Supplementary information to the manuscript

Livestock: on our plates or eating at our table? A new analysis of the feed/food debate

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Contents

1. Overview of the Global Livestock Environmental Assessment Model - GLEAM

Feed rations were estimated with the Global Livestock Environmental Assessment Model (GLEAM, Gerber et al., 2013) developed at FAO. GLEAM is a spatially explicit model that represents bio-physical processes and activities along livestock supply chains under a life cycle assessment approach. It has a high level of quantitative details on herd production functions and resource flows, with the aim of exploring the environmental implications of production practices for the main commodities, farming systems and regions.

GLEAM 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 information for a given production system, thereby enabling calculation 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 herd module determines the structure of the herd and the characteristics of the average

animal in each cohort (defined as a class of animals within a herd or flock grouped by their age and sex). The manure module calculates the rate at which the nitrogen is excreted and deposited on pastures and crops. Feed rations and associated land are calculated within the feed module. The system module calculates the animals' energy requirements and total production of meat, milk and eggs. Greenhouse gas emissions from different sources are allocated to products and services (milk, meat and eggs, fiber and draught draft power) in the allocation module. For the assessment of livestock feed rations, only the herd module, the feed module and the system module were used. A full description of the model, the variables and the equations are available for download from http://www.fao.org/gleam/resources. This document summarizes the main features used for the assessment of feed rations.

2. Data resolution and disaggregation

Data on production practices and productivity were collected from the literature and experts consultations at different levels of aggregation: production systems, country levels, agro-ecological zones, or a combination thereof. Additional data, such as livestock numbers, pasture and availability of feedstuffs was available in the form of GIS grids (raster layers). GIS can store observed data for specific locations and it can model new information from these data, as well as calculate regional summaries. The use of GIS thus permits incorporation of spatial heterogeneity into the modelling process. In this way, feed rations can be estimated for any location of the globe, using the most accurate information available at this scale of analysis, and then aggregated along the desired category, such as farming systems, country group, commodity and animal species. Data collection involved extensive research of databases, literature sources and expert opinion. The study's main data sources included:

- Gridded Livestock of the World (Robinson et al., 2014);
- Geo-referenced databases on crop yields and harvested areas (IIASA/FAO, 2012);
- Gross primary production for grassland (Haberl et al., 2007);
- Reports from the Consultative Group on International Agricultural Research (CGIAR);
- Statistics from FAO (FAOSTAT, 2015);
- Peer-reviewed journals.

In its second version, GLEAM 2.0 incorporates over 9,000 discrete supply chains, defined here as unique combinations of commodity, farming system, country and agro-ecological zone. The geographical area corresponding to each of these sets is further decomposed into GLEAM production units: grid cells, or pixels, with a resolution of 5 arc minutes, or ca. 10 km x 10 km at the equator.

3. Farming systems and herd simulation

A farming system typology was adapted from the classification principles set out by Seré & Steinfeld (1996), namely, the feed-base and the agroecological conditions of production systems. GLEAM 1.0 differentiates the 11 main livestock commodities: meat and milk from cattle, sheep, goats and buffalo; meat from pigs and meat and eggs from chickens. Ruminant production is differentiated into feedlot (for beef only), mixed and grazing systems; pig production into backyard, intermediate and industrial systems and chicken production into backyard, layers and broilers (Table SI 1).

Table SI 1. Characteristics of livestock production systems used in GLEAM

Production system	Characteristics	Housing
Ruminant species		
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 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
Feedlots	Fully market-oriented and specialized feeding operations which fatten animals prior to slaughter. A high share of the diet consists of high-energy feed materials.	Although it can vary among different operations, animals are kept in fully enclosed areas to facilitate the fattening process.
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.

The cattle feedlot system was added in GLEAM 2.0, using the following methodology. Input data were collected about: total animal in feedlots at the lowest administrative level possible, average feedlot capacity, number of days of the fattening cycle, feedlot herd parameters, average feed rations and manure management. All data required were obtained through literature review and expert opinion and, depending on the availability, at national or sub-national level. Sources of information include national statistics, Agribenchmark (2013) and consultations with national experts. In the global grid used for livestock distribution, cells with the highest density of cattle were classified as having feedlot systems. For each administrative unit where a number of cattle on feed was available, cells were ranked according to the animal density and iteratively extracted

starting from the highest density one. The extraction continued until reaching a total number of animals that was less than or equal to a maximum threshold defined for each administrative unit. The threshold accounted for the total number of animals in feedlot systems in one year and was calculated multiplying the average feedlot capacity by the number of fattening cycles along the year. Once the spatial distribution of feedlot systems was defined, all animals in the selected cells were considered as fattening animals and their dynamic was integrated and modeled with the rest of the herd according to the specific herd parameters available for feedlots. All subsequent evaluation performed by the model for these systems were than executed using their specific input parameters about animal productivity, feed rations and manure management.

