Food and Agriculture Organization of the United Nations

GLOBAL LIVESTOCK ENVIRONMENTAL ASSESSMENT MODEL

Model description

Version 1.0

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Global Livestock Environmental Assessment Model

Reference documentation

Version 1.0

Contents

CHAPTER 1 – INTRODUCTION

The Global Livestock Environmental Assessment Model (GLEAM) was developed to address the need for a comprehensive tool to evaluate the environmental impacts of the livestock sector and to support stakeholders in their efforts towards more sustainable practices than ensure the livelihood of producers and mitigates the environmental burdens.

1.1 – MODEL OVERVIEW

GLEAM is a modelling framework based on a Life Cycle Assessment (LCA) method that covers the 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, which runs in a Geographic Information System (GIS) environment, provides spatially disaggregated estimations on greenhouse gas (GHG) emissions and commodity production for a given production system, thereby enabling the calculation of the emission intensity for any combination of commodity, farming systems and location at different spatial scales.

GLEAM is built on five modules reproducing the main stages of livestock production: the herd module, the manure module, the feed module, the system module and the allocation module. The overall structure is shown in Figure 1.1. Each module is explained in detail in their corresponding chapter.

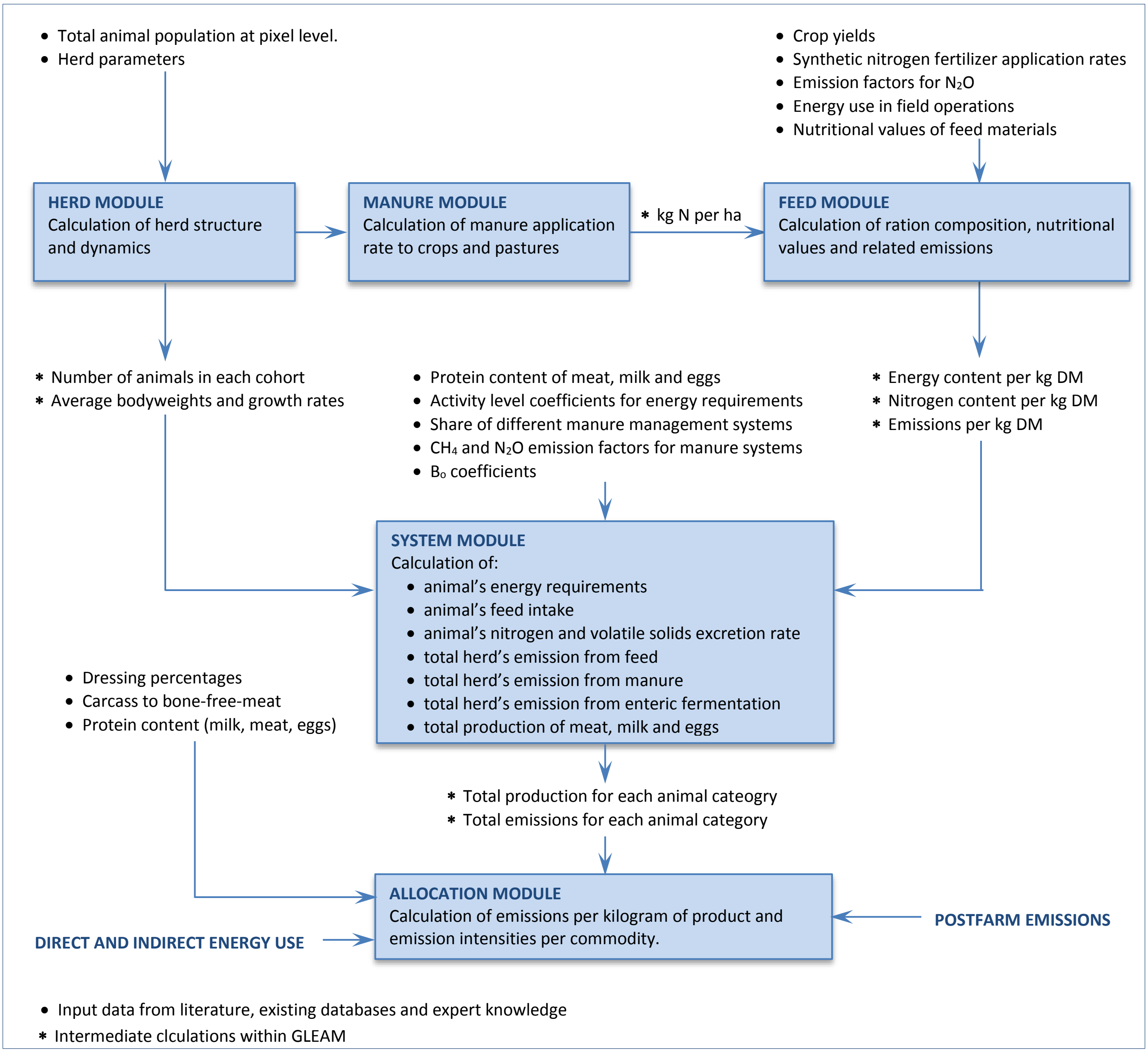

***Figure 1.1** - Overview of GLEAM structure.*

1.2 – GENERAL PRINCIPLES OF LCA

The LCA approach, which is defined in ISO standards 14040 and 14044 (ISO, 2006a and ISO, 2006b), is now widely accepted in agriculture and other industries as a method for evaluating the environmental impact of production, and for identifying the resource and emission-intensive processes 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 and environmental impacts, as well as to consider multiple parameters (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 that changes within a production process may have on the overall life-cycle balance of environmental burdens. This 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 reference unit that denotes the useful output of the production system is known as the functional unit, and it has a defined quantity and quality. The functional unit can be based on a defined quantity, such as 1 kg of product, or it may be based on an attribute of a product or process, such as 1 kg of carcass weight. The functional units used to report GHG emissions are expressed as a kg of carbon dioxide equivalents (CO_2-eq) per kg of protein. This allows the comparison between different livestock products.

1.2.2 – System boundary

GLEAM covers the entire livestock production chain, from feed production through to the final processing of product, including transport to the retail distribution point (Figure 1.2). All aspects related to the final consumption lie outside the defined system, and are thus excluded from this assessment. Livestock production is complex, with a number of interacting processes that include crop and pasture production, manure handling, feed processing and transport, animal raising and management, etc. This requires modelling the flow of all products through internal chains on the farm and also allowing for imports and exports from the farm. The model therefore provides a means of integrating all these processes and linking all components in a manner that adequately captures major interactions among biological and physical processes: land used for feed production; feed that originates from off-site production, including by-products and feed crops produced and transported over longer distances; manure, which is partly outside the 'cradle-to-farm gate' system boundary as it can be used as a fertilizer on food crops or where manure is used as fuel and finally other external inputs such as energy, fertilizer, pesticides, on-farm machinery, etc.

Those connections require the development of specific models and attribution techniques for the allocation of emissions among different processes, uses and outputs. These compartments not only represent different activities in the production process such as animal production, feed production, manure management, etc., but also define the inter-linkages among production processes such as the link between animal performance, animal feed requirements (energy and protein requirements) and the production of outputs such as manure, edible and non-edible products, services and emissions.

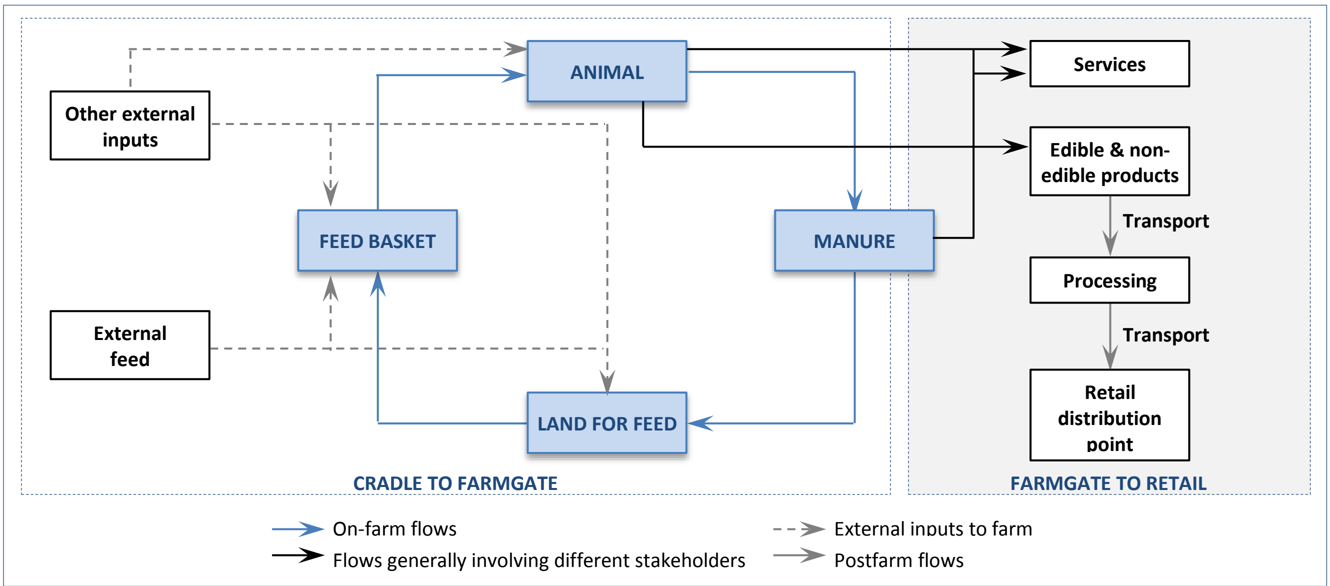

***Figure 1.2** – System boundary used in GLEAM.*

1.3 – SOURCES OF EMISSIONS

GLEAM covers the emissions of the three major GHGs associated with animal food chains, namely methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). Table 1.1 shows the emission sources that were included.

TABLE 1.1. Emission factor from fossil fuel consumption

Source of emissions		Description
Feed N_2O	applied and deposited manure	Direct and indirect nitrous oxide emissions from manure deposited on the fields and used as organic fertilizer
	fertilizer and crop residues	Direct and indirect nitrous oxide emissions from applied synthetic nitrogenous fertilizer and crop residues
Feed CO_2	fertilizer production	Carbon dioxide emissions from the manufacturing of synthetic nitrogenous fertilizers
	field operations	Carbon dioxide emissions arising from the use of fossil fuels during field operations
	processing and transport	Carbon dioxide generated during the processing of crops and the transport by land and/or sea
	blending	Carbon dioxide arising from the production of compound feed
Feed land-use change CO_2	soybean cultivation	Carbon dioxide emission due to LUC derived from the cultivation of soybean
	pasture expansion	Carbon dioxide emission due to LUC derived from the expansion of pastures
Enteric fermentation CH_4		Methane emissions caused by enteric fermentation
Manure management CH_4		Methane emissions arising from manure storage and management
Manure management N_2O		Nitrous oxide emissions arising from manure storage and management
Direct energy use CO_2		Carbon dioxide arising from energy use on-farm for ventilation, heating, etc.
Embedded energy use CO_2		Carbon dioxide arising from energy use during the construction of farm buildings and equipment
Postfarm CO_2		Carbon dioxide emissions from the processing and transport of livestock products

1.4 – DATA RESOLUTION AND DISAGGREGATION

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

Basic input data can be defined as primary data such as animal numbers, herd parameters, mineral fertilizer application rates, temperature, etc. and are data taken from other sources such as literature, databases and surveys. Intermediate data are an output of the modelling procedure required in further calculation in GLEAM and may include data on growth rates, animal cohort groups, feed rations, animal energy requirements, etc.

TABLE 1.2. Characteristics of livestock production systems used in GLEAM

Parameters	Cell[1]	Sub-national	National	Regional[2]	Global
Herd					
Animal numbers	X				
Live weights		X →	→	X	
Herd dynamics' rates		X →	→	X	
Manure					
N losses rates					X
Management system		X →	→	X	
Leaching rates				X	
Feed					
Crop yields	X				
Harvested area	X				
N fertilizer application rate			X		
N residues	X[3]			X[4]	
Feed ration			X[5] →	X	
Digestibility and energy content			X →	→	X
N content				X →	X
Energy in field operations and transport					X
Transport distances					X
Lan-use change					
Soybean			X		
Pasture			X		
Animal productivity					
Yield (milk, eggs, fibres)			X →	X	
Dressing percentage			X →	X	
Fat and protein content			X →	→	X
Product farmgate prices[6]			X →	X	
Postfarm					
Transport distances of animals or products			X		
Energy use			X		
Annual average temperature	X				
Direct and indirect energy			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] Animal numbers and annual average temperature: approx. 5 km x 5 km at the equator; harvested area and N residues: approx. 10 km x 10 km at the equator.

[2] Geographic regions or agro-ecological zones.

[3] For monogastrics

[4] For ruminants

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

[6] Only for allocation in small ruminants.

1.5 – PRODUCTION SYSTEMS CLASSIFICATION

GLEAM distinguishes between two production systems for cattle, buffaloes, sheep and goats (grassland based and mixed farming systems), three for pigs (backyard, intermediate and industrial) and three for chicken (backyard, layers and broilers) (see Table 1.3). The classification is based on Seré and Steinfeld (1996). Farming typologies are further classified according to their agro-ecological zone:

- **Temperate.** It 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.** It includes arid and semi-arid tropics and subtropics, with a growing period of less than 75 days and 75-180 days, respectively.
- **Humid.** It 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 used in GLEAM

Production system	Characteristics	Housing
Ruminant species		
Grassland based (or grazing) systems	Livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per hectare of agricultural land.	Not applicable
Mixed farming systems	Livestock production systems in which more than 10 percent of the dry matter fed to animals comes from crop by-products and/or stubble or more than 10 percent of the value of production comes from non-livestock farming activities.	Not applicable
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 percent 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 percent 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 percent) 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).

CHAPTER 2 – HERD MODULE

The use of the IPCC (2006) Tier 2 methodology requires the animal population to be categorized into distinct cohorts based on animal type, weight, phase of production and feeding situation. The functions of the herd module are:

- Calculate the **herd structure**, i.e. the proportion of animals in each cohort and the rate at which animals move between them.
- Calculate the **average characteristics** of the animals in each cohort, i.e. the average weight and growth rate.

Sections 2.1 to 2.5 describe the variables and equations involved in the simulation of the herd.

2.1 – LIVESTOCK DISTRIBUTION MAPS

2.1.1 – Ruminant species distribution

Total ruminant numbers at national level are taken from FAOSTAT and the geographic distribution is based on the Gridded Livestock of the World (FAO, 2007).

2.1.2 – Monogastric species distribution

Total pig and chicken numbers at a national level are reported in FAOSTAT. The spatial distributions used in GLEAM are based on maps developed in the context of FAO's Global Livestock Impact Mapping System (GLIMS) (Franceschini *et al.*, 2009). Regression (based on reported data of the proportions of backyard pigs) was used to estimate the proportion of the pigs in each country in the backyard herd. A simplified version of the procedure described in FAO (2011), taken from the Global Rural Urban Mapping Project dataset (CIESIN, 2005), was then used to distribute the backyard pigs among the rural population. Reported data, supplemented by expert opinion, was used to determine the proportions of the remaining non-backyard pigs in intermediate and industrial systems. A similar procedure was undertaken to determine the spatial distribution of chickens.

2.2 – HERD SIMULATION: LARGE RUMINANTS

This section provides the description of parameters and equations for cattle and buffaloes. Input data and parameters are described in Table 2.1 while equations are provided in subsection 2.2.2.

2.2.1 – Input and output data and variables

Tables 2.1 and 2.2 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.3 to 2.5.

TABLE 2.1. Cattle and buffaloes input data and parameters

Variable	Name and description	Unit
AFC	Age at first calving	year
AFkg	Live weight of adult cows	kg
AMkg	Live weight of adult bull	kg
Ckg	Live weight of calves at birth	kg
DCR	Dairy cow ratio	dimensionless
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	Fertility rate of replacement female animals. **Note**: standard value is 0.95	dimensionless
MFR	Bull to cow ratio	dimensionless
MFSkg	Live weight of female fattening animals at slaughter	kg
MMSkg	Live weight of male fattening animals at slaughter	kg
NBUFF2	Total number of buffaloes per grid cell	animal
NCOWS2	Total number of cattle per grid cell	animal
RRF	Replacement adult cows	percentage

TABLE 2.2. Cattle and buffaloes output variables

Variable	Name and description	Unit
OUTPUT - Animal numbers		
CF	Female calves	animal·year^{-1}
CM	Male calves	animal·year^{-1}
AF	Adult females, producing milk and calves	animal·year^{-1}
RF	Replacement females, producing calves to replace adult females	animal·year^{-1}
MF	Meat females, surplus animals fattened for meat production	animal·year^{-1}
AM	Adult males, used for reproduction and draught power	animal·year^{-1}
RM	Replacement males, to replace culled and dead adult males	animal·year^{-1}
MM	Meat males, surplus animals fattened for meat production	animal·year^{-1}
DCATTLE	Total animal numbers in the cattle dairy herd	animal·year^{-1}
DBUFFALO	Total animal numbers in the buffalo dairy herd	animal·year^{-1}
…exit	Number of sold animals from a given cohort	animal numbers
…in	Number of animals entering a given cohort	animal numbers
…kg	Live weight of a given cohort's animal	animal numbers
…x	Number of death animals in a given cohort	kilogram
OUTPUT - Growth rates		
DWGF	Annual average growth rate of female animals from calf to adult weight	kg·animal^{-1}·day^{-1}
DWGM	Annual average growth rate of male animals from calf to adult weight	kg·animal^{-1}·day^{-1}

TABLE 2.3. Herd parameters for dairy cattle, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Live weight (kg)									
Adult cow	747	500	593	518	371	486	463	346	551	325
Adult bull	892	653	771	673	477	326	601	502	717	454
Calves at birth	41	33	38	36	20	28	31	23	38	20
Female at slaughter	564	530	534	530	329	256	410	87	540	274
Male at slaughter	605	530	540	530	367	243	410	141	540	278
	Rate (percentage)									
Replacement adult cow	35	31	31	27	15	28	22	21	21	10
Fertility	77	83	83	84	73	80	80	75	80	72
Death rate female calves	8	8	8	8	20	15	10	22	9	20
Death rate male calves	8	8	8	8	20	15	10	50	9	20
Death rate other animals	3	4	4	4	6	6	4	8	9	6
Age at first calving (years)	2.1	2.3	2.3	2.2	3.4	2.5	2.1	3.1	2.6	4.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.4. Herd parameters for beef cattle, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Live weight (kg)									
Adult cow	649	-	529	530	431	501	403	350	419	271
Adult bull	843	-	688	689	563	542	524	505	545	347
Calves at birth	40	-	35	35	29	33	27	23	28	20
Female at slaughter	606	-	529	530	445	223	403	73	392	349
Male at slaughter	565	-	529	530	478	218	403	68	400	288
	Rate (percentage)									
Replacement adult cow	14	-	15	15	21	16	22	21	14	11
Fertility	93	-	93	93	75	90	93	75	73	59
Death rate female calves	11	-	10	10	18	15	10	22	14	19
Death rate male calves	11	-	10	10	18	15	10	50	14	19
Death rate other animals	4	-	3	3	7	7	3	8	6	7
Age at first calving (years)	2.0	-	2.3	2.3	2.8	2.5	2.1	3.1	3.4	3.9

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.5. Herd parameters for buffaloes, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Live weight (kg)									
Adult female	650	650	648	559	500	380	0	485	650	0
Adult male	800	800	800	700	610	398	0	532	900	0
Calves at birth	38	38	38	38	32	24	0	31	38	0
Female at slaughter	350	440	352	481	310	190	0	215	400	0
Male at slaughter	350	440	352	380	309	190	0	135	475	0
	Rate (percentage)									
Replacement adult cow	10	20	10	20	16	20	0	20	10	0
Fertility	76	68	76	68	69	57	0	53	75	0
Death rate female calves	8	8	8	8	18	29	0	24	7	0
Death rate male calves	8	8	8	8	18	28	0	44	7	0
Death rate other animals	4	4	4	4	6	6	0	9	2	0
Age at first calving (years)	2.5	3.6	2.5	3.2	3.1	4.0	0	4.0	3.0	0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

2.2.2 – Herd equations – Large ruminants

Female animals in the dairy herd are estimated first. Male numbers are calculated in a second step while non-dairy herd numbers are calculated last. Average weights and growth rates of each cohort are calculated last.

