEAT | Wheat | Equation 3.19 | 1 | Equation 6.10b[b] |
| **7** | MAIZE | Maize | Equation 3.19 | 1 | Equation 6.10b[b,c] |
| **8** | BARLEY | Barley | Equation 3.19 | 1 | Equation 6.10b[b] |
| **9** | MILLET | Millet | Equation 3.19 | 1 | Equation 6.10b[b] |
| **10** | RICE | Rice | Equation 3.19 | 1 | Equation 6.10b[b] |
| **11** | SORGHUM | Sorghum | Equation 3.19 | 1 | Equation 6.10b[b] |
| **12** | SOY | Soybean | Equation 3.19 | 1 | 1 |
| **13** | TOPS | Sugarcane (crop residues) – Equation 3.2 | Equation 3.19 | 0.70 | Equation 6.10a[b] |
| **14** | LEAVES | NA[a] | NA | NA | NA |
| **15** | BNFRUIT | Banana fruits | Equation 3.19 | 1 | Equation 6.10b[b] |
| **16** | BNSTEM | Banana fruits (crop residues) – Equation 3.2 | Equation 3.19 | 0.50 | Equation 6.10a[b] |
| **17** | MLSOY | Soybean | Equation 3.19 | 1 | 0.80 |
| **18** | MLCTTN | Cotton | Equation 3.19 | 1 | 0.45 |
| **19** | MLOILSDS | Sunflower | Equation 3.19 | 1 | 0.60 |
| **20** | GRNBYDRY | Grains average yield[d] | Equation 3.19 | 1 | 0.17 |
| **21** | GRAINS | | | 1 | |
| **Non-local feed materials[d]** | | | | | |
| **21** | PULSES | Pulses | NA | 1 | Equation 6.10b[b] |
| **22** | CASSAVA | Cassava | NA | 1 | 1 |
| **23** | WHEAT | Wheat | NA | 1 | Equation 6.10b[b] |
| **24** | MAIZE | Maize | NA | 1 | 1 |
| **25** | BARLEY | Barley | NA | 1 | Equation 6.10b[b] |
| **26** | MILLET | Millet | NA | 1 | Equation 6.10b[b] |
| **27** | RICE | Rice | NA | 1 | Equation 6.10b[b] |
| **28** | SORGHUM | Sorghum | NA | 1 | Equation 6.10b[b] |
| **29** | SOY | Soybean[e] | NA | 1 | 1 |
| **30** | RAPESEED | Rapeseed | NA | 1 | 1 |
| **31** | SOYOIL | Soybean | NA | 1 | 0.17 |
| **32** | MLSOY | Soybean | NA | 1 | 0.80 |
| **33** | MLCTTN | Cotton | NA | 1 | 0.45 |
| **34** | MLRAPE | Rapeseed | NA | 1 | 0.58 |
| **35** | PKEXP | Oil palm fruit[e] | NA | 1 | 0.03 |
| **36** | MLOILSDS | Sunflower | NA | 1 | 0.58 |
| **37** | FISHMEAL | NA[a] | NA | NA | NA |
| **38** | MOLASSES | Sugarcane | NA | 1 | 0.13 |
| **39** | GRNBYDRY | Grains average yield[f] | NA | 1 | 0.17 |
| **40** | GRNBYWET | Barley | NA | 1 | 1 |
| **41** | SYNTHETIC | NA[a] | NA | NA | NA |
| **42** | LIMESTONE | NA[a] | NA | NA | NA |

[a] No yield is required for these feed materials: their share in the feed rations and their emission intensities are defined by default values.
[b] For these feed materials, the MFA is only used for the allocation of the emissions from feed production (see Chapter 6, Section 6.5) and is calculated with a specific equation.
[c] In industrialized countries, the MFA value of local MAIZE is assumed to be 1, because there is no use for the crop residues.
[d] These materials are sourced from various locations and there is little link between the production site and location where are consumed by the animals. For this reason, average yields, weighted by the harvested areas, were used at regional or, if necessary, continental level. Yields, FUE and MFA of these feed materials are used exclusively for the allocation of the emissions from feed production (see Chapter 6, Section 6.5).
[e] To account for the high level of international trade of these feed materials, average country specific yields were calculated as follows: the average national yield was used for net exporters; for all other countries, a global mean of the yields of all net exporters, weighted by the net export, was calculated and, in a second step, an average between this global yield and each national yield was calculated, weighted by the amount of imported and locally produced product in each country.
[f] Average yield weighed by the hectares of harvested area of wheat, maize, barley, millet, sorghum, rice and other cereals.

## *3.3.2 – Proportion of local feed materials*

The first step is the calculation of the proportion of locally-produced feed materials as shown in Equation 3.20.

**Equation 3.20**

$LOCALFRAC_T$ = $1 – (SWILLFRAC_T + NONLOCALFRAC_T)$

Where:

$LOCALFRAC_T$ = fraction of locally-produced feed materials in the ration of species and system *T*, fraction

$SWILLFRAC_T$ = fraction of swill in the ration of species and system *T*, fraction

$NONLOCALFRAC_T$ = fraction of non-local feed materials in the ration of species and system *T*, fraction

$SWILLFRAC_T$ and $NONLOCALFRAC_T$ are defined base on literature surveys and expert opinion.

## *3.3.3 – Total locally-produced feed available*

The estimation of available local feed is based on the yield and cultivated area of several crops as shown in Equation 3.21.

**Equation 3.21**

LOCALFEEDKG = $\sum_i(DMYN_i * Frac_i * Area_i)$
for i = 3-13, 15-20 (excluding 4, 13-16 for chickens)

Where:

LOCALFEEDKG = total dry matter of locally-produced feed materials per cell, kg

$DMYN_i$ = net dry matter yield of feed material *i*, $kg \cdot ha^{-1}$

$Frac_i$ = fraction of the yield of feed material *i* that is harvested to be used as feed, fraction. The following default values are used: 0.1 for i = 3, 5 to 12; 0.5 for i = 4; 0.15 for i = 16; 1 for other feed materials.

$Area_i$ = harvested area of feed material *i*, ha

i = feed material *i* from Table 3.14

## *3.3.4 – Comparison with energy requirements and total intake of local feed materials*

The total amount of local feed is compared with the animal requirements on an annual basis in the case of pigs. It is assumed that there is sufficient feed when the total available amount in a year represents 10 times the bodyweight.

**Deficiency conditions**

LOCALFEEDKG / LWTOT < 10

**Sufficiency conditions**

LOCALFEEDKG / LWTOT ≥ 10

Where:

LOCALFEEDKG = total dry matter of locally-produced feed materials per cell, kg

LWTOT = total monogastric species live weight depending on locally-produced feed, kg. It is calculated using Equation 3.22.

**Equation 3.22**

LWTOT = $\sum_T [\sum_c (N_{T,c} * LW_{T,c}) * LOCALFRAC_T]$

Where:

LWTOT = total monogastric species live weight depending on locally-produced feed, kg

$N_{T,c}$ = number of animals of species and system *T* and cohort *c*, heads

$LW_{T,c}$ = average live weight of animals of species and system *T* and cohort *c*, $kg \cdot head^{-1}$

$LOCALFRAC_T$ = fraction of locally-produced feed materials in the ration of species and system *T*, fraction

In situations of deficiency, grass and leaves are added to the diet. Grass and leaves are added in amounts equivalents to the 10 and 15% of the total locally-produced dry matter.

**Equation 3.23**

GRASSF = 0.10 * LOCALFEEDKG

LEAVES = 0.15 * LOCALFEEDKG

Where:

GRASSF = total dry matter of ‘fresh grass’ feed available for monogastric species’ consumption, kg

LEAVES = total dry matter of ‘leaves’ feed available for monogastric species’ consumption, kg

LOCALFEEDKG = total dry matter of locally-produced feed materials per cell, kg

Therefore, the final amount of local feed materials is calculated as:

**Equation 3.24**

For pigs:

LOCALFEEDKGFINAL = 1.25 * LOCALFEEDKG

For chickens:

LOCALFEEDKGFINAL = LOCALFEEDKG

Where:

LOCALFEEDKGFINAL = total dry matter of available locally-produced feed materials, kg

LOCALFEEDKG = total dry matter of locally-produced feed materials per cell, kg

### *3.3.5 – Individual share of local feed materials*

The estimation of individual shares of local feeds is calculated as shown in Equation 3.25.

**Equation 3.25**

a. $FEED_{i,T}$ = $LOCALFRAC_T$ * GRASSF / LOCALFEEDKGFINAL
for i = 2 (only for pigs)

b. $FEED_{i,T}$ = $LOCALFRAC_T$ * LEAVES / LOCALFEEDKGFINAL
for i = 14 (only for pigs)

c. $FEED_{i,T}$ = $LOCALFRAC_T$ * ($DMYN_i$ * $Frac_i$ * $Area_i$) / LOCALFEEDKGFINAL
for i = 3 to 13, 15 to 20 (excluding 4, 13, 15, 16 for chickens)

Where:

$FEED_{i,T}$ = fraction of feed material *i* in the ration of species and system *T*, fraction

$LOCALFRAC_T$ = fraction of locally-produced feed materials in the ration of species and system *T*, fraction

GRASSF = total dry matter of ‘fresh grass’ feed available for monogastric species’ consumption, kg

LEAVES = total dry matter of ‘leaves’ feed available for monogastric species’ consumption, kg

$DMYN_i$ = net dry matter yield of feed material *i*, $kg \cdot ha^{-1}$

$Frac_i$ = fraction of the yield of feed material *i* that is harvested to be used as feed, fraction. The following default values are used: 0.1 for i = 3, 5 to 12; 0.5 for i = 4; 0.15 for i = 16; 1 for other feed materials.

$Area_i$ = harvested area of feed material *i*, ha

LOCALFEEDKGFINAL = total dry matter of available locally-produced feed materials, kg

i = feed material *i* from Table 3.14

### 3.3.6 – Individual share of non-local feed materials

The individual share of non-local materials is calculated in different ways, depending on the particular species and production system. Tables 3.16 to 3.21 (Supplement S1) present average rations for monogastric species.

PIGS – BACKYARD SYSTEMS

The fraction of non-local feed materials in the ration is equally shared between cottonseed cakes and oilseeds cakes.

**Equation 3.26**

$FEED_i$ = NONLOCALfrac / 2
for i = 33, 36

Where:

$FEED_{i,}$ = fraction of feed material *i* in the ration, fraction
NONLOCALFRAC = fraction of non-local feed materials in the ration, fraction
i = feed material i from Table 3.14

PIGS – INTERMEDIATE & INDUSTRIAL SYSTEMS

The non-local feed materials are fed to animals as part of a mixed concentrate feed. Data about the composition of concentrate feed for commercial pigs are based on literature, surveys and expert knowledge. The fraction of each non-local feed material in the total ration is calculated as follows.

**Equation 3.27**

$FEED_{i,T}$ = $NONLOCALFRAC_T * CF_i$
for i = 21 to 42

Where:

$FEED_{i,T,}$ = fraction of feed material *i* in the ration of system *T*, fraction
$NONLOCALFRAC_T$ = fraction of non-local feed materials in the ration of system *T*, fraction
$CF_{i,T}$ = fraction of feed material *i* in the composition of concentrate feed, fraction
i = feed material i from Table 3.14

CHICKENS

It is assumed that non-local feed materials make no contribution of to the diet of backyard animals. Therefore, the final ration for that system is already defined in Equation 3.25.

Diets for layers and broiler systems are fully characterized based on literature reviews, national consultation and expert knowledge.

## 3.4 – NUTRITIONAL VALUES

Feed nutritional value in GLEAM are taken from several sources including FEEDEPEDIA, NRC guidelines for pigs and poultry and CVB tables from the Dutch feed board database (Tables 3.22 and 3.23; Supplement S1). Using nutritional information on feedstuffs, average values of digestibility, gross and metabolizable energy and nitrogen content are calculated for each species, production system and feeding group following Equation 3.28.

**Equation 3.28**

a. $DIET_{DI}$ = $\sum_i(FEED_i * DI_i)$
b. $DIET_{GE}$ = $\sum_i(FEED_i * GE_i)$
c. $DIET_{ME}$ = $\sum_i(FEED_i * ME_i)$
d. $DIET_{Ncont}$ = $\sum_i(FEED_i * Ncont_i)$

Where:

$DIET_{DI}$ = average digestibility of ration, percentage
$DIET_{GE}$ = average gross energy content of ration, $MJ \cdot kgDM^{-1}$
$DIET_{ME}$ = average metabolizable energy content of ration, $MJ \cdot kgDM^{-1}$
$DIET_{Ncont}$ = average nitrogen content of ration, $gN \cdot kg\ DM^{-1}$

| | | |
|---|---|---|
| $FEED_i$ | = | fraction of feed material *i* in the ration, fraction |
| $DI_i$ | = | digestibility of feed material *i*, percentage |
| $GE_i$ | = | gross energy content of feed material *i*, $MJ \cdot kgDM^{-1}$ |
| $ME_i$ | = | metabolizable energy content of feed material *i*, $MJ \cdot kgDM^{-1}$ |
| $Ncont_i$ | = | nitrogen content of feed material *i*, $gN \cdot kg\ DM^{-1}$ |

## 3.5 – ENERGY REQUIREMENTS

The gross energy requirement is the sum of the requirements for maintenance, milk production, pregnancy, animal activity, weight gain and production. The method estimates the energy requirement for maintenance as a function of live weight and the energy for activity as the energy expended in walking, grazing or scavenging. Energy requirement for production, instead, depends on the level of productivity (e.g. milk yield, live weight gain, fibre production, egg production). Requirements can also be influenced by the physiological state (pregnancy), ambient temperature and the stage of maturity of the animal. Based on production and management practices, the net energy and feed requirements of all animals are calculated. Data from the herd module (i.e. the number of animals in each category, their average weights, growth rates, fertility rates and yields) were combined with input data on: egg weight, protein/fat fraction of the milk, ambient temperature, and activity levels.

For schematic representation of the energy requirement and feed intake calculation, see Figures 3.6 and 3.7.

***Figure 3.6** – Schematic representation of the energy requirement and feed intake for ruminants*

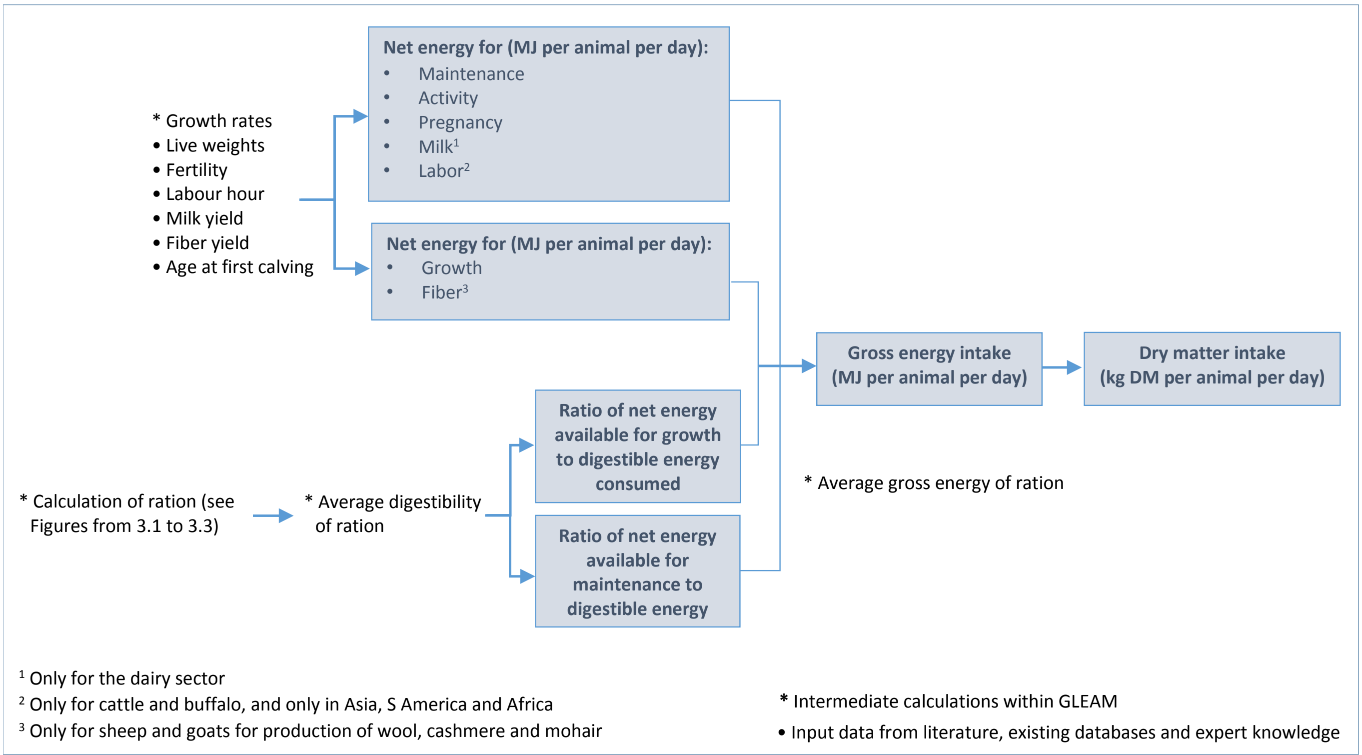
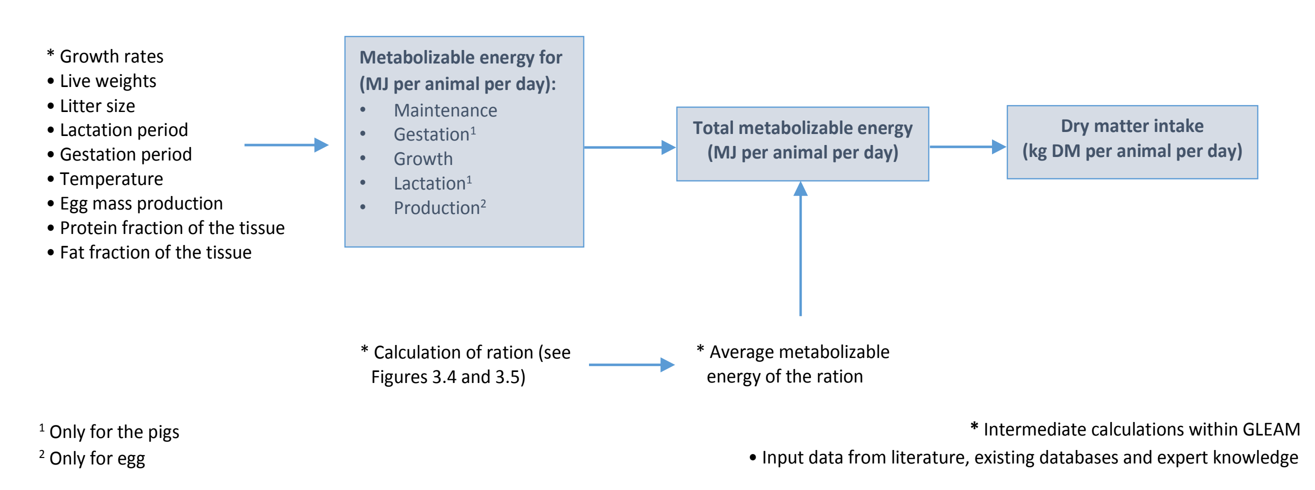


***Figure 3.7 –** Schematic representation of the energy requirement and feed intake for monogastrics*




## *3.5.1 – Energy requirement of ruminants*

GLEAM uses the IPCC Tier 2 algorithms to calculate the energy requirements for each cohort (IPCC, 2006). Table 3.24 summarizes the equations used to estimate the daily gross energy (GE) needs:

**TABLE 3.24.** Equations used to estimate GE for ruminant species

| Metabolic function | Abbreviation | Equations for large ruminants | Equations for small ruminants |
|---|---|---|---|
| **Maintenance** | $NE_{main}$ | Equation 3.29 | Equation 3.29 |
| **Activity** | $NE_{act}$ | Equation 3.30 | Equation 3.31 |
| **Growth** | $NE_{gro}$ | Equation 3.32 | Equation 3.33 |
| **Milk production** | $NE_{lact}$ | Equation 3.34 | Equation 3.35 |
| **Draught power** | $NE_{work}$ | Equation 3.36 | Not applicable |
| **Production of fibre** | $NE_{fiber}$ | Not applicable | Equation 3.37 |
| **Pregnancy** | $NE_{preg}$ | Equation 3.38 | Equation 3.39 |
| **Ratio of net energy available in diet for maintenance to digestible energy consumed** | REM | Equation 3.40 | Equation 3.40 |
| **Ratio of net energy available for growth in a diet to digestible energy consumed** | REG | Equation 3.41 | Equation 3.41 |
| **Daily gross energy** | GE | Equation 3.42 | Equation 3.42 |

### *3.5.1.1 – Net energy for maintenance ($NE_{main}$)*

$NE_{main}$ is the net energy required for the maintenance of basal metabolic activity. It is estimated as follows:

**Equation 3.29**

$$NE_{main,c} = C_{main,c} * LW_c^{\ 0.75}$$

Where:

$NE_{main,c}$ = net energy required by animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$C_{main,c}$ = coefficient for $NE_{main}$ for each cohort *c*, $MJ \cdot kg^{-0.75} \cdot day^{-1}$. Values are given in Table 3.25.

$LW_c$ = average live weight of the animals in cohort *c*, $kg \cdot head^{-1}$

**TABLE 3.25.** Coefficient for calculating $NE_{main}$

| Animal category | GLEAM cohorts | $C_{main}$ ($MJ \cdot kg^{-0.75} \cdot day^{-1}$) |
|---|---|---:|
| **Cattle and Buffaloes, lactating cows** | AF | 0.386 |
| **Cattle and Buffaloes, non-lactating cows** | RF, MF, MFf | 0.322[a] |
| **Cattle and Buffaloes, bulls** | RM, MM, MMf | 0.370[a] |
| **Sheep and Goats, lamb/kid to 1 year** | RFA, MF | 0.236 |
| **Sheep and Goats, intact male lambs/kids to 1 year** | RMA, MM | 0.271 |
| **Sheep and Goats, older than 1 year** | AF, RFB | 0.217 |
| **Sheep and Goats, intact males older than 1 year** | AM, RMB | 0.250 |

[a] $C_{main}$ of replacement animals is multiplied by 0.974. This prevents an overestimation of $NE_{main}$ resulting from using the average live weight for the entire growing period instead of the average of live weights from each day.

### 3.5.1.2 – Net energy for activity ($NE_{act}$)

$NE_{act}$ is the net energy required for obtaining food, water and shelter based on the feeding situation and not directly related to the feed quality.

**Equation 3.30 – Large ruminants**

$NE_{act,c} = C_{act,c} * NE_{main,c}$

Where:

$NE_{act,c}$ = net energy for animal activity in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$C_{act,c}$ = coefficient for $NE_{act}$ which depends on the animal feeding condition in cohort *c*, fraction. Values are given in Table 3.26.

$NE_{main,c}$ = net energy required by animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

**Equation 3.31– Small ruminants**

$NE_{act,c} = C_{act,c} * LW_c$

Where:

$NE_{act,c}$ = net energy for animal activity in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$C_{act,c}$ = coefficient for $NE_{act}$ which depends on the animal feeding condition in cohort *c*, $MJ \cdot kg^{-1} \cdot day^{-1}$. Values are given in Table 3.26.