4. Modeling of feed rations

Feed rations were modeled differently for ruminants and monogastrics. For ruminants, in industrialized regions, the composition and relative portions of the feed ration materials are taken from national inventory reports, literature and targeted surveys. For developing countries, due to scanty information, a feed allocation scheme was developed based on the availability of feed resources (yields of crops and forage) and animals requirements (energy). First, the proportion of by-products and concentrates in the ration was defined based on surveys, literature and expert knowledge. The total roughage availability in each pixel is calculated based on the dry matter (DM) yields per hectare of pasture, fodder and crop residues and the land area of the respective feeds. Data for this calculation was obtained from a number of sources: FAOSTAT for specific crops (e.g. soybean and palm); GAEZ for 20 crops; and Haberl et al. (2007) to estimate the above-ground net primary productivity for pasture. Feed requirements, based on energy for maintenance, labor, grazing, gestation and lactation, for all ruminant species, were then assessed by expressing the different ruminant species and categories of animals in cattle equivalent, to take into account the fact that these animals are competing for the same feed resource. To assess the feed availability, a ratio between the total roughage availability and ruminant species biomass was obtained. Total ruminant annual feed requirements were then checked based on the assumption that an animal consumes about 2 to 3 percent of its bodyweight on a daily basis and hence, on an annual basis, DMI will range between 7.3 and 14 kg DM. The total amount of roughage feed available was then compared to the animal feed requirements within each cell to provide an indication of feed adequacy in terms of sufficiency, deficiency or surplus for any given location. In situations where ample feed is not available to meet the requirements of the animals, the feed ration is supplemented with leaves and hay. The proportion of each roughage material within the feed ration was then obtained by dividing the quantity available of each roughage material by the total available roughage. The proportions of roughages plus the by-products and concentrate proportions form the total feed ration.

For monogastrics, feed materials were divided into three main categories: swill and scavenging, non-local feed materials and locally-produced feed materials. 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. The proportion of the non-local feeds was defined for each country, where possible, using availability (yields) and existing literature: FAO (2001); Ndindana et al. (2002); Tra (2003); van der Werf et al. (2005); Grant Clark et al. (2005); FAO (2006); Hu (2007) and Rabobank (2008); FAO (2003); Petri and Lemme (2007); Thiele and Pottgüter (2008); Pelletier (2008); FAO (2010); Wiedemann and McGahan (2011); Nielsen et al. (2011); CEREOPA (2011);

Jeroch (2011); Leinonen et al. (2012a, 2012b) and Wiedemann et al. (2012). Gaps in the literature were filled through discussions with experts (both within FAO and the industry) and also through primary data gathering (a questionnaire survey of commercial egg producers was undertaken with the assistance of the International Egg Commission).

Tables SI 2 and SI 3 present the summary of the feed intake and rations by animal and by country groups, production systems and feed material. Tables SI 4 to SI 14 present detailed average rations for the different livestock production systems at regional level. Regions are reported using the following abbreviations: 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 SI 2. Global livestock feed intake by regions, species and systems (Million tones/year)