2.2.2.1 – Dairy herd - Female section

AF = DCR * NCOWS2[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

MFexit = $MFin * (1 – (DR2 / 100))^{AFC * (MFSkg – Ckg) / (AFkg – Ckg)}$

MFx = MFin – MFexit

MF = (MFin + MFexit) / 2 * (AFC * (MFSkg – Ckg) / (AFkg – Ckg))

Unit: *heads·year*$^{-1}$

2.2.2.2 – Dairy herd - Male section

AM = AF * MFR

AMx = AM * (DR2 / 100)

AMexit = AM / AFC – AMx

AMin = AM / AFC

RMin = $AMin / (1 – (DR2 / 100))^{AFC}$

RMx = RMin – AMin

RM = (RMin + AMin) / 2 * AFC

MMin = CMin – RMin

MMexit = $MMin * (1 – (DR2 / 100))^{AFC * (MMSkg – Ckg) / (AMkg – Ckg)}$

MMx = MMin – MMexit

MM = (MMin + MMexit) / 2 * (AFC * (MMSkg – Ckg) / (AMkg – Ckg))

DCATTLE[b] = AF + RF + MF + AM + RM + MM

Unit: *heads·year*$^{-1}$

[a] Use NCOWS2 or NBUFF2 accordingly to the species.
[b] Use DCATTLE or DBUFFALO accordingly to the species.

2.2.2.3 – Beef herd

BCATTLE = NCOWS2 – DCATTLE

IF DCATTLE = 0

AF = NCOWS2 * (1 – MFR)

ELSE

AF = (AFD / DCATTLE) * BCATTLE

Once AF in non-dairy herd is estimated, the model follows the equations shown previously.

2.2.2.4 – 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

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

DWGF = (AFkg – Ckg) / (365 * AFC)

DWGM = (AMkg – Ckg) / (365 * AFC)

Unit: $kg \cdot animal^{-1} \cdot day^{-1}$

2.3 – HERD SIMULATION: SMALL RUMINANTS

This section provides the description of parameters and equations for sheep and goats. Input data and parameters are described in Table 2.6. Equations and results are provided in subsection 2.3.2.

2.3.1 – Input and output data and variables

Tables 2.6 and 2.7 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.8 and 2.9.

TABLE 2.6. Sheep and goats input data and parameters

Variable	Name and description	Unit
AFC	Age at first lambing or kidding	year
AFkg	Live weight of adult female animals	kg
AMkg	Live weight of adult male animals	kg
Ckg	Live weight of lambs or kids at birth	kg
DR1	Death rate of lambs or kids	percentage
DR2	Death rate other animals than lambs or kids	percentage
DSR	Dairy sheep or goats ratio, fraction of dairy sheep or goats of the total population	dimensionless
FR	Fertility rate of adult female animals	percentage
FRRF	Fertility rate of replacement female animals. **Note**: standard value: 0.95	dimensionless
LINT	Lambing or kidding interval, period between two parturitions	days
LITSIZE	Litter size, number of lambs or kids per parturition	animal
MFR	Ram to ewe (sheep) or does to bucks (goats) ratio	dimensionless
MFSkg	Live weight of female fattening animals at slaughter	kg
MMSkg	Live weight of male fattening animals at slaughter	kg
NGOAT2	Total number of goats, per grid cell	animal
NSHEEP2	Total number of sheep, per grid cell	animal
RRF	Replacement rate female animals	percentage

TABLE 2.7. Sheep and goats output variables

NAME	VARIABLE DESCRIPTION	UNIT
OUTPUT - Animal numbers		
C	Lambs or kids	animal·year^{-1}
AF	Adult females, producing milk and lambs or kids	animal·year^{-1}
RF	Replacement females, producing calves to replace adult females	animal·year^{-1}
RF1	Replacement females at the end of first year	animal·year^{-1}
RFA	Replacement females in the midst of first year	animal·year^{-1}
RFB	Replacement females in the midst of the second year	animal·year^{-1}
MF	Meat females, surplus animals fattened for meat production	animal·year^{-1}
AM	Adult males, used for reproduction	animal·year^{-1}
RM	Replacement males, to replace culled and dead adult males	animal·year^{-1}
RM1	Replacement males at the end of first year	animal·year^{-1}
RMA	Replacement males in the midst of first year	animal·year^{-1}
RMB	Replacement males in the midst of the second year	animal·year^{-1}
MM	Meat males, surplus animals fattened for meat production	animal·year^{-1}
DSHEEP	Total animal numbers in the sheep dairy herd	animal·year^{-1}
DGOAT	Total animal numbers in the goats dairy herd	animal·year^{-1}
…exit	Number of sold animals from a given cohort	animal numbers
…in	Number of animals entering a given cohort	animal numbers
…x	Number of death animals in a given cohort	animal numbers
…kg	Live weight of a given cohort's animal	kilogram
OUTPUT – Growth rates		
DWGF	Annual average growth rate of female animals from calf to adult weight	kg·animal^{-1}·day^{-1}
DWGM	Annual average growth rate of male animals from lamb or kid to adult weight	kg·animal^{-1}·day^{-1}

TABLE 2.8. Herd parameters for sheep, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Live weight (kg)									
Adult female	80	49	62	44	41	47	70	35	59	38
Adult male	108	101	82	85	55	65	98	45	81	51
Lams at birth	4	3	4	3	3	4	4	3	3	3
Female at slaughter	27	21	29	21	26	26	35	24	29	24
Male at slaughter	27	21	29	21	26	26	35	24	29	24
	Rate (percentage)									
Replacement female	21	23	29	22	21	16	24	18	20	17
Fertility	92	95	91	90	83	77	100	81	91	76
Death rate lambs	19	17	18	18	25	31	9	24	18	33
Death rate other animals	8	2	3	5	12	14	4	12	12	13
Age at first lambing (years)	2.1	1.9	1.6	1.8	1.4	1.6	1.8	1.6	2.0	1.5

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.9. Herd parameters for goats, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Live weight (kg)									
Adult female	64	55	59	50	37	44	50	32	35	29
Adult male	83	100	88	100	53	60	81	42	50	36
Kids at birth	6.4	2.2	4.0	5.0	2.7	3.9	3.6	2.7	3.5	2.2
Female at slaughter	36	30	26	30	32	27	38	25	27	19
Male at slaughter	36	30	26	30	32	27	28	25	28	19
	Rate (percentage)									
Replacement female	30	18	17	18	19	24	21	19	24	16
Fertility	85	90	87	90	87	88	87	81	80	87
Death rate kids	18	5	4	5	31	37	12	15	14	27
Death rate other animals	9	2	2	2	7	16	6	5	5	7
Age at first kidding (years)	1.4	1.3	1.3	1.3	1.6	1.1	1.4	1.8	1.5	2.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

2.3.2 – Herd equations – Small ruminants

Small ruminant calculations follow the same structure as large ruminants. Dairy female animals are calculated in the first place, followed by male animals. Non-dairy animals are estimated in the consequent step.

2.3.2.1 – Dairy herd - Female section

AF	=	DSR * NSHEEP2[c]
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
MFexit	=	$MFin * (1 - (DR1 / 100))^{AFC * (MFSkg - Ckg) / (AFkg - Ckg)}$
MFx	=	MFin – MFexit
MF	=	(MFin + MFexit) / 2 * (AFC * (MFSkg – Ckg) / (AFkg – Ckg))

Unit: *heads·year*$^{-1}$

2.3.2.2 – Dairy herd - Male section

AM	=	AF * MFR
AMx	=	AM * (DR2 / 100)
AMexit	=	AM / (3 * AFC[d]) – 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
MMexit	=	$MMin * (1 - (DR1 / 100))^{AFC * (MMSkg - Ckg) / (AMkg - Ckg)}$
MMx	=	MMin – MMexit
MM	=	(MMin + MMexit) / 2 * (AFC * (MMSkg – Ckg) / (AMkg – Ckg))
DSHEEP[e]	=	AF + RF + MF + AM + RM + MM
AFD	=	AF

Unit: *heads·year*$^{-1}$

2.3.2.3 – Meat herd

BSHEEP = NSHEEP2 – DSHEEP

IF DSHEEP = 0
 AF = NSHEEP2 * (1 – MFR)

ELSE
 AF = (AFD / DSHEEP) * BSHEEP

[c] Use NSHEEP2 or NGOAT2 accordingly to the species.

[d] With 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. We assume 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.

[e] Use DSHEEP or DGOAT accordingly to the species.

Once AF in non-dairy herd is estimated, the model follows the equations shown in Sections 2.3.2.1 and 2.3.2.2.

2.3.2.4 – 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*$^{-1}$

2.4 – HERD SIMULATION: PIGS

This section provides the description of parameters and equations for pigs. Input data and parameters are described in Table 2.10. Equations are provided in subsection 2.4.2.

2.4.1 – Input and output data and variables

Tables 2.10 and 2.11 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.12 to 2.14.

TABLE 2.10. Pigs input data and parameters

Variable	Name and description	Unit
AFkg	Live weight of adult female animals	kg
AMkg	Live weight of adult male animals	kg
Ckg	Live weight of piglets at birth	kg
DR1	Death rate of piglets before weaning age	percentage
DRF2	Death rate of fattening animals	percentage
DRR2A	Death rate of replacement animals between weaning and adult ages	percentage
DRR2B	Death rate of adult replacement animals	percentage
DWG2	Average daily weight gain of fatteners	kg·animal^{-1}·day^{-1}
FR	Fertility rate of adult female, parturitions per year	parturition·year^{-1}
FRRF	Fertility rate of replacement female animals. **Note**: standard value is 0.95	dimensionless
LITSIZE	Litter size, number of piglets per parturition	animal·parturition^{-1}
M2Skg	Live weight of fattening animals at slaughter	kg·animal^{-1}
MFR	Boar to sow ratio	dimensionless
NPIGS	Total animal number, per cell and production system	animal·year^{-1}
RRF	Replacement rate female animals	percentage
RRM	Replacement rate male animals	percentage
Wkg	Live weight of piglets at weaning age	kg

TABLE 2.11. Pigs output variables

NAME	VARIABLE DESCRIPTION	UNIT
OUTPUT - Animal numbers		
C	Piglets	heads·year^{-1}
AF	Adult females, producing piglets	heads·year^{-1}
RF	Replacement females, producing piglets to replace 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}
PIGTOT	Total animal number per production system	heads·year^{-1}
…exit	Number of sold animals from a given cohort	animal numbers
…in	Number of animals entering a given cohort	animal numbers
…x	Number of death animals in a given cohort	animal numbers
…kg	Live weight of a given cohort's animal	kilogram
OUTPUT - Average weights and growth rates		
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}

TABLE 2.12. Herd parameters for backyard pig production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females (kg)	-	105	-	105	-	104		103	127	64
Live weight of adult males (kg)	-	120	-	120	-	120		113	140	71
Live weight of piglets at birth (kg)	-	1.00	-	1.00	-	0.97		0.80	1.00	1.00
Live weight of weaned piglets (kg)	-	6.0	-	6.0	-	6.0		6.2	6.2	6.0
Live weight of slaughter animals (kg)	-	90	-	90	-	85		90	88	60
Daily weight gain for fattening animals (kg/day/animal)	-	0.40	-	0.40	-	0.30		0.32	0.35	0.18
Weaning age (days)	-	50	-	50	-	49		50	50	90
Age at first farrowing (years)	-	1.5	-	1.5	-	1.5		1.5	1.5	1.5
Sows replacement rate (percentage)	-	10	-	10	-	10		10	10	10
Fertility (parturition/sow/year)	-	1.6	-	1.6	-	1.5		1.8	1.6	1.6
Death rate of piglets (percentage)	-	17.0	-	17.0	-	17.0		17.0	17.0	22.0
Death rate of adult animals (percentage)	-	2.0	-	2.0	-	2.0		2.0	2.0	2.0
Death rate of fattening animals (percentage)	-	3.0	-	3.0	-	3.0		3.0	3.0	3.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.13. Herd parameters for intermediate pig production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females (kg)	-	-	-	225	-	175	-	175	230	225
Live weight of adult males (kg)	-	-	-	265	-	195	-	195	255	250
Live weight of piglets at birth (kg)	-	-	-	1.2	-	1.2	-	1.2	1.2	1.2
Live weight of weaned piglets (kg)	-	-	-	7	-	7	-	7	7	8
Live weight of slaughter animals (kg)	-	-	-	100	-	99	-	100	100	90
Daily weight gain for fattening animals (kg/day/animal)	-	-	-	0.50	-	0.48	-	0.48	0.50	0.30
Weaning age (days)	-	-	-	40	-	40	-	40	40	42
Age at first farrowing (years)	-	-	-	1.25	-	1.25	-	1.25	1.25	1.25
Sows replacement rate (percentage)	-	-	-	15	-	15	-	15	15	15
Fertility (parturition/sow/year)	-	-	-	1.8	-	1.8	-	1.8	1.8	1.8
Death rate of piglets (percentage)	-	-	-	15.0	-	15.0	-	15.0	16.0	20.0
Death rate of adult animals (percentage)	-	-	-	3.0	-	3.0	-	3.0	3.0	3.0
Death rate of fattening animals (percentage)	-	-	-	2.0	-	2.0	-	2.0	2.0	1.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.14. Herd parameters for industrial pig production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females (kg)	220	225	225	225	-	175	-	-	230	-
Live weight of adult males (kg)	250	265	265	265	-	195	-	-	255	-
Live weight of piglets at birth (kg)	1.2	1.2	1.2	1.2	-	1.2	-	-	1.2	-
Live weight of weaned piglets (kg)	7.0	7.0	7.1	7.0	-	7.0	-	-	7.0	-
Live weight of slaughter animals (kg)	115	116	116	116	-	114	-	-	115	-
Daily weight gain for fattening animals (kg/day/animal)	0.66	0.66	0.64	0.66	-	0.67	-	-	0.69	-
Weaning age (days)	30	34	27	34	-	30	-	-	20	-
Age at first farrowing (years)	1.25	1.25	1.25	1.25	-	1.00	-	-	1.25	-
Sows replacement rate (percentage)	48	22	43	22	-	30	-	-	30	-
Fertility (parturition/sow/year)	2.4	2.1	2.3	2.1	-	2.1	-	-	2.2	-
Death rate of piglets (percentage)	15.0	15.0	13.5	15.0	-	11.7	-	-	15.0	-
Death rate of adult animals (percentage)	6.4	3.4	4.9	3.4	-	5.6	-	-	6.4	-
Death rate of fattening animals (percentage)	7.8	4.7	3.9	4.7	-	5.0	-	-	5.6	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

2.4.2 – Herd equations – Pigs

Female and male reproductive and replacement animals are calculated first, while fatteners are calculated in a second step. The last section estimates the average characteristics and growth rates of each cohort.

2.4.2.1 – 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}*

RFin = $((AF * (RRF / 100)) / FRRF) / (1 – (DRR2A / 100))^{(AFkg – Wkg) / (365 * DWGF) + (WA / 365)}$
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}*

2.4.2.2 – 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}*

AMexit = AM * RRM / 100 – AMx

AMin = AM * RRM / 100

RMin = $AMin / (1 – (DRR2A / 100))^{(AMkg – Wkg) / (365 * DWGM) + (WA / 365)}$

RMx = RMin – AMin

RM = (RMin + AMin) / 2 * ((AMkg – Wkg) / (365 * DWGM) + (WA / 365))

MMin = Cin / 2 – RMin

Unit: $heads \cdot year^{-1}$

2.4.2.3 – Fattening section

M2in = MFin + MMin

M2exit = $M2in * (1 – (DRF2 / 100))^{(M2Skg – Wkg) / (365 * DWG2)}$

M2x = M2in – M2exit

M2 = (M2in + M2exit) / 2 * ((M2Skg – Wkg) / (365 * DWG2))

Unit: $heads \cdot year^{-1}$

2.4.2.4 – Average weights and growth rates

RFkg = (AFkg – Wkg) / 2 + Wkg

RMkg = (AMkg – Wkg) / 2 + Wkg

M2kg = (M2Skg – Wkg) /2 + Wkg

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

DWGF = AFkg / ((AFkg + AMkg) / 2) * DWG2

DWGM = AMkg / ((AFkg + AMkg) / 2) * DWG2

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

2.5 – HERD SIMULATION: CHICKEN

This section provides the description of parameters and equations for chicken. Input data and parameters are described in Table 2.15. Equations are provided in subsections 2.5.2 to 2.5.4.

2.5.1 – Input and output data and variables

Tables 2.15 and 2.16 provide the list of input data and parameters and output variables, respectively. Regional values for selected variables are provided in Tables 2.17 to 2.19.