$LW_c$ = average live weight of the animals in cohort *c*, $kg \cdot head^{-1}$

**TABLE 3.26.** Activity coefficients for different feeding situations

| Situation | Definition | $C_{act}$ |
|---|---|---|
| **Cattle and Buffaloes (fraction)** | | |
| Stall | Animals are confined to small area with the result of little to none energy expenditure | 0.00 |
| Pasture | Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed | 0.17[a] |
| Grazing in large areas | Animals graze in open range land or hilly terrain and expend significant energy to acquire feed | 0.36[a] |
| **Sheep and Goats ($MJ \cdot kg^{-1} \cdot day^{-1}$)** | | |
| Housed ewes/does | Animals are confined due to pregnancy in the final trimester (50 days) | 0.0090 |
| Grazing flat pasture | Animals walk up to 1000 meters per day and expend very little energy to acquire feed | 0.0107[a] |
| Grazing hilly pasture | Animals walk up to 5000 meters per day and expend significant energy to acquire feed | 0.0240[a] |

[a] In order to reflect the proportion of animals grazing, $C_{act}$ is multiplied by the share of Pasture/Range/Paddock manure management system (MMSpasture / 100).

### 3.5.1.3 – Net energy for growth ($NE_{gro}$)

$NE_{gro}$ is the net energy required for growth, that is, for gaining weight. These equations are applied to replacement and fattening animals (both in feedlots and outside feedlots).

**Equation 3.32 – Large ruminants**

a. $NE_{gro,cf} = 22.02 * (LW_{cf} /( C_{gro} * AFkg))^{0.75} * DWGF^{1.097}$

b. $NE_{gro,cm} = 22.02 * (LW_{cm} / (C_{gro} * AMkg))^{0.75} * DWGM^{1.097}$

c. $NE_{gro,MFf} = 22.02 * (MFfkg / (C_{gro} * LWENDF))^{0.75} * DWGFF^{1.097}$

d. $NE_{gro,MMf} = 22.02 * (MMfkg / (C_{gro} * LWENDM))^{0.75} * DWGFM^{1.097}$

Where:

$NE_{gro}$ = net energy required by animal for growth in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

LW = average live weight of growing animals, $kg \cdot head^{-1}$

$C_{gro}$ = dimensionless coefficient given in Table 3.27

AFkg = average live weight of adult female animals, $kg \cdot head^{-1}$

AMkg = average live weight of adult male animals, $kg \cdot head^{-1}$

DWGF = average daily growth rate of female animals from calf to adult animal, $kg \cdot head^{-1} \cdot day^{-1}$

DWGM = average daily growth rate of male animals from calf to adult animal, $kg \cdot head^{-1} \cdot day^{-1}$

DWGFF = average daily growth rate of female animals in feedlots, $kg \cdot head^{-1} \cdot day^{-1}$

DWGMF = average daily growth rate of male animals in feedlots, $kg \cdot head^{-1} \cdot day^{-1}$

| | | |
|---|---|---|
| cf | = | cohorts of replacement (RF) or fattening female animals (MF) |
| cm | = | cohorts of replacement (RM) or fattening male animals (MM) |
| MFf | = | cohort of feedlot female animals |
| MMf | = | cohort of feedlot male animals |

**TABLE 3.27.** Constants for calculating $NE_{gro}$

| Animal category | GLEAM cohorts | C (dimensionless) |
|---|---|---|
| **Cattle and Buffaloes** | | |
| Female animals | RF, MF, MFf | 0.8 |
| Male animals | RM<br>MM, MMf | 1.2<br>1.0 |

**Equation 3.33 – Small ruminants**

$$NE_{gro,c} = DWG_c * (a_c + b_c * Ckg) + 0.5 * b_c * DWG_c^2$$

Where:

| | | |
|---|---|---|
| $NE_{gro,c}$ | = | net energy required by animal for growth in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $DWG_c$ | = | average daily weight gain in cohort *c*, $kg \cdot head^{-1} \cdot day^{-1}$ |
| $a_c$, $b_c$ | = | constants given in Table 3.28 for cohort *c* |
| Ckg | = | live weight of lambs/kids at birth, $kg \cdot head^{-1}$ |
| c | = | cohort of replacement or fattening animals |

**TABLE 3.28.** Constants for calculating $NE_{gro}$

| Animal category | GLEAM cohorts | a ($MJ \cdot kg^{-1}$) | b ($MJ \cdot kg^{-2}$) |
|---|---|---|---|
| **Sheep and Goats** | | | |
| Females | RF, RFA, RFB, MF | 2.1 | 0.45 |
| Intact males | RM, RMA, RMB, MM | 2.5 | 0.35 |

### *3.5.1.4 – Net energy for milk production ($NE_{lact}$)*

$NE_{lact}$ is the net energy required for milk production. These equations are applied to adult females only.

**Equation 3.34 – Large ruminants**

$$NE_{lact,AF} = Milk * (1.47 + 0.40 * Fat)$$

Where:

| | | |
|---|---|---|
| $NE_{lact,AF}$ | = | net energy required by animal for lactation in the adult females cohort *AF*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| Milk | = | daily milk production (assumed to be null for the specialized meat herds), kg $milk \cdot cow^{-1} \cdot day^{-1}$ |
| Fat | = | fat content of milk, percentage by weight |

**Equation 3.35 – Small ruminants**

$$NE_{lact,AF} = Milk * EV_{milk}$$

Where:

| | | |
|---|---|---|
| $NE_{lact,AF}$ | = | net energy required by animal for lactation in the adult females cohort *AF*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| Milk | = | daily milk production (assumed to be null for the specialized meat herds), kg $milk \cdot ewe/doe^{-1} \cdot day^{-1}$ |
| $EV_{milk}$ | = | net energy to produce 1 kg of milk. Default value of 4.6 $MJ \cdot kg\ milk^{-1}$ is used, assuming a 7% fat content |

### *3.5.1.5 – Net energy for draught power ($NE_{work}$)*

$NE_{work}$ is the net energy required for animal work, used to estimate the energy required for draught power from cattle and buffalo bulls. It is estimated that 10% of a day's maintenance energy is used per hour of work.

**Equation 3.36**

$$NE_{work,AM} = 0.10 * NE_{main,AM} * Hours$$

Where:

| | | |
|---|---|---|
| $NE_{work,AM}$ | = | net energy required by animal for work in the adult males cohort *AM*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $NE_{main,AM}$ | = | net energy required by animal for maintenance in the adult males cohort *AM*, $MJ \cdot head^{-1} \cdot day^{-1}$ |

Hours = number of hours of work per day, $h \cdot head^{-1} \cdot day^{-1}$

### 3.5.1.6 – Net energy for production of fibre ($NE_{fibre}$)

$NE_{fibre}$ is the net energy required by small ruminants for producing fibre such as wool, cashmere and mohair. These equations are applied to adult and fattening animals.

**Equation 3.37**

$NE_{fibre,c}$ = $EV_{fibre}$ * $Production_{fibre,c}$

Where:

$NE_{fibre,c}$ = net energy required by animal for fibre production in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$EV_{fibre}$ = energy value per kilogram of fibre. Default value of 24 $MJ \cdot kg\ fibre^{-1}$ is used

$Production_{fibre,c}$ = annual production of fibre by animal in cohort *c*, $kg\ fibre \cdot head^{-1} \cdot year^{-1}$

c = cohorts of adult and fattening animals

### 3.5.1.7 – Net energy for pregnancy ($NE_{preg}$)

$NE_{preg}$ is the net energy required for pregnancy. For large ruminants, it is estimated that 10% of $NE_{main}$ is needed for a 281-day gestation period (Equation 3.38). For small ruminants, this percentage varies depending on the litter size (Equation 3.39). The equation is applied to adult and replacement females only.

**Equation 3.38 – Large ruminants**

a. $NE_{preg,AF}$ = $NE_{main,AF}$ * 0.1 * FR / 100

b. $NE_{preg,RF}$ = $NE_{main,RF}$ * 0.1 / (AFC / 2)

Where:

$NE_{preg,AF}$ = net energy required by adult females for pregnancy, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{preg,RF}$ = net energy required by replacement females for pregnancy, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{main,AF}$ = net energy required by adult females for maintenance, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{main,RF}$ = net energy required by replacement females for maintenance, $MJ \cdot head^{-1} \cdot day^{-1}$

FR = fertility rate of adult females, percentage

AFC = age at first calving, year

**Equation 3.39 – Small ruminants**

a. $NE_{preg,AF}$ = $NE_{main,AF}$ * (0.077 * (2 – LITSIZE) + 0.126 * (LITSIZE – 1)) * (365 * FR / LINT/100)

b. $NE_{preg,RF}$ = $NE_{main,RF}$ * 0.077

Where:

$NE_{preg,AF}$ = net energy required by adult females for pregnancy, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{preg,RF}$ = net energy required by replacement females for pregnancy, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{main,AF}$ = net energy required by adult females for maintenance, $MJ \cdot head^{-1} \cdot day^{-1}$

$NE_{main,RF}$ = net energy required by replacement females for maintenance, $MJ \cdot head^{-1} \cdot day^{-1}$

LITSIZE = litter size, number of lambs/kids per parturition, head

LINT = lambing or kidding interval, period between two parturitions, days

FR = fertility rate of adult females, percentage

AFC = age at first calving, year

### 3.5.1.8 – Ratio of net energy in the feed intake for maintenance to digestible energy (REM)

The ratio of net energy available in the feed intake for maintenance to digestible energy consumed (REM) for ruminant species is calculated following Equation 3.40 below:

**Equation 3.40**

$REM_{fg}$ = $1.123 – (4.092 \cdot 10^{-3} * DIET_{DI,fg}) + (1.126 \cdot 10^{-5} * DIET_{DI,fg}{}^{2}) – (25.4 / DIET_{DI,fg})$

Where:

$REM_{fg}$ = ratio of net energy available in the diet for maintenance to digestible energy for the feeding group *fg*, fraction
$DIET_{DI,fg}$ = average digestibility of ration for the feeding group *fg*, percentage
fg = feeding group as shown in Table 3.3

### *3.5.1.9 – Ratio of net energy available in the feed intake for growth to digestible energy consumed (REG)*

The ratio of net energy available in the feed intake for growth to digestible energy consumed (REG) for ruminant species is calculated following Equation 3.41below:

**Equation 3.41**

$$REG_{fg} = 1.164 - (5.160 \cdot 10^{-3} * DIET_{DI,fg}) + (1.308 \cdot 10^{-5} * DIET_{DI,fg}^{2}) - (37.4 / DIET_{DI,fg})$$

Where:
$REG_{fg}$ = ratio of net energy available in the diet for growth to digestible energy consumed for the feeding group *fg*, fraction
$DIET_{DI,fg}$ = average digestibility of ration for the feeding group *fg*, percentage
fg = feeding group as shown in Table 3.3

### *3.5.1.10 – Total gross energy (GE)*

The gross energy requirement is based on the amount of net energy requirements and the energy availability of the feed intake as showed in the equation below, using the relevant terms for each species and animal category:

**Equation 3.42**

$$GE_{tot,c} = ((NE_{main,c} + NE_{act,c} + NE_{lact,c} + NE_{work,c} + NE_{preg,c}) / REM_{fg}) + ((NE_{gro,c} + NE_{fibre,c}) / REG_{fg})) / (DIET_{DI,fg} / 100)$$

Where:
$GE_{tot,c}$ = total gross energy requirement by animal in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{main,c}$ = net energy required by animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{act,c}$ = net energy for animal activity in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{gro,c}$ = net energy required by animal for growth in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{lact,c}$ = net energy required by animal for lactation in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{work,c}$ = net energy required by animal for work in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{fibre,c}$ = net energy required by animal for fibre production in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$NE_{preg,c}$ = net energy required by animal for pregnancy in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$
$REM_{fg}$ = ratio of net energy available in the diet for maintenance to digestible energy consumed for the feeding group *fg*, fraction
$REG_{fg}$ = ratio of net energy available in the diet for growth to digestible energy consumed for the feeding group *fg*, fraction
fg = feeding group as shown in Table 3.3

## 3.5.2 – Energy requirement of pigs

As the 2006 IPCC guidelines do not include equations for calculating the energy requirement of monogastric species, equations for pigs were derived from NRC (1998). The formulas were adjusted in light of recent farm data supplied by Bikker (personal communication 2011). The model distinguishes four groups with respect their nutrition needs: sows, boars, replacement animals and fattening pigs. The table below summarizes the equations used to estimate the energy requirements for pigs:

**TABLE 3.29.** Equations used to estimate ME for pigs

| Metabolic function | Abbreviation | Equation |
|---|---|---|
| **Maintenance** | $ME_{main}$ | Equation 3.43 |
| **Gestation** | $ME_{gest}$ | Equation 3.44 |
| **Lactation** | $ME_{lact}$ | Equation 3.45 |
| **Growth** | $ME_{prot}$ / $ME_{fat}$ | Equation 3.46/3.47 |
| **Total energy requirement** | | |
| Adult females (AF) | $ME_{tot}$ | Equation 3.48a |
| Adult males (AM) | $ME_{tot}$ | Equation 3.48b |
| Replacement females (RF) | $ME_{tot}$ | Equation 3.48c |
| Replacement males (RM) | $ME_{tot}$ | Equation 3.48d |
| Fattening animals (M2) | $ME_{tot}$ | Equation 3.48e |

### 3.5.2.1 – Energy requirement for maintenance ($ME_{main}$)

$ME_{main}$ is the metabolizable energy requirement for maintenance.

**Equation 3.43**

$$ME_{main,c} = C_{main} * LW_c^{0.75} * C_{act}$$

Where:

$ME_{main,c}$ = metabolizable energy required by animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$C_{main}$ = coefficient for maintenance energy requirement, $MJ \cdot kg^{-0.75} \cdot day^{-1}$. Default value of 0.444 is used

$LW_c$ = average live weight for maintenance energy requirement of the animals in cohort *c*, $kg \cdot head^{-1}$. Values are given in Table 3.30

$C_{act}$ = dimensionless coefficient for activity that depends on animal feeding condition, with 1.125 for backyard and 1.000 for intermediate and industrial systems

**TABLE 3.30.** Average live weight for maintenance energy requirements for pigs

| Animal cohort | Weight ($kg \cdot animal^{-1}$) |
|---|---|
| **Adult females (idle)** | AFkg |
| **Adult females (gestation)** | AFkg + (LITSIZE * Ckg + 0.15 * AFkg) / 2 |
| **Adult females (lactation)** | (AFkg + 0.15 * AFkg) / 2 |
| **Adult males** | AMkg |
| **Replacement females** | RFkg |
| **Replacement males** | RMkg |
| **Fattening animals** | M2kg |

Where:
LITSIZE = litter size, number of piglets per parturition, $heads \cdot parturition^{-1}$
Ckg = live weight of piglets at birth, $kg \cdot head^{-1}$
AFkg = average live weight of adult females, $kg \cdot head^{-1}$
AMkg = average live weight of adult males, $kg \cdot head^{-1}$
RFkg = average live weight of replacement females, $kg \cdot head^{-1}$
RMkg = average live weight of replacement males, $kg \cdot head^{-1}$
M2kg = average live weight of meat animals, $kg \cdot head^{-1}$

### *3.5.2.2 – Energy requirement for gestation ($ME_{gest}$)*

$ME_{gest}$ is the metabolizable energy requirement for gestation. This equation is applied only to adult and replacement females. In the second case, only a part of the animals is at reproductive age. Therefore, the energy requirement for this cohort must be corrected by the age at first farrowing of the animals.

**Equation 3.44**

$$ME_{gest,c} = C_{gest} * LITSIZE * C_{adj,c}$$

Where:

| | | |
|---|---|---|
| $ME_{gest}$ | = | metabolizable energy required by animal for gestation in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $C_{gest}$ | = | coefficient for gestation energy requirement, $MJ \cdot piglet^{-1}$. Default value of 0.148 is used |
| LITSIZE | = | litter size, number of piglets per parturition, $heads \cdot parturition^{-1}$ |
| $C_{adj,c}$ | = | coefficient of adjustment to account for the reproductive part of the cohort *c*, year. A value of 1 is used for adult females and a value of 1 / AFCF is used for replacement females (AFCF is the age at parturition based on the daily weight gain, see section 2.3.2.1). |
| c | = | cohort of adult or replacement females |

### *3.5.2.3 – Energy requirement for lactation ($ME_{lact}$)*

$ME_{lact}$ is the metabolizable energy requirement for lactation. This equation is applied only to adult and replacement females. In the second case, only a part of the animals is at reproductive age. Therefore, the energy requirement for this cohort must be corrected by the age at first farrowing of the animals.

**Equation 3.45**

$$ME_{lact,c} = LITSIZE *( (1 – 0.5 * (DR1 / 100)) * (C_{lact} * (Wkg - Ckg) * 1000 / Lact) – (C_{wloss} / C_{conv})) * C_{adj,c}$$

Where:

| | | |
|---|---|---|
| $ME_{lact,c}$ | = | metabolizable energy required by animal for lactation in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| LITSIZE | = | litter size, number of lambs/kids per parturition, $heads \cdot parturition^{-1}$ |
| DR1 | = | death rate of piglets, percentage |
| $C_{lact}$ | = | coefficient for lactation energy requirement, $MJ \cdot g\ live\ weight^{-1}$. Default value of 20.59 is used. |
| Wkg | = | live weight of piglets at weaning age, $kg \cdot head^{-1}$ |
| Ckg | = | live weight of piglets at birth, $kg \cdot head^{-1}$ |
| Lact | = | duration of lactation period, days |
| $C_{wloss}$ | = | coefficient for weight loss from sow due to lactation, $MJ \cdot head^{-1} \cdot day^{-11}$. Default value of 0.38 is used. |
| $C_{conv}$ | = | efficiency for intake to milk energy conversion, fraction. Default value of 0.67 is used. |
| $C_{adj,c}$ | = | coefficient of adjustment to account for the reproductive part of the cohort *c*, year. A value of 1 is used for adult females and a value of 1 / AFCF is used for replacement females (AFCF is the age at parturition based on the daily weight gain, see section 2.3.2.1). |
| c | = | cohort of adult or replacement females |

### *3.5.2.4 – Energy requirement for growth ($ME_{prot}$ and $ME_{fat}$)*

$ME_{prot}$ and $ME_{fat}$ are the metabolizable energy requirements for the generation, during growth, of proteins and fat , respectively. It is assumed that all growth is either fat or protein tissue. These equations are applied only to replacement and fattening animals.

**Equation 3.46**

$$ME_{prot,c} = DWG_c * PTissue * Prot * C_{MEprot}$$

Where:

| | | |
|---|---|---|
| $ME_{prot,c}$ | = | metabolizable energy required for generating new protein in tissues for cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $DWG_c$ | = | daily weight gain by animal in cohort *c*, $kg \cdot head^{-1} \cdot day^{-1}$ |
| PTissue | = | fraction of protein tissue in the daily weight gain, fraction. Default values of 0.60, 0.65 and 0.7 for backyard, intermediate and industrial systems are used, respectively. |
| Prot | = | fraction of protein in protein tissue, fraction. Default value of 0.23 is used |

$C_{MEprot}$ = metabolizable energy required for protein in protein tissue, MJ·kg protein$^{-1}$. Default value of 54.0 is used.
c = cohort of replacement and fattening animals

**Equation 3.47**

$ME_{fat,c}$ = $DWG_c$ * (1 - PTissue) * Fat * $C_{MEfat}$

Where:

$ME_{fat,c}$ = metabolizable energy required for generating new fat in adipose tissue for cohort *c*, MJ·head$^{-1}$·day$^{-1}$
$DWG_c$ = daily weight gain by animal in cohort *c*, kg·head$^{-1}$·day$^{-1}$
PTissue = fraction of protein tissue in the daily weight gain, fraction. Default values of 0.60, 0.65 and 0.7 for backyard, intermediate and industrial systems are used, respectively.
Fat = fraction of fat in adipose tissue, fraction. Default value of 0.90 is used
$C_{MEfat}$ = metabolizable energy required for fat in adipose tissue, MJ·kg fat$^{-1}$. Default value of 52.3 is used.
c = cohort of replacement and fattening animals

### *3.5.2.5 – Total energy requirement ($ME_{tot}$)*

$ME_{tot}$ is the total metabolizable energy requirement for each animal in a given cohort.

**Equation 3.48**

a. $ME_{tot,AF}$ = Gest * ($ME_{main\text{-}gestation,AF}$ + $ME_{gest}$) + Lact * ($ME_{main\text{-}lactation,AF}$ + $ME_{lact}$) + Idle * ($ME_{main\text{-}idle,AF}$)
b. $ME_{tot,AM}$ = $ME_{main,AM}$
c. $ME_{tot,RF}$ = Gest * ($ME_{gest,RF}$) + Lact * ($ME_{lact,RF}$) + 365 * AFCF * ($ME_{main,RF}$ + $ME_{prot,RF}$ + $ME_{fat,RF}$)
d. $ME_{tot,RM}$ = $ME_{main,RM}$ + $ME_{prot,RM}$ + $ME_{fat,RM}$
e. $ME_{tot,M2}$ = $ME_{main,M2}$ + $ME_{prot,M2}$ + $ME_{fat,M2}$

Where:

$ME_{tot}$ = total metabolizable energy required for a given cohort, MJ·head$^{-1}$·day$^{-1}$
$ME_{main}$ = metabolizable energy required by animal for maintenance for a given cohort, MJ·head$^{-1}$·day$^{-1}$. For adult females, the model distinguishes between idle, gestation and lactation periods (see Equation 3.43)
$ME_{gest}$ = metabolizable energy required by animal for gestation for a given cohort, MJ·head$^{-1}$·day$^{-1}$
$ME_{lact}$ = metabolizable energy required by animal for lactation for a given cohort, MJ·head$^{-1}$·day$^{-1}$
$ME_{prot}$ = metabolizable energy required by animal for generation of new proteins in protein tissue for a given cohort, MJ·head$^{-1}$·day$^{-1}$
$ME_{fat}$ = metabolizable energy required by animal for generation of new fat in adipose tissue for a given cohort, MJ·head$^{-1}$·day$^{-1}$
Gest = duration of gestation period, days
Lact = duration of lactation period, days
Idle = duration of idle period, days
AFCF = age at first parturition, year

## 3.5.3 – Energy requirement of chickens

Equations for chickens were derived from Sakomura (2004). The model partitions the total metabolizable energy intake into maintenance, growth and production. It is assumed that layers and broilers are kept in housing with a controlled environment where the ambient temperature is constant at 20 °C. For backyard systems, the average annual temperature is used in the estimation of energy for maintenance. Table 3.31 summarizes the equations used to estimate the energy requirements for chicken.

**TABLE 3.31.** Equations used to estimate ME for chickens

| Metabolic function | Abbreviation | Equation |
|---|---|---|
| **Maintenance** | $ME_{main}$ | Equation 3.49 |
| **Growth** | $ME_{gro}$ | Equation 3.50 |
| **Production** | $ME_{prod}$ | Equation 3.51 |
| **Total energy requirement** | | |
| Backyard production systems | | |
| Reproductive hens | $ME_{tot}$ | Equation 3.52a |
| Reproductive roosters | $ME_{tot}$ | Equation 3.52b |
| Surplus hens when adults (laying eggs) | $ME_{tot}$ | Equation 3.52a |
| Growing female and male chicks for replacement | $ME_{tot}$ | Equation 3.52b |
| Surplus hens when growing (not laying eggs) | $ME_{tot}$ | Equation 3.52b |
| Surplus roosters | $ME_{tot}$ | Equation 3.52b |
| Layers production systems | | |
| Reproductive hens | $ME_{tot}$ | Equation 3.52a |
| Reproductive roosters | $ME_{tot}$ | Equation 3.52b |
| Growing female and male chicks for replacement | $ME_{tot}$ | Equation 3.52b |
| Surplus roosters | $ME_{tot}$ | Equation 3.52b |
| Laying hens (before laying period and during molting period) | $ME_{tot}$ | Equation 3.52b |
| Laying hens (during laying period) | $ME_{tot}$ | Equation 3.52a |
| Broiler production system | | |
| Reproductive hens | $ME_{tot}$ | Equation 3.52a |
| Reproductive roosters | $ME_{tot}$ | Equation 3.52b |
| Growing female and male chicks for replacement | $ME_{tot}$ | Equation 3.52b |
| Broiler animals | $ME_{tot}$ | Equation 3.52b |

### 3.5.3.1 – Energy requirement for maintenance ($ME_{main}$)

$ME_{main}$ is the metabolizable energy requirement for maintenance.