			Total intake	Roughages	Swill	Cereal grains	2nd grade grain	Brans, spent brewer and biofuel grains	Soybean cakes	Other oil seed cakes	Other edible	Other non-edible	Total human-edible feed intake	Total in competition with food production
Non OECD	Cattle & buffaloes	Grazing	1,148	1,092	-	10	-	35	2	8	-	2	11	13
		Mixed	2,326	2,079	-	65	-	112	12	25	-	34	77	88
		Feedlots*	37	14	-	14	-	6	1	2	-	-	15	16
	Small Ruminants	Grazing	215	208	-	-	-	6	-	1	-	-	-	1
		Mixed	238	226	-	1	-	9	-	1	-	-	1	1
	Poultry	Backyard	73	-	28	-	21	11	6	3	2	1	8	15
		Layers	141	-	-	87	-	6	7	6	21	14	115	123
		Broilers	219	-	-	155	-	-	52	2	3	6	210	262
	Pigs	Backyard	217	32	42	-	66	33	27	11	2	3	30	57
		Intermediate	85	7	3	43	-	11	14	2	3	2	59	73
		Industrial	81	-	-	52	-	5	14	2	4	3	70	84
OECD	Cattle & buffaloes	Grazing	340	293	-	24	-	11	4	5	-	3	28	32
		Mixed	396	307	-	48	-	14	8	11	-	8	56	64
		Feedlots*	71	17	-	51	-	1	1	-	-	1	52	54
	Small Ruminants	Grazing	32	29	-	1	-	1	-	-	-	1	1	1
		Mixed	45	39	-	1	-	3	-	-	-	2	1	1
	Poultry	Backyard	1	-	-	-	-	-	-	-	-	-	-	0
		Layers	40	0	-	27	-	-	4	1	5	4	36	40
		Broilers	124	-	-	82	-	-	24	5	7	6	113	137
	Pigs	Backyard	6	2	1	-	2	1	-	-	-	-	-	0
		Intermediate	6	-	-	4	-	1	1	-	-	-	5	5
		Industrial	155	-	-	105	-	7	23	12	3	5	131	154
World	Ruminants		4,849	4,304	-	214	-	199	28	53	-	51	242	270
	Monogastrics		1,147	41	75	554	90	76	173	45	50	43	777	949
	All		5,996	4345	75	768	90	275	201	98	50	95	1,019	1,220

* Figures reported for fattening phase in feedlots (3 to 6 months). DM = dry matter. Roughages = fresh grass, hay, silage, crop residues such as straws and sugar cane tops, tree leaves and fodder beet. Other oil seed cakes: rape, canola, cotton and palm kernel. Other edible: cassava pellets, beans and unprocessed soy beans, rapeseed and soy oil. Other non-edible: corn gluten feed and meal, pulp, molasses, fish meal, synthetic amino acids, lime. Cereal grains = grains from wheat, maize, barley, millet, rice, sorghum, oat, buckwheat and fonio. In competition with food production: edible + soybean cakes

Table SI 3. Global livestock feed rations by regions, species and systems (kg DM/animal/year)

			Total intake	Roughages	Swill	Cereal grains	2nd grade grain	Brans, spent brewer and biofuel grains	Soybean cakes	Other oil seed cakes	Other edible	Other non-edible	Total human-edible feed intake	Total in competition with food production
Non OECD	Cattle & buffaloes	Grazing	2,680	2,550	-	22	-	81	4	21	-	4	22	26
		Mixed	2,531	2,262	-	73	-	122	13	58	-	37	71	84
		Feedlots*	1,784	670	-	670	-	307	44	93	-	9	670	714
	Small Ruminants	Grazing	270	260	-	1	-	8	-	1	-	-	1	1
		Mixed	238	226	-	1	-	9	-	1	-	-	1	1
	Poultry	Backyard	20	-	8	-	6	3	2	1	1	-	1	2
		Layers	26	-	-	16	-	1	1	1	4	3	20	21
		Broilers	34	-	-	24	-	-	8	-	-	1	24	32
	Pigs	Backyard	506	75	99	-	154	77	64	25	6	7	6	69
		Intermediate	563	46	23	285	-	73	91	14	19	10	305	395
		Industrial	628	1	-	408	-	42	109	14	30	24	438	547
OECD	Cattle & buffaloes	Grazing	3,178	2,740	-	223	-	105	38	57	-	28	223	260
		Mixed	2,898	2,244	-	348	-	101	62	111	-	58	348	417
		Feedlots*	2,022	481	-	1,448	-	27	37	22	-	24	1,448	1,485
	Small Ruminants	Grazing	297	267	-	7	-	12	1	9	-	8	7	8
		Mixed	301	261	-	8	-	17	1	14	-	12	8	9
	Poultry	Backyard	25	-	5	-	11	6	-	2	-	-	-	-
		Layers	27	-	-	18	-	-	3	-	3	2	21	24
		Broilers	40	-	-	26	-	-	8	2	2	2	28	36
	Pigs	Backyard	574	187	64	-	189	94	14	18	-	7	-	14
		Intermediate	583	42	-	343	-	69	67	33	10	17	354	421
		Industrial	637	-	-	432	-	30	93	49	14	19	446	539

