KEY MESSAGES OF CHAPTER 4

- Enteric fermentation and feed production are the main emission sources for ruminants.

- Beef produced by dairy cattle has generally lower emission intensity than beef produced by specialised beef cattle. This is explained by the fact that emissions from reproductive animals are allocated to milk and meat in the case of the dairy herd, and to meat only in the case of the beef herd.

- Beef and milk production have higher emission intensities in systems characterized by low productivity. This is due to low feed digestibility, less efficient herd management practices and low reproduction performance. This relationship between emission intensity and productivity is not clearly observed for monogastric species, as highly productive systems rely on high emission intensity feed.

- In Latin America and the Caribbean, one-third of the emissions from beef production are related to pasture expansion into forested areas.

- In pork and poultry supply chains, emissions mainly derive from feed production explained by the use of high emission intensity feed. For pork and chicken egg production, manure storage and processing are also an important source of emissions.

- Emissions related to energy consumption account for as much as 40 percent of emissions in pork and poultry supply chains.

- In pork production, lowest emission intensities are in backyard systems which rely on feed with low emissions, and among industrial systems which are most efficient at converting feed into animal products.

- Chicken meat and eggs have low emission intensities compared with other livestock products.

- For livestock production systems, N_2O, CH_4 and CO_2 emissions are losses of N, energy and organic matter that undermine the efficiency and productivity of production units.

EMISSIONS BY SPECIES

This chapter presents a summary analysis of emissions by animal species. A complete and detailed analysis including a detailed sensitivity analysis and a comparison of results with other studies is available in FAO (2013a and 2013b).

4.1 CATTLE

GHG emissions from cattle represent about 65 percent of the livestock sector emissions (4.6 gigatonnes CO_2-eq), making cattle the largest contributor to total sector emissions. Beef production contributes 2.9 gigatonnes or 41 percent of total sector emissions while emissions from milk production amount to 1.4 gigatonnes or 20 percent of total sector emissions.[11] Emissions allocated to other goods and services such as animal draught power and manure used as fuel represent 0.3 gigatonnes (Figure 10). These goods and services supplied by livestock are particularly important in South Asia and sub-Saharan Africa, where they account for almost 25 percent of emissions.

Average emission intensities are 2.8 kg CO_2-eq per kg of fat and protein corrected milk[12] for milk and 46.2 kg CO_2-eq per kg of carcass weight for beef.

Main emission sources: enteric fermentation and feed fertilization

Enteric fermentation is the main source of emissions from cattle. Related emissions amount to 1.1 gigatonnes, representing 46 percent and 43 percent of the total emissions in dairy and beef supply chains, respectively (Figures 7, 8, 9 and 10).

Feed emissions, including emissions from pasture management, form the second largest category of emissions, contributing about 36 percent to milk and beef emissions. Nitrous oxide emissions dominate, mostly originating from feed fertilization. When emissions from pasture expansion are added, feed emissions represent more than half of the emissions in specialized beef systems; dairy systems are generally not associated with pasture expansion.

Carbon dioxide emissions from energy use in feed supply chains represent about 10 percent of overall emissions. Emissions from energy consumption on farms and in processing are negligible in beef and limited in dairy (about 8 percent of emissions).