**Equation 3.49**

$ME_{main,c}$ = $LW_c^{0.75} * TEMPreg_c * C_{act}$

Where:

$ME_{main,c}$ = metabolizable energy required by animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$LW_c$ = average live weight of the animal in cohort *c*, $kg \cdot head^{-1}$.

$TEMPreg_c$ = regression function depending on the temperature for cohort *c*, $MJ \cdot kg^{-0.75} \cdot day^{-1}$. Values are given in Table 3.32.

$C_{act}$ = dimensionless coefficient for activity with a value of 1.25 for backyard and 1.0 for layers and broilers.

**TABLE 3.32.** Temperature regression function for maintenance energy requirements

| Animal cohort | $TEMPreg_c$ ($MJ \cdot kg^{-0.75} \cdot day^{-1}$) |
|---|---|
| **Backyard production systems** | |
| Reproductive adults (AF, AM) | $0.693 - 9.9 \cdot 10^{-3} * T^a$ |
| Surplus hens when adults (laying eggs) (MF2) | |
| Growing female and male chicks for replacement (RF, RM) | if $T < LCT^b$: $0.386 + 0.03 * (LCT - T)$<br>if $T \geq LCT$: $0.386 + 3.7 \cdot 10^{-3} * (T - LCT)$ |
| Surplus hens when growing (not laying eggs) (MF1) | |
| Surplus roosters (MM) | |
| **Layers production systems** | |
| Reproductive adults (AF, AM) | $0.693 - 9.9 \cdot 10^{-3} * T$ |
| Growing female and male chicks for replacement (RF, RM) | 0.390 |
| Surplus roosters | |
| Laying hens (before laying period) (MF1) | |
| Laying hens (during laying period) (MF2, MF3, MF4) | $0.693 - 9.9 \cdot 10^{-3} * T$ |
| **Broiler production system** | |
| Reproductive adults (AF, AM) | $0.806 - 0.026 * T + 0.5 \cdot 10^{-3} * T^2$ |
| Growing female and male chicks for replacement (RF, RM) | $0.727 - 7.86 \cdot 10^{-3} * T$ |
| Broiler animals (M2) | $1.287 - 0.065 * T + 1.3 \cdot 10^{-3} * T^2$ |

[a] Temperature (°C): average annual value for backyard systems; standard value of 20 for industrial Layers and Broilers systems.
[b] Low critic temperature (°C): calculated as $24.54 - 5.65 * F$, where F is feathering score (0-1). It is assumed a feathering score of 1.

### *3.5.3.2 – Energy requirement for growth ($ME_{gro}$)*

$ME_{gro}$ is the metabolizable energy requirement for growth.

**Equation 3.50**

$$ME_{gro,c} = DWG_c * 1000 * C_{gro,c}$$

Where:

$ME_{gro,c}$ = metabolizable energy required by animal for growth in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$

$DWG_c$ = daily weight gain of animals in cohort *c*, $kg \cdot head^{-1} \cdot day^{-1}$. The DWG for reproductive adults in Broilers is taken from Layers.

$C_{gro,c}$ = growth coefficient for cohort *c*, $MJ \cdot kg^{-1}$. Values are given in Table 3.33

**TABLE 3.33.** Growth coefficient for chickens

| Animal cohort | $C_{gro}$ ($MJ \cdot g^{-1}$) |
|---|---|
| **Backyard production systems** | |
| Reproductive adults (AF, AM) | 0.028 |
| Surplus hens when adults (laying eggs) (MF2) | |
| Growing female and male chicks for replacement (RF, RM) | 0.021 |
| Surplus hens when growing (not laying eggs) (MF1) | |
| Surplus roosters (MM) | |
| **Layers production systems** | |
| Reproductive adults (AF, AM) | 0.028 |
| Growing female and male chicks for replacement (RF, RM) | 0.021 |
| Surplus roosters | |
| Laying hens (before laying period) (MF1) | |
| Laying hens (during laying period) (MF2, MF3, MF4) | 0.028 |
| **Broiler production system** | |
| Reproductive adults (AF, AM) | 0.032 |
| Growing female and male chicks for replacement (RF, RM) | 0.010 |
| Broiler animals (M2) | 0.017 |

### *3.5.3.3 – Energy requirement for egg production ($ME_{egg}$)*

$ME_{egg}$ is the metabolizable energy requirement for egg production. It applied only to the laying animals, specifically: reproductive females for all systems (AF), laying surplus females for backyard chickens (MF2) and surplus females during the first and second laying period for layers (MF2, MF3, MF4).

**Equation 3.51**

| | | |
|---|---|---|
| $ME_{egg,c}$ | = | $10^{-3} * EGG * C_{egg}$ |

Where:

| | | |
|---|---|---|
| $ME_{egg,c}$ | = | metabolizable energy required by animal for egg production in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| EGG | = | egg mass production, g $egg \cdot animal^{-1} \cdot day^{-1}$ |
| $C_{egg}$ | = | energy requirement coefficient for egg production, $kJ \cdot g\ egg^{-1}$. Default value of 10.03 is used. |
| c | = | cohorts of laying females |

### 3.5.3.4 – Total energy requirement ($ME_{tot}$)

$ME_{tot}$ is the total metabolizable energy requirement for each animal in a given cohort.

**Equation 3.52**

| | | |
|---|---|---|
| a. $ME_{tot,c}$ | = | $ME_{main,c} + ME_{gro,c} + ME_{egg,c}$ |
| | | for c = cohorts of laying females |
| b. $ME_{tot,c}$ | = | $ME_{main,c} + ME_{gro,c}$ |
| | | for c = cohorts other than laying females |

Where:

| | | |
|---|---|---|
| $ME_{tot,c}$ | = | total metabolizable energy required by the animal in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $ME_{main,c}$ | = | metabolizable energy required by the animal for maintenance in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $ME_{gro,c}$ | = | metabolizable energy required by the animal for growth in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $ME_{egg,c}$ | = | metabolizable energy required by the animal for egg production in cohort *c*, $MJ \cdot head^{-1} \cdot day^{-1}$ |

## 3.6 – FEED INTAKE

For each cohort and each species, the feed intake is calculated by dividing the total animal's energy requirement by the average energy content of the ration following Equations 3.53 and 3.54.

**Equation 3.53 - Ruminants**

| | | |
|---|---|---|
| $DMI_{T,c}$ | = | $GE_{tot,T,c} / DIET_{GE,T,fg}$ |

Where:

| | | |
|---|---|---|
| $DMI_{T,c}$ | = | daily feed intake per animal in cohort *c* for species and system *T*, kg $DM \cdot head^{-1} \cdot day^{-1}$ |
| $GE_{tot,T,c}$ | = | total gross energy requirement by animal in cohort *c* for species and system *T*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $DIET_{GE,T,fg}$ | = | average gross energy content of ration for feeding group *fg* for species and system *T*, $MJ \cdot kgDM^{-1}$ |
| c | = | animal cohort *c* for each ruminant species |
| fg | = | feeding group as shown in Table 3.3 |

**Equation 3.54 - Monogastrics**

| | | |
|---|---|---|
| $DMI_{T,c}$ | = | $ME_{tot,T,c} / DIET_{ME}$ |

Where:

| | | |
|---|---|---|
| $DMI_{T,c}$ | = | daily feed intake per animal in cohort *c* for species and system *T*, kg $DM \cdot head^{-1} \cdot day^{-1}$ |
| $ME_{tot,T,c}$ | = | total gross energy requirement by animal in cohort *c* for species and system *T*, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| $DIET_{ME}$ | = | average metabolizable energy content of ration, $MJ \cdot head^{-1} \cdot day^{-1}$ |
| c | = | animal cohort *c* for each monogastric species |

# CHAPTER 4 – ANIMAL EMISSIONS MODULE

This chapter describes how to estimate emissions at herd level associated with animal production, specifically emissions from enteric fermentation and manure management.

The functions of the 'Animal emissions' module are to:

- Calculate the **enteric emissions**.
- Calculate the **methane** and **nitrous oxide** emissions arising from the **manure management**.
- Totalize the **feed, enteric** and **manure management** emissions **for the whole herd or flock**.

For a schematic representation of the animal emissions module, see Figure 4.1.

## 4.1 – MANURE MANAGEMENT SYSTEMS

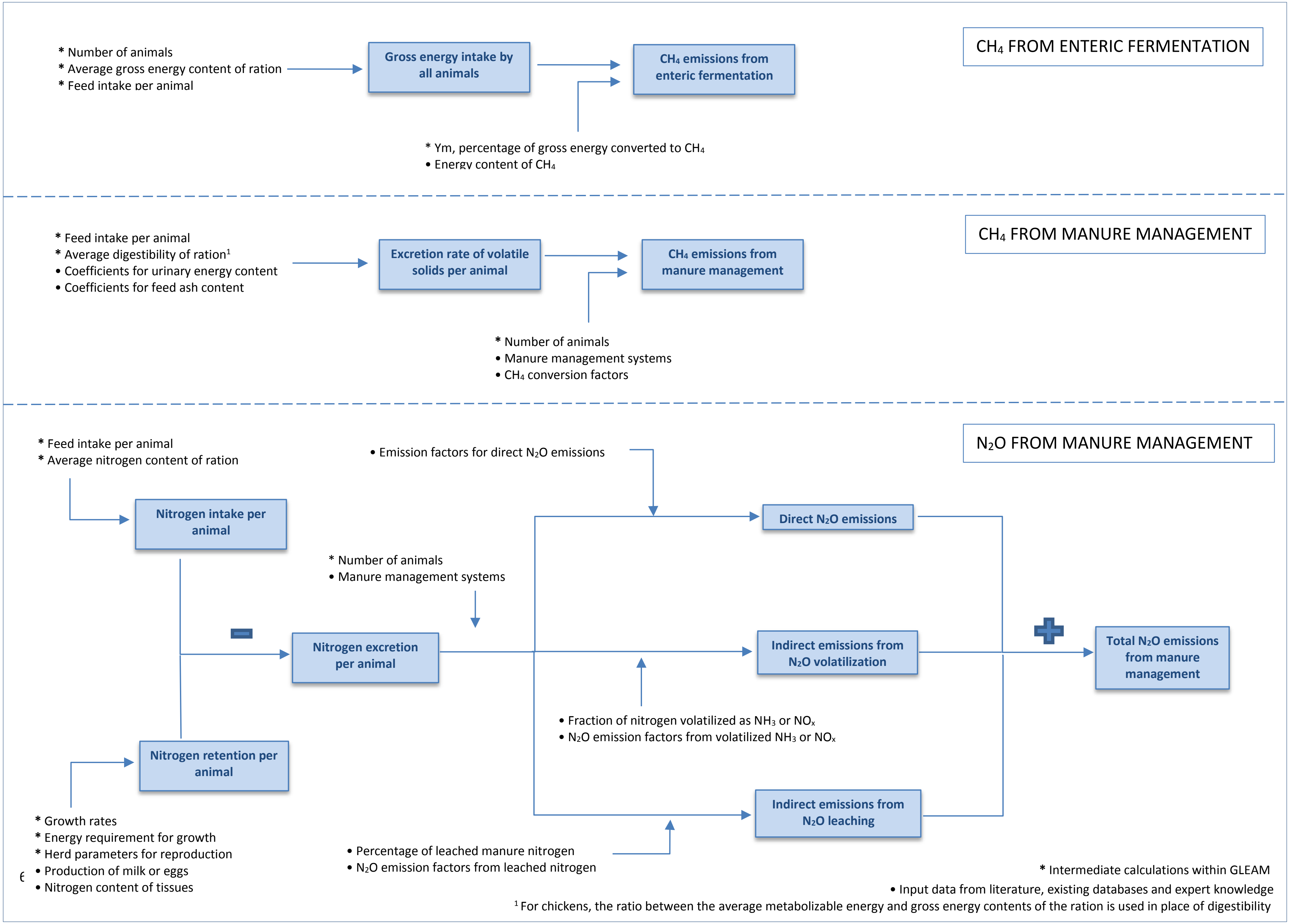
GLEAM uses the IPCC (2006) classification of manure management systems (MMS), defined in Table 4.1. On a global scale, there is very limited data available on how manure is managed. Consequently, GLEAM relies on various data sources such as national inventory reports, literature and expert knowledge to define the MMS and the share of manure allocated to each system. Regional MMS percentages are shown in Tables 4.2 to 4.11 (Supplement S1).

**TABLE 4.1.** Manure management systems definitions

| Manure management system | Description |
|---|---|
| **Pasture/Range/Paddock** | The manure from pasture and range animals is allowed to lie as deposited, and is not managed. |
| **Daily spread** | Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. |
| **Solid storage** | The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of sufficient amount of bedding material or loss of moisture by evaporation. |
| **Dry lot** | A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. |
| **Liquid/Slurry** | Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year. It can present natural crusts (formed by the fibrous material contained in the manure) or not. |
| **Uncovered anaerobic lagoon** | A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields. |
| **Burned for fuel** | The dung and urine are excreted on the fields. The sun dried dung cakes are burned for fuel. |
| **Pit storage** | Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year. |
| **Anaerobic digester** | Animal excreta with or without straw are collected and anaerobically digested in a containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by microbial reduction of complex organic compounds into $CO_2$ and $CH_4$, which is captured and flared or used as fuel. |
| **Composting – Intensive windrow** | Composting (biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production) in windrows with regular (at least daily) turning for mixing and aeration. |
| **Poultry manure with litter** | May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as high-rise manure management system and is a passive windrow composting when designed and operated properly. |

**Source:** IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, 2006.

***Figure 4.1** – Schematic representation of the animal emissions module*



## 4.2 – METHANE EMISSIONS FROM ENTERIC FERMENTATION

Methane is produced during the digestive process in ruminant species and pigs. Emissions from chickens, although present, are negligible. Enteric emissions are closely related to the composition of the diet, particularly to the energy content. 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.

Enteric emissions were calculated as follows:

**Equation 4.1**

$CH_{4\text{-Enteric},T,c}$ = $N_{T,c} * 365 * DIET_{GE,T} * DMI_{T,c} * (Y_{mT,c} / 100) / 55.65$

Where:

$CH_{4\text{-Enteric},T,c}$ = methane emissions from enteric fermentation for cohort *c*, species and system *T*, kg $CH_4 \cdot year^{-1}$

$N_{T,c}$ = number of animals in cohort *c*, species and system *T*, heads

$DIET_{GE,T}$ = average gross energy content of ration for species and system *T*, $MJ \cdot kgDM^{-1}$

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg $DM \cdot head^{-1} \cdot day^{-1}$

$Y_{mT,c}$ = methane conversion factor for cohort *c,* species and system *T*, percentage of energy in feed converted into methane. Values are given in Table 4.12.

55.65 = energy content of methane, $MJ \cdot kg\ CH_4^{-1}$

**TABLE 4.12.** Methane conversion factors for different species and cohorts

| Animal cohort | $Y_m$ (% of energy converted into $CH_4$) |
|---|---|
| **Cattle and Buffaloes** | |
| Cattle (non-feedlot animals) | $9.75 – 0.05 * DIET_{DI,fg}$[a] |
| Feedlot animals | 3 |
| Buffaloes | $9.75 – 0.05 * DIET_{DIfg}$[a] |
| **Sheep and Goats** | |
| Adult reproductive animals | $9.75 – 0.05 * DIET_{DI,fg}$[a] |
| Young replacement and fattening animals | $7.75 – 0.05 * DIET_{DI,fg}$[a] |
| **Pigs** | |
| Adult reproductive animals | 1.01 |
| Replacement and fattening animals | 0.39 |

Where:

$DIET_{DI}$ = average digestibility of ration for the feeding group *fg* (See Table 3.2), percentage

## 4.3 – METHANE EMISSIONS FROM MANURE MANAGEMENT

Methane emissions from manure management were calculated using the IPCC Tier 2 method, which requires the estimation of the excretion rate of volatile solids (VS) per animal and the estimation of the proportion of VS that are converted to $CH_4$. Methane emissions are calculated following Equation 4.2:

**Equation 4.2**

$CH_{4\text{-Manure},T,c}$ = $N_{T,c} * [(365 * VS_{T,c}) * (B_{o,T} * 0.67 * \sum_S((MCF_S / 100) * MS_{T,S}))]$

Where:

$CH_{4\text{-Manure},T,c}$ = total methane emissions from manure management for cohort *c,* species and system *T*, kg $CH_4 \cdot year^{-1}$

$N_{T,c}$ = number of animals in cohort *c*, species and system *T*, heads

$VS_{T,c}$ = daily volatile solid excreted by animal in cohort *c*, species and system *T,* kg $VS \cdot head^{-1} \cdot day^{-1}$

$B_{o,T}$ = maximum methane producing capacity for manure for species and system *T*, $m^3\ CH_4 \cdot kg\ VS^{-1}$

$MCF_S$ = methane conversion factor for each manure management system *S*, percentage. Values are given in Table 4.13

$MS_{T,S}$ = fraction of manure handled by manure management *S* for species and system *T*, fraction

0.67 = conversion factor from volume of methane into kg of gas, kg $CH_4 \cdot m^{-3}$

**TABLE 4.13.** Methane conversion factors for manure management systems

| Manure management system | $MCF_S$ (%) depending on temperature T (°C) | | |
|---|---|---|---|
| | T ≤ 14 | 14 < T < 26 | T ≥ 26 |
| **Pasture/Range/Paddock** | 1.0 | 1.5 | 2.0 |
| **Daily spread** | 0.1 | 0.5 | 1.0 |
| **Solid storage** | 2.0 | 4.0 | 5.0 |
| **Dry lot** | 1.0 | 1.5 | 2.0 |
| **Liquid/Slurry** | 19.494 – 1.5573 * T + 0.1351 * $T^2$ | | |
| **Liquid/Slurry with crust** | 10.655 – 0.8181 * T + 0.0803 * $T^2$ | | |
| **Uncovered anaerobic lagoon** | 44.953 + 2.6993 * T – 0.0527 * $T^2$ | | |
| **Pit storage (< 1 month)** | 3.0 | 3.0 | 30.0 |
| **Pit storage (> 1 month)** | 19.494 – 1.5573 * T + 0.1351 * $T^2$ | | |
| **Pit storage (> 1 month) for chickens** | 2.0 | 4.0 | 5.0 |
| **Anaerobic digester** | 10.0 | 10.0 | 10.0 |
| **Composting – intensive windrow** | 0.5 | 1.0 | 1.5 |
| **Burned for fuel** | 10.0 | 10.0 | 10.0 |
| **Poultry manure with litter** | 1.5 | 1.5 | 1.5 |

GLEAM calculates the VS excretion rate using Equation 4.3 for ruminants, Equation 4.4 for pigs and Equation 4.5 for chicken. All three are based on Equation 10.24 from IPCC (2006).

**Equation 4.3 - Ruminants**

$VS_{T,c}$ = $DMI_{T,c}$ * (1.04 – $DIET_{DI,fg}$ / 100) * 0.92

Where:

$VS_{T,c}$ = daily volatile solid excreted by animal in cohort *c*, species and system *T*, kg VS·head$^{-1}$·day$^{-1}$

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg DM·head$^{-1}$·day$^{-1}$

$DIET_{DI}$ = average digestibility of ration for feeding group *fg*, percentage

fg = feeding group as shown in Table 3.3

The formula is a modification of the original IPCC equation. First, the average gross energy content of the ration is used instead of a fixed value of 18.45 MJ·kg DM$^{-1}$. Thus, GE / $DIET_{GE}$ equals the daily intake, DMI. Second, it is assumed that Urinary energy is 4% and the Ash content in feed is 8%. Therefore, GE * (GE + UE) becomes 1.04 and 1 – ASH becomes 0.92.

**Equation 4.4 - Pigs**

$VS_{T,c}$ = $DMI_{T,c}$ * (1.02 – $DIET_{DI,T}$ / 100) * 0.80

Where:

$VS_{T,c}$ = daily volatile solid excreted by animal in cohort *c*, species and system *T*, kg VS·head$^{-1}$·day$^{-1}$

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg DM·head$^{-1}$·day$^{-1}$

$DIET_{DI}$ = average digestibility of ration for system *T*, percentage

It is assumed that Urinary energy is 2% and the Ash content in feed is 20%. Therefore, GE * (GE + UE) becomes 1.02 and 1 – ASH becomes 0.80.

**Equation 4.5 - Chickens**

$VS_{T,c}$ = $DMI_{T,c}$ * (1.0 – $DIET_{ME,T}$ / $DIET_{GE,T}$) * 0.70

Where:

$VS_{T,c}$ = daily volatile solid excreted by animal in cohort *c*, species and system *T*, kg VS·head$^{-1}$·day$^{-1}$

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg DM·head$^{-1}$·day$^{-1}$

$DIET_{ME,T}$ = average metabolizable energy content of ration for system *T*, MJ·kg DM$^{-1}$

$DIET_{GE,T}$ = average gross energy content of ration for system *T*, MJ·kg DM$^{-1}$

It is assumed that Urinary energy is 0% and the Ash content in feed is 30%. Therefore, GE * (GE + UE) becomes 1 and 1 – ASH becomes 0.70.

## 4.4 – NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

Nitrous oxide emissions from manure management using a Tier 2 approach requires the estimation of the rate of nitrogen excretion per animal and the estimation of the proportion of the excreted nitrogen that is converted to $N_2O$. The nitrogen excretion rates are calculated as the difference between intake and retention. Nitrogen intake depends on the feed intake and the nitrogen content of feed. Nitrogen retention is the amount of nitrogen that is retained in tissues, either as growth, pregnancy, live weight gain or production of milk or eggs.

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. GLEAM uses the IPCC (2006) default emission factors for direct and indirect $N_2O$ emissions, along with variable nitrogen leaching rates.

### *4.4.1 – Nitrogen excretion rate*

GLEAM calculates nitrogen excretion rates following Equations 4.6, which is based on Equations 10.31 to 10.33 from IPCC (2006), as depicted below:

**Equation 4.6**

$$Nx_{T,c} = 365 * ((DMI_{T,c} * DIET_{Ncont,T}) - N_{retentionT,c})$$

Where:

$Nx_{T,c}$ = nitrogen excretion per animal in cohort *c*, species and system *T,* kg N·head$^{-1}$·year$^{-1}$

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg DM·head$^{-1}$·day$^{-1}$

$DIET_{Ncont,T}$ = average nitrogen content of ration for species and system *T*, kg N·kg DM diet$^{-1}$

$N_{retentionT,c}$ = daily nitrogen retention in cohort *c*, species and system *T*, kg N·head$^{-1}$·day$^{-1}$. See Table 4.14.