* Figures reported for fattening phase in feedlots (3 to 6 months). DM = dry matter. Roughages = fresh grass, hay, silage, crop residues such as straws and sugar cane tops, tree leaves and fodder beet. Other oil seed cakes: rape, canola, cotton and palm kernel. Other edible: cassava pellets, beans and unprocessed soy beans, rapeseed and soy oil. Other non-edible: corn gluten feed and meal, pulp, molasses, fish meal, synthetic amino acids, lime. Cereal grains = grains from wheat, maize, barley, millet, rice, sorghum, oat, buckwheat and fonio. In competition with food production: edible + soybean cakes

Table SI 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	-	-	-	-	-	-

Table SI 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	-	-	-	-	-	-

Table SI 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	-	-	-	-	-	-	-

Table SI 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	-	-	-	-	-	-		-	-	-

Table SI 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	-	-	-

Table SI 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	-	-	-

Table SI 10. Industrial pig feed rations, 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(-)

Table SI 11. Backyard pig feed rations, 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

Table SI 12. Intermediate pig feed rations, 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

Table SI 13. Backyard chicken feed rations, 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

Table SI 14. Layer chicken feed rations, 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)	1	1	1	1	1	1	1	1	1	1
Limestone	8	7	8	7	7	8	7	6	7	7

Table SI 15. Broiler chicken feed rations, 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)	1	1	1	1	1	1	1	1	1	1
Limestone	1	1	1	1	1	1	2	1	1	1

5. Allocation method for land-use to different co-products

When different co-products are produced from one crop (e.g. grain and straw, oil and oil seed cakes), an allocation method was used to determine the share of land attributable to each material. The method is based on the approach developed by Gerber et al. (2013) for the calculation of greenhouse gas emissions. It relies on the relative mass fraction and value of the different co-products and by-products. Digestibility was used as a proxy of value and the mass fraction reflects the weight of different parts of the plant in dry matter.

The formula used to calculate land-use for feed components is the following:

$$LU = \frac{1}{DMYG_{crop} * FUF} * \frac{EFA}{MFA}$$

where LU is the land-use in ha, $DMYG_{crop}$ is the dry matter yield of the feed component in kg/ha, FUF is the Feed Use Fraction, EFA is the economic fraction allocation and MFA is the Mass fraction allocation.
In the case the feed component is a crop residue, such as straws, the formula used to calculate land-use is the following:

$$LU = \frac{1}{DMYG_{crop\ residue} * FUF + DMYG_{crop}} * \frac{EFA}{MFA}$$

where LU is the land-use in ha, $DMYG_{crop\ residue}$ is the dry matter yield of the feed component in kg/ha (calculated following IPCC 2006 Table 11.2), $DMYG_{crop}$ is the dry matter yield of the relative crop in kg/ha, FUF is the feed use fraction, EFA is the economic fraction allocation and MFA is the Mass fraction allocation. Values of the different factors are presented in Table SI 16.

Table SI 16. Sources and values of the factors used for the calculation of land used to produce the different feed materials

Feed material	Source for Dry Matter Yield (DMY)	Feed Use Fraction (FUF)	Mass Fraction Allocation (MFA)	Economic Fraction Allocation (EFA)
Grass and legume grass, fresh and dry	Net Primary Productivity (Haberl et al. 2007)	0.53*	1	1
Cereal straws and sugar cane tops	Based on IPCC (2006)	0.73**	Formula 1	Formula 2
Silages	GAEZ and IPCC (2006)	1	1	1
Tree leaves	Authors' own assumptions	1	1	1
Fodder beet	GAEZ	1	1	1
Cereal grains	GAEZ	1	1	1
Soybean cakes	GAEZ	1	0.80	0.72
Rapeseed cakes	GAEZ	1	0.58	0.28
Cotton seed cakes	GAEZ	1	0.45	0.23*
Other oil seed cakes	GAEZ	1	0.58	0.28
Palm kernel expeller	GAEZ	1	0.03	0.01
Corn gluten meal	GAEZ	1	0.05	0.10
Corn gluten feed	GAEZ	1	0.21	0.06
Sugar beet pulp	GAEZ	1	0.19	0.11
Molasses	GAEZ	1	0.13	0.06
Brans and cereals middling	GAEZ	1	0.17	0.04
Spent distiller, breweries, biofuel grains	GAEZ	1	1	0.08
Swill	Authors' own assumptions	1	1	1
Pulses	GAEZ	1	Formula 3	Formula 4
Pulses straw	GAEZ	0.90	Formula 1	Formula 2
Cassava	GAEZ	1	1	1
Rapeseed	GAEZ	1	1	1
Soybeans	GAEZ	1	1	1
Soy oil	GAEZ	1	0.17	0.27
Banana fruits	GAEZ	1	Formula 3	Formula 4
Banana stems	GAEZ	0.50	Formula 1	Formula 2
Fishmeal	Authors' own assumptions	1	1	1
Synthetic amino acids and lime	Authors' own assumptions	1	1	1