Higher emission intensity of the specialized beef herd

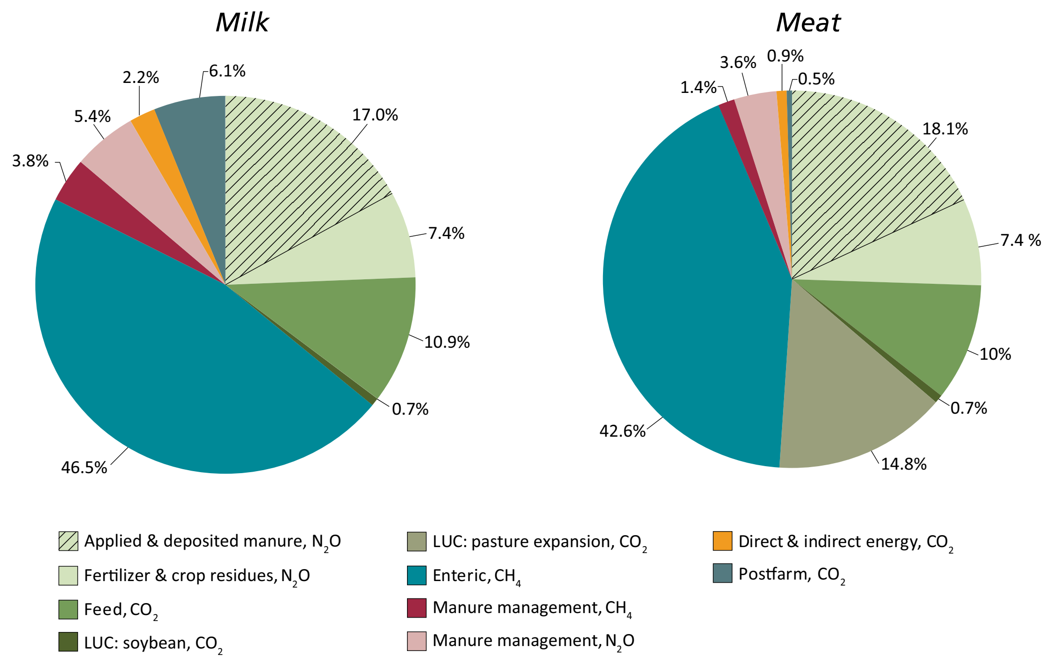
There is a distinct difference in emission intensity between beef produced from dairy herds and from specialized beef herds: the emission intensity

---

[11] Unless otherwise stated, the term "beef" refers to meat from both dairy and specialized beef herds.

[12] Milk is normalized in fat and protein corrected milk, to account for the heterogeneity in milk production.

FIGURE 7. Global emissions from cattle milk and beef supply chains, by category of emissions



Source: GLEAM.

TABLE 5. Global production, emissions and emission intensity for cattle milk and beef

Herd	**System**	**Production** *(Million tonnes)*		**Emissions** *(Million tonnes CO_2-eq)*		**Emission intensity** *(kg CO_2-eq/kg product)*	
		Milk[1]	**Meat**[2]	**Milk**	**Meat**	**Milk**[1]	**Meat**[2]
Dairy	Grazing	77.6	4.8	227.2	104.3	2.9[3]	21.9[3]
	Mixed	430.9	22.0	1 104.3	381.9	2.6[3]	17.4[3]
	Total dairy	**508.6**	**26.8**	**1 331.1**	**486.2**	**2.6[3]**	**18.2[3]**
Specialized beef	Grazing		8.6		875.4		102.2[3]
	Mixed		26.0		1 462.8		56.2[3]
	Total beef		**34.6**		**2 338.4**		**67.6 [3]**
Post-harvest emissions[4]				87.6	12.4		
Totals		**508.6**	**61.4**	**1 419.1**	**2 836.8**	**2.8[5]**	**46.2[5]**

[1] Product: FPCM.

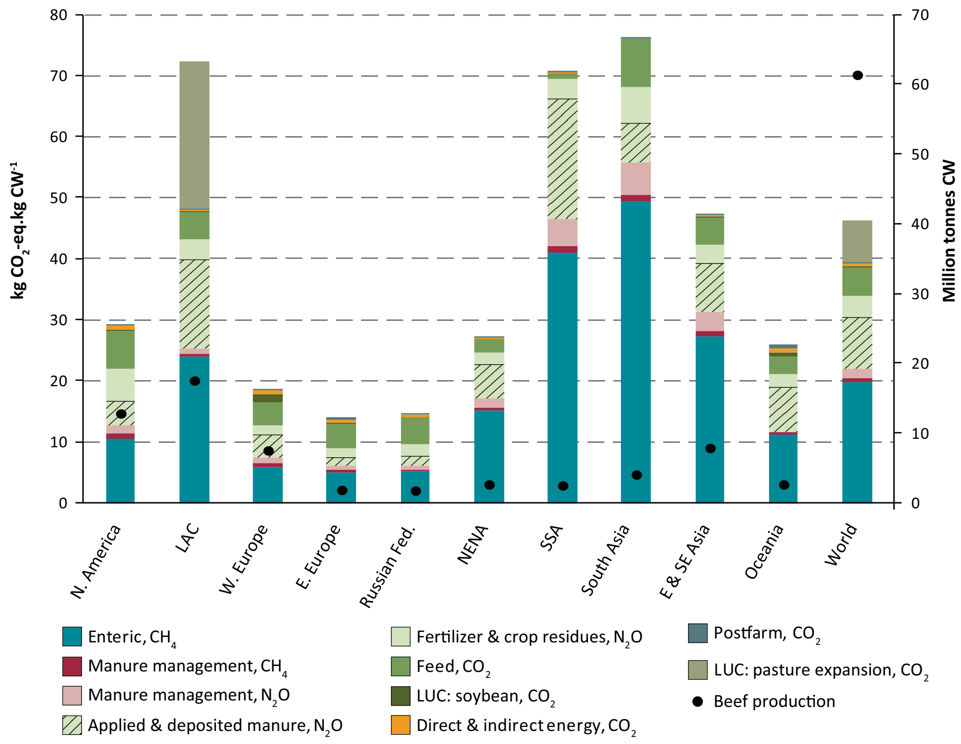
[2] Product: carcass weight (CW).