**TABLE 4.14.** Nitrogen retention formulas for species and cohorts

| Livestock category/cohort | Nitrogen retention |
|---|---|
| **Ruminant species: adult females (AF)** | Equation 4.7a |
| **Ruminant species: adult males (AM)** | N retention is assumed to be null |
| **Ruminant species: other cohorts (RF, RM, MF, MM)** | Equation 4.7b |
| **Pigs: adult females (AF)** | Equation 4.8a |
| **Pigs: adult males (AM)** | N retention is assumed to be null |
| **Pigs: replacement females (RF)** | Equation 4.8b |
| **Pigs: other cohorts (RM, M2)** | Equation 4.8c |
| **Chickens: laying hens (AF, MF2, MF4)** | Equation 4.9a |
| **Chickens: laying hens during the molting period (MF3)** | N retention is assumed to be null |
| **Chickens: other cohorts (AM, RF, RM,MF1, MM, M2)** | Equation 4.9b |

**Equation 4.7 - Ruminants**

a. $N_{retention,AF} = (Milk * Milk_{prot} / 6.38) + (Ckg/365 * (268 - (7.03 * NE_{gro,RF} / DWG_{RF})) * 10^{-3} / 6.25)$

b. $N_{retention,c} = (DWG_c * (268 - (7.03 * NE_{gro,c} / DWG_c)) * 10^{-3} / 6.25)$

Where:

$N_{retention,AF}$ = daily nitrogen retention by animal in cohort *AF*, kg N·head$^{-1}$·day$^{-1}$

$N_{retention,c}$ = daily nitrogen retention by animal in cohort *c*, kg N·head$^{-1}$·day$^{-1}$

Milk = average daily production of milk, applicable only to milking animals, kg milk·head$^{-1}$·day$^{-1}$

$Milk_{prot}$ = average fraction of protein in milk, fraction

6.38 = conversion from milk protein to milk nitrogen, kg protein·kg N$^{-1}$

Ckg = average live weight of calves, kg·head$^{-1}$·day$^{-1}$

$DWG_{RF}$ = average daily weight gain for cohort *RF*, kg·head$^{-1}$·day$^{-1}$

$DWG_c$ = average daily weight gain for cohort *c*, kg·head$^{-1}$·day$^{-1}$

268 and 7.03 = constants from IPCC (2006)

$NE_{gro,RF}$ = net energy required by animal for growth in cohort *RF*, MJ·head$^{-1}$·day$^{-1}$

$NE_{gro,c}$ = net energy required by animal for growth in cohort *c*, MJ·head$^{-1}$·day$^{-1}$

| | | |
|---|---|---|
| 6.25 | = | conversion from dietary protein to dietary nitrogen, kg protein·kg $N^{-1}$ |
| AFC | = | age at first calving, years |
| c | = | cohort for animals other than adult males (See Table 4.14). |

**Equation 4.8 - Pigs**

a. $N_{retention,AF}$ = $((0.025 * LITSIZE * FR * (Wkg - Ckg) / 0.98) + (0.025 * LITSIZE * FR * Ckg)) / 365$

b. $N_{retention,RF}$ = $0.025 * DWG_c * AFCF^{-1} * (((0.025 * LITSIZE * FR * (Wkg - Ckg) / 0.98) + (0.025 * LITSIZE * FR * Ckg)) / 365)$

c. $N_{retention,c}$ = $0.025 * DWG_c$

Where:

| | | |
|---|---|---|
| $N_{retention,AF}$ | = | daily nitrogen retention by animal in cohort *AF*, kg N·$head^{-1}$·$day^{-1}$ |
| $N_{retention,RF}$ | = | daily nitrogen retention by animal in cohort *RF*, kg N·$head^{-1}$·$day^{-1}$ |
| $N_{retention,c}$ | = | daily nitrogen retention by animal in cohort *c*, kg N·$head^{-1}$·$day^{-1}$ |
| 0.025 | = | average content of nitrogen in live weight, kg N·kg $head^{-1}$ |
| LITSIZE | = | litter size, heads |
| FR | = | fertility rate of sows, parturitions·$year^{-1}$ |
| Wkg | = | live weight of piglet at weaning age, kg·$head^{-1}$ |
| Ckg | = | live weight of piglets at birth, kg·$head^{-1}$ |
| 0.98 | = | protein digestibility as fraction, fraction |
| $DWG_c$ | = | average daily weight gain for cohort *c*, kg·$head^{-1}$·$day^{-1}$ |
| AFCF | = | age at first parturition, year |
| c | = | cohort for animals other than adult males (See Table 4.14). |

**Equation 4.9 - Chickens**

a. $N_{retention,c}$ = $N_{LW} * DWG + N_{EGG} * 10^{-3} * EGG$
for c = cohorts of laying females

b. $N_{retention,c}$ = $N_{LW} * DWG$
for c = cohorts other than laying and molting females (see table 4.14).

Where:

| | | |
|---|---|---|
| $N_{retention,c}$ | = | daily nitrogen retention by animal in cohort *c*, kg N·$head^{-1}$·$day^{-1}$ |
| $N_{LW}$ | = | average content of nitrogen in live weight, kg N·kg $head^{-1}$. Default value of 0.028 is used. |
| DWG | = | average daily weight gain for cohort *c*, kg·$head^{-1}$·$day^{-1}$ |
| $N_{EGG}$ | = | average content of nitrogen in eggs, kg N·kg $egg^{-1}$. Default value of 0.0185 is used. |
| EGG | = | egg mass production, g egg·$head^{-1}$·$day^{-1}$ |

### *4.4.2 – Direct $N_2O$ emissions*

GLEAM calculates direct emissions using Equation 4.10, based on Equation 10.25 from IPCC (2006).

**Equation 4.10**

$N_2O_{Direct,T,c}$ = $(44 / 28) * N_{T,c} * Nx_{T,c} * \sum_S(EF_{Dir,S} * MS_S)$

Where:

| | | |
|---|---|---|
| $N_2O_{Direct,T,c}$ | = | total direct nitrous oxide emissions from manure management from cohort *c*, species and system *T*, kg $N_2O$·$year^{-1}$ |
| $EF_{Dir,S}$ | = | emission factor for direct nitrous oxide emissions from manure management system *S*, kg $N_2O$-N·kg $N^{-1}$. Values are shown in Table 4.15. |
| $N_{T,c}$ | = | number of animals in cohort *c*, species and system *T*, head |
| $Nx_{T,c}$ | = | nitrogen excretion per animal in cohort c, species and system T, kg N·head-1·year-1 |
| $MS_S$ | = | fraction of manure handled by manure management system S, fraction |
| 44 / 28 | = | conversion factor from N2O-N to N2O emissions. |

**TABLE 4.15.** Emission factor for direct emissions for different manure management systems

| Manure management system | $EF_{Dir,S}$ (kg $N_2O$-N·kg $N^{-1}$) |
|---|---|
| **Pasture/Range/Paddock** | -[a] |
| **Daily spread** | 0.000 |
| **Solid storage** | 0.005 |
| **Dry lot** | 0.020 |
| **Liquid/Slurry** | 0.000 |
| **Liquid/Slurry with crust** | 0.005 |
| **Uncovered anaerobic lagoon** | 0.000 |
| **Pit storage (< 1 month)** | 0.002 |
| **Pit storage (> 1 month)** | 0.002 |
| **Pit storage (> 1 month) for chickens** | 0.001 |
| **Anaerobic digester** | 0.000 |
| **Composting – intensive windrow** | 0.100 |
| **Burned for fuel** | -[b] |
| **Poultry manure with litter** | 0.001 |

[a] **Ruminants**: emissions from 'Pasture' for ruminant species are calculated in the feed emissions module, as manure used as organic fertilizer, to avoid double-counting. Therefore, $EF_{Dir,S}$ = 0. **Monogastrics:** it is assumed to be similar to drylot. Thus, $EF_{Dir,S}$ = 0.020.
[b] The emission factor is corrected by the fraction of energy not assimilated. **Ruminants**: $EF_{Dir,S}$ = 0.020 * (100 - $DIET_{DI}$) / 100. **Monogastrics**: $EF_{Dir,S}$ = 0.020 * (1 – $DIET_{ME}$ / $DIET_{GE}$).

## 4.4.3 – Indirect $N_2O$ emissions: volatilization

GLEAM calculates indirect emissions from volatilization using Equation 4.11, based in Equation 10.26 from IPCC (2006).

**Equation 4.11**

$$N_2O_{Vol,T,c} = (44 / 28) * EF_{Vol} * N_{T,c} * Nx_{T,c} * \sum_S(MS_S * (Frac_{GasMS,S} / 100))$$

Where:

$N_2O_{Vol,T,c}$ = indirect $N_2O$ emissions due to volatilization from manure management from cohort *c*, species and system *T*, kg $N_2O$·year$^{-1}$

$EF_{Vol}$ = emission factor for $N_2O$ emissions from N volatilized as $NH_3$ and $NO_x$, kg $N_2O$-N·kg N volatilized$^{-1}$. Default value of 0.01 is used.

$N_{T,c}$ = number of animals in cohort *c*, species and system *T*, head

$Nx_{T,c}$ = nitrogen excretion per animal in cohort *c*, species and system *T,* kg N·head$^{-1}$·year$^{-1}$

$MS_S$ = fraction of manure handled by manure management system *S*, fraction

$Frac_{GasMS,S}$ = percentage of manure nitrogen that volatilizes as $NH_3$ and $NO_x$ in the manure management system *S*, percentage. Values are given in Table 4.16.

44 / 28 = conversion factor from $N_2O$-N to $N_2O$ emissions.

## 4.4.4 – Indirect $N_2O$ emissions: leaching

GLEAM calculates indirect emissions from volatilization using Equation 4.12, based on Equation 10.28 from IPCC (2006).

**Equation 4.12**

$$N_2O_{Leach,T,c} = (44 / 28) * EF_{Leach} * N_c * Nx_c * \sum_S(MS_S * (Frac_{LeachMS,S} / 100))$$

Where:

$N_2O_{Leach,T,c}$ = indirect $N_2O$ emissions due to leaching from manure management from cohort *c*, species and system *T*, kg $N_2O$·year$^{-1}$

$EF_{Leach}$ = emission factor for $N_2O$ emissions from leaching and runoff, kg $N_2O$-N·kg N leached$^{-1}$. Default value of 0.0075 is used.

$N_{T,c}$ = number of animals in cohort *c*, species and system *T*, head

$Nx_{T,c}$ = nitrogen excretion per animal in cohort *c*, species and system *T,* kg N·head$^{-1}$·year$^{-1}$

$MS_S$ = fraction of manure handled by manure management system *S*, fraction

$Frac_{LeachMS,S}$ = percentage of managed manure nitrogen lost due to leaching and runoff in the manure management system *S*, percentage. Values are given in Table 4.17.

44 / 28 = conversion factor from $N_2O$-N to $N_2O$ emissions.

**TABLE 4.16.** Values for nitrogen losses due to volatilization of $NH_3$ and $NO_x$ from manure management

| Livestock category | Manure management system | $Frac_{GasMS}$ (%) |
|---|---|---|
| **Dairy cattle** | Pasture/Range/Paddock | 0 |
| | Daily spread | 7 |
| | Solid storage | 30 |
| | Dry lot | 20 |
| | Liquid/Slurry | 40 |
| | Uncovered anaerobic lagoon | 35 |
| **Beef cattle and Buffaloes** | Pasture/Range/Paddock | 0 |
| | Daily spread | 7 |
| | Solid storage | 45 |
| | Dry lot | 30 |
| | Liquid/Slurry | 40 |
| | Uncovered anaerobic lagoon | 35 |
| **Feedlot cattle** | Solid storage | 45 |
| | Dry lot | 30 |
| | Liquid/Slurry | 40 |
| | Uncovered anaerobic lagoon | 35 |
| | Pit storage | 28 |
| | Composting – intensive windrow | 30 |
| **Small ruminants** | Pasture/Range/Paddock | 0 |
| | Daily spread | 7 |
| | Solid storage | 12 |
| | Dry lot | 30 |
| | Liquid/Slurry | 40 |
| | Uncovered anaerobic lagoon | 35 |
| **Pigs** | Pasture/Range/Paddock | 20 |
| | Daily spread | 7 |
| | Solid storage | 45 |
| | Dry lot | 30 |
| | Liquid/Slurry | 48 |
| | Liquid/Slurry with crust | 48 |
| | Uncovered anaerobic lagoon | 40 |
| | Pit storage (< 1 month) | 25 |
| | Pit storage (> 1 month) | 25 |
| | Anaerobic digester | 0 |
| **Chickens** | Pasture/Range/Paddock | 20 |
| | Daily spread | 7 |
| | Solid storage | 45 |
| | Dry lot | 30 |
| | Liquid/Slurry | 48 |
| | Liquid/Slurry with crust | 48 |
| | Uncovered anaerobic lagoon | 40 |
| | Pit storage (< 1 month) | 55 |
| | Pit storage (> 1 month) | 55 |
| | Anaerobic digester | 0 |
| | Poultry manure with litter | 40 |

**TABLE 4.17** Values for nitrogen losses due to leaching and runoff from manure management (%)

| Region | Solid MMS | Liquid MMS |
|---|---|---|
| **North America** | 4 | 2 |
| **Russian Federation** | 4 | 4 |
| **Western Europe** | 4 | 2 |
| **Eastern Europe** | 4 | 4 |
| **Near East and North Africa** | 2-10* | 15-20* |
| **Oceania** | 2 | 15 |
| **South Asia** | 2-10* | 15-20* |
| **Latin America and the Caribbean** | 2-10* | 15-20* |
| **Sub-Saharan Africa** | 2-10* | 15-20* |

* Variation in percentages depending on the combination of production systems (grassland or mixed) and agro-ecological zones.

# 4.5 – TOTALIZING EMISSIONS AT HERD OR FLOCK LEVEL

The last step of the animal emissions module is to totalize, for the entre herd or flock, the emissions related to animal production (enteric fermentation and manure management).

**Equation 4.13**

d. $CH_{4\text{-Enteric},T}$ = $\sum_c(CH_{4\text{-Enteric},T,c})$

e. $CH_{4\text{-Manure},T}$ = $\sum_c(CH_{4\text{-Manure},T,c})$

f. $N_2O_{\text{-Manure},T}$ = $\sum_c(N_2O_{Direct,T,c} + N_2O_{Vol,T,c} + N_2O_{Leach,T,c})$

Where:

$CH_{4\text{-Enteric},T}$ = total methane emissions from enteric fermentation for species and system *T*, kg $CH_4 \cdot year^{-1}$

$CH_{4\text{-Manure},T}$ = total methane emissions from manure management for species and system *T*, kg $CH_4 \cdot year^{-1}$

$N_2O_{\text{-Manure},T}$ = total nitrous oxide emissions from manure management for species and system *T*, kg $N_2O \cdot year^{-1}$

$CH_{4\text{-Enteric},T,c}$ = methane emissions from enteric fermentation for species and system *T* and cohort *c*, kg $CH_4 \cdot year^{-1}$

$CH_{4\text{-Manure},T,c}$ = methane emissions from manure management for species and system *T* and cohort *c*, kg $CH_4 \cdot year^{-1}$

$N_2O_{Direct,T,c}$ = direct nitrous oxide emissions from manure management for species and system *T* and cohort *c*, kg $N_2O \cdot year^{-1}$

$N_2O_{Vol,T,c}$ = indirect nitrous oxide emissions due to volatilization from manure management for species and system *T* and cohort *c*, kg $N_2O \cdot year^{-1}$

$N_2O_{Leach,T,c}$ = indirect nitrous oxide emissions due to leaching from manure management for species and system *T* and cohort *c*, kg $N_2O \cdot year^{-1}$

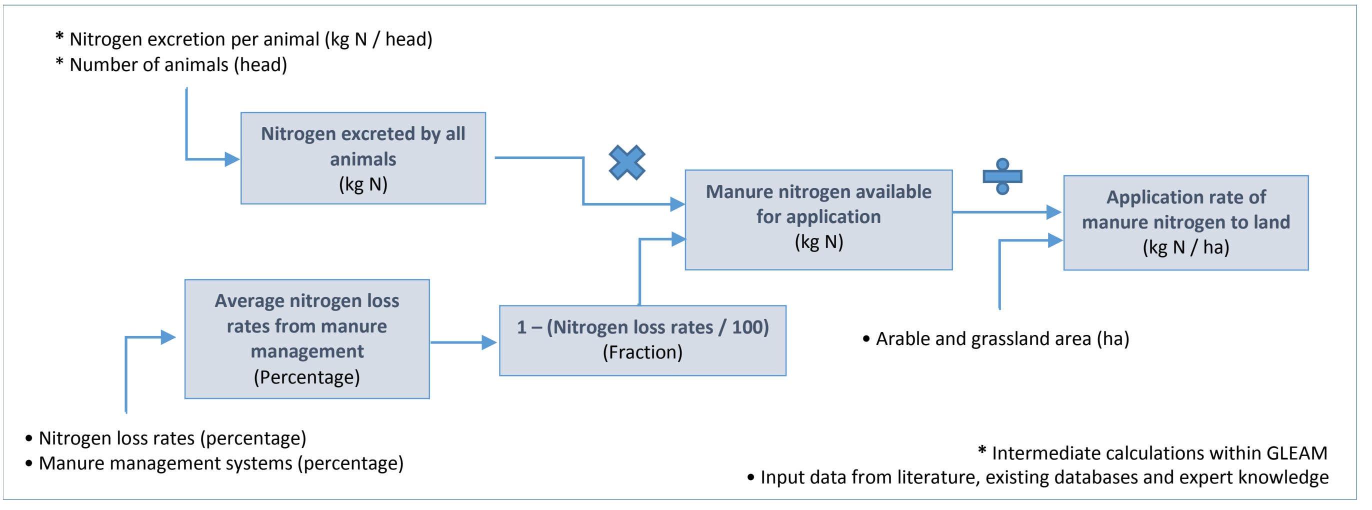
# CHAPTER 5 – MANURE MODULE

Manure management and application is a key component of crop and livestock production systems. Manure contributes to soil fertility and to nutrient and energy cycles. It is also responsible for emissions of $N_2O$ and $CH_4$. GLEAM estimates GHG emissions from manure storage and management, and from its application on crops used as livestock feed and on pastures.

The function of the 'Manure' module is to calculate the losses of nitrogen through manure management and the rate at which excreted nitrogen is applied and deposited in feed crops' fields and pastures. Actual emissions of $N_2O$ (and $CH_4$) are calculated in the Animal emissions module.

For a schematic representation of the manure module, see Figure 5.1.

***Figure 5.1** – Schematic representation of the manure module*




## 5.1 – NITROGEN EXCRETION RATES

Total excreted nitrogen is based upon IPCC Tier 2 approach as defined in Section 4.4.1 and calculated in Equation 5.1.

**Equation 5.1**

$$NEX_T = \sum_c (N_{T,c} * Nx_{T,c})$$

Where:

$NEX_T$ = total nitrogen excreted from all animals of species and system *T*, kg N

$N_{T,c}$ = number of animals from species and system *T* and from cohort *c*, head

$Nx_{T,c}$ = nitrogen excretion by animal of species and system *T* and cohort *c* (Equation 4.6), kg N·head$^{-1}$

## 5.2 – NITROGEN LOSSES FROM MANAGEMENT

Total nitrogen losses are calculated following Equation 5.2.

**Equation 5.2**

$$NLOSS_T = \sum_S (MMS_{T,S} * NLOSS_S / 100)$$

Where:

$NLOSS_T$ = average nitrogen loss rates from all animals of species and system *T*, percentage

$MMS_{T,S}$ = share of manure management system *S* for species and system *T*, percentage

$NLOSS_S$ = nitrogen losses rates from manure management *S*, percentage. Values are taken from IPCC Guidelines (Table 10.23, Chapter 10, Volume 4).

## 5.2 – APPLICATION RATES TO ARABLE AND PASTURE LAND

Nitrogen application rate to arable and pasture land per hectare are calculated following Equation 5.3. Data on arable and pasture land were obtained from Latham et. al. 2014.

**Equation 5.3**

$$NMANUREHA = \sum_T (NEX_T * (1 - NLOSS_T / 100)) / (ARABLEHA + PASTUREHA)$$

Where:

NMANUREHA = total nitrogen per hectare available for application, kg N·ha$^{-1}$

$NEX_T$ = total nitrogen excreted from all animals of species and system *T*, kg N

$NLOSS_T$ = average nitrogen loss rates from all animals of species and system *T*, percentage

ARABLEHA = total hectares of arable land, ha

PASTUREHA = total hectares of pastureland, ha

# CHAPTER 6 – FEED EMISSIONS MODULE

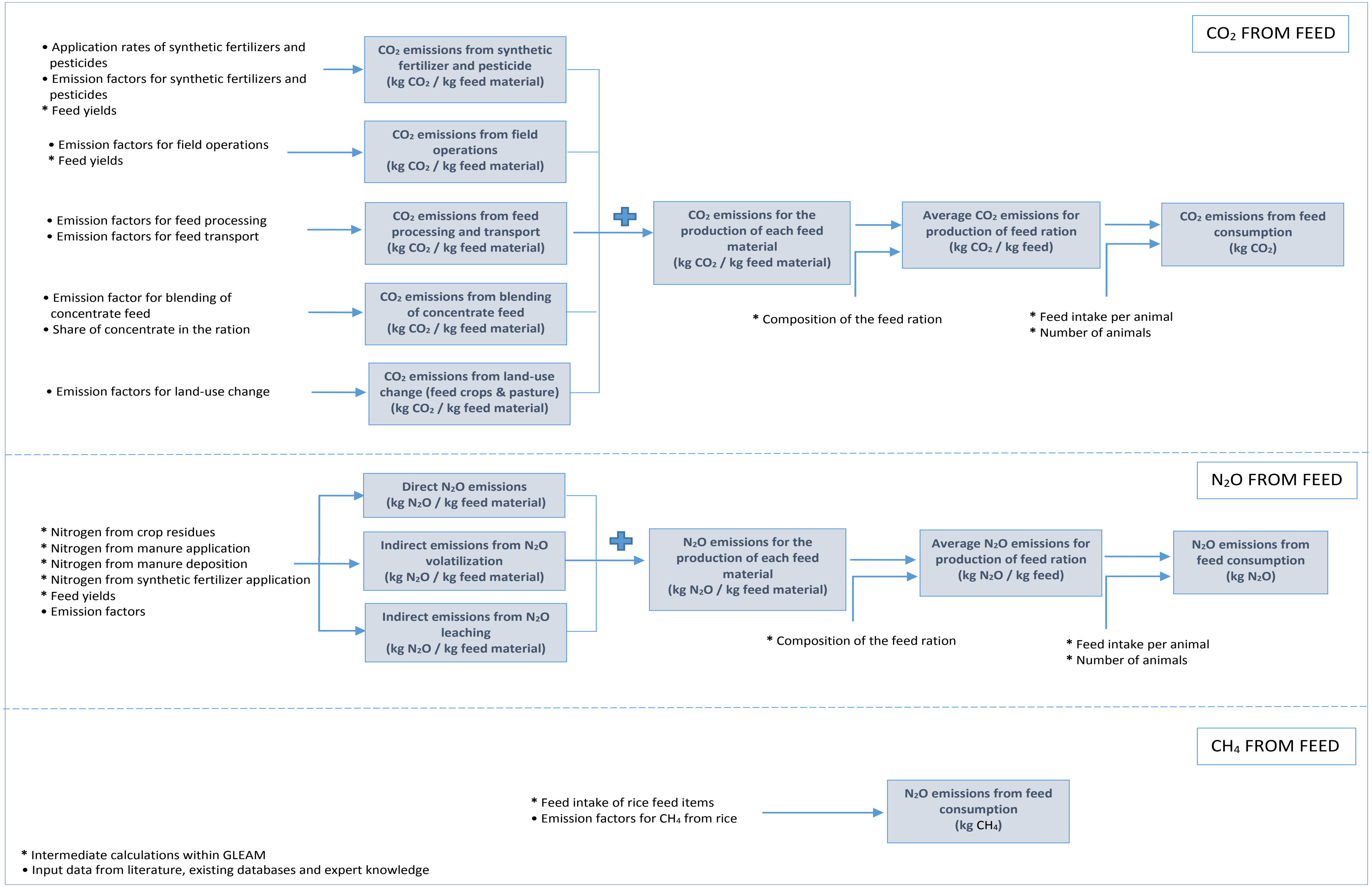
Emissions associated with feed production arise from different sources and include different GHGs. First, emissions of carbon dioxide are associated with the production of synthetic fertilizers and pesticides, energy consumption for tillage, crop management, harvest and storage and, in the case of some feed materials such as by-products, with processing. For some crops emissions include the transport and the energy used in blending and pelleting.