TABLE 2.15. Chicken input data and parameters

Variable	Name and description	Unit
COMMON VARIABLES		
AFC	Age at first laying (female) and when pullets become adult chicken (male)	days
MFR	Rooster to hen ratio per production system	dimensionless
Ckg	Live weight of pullets at birth	kg
DR1	Pullet mortality rate during the first 16-17 weeks. Not an annual rate	percentage
FRRF	Fertility rate of replacement female animals. **Note**: standard value is 0.95.	dimensionless
EGGSyear	Annual laid eggs per hen per production system	eggs·year^{-1}
EGGwght	Average egg weight	gr·egg^{-1}
HATCH	Hatchability, fraction of laid eggs that actually give a pullet	dimensionless
NCHK	Total number of chicken in a grid cell per production system	animal
PRODUCTION SYSTEM VARIABLES – Backyard systems		
AFS	Age at which adult animals are slaughtered	days
CYCLE	Number of laying cycles	# cycles
CLTSIZE	Laid eggs per cycle	eggs·cycle^{-1}
DR2	Death rate adult females and males	percentage
AF2kg	Live weight of females at the end of the laying period	kg·animal^{-1}
AM2kg	Live weight of males at the end of the laying period	kg·animal^{-1}
M2Skg	Live weight of surplus animals at slaughter	kg·animal^{-1}
PRODUCTION SYSTEM VARIABLES – Layers systems		
DRL2	Death rate for the laying period	percentage
DRM	Death rate during the molting period. **Note**: standard value is 15	percentage
LAY1weeks	Length of the first laying period	weeks
LAY2weeks	Length of the second laying period. **Note**: standard value is 30	weeks
MOLTweeks	Length of the molting period. **Note**: standard value is 6	weeks
AF1kg, AF2kg	Live weight of female reproductive animals at the start and end of the laying period	kg·animal^{-1}
PRODUCTION SYSTEM VARIABLES – Broilers systems		
A2S	Age at slaughter for broiler animals	year
BIDLE	Idle days between two production cycles. **Note**: standard value is 14	days
DRB2	Death rate for broiler animals laying period	percentage
DRL2	Death rate for the laying period	percentage
LAYweeks	Length of the laying period	weeks
AF1kg, AF2kg	Live weight of female reproductive animals at the start and end of the laying period	kg·animal^{-1}
M2Skg	Live weight at slaughter of female and male broiler animals	kg·animal^{-1}

TABLE 2.16. Chicken output variables

NAME	VARIABLE DESCRIPTION	UNIT
…exit	Number of sold animals from a given cohort	animal numbers
…in	Number of animals entering a given cohort	animal numbers
…x	Number of death animals in a given cohort	animal numbers
…kg	Live weight of a given cohort's animal	kilogram
OUTPUT – Common variables		
AF	Adult females, producing eggs	heads·year^{-1}
AM	Adult males, used for reproduction	heads·year^{-1}
C	Pullets	heads·year^{-1}
RF	Replacement females, producing eggs to replace adult females	heads·year^{-1}
RM	Replacement males, to replace sold and dead adult males	heads·year^{-1}
MM	Surplus males, sold for meat	heads·year^{-1}
RFkg, RMkg	Average live weight of replacement females and males, respectively	kg·animal^{-1}
OUTPUT – Backyard systems		
MF1, MF2	Growing and adult surplus females	heads·year^{-1}
AF1kg, AM1kg	Live weight of female and male reproductive at the start of the laying period	kg·animal^{-1}
AFkg, AMkg	Average live weight of adult females and males, respectively	kg·animal^{-1}
MMSkg	Live weight of male surplus animals at slaughter	kg·animal^{-1}
DWGF1	Average daily weight gain of all hens in their youth period	kg·animal^{-1}·day^{-1}
DWGF2	Average daily weight gain of reproductive and surplus hens in their laying and fattening period	kg·animal^{-1}·day^{-1}
DWGM1	Average daily weight gain of all male chickens in their youth period	kg·animal^{-1}·day^{-1}
DWGM2	Average daily weight gain of reproductive roosters in their reproductive period	kg·animal^{-1}·day^{-1}
EGGconsAF	Number of eggs used for reproduction	egg·animal^{-1}·year^{-1}
OUTPUT – Layers systems		
MF1, MF2, MF3, MF4	Growing and adult surplus females in the first (1, 2) and second (3, 4) laying period	heads·year^{-1}
AF1kg, AM1kg	Live weight of female and male reproductive at the start of the laying period	kg·animal^{-1}
AF2kg, AM2kg	Live weight of female and male reproductive at the end of the laying period	kg·animal^{-1}
AFkg, AMkg	Average live weight of adult females and males, respectively	kg·animal^{-1}
MF11kg, MF22kg	Average live weight of laying hens during their growing and laying period, respectively	kg·animal^{-1}
MF3kg, MF4kg	Live weight of female reproductive at the start and end of the second laying period	kg·animal^{-1}
MMkg	Average live weight of surplus male animals	kg·animal^{-1}
DWGF1	Average daily weight gain of all hens in their youth period	kg·animal^{-1}·day^{-1}
DWGF2	Average daily weight gain of layers and reproductive hens in their laying period	kg·animal^{-1}·day^{-1}
DWGM1	Average daily weight gain of all male chickens in their youth period	kg·animal^{-1}·day^{-1}
DWGM2	Average daily weight gain of reproductive roosters in their reproductive period	kg·animal^{-1}·day^{-1}
OUTPUT – Broiler systems		
M2	Adult female and male broiler animals	heads·year^{-1}
AM1kg, AM2kg	Live weight of male reproductive at the start and the end of the reproductive period	kg·animal^{-1}
DWGF	Average daily weight gain of reproductive female animals	kg·animal^{-1}·day^{-1}
DWGM	Average daily weight gain of reproductive male animals	kg·animal^{-1}·day^{-1}
DWGB	Average daily weight gain of broiler animals	kg·animal^{-1}·day^{-1}

TABLE 2.17. Herd parameters for backyard chicken production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females at the end of laying period (kg)	-	1.6	-	1.61	1.26	1.46	-	1.24	1.50	1.27
Live weight of adult males at the end of reproductive period (kg)	-	2.10	-	2.10	1.87	1.77	-	1.55	1.90	1.92
Live weight of surplus animals at slaughter (kg)	-	1.30	-	1.34	1.00	1.30	-	0.89	1.15	1.15
Live weight of pullets at hatching (kg)	-	0.045	-	0.045	0.029	0.035	-	0.035	0.030	0.025
Egg weight (g)	-	57.50	-	57.50	42.27	43.80	-	44.00	52.00	51.26
Age at first egg production (days)	-	150	-	150	180	195	-	185	177	168
Age at slaughter, females (days)	-	735	-	735	926	881	-	926	926	982
Number of laying cycles	-	3.3	-	3.3	2.8	3.3	-	3.0	3.3	3.6
Annual eggs laid (eggs/hen/year)	-	159	-	159	106	50	-	87	100	45
Hatchability of eggs (percentage)	-	0.80	-	0.80	0.78	0.76	-	0.75	0.79	0.80
Death rate of juvenile chicken (percentage)	-	9.0	-	9.0	56.0	45.0	-	49.0	58.0	66.0
Death rate adult animals (percentage)	-	20.0	-	20.0	21.0	21.0	-	24.0	20.0	24.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.18. Herd parameters for layers chicken production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females at the start of laying period (kg)	1.26	1.25	1.56	1.46	1.29	1.48	-	1.32	1.36	-
Live weight of adult females at the end of laying period (kg)	1.51	1.95	1.87	1.89	1.92	1.92	-	1.55	1.62	-
Live weight of pullets at hatching (kg)	0.04	0.04	0.04	0.04	0.04	0.04	-	0.04	0.04	-
Egg weight (g)	54	57	57	57	49	53	-	53	51	-
Age at first egg production (days)	119	119	119	119	126	119	-	126	119	-
Number of laying cycles	279	320	305	298	315	286	-	302	310	-
Hatchability of eggs (percentage)	0.8	0.8	0.8	0.8	0.8	0.8	-	0.8	0.8	-
Death rate of juvenile chicken (percentage)	3.5	2.5	2.9	3.4	4.2	3.8	-	2.6	4.4	-
Death rate adult animals in the first laying period (percentage)	9.2	5.5	7.0	6.8	6.5	13.4	-	9.2	7.5	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 2.19. Herd parameters for broiler chicken production systems, regional averages

Parameter	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Live weight of adult females at the start of laying period (kg)	1.25	-	1.56	1.52	1.31	1.48	-	1.29	1.34	-
Live weight of adult females at the end of laying period (kg)	1.51	-	1.88	1.86	1.91	1.89	-	1.60	1.80	-
Live weight of broilers at slaughter (kg)	2.67	-	2.32	2.19	1.92	2.07	-	2.00	2.47	-
Live weight of pullets at hatching (kg)	0.04	-	0.04	0.04	0.04	0.04	-	0.04	0.04	-
Egg weight (g)	54	-	57	57	48	50	-	50	51	-
Age at first egg production (days)	119	-	119	119	119	133	-	119	119	-
Age of broilers at slaughter (kg)	44	-	44	40	40	44	-	40	44	-
Annual eggs laid (eggs/hen/year)	278	-	305	291	305	289	-	273	313	-
Hatchability of eggs (percentage)	0.8	-	0.8	0.8	0.8	0.80	-	0.79	0.8	-
Death rate of juvenile chicken (percentage)	3.46	-	2.8	3.8	4.10	3.7	-	2.30	4.00	-
Death rate of reproductive animals (percentage)	9.2	-	6.7	7.3	7.3	12.9	-	10.4	8.4	-
Death rate of broiler animals (percentage)	3.6	-	4.3	4.8	5.9	4.9	-	5.0	3.0	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

2.5.2 – Herd equations – Backyard chicken

Reproductive female and male animals are estimated first, followed by fattening animals and egg production. Average weights and growth rates are calculated in the last step.

2.5.2.1 – Reproductive female section

AF = NCHK / 100
AFin = AF * (365 / (AFS – AFC))
AFx = AF * (DR2 / 100)
AFexit = AF * (365 / (AFS – AFC)) – 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 * (365 / (AFS – AFC))) / FRRF) / (1 – (DR1 / 100))
RFexit = ((AF * (365 / (AFS – AFC))) / FRRF) – AFin
RFx = RFin – (AFin + RFexit)
RF = (RFin + AFin) / 2 * (AFC / 365)
MF1in = Cin / 2 – RFin
Unit: *heads·year*$^{-1}$

2.5.2.2 – Reproductive male section

AM = AF * MFR
AMx = AM * (DR2 / 100)
AMexit = AM * (365 / (AFS – AFC)) – AMx
AMin = AM * (365 / (AFS – AFC))
RMin = AMin / (1 – (DR1 / 100))
RMx = RMin – AMin
RM = (RMin + AMin) / 2 * (AFC / 365)
MMin = Cin / 2 – RMin
Unit: *heads·year*$^{-1}$

2.5.2.4 – Male fattening section

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

2.5.2.5 – 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*$^{-1}$

2.5.2.6 – 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*$^{-1}$

2.5.3 – Herd equations – Layers

Similarly to backyard systems, reproductive female and male animals are estimated in the first place. Second, animals in the laying period and egg production are estimated. Male surplus and average weights and growth rates constitute the last two steps.

2.5.3.1 – Lay time

IF molting is not done
LAYtime = LAY1weeks / 52
IF molting is done
LAYtime = (LAY1weeks + LAY2weeks + MOLTweeks) / 52
Unit: *year*

2.5.3.2 – 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*$^{-1}$

2.5.3.3 – 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*$^{-1}$

2.5.3.4 – 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) * LAYtime

IF MOLT is not done

MF4exit = MF2exit

MF3 = 0

MF4 = 0

Unit: *heads·year*$^{-1}$

IF MOLT is done

MF3exit = MF2exit * (1 – (DRM / 100))

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*$^{-1}$

2.5.3.5 – 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*$^{-1}$

2.5.3.6 – 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
MF3kg	=	MF2kg
MF4kg	=	MF2kg
AMkg	=	(AM2kg – AM1kg) / 2 + AM1kg
RMkg	=	(AM1kg – Ckg) / 2 + Ckg
MMkg	=	(MM1kg – Ckg) / 2 + Ckg

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

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

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

2.5.4 – Herd equations – Broilers

Reproductive female and male animals are estimated first. Broiler animals are estimated in a second step. Average weights and growth rates of each cohort are calculated last.

2.5.4.1 – 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: $heads \cdot year^{-1}$

2.5.4.2 – 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: $heads \cdot year^{-1}$

2.5.4.3 – Broilers section

M2in = MFin + MMin

M2exit = M2in * (1 – (DRB2 / 100))

M2x = M2in – M2exit

M2 = ((M2in + M2exit) / 2) * (A2S + (BIDLE / 365))

Unit: *heads·year^{-1}*

2.5.4.4 – 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 – MANURE MODULE

Application of manure is a key element in crop production which has large implications in nutrient cycling and emissions. GLEAM considers the impact, in terms of GHG emissions, of manure application in crops used as livestock feed.

The function of the manure module is:

- Calculate the **rate** at which **excreted nitrogen is applied and deposited** in feed crops' fields

This chapter focuses on the method to estimate the application rate of manure nitrogen to feed crops and pastures.

3.1 – MANURE MANAGEMENT SYSTEMS

GLEAM uses the IPCC (2006) classification of manure management systems (MMS), defined in Table 3.1. On a global scale, there are very limited data available on how manure is managed and the proportion of the manure managed in each system. 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 3.2 to 3.5.

TABLE 3.1. Manure management systems definitions

Manure 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.
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.
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.

TABLE 3.2. Dairy cattle manure management systems, regional averages

Manure system	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage									
Burned for fuel	-	-	-	-	3.6	1.5	-	20.0-	0.4	6.9
Daily spread	9.5	-	2.3	1.4	-	-	1.2	-	-	-
Drylot	-	-	-	-	39.4	29.1	-	54.4	41.5	34.8
Uncovered anaerobic lagoon	27.2	-	0.1	-	-	-	4.6	-	-	-
Liquid slurry	26.3	-	41.6	10.2	-	3.1	0.1	-	-	-
Pasture, range, paddock	11.8	22.5	26.6	17.0-	46.1	30.7	94.2	23.5	53.5	39.7
Solid storage	25.2	77.5	29.5	71.3	10.9	35.7	-	2.0-	4.7	18.5

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 3.3. Beef cattle manure management systems, regional averages

Manure system	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage									
Burned for fuel	-	-	-	-	9.3	9.3	-	20.0	0.2	6.2
Daily spread	-	-	4.2	-	-	-	-	-	-	-
Drylot	12.8	-	0.1	-	34.9	34.9	-	58.2	4.8	34.3
Uncovered anaerobic lagoon	-	-	-	-	-	-	-	-	-	-
Liquid slurry	0.7	-	22.1	65.0	-	-	-	-	-	-
Pasture, range, paddock	43.4	-	47.6	33.0	42.8	42.8	1-0.0	20.3	91.8	46.5
Solid storage	43.2	-	25.9	2.0	12.9	12.9	-	1.4	3.2	13.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 3.4. Buffalo milk production manure management systems, regional averages

Manure system	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage									
Burned for fuel	17.4	-	3.4	13.0	50.8	31.0	-	37.8	50.7	-
Daily spread	40.2	-	61.9	67.8	9.2	13.3	-	1.3	1.2	-
Drylot	42.4	-	34.7	18.2	-	-	-	-	-	-
Uncovered anaerobic lagoon	-	-	-	-	-	-	-	-	-	-
Liquid slurry	-	-	-	-	38.9	53.6	-	40.4	48.0	-
Pasture, range, paddock	-	-	-	1.0	-	-	-	-	-	-
Solid storage	-	-	-	-	1.1	2.0	-	19.9	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 3.5. Small ruminants manure management systems, regional averages

Manure system	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage									
Drylot	-	-	-	-	37.5	0.8	-	12.8	3.7	9.3
Pasture, range, paddock	47.4	18.0	83.8	64.6	57.2	56.7	1-0.0	85.0	83.3	84.4
Solid storage	53.0	82.0	16.2	35.2	5.2	42.3	-	2.0	12.7	6.2

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

3.2 – NITROGEN EXCRETION, LOSSES AND APPLICATION RATES

3.2.1 – Nitrogen excretion rates

Total excreted nitrogen is based upon IPCC values (Table 10.19, Chapter 10, Volume 4) and calculated in Equation 3.1.

Equation 3.1

$$NEX = \sum_T (N * N_{ex})_T$$

Where:

NEX = total nitrogen excreted from all species, kg N·hectare^{-1}

N = number of animals from species T, animals·hectare^{-1}

N_{ex} = nitrogen excretion per head, kg N·animal^{-1}

T = animal species or category T

3.2.2 – Nitrogen losses from manure management

Total nitrogen losses are calculated, based on IPCC parameters (Table 10.23, Chapter 10, Volume 4), following Equation 3.2.

Equation 3.2

NLOSS = $\sum_{T}(MMS_{MS} * NLOSS_{MS})_{T}$

Where:

NLOSS = average nitrogen loss per hectare, kg N·hectare^{-1}

MMS_{MS} = share of manure management system MS for species *T* per hectare, dimensionless

$NLOSS_{MS}$ = nitrogen losses from manure management MS, kg N·hectare^{-1}

T = animal species or category *T*

3.2.3 – Application rates to crop feeds

Nitrogen application rate to crop feeds per hectare are calculated as follows:

Equation 3.3

NMANUREHA = NEX - NLOSS

Where:

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

NEX = total nitrogen excreted from all species, kg N·hectare^{-1}

NLOSS = average nitrogen loss per hectare, kg N·hectare^{-1}

CHAPTER 4 – FEED MODULE

Animal diets are one of the most important aspects of livestock production. They largely determine animals' productivity and emissions such as enteric fermentation or emissions related to feed production.

The functions of the feed module are:

- Calculate the **composition** of the ration for each species, production system and location;
- Calculate the **nutritional values** of the ration per kilogram of feed dry matter, and;
- Calculate the **related GHG emissions** per kilogram of feed dry matter.

This chapter describes the procedures on the estimation of different aspects of feed rations, from its production to its environmental impact.

4.1 – CROP YIELDS

Crops are used as animal feed, both in direct form or as crop by-products and crop residues. Data on yields per hectare of pasture, fodder, crop residues and their respective land area were gathered from a variety of sources: FAOSTAT for specific crops (e.g. fodder beet, soybean, rapeseed, cottonseed, sugar beet and palm fruit); You *et al.* (2010) from the Spatial Production Allocation Model (SPAM) for 20 crops; and Haberl *et al.* (2007) to estimate the above-ground net primary productivity for pasture.

4.2 – RUMINANTS' RATION

For all ruminant species, three feeding groups were defined due to their distinctive feeding necessities: adult females, replacement animals and adult males and surplus males and female animals (Table 4.1). For ruminants in industrialized countries, rations are taken from national inventory reports, literature reviews and expert knowledge while in developing regions, the ration is determined based on the availability of feed resources (yields of crops residues and forages) and animal requirements.

TABLE 4.1. Feeding groups for ruminant species

Animal category	GLEAM cohorts
Cattle and Buffaloes	
Group 1	AF
Group 2	AM, RF, RM
Group 3	MF, MM
Small ruminants	
Group 1	AF
Group 2	AM, RF, RFA, RFB, RM, RMA, RMB
Group 3	MF, MM

4.2.2 – Estimating the ration

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

4.2.2.1 – Proportion of roughages

First, the proportion of roughages for all species in a given area (Equation 4.1) is calculated based on the average 'by-products' and 'concentrate' fractions (Equations 4.2 and 4.3, respectively).

TABLE 4.2. List of feed items for ruminant species

Number	Item	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*) plants.
8	MAIZESIL	Silage from whole maize (*Zea mays*) plants.
9	RSTRAW	Residual plant material such as straw, brans, leaves, etc. from rice (*Oryza spp.*) cultivation.
10	WSTRAW	Residual plant material such as straw, brans, leaves, etc. from wheat (*Triticum spp*.) cultivation.
11	BSTRAW	Residual plant material such as straw, brans, leaves, etc. from barley (*Hordeum vulgare*) cultivation.
12	ZSTOVER	Residual plant material such as straw, brans, leaves, etc. from maize (*Zea mays*) cultivation.
13	MSTOVER	Residual plant material such as straw, brans, leaves, etc. from millet (*Pennisetum glaucum, Eleusine coracana, Panicum miliaceum, etc*) cultivation.
14	SSTOVER	Residual plant material such as straw, brans, leaves, etc. from sorghum (*Sorghum spp.*) cultivation.
15	TOPS	Residual plant material such as straw, brans, leaves, etc. from sugarcane (*Saccharum spp.*) cultivation.
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.
Grains		
18	GRAINS	Grains from barley (*Hordeum vulgare*).
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-product from the extraction of palm oil (*Elaeis guineensis*) kernel oil production, commonly referred to as 'kernel expeller'.
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. It is a viscous, dark and sugar-rich material.
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 mills.

Equation 4.1

$$RFRAC_{avgT} = 1 - (BY_{avgT} + CONC_{avgT})$$

Where:

$RFRAC_{avgT}$ = weighted average fraction of roughages in the diet for species *T*, dimensionless

BY_{avgT} = weighted average fraction of by-products in the diet for species *T*, dimensionless

$CONC_{avgT}$ = weighted average fraction of concentrates in the diet for species *T*, dimensionless

Equation 4.2

$$BY_{avgT} = (BY_1 * (AF * AFkg) + BY_2 * (RF * RFkg + RM * RMkg + AM * AMkg) + BY_3 * (MF * MFkg + MM * MMkg)) / (AF * AFkg + RF * RFkg + MF * MFkg + AM * AMkg + RM * RMkg + MM * MMkg)$$

Where:

BY_{avgT}	=	weighted average fraction of by-products in the diet for species *T*, dimensionless
BY_{fg}	=	fraction of by-products in the diet for the feeding group *fg*, dimensionless
AF, RF…	=	animal numbers from the different cohorts as calculated in the herd module, animals·year^{-1}
AFkg, RFkg…	=	average live weights for animals within each cohort as calculated in the herd module, kg·animal^{-1}

Equation 4.3

$$CONC_{avgT} = (CONC_1 * (AF * AFkg) + CONC_2 * (RF * RFkg + RM * RMkg + AM * AMkg) + CONC_3 * (MF * MFkg + MM * MMkg)) / (AF * AFkg + RF * RFkg + MF * MFkg + AM * AMkg + RM * RMkg + MM * MMkg)$$

Where:

$CONC_{avgT}$	=	weighted average fraction of concentrates in the diet for species *T*, dimensionless
$CONC_{fg}$	=	fraction of concentrates in the diet for the feeding group *fg*, dimensionless
AF, RF…	=	animal numbers from the different cohorts as calculated in the herd module, animals·year^{-1}
AFkg, RFkg…	=	average live weights for animals within each cohort as calculated in the herd module, kg·animal^{-1}

4.2.2.2 – Total available roughages

GLEAM estimates the total availability of roughages in each pixel by calculating the total dry matter yields of pasture, fodder and crop residues (Equation 4.4).