[3] Does not include post-harvest emissions.

[4] Computed at commodity and country level.

[5] Includes post-harvest emissions.

FIGURE 8. Regional variation in beef production and GHG emission intensities



Source: GLEAM.

of beef from specialized beef herds is almost fourfold that produced from dairy herds (68 vs. 18 kg CO$_2$-eq per kg of carcass weight) (Table 5).

This difference is primarily due to the fact that dairy herds produce both milk and meat while, on the other hand, specialized beef herds mostly produce beef. As a consequence, emissions from dairy herds are attributed to milk and meat while emissions from beef herds are allocated to meat (in both cases, a limited fraction is allocated to other goods and services, such as draught power, and manure used as fuel).

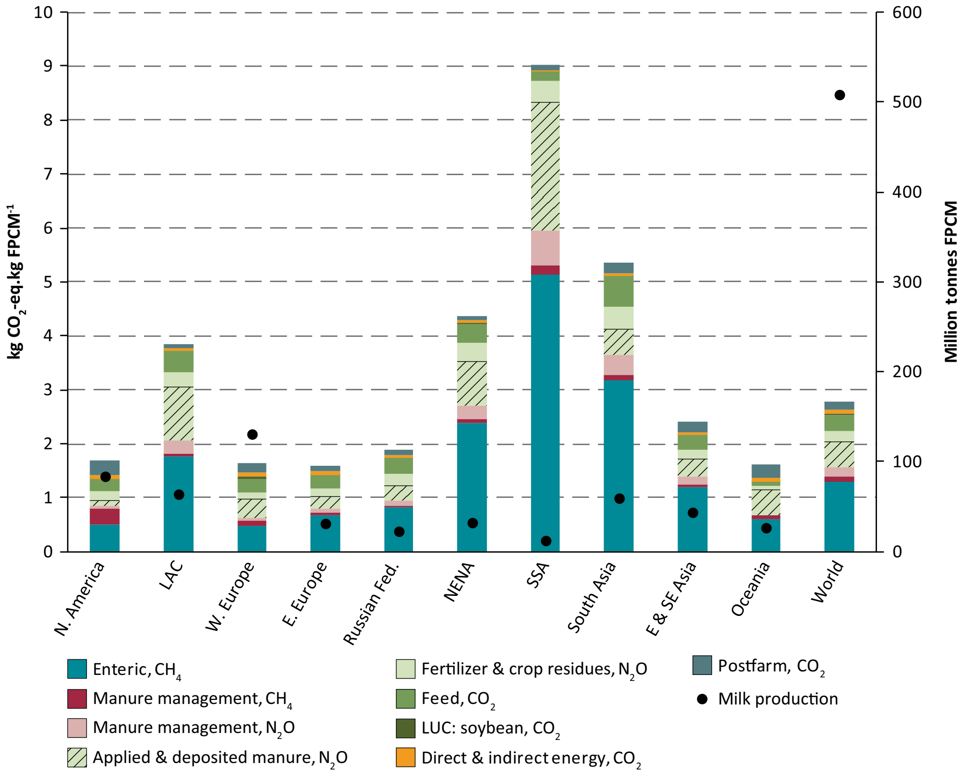
A closer look at emission structure shows that emissions from reproductive animals (the "breeding overhead") exclusively explain the difference: when only fattening animals are considered, specialized beef and surplus dairy calves have similar emission intensity per kg of carcass weight. In addition, the breeding cohorts represent 69 percent of the herd in specialized beef herds, compared with 52 percent in dairy systems.