Second, nitrous oxide emissions derive from fertilizer application, manure application and deposition and nitrogen from crop residues, in the form of direct and indirect emissions, through volatilization and leaching. Finally, methane emissions can arise from rice cultivation (rice used as feed).

The functions of the 'Feed emissions' module are to:

- Calculate the **GHG emissions** related to feed production.
- Calculate the **total emissions** related to the **feed consumption**.
- Totalize the **feed** emissions **for the whole herd or flock**.

**Figure 6.1 –** Schematic representation of the feed emissions module



# 6.1 – CO2 EMISSIONS

## 6.1.1 – Synthetic N, P and K fertilization and pesticides manufacture

Synthetic nitrogen, phosphorus and potassium fertilizer, as well as pesticides application rates were defined at a national level, based on the LEAP database (LEAP, 2015). $CO_2$ emissions related to the manufacture and transport of fertilizers and pesticides were calculated using Equation 6.1:

**Equation 6.1**

a. $CO2NFERTHA_i = NFERTHA_i * EF_{NFERT}$

b. $CO2PFERTHA_i = PFERTHA_i * EF_{PFERT}$

c. $CO2KFERTHA_i = KFERTHA_i * EF_{KFERT}$

d. $CO2PESTHA_i = PESTHA_i * EF_{PEST}$

Where:

$CO2...HA_i$ = carbon dioxide emissions from product … (N, P, K fertilizer or pesticides) manufacturing for feed material *i*, kg $CO_2 \cdot ha^{-1}$

$...HA_i$ = application rate of product … (N, P, K fertilizer or pesticides) for feed material *i*, kg $N \cdot ha^{-1}$

$EF_{...}$ = regional emission factor of N, P, K fertilizer manufacture or global emission factor for pesticides manufacture, kg $CO_2 \cdot kg$ $product^{-1}$.

## 6.1.2. – Field operations

Energy is used on-farm for a variety of field operations required for crop cultivation, such as: ploughing, seedbed preparation, sowing, fertilization (lime, organic and synthetic fertilizer application), pesticide spraying, weed control, irrigation and harvesting. Data on the type and amount of energy required and emissions associated per hectare of each feed crop were taken from literature review, existing databases (LEAP, 2015), expert knowledge and surveys (Tables 6.1 and 6.2; Supplement S1). Field operations are undertaken using non-mechanized power sources, i.e. human or animal labour, in some countries. To reflect this variation, the emissions per hectare were adjusted according to the proportion of the field operations undertaken using non-mechanized power sources for each feed material (Tables 6.3 and 6.4; Supplement S1).

## 6.1.3 – Feed transport and processing

Forage, local feeds and swill, by definition, are transported over minimal distances and therefore emissions for transport are set to zero. Non-local feeds for monogastrics and by-products and concentrate for ruminants are assumed to be transported between 100 km and 700 km by road to their place of processing. In countries where more feed is consumed than produced (i.e. net importers), feed materials that are known to be traded globally (e.g. soybean cakes and palm kernel cakes) 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. Data on transport distances, energy consumption for processing activities and associated emissions for each feed materials were taken from literature review, existing databases and expert knowledge (Tables 6.5 and 6.6; Supplement S1).

## 6.1.4 – Blending and transport of concentrate feed

In addition, energy is used in feed mills for blending concentrate feed materials, in some cases for transforming the blended materials into pellets, and to transport them to their point of sale. It was assumed that an average of 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, which results in an emission factor of **0.0786 kg $CO_2$-eq·kg concentrate feed$^{-1}$**. Therefore, emissions from blending and transport of concentrate feed are calculated as follows:

**Equation 6.2 - Ruminants**

$CO_2kg_{-blend,i.c,T} = EF_{blend} * CONC_{fg,T} * CF_{i,T}$

for i = 18 to 29 from Table 3.2

Where:

$CO_2kg_{-blend,i,c,T}$ = total carbon dioxide emissions from blending and transport of concentrate feed per kg of dry matter for feed material *i*, cohort *c*, species and system *T,* kg $CO_2 \cdot kg$ $DM^{-1}$.

| | | |
|---|---|---|
| $EF_{blend}$ | = | emission factor for blending and transport of concentrate feed, kg CO2·kg DM-1. Default value of 0.0786. |
| $CONC_{fg,T}$ | = | fraction of concentrates in the diet for the feeding group fg, species and system T, fraction |
| $CFi_{,T}$ | = | fraction of feed material i in the composition of concentrate feed for species and system T, fraction |

**Equation 6.3 - Monogastrics**

$CO_2kg_{-blend,i.c,T}$ = $EF_{blend}$ * $FEED_{i,T}$
for i = 21 to 42 from Table 3.14

| | | |
|---|---|---|
| $CO_2kg_{-blend,i,c,T}$ | = | total carbon dioxide emissions from blending and transport of concentrate feed per kg of dry matter for feed material *i*, cohort *c*, species and system *T,* kg $CO_2$·kg $DM^{-1}$. |
| $EF_{blend}$ | = | emission factor for blending and transport of concentrate feed, kg $CO_2$·kg $DM^{-1}$. Default value of 0.0786. |
| FEEDi,T | = | fraction of feed material i in the ration of species and system T, fraction. Described in section 3.3.5 |

### *6.1.5 – Land-use change: approach for feed crops*

Land-use change is a highly complex process. It results from the interaction of diverse drivers which may be direct or indirect and can involve numerous transitions, such as clearing, grazing, cultivation, abandonment and secondary forest re-growth. From a climate change point of view, deforestation is the land-use change process generating most GHG emissions (IPCC, 2007). The debate surrounding the key drivers of deforestation is ongoing and so is the attribution of GHG emissions to these drivers.

In GLEAM, land-use changes are considered as the transformation of forest to arable land for feed crops and that of forest to pasture. Emissions are generally quantified according to IPCC Tier I guidelines (IPCC, 2006).

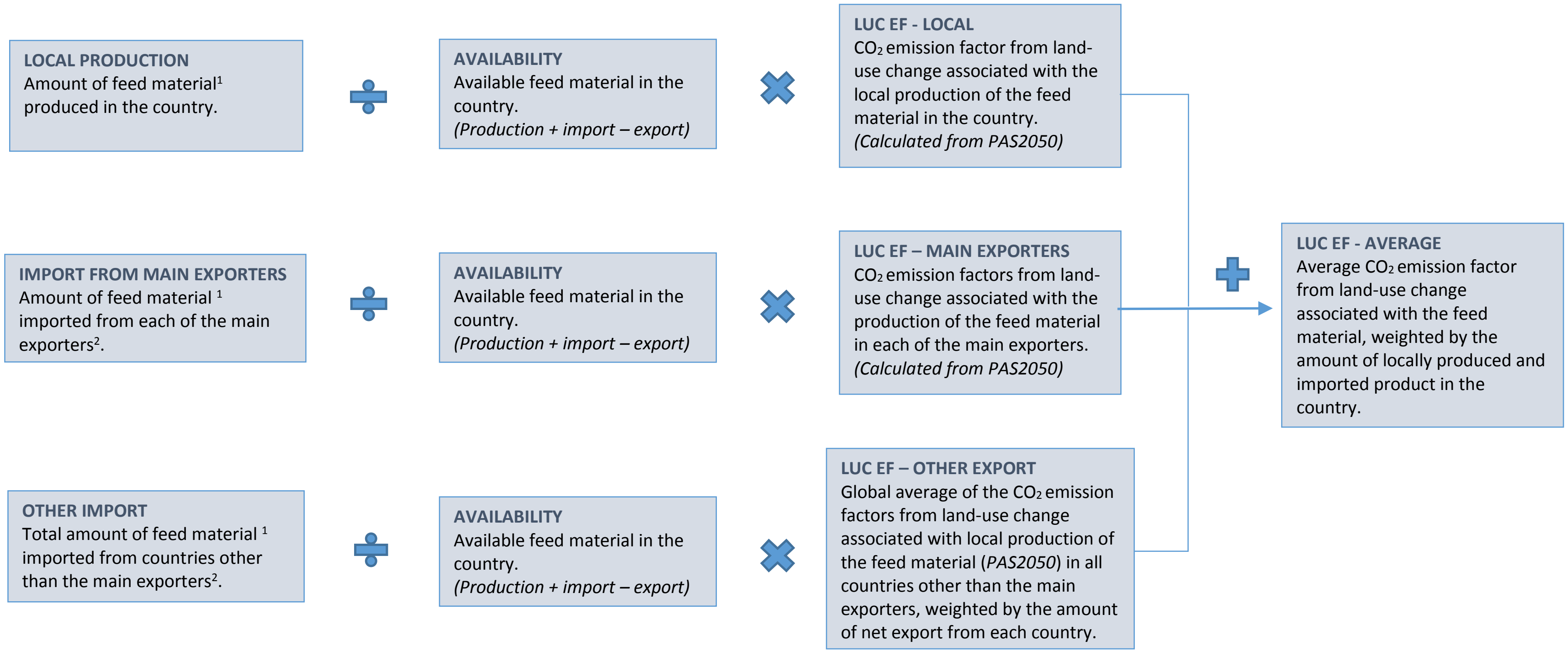
The expansion of feed crops is limited to soybean and to palm oil production. This decision results from the observation of trends in land-use transitions and crop expansions: over the 1990–2010 period, which is used as the reference time period in GLEAM for the analysis of land-use change, the main global cropland expansions were for maize, soybean production and palm. However, only soybean and palm tree production was correlated with an increased demand for feed.

Emissions related to LUC for soybean and palm kernel cakes were calculated using the PAS2050 tool (BSI, 2008), which provides an estimate of emissions associated with the cultivation of soybean and palm oil trees at national level (Tables 6.7 and 6.8; Supplement S1).

GHG emissions related to land-use change were attributed to the systems and regions that use feed resources associated with deforestation. Trade matrices were used to track international flows of soybean, soybean cake, soybean oil and palm kernel cakes and to estimate the share of products from deforested areas in the ration of animals.

Due to their role in driving land use change, the analysis focused on soybean products imported from Brazil, Argentina and Paraguay and palm kernel cake imported from Indonesia and Malaysia. These countries, in addition to being major exporters also have some of the highest deforestation rates associated with the expansion of soybean and palm tree production. Within Latin America, 95% of the soybean area expansion that took place over the period 1990–2010 happened in Brazil, Argentina and Paraguay; while in South-east Asia, 94% of the palm expansion during the same period took place in Indonesia and Malaysia. For the share of these feed materials imported from other countries, instead, a global average emission factor weighted by the net export was used. For a schematic representation of the calculation of the average emission factors for LUC associated with the production and import of soy products and palm kernel cake in each country see Figure 6.2 Further explanations and sensitivity analyses are available in FAO (2013a) and FAO (2013b).

***Figure 6.2** – Schematic representation of the calculation of the average emission factors for land-use change associated with the production and import of soybean products and palm kernel cake in a given country.*




[1] Emissions from land-use change were calculated for the following feed materials: **s**oybeans, soybean cake, soybean oil and palm kernel cake. For soybean cake and oil, data on production and trade for both the co-product and soybeans were used, to account also for the amount of co-product produced from imported soybeans.

[2] The following countries were considered as main exporters: Brazil, Argentina and Paraguay for soy products; Indonesia and Malaysia for palm.

### *6.1.6 – Land-use change: pasture expansion*

At global level, a large share of deforested area is destined to pasture expansion. Table 6.9 shows the net changes for different land use categories across regions.

**TABLE 6.9** Net changes in area for main land-use categories (1990-2010)

| Countries | Arable land & permanent crops | Pasture area | Forest area | Other land |
|---|---|---|---|---|
| | Area (1,000 hectare) | | | |
| **Africa** | 55,989 | -20,894 | -67,458 | 32,488 |
| **Asia*** | 6,321 | 48,722 | 25,263 | -64,821 |
| **Europe** | -78,727 | -230,713 | 3,524 | -150,747 |
| **North America** | -32,696 | 9,676 | 5,299 | 23,443 |
| **Latin America and the Caribbean** | 37,426 | 20,177 | -86,199 | 25,366 |
| **Oceania** | -6,937 | -63,397 | -4,824 | 75,171 |

* Central Asia is excluded due to incomplete dataset.

Emissions from deforestation associated with pasture expansion were quantified for Latin America only. This simplification results from the observation that, during the period 1990–2010, significant pasture expansions and simultaneous forest area decrease occurred in Latin America and Africa. However, grazing does not appear to be a significant driver of deforestation in Africa. In Latin America, the quantification of emissions was limited to the four countries accounting for over 97% of the regional area converted from forest to pasture (i.e. Brazil, Chile, Nicaragua and Paraguay).

Emissions associated with the expansion of pasture into forest areas in Latin America were attributed to beef in grassland base systems production in those countries in which the conversion occurred. In absolute term, this is equal to 387 million tonnes per year.

The approach is based on the IPCC stock-based approach termed the *Stock-Difference Method*, which can be applied where carbon stocks are measured at two points in time to assess carbon stock changes (IPCC, 2006). The calculations of land-use change were accomplished in two steps: first, the assessment of land-use dynamics; and second, the carbon emissions based on land-use dynamics and biophysical conditions. A complete assessment of carbon emissions from LUC involves the quantification of several key elements including deforestation rates, land-use dynamics, and initial carbon stocks in biomass and soil.

#### *Total land area converted*

Changes in land-use area were estimated on the basis of the Tier 1 approach outlined in Chapter 3 of the IPCC guidelines, which estimates the total change in area for each individual land-use category in each country. Table 6.10 presents the countries in which the increase in pasture area was largely facilitated by a decrease in forest area, and our estimates show that about 13 million hectares were deforested for pasture establishment.

**TABLE 6.10** Pasture expansion against forestland in Latin America (1900-2010)

| Countries | Change in pasture area (1,000 hectare) | Share of regional expansion (percentage) |
|---|---|---|
| **Brazil** | 11,800 | 71.9 |
| **Chile** | 1,165 | 7.1 |
| **Paraguay** | 2,040 | 12.4 |
| **Nicaragua** | 670 | 4.1 |
| **Other*** | 726 | 4.4 |
| **Total** | 16,401 | 100.0 |

* Other include: Honduras, Ecuador, Panama, El Salvador and Belize

#### *Changes in carbon stocks from biomass, dead organic matter and soil organic carbon*

Changes in carbon stocks from above- and below-ground biomass were calculated using the Equation 2.16 from IPCC 2006 guidelines (Chapter 2, Volume 4). Following the Tier 1 approach, default biomass after conversion of forest to grassland is 0 tonnes of dry matter per hectare, under the assumption that all biomass is cleared. Due to the lack of data on below-ground biomass, the ratio of below-to-above ground biomass (root-to-shoot ratio) was used to estimate the below-ground component of biomass. The approach to estimating changes in carbon stocks in dead wood and litter pools is to estimate the carbon stocks in the old and new land-use categories and apply this change in the year of conversion. Equation 2.23 (IPCC, 2006, Volume 4, Chapter 2) was used to estimate changes in carbon stocks from dead organic matter. Tier 1 default factors for dead wood and litter were taken from IPCC (2006, Volume 4, Chapter 2, Table 2.2).

The calculation of soil organic carbon losses per hectare of area transformed from forest to grassland is based on equation 2.25 in IPCC (2006, Volume 4, Chapter 2), which takes into account changes in soil carbon stocks associated with type of land use, management practices and input of organic matter (fertilization, irrigation, liming and grazing intensity) in the soil. To establish SOC stocks, the soil divisions were further aggregated into dominant soil type classes defined in IPCC guidelines based on the World Reference Base for Soil Resources classification. The 2006 IPCC guidelines provide average default SOC stocks for the dominant soil classes clustered by eco-region. For Tier 1, all stock change factors were assumed to be equal to 1 for forest land, corresponding to the default values in IPCC guidelines. For grasslands, stock change factors used for land use and input were also assigned a value of 1. Results, in Table 6.11, show a net decrease in SOC with losses ranging between 1.1 to 2.3 t C $ha^{-1}$.

**TABLE 6.11.** Soil organic carbon pool at 0-30 cm depth

| Countries | Soil C stocks under forest | Soil C stocks under grassland | Net change in carbon stocks | Net annual change |
|---|---|---|---|---|
| | tonnes C·$ha^{-1}$ | | tonnes C·$ha^{-1}$ | tonnes C·$ha^{-1}$·$year^{-1}$ |
| **Brazil** | 60 | 58.20 | -1.8 | -0.11 |
| **Chile** | 44 | 42.68 | -1.3 | -0.08 |
| **Paraguay** | 65 | 63.05 | -2.0 | -0.12 |
| **Nicaragua** | 35 | 33.95 | -1.1 | -0.07 |
| **Honduras** | 56 | 54.32 | -1.7 | -0.11 |
| **Ecuador** | 78 | 75.66 | -2.3 | -0.15 |
| **Panama** | 65 | 63.05 | -2.0 | -0.12 |
| **El Salvador** | 50 | 48.50 | -1.5 | -0.09 |
| **Belize** | 65 | 63.05 | -2.0 | -0.12 |

# 6.2 – NITROUS OXIDE EMISSIONS

The emissions of nitrous oxide from cropping arise from three main sources of nitrogen inputs: 1) manure applied on crops or deposited on pastures, 2) synthetic fertilizers and 3) crop residues. From all of these nitrogen sources, nitrous oxide can be released through direct emissions and indirect ones from leaching and volatilization processes, similarly to what has been described in Section 4.4 for manure management. All were calculated using IPCC (2006) Tier 1 methodology.

## *6.2.1 – Nitrogen from manure applied on crops or deposited on pastures*

Manure nitrogen application rates were calculated in the manure module (Chapter 5). This input of applied manure nitrogen is used for most of the feed materials, with the exception of fresh grass in ruminant feed rations (see feed materials 1 and 4 in Table 3.2). Regarding Feed materials 1 and 4, manure deposited on pastures by grazing animals is an alternative source of nitrogen. This input of manure nitrogen is calculated as follows:

**Equation 6.4**

$$Ngraze_{i,T} = DMYG_i * (Ncont_i / 1000) * (\sum_c(N_{T,c} * N_{X,T,c})) / (\sum_c(N_{T,c} * (DMI_{T,c} * DIET_{Ncont,T} * 365)))$$

for i = 1 and 4 from Table 3.2 (only for ruminants)

Where:

$Ngraze_{i,T}$ = nitrogen input rate from manure deposited on pastures for feed material *i* , species and system *T* (only ruminants), kg N·$ha^{-1}$

$DMYG_i$ = gross dry matter yield of feed material *i*, kg·$ha^{-1}$

$Ncont_i$ = nitrogen content of feed material *i*, gN·kg $DM^{-1}$

$N_{T,c}$ = number of animals in cohort *c*, species and system *T* (only ruminants), head

$Nx_{T,c}$ = nitrogen excretion per animal in cohort *c*, species and system *T* (only ruminants), kg N·$head^{-1}$·$year^{-1}$

DMIT,c = daily feed intake per animal in cohort c for species and system T, kg DM·head-1·day-1

DIETNcont,T = average nitrogen content of ration for species and system T, kg N·kg DM diet-1

Emissions of nitrous oxide per hectare of each feed material from manure applied on crops or deposited on pastures are then calculated using Equations 6.5.a (deposited on pasture) and 6.5.b (applied on crops):

**Equation 6.5**

a. $N_2Oha_{-manure,i}$ = $Ngraze_{i,T} * (EF_{dir-p} + Frac_{vol1} * EF_{vol} + Frac_{leach} * EF_{leach}) * 44 / 28$
for i = 1 and 4 from Table 3.2 (only for ruminants)

b. $N_2Oha_{-manure,i}$ = $NMANUREHA * (EF_{dir} + Frac_{vol1} * EF_{vol} + Frac_{leach} * EF_{leach}) * 44 / 28$
for i = other feed materials

Where:

$N_2Oha_{-manure,i}$ = total nitrous oxide emissions from manure application or deposition per hectare of feed material *i*, kg $N_2O \cdot ha^{-1}$

$Ngraze_{i,T}$ = nitrogen input rate from manure deposited on pastures for feed material *i* , species and system *T* (only ruminants), kg $N \cdot ha^{-1}$

NMANUREHA = total nitrogen per hectare available for application, kg $N \cdot ha^{-1}$

$EF_{dir-p}$ = emission factor for direct nitrous oxide emissions from manure deposited on pasture, kg $N_2O\text{-}N \cdot kg\ N^{-1}$. Default value of 0.02 is used for large ruminants and 0.01 for small ruminants.

$EF_{dir}$ = emission factor for direct nitrous oxide emissions, kg $N_2O\text{-}N \cdot kg\ N^{-1}$. Default value of 0.01 is used (0.03 for rice feed materials).

$EF_{vol}$ = emission factor for $N_2O$ emissions from N volatilized as $NH_3$ and $NO_x$, kg $N_2O\text{-}N \cdot kg$ N volatilized$^{-1}$. Default value of 0.01 is used.

$EF_{leach}$ = emission factor for $N_2O$ emissions from leaching and runoff, kg $N_2O\text{-}N \cdot kg$ N leached$^{-1}$. Default value of 0.0075 is used.

$Frac_{vol1}$ = fraction of nitrogen from manure applied or deposited on crops and pastures that volatilizes as $NH_3$ and $NO_x$, fraction. Default value of 0.2 is used.

$Frac_{leach}$ = fraction of nitrogen lost due to leaching and runoff, fraction. Default value of 0.3 is used.

44 / 28 = conversion factor from $N_2O$-N to $N_2O$ emissions.

### 6.2.2. – Nitrogen from synthetic fertilizers

Application rates of synthetic nitrogen fertilizer were defined at a national level (Section 6.1.1; LEAP, 2015). Emissions of nitrous oxide per hectare of each feed material from synthetic fertilizers are calculated using Equation 6.6:

**Equation 6.6**

$N_2Oha_{-fert,i}$ = $NFERTHA_i * (EF_{dir} + Frac_{vol2} * EF_{vol} + Frac_{leach} * EF_{leach}) * 44 / 28$

Where:

$N_2Oha_{-fert,i}$ = total nitrous oxide emissions from application of nitrogen fertilizer per hectare of feed material *i*, kg $N_2O \cdot ha^{-1}$

$NFERTHA_i$ = application rate of nitrogen fertilizer for feed material *i*, kg $N \cdot ha^{-1}$

$EF_{dir}$ = emission factor for direct nitrous oxide emissions, kg $N_2O\text{-}N \cdot kg\ N^{-1}$. Default value of 0.01 is used (0.03 for rice feed materials).

$EF_{vol}$ = emission factor for $N_2O$ emissions from N volatilized as $NH_3$ and $NO_x$, kg $N_2O\text{-}N \cdot kg$ N volatilized$^{-1}$. Default value of 0.01 is used.

$EF_{leach}$ = emission factor for $N_2O$ emissions from leaching and runoff, kg $N_2O\text{-}N \cdot kg$ N leached$^{-1}$. Default value of 0.0075 is used.

$Frac_{vol2}$ = fraction of nitrogen from synthetic fertilizers or crop residues that volatilizes as $NH_3$ and $NO_x$, fraction. Default value of 0.1 is used.