Equation 4.4

$$RYIELD = \sum(DMY_{1,9\text{-}15} * Area_{1,9\text{-}15})$$

Where:

RYIELD	=	total dry matter available from roughages in a pixel, kg
DMY_i	=	dry matter yield of feed material *i*, kg·hectare^{-1}
$Area_i$	=	land area of feed material *i*, hectares

4.2.2.3 – Total annual feed requirement

Feed requirements from ruminant species within a pixel are estimated on the basis that daily dry matter feed intake must be between 2 and 3 percent of live bodyweight (IPCC, 2006). This effectively means that the ration between annual intake and live weight must be between 7.30 and 10.95 (365 * 0.02 * LW / LW and 365 * 0.03 * LW / LW). When considering roughages only, however, those values are calculated as 7.30 * (1 – RFRACavgT) and 10.95 * (1 – RFRACavgT).

4.2.2.4 – Annual intake ratio and feed adequacy conditions

Total amount of roughages available is compared with the animal requirements within each pixel, providing an indication of feed adequacy in terms of sufficiency, deficiency or surplus:

Surplus conditions

$$RYIELD / LWTOT_{eq} \geq (0.04 * 365) * (1 - RFRAC_{avgT})$$

Deficiency conditions

$$RYIELD / LWTOT_{eq} < (0.02 * 365) * (1 - RFRAC_{avgT})$$

Sufficiency conditions

$$(0.02 * 365) * (1 - RFRAC_{avg}) \leq RYIELD / LWTOT_{eq} < (0.04 * 365) * (1 - RFRAC_{avg})$$

Where:

RYIELD	=	total dry matter available from roughages in a pixel, kg
$LWTOT_{eq}$	=	total ruminant species live weight in cattle equivalent terms, kg. It is calculated as shown in Equation 4.5.
$RFRAC_{avgT}$	=	weighted average fraction of roughages in the diet for species *T*, dimensionless
0.04, 0.02	=	daily intake as fraction of body weight, dimensionless.

Equation 4.5

$$LWTOT_{eq} = \sum_T [C_{LSU} * N_T * ((AF * AFkg + RF * RFkg + MF * MFkg + AM * AMkg + RM * RMkg + MM * MMkg) / (AF + RF + MF + AM + RM + MM))_T]$$

Where:

$LWTOT_{eq}$ = total ruminant species live weight in cattle equivalent terms, kg

C_{LSU} = LSU coefficients, with values of 1 for cattle and buffaloes and 0.2 for small ruminants, dimensionless

N_T = number of head of livestock species *T*, animals

AF, RF… = animal numbers from the different cohorts as calculated in the herd module, animals

AFkg, RFkg… = average live weights for animals within each cohort as calculated in the herd module, $kg \cdot animal^{-1}$

In situations of deficiency, leaves and hay from adjacent areas are included in the ration following:

Equation 4.6

$$LEAVES = (0.003 * 365) * LWTOT_{eq}$$

IF $(RYIELD + LEAVES) / LWTOT_{eq} > (0.02 * 365) * (1 - RFRAC_{avgT})$

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

IF $(RYIELD + LEAVES) / LWTOT_{eq} < (0.02 * 365) * (1 - RFRAC_{avgT})$

Hay from adjacent areas is added as:

$$GRASSH2 = LWTOT_{eq} * ((0.02 * 365) * (1 - RFRAC_{avgT}) - ((RYIELD + LEAVES) / LWTOT_{eq}))$$

Where:

LEAVES = total ruminant species' dry matter intake of 'leaves' feed, kg

GRASSH2 = total ruminant species' dry matter intake of 'hay from adjacent areas', kg

The final amount of roughages is calculated as:

Equation 4.7

$$RYIELDFINAL = RYIELD + LEAVES + GRASSH2$$

Where:

RYIELDFINAL = total dry matter of roughages per pixel, kg

4.2.2.5 – Share of individual feed materials

The final step is to estimate the share of individual feed materials in the animal diet. First, the contribution of roughages components is calculated using the values from steps 2 and 4:

Equation 4.8

$$GRASSfrac = DMY_1 * Area_1 / RYIELDFINAL$$
$$GRASSH2frac = GRASSH2 / RYIELDFINAL$$
$$RSTRAWfrac = DMY_9 * Area_9 / RYIELDFINAL$$
$$WSTRAWfrac = DMY_{10} * Area_{10} / RYIELDFINAL$$
$$BSTRAWfrac = DMY_{11} * Area_{11} / RYIELDFINAL$$
$$ZSTOVERfrac = DMY_{12} * Area_{12} / RYIELDFINAL$$
$$MSTOVERfrac = DMY_{13} * Area_{13} / RYIELDFINAL$$
$$SSTOVERfrac = DMY_{14} * Area_{14} / RYIELDFINAL$$
$$TOPSfrac = DMY_{15} * Area_{15} / RYIELDFINAL$$
$$LEAVESfrac = LEAVES / RYIELDFINAL$$

Where:

FEEDfrac	=	fraction of an individual feed component in the total amount of roughages, dimensionless
DMY_i	=	dry matter yield of feed component *i* per pixel, $kg \cdot ha^{-1}$
$Area_i$	=	land area of feed material *i* per pixel, hectares
RYIELDFINAL	=	total dry matter of roughages per pixel, kg
LEAVES	=	total ruminant species' dry matter intake of 'leaves', kg
GRASSH2	=	total ruminant species' dry matter intake of 'hay from adjacent areas', kg

The fraction of grass is allocated between fresh grass and hay based on the agro-ecological zone as shown in Table 4.3.

TABLE 4.3 Partitioning of grass

Agro-ecological zone	Partitioning of grass
Arid and hyper-arid	GRASSFfrac = GRASSfrac GRASSHfrac = 0
Temperate and tropical highlands	GRASSFfrac = GRASSfrac * $MMS_{pasture}$ / 100 GRASSHfrac = GRASSfrac * (100 – $MMS_{pasture}$) / 100
Humid	GRASSFfrac = GRASSfrac GRASSHfrac = 0

The final step is to estimate the share of each roughage material for each feeding group:

Equation 4.9

$$GRASSF_{fg} = GRASSFfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$GRASSH2_{fg} = GRASSH2frac * (1 - (BY_{fg} + CONC_{fg}))$$
$$RSTRAW_{fg} = RSTRAWfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$WSTRAW_{fg} = WSTRAWfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$BSTRAW_{fg} = BSTRAWfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$ZSTOVER_{fg} = ZSTOVERfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$MSTOVER_{fg} = MSTOVERfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$SSTOVER_{fg} = SSTOVERfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$TOPS_{fg} = TOPSfrac * (1 - (BY_{fg} + CONC_{fg}))$$
$$LEAVES_{fg} = LEAVESfrac * (1 - (BY_{fg} + CONC_{fg}))$$

Where:

$FEED_{fg}$	=	fraction of an individual feed component in the ration of feeding group *fg*, dimensionless
FEEDfrac	=	fraction of an individual feed component in the total amount of roughages, dimensionless
BY_{fg}	=	fraction of by-products in the diet for the feeding group *fg*, dimensionless
$CONC_{fg}$	=	fraction of concentrates in the diet for the feeding group *fg*, dimensionless

4.2.2.6 – Calculating the share of individual 'by-products' and 'concentrate' feed materials

The share of individual 'by-product' and 'concentrate' feed materials are calculated in Equation 4.10. 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.

Equation 4.10

$$FEED_{18\text{-}21,23\text{-}27,29\text{-}fg} = CONC_{fg} * CF_{18\text{-}21,23\text{-}27,29}$$
$$GRNBYDRY_{fg} = BY_{fg} / 2 + CONC_{fg} * CF_{GRNBYDRY}$$
$$GRNBYWET_{fg} = BY_{fg} / 2 + CONC_{fg} * CF_{GRNBYWET}$$

Where:

$FEED_{i\text{-}fg}$	=	fraction of feed material *i* in the ration of feeding group *fg*, dimensionless
BY_{fg}	=	fraction of by-products in the diet for the feeding group *fg*, dimensionless
$CONC_{fg}$	=	fraction of concentrates in the diet for the feeding group *fg*, dimensionless
CF_i	=	fraction of feed material *i* in the composition of compound feed, dimensionless

Tables 4.4 to 4.9 present average rations for ruminant species at regional level.

TABLE 4.4. Dairy cattle feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	14.4	23.8	33.2	22.5	41.4	22.4	68.3	10.7	54.9	56.8
Hay	17.0	23.8	16.6	22.8	17.8	19.2	5.6	14.2	15.4	18.1
Legumes and silage	30.6	34.3	22.6	33.2	0.3	2.7	10.4	-	-	-
Crop residues	-	1.8	2.5	1.8	31.7	38.4	-	60.1	8.7	17.0
Sugarcane tops	-	-	-	-	1.6	0.6	-	3.5	2.6	1.9
Leaves	-	-	-	-	3.6	2.3	-	6.1	6.5	3.0
By-products and concentrates										
Bran	4.4	2.9	2.0	3.0	0.6	0.5	2.5	0.2	0.4	0.1
Oilseed meals	6.4	4.6	8.5	5.7	2.3	6.7	1.3	5.2	6.4	3.1
Wet distilleries grain	4.3	-	-	-	-	-	-	-	-	-
Grains	22.8	7.2	13.2	9.1	0.2	7.2	11.8	-	4.9	0.1
Molasses	-	-	0.1	-	0.5	-	-	-	0.1	0.1
Pulp	-	1.8	1.3	1.8	-	-	-	-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.5. Beef cattle feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	35.2	-	36.0	21.0	24.9	23.6	63.5	8.0	65.1	61.1
Hay	39.4	-	14.8	21.9	36.7	18.7	6.8	12.5	9.4	12.6
Legumes and silage	7.8	-	23.1	32.3	2.1	0.7	10.7	-	-	-
Crop residues	-	-	3.8	2.1	242	46.2	-	68.0	10.2	19.4
Sugarcane tops	-	-	-	-	0.1	0.8	-	3.6	2.5	3.7
Leaves	-	-	-	-	9.2	2.8	-	5.9	4.1	1.6
By-products and concentrates										
Bran	0.9	-	1.7	3.5	0.3	0.2	3.8	0.1	0.1	-
Oilseed meals	0.6	-	7.6	6.6	1.9	2.7	1.5	1.9	3.9	1.4
Wet distilleries grain	1.0	-	-	-	-	-	-	-	-	-
Grains	15.1	-	10.6	10.5	0.6	4.2	13.7	-	4.7	0.1
Molasses	-	-	0.7	-	-	-	-	-	-	-
Pulp	-	-	1.7	2.1	-	-	-	-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.6. Dairy buffaloes feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	-	-	1.7	38.9	3.4	35.7	-	5.2	65.3	-
Hay	15.6	-	16.1	25.9	10.7	13.7	-	20.1	12.2	-
Legumes and silage	34.4	-	33.7	17.3	-	-	-	-	-	-
Crop residues	5.2	-	5.0	-	72.8	39.5	-	54.8	8.4	-
Sugarcane tops	-	-	-	-	5.8	2.2	-	4.7	2.2	-
Leaves	-	-	-	-	4.0	2.3	-	8.1	5.2	-
By-products and concentrates										
Bran	4.7	-	0.8	4.6	1.6	3.3	-	3.6	3.4	-
Oilseed meals	10.9	-	11.5	5.2	1.6	3.3	-	3.6	3.4	-
Wet distilleries grain	7.3	-	7.0	-	-	-	-	-	-	-
Grains	15.6	-	18.2	8.1	-	-	-	-	-	-
Molasses	-	-	-	-	-	-	-	-	-	-
Pulp	6.2	-	6.0	-	-	-	-	-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.7. Meat buffaloes feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	-	41.1	-	-	38.9	37.8		5.9	68.0	-
Hay	-	27.4	-	-	27.7	12.0		19.8	13.2	-
Legumes and silage	-	18.3	-	-	-	-		-	-	-
Crop residues	-	-	-	-	29.8	43.5		60.1	8.9	-
Sugarcane tops	-	-	-	-	-	2.1		4.7	2.3	-
Leaves	-	-	-	-	2.2	2.5		7.5	5.3	-
By-products and concentrates										
Bran	-	4.7	-	-	0.7	1.1		1.0	1.1	-
Oilseed meals	-	3.3	-	-	0.7	1.1		1.0	1.1	-
Wet distilleries grain	-	-	-	-	-	-		-	-	-
Grains	-	5.2	-	-	-	-		-	-	-
Molasses	-	-	-	-	-	-		-	-	-
Pulp	-	-	-	-	-	-		-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.8. Dairy small ruminant feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	29.7	32.0	24.9	32.5	46.4	23.0	62.2	23.9	74.9	58.8
Hay	37.5	24.6	19.3	25.0	7.0	33.8	6.9	6.3	11.9	4.9
Legumes and silage	2.6	9.8	6.6	10.0	0.7	-	7.8	-	-	-
Crop residues	-	11.5	16.4	11.8	38.4	26.9	1.1	53.9	8.7	31.1
Sugarcane tops	-	-	-	-	2.2	0.3	-	2.3	2.1	3.9
Leaves	-	-	-	-	0.9	2.1	-	1.6	0.3	0.2
By-products and concentrates										
Bran	5.8	8.6	11.3	8.2	2.1	6.9	9.8	6.0	1.0	0.6
Oilseed meals	2.1	2.3	4.3	2.1	1.7	6.9	0.6	6.0	1.0	0.6
Wet distilleries grain	-	-	-	-	-	-	-	-	-	-
Grains	17.2	3.6	5.4	3.3	0.2	-	5.5	-	-	-
Molasses	0.2	-	0.7	-	-	-	-	-	-	-
Pulp	4.9	7.6	11.1	7.2	0.3	-	6.1	-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.9. Meat small ruminant feed rations, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Roughages										
Fresh grass	34.8	38.2	45.4	37.0	34.9	19.7	75.4	25.7	68.9	57.9
Hay	44.0	29.4	21.6	29.0	22.2	32.6	7.5	6.6	18.8	8.8
Legumes and silage	3.0	11.8	9.7	12.0	0.6	-	9.3	-	-	-
Crop residues	-	13.7	13.0	13.9	37.4	39.2	1.2	55.9	9.9	27.9
Sugarcane tops	-	-	-	-	1.8	0.3	-	4.2	1.4	5.2
Leaves	-	-	-	-	2.2	1.5	-	1.7	0.2	0.2
By-products and concentrates										
Bran	0.2	-3.6	2.8	4.3	0.5	3.3	4.7	3.0	0.4	-
Oilseed meals	0.5	-0.2	2.2	0.3	0.3	3.3	0.1	3.0	0.4	-
Wet distilleries grain	-	-	-	-	-	-	-	-	-	-
Grains	17.3	-0.4	0.7	0.5	-	-	0.9	-	-	-
Molasses	0.2	-	1.3	-	-	-	-	-	-	-
Pulp	-	-2.6	3.4	3.1	-	-	1.0	-	-	-

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

4.3 – MONOGASTRICS' RATION

The feed materials used for pigs and chickens are divided into three main categories: swill and scavenging, non-local feed materials and locally-produced feed materials (Table 4.10). The proportions of the three main feed groups making up the ration were defined for each of the production systems, based on literature and expert knowledge. Gaps in the literature were filled through discussions with experts and also through primary data gathering. Layers and broilers' ration are based on literature, national consultation and expert knowledge.

4.3.1 – Estimating the ration

4.3.1.1 – Proportion of local feed materials

The proportion of locally-produced feed materials are consumed by pigs and backyard chickens and is calculated as:

Equation 4.11

LOCALfrac = 1 – (SWILLfrac + NONLOCALfrac)

Where:

LOCALfrac = fraction of locally-produced materials in the ration, dimensionless

SWILLfrac = fraction of swill in the ration, dimensionless

NONLOCALfrac = fraction of non-local feed materials in the ration, dimensionless

4.3.1.2 – 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 4.12.

Equation 4.12

LOCALYIELD = $\sum(DMY_{3\text{-}13,15\text{-}20} * Area_{3\text{-}13,15\text{-}20})$

Where:

LOCALYIELD = total amount of locally-produced feed materials, kg

DMY = dry matter yield of feed material, kg·hectare^{-1}

$Area_i$ = land area of feed material *i*, hectares

TABLE 4.10. List of feed items for monogastrics

Number	Item	Description
Swill and scavenging		
1	SWILL	Household food 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	Residual plant material such as straw, brans, leaves, etc. 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	Residual plant material such as straw, brans, leaves, etc. 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 rapeseed (*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 canola oil production, commonly referred to as 'canola cakes'.
35	PKEXP	By-products from the production of kernel palm oil, commonly referred to as 'kernel expeller'.
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 production of sugar. It is a dark, viscous and sugar-rich material.
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 favour the formation of the egg shell.
43	CONC	Concentrate feed from mills.

[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 by-products, second grade crops, crop residues or forages.
[b] Feed materials that are blended at a feed mill to produce compound 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.

4.3.1.3 – Annual intake ratio and feed adequacy conditions

The total amount of local feed is compared with the animal requirements based on bodyweight. It is assumed that there is sufficient feed when the total available amount represents 10 times the bodyweight.

Deficiency conditions

LOCALYIELD / LWTOT < 10 * LWTOT

Sufficiency conditions

LOCALYIELD / LWTOT ≥ 10 * LWTOT

Where:

LOCALYIELD = total amount of locally-produced feed materials, kg

LWTOT = total pigs and backyard chicken live weight, kg. It is calculated as shown in Equation 4.13.

Equation 4.13

$$LWTOT_{eq} = \sum_T [N_T * ((\sum_c Cohort_c * LW_c) / (\sum_c Cohort_c))_T]$$

Where:

$LWTOT_{eq}$ = total ruminant species live weight in cattle equivalent terms, kg

N_T = number of animals of livestock species *T*, animals

$Cohort_c$ = number of animals of cohort *c*, animals

LW_c = live weight of cohort *c*, kg·animal^{-1}

In situations of deficiency, grass and leaves are added for pigs as follows:

Equation 4.14

GRASSF = 0.10 * LOCALYIELD

LEAVES = 0.15 * LOCALYIELD

Where:

LEAVES = total ruminant species' dry matter intake of 'leaves' feed, kg

GRASSH2 = total ruminant species' dry matter intake of 'hay from adjacent areas', kg

The final amount of local materials is calculated as:

Equation 4.15

LOCALYIELDFIN = 1.25 * LOCALYIELD

Where:

LOCALYIELDFIN = total dry matter of locally-produced feed materials per pixel, kg

4.3.1.4 – Calculating the share of individual local feed materials

The proportion of local feed materials are calculated following Equation 4.16:

Equation 4.16

$$FEED_i = LOCALYIELD_i * LOCALfrac$$

Where:

$FEED_i$ = fraction of an feed component *i* in the ration, dimensionless

$LOCALYIELD_i$ = total amount of locally-produced feed material *i*, kg

LOCALfrac = fraction of locally-produced materials in the ration, dimensionless

Tables 4.11 to 4.16 present average rations for monogastric species.