Because of differences in feed quality and herd management, grazing systems generally have higher emission intensities than mixed systems.[13] Average emission intensities are particularly high for specialized beef raised in grazing systems in Latin America and the Caribbean, due to the land-use change emissions related to pasture expansion. The difference in emission intensities between grazing and mixed systems is less pronounced for beef from dairy herds and negligible for milk.

---

[13] Mixed and grazing systems are defined on the basis of animal diet and mix of products in farm output (Chapter 2).

FIGURE 9. Regional variation in cattle milk production and GHG emission intensities



Source: GLEAM.

Higher emission intensities in low productivity systems

Beef production

Emission intensities for beef are highest in South Asia, sub-Saharan Africa, Latin America and the Caribbean, and East and Southeast Asia (Figure 8). Higher emissions are largely caused by low feed digestibility (leading to higher enteric and manure emissions), poorer animal husbandry and lower slaughter weights (slow growth rates leading to more emissions per kg of meat produced) and higher age at slaughter (longer life leading to more emissions).

In Latin America and the Caribbean, one-third of the emissions (24 kg CO_2-eq/kg carcass weight) from beef production is estimated to come from pasture expansion into forested areas. This estimate is to be taken with caution, given the numerous methodological and data uncertainties affecting land-use change emissions estimates (Chapter 2) (FAO, 2013a and 2013b).

In Europe, about 80 percent of the beef is produced from dairy animals (surplus calves and culled cows), resulting in lower emission intensities, as explained above.

Milk production

Generally, the emission intensity of milk production is lowest in industrialized regions of the world (below 1.7 kg CO_2-eq/kg milk, compared with regional averages going as high as 9 kg CO_2-eq/kg milk). Better animal feeding and nutrition

TABLE 6. Global production, emissions and emission intensity for buffalo milk and meat

System	Production (Million tonnes)		Emissions (Million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Milk[1]	**Meat[2]**	**Milk**	**Meat**	**Milk[1]**	**Meat[2]**
Grazing	2.7	0.1	9.0	4.7	3.4[3]	36.8[3]
Mixed	112.6	3.2	357.9	175.2	3.2[3]	54.8[3]
Post-harvest emissions[4]			23.0	0.3		
Totals	**115.2**	**3.4**	**389.9**	**180.2**	**3.4[5]**	**53.4[5]**

[1] Product: FPCM.

[2] Product: CW.

[3] Does not include postfarm emissions.

[4] Computed at commodity and country level.

[5] Includes postfarm emissions.

reduce CH_4 and manure emissions (lower release of N and volatile solids). Higher milk yields imply a shift of the cow's metabolism in favour of milk and reproduction as opposed to body maintenance, contributing to lower emission intensities.

In low productivity regions, enteric fermentation is the main emission source. In industrialized regions, feed production and processing, and manure together are as important a source of emissions as enteric fermentation.

Manure management emissions are relatively high in North America where, on average, 27 percent of manure from the dairy sector is managed in liquid systems that produce greater quantities of CH_4 emissions.

4.2 BUFFALO

Total GHG emissions from buffalo production (meat, milk and other products and services) represent 9 percent of the sector's emissions. They amount to 618 million tonnes CO_2-eq, of which 390 million tonnes come from milk production, 180 million tonnes from meat production and 48 million tonnes CO_2-eq from other goods and services, such as manure used as fuel and draught power (Table 6).

Main emission sources: enteric fermentation and feed fertilization

Over 60 percent of emissions from buffalo meat and milk production come from enteric fermentation, compared with 45 percent for cattle. The difference is due to the generally lower digestibility of feed rations (Figure 11).

The fertilization of feed crops is the second largest emission source, representing 17 percent for milk production and 21 percent for meat production.

Emissions originating from land-use change are close to nil, given the absence of buffalo in areas where pasture is expanding as well as the limited presence of soybean products in the ration.