$Frac_{leach}$ = fraction of nitrogen lost due to leaching and runoff, fraction. Default value of 0.3 is used.

44 / 28 = conversion factor from $N_2O$-N to $N_2O$ emissions.

### 6.2.3. – Nitrogen release during crop residues decomposition

Nitrogen from crop residues was calculated using the crop yields and the IPCC crop residues formulae (Table 11.2, Chapter 11, Volume 4), following Equation 6.7:

**Equation 6.7**

$$Ncr_i = (DMYGcr_i * N_{AG,i} * (1 - FracRemove_i)) + (R_{BG\text{-}BIO,i} * (DMYGcr_{i} + DMYGcrop_i) * N_{BG,i})$$

Where:

$Ncr_i$ = annual amount of N in crop residues (above and below ground) of feed material *i*, kg N·ha$^{-1}$

$DMYGcr_i$ = crop gross dry matter yield of feed material *i*, kg DM·ha$^{-1}$

$DMYGcrop_i$ = crop residues gross dry matter yield of feed material *i*, kg DM·ha$^{-1}$

$N_{AG,i}$ = nitrogen content of above-ground residues for feed material *i*, kg N·kg DM$^{-1}$. Values are given in Tables 6.12 and 6.13 (Supplement S1).

$FracRemove_i$ = fraction of above-ground residues of feed material *i* removed annually for purpose such as feed, bedding and construction, fraction. A default value of 0.45 is used with the exception of few countries, whose values are given in Table 6.14 (Supplement S1).

$R_{BG\text{-}BIO,i}$ = fraction of below-ground residues to above ground biomass ($DMYGcr_i$ + $DMYGcrop_i$) for feed material *i*, fraction. Values are given in Tables 6.12 and 6.13 (Supplement S1).

$N_{BG,i}$ = nitrogen content of below-ground residues for feed material *i*, kg N·kg DM$^{-1}$. Values are given in Tables 6.12 and 6.13 (Supplement S1).

Emissions of nitrous oxide per hectare of each feed material from crop residues are then calculated using Equation 6.8:

**Equation 6.8**

$$N_2Oha_{\text{-}cr,i} = Ncr_i * (EF_{dir} + Frac_{vol2} * EF_{vol} + Frac_{leach} * EF_{leach}) * 44 / 28$$

Where:

$N_2Oha_{\text{-}cr,i}$ = total nitrous oxide emissions from crop residues per hectare of feed material *i*, kg $N_2O$·ha$^{-1}$

$Ncr_i$ = annual amount of N in crop residues (above and below ground) of feed material *i*, kg N·ha$^{-1}$

$EF_{dir}$ = emission factor for direct nitrous oxide emissions, kg $N_2O$-N·kg N$^{-1}$. Default value of 0.01 is used (0.03 for rice feed materials).

$EF_{vol}$ = emission factor for $N_2O$ emissions from N volatilized as $NH_3$ and $NO_x$, kg $N_2O$-N·kg N volatilized$^{-1}$. Default value of 0.01 is used.

$EF_{leach}$ = emission factor for $N_2O$ emissions from leaching and runoff, kg $N_2O$-N·kg N leached$^{-1}$. Default value of 0.0075 is used.

$Frac_{vol2}$ = fraction of nitrogen from synthetic fertilizers or crop residues that volatilizes as $NH_3$ and $NO_x$, fraction. Default value of 0.2 is used.

$Frac_{leach}$ = fraction of nitrogen lost due to leaching and runoff, fraction. Default value of 0.3 is used.

44 / 28 = conversion factor from $N_2O$-N to $N_2O$ emissions.

## 6.3 – METHANE EMISSIONS FROM RICE USED FOR FEED

Rice differs from all the other feed crops in that it produces significant amounts of $CH_4$. These emissions per hectare are highly variable and depend on the water regime during and prior to cultivation, and the nature of the organic amendments. The average $CH_4$ flux per hectare of rice was calculated for each country using the IPCC Tier 1 methodology as described in the Volume 4, Chapter 5.5.

## 6.4 – GHG EMISSIONS ARISING FROM THE PRODUCTION OF NON-CROP FEED MATERIALS

Default values of **1.4**, **3.6** and **0.08** kg $CO_2$-eq·kg.feed$^{-1}$ for fishmeal, synthetic additives and limestone were used, respectively. Emissions for leaves and swill were assumed to be null.

## 6.5 – ALLOCATION OF EMISSIONS BETWEEN CROP AND CROP CO-PRODUCTS

In order to calculate the emission intensity of each feed material, emissions need to be allocated between the crop and crop co-products, such as crop residues or agro-industrial by-products. To this purpose, three allocation factors are used: 1) the MFA (see Sections 3.2.1 and 3.3.1), defining the crop or co-product mass as a fraction of the total mass, 2) the Economic Fraction Allocation (EFA), which defines the crop or co-product value as a fraction of the total value and 3) the second-grade allocation (A2), to account for the low economic value of second-grade crops (feed materials 3, 6 to 14 and 17 from Table 3.14). The general equations used are as follows:

**Equation 6.9**

a. $CO_2kg_{-Nfert,i} = CO2NFERTHA_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

b. $CO_2kg_{-Pfert,i} = CO2PFERTHA_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

c. $CO_2kg_{-Kfert,i} = CO2KFERTHA_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

d. $CO_2kg_{-pest,i} = CO2PESTHA_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

e. $CO_2kg_{-crop,i} = CO2CROPha_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

f. $CO_2kg_{-proc,i} = CO2PROCkg_i * EFA_i / MFA_i * A2_i$

g. $CO_2kg_{-LUC,i} = CO_2LUCha_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i$

h. $N_2Okg_{-manure,i} = N_2Oha_{-manure,i} / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

i. $N_2Okg_{-fert,i} = N_2Oha_{-fert,i} / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

l. $N_2Okg_{-cr,i} = N_2Oha_{-cr,i} / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

m. $CH_4kg_i = CH_4ha_i / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i}) * EFA_i / MFA_i * A2_i$

Where:

| | | |
|---|---|---|
| $CO_2kg_{i\text{-}Nfert,i}$ | = | total carbon dioxide emissions from N fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-Pfert\ ,i}$ | = | total carbon dioxide emissions from P fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-Kfert,i}$ | = | total carbon dioxide emissions from K fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-pest,i}$ | = | total carbon dioxide emissions from pesticides manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-crop,i}$ | = | total carbon dioxide emissions from field operations per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-proc,i}$ | = | total carbon dioxide emissions from transport and processing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $CO_2kg_{-LUC,i}$ | = | total carbon dioxide emissions from land-use change per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$ |
| $N_2Okg_{i\text{-}manure,i}$ | = | total nitrous oxide emissions from manure application or deposition per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$ |
| $N_2Okg_{i\text{-}fert,i}$ | = | total nitrous oxide emissions from application of nitrogen fertilizer per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$ |
| $N_2Okg_{i\text{-}cr,i}$ | = | total nitrous oxide emissions from crop residues per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$ |
| $CH_4kg_i$ | = | total methane emissions per kilogram of dry matter of feed material *i*, kg $CH_4 \cdot kg\ DM^{-1}$ |
| $CO2NFERTHA_i$ | = | carbon dioxide emissions from N fertilizer manufacturing per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in section 6.1.1 |
| $CO2PFERTHA_i$ | = | carbon dioxide emissions from P fertilizer manufacturing per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in section 6.1.1 |
| $CO2KFERTHA_i$ | = | carbon dioxide emissions from K fertilizer manufacturing per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in section 6.1.1 |
| $CO2PESTHA_i$ | = | carbon dioxide emissions from pesticides manufacturing per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in section 6.1.1 |

$CO2CROPha_i$ = carbon dioxide emissions from field operations per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in section 6.1.2

$CO2PROCkg_i$ = carbon dioxide emissions from transport and processing per kg of parental crop of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$. Described in section 6.1.3

$CO_2LUCha_i$ = carbon dioxide emissions from land-use change per hectare of feed material *i*, kg $CO_2 \cdot ha^{-1}$. Described in sections 6.1.5 and 6.1.6

$N_2Oha_{-manure,i}$ = total nitrous oxide emissions from manure application or deposition per hectare of feed material *i*, kg $N_2O \cdot ha^{-1}$. Described in section 6.2.1

$N_2Oha_{-fert,i}$ = total nitrous oxide emissions from application of nitrogen fertilizer per hectare of feed material *i*, kg $N_2O \cdot ha^{-1}$. Described in section 6.2.2

$N_2Oha_{-cr,i}$ = total nitrous oxide emissions from crop residues per hectare of feed material *i*, kg $N_2O \cdot ha^{-1}$. Described in section 6.2.3

$CH_4ha_i$ = total methane emissions per hectare of feed material *i*, kg $CH_4 \cdot ha^{-1}$. Described in section 6.3

$DMYG_{crop,i}$ = crop gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$DMGY_{cr,i}$ = crop residues gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$FUE_{crop,i}$ = crop feed use efficiency for feed material *i*, i.e. fraction of the gross yield of the crop that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$FUE_{cr,i}$ = crop residues feed use efficiency for feed material *i*, i.e. fraction of the gross yield of the crop residues that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$EFA_i$ = economic fraction allocation, i.e. crop or co-product value as a fraction of the total value (of the crop and co-product) for feed material *i*, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$MFA_i$ = mass fraction allocation, i.e. crop or co-product mass as a fraction of the total mass (crop and co-product) for feed material *i*, fraction. Values are given in Tables 3.4 and 3.15 for ruminant and monogastric species, respectively.

$A2_i$ = second-grade allocation, i.e. ratio of the economic value of second-grade crop to the economic value of its first-grade equivalent for feed material *i* (applied only in backyard systems for monogastric species to feed materials 3, 6 to 14 and 17 from Table 3.14), fraction. Default value of 0.2 is used.

For most of the feed materials, the default MFA factors are shown in Tables 3.4 (for ruminant species) and 3.15 (for monogastric species). For crop residues or grains (whose crop residues are used either as feed or for bedding), dry matter yields and FUE are used to determine the MFA factors, as shown in Equation 6.10.a (for crop residues) and 6.10.b (for grains):

**Equation 6.10**

a. $MFA_{,i} = (DMGY_{cr,i} * FUE_{cr,i}) / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i})$

for i = 9 to 15 from Table 3.2 (for ruminant species)

for i = 4, 13 and 16 from Table 3.14 (for monogastric species)

b. $MFA_{,i} = (DMGY_{crop,i} * FUE_{crop,i}) / (DMYG_{crop,i} * FUE_{crop,i} + DMGY_{cr,i} * FUE_{cr,i})$

for i = 3, 6 to 11, 15, 21, 23, and 25 to 28 from Table 3.14

Where:

$MFAi$ = mass fraction allocation, i.e. crop or crop residues mass as a fraction of the total mass (crop and crop residues) for feed material i, fraction

$DMYG_{crop,i}$ = crop gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$DMGY_{cr,i}$ = crop residues gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$FUE_{crop,i}$ = crop feed use efficiency for feed material *i*, i.e. fraction of the gross yield of the crop that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$FUE_{cr,i}$ = crop residues feed use efficiency for feed material *i*, i.e. fraction of the gross yield of the crop residues that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

If no crop residues are used for feed or bedding, dry matter yield and mass fraction allocation of the residues are assumed to be zero, effectively allocating 100% of the emissions to the crop. As for MFA, the EFA factors are default values for many feed materials (Tables 6.15 and 6.16 for ruminant and monogastric species, respectively), but for grains and crop residues they are calculated as follows:

**Equation 6.11**

a. $EFA_{,i}$ = $(DMGY_{cr,i} * FUE_{cr,i} * VR_{cr,i}) / (DMYG_{crop,i} * FUE_{crop,i} * VR_{crop,i} + DMGY_{cr,i} * FUE_{cr,i} * VR_{cr,i})$
for i = 9 to 15 from Table 3.2 (for ruminant species)
for i = 4, 13 and 16 from Table 3. 14 (for monogastric species)

b. $EFA_{,i}$ = $(DMGY_{crop,i} * FUE_{crop,i} * VR_{crop,i}) / (DMYG_{crop,i} * FUE_{crop,i} * VR_{crop,i} + DMGY_{cr,i} * FUE_{cr,i} * VR_{cr,i})$
for i = 3, 6 to 11, 15, 21, 23, and 25 to 28 from Table 3. 14

Where:

EFAi = economic fraction allocation, i.e. crop or crop residues value as a fraction of the total value (of the crop and crop residues) for feed material i, fraction

$DMYG_{crop,i}$ = crop gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$DMGY_{cr,i}$ = crop residues gross dry matter yield for feed material *i*, kg $DM \cdot ha^{-1}$

$FUE_{crop,i}$ = crop feed use efficiency for feed material *i*, i.e. fraction of the gross yield of the crop that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$FUE_{cr,i}$ = crop residues feed use efficiency for feed material i, i.e. fraction of the gross yield of the crop residues that is effectively used as feed, fraction. Values are given in Tables 6.13 and 6.14 for ruminant and monogastric species, respectively (Supplement S1).

$VR_{crop,i}$ = value ratio of the crop per mass unit of crop and crop residues for feed material *i*, fraction. The price ratio can be used, if available. Otherwise, the digestibility of crop and crop residues can be used as a proxy of their respective value. Values are given in Tables 6.15 and 6.16 for ruminant and monogastric species, respectively.

$VR_{cr,i}$ = value ratio of the crop residues per mass unit of crop and crop residues for feed material *i*, fraction. The price ratio can be used, if available. Otherwise, the digestibility of crop and crop residues can be used as a proxy of their respective value. Values are given in Tables 6.15 and 6.16 for ruminant and monogastric species, respectively.

An allocation factor of 0.2 (A2 in Equation 6.9) is used for second-grade crops, effectively reducing the emissions associated to their production in a roughly proportionate way to their economic value. Clearly, the relative value could potentially vary for different crops and locations depending on supply and demand, or the extent to which there is a market for second-grade crops and the price of alternative feedstuffs.

TABLE 6.15. Parameters for allocation of emissions to feed materials of ruminant species

| Number | Material | $FUE_{crop}$ | $FUE_{cr}$ | EFA | $VR_{crop}$ | $VR_{cr}$ |
|---|---|---|---|---|---|---|
| **Roughages** | | | | | | |
| **1** | GRASSF | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **2** | GRASSH | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **3** | GRASSH2 | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **4** | GRASSLEGF | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **5** | GRASSLEGH | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **6** | ALFALFAH | Table 3.5 (Supplement S1)[a] | NA | 1 | NA | NA |
| **7** | GRAINSIL | 1 | NA | 1 | NA | NA |
| **8** | MAIZESIL | 1 | NA | 1 | NA | NA |
| **9** | RSTRAW | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.66 | 0.34 |
| **10** | WSTRAW | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.67 | 0.33 |
| **11** | BSTRAW | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.67 | 0.33 |
| **12** | ZSTOVER | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.61 | 0.39 |
| **13** | MSTOVER | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.63 | 0.37 |
| **14** | SSTOVER | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.63 | 0.37 |
| **15** | TOPS | 1 | Table 3.5 (Supplement S1)[a] | Equation 6.11a | 0.55 | 0.45 |
| **16** | LEAVES | Table 3.4 | NA | 1 | NA | NA |
| **17** | FDDRBEET | Table 3.4 | NA | 1 | NA | NA |
| **Cereals** | | | | | | |
| **18** | GRAINS | Table 3.4 | NA | 1 | NA | NA |
| **19** | CORN | Table 3.4 | NA | 1 | NA | NA |
| **By-products** | | | | | | |
| **20** | MLSOY | Table 3.4 | NA | 0.72 | NA | NA |
| **21** | MLRAPE | Table 3.4 | NA | 0.28 | NA | NA |
| **22** | MLCTTN | Table 3.4 | NA | 0.23 | NA | NA |
| **23** | PKEXP | Table 3.4 | NA | 0.01 | NA | NA |
| **24** | MZGLTM | Table 3.4 | NA | 0.10 | NA | NA |
| **25** | MZGLTF | Table 3.4 | NA | 0.06 | NA | NA |
| **26** | BPULP | Table 3.4 | NA | 0.11 | NA | NA |
| **27** | MOLASSES | Table 3.4 | NA | 0.06 | NA | NA |
| **28** | GRNBYDRY | Table 3.4 | NA | 0.04 | NA | NA |
| **29** | GRNBYWET | Table 3.4 | NA | 0.08 | NA | NA |

[a] For these feed materials the FUE is spatially explicit.

TABLE 6.16. Parameters for allocation of emissions to feed materials of monogastric species

| Number | Material | $FUE_{crop}$ | $FUE_{cr}$ | EFA | $VR_{crop}$ | $VR_{cr}$ |
|---|---|---|---|---|---|---|
| **Swill and scavenging** | | | | | | |
| **1** | SWILL | Table 3.15 | NA | 1 | NA | NA |
| **Locally-produced feed materials** | | | | | | |
| **2** | GRASSF | Table 3.15 | NA | 1 | NA | NA |
| **3** | PULSES | Table 3.15 | 0.90 | Equation 6.11b | 0.67 | 0.33 |
| **4** | PSTRAW | 1 | Table 3.15 | Equation 6.11a | 0.67 | 0.33 |
| **5** | CASSAVA | Table 3.15 | NA | 1 | NA | NA |
| **6** | WHEAT | Table 3.15 | 0.70[a] | Equation 6.11b | 0.67[c] | 0.33[d] |
| **7** | MAIZE | Table 3.15 | 0.70[b] | Equation 6.11b | 0.62[e] | 0.38[f] |
| **8** | BARLEY | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **9** | MILLET | Table 3.15 | 0.70 | Equation 6.11b | 0.61 | 0.39 |
| **10** | RICE | Table 3.15 | 0.70 | Equation 6.11b | 0.68 | 0.32 |
| **11** | SORGHUM | Table 3.15 | 0.70 | Equation 6.11b | 0.61 | 0.39 |
| **12** | SOY | Table 3.15 | NA | 1 | NA | NA |
| **13** | TOPS | 1 | Table 3.15 | Equation 6.11a | 0.52 | 0.48 |
| **14** | LEAVES | NA | NA | NA | NA | NA |
| **15** | BNFRUIT | Table 3.15 | 0.50 | Equation 6.11b | 0.67 | 0.33 |
| **16** | BNSTEM | 1 | Table 3.15 | Equation 6.11a | 0.67 | 0.33 |
| **17** | MLSOY | Table 3.15 | NA | 0.72 | NA | NA |
| **18** | MLCTTN | Table 3.15 | NA | 0.30 | NA | NA |
| **19** | MLOILSDS | Table 3.15 | NA | 0.23 | NA | NA |
| **20** | GRNBYDRY | Table 3.15 | NA | 0.04 | NA | NA |
| **Non-local feed materials** | | | | | | |
| **21** | PULSES | Table 3.15 | 0 | Equation 6.11b | 0.67 | 0.33 |
| **22** | CASSAVA | Table 3.15 | NA | 1 | NA | NA |
| **23** | WHEAT | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **24** | MAIZE | Table 3.15 | NA | 1 | NA | NA |
| **25** | BARLEY | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **26** | MILLET | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **27** | RICE | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **28** | SORGHUM | Table 3.15 | 0.90 | Equation 6.11b | 0.80 | 0.20 |
| **29** | SOY | Table 3.15 | NA | 1 | NA | NA |
| **30** | RAPESEED | Table 3.15 | NA | 1 | NA | NA |
| **31** | SOYOIL | Table 3.15 | NA | 0.27 | NA | NA |
| **32** | MLSOY | Table 3.15 | NA | 0.72 | NA | NA |
| **33** | MLCTTN | Table 3.15 | NA | 0.23 | NA | NA |
| **34** | MLRAPE | Table 3.15 | NA | 0.28 | NA | NA |
| **35** | PKEXP | Table 3.15 | NA | 0.01 | NA | NA |
| **36** | MLOILSDS | Table 3.15 | NA | 0.28 | NA | NA |
| **37** | FISHMEAL | NA | NA | NA | NA | NA |
| **38** | MOLASSES | Table 3.15 | NA | 0.06 | NA | NA |
| **39** | GRNBYDRY | Table 3.15 | NA | 0.04 | NA | NA |
| **40** | GRNBYWET | Table 3.15 | NA | 0.08 | NA | NA |
| **41** | SYNTHETIC | NA | NA | NA | NA | NA |
| **42** | LIMESTONE | NA | NA | NA | NA | NA |

[a] The value is 0.90 for industrialized countries.
[b] The value is null for industrialized countries.
[c] The value is 0.80 for industrialized countries.
[d] The value is 0.20 for industrialized countries.
[e] The value is 1 for industrialized countries.
[f] The value is null for industrialized countries.

## 6.6 – EMISSIONS FROM FEED CONSUMPTION

Before totalizing emissions at herd or flock level (see Section 6.7), emissions related to feed consumption must be totalized by cohort. This is done by combining the emissions for each feed material (see Section 6.5.) and the average feed dry matter intake per animal of each cohort (see Section 3.6) as shown in Equation 6.12.

**Equation 6.12**

a. $CO_{2\text{-Feed},T,c} = 365 * N_{T,c} * DMI_{T,c} * \sum_i (CO_2kg_{\text{-blend},i,c,T} + (CO_2kg_{\text{-Nfert},i} + CO_2kg_{\text{-Pfert},i} + CO_2kg_{\text{-Kfert},i} + CO_2kg_{\text{-pest},i} + CO_2kg_{\text{-crop},i} + CO_2kg_{\text{-proc},i} + CO_2kg_{\text{-non-crop},i}) * FEED_{i,T,c})$

b. $CO_{2\text{-Feed-LUC},T,c} = 365 * N_{T,c} * DMI_{T,c} * \sum_i (CO_2kg_{\text{-LUC},i} * FEED_{i,T,c})$

c. $N_2O_{\text{-Feed-man},T,c} = 365 * N_{T,c} * DMI_{T,c} * \sum_i (N_2Okg_{\text{-manure},i} * FEED_{i,T,c})$

d. $N_2O_{\text{-Feed-fr\&cr},T,c} = 365 * N_{T,c} * DMI_{T,c} * \sum_i ((N_2Okg_{\text{-fert},i} + N_2Okg_{\text{-cr},i}) * FEED_{i,T,c})$

e. $CH_{4\text{-Feed},T,c} = 365 * N_{T,c} * DMI_{T,c} * \sum_i (CH_4kg_i * FEED_{i,T,c})$ [g]

Where:

$CO_{2\text{-Feed},T,c}$ = carbon dioxide emissions from energy use associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$CO_{2\text{-Feed-LUC},T,c}$ = carbon dioxide emissions from land-use change associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_2O_{\text{-Feed-man},T,c}$ = nitrous oxide emissions from manure application or deposition associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_2O_{\text{-Feed-fr\&cr},T,c}$ = nitrous oxide emissions from nitrogen fertilizer and crop residues associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$CH_{4\text{-Feed},T,c}$ = methane emissions from feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_{T,c}$ = number of animals in cohort *c*, species and system *T*, head

$DMI_{T,c}$ = daily feed intake per animal in cohort *c* for species and system *T*, kg $DM \cdot head^{-1} \cdot day^{-1}$

$FEED_{i,T,c}$ = fraction of feed material *i* in the ration of cohort *c*, species and system *T*, fraction

$CO_2kg_{\text{-blend},i,c,T}$ = total carbon dioxide emissions from blending and transport of concentrate feed per kg of dry matter for feed material *i*, cohort *c*, species and system *T*, kg $CO_2 \cdot kg\ DM^{-1}$. Described in section 6.1.4

$CO_2kg_{i\text{-Nfert},i}$ = total carbon dioxide emissions from N fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-Pfert},i}$ = total carbon dioxide emissions from P fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-Kfert},i}$ = total carbon dioxide emissions from K fertilizer manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-pest},i}$ = total carbon dioxide emissions from pesticides manufacturing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-crop},i}$ = total carbon dioxide emissions from field operations per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-proc},i}$ = total carbon dioxide emissions from transport and processing per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$CO_2kg_{\text{-non-crop},i}$ = total carbon dioxide emissions from the production of non-crop feed material *i* per kg of dry matter, kg $CO_2 \cdot kg\ DM^{-1}$. Described in section 6.5

$CO_2kg_{\text{-LUC},i}$ = total carbon dioxide emissions from land-use change per kilogram of dry matter of feed material *i*, kg $CO_2 \cdot kg\ DM^{-1}$

$N_2Okg_{i\text{-manure},i}$ = total nitrous oxide emissions from manure application or deposition per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$

$N_2Okg_{i\text{-fert},i}$ = total nitrous oxide emissions from application of nitrogen fertilizer per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$

$N_2Okg_{i\text{-cr},i}$ = total nitrous oxide emissions from crop residues per kilogram of dry matter of feed material *i*, kg $N_2O \cdot kg\ DM^{-1}$

$CH_4kg_i$ = total methane emissions per kilogram of dry matter of feed material *i*, kg $CH_4 \cdot kg\ DM^{-1}$

[g] Methane emissions related to feed (due to emission from paddy rice cultivation) are only applicable to monogastric species.