TABLE 4.11. Backyard pig production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Swill	-	20	-	19	-	20	-	-	19	19
Roughages and crop residues										
Pulses straw (local)	-	5	-	7	-	2	-	-	1	14
Sugarcane tops (local)	-	-	-	1	-	5	-	-	27	6
Banana residues (local)	-	-	-	-	-	-	-	-	4	2
Food crops										
Pulses (local)	-	1	-	1	-	-	-	-	-	2
Cassava (local)	-	-	-	-	-	-	-	-	1	7
Wheat (local)	-	18	-	12	-	6	-	-	1	-
Maize (local)	-	1	-	7	-	7	-	-	5	8
Barley (local)	-	7	-	5	-	-	-	-	-	-
Millet (local)	-	-	-	-	-	-	-	-	-	2
Rice (local)	-	-	-	-	-	17	-	-	2	3
Sorghum (local)	-	-	-	-	-	-	-	-	1	3
Soybean (local)	-	-	-	-	-	1	-	-	2	-
Banana (local)	-	-	-	-	-	-	-	-	1	2
By-products and concentrates										
Soybean meal (local)	-	1	-	1	-	8	-	-	15	1
Oilseed meal (local)	-	13	-	17	-	8	-	-	5	9
Oilseed meal (non-local)	-	10	-	8	-	5	-	-	5	2
Cottonseed meal (local)	-	-	-	-	-	1	-	-	1	3
Cottonseed meal (non-local)	-	10	-	8	-	5	-	-	5	2
Dry by-product grain industries (local)	-	13	-	12	-	15	-	-	5	8

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.12. Intermediate pig production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Swill	-	-	-	-	-	4	-	-	1	3
Roughages and crop residues										
Pulses straw (local)	-	2	2	2	-	1	-	7	1	9
Sugarcane tops (local)	-	-	-	-	-	4	-	10	18	2
Banana residues (local)	-	-	-	-	-	-	-	2	3	4
Food crops										
Pulses (local)	-	-	-	-	-	-	-	1	-	1
Pulses (non-local)	-	-	2	-	-	-	-	-	-	-
Cassava (local)	-	-	-	-	-	-	-	-	-	7
Cassava (non-local)	-	-	-	-	-	1	-	1	1	7
Wheat (local)	-	9	11	9	-	3	-	3	1	-
Wheat (non-local)	-	24	8	21	-	2	-	-	8	-
Maize (local)	-	-	10	2	-	4	-	2	5	4
Maize (non-local)	-	14	12	17	-	25	-	6	18	12
Barley (local)	-	4	6	3	-	-	-	-	-	-
Barley (non-local)	-	7	7	6	-	2	-	-	-	-
Millet (local)	-	-	-	-	-	-	-	1	-	1
Millet (non-local)	-	-	-	-	-	-	-	-	-	7
Rice (local)	-	-	-	-	-	12	-	8	1	2
Rice (non-local)	-	-	-	-	-	3	-	12	1	3
Sorghum (local)	-	-	-	-	-	-	-	-	1	2
Sorghum (non-local)	-	-	-	-	-	-	-	11	4	10
Soybean (local)	-	-	-	-	-	1	-	-	1	-
Soybean (non-local)	-	-	-	-	-	2	-	-	3	-
Banana	-	-	-	-	-	-	-	1	1	1
By-products and concentrates										
Soybean meal (local)	-	1	2	-	-	4	-	1	9	1
Soybean meal (non-local)	-	10	10	10	-	8	-	10	10	3
Oilseed meal (local)	-	6	5	7	-	6	-	6	4	8
Oilseed meal (non-local)	-	7	5	7	-	-	-	-	-	-
Cottonseed meal (local)	-	-	-	-	-	1	-	1	1	2
Cottonseed meal (non-local)	-	-	-	-	-	-	-	4	-	-
Dry by-product grain industries (local)	-	7	13	7	-	10	-	7	4	5
Dry by-product grain industries (non-local)	-	4	3	4	-	4	-	2	1	-
Molasses (non-local)	-	-	2	-	-	-	-	-	-	1
Fishmeal (non-local)	-	3	-	2	-	1	-	2	1	2
Complements (amino acids, minerals) (non-local)	-	1	1	1	-	1	-	1	1	1

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.13. Industrial pig production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Food crops										
Pulses (non-local)	-	-	3	-	-	-	-	-	-	(-)-
Cassava (non-local)	-	-	-	-	-	1	-	2	1	11(4)
Wheat (non-local)	10	34	26	27	-	4	20	-	12	(-)-
Maize (non-local)	54	20	13	28	-	55	-	12	50	18(2)
Barley (non-local)	17	10	22	9	-	3	16	-	-	(-)-
Millet (non-local)	-	-	-	-	-	-	-	-	-	10(1)
Rice (non-local)	-	-	-	-	-	3	-	23	1	5(1)
Sorghum (non-local)	-	-	-	-	-	1	43	22	11	19(1)
Soybean (non-local)	-	-	-	-	-	4	-	1	2	-(-)
By-products and concentrates										
Soybean meal (non-local)	11	15	16	15	-	17	19	21	19	6(1)
Oilseed meal (non-local)	1	10	11	10	-	-	-	-	-	-(5)
Cottonseed meal (non-local)	-	-	-	-	-	-	-	9	-	-(1)
Dry by-product grain industries (non-local)	4	5	5	6	-	9	-	5	1	-(3)
Molasses (non-local)	-	-	2	-	-	-	-	-	1	1(-)
Fishmeal (non-local)	1	4	-	3	-	1	-	4	1	3(-)
Complements (amino acids, minerals) (non-local)	2	2	2	2	-	2	2	2	2	2(-)

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.14. Backyard chicken production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Swill	-	20	20	20	40	40	-	40	40	40
Food crops										
Pulses (local)	-	1	-	1	1	1	-	1	-	2
Cassava (local)	-	-	-	-	-	3	-	-	2	8
Wheat (local)	-	27	17	16	15	5	-	12	1	1
Maize (local)	-	1	23	11	2	-	-	2	7	11
Barley (local)	-	10	4	6	4	-	-	2	-	-
Millet (local)	-	1	-	-	-	-	-	-	-	3
Rice (local)	-	-	-	-	1	14	-	14	6	3
Sorghum (local)	-	-	-	-	3	1	-	-	1	3
Soybean (local)	-	-	1	-	-	1	-	-	3	-
By-products and concentrates										
Soybean meal (local)	-	2	4	1	-	5	-	2	20	2
Oilseed meal (local)	-	19	8	26	18	18	-	6	12	11
Cottonseed meal (local)	-	-	-	-	3	1	-	5	2	6
Dry by-product grain industries (local)	-	19	22	17	13	11	-	15	7	11

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.15. Layer chicken production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Food crops										
Wheat (non-local)	2	52	44	48	22	3	32	30	4	7
Maize (non-local)	65	-	22	9	42	57	10	27	29	59
Barley (non-local)	-	30	-	16	-	-	-	-	-	-
Sorghum (non-local)	-	-	-	-	-	-	21	-	37	-
Soybean (non-local)	2	-	19	2	15	18	4	-	3	3
By-products and concentrates										
Soybean meal (non-local)	22	-	1	3	4	3	2	8	14	14
Oilseed meal (non-local)	-	8	-	5	2	3	9	9	5	9
Dry by-product grain industries (non-local)	-	-	1	-	-	5	-	8	-	-
Rapeseed (non-local)	-	-	4	7	7	1	8	-	-	-
Fishmeal (non-local)	-	2	-	2	-	-	5	10	-	-
Complements (amino acids, minerals) (non-local)	1	1	1	1	1	1	1	1	1	1
Limestone	8	7	8	7	7	8	7	6	7	7

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.16. Broiler chicken production system feed ration, regional averages

Feed component	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	percentage of total dry matter intake									
Food crops										
Wheat (non-local)	-	38	40	39	16	13	33	18	-	6
Maize (non-local)	62	30	24	28	44	47	5	38	70	64
Barley (non-local)	-	-	-	-	7	4	7	5	-	-
Sorghum (non-local)	-	-	5	-	7	7	21	9	-	-
Soybean (non-local)	2	25	15	25	-	-	3	-	-	-
By-products and concentrates										
Soybean meal (non-local)	24	-	10	-	25	25	16	24	28	28
Oilseed meal (non-local)	5	5	2	6	2	1	2	2	-	-
Rapeseed (non-local)	-	-	1	-	-	-	1	-	-	-
Rapeseed meal (non-local)	-	-	1	-	-	-	4	-	-	-
Fishmeal (non-local)	5	-	-	-	2	1	5	2	-	-
Complements (amino acids, minerals) (non-local)	1	1	1	1	1	1	1	1	1	1
Limestone	1	1	1	1	1	1	2	1	1	1

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

4.4 – NUTRITIONAL VALUES

Nutritional values were obtained from several sources such as FEEDEPEDIA, NRC guidelines for pigs and poultry and CVB tables from the Dutch feed board database. Average nutritional values were calculated by multiplying the percentage of each feed material in the ration to obtain an average energy and nitrogen content per kilogram of dry matter for the whole ration:

Equation 4.17

$$RATION_{NUT} = \sum_i (FEED_i * NUTVALUE_i)$$

Where:

$RATION_{NUT}$ = average ration's digestibility or nitrogen content, percentage and g N·kg DM^{-1}, respectively

$FEED_i$ = fraction of an feed component *i* in the ration, dimensionless

$NUTVALUE_i$ = digestibility or nitrogen content of feed component *i*, percentage and g N·kg DM^{-1}, respectively

Tables 4.17 and 4.18 summarize the nutritional values of animal rations at regional level.

TABLE 4.17. Nutritional values, regional averages

Livestock category	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Digestibility (percentage)									
Dairy cattle	72	73	77	74	56	59	73	53	62	57
Beef cattle	68	-	76	74	58	57	73	51	63	57
Buffaloes	73	71	76	73	52	56	-	52	61	-
Small ruminants	66	65	70	67	56	56	70	54	59	56
	Nitrogen content (g N·kg DM ration^{-1})									
Dairy cattle	22.6	22.6	26.5	22.9	13.1	16.1	24.2	15.2	19.8	16.7
Beef cattle	21.9	21.9	25.4	22.5	16.5	16.2	24.1	13.2	19.4	15.4
Buffaloes	20.9	23.5	21.9	23.4	12.6	15.1	-	12.6	18.6	-
Small ruminants	22.7	21.8	23.8	21.7	13.9	16.4	23.7	14.2	17.7	15.9

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

TABLE 4.18. Nutritional values, regional averages

Livestock category	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
	Digestibility (percentage)									
Pigs (backyard)	-	66	-	66	-	68	-	63	64	64
Pigs (intermediate)	-	77	76	77	-	76	-	71	75	74
Pigs (industrial)	83	80	78	80	-	83	82	79	85	79
Chicken (backyard)	-	62	65	61	63	62	-	63	61	65
Chicken (layers)	74	73	74	73	73	73	72	71	74	73
Chicken (broilers)	72	74	72	73	72	72	71	72	73	73
	Nitrogen content (g N·kg DM ration^{-1})									
Pigs (backyard)	-	38.1	-	37.5	-	34.7	-	30.9	35.2	26.7
Pigs (intermediate)	-	36.2	32.5	35.8	-	31.8	-	31.4	33.5	25.7
Pigs (industrial)	27.6	38.4	36.5	37.0	-	32.6	32.1	39.5	32.5	26.4
Chicken (backyard)	-	33.6	30.0	35.7	35.7	37.0	-	32.7	43.9	33.3
Chicken (layers)	30.1	24.6	27.6	27.2	28.5	28.0	31.4	37.1	28.7	30.0
Chicken (broilers)	39.2	32.2	33.3	32.8	34.9	34.8	37.3	35.3	33.7	34.0

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

4.5 – RELATED EMISSIONS

4.5.1 – Carbon dioxide emissions

This section describes the sources of CO_2 emissions related to feed production.

4.5.1.1 – Nitrogen fertilizer manufacture

Synthetic nitrogen application rates were defined for each crop at a national level, based on existing data sets (primarily FAO's Fertilizer use statistics). CO_2 emissions related to the manufacture of synthetic nitrogenous fertilizer were calculated following Equation 4.16:

Equation 4.16

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

Where:

$CO2NFERTHA_i$ = CO_2 emissions from synthetic fertilizer manufacturing for feed material *i*, kg CO_2·hectare^{-1}

$NFERTHA_i$ = N fertilizer application rate for feed material *i*, kg N·hectare^{-1}

EF_{NFERT} = emission factor for synthetic fertilizer manufacture, kg CO_2·kg N^{-1}. Default value of 6.8 was used.

4.5.1.2 – Field operations

Energy is used on-farm for a variety of field operations required for crop cultivation. Data on the type and amount of energy required per hectare or kilogram of each feed material parent crop was taken from literature review, existing databases and expert knowledge. Emissions per hectare were estimated using Equation 4.17. Field operations are undertaken using non-mechanized power sources, i.e. human or animal labour, in some countries. To reflect this variation, the energy consumption rates were adjusted according to the proportion of the field operations undertaken using non-mechanized power sources.

Equation 4.17

$CO2CROPHA_i$ = $Mech * (\sum Energy_s * EF_{FIELD,s})$

Where:

$CO2CROPHA_i$ = carbon dioxide emissions from field operations for feed material *i*, kg $CO_2 \cdot ha^{-1}$

Mech = fraction representing the mechanization level, dimensionless

$Energy_s$ = energy use from source *s*, energy$\cdot ha^{-1}$.

$EF_{FIELD,s}$ = emission factor for energy source *s*, kg $CO_2 \cdot$energy type^{-1}.

4.5.1.3 – Feed transport and processing

Pasture, local feeds and swill, by definition, are transported minimal distances and therefore are allocated zero emissions for transport. Non-local feeds are assumed to be transported between 100 km and 700 km by road to their place of processing. In countries where more of feed is consumed than is produced (i.e. net importers), feed materials that are known to be transported globally (e.g. soy cakes) also receive emissions that reflect typical sea transport distances.

4.5.1.4 – Blending and transport of compound feed

In addition, energy is used in feed mills for blending non-local feed materials to produce compound feed and to transport it to its point of sale. It was assumed that 186 MJ of electricity and 188 MJ of gas were required to blend 1,000 kg of DM, and that the average transport distance was 200 km, arising to **0.0786 kg CO_2-eq·kg compound feed^{-1}**. Default values of 0.46, 3.6 and 0.08 kg $CO_2 \cdot$kg feed^{-1} for cassava, fishmeal, synthetic and limestone were used, respectively.

4.5.1.5 – Land-use change: approach for feed crops

GLEAM covers the emissions from land-use change is focused on one specific feed product, soybean, in specific countries in Latin America. This is based on observed land use trends, feed crop expansion trends and trade flows patterns as well as findings from previous studies such as Wessenaar *et al.* (2007) and Cederberg *et al.* (2011).

The approach used uses IPCC guidelines as a basis for the quantification of LUC emissions. This choice is largely based on the fact that the IPCC approach meets the UNFCCC needs for calculating and reporting of GHG emissions from LUC. The cropland part of this assessment also relies on other guidelines such as the PAS2050 (also based on IPCC guidelines) for input data such as emission factors. The IPCC guidelines (2006) recommend that emissions are amortized across a 20-year period. Because of data availability (forestry inventories are only available from 1990), the rates of LUC are taken as the average over the 16-year period (1990-2006). This practically discounts four years of emissions.

Agriculture has been a major driving force behind land transformation; globally, agricultural land area increased by 83 million hectares over the period 1990-2006. In most regions, cropland has increased at the expense of both pasture and forest land (Figure 4.1). The most affected regions in terms of crop expansion are Latin America, Asia and Africa. Declining agricultural land is observable in Europe and North America where agricultural land abandonment has resulted in reforestation. During the period considered (1990-2006), deforestation occurred mainly in Africa and Latin America. More recent trends in deforestation, particularly in Asia, and their association with feed production are therefore not considered here.

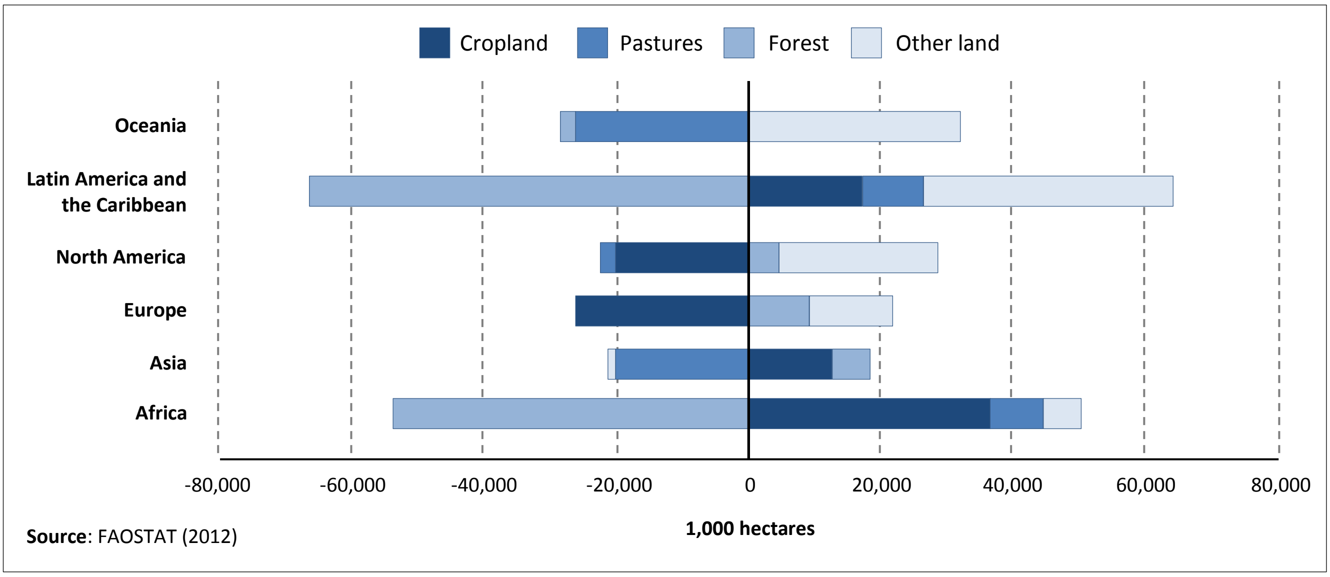

Figure 4.1 - Net land conversion between 1990 and 2006, by region.

A comparison of the two major crops driving agricultural expansion reveals key regional differences with regard to the importance of specific crop expansion at regional level (Figure 4.2). The expansion of soybean area has been significant in North and South America, while maize expansion is more important in Africa and Asia.

A number of conclusions can be drawn from these regional trends: (i) deforestation for crop expansion has been a main LUC phenomena in Africa, however crop expansion in the region has been largely driven by the expansion of maize which is not used for livestock in the region; (ii) in Asia and North America, soybean and maize expansion occurred, however in these regions the overall trend has been one of increasing forest area and reduction in grassland; and (iii) in Latin America, trends in land conversion, particularly deforestation, are closely linked to the expansion of soybean.

The reported annual increase of soybean area in Brazil is 534,000 ha. It was assumed a simplified pattern of deforestation in the Amazon, in which cleared land is first used as pasture and/or crop land, and then left as fallow land. The latter, classified as "other land" in FAOSTAT, is occupied by weeds, grasses, shrubs and, partly, by secondary forest. Under this assumption, every year roughly 2.9 million hectares are converted to arable land and grassland. At the same time, agricultural land is abandoned at a rate of 1.6 million hectares per year. The annual net increase of arable land and grassland is 0.53 and 0.75 million hectares, respectively. Therefore, it was assumed that all incremental soybean area is gained at the expense of forest area.