*Average value reported (the original values are region and system specific). **Average value reported (the original values are region specific). DE = digestible energy

Formula 1: $MFA = \frac{DMY_{crop\ residue} * FUF}{DMY_{crop\ residue} * FUF + DMY_{crop}}$ Formula 2: $EFA = \frac{DMY_{crop\ residue} * FUF * DE_{crop\ residue}}{DMY_{crop\ residue} * FUF * DE_{crop\ residue} + DMY_{crop} * DE_{crop}}$

Formula 3: $MFA = \frac{DMY_{crop} * FUF}{DMY_{crop\ residue} * FUF + DMY_{crop}}$ Formula 4: $EFA = \frac{DMY_{crop} * FUF * DE_{crop}}{DMY_{crop\ residue} * FUF * DE_{crop\ residue} + DMY_{crop} * DE_{crop}}$

6. Projections of sector's trends

The OECD-FAO Agricultural Outlook for 2016-2025 (OECD/FAO, 2016) was used to analyse future trends in the livestock sector and their implications for feed demand and land-use, as compared to the reference year 2010. Conservative FCR improvements (0 to 5% lower depending on the species), and more optimistic improvements (5 to 15% lower FCR) were considered derived from Wirsenius et al. (2010). Yields on grasslands were considered constant between 2010 and 2025.

Table SI 17. Projected meat production and crop yields by 2025 (OECD/FAO, 2016) and related animal feed demand and area needed: range, lower bound corresponding to optimistic improvement in FCR and upper bound to conservative improvement in FCR

		Meat production 2010 (Mt cwe)	Meat production 2025/2010 (%)	Range of FCR improve-ment (%)	Crop yields 2025/2010 (%)	Human-edible feed intake 2010 (Mt DM)	Non-human-edible feed intake 2010 (Mt DM)	Human-edible feed intake 2025 (Mt DM)	Non-human-edible feed intake 2025 (Mt DM)	Area of human - edible feed 2025 (million ha)	Area of non-human-edible feed 2025 (million ha)
Non OECD	Cattle & buffaloes	46.3	21	[5-15]	25	124	3,387	[131-143]	[3,568-3,907]	[36-39]	[1,069-1,171]
	Small Ruminants	11.6	33	[5-15]	25	2	451	[2.2-2.4]	[523-573]	[0.6-0.7]	[1,033-1,131]
	Poultry	71.8	32	[5-10]	25	263	170	[315-330]	[203-213]	[71-74]	[52-54]
	Pigs	92.8	19	[5-10]	25	103	279	[112-117]	[304-318]	[32-33]	[24-25]
OECD	Cattle & buffaloes	28.0	4	[0-5]	10	134	673	[133-140]	[669-703]	[28-30]	[138-145]
	Small Ruminants	2.5	15	[0-5]	10	5	73	[5.0-5.3]	[80-84]	[0.8-0.9]	[36-38]
	Poultry	41.3	24	[0-5]	10	118	47	[139-146]	[55-58]	[21-22]	[19-20]
	Pigs	39.8	10	[0-5]	10	114	53	[119-125]	[56-58]	[24-25]	[8.9-9.3]
Total non OECD		222.6	24	-	-	492	4,287	[560-593]	[4,597-5,011]	[139-148]	[2,178-2,381]
Total OECD		111.5	14	-	-	370	846	[396-416]	[860-903]	[74-77]	[202-212]
Total World		334.1	21	-	-	863	5,133	[956-1,009]	[5,457-5,914]	[213-225]	[2,379-2,593]

Mt = million tons DM=dry matter Cwe=carcass weight equivalent FCR=Feed Conversion Ratio

7. Validation of feed ration by literature review

An extensive literature review was also carried out to validate GLEAM feed rations. 121 peer reviewed international and national publications presenting feed rations for combinations of species, systems and regions were analyzed and compared to GLEAM outputs. No significant discrepancies were identified and main feed components as well as their share in the total dry matter intake were confirmed. References used for the feed review are presented in Table SI 18 for each system.