## 6.7 – TOTALIZING EMISSIONS AT HERD OR FLOCK LEVEL

The last step of the feed emission module is to totalize, for the entre herd or flock, the emissions related to feed consumption.

**Equation 6.13**

a. $CO_{2\text{-Feed},T} = \sum_c(CO_{2\text{-Feed},T,c})$

b. $CO_{2\text{-Feed-LUC},T} = \sum_c(CO_{2\text{-Feed-LUC},T,c})$

c. $N_2O_{\text{-Feed-man},T} = \sum_c(N_2O_{\text{-Feed-man},T,c})$

d. $N_2O_{\text{-Feed-fr\&cr},T} = \sum_c(N_2O_{\text{-Feed-fr\&cr},T,c})$

e $CH_{4\text{-Feed},T} = \sum_c(CH_{4\text{-Feed},T,c})$ [h]

Where:

$CO_{2\text{-Feed},T}$ = total carbon dioxide emissions from energy use associated with feed consumption of species and system *T*, kg $CO_2 \cdot year^{-1}$

$CO_{2\text{-Feed-LUC},T}$ = total carbon dioxide emissions from land-use change associated with feed consumption of species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_2O_{\text{-Feed-man},T}$ = total nitrous oxide emissions from manure application or deposition associated with feed consumption of species and system *T*, kg $N_2O \cdot year^{-1}$

$N_2O_{\text{-Feed-fr\&cr},T}$ = total nitrous oxide emissions from nitrogen fertilizer and crop residues associated with feed consumption of species and system *T*, kg $N_2O \cdot year^{-1}$

$CH_{4\text{-Feed},T}$ = total methane emissions from feed consumption of species and system *T*, kg $CH_4 \cdot year^{-1}$

$CO_{2\text{-Feed},T,c}$ = carbon dioxide emissions from feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$CO_{2\text{-Feed},T,c}$ = carbon dioxide emissions from land-use change associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_2O_{\text{-Feed-man},T,c}$ = nitrous oxide emissions from manure application or deposition associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$N_2O_{\text{-Feed-fr\&cr},T,c}$ = nitrous oxide emissions from nitrogen fertilizer and crop residues associated with feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

$CH_{4\text{-Feed},T,c}$ = methane emissions from feed consumption of cohort *c*, species and system *T*, kg $CO_2 \cdot year^{-1}$

[h] Methane emissions related to feed (due to emission from paddy rice cultivation) are only applicable to monogastric species.

# CHAPTER 7 – EMISSIONS FROM ENERGY USE

This chapter presents the approach and coefficients applied in GLEAM for estimating the GHG emissions from the direct, non-feed related on-farm energy use and embedded energy in farm buildings and equipment.

## 7.1 – EMISSIONS FROM CAPITAL GOODS – INDIRECT ENERGY USE

Capital goods including machinery, tools and equipment, buildings such animal housing, forage and manure storage are a means of production. Though not often considered in LCAs, capital goods carry with them embodied emissions associated with manufacture and maintenance. These emissions are primarily caused by the energy used to extract and process typical materials that make up capital goods such as steel, concrete or wood. The quantification of embedded energy in capital goods covered in GLEAM includes farm buildings (animal housing, feed and manure storage facilities) and farm equipment such as milking and cooling equipment, tractors and irrigation systems. To determine the effective annual energy requirement, the total embodied energy of the capital energy inputs are discounted and a 20 years straight-line depreciation for buildings, 10 years for machinery and equipment and 30 years for irrigation systems are assumed.

For ruminant species, different levels of housing are defined with varying degrees of quality. In a further step, these types are distributed across the production systems (grassland and mixed), AEZs (arid, humid and temperate), and country grouping based on the level of economic development based on literature research and expert knowledge. Tables 7.1 and 7.2 (Supplement S1) present the average emission factors for ruminant species.

For monogastric species, three different levels of housing were defined with varying degrees of quality. Emissions related to each type were calculated using the embodied energy use from the Swiss Centre for Life Cycle Inventories database – EcoInvent. Tables 7.3 and 7.4 (Supplement S1) present the average emission factors for pigs and chickens, respectively.

## 7.2 – EMISSIONS RELATED TO ON-FARM ENERGY USE – DIRECT ENERGY USE

Direct on-farm energy includes the emissions arising from energy use on-farm required for livestock production. Energy that is used in feed production and transport is not included, as these emissions are included in the feed category. Energy is required for a variety of purposes such as lighting, ventilation, washing, cooling, heating, milking, etc. Tables 7.5 to 7.7 (Supplement S1) present emission factors from direct energy use based on literature research and existing databases.

# CHAPTER 8 – POST-FARM EMISSIONS

GLEAM covers the emissions from post-farm gate activities as part of livestock supply chains. These activities comprise four stages: transport of raw livestock commodities (meat, milk and eggs) to a processing center, processing of raw commodities into livestock products, packaging and transport to retail point.

## 8.1 – EMISSIONS FROM TRANSPORT

The food sector is transport-intensive – large quantities of food are transported in large volumes and over long distances. This transport can sometimes be of significance but, in terms of the overall contribution to the life cycle carbon footprint of a product, most LCA studies have found that the contribution of transport is relatively small. The carbon implications of food transport is not only a question of distance. A number of other variables, such as transport mode, efficiency of transport loads and the condition of infrastructure (road quality), fuel type, etc., are important determinants of the carbon intensity of products.

Emissions related to transport were estimated for the different phases, that is: transportation of fresh products (raw milk, animals and eggs) to processing plants and from processing plants to retail centers. In the case of international trade, emissions were calculated for transport from slaughter plant to the port of export, from there to the port of import, and finally from the port of import to the retail point for distribution.

Emissions from transporting animal products to processing plants or from processing plants to retail points are calculated following Equation 8.1.

**Equation 8.1**

$$EFTRANS_{FP} = D_{FP} * EF_{mode}$$

Where:

$EFTRANS_{FP}$ = emission factor for product transport, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$

$D_{FP}$ = average distance between the farm and the slaughter plant or from processing plants to retail points, km

$EF_{mode}$ = emission factor of transport mode, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$

Due to the complexity of movements and data limitations, several simplifications and assumptions were made for the different commodities.

### *8.1.1 – Transport of animals to slaughter plants*

**Animals transported to slaughter plants:** not all animals produced are slaughtered in slaughter plants/abattoirs: slaughtering may also take place on-farm or may be carried out by local butchers within the vicinity of production. For industrialized countries, it was assumed that 98% of the animals are slaughtered in slaughterhouses. In developing countries, the share of animals transported to slaughter plants varied between 15 and 75% based on the assumption that slaughtering infrastructure is generally lacking and that animals are often slaughtered in closer proximity to where they are raised, with slaughter being carried out by local butchers or household slaughter. Other factors taken into consideration include the importance of exports within the economy, where we assumed that key exporting developing countries such as Brazil, Argentina, Paraguay, Botswana and Namibia would have a higher share of animals slaughtered in slaughter plants.

**Average distance between farm and slaughter plant:** data on distances between farms and slaughter plants were taken from literature for industrialized regions: an average of 80 km for Europe and 200 km for North America. In developing countries it was assumed that slaughter takes place within 50 km on average.

**Emission intensity:** based on secondary data, 0.21 and 0.38 kg $CO_2$-eq·tonne $CW^{-1}$·$km^{-1}$ emission factors were used for industrialized and developing countries, respectively.

### *8.1.2 – Transport of milk to processing plants*

The proportion of milk processed in dairy plants varies by region. In industrialized countries, 95 to 100% of the milk is transported to a dairy plant for processing, while other region present much lower percentages. An average distance of 50 km from farm to processing plant was assumed. An emission factor of $1.8 \cdot 10^{-4}$ kg $CO_2$-eq·kg raw $milk^{-1}$·$km^{-1}$ was used (FAO, 2013a).

### *8.1.3 – Transport of eggs to grading plants*

Country-specific data on the importance of grading was taken from literature review and expert consultation. Average distances of 50 to 200 km from farm to grading plants for developing and industrialized countries were assumed. Based on secondary data, an average of 0.20 kg $CO_2$-eq·tonne eggs$^{-1}$·km$^{-1}$ was adopted as the emission intensity for transportation (SIK, 2010).

### *8.1.4 – Transport of processed meat to retail points*

Transport and distribution emissions sources comprise emissions from fuel combustion during transport, as well as emissions from energy consumption for refrigeration and refrigerant leakage from chilled vehicles or container ships. Two modes of transport were considered in this phase: refrigerated road transport and marine transport. Refrigerated road transport covered here refers to transport between the processing plant and the domestic market and, in the case of international trade, transport from plant to port and entry port to retail distribution center in importing country. Emission intensities of 0.18 and 0.20 kg $CO_2$-eq·tonne carcass$^{-1}$·km$^{-1}$ were estimated for chilled and frozen transportation. Emissions from the international trade of meat were calculated on the basis of the amount and type of product traded, distances between the slaughterhouse and retail center, and the average GHG emission per kg of product transported. Based on secondary data, average emissions of 0.025 and 0.05 kg $CO_2$-eq·tonne carcass$^{-1}$·km$^{-1}$ for large and small container ships transporting carcasses were used.

### *8.1.5 – Transport of processed milk to retail points*

The transportation of processed milk takes into account the international trade of powdered milk. Detailed international trade data was retrieved from FAOSTAT to identify the main exporters and importers of powdered milk. Transport distances were estimated for road and vessel transport using online tools such as Sea Distances website (https://sea-distances.org/). Average emission intensities of 0.07, 0.03 and 0.02 kg $CO_2$-eq·tonne powdered milk$^{-1}$·km$^{-1}$ for road transport, small and large container ship were used.

## 8.2 – PROCESSING AND PACKAGING

Energy consumption is the most important source of GHG emissions from the post-farm gate supply food chain. Table 8.1 (Supplement S1) presents average regional and country $CO_2$ emission coefficients applied in this analysis. $CO_2$ intensities are determined by the composition of the energy sources employed and average GHG emissions from electricity consumption was modelled as a mix of existing electricity sources (e.g. coal, hydro, nuclear, oil, etc.) in different countries and regions taken from the International Energy Agency (IEA, 2013).

Based on literature, available databases (such as EcoInvent) and personal communications, data on energy consumption related to animal products processing and packaging were collected (Table 8.2; Supplement S1). These were combined with the data from the IEA to estimate the emissions caused by the processing and packaging of meat, milk and eggs. Emission factors per kilogram of product are estimated using the values from Tables 8.1 and 8.2 for both processing and packaging.

**Equation 8.2**

a. EFPROCC = $EF_{energy} * EC_{PROC}$

b. EFPACK = $EF_{energy} * EC_{PACK}$

where:

EFPROC = emission factor for processing, kg $CO_2$-eq·kg CW$^{-1}$ / kg $CO_2$-eq·kg milk$^{-1}$/ kg $CO_2$-eq·kg egg$^{-1}$

EFPACK = emission factor for packaging, kg $CO_2$-eq·kg CW$^{-1}$ / kg $CO_2$-eq·kg milk$^{-1}$/ kg $CO_2$-eq·kg egg$^{-1}$

$EF_{energy}$ = emission factor for energy consumption, kg $CO_2$-eq ·MJ$^{-1}$. Values are given in Table 8.1 (Supplement S1)

$EC_{PROC}$ = energy consumption for processing, MJ·kg CW-1 / MJ ·kg milk-1/ MJ ·kg egg-1. Values are given in Table 8.2 (Supplement S1)

ECPACK = energy consumption for packaging, MJ·kg CW-1 / MJ ·kg milk-1/ MJ ·kg egg-1. Values are given in Table 8.2 (Supplement S1)

## 8.3 – TOTAL POST-FARM EMISSION FACTORS

Total emission factors from post-farm are calculated using Equation 8.3.

**Equation 8.3**

EFPF = $EFTRANS_{FP}$ + EFPROCC + EFPACK

Where:

| | | |
|---|---|---|
| EFPF | = | post-farm emission factor, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$ |
| $EFTRANS_{FP}$ | = | emission factor for product transport, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$ |
| EFPROC | = | emission factor for processing, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$ |
| EFPACK | = | emission factor for packaging, kg $CO_2$-eq·kg $CW^{-1}$ / kg $CO_2$-eq·kg $milk^{-1}$/ kg $CO_2$-eq·kg $egg^{-1}$ |

Final post-farm emissions are associated with animal commodities as depicted in Section 9.2.

# CHAPTER 9 – ALLOCATION MODULE

One of the principles of LCA methodology is to allocate emissions among different products and outputs. The approach used in GLEAM to allocate emissions is described in the following sections.

The functions of the 'Allocation' module are:

- Calculate the **total livestock production**;
- Calculate the **total emissions** and the **emission intensity** of each commodity.

For a schematic representation of the allocation module, see Figures 9.1 and 9.2,

***Figure 9.1** – Schematic representation of the allocation module for ruminant species*

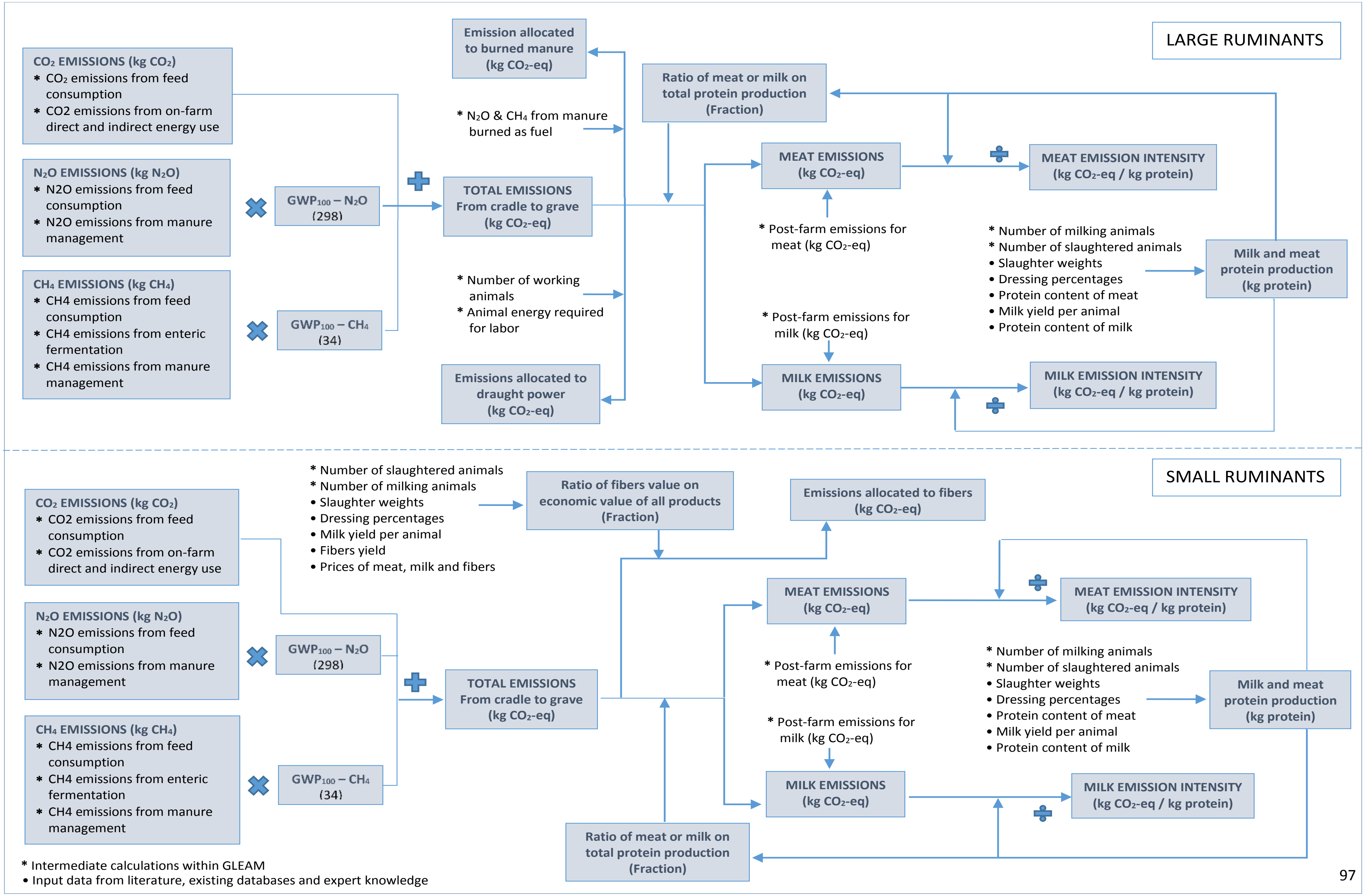
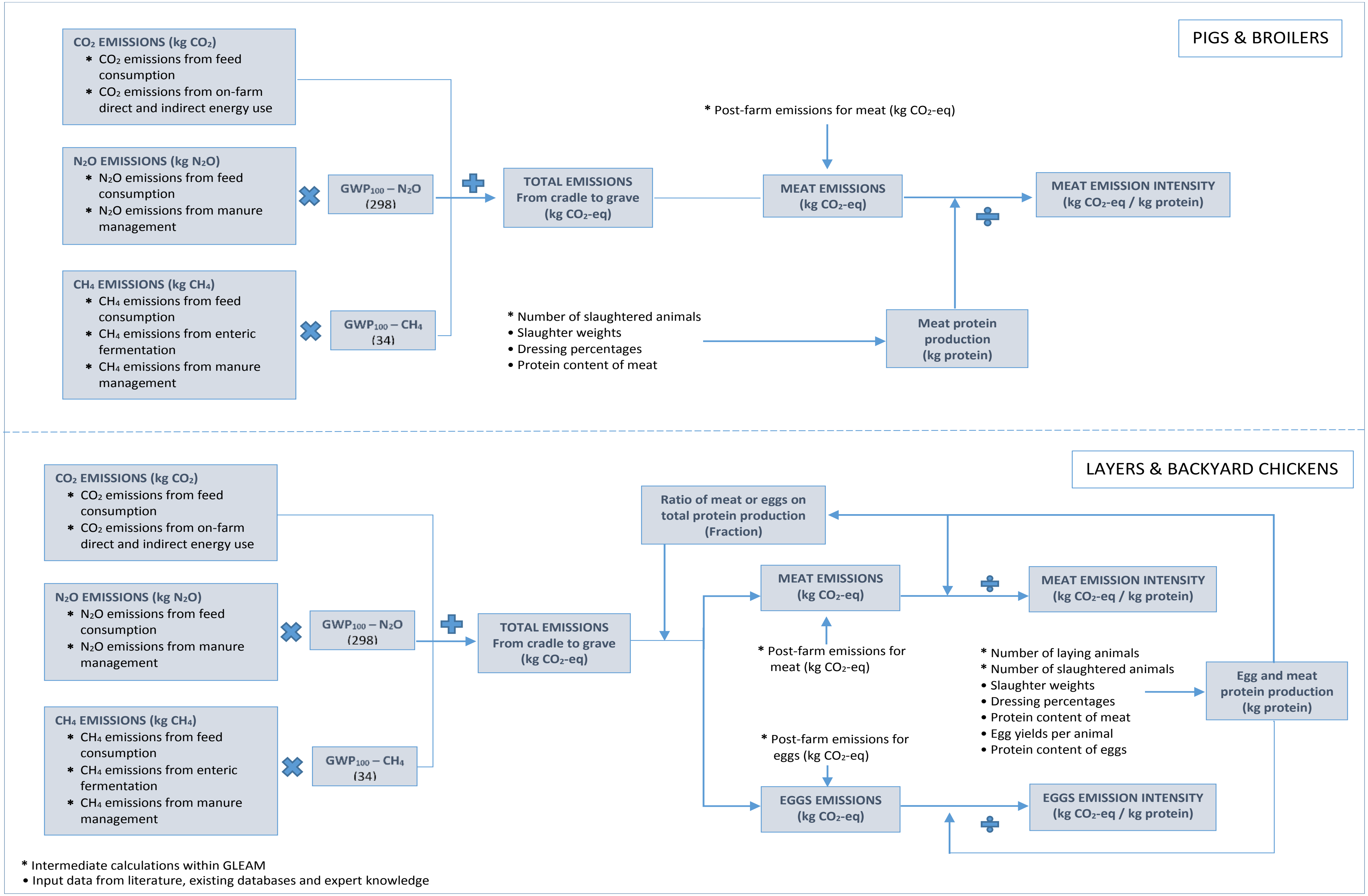


***Figure 9.2** – Schematic representation of the allocation module for monogastric species*



# 9.1 – TOTAL LIVESTOCK PRODUCTION

This section describes the equations used to calculate the total amount of animal commodities produced by each species and production system, namely meat, milk, eggs and fibre. All commodities, except fibre, are expressed in terms of protein to allow emission intensities comparison and aggregation between them.

## 9.1.1 – Production of milk

Total milk production is calculated based on average milk production per animal and number of milking animals. Total milk is then converted into amount of protein.

**Equation 9.1**

$$MILKTOT_{prot,T} = AF_T * MILK_{yield,T} * MILK_{prot,T}$$

Where:

$MILKTOT_{prot,T}$ = total amount of milk protein produced by species and production system *T*, kg protein·year$^{-1}$

$AF_T$ = milking animals by species and production system *T*, heads

$MILK_{yield,T}$ = average milk production per milking animal of species and production system *T*, kg milk·head$^{-1}$·year$^{-1}$

$MILK_{prot,T}$ = average milk protein content of species and production system *T*, fraction

## 9.1.2 – Production of meat

Total meat production is calculated from the total number of animals that leave the herd for slaughter and average live weights. Live weight production is then expressed in total amount of protein using dressing percentage data, bone-free-meat to carcass weight ratio and average protein content in meat.

**Equation 9.2**

$$MEATTOT_{prot,T} = BFM_T * MEAT_{prot,T} * \sum_c(N_{exit,T,c} * LW_{,T,c} * DP_T / 100)$$

Where:

$MEATTOT_{prot,T}$ = total amount of meat protein produced by species and production system *T*, kg protein

$BFM_T$ = bone-free-meat to carcass weight ratio for species and production system *T*, fraction. Values are shown in Table 9.1.

$MEAT_{prot,T}$ = average fraction of protein in meat of species and production system *T*, fraction. Values are shown in Table 9.1.