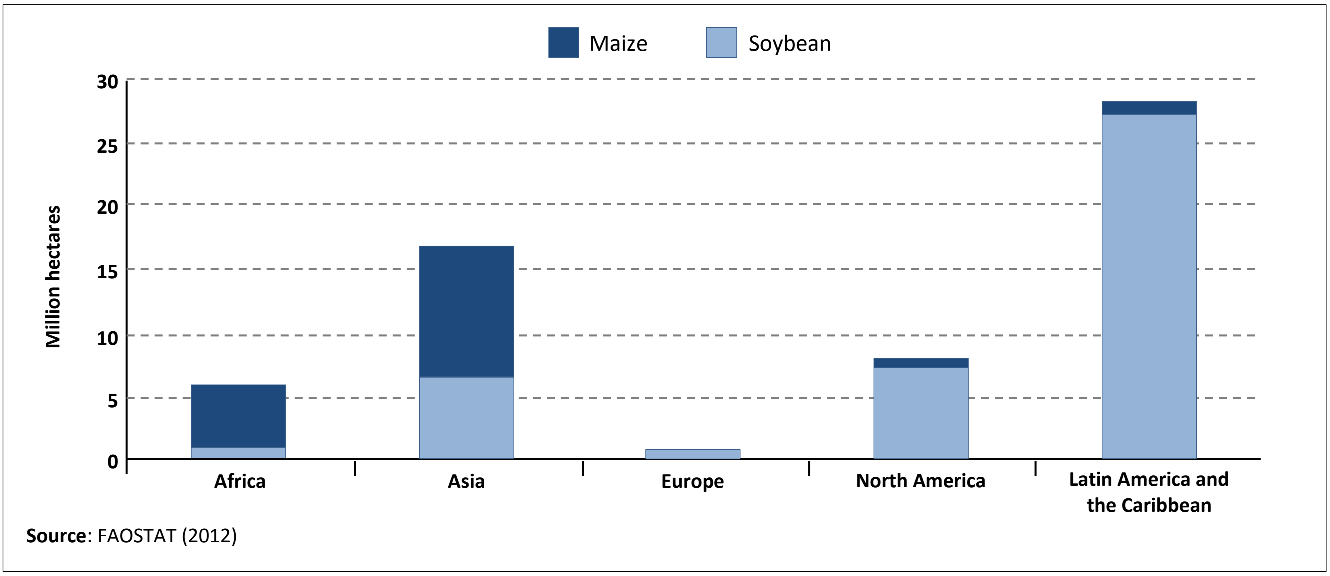

Figure 4.2 – Maize and soybean area expansion between 1990 and 2006, by region.

Emissions related to LUC were taken from PAS2050 guidelines (BSI, 2008) that estimate deforestation (conversion of forest to annual cropland) releases in Brazil at an average 37 t CO_2-eq·hectare^{-1}, and conversion of forest and shrub land to annual crop in Argentina at 17 and 2.2 t CO_2-eq·hectare^{-1}, respectively. GHG emissions from soybean-driven LUC were calculated as the accumulated emissions for one year resulting from the total area deforested during the period 1987-2007 divided by the total soybean production in 2007.

Based on this data, two LUC emission intensities were estimated for soybean cake produced in Brazil and Argentina, respectively: **7.69** and **0.93 kg CO_2-eq·kg soybean cake^{-1}**. Soybeans and soybean cake produced elsewhere were assumed not to be associated with LUC.

4.5.1.6 – Land-use change: pasture expansion

It has been argued that while forest conversion to soybean cultivation is occurring, the majority of deforested area is destined to pasture formation. Table 4.19 shows the net changes for different land use categories across regions. Pasture expansion and forest area declination have been notable in Latin America and Africa.

TABLE 4.19. Net changes in area for main land-use categories (1990-2006)

Countries	Arable land & permanent crops	Pasture area	Forest area	Other land
	Area (thousand hectares)			
Africa	36,025	8,863	-53,700	7,001
Asia*	12,149	-20,506	6,855	-1,068
Europe	-55,646	-152,441	261	-96,796
North America	-20,073	-1,954	5,387	23,811
Latin America and the Caribbean	15,753	11,069	-67,870	37,973
Oceania	-263	-28,408	-2,112	30,926

* Central Asia is excluded due to incomplete dataset.

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 4.20 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 4.20. Pasture expansion against forestland in Latin America (1900-2006)

Countries	Change in pasture area (1,000 hectare)	Share of regional expansion (percentage)
Brazil	10,212.3	77.2
Chile	1,150.0	8.7
Paraguay	1,040.0	7.9
Nicaragua	454.3	3.4
Other*	365.0	2.8
Total	13,221.6	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 is 0 tonnes of dry matter per hectare. 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. Table 4.21 presents the estimates of above- and below-ground biomass. A default factor of 0.50 tonnes C·tonne DM^{-1} for woody biomass was used to convert biomass into carbon stocks per hectare.

TABLE 4.21. Pasture expansion against forestland in Latin America (1900-2006)

Countries	Above-ground biomass (tonnes DM·ha^{-1})	Ratio of below- to above- ground biomass	Below-ground biomass (tonnes DM·ha^{-1})	Total biomass (tonnes DM·ha^{-1})
Brazil	220	0.24	52.8	272.8
Chile	220	0.24	52.8	272.8
Paraguay	210	0.24	50.4	260.4
Nicaragua	210	0.24	50.4	260.4
Other*	220	0.24	52.8	272.8

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

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 (Table 4.22) show a net decrease in SOC with losses ranging between 1.1 to 2.3 t C ha^{-1}.

TABLE 4.22. 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

4.5.2 – Nitrous oxide emissions

The emission of nitrous oxide (N_2O) from cropping includes direct and indirect N_2O from leaching and volatilization emissions. All were calculated using IPCC (2006) Tier 1 methodology. Manure nitrogen application rates were calculated in the manure module. Crop residue nitrogen was calculated using the crop yields and the IPCC crop residue formulae (Table 11.2, Chapter 10, Volume 4).

4.5.3 – Methane emissions

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.

4.5.4 – Allocation of emissions between the crop and its by-product

In order to calculate the emission intensity of each feed material, emissions need to be allocated between the crop and its by-products, such as crop residues or meals. The general equation used is:

Equation 4.18

GHGkgDM = GHGha / (DMYGcrop * FUEcrop + DMGYby * FUEby) * EFA / MFA * A2

Where:

GHGkgDM	=	CO_2, CH_4 or N_2O emissions per kilogram of dry matter of a given feed material, kg gas·kg DM^{-1}
GHGha	=	CO_2, CH_4 or N_2O emissions per hectare, kg gas·$hectare^{-1}$
DMYGcrop	=	crop dry matter yield, kg DM·$hectare^{-1}$
DMGYby	=	crop residue dry matter yield, kg DM·$hectare^{-1}$
FUEcrop	=	crop feed use efficiency, i.e. fraction of crop gross yield that is harvested, dimensionless
FUEby	=	crop residue or by-product feed use efficiency, i.e. fraction of crop residue or by-product that is harvested, dimensionless
EFA	=	economic fraction allocation, i.e. crop or by-product value as a fraction of the total crop or by-product value, dimensionless
MFA	=	mass fraction allocation, i.e. crop or by-product mass as a fraction of the total crop or by-product mass, dimensionless
A2	=	second grade allocation, i.e. ratio of the economic value of second grade crop to the economic value of its first grade equivalent, dimensionless

Dry matter yields and estimated harvest fractions were used to determine the mass fractions. Where crop residues were not used, they were assumed to have a value of zero, effectively allocating 100 percent of the emissions to the crop.

When second grade crops were considered, they were allocated a fraction (A2 = 0.2) of the total emissions arising from their production, roughly proportionate 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. This is an important assumption, which will be investigated and refined in the future.

CHAPTER 5 – SYSTEM MODULE

Feed intake for each species and cohort are calculated based on the ration, its nutritional values and animals' energy requirements.

The functions of the system module are:

- Calculate the average **energy requirement** and **feed intake** of each animal in all the cohorts.
- Calculate the total feed emissions and land use arising from the production, processing and transport of the feed.
- Calculate the **enteric emissions**.
- Calculate the **methane** and **nitrous oxide** emissions arising from the **manure management**.

This chapter describes how to estimate energy requirements, feed intake and emissions associated with animal production at herd level.

5.1 – ENERGY REQUIREMENTS

The gross energy requirement is the sum of the requirements for maintenance, lactation, pregnancy, animal activity, weight gain and production. The method estimates a maintenance requirement (as a function of live-weight and energy expended in feeding); a production energy requirement influenced by the level of productivity (e.g. milk yield, live-weight gain, wool production, egg production); physiological state (pregnancy and lactation); and the stage of maturity of the animal. Based on production and management practices, the net energy and feed requirements of all animals are calculated. Data from the herd module (i.e. the number of animals in each category, their average weights and growth rates, fertility rates and yields) were combined with input data on parameters (egg weight, protein/fat fraction, temperature, activity levels).

5.1.1 – Energy requirement ruminants

The model uses the IPCC Tier 2 algorithms to calculate the energy requirements for each cohort (IPCC, 2006). Table 5.1 summarizes the equations used to estimate the daily gross energy (GE):

TABLE 5.1. Equations used to estimate GE for ruminant species

Metabolic function	Abbreviation	Equations for large ruminants	Equations for small ruminants
Maintenance	NE_{main}	Equation 5.1	Equation 5.1
Activity	NE_{act}	Equation 5.2	Equation 5.3
Growth	NE_{gro}	Equation 5.4	Equation 5.5
Lactation	NE_{lact}	Equation 5.6	Equation 5.7
Draught power	NE_{work}	Equation 5.8	Not applicable
Production of fibre	NE_{fiber}	Not applicable	Equation 5.9
Pregnancy	NE_{preg}	Equation 5.10	Equation 5.10
Ratio of net energy available in diet for maintenance to digestible energy consumed	REM	Equation 5.11	Equation 5.11
Ratio of net energy available for growth in a diet to digestible energy consumed	REG	Equation 5.12	Equation 5.12
Daily gross energy	GE	Equation 5.13	Equation 5.13

5.1.1.1 – Net energy for maintenance (NE_{main})

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

Equation 5.1

$$NE_{main} = C_{main} * LW^{0.75}$$

Where:

NE_{main} = net energy required by the animal for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

C_{main} = coefficient for NE_{main} for each cohort, $MJ \cdot kg^{-0.75} \cdot day^{-1}$. Values are given in Table 5.2.

LW = live weight of the animal in a given cohort, $kg \cdot animal^{-1}$

TABLE 5.2. 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	0.322[a]
Cattle and Buffaloes, bulls	RM, MM	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.

5.1.1.2 – Net energy for activity (NE_{act})

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

Equation 5.2

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

Where:

NE_{act} = net energy for animal activity, $MJ \cdot animal^{-1} \cdot day^{-1}$

C_{act} = coefficient for NE_{act} which depends on the animal feeding condition, dimensionless. Values are given in Table 5.3.

NE_{main} = net energy for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

Equation 5.3

$$NE_{act} = C_{act} * LW$$

Where:

NE_{act} = net energy for animal activity, $MJ \cdot animal^{-1} \cdot day^{-1}$

C_{act} = coefficient for NE_{act} which depends on the animal feeding condition, $MJ \cdot animal^{-1} \cdot day^{-1}$. Values are given in Table 5.3.

LW = live weight of the animal in a given cohort, $kg \cdot animal^{-1}$

TABLE 5.3. Activity coefficients for different feeding situations

Situation	Definition	C_{act}
Cattle and Buffaloes (dimensionless)		
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 ($MJ \cdot animal^{-1} \cdot day^{-1}$)		
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).

5.1.1.3 – Net energy for growth (NE_{gro})

NE_{gro} is the net energy required for growth, that is, for gaining weight. This equation is applied to replacement and fattening animals.

Equation 5.4

$$NE_{gro} = 22.02 * (BW / C_{gro} * MW)^{0.75} * DWG^{1.097}$$

Where:

NE_{gro} = net energy for animal growth, $MJ \cdot animal^{-1} \cdot day^{-1}$

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

C_{gro} = dimensionless coefficient given in Table 5.4

MW = average live weight of adult animals, $kg \cdot animal^{-1}$

DWG = average daily weight gain, $kg \cdot animal^{-1} \cdot day^{-1}$

Equation 5.5

$$NE_{gro} = DWG * (a + b * Ckg) + 0.5 * b * DWG^2$$

Where:

NE_{gro} = net energy for animal growth, $MJ \cdot animal^{-1} \cdot day^{-1}$

DWG = average daily weight gain, $kg \cdot animal^{-1} \cdot day^{-1}$

a,b = constants given in Table 5.4

Ckg = live weight of lambs/kids at birth, $kg \cdot animal^{-1}$

TABLE 5.4. Constants for calculating NE_{gro}

Animal category	GLEAM cohorts	C (dimensionless)	a ($MJ \cdot kg^{-1}$)	b ($MJ \cdot kg^{-2}$)
Cattle and Buffaloes				
Female animals	RF, MF	0.8	Not applicable	Not applicable
Male animals	RM, MM	1.2	Not applicable	Not applicable
Sheep and Goats				
Females	RF, RFA, RFB, MF	Not applicable	2.1	0.45
Intact males	RM, RMA, RMB, MM	Not applicable	2.5	0.35

5.1.1.4 – Net energy for lactation (NE_{lact})

NE_{lact} is the net energy required for lactation.

Equation 5.6

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

Where:

NE_{lact} = net energy for lactation, $MJ \cdot animal^{-1} \cdot day^{-1}$

Milk = daily milk production, kg $milk \cdot cow^{-1} \cdot day^{-1}$

Fat = fat content of milk, percentage by weight

Equation 5.7

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

Where:

NE_{lact} = net energy for lactation, $MJ \cdot animal^{-1} \cdot day^{-1}$

Milk = daily milk production, kg milk·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

5.1.1.4 – 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 percent of a day's maintenance energy is used per hour of work.

Equation 5.8

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

Where:

NE_{work} = net energy for animal work, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{main} = net energy for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

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

5.1.1.5 – Net energy for production of fibre (NE_{fibre})

NE_{fibre} is the net energy required for producing fibres such as wool, cashmere and mohair.

Equation 5.9

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

Where:

NE_{fibre} = net energy for fibre production, $MJ \cdot animal^{-1} \cdot day^{-1}$

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

$Production_{fibre}$ = annual production of fibre, $kg\ fibre \cdot animal^{-1} \cdot year^{-1}$

5.1.1.6 – Net energy for pregnancy (NE_{preg})

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

Equation 5.10

$$NE_{preg} = C_{preg} * NE_{main} * Frac_{preg}$$

Where:

NE_{preg} = net energy for pregnancy, $MJ \cdot animal^{-1} \cdot day^{-1}$

C_{preg} = coefficient for pregnancy, dimensionless. Values are given in Table 5.5

$Frac_{preg}$ = fraction of reproductive animals that are pregnant, dimensionless

TABLE 5.5. Coefficients to calculate NE_{preg}

Animal category	GLEAM cohorts	C_{preg}	$Frac_{preg}$
Cattle and Buffaloes	AF, RF	0.10	AF: FR / 100 RF: 0.5 * AFC
Small ruminants	AF, RFB	AF: 0.077 * (2 – LITSIZE) + 0.126 * (LITSIZE – 1) RFB: 0.077	AF: (365 * FR) / LINT RFB: 1

5.1.1.7 – Ratio of net energy in the diet for maintenance to digestible energy (REM)

REM is calculated as follows:

Equation 5.11

$$REM = 1.123 - (4.092 \cdot 10^{-3} * DE_{fg}) + (1.126 \cdot 10^{-6} * DE_{fg}^{2}) - (25.4 / DE_{fg})$$

Where:

REM = ratio of net energy available in the diet for maintenance to digestible energy, dimensionless

DE_{fg} = digestible energy of diet for the feeding group *fg*, percentage. Feeding groups are shown in Table 4.1

5.1.1.8 – Ratio of net energy available in the diet for growth to digestible energy consumed (REG)

REG is calculated as follows:

Equation 5.12

$$REG = 1.164 - (5.160 \cdot 10^{-3} * DE_{fg}) + (1.308 \cdot 10^{-5} * DE_{fg}^{2}) - (37.4 / DE_{fg})$$

Where:

REG = ratio of net energy available in the diet for growth to digestible energy consumed, dimensionless

DE_{fg} = digestible energy of diet for the feeding group *fg*, percentage. Feeding groups are shown in Table 4.1

5.1.1.9 – Total gross energy (GE)

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

Equation 5.13

$$GE = (((NE_{main} + NE_{act} + NE_{lact} + NE_{work} + NE_{preg}) / REM) + ((NE_{gro} + NE_{fibre}) / REG) / (DE / 100))$$

Where:

GE = gross energy requirement, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{main} = net energy required by the animal for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{act} = net energy for animal activity, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{gro} = net energy for animal growth, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{lact} = net energy for lactation, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{work} = net energy for animal work, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{fibre} = net energy for fibre production, $MJ \cdot animal^{-1} \cdot day^{-1}$

NE_{preg} = net energy for pregnancy, $MJ \cdot animal^{-1} \cdot day^{-1}$

REM = ratio of net energy available in the diet for maintenance to digestible energy consumed, dimensionless

REG = ratio of net energy available in the diet for growth to digestible energy consumed, dimensionless

5.1.2 – Energy requirement for pigs

As the 2006 IPCC guidelines donot 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 5.7. Equations used to estimate ME for pigs

Metabolic function	Abbreviation	Equation
Maintenance	ME_{main}	Equation 5.14
Gestation	ME_{gest}	Equation 5.15
Lactation	ME_{lact}	Equation 5.16
Growth	ME_{prot} / ME_{fat}	Equation 5.17
Total energy requirement		
Sows	ME_{tot}	Equation 5.18a
Boars	ME_{tot}	Equation 5.18b
Replacement females	ME_{tot}	Equation 5.18c
Replacement males	ME_{tot}	Equation 5.18d
Fattening animals	ME_{tot}	Equation 5.18e

5.1.2.1 – Energy requirement for maintenance (ME_{main})

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

Equation 5.14

$$ME_{main} = C_{main} * LW^{0.75} * C_{act}$$

Where:

ME_{main} = metabolizable energy required by the animal for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

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

LW = average live weight of the animal in a given cohort, $kg \cdot animal^{-1}$. Values are given in Table 5.8

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 5.8. Average live weight for maintenance energy requirements for pigs

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

5.1.2.2 – Energy requirement for gestation (ME_{gest})

ME_{gest} is the metabolizable energy requirement for gestation.

Equation 5.15

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

Where:

ME_{gest} = metabolizable energy required by the animal for gestation, $MJ \cdot animal^{-1} \cdot day^{-1}$

C_{gest} = coefficient for gestation energy requirement, $MJ \cdot piglet^{-1}$. Default value of 0.148 is used

LITSIZE = litter size, # piglets

C_{adj} = coefficient to adjust to annual values with a value of 1 for sows and 1 / AFC for replacement females

5.1.2.3 – Energy requirement for lactation (ME_{lact})

ME_{lact} is the metabolizable energy requirement for lactation.

Equation 5.16

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

Where:

ME_{lact} = metabolizable energy required by the animal for lactation, $MJ \cdot animal^{-1} \cdot day^{-1}$

LITSIZE = litter size, # piglets

DR1 = death rate of piglets, percentage

C_{lact} = coefficient for lactation energy requirement, $MJ \cdot kg\ animal^{-1}$. Default value of 20.59 is used.

Wkg = live weight of piglets at weaning age, $kg \cdot animal^{-1}$

Ckg = live weight of piglets at birth, $kg \cdot animal^{-1}$

Lact = duration of lactation period, days

C_{wloss} = coefficient for weight loss from sow due to lactation, $MJ \cdot animal^{-1} \cdot day^{-1}$. Default value of 0.38 is used.

C_{conv} = efficiency for intake to milk energy conversion, dimensionless. Default value of 0.67 is used.

5.1.2.4 – Energy requirement for growth (ME_{prot} and ME_{fat})

ME_{prot} and ME_{fat} are is the metabolizable energy requirements for the generation of protein and fat during growth in protein and fat tissue, respectively. It is assumed that all growth is either fat or protein tissue.