Table SI 18: List of publications used for GLEAM feed rations validation

LAC Dairy Cattle Poncheki et al 2015 Chizzotti et al 2015 Angarita et al 2015 de Leis et al 2015 **LAC Beef Cattle** Arias et al 2015 Picasso et al 2014 Newbold et al 2014 Hulshof et al 2015 **LAC Small Ruminant Milk & Meat** Genin et al 1994 de Vargas Junior 2014 Pfister & Malechek 1986 LAC Industrial Pigs Moreira et al 2004 Pereyra et al 2008 **LAC Broilers** Romero-Sanchez Hamme & Machado Junior Kebreab et al 2005 **LAC Layers** Mohammed et al 2012 **E & SE Asia Dairy Cattle** Lou et al 2015 Bingsheng 2002 Oshita et al 2007 Zemmelink and Ibrahim 2000 Salgado et al 2013 **E & SE Asia Beef Cattle** Candra et al 2015 Ogino et al 2004 Cherdthong et al 2011a Cherdthong et al 2011b Wanaput et al 2012	**E & SE Asia Backyard Pigs** Bingsheng 2002 Nakai 2008 Peters 2004 Fang & Fuller 1998 Paris 2002 Loc et al 1997 **E & SE Asia Intermediate Pigs** Malavanh & Preston 2006 Bingsheng 2002 Lemke et al 2006 Kunavongkrit & Heard 2000 Jones 2002 Lemke et al 2007 Tu et al 2010 Huong Tra 2003 Peters et al 2005 Malavanh et al 2008 Lemke & Zarate 2008 **E & SE Asia Industrial Pigs** Vu et al 2010 Li et al 2000 Ly et al 2003 Thieu et al 2008 **E & SE Asia Broilers** Lou et al 2015 Minh & Ogle 2005 Lu et al 2014 Jin et al 2014 Srinongkote et al 2004 **E & SE Asia Layers** Lou et al 2015 Minh & Ogle 2005 Furusawa et al 2000 **South Asia Dairy Cattle** Padmakumar et al 2015 York 2010 York 2010b Huque 2014 Islam et al 2010	**South Asia Backyard Pigs** Rahman et al 2008 Niraula et al 2015 Kokrajihar et al 2007 Hossain et al 2011 **SSA Dairy & Beef Cattle** Wafula et al 2015 Wondatir & Darntew 2015 Ngongoni et al 2006 Sidibe-Anago et al 2006 Rufino et al 2007 Khalili et al 1992 Varvikko and Khalili 1993 **SSA Small Ruminant Milk & Meat** Makembe & Ndlovu 1996 Greyling at al 2004 Okagbare et al 2004 Megersa et al 2013 Ayantunde et al 2014 Rey & Das 1997 Tuah Bosman et al 1996 Nyamangara & Ndlovu 1995 **SSA Backyard Pigs** Permin et al 1999 Nsoso et al 2006 Mutua et al 2012 **LAC Dairy Buffalo** Gagliostro et al 2015 Franzolin et al 2012 **SA Beef Cattle** Sahoo et al 2000 Akter & Khandaker 2010 Rahman 2009 Ghebrehiwet et al 1988	**SA Dairy Buffalo** Ahmad et al 2014 Sarwar et al 2011 Zia-ul-Hassan et al 2011 Padmakumar et al 2015 York 2010 Touqir et al 2007 Islam 2013 **SA Broiler Chicken** Roy et al 2010 Chacrabati et al 2013 Aktar et al 2011 Shariatmadari Vadivel & Pugalenthi 2010 **SSA Industrial Pigs** Lekule & Kyvsgaard 2003 Amaefule et al 2006 Ndindana et al 2002 Ncube et al 2003 Fonunyan Ilemobade & Balogun 1981 Manjeti et al 1996 Oddoye et al 2009 **SSA Broiler Chicken** Ayssiwede et al 2010 Akanji 2015 Hassan et al 2003 Kana et al 2011 Agwunobi 1999

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