$N_{exit,T,c}$ = number of animals slaughtered by species and production system *T* and cohort *c*, # animals

$LW_{,T,c}$ = live weight of slaughtered animals by species and production system *T* and cohort *c*, kg LW·animal$^{-1}$·year$^{-1}$

$DP_T$ = dressing percentage of species and production system *T*, percentage. Values are given in Table 9.2 (Supplement S1).

**TABLE 9.1.** Bone-free-meat to carcass weight ratio and protein content

| Species | BFM (fraction) | $MEAT_{prot}$ (kg protein·kg meat$^{-1}$) |
|---|---|---|
| Large ruminants | 0.75 | 0.2113 |
| Sheep | 0.70 | 0.2013 |
| Goats | 0.70 | 0.1920 |
| Pigs | 0.65 | 0.2020 |
| Chickens | 0.75 | 0.1900 |

## *9.1.3 – Production of eggs*

Total egg production is calculated from the backyard and layer systems exclusively following Equation 9.3.

**Equation 9.3**

$EGGTOT_{prot,T} = 10^3 * EGG_{prot} * EGGwght_T * EGGSyear_T * N_{Hens,T}$

Where:

$EGGTOT_{prot,T}$ = total amount of egg protein produced by production system *T*, kg protein·year$^{-1}$

$EGG_{prot}$ = average protein fraction in eggs, fraction. Default value of 0.1240 was used.

$EGGwght_T$ = average egg weight for production system *T*, g·egg$^{-1}$

$EGGSyear_T$ = annual laid eggs per hen per production system *T*, # eggs·hen$^{-1}$·year$^{-1}$. In the case of laying hens used for reproduction (AF) in the Backyard production system, EGGSyear is replaced by the variable EGGconsAF, representing the annual number of laid eggs per hen available for human consumption, as defined in Table 2.18 and section 2.4.2.1.

$N_{Hens,T}$ = number of laying hens in production system *T*, # animals. For the Layers production system, laying hens used for reproduction (AF) are excluded, since it is assumed that all eggs laid by this cohort in industrial systems are used exclusively for reproduction.

## *9.1.4 – Production of fibre*

The production of fibers comprises three fibers: wool for sheep; cashmere and mohair for goats. Their total production is calculated combining the number of reproductive and surplus animals producing fibre with the yield of product per animal from FAOSTAT.

It is assumed that all reproductive and surplus animals produce wool, as shown in Equation 9.4.

**Equation 9.4 - Wool**

$WOOLTOT_{,T} = WOOL_{yield,T} * \sum_c (N_{T,c})$

Where:

$WOOLTOT_{,T}$ = total amount of wool produced by system *T*, kg·year$^{-1}$

$WOOL_{yield,T}$ = average wool production per producing animal in system *T*, kg·head$^{-1}$·year$^{-1}$

c = cohort of reproductive (AF, AM) or surplus (MF, MM) animals

$N_{,T,C}$ = number of animals in system *T* and cohort *c*, heads

For goats, it is assumed that only a fraction of the animals produce cashmere or mohair. This fraction was obtained at national level from FAOSTAT. Cashmere and mohair production occurs in a few select countries. The total production of cashmere and mohair is calculated as follows:

**Equation 9.5 – cashmere and mohair**

a. $CSHTOT_{,T} = CSH_{yield,T} * \sum_c (N_{T,c}) * CSH_{ratio}$

b. $MHRTOT_{,T} = MHR_{yield,T} * \sum_c (N_{T,c}) * MHR_{ratio}$

Where:

$CSHTOT_{,T}$ = total amount of cashmere produced by system *T*, kg·year$^{-1}$

$MHRTOT_{,T}$ = total amount of mohair produced by system *T*, kg·year$^{-1}$

$CSH_{yield,T}$ = average cashmere production per producing animal in system *T*, kg·head$^{-1}$·year$^{-1}$

$MHR_{yield,T}$ = average mohair production per producing animal in system *T*, kg·head$^{-1}$·year$^{-1}$

$N_{,T,C}$ = number of animals in system *T* and cohort *c*, heads

$CSH_{ratio}$ = ratio of goats producing cashmere, fraction

$MHR_{ratio}$ = ratio of goats producing mohair, fraction

c = cohort of reproductive (AF, AM) or surplus (MF, MM) animals

## 9.2 – AGGREGATION OF TOTAL EMISSIONS

The total emissions from different stages of the supply chain, calculated with the methods described in the previous chapters are aggregated to estimate the total amount of emissions for each species and production system. These total emissions are then allocated to the different co-products from each supply chain, following the allocation methods described in Section 9.3. Post-farm gate emissions are allocated directly to the respective product in the allocation phase.

Emissions from the three greenhouse gases are summed up. Methane and nitrous oxide emissions are converted into carbon dioxide equivalent ($CO_2$-eq) using the 100-years Global Warming Potential ($GWP_{100}$) values from the AR5 IPCC report (2014): 34 for methane and 298 for nitrous oxide. The $GWP_{100}$ is the measure of the ability of a certain gas to trap heat in the atmosphere compared to that of a similar mass of carbon dioxide, over a period of 100 years. Equation 9.6 is used to aggregate the total emissions arising from the whole supply chain of each species and production system.

**Equation 9.6**

$$GHGTOT_{,T} = CO_{2\text{-Feed},T} + CO_{2\text{-Feed-LUC},T} + (N_2O_{\text{-Feed-man},T} + N_2O_{\text{-Feed-fr\&cr},T} + N_2O_{\text{-Manure},T}) * GWP_{100}\text{-}N_2O + (CH_{4\text{-Feed},T} + CH_{4\text{-Enteric},T} + CH_{4\text{-Manure},T}) * GWP_{100}\text{-}CH_4 + GHG_{nrgd,T} + GHG_{nrge,T}$$

Where:

$GHGTOT_{,T}$ = total emission from species and system *T* (excluding post-farm emissions), kg $CO_2$-eq·year$^{-1}$

$CO_{2\text{-Feed},T}$ = total carbon dioxide emissions from energy use associated with feed consumption of species and system *T*, kg $CO_2$·year$^{-1}$

$CO_{2\text{-Feed-LUC},T}$ = total carbon dioxide emissions from land-use change associated with feed consumption of species and system *T*, kg $CO_2$·year$^{-1}$

$N_2O_{\text{-Feed-man},T}$ = total nitrous oxide emissions from manure application or deposition associated with feed consumption of species and system *T*, kg $N_2O$·year$^{-1}$

$N_2O_{\text{-Feed-fr\&cr},T}$ = total nitrous oxide emissions from nitrogen fertilizer and crop residues associated with feed consumption of species and system *T*, kg $N_2O$·year$^{-1}$

$N_2O_{\text{-Manure},T}$ = total nitrous oxide emissions from manure management for species and system *T*, kg $N_2O$·year$^{-1}$

$CH_{4\text{-Feed},T}$ = total methane emissions from feed consumption of species and system *T*, kg $CH_4$·year$^{-1}$. Monogastric species only.

$CH_{4\text{-Enteric},T}$ = total methane emissions from enteric fermentation for species and system *T*, kg $CH_4$·year$^{-1}$

$CH_{4\text{-Manure},T}$ = total methane emissions from manure management for species and system *T*, kg $CH_4$·year$^{-1}$

$GHG_{nrgd,T}$ = total emissions from on-farm direct use of energy for species and system *T*, kg $CO_2$-eq·year$^{-1}$

$GHG_{nrge,T}$ = total emissions from use of energy embedded in manufacture and maintenance of farm capital goods for species and system *T*, kg $CO_2$-eq·year$^{-1}$

$GWP_{100}$-$N_2O$ = global warming potential of nitrous oxide for 100 years' horizon, kg $CO_2$-eq·kg $N_2O$. Value of 298 was used.

$GWP_{100}$-$CH_4$ = global warming potential of methane 100 years' horizon, kg $CO_2$-eq·kg $CH_4$. Value of 34 was used.

Total post-farm emissions are calculated separately using the emission factors from Section 8.3, following Equation 9.7:

**Equation 9.7**

a. $GHG_{\text{-PFmeat},T} = EFPF_{meat,T} * (MEATTOT_{prot,T} / (BFM_T * MEAT_{prot,T}))$

b. $GHG_{\text{-PFmilk},T} = EFPF_{milk,T} * (MILKTOT_{prot,T} / MILK_{prot,T})$

b. $GHG_{\text{-PFeggs},T} = EFPF_{eggs,T} * (EGGTOT_{prot,T} / EGG_{prot})$

Where:

$GHG_{\text{-PFmeat},T}$ = total post-farm emissions for meat of species and system *T*, kg $CO_2$-eq·year$^{-1}$

$GHG_{\text{-PFmilk},T}$ = total post-farm emissions for milk of species and system *T*, kg $CO_2$-eq·year$^{-1}$

$GHG_{\text{-PFeggs},T}$ = total post-farm emissions for eggs of species and system *T*, kg $CO_2$-eq·year$^{-1}$

| | | |
|---|---|---|
| $EFPF_{meat,T}$ | = | post-farm emission factor for meat of species and system *T*, kg $CO_2$-eq·kg $CW^{-1}$. Emissions for backyard systems of monogastrics are assumed to be null. |
| $EFPF_{milk,T}$ | = | post-farm emission factor for milk of species and system *T*, kg $CO_2$-eq·kg $milk^{-1}$ |
| $EFPF_{eggs,T}$ | = | post-farm emission factor for eggs of species and system *T*, kg $CO_2$-eq·kg $egg^{-1}$. Emissions for backyard chickens are assumed to be null. |
| $MEATTOT_{prot,T}$ | = | total amount of meat protein produced by species and production system *T*, kg protein |
| $BFM_T$ | = | bone-free-meat to carcass weight ratio for species and production system *T*, fraction. Values are shown in Table 9.1. |
| $MEAT_{prot,T}$ | = | average fraction of protein in meat of species and production system *T*, fraction. Values are shown in Table 9.1. |
| $MILKTOT_{prot,T}$ | = | total amount of milk protein produced by species and production system *T*, kg protein·$year^{-1}$ |
| $MILK_{prot,T}$ | = | average milk protein content of species and production system *T*, fraction |
| $EGGTOT_{prot,T}$ | = | total amount of egg protein produced by production system *T*, kg protein·$year^{-1}$ |
| EGGprot | = | average protein fraction in eggs, fraction. Default value of 0.1240 was used. |

# 9.3 – ALLOCATION OF EMISSIONS AND EMISSION INTENSITIES

## *9.3.1 – Allocation in ruminant species*

Emissions in ruminant herds are allocated between edible commodities, i.e. meat and milk, and non-edible ones, namely manure used as fuel and draught power from large ruminants (cattle and Buffaloes) and fiber for small ruminants. Emissions related to non-edible commodities are calculated first and deducted from the total emissions, before these are attributed to meat and milk.

As a first step, $CH_4$ and $N_2O$ emissions from manure burned for fuel are calculated applying Equations 4.2, 4.10, 4.11 and 4.12 to the manure management system “burned for fuel” only. Therefore, these emissions are deducted from the rest of the manure emissions and allocated to fuel. The remaining emissions from manure are allocated to the other commodities.

To allocate emissions to draught power services, total emissions from draught animals alone are calculated. Then, a fraction of these emissions is allocated to draught power using as allocation factor the ratio of the net energy required for labor to the total net energy required by these animals. The remaining part of the emissions from draught animals is then allocated entirely to meat.

The allocation of emissions to fibre is based on the market value, taken from FAOSTAT, of all of the outputs (meat, milk and fibre). The total economic value of each of these co-products was calculated, multiplying the FAOSTAT prices by the respective total production. Finally, fractions of the economic value of each co-product within the total economic value produced by the system is used as allocation factor to partition emissions between fibre and edible products.

The remaining emissions are allocated between milk and meat using the proportions of proteins production from the two products as allocation factor. Once those emissions are allocated, the respective post-farm emissions are added to the final amount of each commodity. Tables 9.3 and 9.4 show an example calculation of emission allocation for large and small ruminant herds, respectively.

A specific allocation is also required for feedlot systems of cattle. Emissions from surplus animals in feedlots are, in fact, allocated entirely to meat. However, on a yearly base, animals spend in feedlots only a certain amount of days, during what is called the “finishing” phase, while they spend the rest of the year (the “rearing” phase) outside of feedlots, in the respective native system (either grassland based or mixed, from both dairy and beef specialized herds). Therefore, the specific emission profile associated with feedlot production must be allocated only to the finishing phase, while the emission intensity per head of feedlot animals during the rearing phase is assumed to be equal to that of the surplus animals in the respective system of origin. Specifically, the total emissions from the rearing phase are calculated, at national level, multiplying the average daily emissions per head of surplus animal, in non-feedlot systems, by the number of days of the rearing phase and the number of animals going to feedlots in one year. Similarly, the total emissions from the finishing phase are calculated multiplying the daily emissions from feedlot animals by the number of days that they spend in feedlots. Finally, the emissions from the two phases are summed together to calculate the total emissions from feedlot animals. Table 9.5 shows an example calculation of allocation of emissions from rearing and finishing phases to feedlot systems. The same approach can be used to allocate both the total emissions and those from specific emission sources.

**TABLE 9.3.** Example of allocation between products from cattle dairy production

| | Animals involved in both meat and milk production (milking cows, reproductive males and replacement animals) | Draught males | Surplus animals |
|---|---|---|---|
| **Total emissions – post-farm excluded ($kg\ CO_2$-eq)** | 1,800,000 | 120,000 | 255,000 |
| **Total emissions from manure burned as fuel ($kg\ CO_2$-eq)** | 100,000 | 10,000 | 15,000 |
| **Ratio of net energy for labor to the total net energy requirement** | - | 0.6 | - |
| **Total emissions allocated to draught power ($kg\ CO_2$-eq)** | - | = (120,000 – 10,000) * 0.6<br>= 66,000 | - |
| **Total emission allocated to meat and milk ($kg\ CO_2$-eq)** | = 1,800,000 – 100,000<br>= 1,700,000 | = 120,000 – 10,000 – 66,000<br>= 44,000 | = 215,000 – 15,000<br>= 200,000 |
| **Total protein (kg)** | Milk: 18,000<br>Meat: 1,500 | Meat: 500 | Meat: 2,000 |
| **Fraction of milk protein** | 0.92 | - | - |
| **Fraction of meat protein** | 0.08 | 1 | 1 |
| **Post-farm emissions ($kg\ CO_2$-eq)** | Milk: 54,000<br>Meat: 24,000 | | |
| **Emission intensity of milk ($kg\ CO_2\text{-eq}\cdot kg\ protein^{-1}$)** | = ((1,700,000 * 0.92) + 54,000) / 18,000<br>= 89.9 | | |
| **Emission intensity of meat ($kg\ CO_2\text{-eq}\cdot kg\ protein^{-1}$)** | = ((1,700,000 * 0.08) + 44,000 + 200,000 + 24,000) / (1,500 + 500 + 2,000)<br>= 101.0 | | |

**TABLE 9.4.** Example of allocation between products from sheep dairy production

| | Animals involved in meat, milk and fibre production | Animals involved in meat and fibre production only |
|---|---|---|
| **Total emissions – post-farm excluded ($kg\ CO_2$-eq)** | 80,000 | 20,000 |
| **Total protein (kg)** | Milk: 500<br>Meat: 50 | Meat: 200 |
| **Total economic value ($)** | Milk: 4,000<br>Meat: 9,000<br>Wool: 700 | |
| **Fraction of milk protein** | 0.90 | - |
| **Fraction of meat protein** | 0.10 | 1 |
| **Total emission allocated to wool ($kg\ CO_2$-eq)** | = 80,000 * (700 / (4,000 + 9,000 + 700))<br>= 4,088 | = 20,000 * (700 / (4,000 + 9,000 + 700))<br>= 1,022 |
| **Total emission allocated to meat and milk ($kg\ CO_2$-eq)** | = 80,000 – 4,088<br>= 75,912 | = 20,000 – 1,022<br>= 18,978 |
| **Post-farm emissions ($kg\ CO_2$-eq)** | Milk: 1,500<br>Meat: 1,250 | |
| **Emission intensity of milk ($kg\ CO_2\text{-eq}\cdot kg\ protein^{-1}$)** | = ((75,912 * 0.9) + 1,500) / 500<br>= 139.6 | |
| **Emission intensity of meat ($kg\ CO_2\text{-eq}\cdot kg\ protein^{-1}$)** | = ((75,912 * 0.1) + 18,978 + 1,250) / (50 + 200)<br>= 111.3 | |

**TABLE 9.5.** Example of allocation of emissions from rearing and finishing phases to feedlot systems

| | Grassland based system | Mixed farming system | Feedlot system |
|---|---|---|---|
| **Daily emissions per surplus animal (kg $CO_2$-eq·head$^{-1}$·day$^{-1}$)** | 2.7 | 2.5 | 1.6 |
| **Number of surplus animals (heads)** | 50 | 100 | 200 |
| **Length of the finishing phase (days)** | - | | 120 |
| **Length of the rearing phase (days)** | = 365 – 120<br>= 245 | | - |
| **Total emissions from the rearing phase (kg $CO_2$-eq)** | = (2.7 * 50 + 2.5 * 100) / (50 + 100) * 245 * 200<br>= 125,767 | | - |
| **Total emissions from the finishing phase (kg $CO_2$-eq)** | - | - | = 1.6 * 120 * 200<br>= 38,400 |
| **Total emissions allocated to feedlots (kg $CO_2$-eq)** | - | - | = 125,767 + 38,400<br>= 164,167 |

## 9.3.2 – Allocation in monogastric species

Emissions for monogastrics are also allocated between edible products, i.e. meat and eggs, in the case of backyard and layers chickens. For pigs and broilers, all emissions are allocated to meat.

For backyard chickens and layers, the first step is to calculate the specific emissions that are from all animals required for egg production, namely laying hens, reproductive males and replacement animals. In a subsequent step, these emissions are allocated on the basis of the amount of egg and meat protein output, while emissions from the remaining part of the flock are allocated entirely to meat. The respective post-farm emissions are added to the final amount of each commodity. Table 9.6 presents a calculation example.

**TABLE 9.6.** Example of allocation between edible products for chickens

| | Animals involved in egg and meat production | Animals involved only in meat production |
|---|---|---|
| **Total emissions (kg $CO_2$-eq)** | 50,000 | 39,000 |
| **Total protein (kg)** | Eggs: 800<br>Meat: 200 | Meat: 500 |
| **Total emission allocated to eggs (kg $CO_2$-eq)** | = 50,000 * (800 / (800 + 200))<br>= 40,000 | - |
| **Total emission allocated to meat (kg $CO_2$-eq)** | = 50,000 * (200 / (800 + 200))<br>= 10,000 | 39,000 |
| **Post-farm emissions (kg $CO_2$-eq)** | Eggs: 1,200<br>Meat: 840 | |
| **Emission intensity of eggs (kg $CO_2$-eq·kg protein$^{-1}$)** | = (40,000 + 1,200) / 800<br>= 51.5 | |
| **Emission intensity of meat (kg $CO_2$-eq·kg protein$^{-1}$)** | = (10,000 + 39,000 + 840) / (200 + 500)<br>= 71.2 | |

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# APPENDIX A – COUNTRY LIST

The country grouping used in GLEAM is based on the 2010 FAO Global Administrative Unit Layers (GAUL). Country classification is done on a purely geographic basis.

**TABLE A1 – Country list and classification**

| Region and country | |
|---|---|
| **LATIN AMERICA AND THE CARIBBEAN (LAC)** | |
| Antigua and Barbuda | Guyana |
| Argentina | Haiti |
| Bahamas | Honduras |
| Barbados | Jamaica |
| Belize | Mexico |
| Bolivia | Nicaragua |
| Brazil | Panama |
| Chile | Paraguay |
| Colombia | Peru |
| Costa Rica | Puerto Rico |
| Cuba | Saint Kitts and Nevis |
| Dominica | Saint Lucia |
| Dominican Republic | Saint Vincent and the Grenadines |
| Ecuador | Suriname |
| El Salvador | Trinidad and Tobago |
| Grenada | Uruguay |
| Guatemala | Venezuela |
| **SUB-SAHARAN AFRICA (SSA)** | |
| Angola | Liberia |
| Benin | Madagascar |
| Botswana | Malawi |
| Burkina Faso | Mali |
| Burundi | Mauritania |
| Cameroon | Mauritius |
| Cape Verde | Mozambique |
| Central African Republic | Namibia |
| Chad | Niger |
| Comoros | Nigeria |
| Congo | Rwanda |
| Côte d'Ivoire | São Tome and Principe |
| Democratic Republic of the Congo | Senegal |
| Djibouti | Seychelles |
| Equatorial Guinea | Sierra Leone |
| Eritrea | Somalia |
| Ethiopia | South Africa |
| Gabon | Swaziland |
| Gambia | Togo |
| Ghana | Uganda |
| Guinea-Bissau | United Republic of Tanzania |
| Guinea | Zambia |
| Kenya | Zimbabwe |
| Lesotho | |
| **NEAR EAST AND NORTH AFRICA (NENA)** | |
| Algeria | Morocco |
| Armenia | Oman |
| Azerbaijan | Qatar |
| Bahrain | Saudi Arabia |
| Cyprus | South Sudan |
| Egypt | Sudan |
| Gaza Strip | Syrian Arab Republic |
| Georgia | Tajikistan |
| Iraq | Tunisia |
| Israel | Turkey |
| Jordan | Turkmenistan |
| Kazakhstan | United Arab Emirates |
| Kuwait | Uzbekistan |

| | |
|---|---|
| Kyrgyzstan | West Bank |
| Lebanon | Western Sahara |
| Libya | Yemen |
| **SOUTH ASIA (SA)** | |
| Afghanistan | Maldives |
| Bangladesh | Nepal |
| Bhutan | Pakistan |
| India | Sri Lanka |
| Iran, Islamic Republic of | |
| **EASTERN EUROPE (EE)** | |
| Belarus | Poland |
| Bulgaria | Romania |
| Czech Republic | Slovakia |
| Hungary | Ukraine |
| Moldova, Republic of | |
| **RUSSIAN FEDERATION (RUS)** | |
| Russian Federation | |
| **EAST ASIA AND SOUTH-EAST ASIA (ESEA)** | |
| Brunei Darussalam | Mongolia |
| Cambodia | Myanmar |
| China | Philippines |
| Democratic People’s Republic of Korea | Republic of Korea |
| Hong Kong | Singapore |
| Indonesia | Thailand |
| Japan | Timor-Leste |
| Lao People’s Democratic Republic | Viet Nam |
| Malaysia | |
| **OCEANIA (OCE)** | |
| Australia | Palau |
| Fiji | Papua New Guinea |
| Kiribati | Samoa |
| Marshall Islands | Solomon Islands |
| Micronesia, Federated States of | Tonga |
| Nauru | Tuvalu |
| New Zealand | Vanuatu |
| Northern Mariana Islands | |
| **WESTERN EUROPE (WE)** | |
| Albania | Lithuania |
| Andorra | Luxemburg |
| Austria | Madeira Islands |
| Belgium | Malta |
| Bosnia and Herzegovina | Monaco |
| Croatia | Montenegro |
| Denmark | Netherlands |
| Estonia | Norway |
| Finland | Portugal |
| France | Republic of Serbia |
| Germany | San Marino |
| Greece | Slovenia |
| Iceland | Spain |
| Ireland | Sweden |
| Italy | Switzerland |
| Latvia | The former Yugoslav Republic of Macedonia |
| Liechtenstein | United Kingdom of Great Britain and Northern Ireland |
| **NORTH AMERICA (NA)** | |
| Bermuda | Greenland |
| Canada | United States of America |