Equation 5.17

ME_{prot}	=	$DWG * PTissue_f * Prot_{conc} * C_{MEprot}$
ME_{fat}	=	$DWG * (1 - PTissue_f) * Fat_{conc} * C_{MEfat}$

Where:

ME_{prot}	=	metabolizable energy required for generation of new protein in protein tissue, $MJ \cdot animal^{-1} \cdot day^{-1}$
ME_{fat}	=	metabolizable energy required for generation of new fat in adipose tissue, $MJ \cdot animal^{-1} \cdot day^{-1}$
DWG	=	daily weight gain, $kg \cdot animal^{-1} \cdot day^{-1}$
$PTissue_{frac}$	=	fraction of protein tissue in the daily weight gain, dimensionless. Default values of 0.6, 0.65 and 0.7 for backyard, intermediate and industrial systems are used, respectively.
$Prot_{conc}$	=	fraction of protein in protein tissue, dimensionless. Default value of 0.23 is used
Fat_{conc}	=	fraction of fat in adipose tissue, dimensionless. Default value of 0.90 is used
C_{MEprot}	=	metabolizable energy required for protein in protein tissue, $MJ \cdot kg\ protein^{-1}$. Default value of 54.0 is used.
C_{MEfat}	=	metabolizable energy required for fat in adipose tissue, $MJ \cdot kg\ fat^{-1}$. Default value of 52.3 is used.

5.1.2.5 – Total energy requirement (ME_{tot})

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

Equation 5.18

a. ME_{tot}	=	$Gest * (ME_{main-gestation} + ME_{gest}) + Lact * (ME_{main-lactation} + ME_{lact}) + Idle * (ME_{main-idle})$
b. ME_{tot}	=	ME_{main}
c. ME_{tot}	=	$Gest * (ME_{preg}) + Lact * (ME_{lact}) + 365 * AFC * (ME_{main} + ME_{prot} + ME_{fat})$
d. ME_{tot}	=	$ME_{main} + ME_{prot} + ME_{fat}$
e. ME_{tot}	=	$ME_{main} + ME_{prot} + ME_{fat}$

Where:

ME_{tot}	=	total metabolizable energy required, $MJ \cdot animal^{-1} \cdot day^{-1}$
Gest	=	duration of gestation period, days
Lact	=	duration of lactation period, days
Idle	=	duration of idle period, days
AFC	=	age at first parturition, year

5.1.3 – Energy requirement for chicken

Equations for chicken 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. The table below summarizes the equations used to estimate the energy requirements for chicken:

TABLE 5.9. Equations used to estimate ME for chickens

Metabolic function	Abbreviation	Equation
Maintenance	ME_{main}	Equation 5.19
Growth	ME_{gro}	Equation 5.20
Production	ME_{prod}	Equation 5.21
Total energy requirement		
Backyard production systems		
Reproductive adults	ME_{tot}	Equation 5.22a
Surplus hens when adults (laying eggs)	ME_{tot}	Equation 5.22b
Growing female and male pullets for replacement	ME_{tot}	Equation 5.22b
Surplus hens when growing (not laying eggs)	ME_{tot}	Equation 5.22b
Surplus roosters	ME_{tot}	Equation 5.22b
Layers production systems		
Reproductive adults	ME_{tot}	Equation 5.22a
Growing female and male pullets for replacement	ME_{tot}	Equation 5.22b
Surplus roosters	ME_{tot}	Equation 5.22b
Laying hens (before laying period)	ME_{tot}	Equation 5.22b
Laying hens (during laying period)	ME_{tot}	Equation 5.22a
Broiler production system		
Reproductive adults	ME_{tot}	Equation 5.22a
Growing female and male pullets for replacement	ME_{tot}	Equation 5.22b
Broiler animals	ME_{tot}	Equation 5.22b

5.1.3.1 – Energy requirement for maintenance (ME_{main})

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

Equation 5.19

$$ME_{main} = LW^{0.75} * Temp_{reg} * C_{act}$$

Where:

ME_{main} = metabolizable energy required by the animal for maintenance, $MJ \cdot animal^{-1} \cdot day^{-1}$

LW = average live weight of the animal in a given cohort, $kg \cdot animal^{-1}$.

$Temp_{reg}$ = regression function depending on the temperature for a given cohort, $MJ \cdot kg^{-0.75} \cdot day^{-1}$. Values are given in Table 5.10.

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

TABLE 5.10. Temperature regression function for maintenance energy requirements

Animal cohort	$Temp_{reg}$ ($MJ \cdot kg^{-0.75} \cdot day^{-1}$)
Backyard production systems	
Reproductive adults	$0.693 – 0.01 * T$
Surplus hens when adults (laying eggs)	
Growing female and male pullets for replacement	if $T < LCT$: $0.386 + 0.03 * (LCT – T)$ if $T \geq LCT$: $0.386 + 3.7 \cdot 10^{-3} * (T – LCT)$
Surplus hens when growing (not laying eggs)	
Surplus roosters	
Layers production systems	
Reproductive adults	$0.693 – 9.9 \cdot 10^{-3} * T$
Growing female and male pullets for replacement	0.386
Surplus roosters	
Laying hens (before laying period)	
Laying hens (during laying period)	$0.693 – 9.9 \cdot 10^{-3} * T$
Broiler production system	
Reproductive adults	$0.807 – 0.026 * T + 5.0 \cdot 10^{-4} * T^2$
Growing female and male pullets for replacement	$0.728 – 7.8 \cdot 10^{-3} * T$
Broiler animals	$1.288 – 0.065 * T + 1.3 \cdot 10^{-3} * T^2$

Low critic temperature (LCT) (°C) is calculated as $24.54 – 5.65 * F$, where F is feathering score (0-1). It is assumed a feathering score of 1.

5.1.3.2 – Energy requirement for growth (ME_{gro})

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

Equation 5.20

$$ME_{gro} = DWG * C_{gro}$$

Where:

ME_{gro} = metabolizable energy required by the animal for growth, MJ·animal^{-1}·day^{-1}

DWG = daily weight gain, kg·animal^{-1}·day^{-1}

C_{gro} = growth coefficient for a given cohort, MJ·kg^{-1}. Values are given in Table 5.11

TABLE 5.11. Growth coefficient for chickens

Animal cohort	C_{gro} (MJ·kg^{-1})
Backyard production systems	
Reproductive adults	0.028
Surplus hens when adults (laying eggs)	
Growing female and male pullets for replacement	0.021
Surplus hens when growing (not laying eggs)	
Surplus roosters	
Layers production systems	
Reproductive adults	0.028
Growing female and male pullets for replacement	0.021
Surplus roosters	
Laying hens (before laying period)	
Laying hens (during laying period)	0.028
Broiler production system	
Reproductive adults	0.032
Growing female and male pullets for replacement	0.010
Broiler animals	0.017

5.1.3.3 – Energy requirement for egg production (ME_{egg})

ME_{egg} is the metabolizable energy requirement for egg production.

Equation 5.21

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

Where:

ME_{egg} = metabolizable energy required by the animal for egg production, MJ·animal^{-1}·day^{-1}

EGG = egg mass production, g egg·animal^{-1}·day^{-1}

C_{egg} = energy requirement coefficient for egg production, kJ·g egg^{-1}. Default value of 10.04 is used.

5.1.3.4 – Total energy requirement (ME_{tot})

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

Equation 5.22

a. $ME_{tot} = ME_{main} + ME_{gro} + ME_{egg}$

b. $ME_{tot} = ME_{main} + ME_{gro}$

Where:

ME_{tot} = total metabolizable energy required by the animal, MJ·animal^{-1}·day^{-1}

ME_{gro} = metabolizable energy required by the animal for growth, MJ·animal^{-1}·day^{-1}

ME_{egg} = metabolizable energy required by the animal for egg production, MJ·animal^{-1}·day^{-1}

5.2 – FEED INTAKE

For each cohort, the feed intake is calculated by dividing the total animal's energy requirement by the energy content of the ration following Equation 5.23.

Equation 5.23

$$DM_{intake} = E_{tot} / E_{ration}$$

Where:

DM_{intake} = feed intake per animal, kg DM·animal^{-1}·day^{-1}

E_{tot} = total animal's energy requirement (GE for ruminants, ME for monogastrics), MJ·animal^{-1}·day^{-1}

E_{ration} = average energy content of ration, MJ·kg DM^{-1}. Default value of 18.45 is used for ruminants.

5.3 – METHANE EMISSIONS FROM ENTERIC FERMENTATION

Emissions from enteric fermentation are a function of feed digestibility, i.e. the percentage of gross energy intake that is metabolized. An enteric methane conversion factor, Y_m (percentage of gross energy converted to methane) is used to calculate the methane emissions from enteric fermentation. A Tier 2 approach is applied for the calculation of enteric CH_4 emissions due to the sensitivity of emissions to diet composition and the relative importance of enteric CH_4 to the overall GHG emissions profile.

Enteric emissions were calculated as follows:

Equation 5.24

$$Enteric = N_T * 365 * GE_T * (Y_m / 100) / 55.65$$

Where:

Enteric = total methane emissions arising from enteric fermentation, kg CH_4·year^{-1}

N_T = number of head of livestock species/category T, # animals

GE_T = gross energy intake from animal ration for species/category T, MJ·animal^{-1}·day^{-1}

Y_m = methane conversion factor, percentage of energy in feed converted into methane. Values are given in Table 5.12.

The factor 55.65 (MJ·kg CH_4^{-1}) is the energy content of methane

TABLE 5.12. Methane conversion factors for different species and cohorts

Animal cohort	Y_m (% of energy converted into CH_4)
Cattle and Buffaloes	$9.75 – 0.05 * DE_{fg}$[a]
Sheep and Goats	
Adult reproductive animals	$9.75 – 0.05 * DE_{fg}$[a]
Young replacement and fattening animals	$7.75 – 0.05 * DE_{fg}$[a]
Pigs	
Adult reproductive animals	1.01
Replacement and fattening animals	0.39

[a] Digestible energy of diet for the feeding group *fg*, percentage. See Table 4.1.

5.4 – METHANE EMISSIONS FROM MANURE MANAGEMENT

Methane emissions from manure management were calculating using the IPCC Tier 2 method, which requires the estimation of the excretion rate of volatile solids (VSx) per animal and the estimation of the proportion of VSx that are converted to CH_4. Methane emissions are calculated following Equation 5.25:

Equation 5.25

$CH_{4Manure}$ = $N_T * [(365 * VS_T) * (B_{oT} * 0.67 * \sum_S(MCF_S / 100) * MS_{T,S}))]$

Where:

$CH_{4Manure}$ = total methane emissions arising from manure management, kg $CH_4 \cdot year^{-1}$

N_T = number of head of livestock species/category T, # animals

VS_T = daily volatile solid excreted for livestock species/category T, kg $VS \cdot animal^{-1} \cdot day^{-1}$

B_{oT} = maximum methane producing capacity for manure from species/category 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 5.13

$MS_{T,S}$ = fraction of livestock species/category T's manure handled by manure management S, dimensionless

The factor 0.67 (kg $CH_4 \cdot m^{-3}$) converts the volume of methane into amount of gas.

TABLE 5.13. 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)	$19.494 – 1.5573 * T + 0.1351 * T^2$		
Anaerobic digester	10.0	10.0	10.0
Burned for fuel	10.0	10.0	10.0
Poultry manure with litter	1.5	1.5	1.5

5.4.1 – Volatile solids excretion rate

GLEAM calculates the VSx excretion rate using Equation 10.24 from IPCC (2006), as depicted below.

Equation 5.26

VS = $(GE * (1 – (DE / 100)) + (UE * GE)) * (1 - ASH) / 18.45$

Where:

VS = volatile solid excretion per day on a dry-matter basis, kg $VS \cdot animal^{-1} \cdot day^{-1}$

GE = gross energy intake, $MJ \cdot animal^{-1} \cdot day^{-1}$

DE = digestibility of the feed, percentage

UE = urinary energy as fraction of GE, dimensionless. Values are given in Table 5.14.

ASH = the ash content of manure calculated as a fraction of the dry matter of feed intake. Values are given in Table 5.14.

The factor 18.45 ($MJ \cdot kg^{-1}$) is the conversion factor for dietary GE per kilogram of dry matter.

TABLE 5.14. Urinary energy and ash content for VS excretion estimation

Livestock category	UE (fraction)	ASH (fraction)
Ruminant species	0.04	0.08
Pigs	0.02	0.20
Chicken	0	0.30

5.5 – 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 per kg of feed. The feed intake depends, in turn, on the animal's energy requirement and the feed energy content. Nitrogen retention is the amount of N retained in tissue, either as growth, pregnancy live weight gain, 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 N_2O and indirect emissions, along with variable nitrogen leaching rates.

5.5.1 – Nitrogen excretion rate

GLEAM calculates nitrogen excretion rates using the Equations 10.31 to 10.33 from IPCC (2006), as depicted below.

Equation 5.27

$$N_{ex} = 365 * ((GE / 18.45 * N_{cont}) - N_{retention})$$

Where:

N_{ex} = annual average nitrogen excretion per head, kg N·animal^{-1}·year^{-1}

GE = gross energy intake, MJ·animal^{-1}·day^{-1}

N_{cont} = average nitrogen content of the diet, kg N·kg DM diet^{-1}

$N_{retention}$ = nitrogen retention by the animal, kg N·animal^{-1}·day^{-1}. See equation 5.28 and 5.29.

The factor 18.45 (MJ·kg^{-1}) is the conversion factor for dietary GE per kilogram of dry matter.

Nitrogen retention depends on the particular species and cohort, as shown in Table 5.15.

TABLE 5.15. Nitrogen retention formulas for species and cohorts

Livestock category/cohort	Nitrogen retention
Ruminant species: adult females	Equation 5.28a
Ruminant species: other than adult females	Equation 5.28b
Pigs: adult sows	Equation 5.29a
Pigs: replacement sows	Equation 5.29b
Pigs: other cohorts	Equation 5.29c
Chicken: laying hens	Equation 5.30a
Chicken: other cohorts	Equation 5.30b

Equation 5.28

a. $N_{retentionR} = (Milk * Milk_{prot} / 6.38) + (DWG * (268 - (7.03 * NE_{gro} / DWG)) / 6.25)$

b. $N_{retentionR} = (DWG * (268 - (7.03 * NE_{gro} / DWG)) / 6.25)$

Where:

$N_{retentionR}$ = nitrogen retention for ruminant species, kg N·animal^{-1}·year^{-1}

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

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

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

DWG = average daily weight gain, kg·animal^{-1}·day^{-1}

268 and 7.03 = constants from Equation 3-8 in NRC (1998)

NE_{gro} = net energy for animal growth, MJ·animal^{-1}·day^{-1}

6.25 = conversion from dietary protein to dietary nitrogen, kg protein·kg N^{-1}

Equation 5.29

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

b. $N_{retentionPIG}$ = 0.025 * WG * AFC^{-1} * (((0.025 * LITSIZE * FR * (Wkg - Ckg) / 0.98) + (0.025 * LITSIZE * FR * Ckg)) / 365)

c. $N_{retentionPIG}$ = 0.025 * WG

Where:

$N_{retentionPIG}$ = nitrogen retention for pigs, kg N·animal^{-1}·year^{-1}

0.025 = average content of nitrogen in live weight, kg N·kg animal^{-1}

LITSIZE = litter size, # piglets

FR =

Wkg =

Ckg = live weight of piglets at birth, kg·animal^{-1}

0.98 = protein digestibility as fraction, dimensionless

WG = daily weight gain, kg·animal^{-1}·day^{-1}

AFC = age at first parturition, year

Equation 5.30

a. $N_{retentionCHK}$ = N_{LW} * DWG + N_{EGG} * 10^{-3} * EGG

b. $N_{retentionCHK}$ = N_{LW} * DWG

Where:

$N_{retentionCHK}$ = nitrogen retention for chicken, kg N·animal^{-1}·year^{-1}

N_{LW} = average content of nitrogen in live weight, kg N·kg animal^{-1}. Default value of 0.028 is used.

DWG = daily weight gain, kg·animal^{-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·animal^{-1}·day^{-1}

5.5.2 – Direct N_2O emissions

GLEAM calculates direct emissions using the Equation 10.25 from IPCC (2006), as depicted below.

Equation 5.31

N_2O_D = (44 / 28) * ($\sum_S$(EF_S * $\sum_T$(N_T * N_{ex} * $MS_{T,S}$)))

Where:

N_2O_D = direct nitrous oxide emissions from manure management, kg N_2O·year^{-1}

EF_S = emission factor for direct emissions from manure management system S, kg N_2O-N·kg N^{-1}. Values are shown in Table 5.16.

N_T = number of head of livestock species/category T, # animals

N_{ex} = annual average nitrogen excretion per head, kg N·animal^{-1}·year^{-1}

$MS_{T,S}$ = fraction of livestock species/category T's manure handled by manure management S, dimensionless

The factor 44 / 28 converts N_2O-N to N_2O emissions.

TABLE 5.16. Emission factor for direct emissions for different manure management systems

Manure management system	EF_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	0.002
Anaerobic digester	0.000
Burned for fuel	0.020
Poultry manure with litter	0.001

[a] It is calculated in the feed module, as manure is used as organic fertilizer, to avoid double-counting.

5.5.3 – Indirect N_2O emissions: volatilization

GLEAM calculates direct emissions using Equations 10.26 and 10.27 from IPCC (2006), as depicted below.

Equation 5.32

$$N_2O_G = (44 / 28) * (EF_4 * \sum_S(\sum_T(N_T * N_{ex} * MS_{T,S} * (Frac_{GasMS} / 100)_{T,S})))$$

Where:

N_2O_G = indirect nitrous oxide emissions due to volatilization from manure management, kg N_2O·year^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water, kg N_2O-N. Default value of 0.01 is used.

N_T = number of head of livestock species/category T, # animals

N_{ex} = annual average nitrogen excretion per head, kg N·animal^{-1}·year^{-1}

$MS_{T,S}$ = fraction of livestock species/category T's manure handled by manure management S, dimensionless

$Frac_{GasMS}$ = percentage of managed manure nitrogen for livestock species/category T that volatilises as NH_3 and NO_x in the manure management system S, percentage. Values are given in Table 5.17.

The factor 44 / 28 converts N_2O-N to N_2O emissions.

5.5.4 – Indirect N_2O emissions: leaching

GLEAM calculates direct emissions using Equations 10.26 and 10.27 from IPCC (2006), as depicted below.

Equation 5.33

$$N_2O_L = (44 / 28) * (EF_5 * \sum_S(\sum_T(N_T * N_{ex} * MS_{T,S} * (Frac_{LeachMS} / 100)_{T,S})))$$

Where:

N_2O_L = indirect nitrous oxide emissions due to leaching from manure management, kg N_2O·year^{-1}

EF_5 = 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 = number of head of livestock species/category T, # animals

N_{ex} = annual average nitrogen excretion per head, kg N·animal^{-1}·year^{-1}

$MS_{T,S}$ = fraction of livestock species/category T's manure handled by manure management S, dimensionless

$Frac_{LeachMS}$ = percentage of managed manure nitrogen lost due to leaching and runoff for livestock species/category T in the manure management system S, percentage. Values are given in Table 5.18.

The factor 44 / 28 converts N_2O-N to N_2O emissions.

TABLE 5.17. 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
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
Chicken	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 5.18 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

CHAPTER 6 – ALLOCATION MODULE

One of the principles of LCA methods is to allocate emissions among different products and outputs. The approach used in GLEAM to allocate emissions is describes in this chapter.

The functions of the allocation module are:

- Calculate the **total livestock production**;
- Calculate the **total emissions** and the **emission intensity** of each commodity.

6.1 – TOTAL LIVESTOCK PRODUCTION

This section describes the equations used to calculate the total amount of animal commodities produced, namely meat, milk, eggs and fibres. All commodities, except fibres, are expressed in terms of protein to allow emission intensities comparison between them.

6.1.1 – 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 6.1

$MILKTOT_{prot}$ = $AF * MILK_{yield} * MILK_{prot}$

Where:

$MILKTOT_{prot}$ = total amount of milk protein, kg protein

AF = milking animals of a given species, # animals

$MILK_{yield}$ = average milk production per animal, kg milk·animal^{-1}·year^{-1}

$MILK_{prot}$ = average protein fraction in milk, kg protein·kg milk^{-1}

6.1.2 – 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, carcass weight to bone-free-meat and average protein content in meat.

Equation 6.2

$MEATTOT_{prot}$ = $BFM * MEAT_{prot} * \sum_c (N_{exit} * LW * DP / 100)_c$

Where:

$MEATTOT_{prot}$ = total amount of meat protein, kg protein

BFM = bone-free-meat to carcass weight ratio, dimensionless. Values are shown in Table 6.1.

$MEAT_{prot}$ = average protein fraction in meat, kg protein·kg milk^{-1}. Default value of 0.18 was used.

N_{exit} = number of animals slaughtered, # animals

LW = live weight of slaughtered animals, kg LW·animal^{-1}

DP = dressing percentage, percentage. Values are given in Table 6.2.

c = denotes cohort *c* for a given species.

TABLE 6.1. Bone-free-meat to carcass weight ratio

Species	BFM (fraction)
Large ruminants	0.75
Small ruminants	0.70
Pigs	0.65
Chicken	0.75

TABLE 6.2. Dressing percentages for ruminant species

	NA	RUSS	WE	EE	NENA	ESEA	OC	SA	LAC	SSA
Dairy cattle										
Adult and replacement female	50	50	50	50	48	50	50	50	50	47
Adult and replacement male	50	50	50	50	48	50	50	50	50	47
Surplus female and male	52	52	52	52	50	55	52	55	52	47
Beef cattle										
Adult and replacement female	55	55	55	55	50	50	50	50	50	47
Adult and replacement male	55	55	55	55	50	50	50	50	50	47
Surplus female and male	60	60	60	60	55	55	55	55	55	47
Buffaloes										
Adult and replacement female	49	49	49	49	49	49	49	49	49	49
Adult and replacement male	50	50	50	50	50	50	50	50	50	50
Surplus female and male	55	55	55	55	55	55	55	55	55	55
Sheep	55	45	48	45	45	49	50	48	49	45
Goats	52	43	43	43	44	48	45	43	44	48
Pigs										
Backyard systems	65	65	65	65	65	65	65	65	65	65
Intermediate systems	75	75	75	75	75	75	75	75	75	75
Industrial systems										
Chicken										
Backyard systems	Laying hen:55 Others: as broilers									
Layers	55	55	55	55	55	55	55	55	55	55
Broilers	68	70	67	70	67	63	66	68	88	65

Regions: NA (North America), RUSS (Russian Federation), WE (Western Europe), EE (Eastern Europe), NENA (Near East and North Africa), ESEA (East and Southeast Asia), OC (Oceania), SA (South Asia), LAC (Latin America and the Caribbean) and SSA (Sub-Saharan Africa)

6.1.3 – Production of eggs

Total egg production is calculated from the backyard and layer systems exclusively following Equation 6.3.

Equation 6.2

$$EGGTOT_{prot} = 10^3 * EGG_{prot} * EGGwght * EGGSyear * Hens$$

Where:

$EGGTOT_{prot}$ = total amount of egg protein, kg protein

EGG_{prot} = average protein fraction in eggs, kg protein·kg egg^{-1}. Default value of 0.12 was used.

EGGwght = average egg weight, gr·egg^{-1}

EGGSyear = annual laid eggs per hen per production system, # eggs·hen^{-1}·year^{-1}

Hens = number of laying hens, # animals

6.2 – EMISSION ALLOCATION AND EMISSION INTENSITIES

6.2.1 – Allocation in ruminant species

Emissions in ruminant herds are allocated between edible commodities, i.e. meat and milk. Emissions related to draught power (large ruminants) and fibres (small ruminants) are calculated first and subtracted from the total emissions.

To allocate emissions to draught power services, total emissions and meat output from draught animals alone is calculated. In a subsequent step, emissions related to meat produced from these animals were estimated as being identical to those of meat produced from non-draught animals, slaughtered at younger age. The difference in emission values is attributed to draught power and subtracted from the total.

The allocation of emissions to fibres was based on the market value, taken from FAOSTAT, of all of the system outputs (meat, milk and fibres). The fractions of the economic value of the co-product within the total economic value were used as an allocation fraction to partition emissions between fibres and edible products.

Tables 6.3 and 6.4 show an example calculation of emission allocation for large and small ruminant herds.

TABLE 6.3. Example of allocation between edible products from cattle dairy production

	Animals involved in both meat and milk production (milking cows, adult males and replacement animals)	Animals involved in meat production only (surplus male and females)
Total emissions (kg CO_2-eq)	1,700,000	350,000
Total protein (kg)	Milk: 18,000 Meat: 1,500	Meat: 2,500
Fraction of milk protein	0.92	-
Fraction of meat protein	0.08	1
Emission intensity of milk (kg CO_2-eq·kg protein^{-1})	= (1,700,000 * 0.92) / 18,000 = 86.8	
Emission intensity of meat (kg CO_2-eq·kg protein^{-1})	= ((1,700,000 * 0.08) + 350,000) / (1,500 + 2,500) = 121.5	

TABLE 6.4. Example of allocation between edible products from sheep dairy production

	Animals involved in meat, milk and fibres production	Animals involved in meat and fibres production only
Total emissions (kg CO_2-eq)	80,000	20,000
Total protein (kg)	Milk: 500 Meat: 50	Meat: 200
Total economic value ($)	Milk: 4,000 Meat: 9,000 Wool: 700	
Fraction of milk protein	0.90	-
Fraction of meat protein	0.10	1
Total emission allocated to wool (kg CO_2-eq)	= 80,000 * (700 / (4,000 + 9,000 + 700)) = 4,088	= 20,000 * (700 / (4,000 + 9,000 + 700)) = 1,022
Total emission allocated to meat and milk (kg CO_2-eq)	= 80,000 – 4,088 = 75,912	= 20,000 – 1,022 = 18,978
Emission intensity of milk	= (75,912 * 0.9) / 500 = 136.6	
Emission intensity of meat	= ((75,912 * 0.1) + 18,978) / (50 + 200) = 106.2	

6.2.2 – Allocation in monogastric species

Emissions for monogastrics are also allocated between edible products, i.e. meat and eggs, in the case of chicken. For pigs and broilers, all emissions were allocated to meat.

For backyard chickens and layers, emissions were allocated by calculating the total emissions from animals required for egg production and for animals not required for egg production. In a subsequent step, total emissions were allocated on the basis of the amount of egg and meat protein output. Table 6.5 present a calculation example.

TABLE 6.5. Example of allocation between edible products for chicken

	Animals involved in egg and meat production	Animals producing meat only
Total emissions (kg CO_2-eq)	50,000	39,000
Total protein (kg)	Eggs: 800 Meat: 200	Meat: 500
Total emission allocated to eggs (kg CO_2-eq)	= 50,000 * (800 / (800 + 200)) = 40,000	-
Total emission allocated to meat (kg CO_2-eq)	= 50,000 * (200 / (800 + 200)) = 10,000	39,000
Emission intensity of eggs	= 40,000 * / 800 = 50.0	
Emission intensity of meat	= (10,000 + 39,000) / (200 + 500) = 70.0	

CHAPTER 7 – POSTFARM EMISSIONS

7.1 – INTRODUCTION

GHG emissions accounted for in the post-farm gate part of the supply chain include emissions related to fuel combustion and energy use in the transport, processing and refrigeration of products. The system boundary in GLEAM is from the farm-gate up to the retail point. During this phase of the life cycle, three distinct emission streams were studied: emissions from the transport and distribution of live animals, milk and meat (domestic and international); GHG emissions from processing and refrigeration; and emissions related to the production of packaging material.

7.2 – ENERGY CONSUMPTION

Energy consumption is the most important source of GHG emissions from the post-farm gate supply food chain. Table 7.1 presents average regional and country CO_2 emission coefficients applied in this analysis. The 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, 2009).

TABLE 7.1. Average regional CO_2 emissions per MJ from electricity and heat generation

Region/country	Emissions (g $CO_2 \cdot MJ^{-1}$)
Europe 27	99
North America	142
Australia	254
New Zealand	84
Japan	120
Other Pacific	139
Russian Federation	90
Latin America	54
Asia (excluding China)	202
China	216
Africa	175

7.3 – EMISISONS RELATED TO TRANSPORT

The food sector is transport-intensive – large quantities of food are transported in large volumes and over long distances. This 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.

The efficiency of different transport modes varies considerably. Transport modes differ significantly in energy intensity and hence GHG emissions. Air transport has a very high climate change impact per tonne transported, whereas sea transport is relatively efficient. Long-distance transport by ship is very energy efficient, with estimates between 10 and 70 g CO_2 per t-km, compared with estimates of 20-120 and 80-250 g CO_2 per t-km for rail and road, respectively (MARINTEK, 2008). Poor road infrastructure has an impact on the emission per unit product transported because it increases fuel consumption. Cederberg *et al.* (2009) found that, in Brazil, due to generally poor road conditions, the consumption of diesel was estimated to be 25 percent higher than under normal road conditions. Different loads also affect the efficiency of utilization of transport per unit of product. Larger loads transported for longer distances are more efficient than lighter loads transported over shorter distances. Food also often requires refrigeration which increases the use of energy and also introduces leakage of refrigerants into the GHG emissions equation (refrigerants are often high in climate impact).

Emissions related to transport were estimated for the different phases, that is, transportation of live animals from the farm to the slaughter plant and transportation of the product from plant to retail centre. In the case of international trade, emissions were calculated for transport from slaughter plant to the port of export to the retail point for distribution. In an effort to estimate the contribution of international freight transport to GHG emissions, we combined data on trade flows, transportation mode, transport emission factors and distances.

7.3.1 – Transport of animals to slaughter plants

Due to the complexity of live animal movements and data limitations, several simplifications and assumptions were made:

- **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 percent of the animals are slaughtered in slaughterhouses. In developing countries, the share of animals transported to slaughter plants varied between 15 and 75 percent 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.

The final emission factor for transport to slaughter plants is calculated following Equation 7.1:

Equation 7.1

$$GHG_{transpSP} = Dist_{f\text{-}p} * EF_{transp} * Share_{sl}$$

Where:

$GHG_{transpSP}$ = GHG emission intensity of the product, kg CO_2-eq·kg CW^{-1}

$Dist_{f\text{-}p}$ = average distance between the farm and the slaughter plant, km

EF_{transp} = emission factor for the mode of transport, kg CO_2-eq·kg CW^{-1}·km^{-1}

$Share_{sl}$ = share of live animals slaughtered at slaughter plants, dimensionless

7.3.2 – Transport and distribution of processed meat to retail points

The calculation of GHG emissions associated with meat transport included the transport of meat from slaughter plant to a retail point. 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.

7.3.2.1 – Road 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 centre in importing country. Emission intensities were found to vary depending on the transport load (tonnage), transport utilization and type of product transported (chilled or frozen). Table 7.2 presents average values used in GLEAM.

TABLE 7.2. Average emissions associated with road transport in kg CO_2-eq·tonne $carcass^{-1}$·km^{-1}

Type of transport	Chilled	Frozen
Carcass	0.18	0.20
Boneless	0.0117	0.130

7.3.2.2 –Ocean transport

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 centre, 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.

CHAPTER 8 – EMISSIONS RELATED TO 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.

8.1 – EMISSIONS RELATED TO 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 was discounted and we assumed a straight-line depreciation of 20 years for buildings, 10 years for machinery and equipment and 30 years for irrigation systems.

8.1.1 – Farm structure

For ruminant species, five different levels of housing were defined with varying degrees of quality. These five housing types were then distributed across the different 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 8.1 and 8.2 present the average emission factor for ruminant species.

TABLE 8.1. Average emissions factors for embedded energy for dairy cattle[a] (kg CO_2-eq·100 kg LW^{-1})

Grouping	System	Arid	Humid	Temperate
OECD	Grassland based	18.2	20.9	37.1
	Mixed farming system	21.1	24.1	39.8
Least developed countries	Grassland based	2.0	2.0	2.2
	Mixed farming system	3.3	3.3	3.9
Non-OECD	Grassland based	4.6	8.2	7.4
	Mixed farming system	5.9	9.7	25.2

a Values for meat herd are assumed to be

TABLE 8.2. Average emissions factors for embedded energy for dairy small ruminants (kg CO_2-eq·25 kg LW^{-1})

Grouping	Arid	Humid	Temperate
OECD	5.65	5.05	6.76
Least developed countries	1.00	0.82	0.73
Non-OECD	2.01	2.62	6.01

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 8.3 and 8.4).

TABLE 8.3. Average emissions factors for embedded energy for pigs (kg CO_2-eq·100 kg LW^{-1})

Grouping	Industrial	Intermediate	Backyard
OECD	4.75	0.37	0.05
Non-OECD LAC	0.46	1.19	0.39
Non-OECD Asia	0.63	1.38	0.34
Non-OECD Europe	2.00	1.00	0.23
Africa	0.12	0.31	0.59

TABLE 8.4. Average emissions factors for embedded energy for commercial chicken

Grouping	Broilers (kg CO_2-eq·100 kg LW^{-1})	Layers (kg CO_2-eq·100 kg egg^{-1})
OECD	5.89	0.70
Non-OECD LAC	1.87	0.20
Non-OECD Asia	1.86	0.37
Non-OECD Europe	1.61	0.45
Africa	1.26	0.17

8.2 – 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 8.5 to 8.7 present emission factors from direct energy use based on literature research and existing databases.

TABLE 8.5. Average emissions factors for direct energy for dairy cattle (kg CO_2-eq·kg $milk^{-1}$)

Grouping	Grassland based			Mixed farming systems		
	Arid	Humid	Temperate	Arid	Humid	Temperate
EU 27	0.059	0.060	0.061	0.060	0.061	0.061
OECD Europe	0.058	0.059	0.060	0.059	0.060	0.060
OECD North America	0.068	0.069	0.071	0.069	0.71	0.071
Australia	0.094	0.095	0.098	0.095	0.098	0.098
Japan	0.064	0.065	0.067	0.065	0.067	0.067
South Korea	0.066	0.067	0.068	0.067	0.068	0.068
New Zealand	0.066	0.067	0.068	0.067	0.068	0.068
Developing countries	0.020	0.020	0.020	0.027	0.027	0.027

TABLE 8.6. Average emissions factors for direct energy for beef cattle and small ruminants (kg CO_2-eq·kg LW^{-1})

Grouping	Beef cattle – Grassland based	Beef cattle – Mixed farming systems	Small ruminants
EU 27	0.18	0.21	0.33
OECD Europe	0.17	0.21	0.33
Non- OECD Europe	0.07	0.09	0.19
United States	0.24	0.29	0.34
Canada	0.12	0.15	0.31
Australia	0.36	0.42	0.38
Japan	0.20	0.24	0.33
South Korea	0.21	0.25	0.34
New Zealand	0.12	0.16	0.31
Non-OECD Pacific	0	0	0.17
Russian Federation	0.07	0.09	0.16
Latin America and the Caribbean	0.07	0.09	0.15
Asia	0.07	0.09	0.19
Africa	0.07	0.09	0.18
Middle East	0.07	0.09	0.18

TABLE 8.7. Average emissions factors for monogastrics (kg CO_2-eq·kg LW^{-1})

Species	Emission factor
Pigs	
Backyard systems	-
Intermediate systems	0.051
Industrial systems	0.197
Chicken	
Backyard systems	-
Layers	0.108
Broilers	0.242

APPENDIX A – COUNTRY LIST

The country grouping used in GLEAM is based on the 2005 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)	
Anguilla	Guatemala
Antigua and Barbuda	Guyana
Argentina	Haiti
Aruba	Honduras
Bahamas	Jamaica
Barbados	Martinique
Belize	Mexico
Bolivia	Montserrat
Brazil	Netherlands Antilles
British Virgin Islands	Nicaragua
Cayman Islands	Panama
Chile	Paraguay
Colombia	Peru
Costa Rica	Puerto Rico
Cuba	Sain Kitts and Nevis
Dominica	Saint Lucia
Dominican Republic	Saint Vincent and the Grenadines
Ecuador	Suriname
El Salvador	Trinidad and Tobago
Falkland Islands (Malvinas)	Turks and Caicos Islands
French Guiana	United States Virgin Islands
Grenada	Uruguay
Guadeloupe	Venezuela
SUB-SAHARAN AFRICA (SSA)	
Angola	Madagascar
Benin	Malawi
Botswana	Mali
Burkina Faso	Mauritania
Burundi	Mauritius
Côte d'Ivore	Mayotte
Cameroon	Mozambique
Cape Verde	Namibia
Central African Republic	Niger
Chad	Nigeria
Comoros	Rwanda
Congo	Réunion
Democratic Republic of the Congo	Sain Helena
Djibouti	São Tomé and Príncipe
Equatorial Guinea	Senegal
Eritrea	Seychelles
Ethiopia	Sierra Leone
Gabon	Somalia
Gambia	South Africa
Ghana	Swaziland
Guinea	Togo
Guinea-Bissau	Uganda
Kenya	United Republic of Tanzania
Lesotho	Zambia
Liberia	Zimbabwe
NEAR EAST AND NORTH AFRICA (NENA)	
Algeria	Morocco
Armenia	Oman
Azerbaijan	Qatar
Bahrain	Republic fo Sudan
Cyprus	Saudi Arabia
Egypt	Syrian Arab Republic

Gaza Strip	Tajikistan
Georgia	Tunisia
Iraq	Turkey
Israel	Turkmenistan
Jordan	United Arab Emirates
Kazakhstan	Uzbekistan
Kuwait	West Bank
Kyrgyzstan	Western Sahara
Lebannon	Yemen
SOUTH ASIA	
Afghanistan	Iran, Islamic Republic of
Bangladesh	Maldives
Bhutan	Nepal
British Indian Ocean Territory	Pakistan
India	Sri Lanka
EASTERN EUROPE	
Belarus	Poland
Bulgaria	Romania
Czech Republic	Slovakia
Hungary	Ukraine
Moldova, Republic of	
RUSSIAN FEDERATION	
Russian Federation	
EAST ASIA AND SOUTH-EAST ASIA	
Brueni Darussalam	Malaysia
Cambodia	Mongolia
China	Myanmar
Christmas Island	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
Macau	Mongolia
OCEANIA	
American Samoa	Northern Mariana Islands
Australia	Palau
Cook Islands	Papua New Guinea
Fiji	Pitcairn
French Polynesia	Saint Pierre et Miquelon
Guam	Samoa
Kiribati	Solomon Islands
Marshall Islands	Tokelau
Micronesia (Federated States of)	Tonga
Nauru	Tuvalu
New Caledonia	Vanuatu
New Zealand	Wake Island
Niue	Wallis and Futuna
Norfolk Island	Palau
WESTERN EUROPE	
Albania	Lietchstenstein
Andorra	Lithuania
Austria	Luxemburg
Belgium	Madeira Islands
Bosnia and Herzegovina	Malta
Croatia	Monaco
Denmark	Montenegro
Estonia	Netherlands
Faroea Islands	Norway
Finland	Portugal
France	Republic of Serbia
Germany	San Marino
Greece	Slovenia
Guernsey	Spain
Iceland	Svalbard and Jan Mayen Islands

Ireland	Sweden
Isle of Man	Switzerland
Italy	The former Yugoslav Republic of Macedonia
Jersey	United Kingdom of Great Britain and Northern Ireland
Latvia	
NORTH AMERICA	
Bermuda	Greenland
Canada	United States of America

APPENDIX B – REFERENCES

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