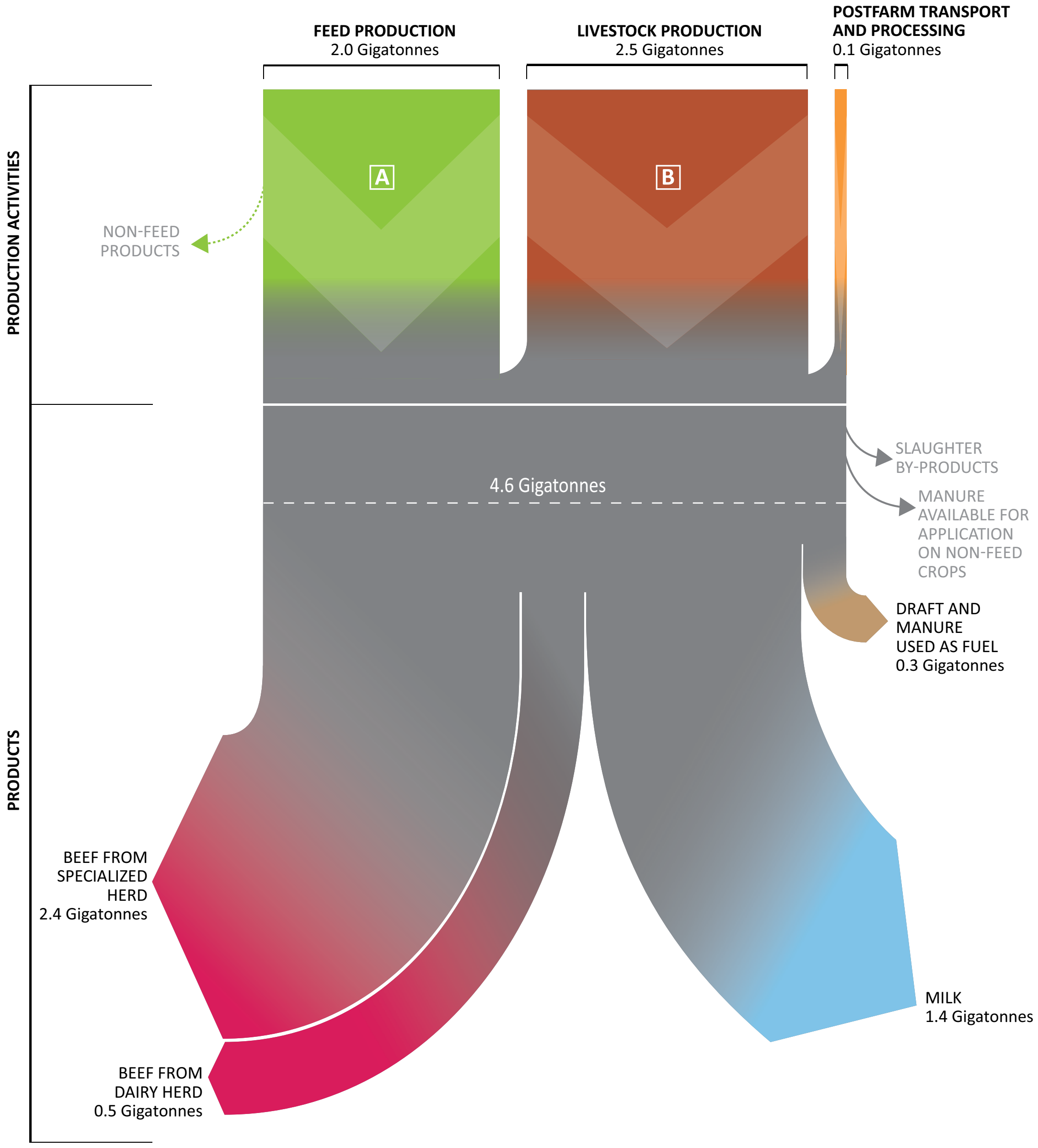
Geographically-concentrated production

Buffalo production is geographically concentrated in South Asia, Near East and North Africa and East and Southeast Asia, with South Asia alone producing as much as 90 percent and 70 percent of the global buffalo milk and meat, respectively. East and Southeast Asia produce 20 percent of buffalo meat; the other regions making limited contributions to meat and milk outputs (Figure 12 and 13).

Milk production

About 80 percent of buffalo milk is produced in mixed systems located in semi-arid climates. Average milk emission intensity ranges from 3.2 in South Asia to 4.8 kg CO_2-eq/kg FPCM in East and Southeast Asia. Milk produced in South Asia has the lowest emission intensity, explained by higher yields.

FIGURE 10. Global flows of emissions in cattle supply chains

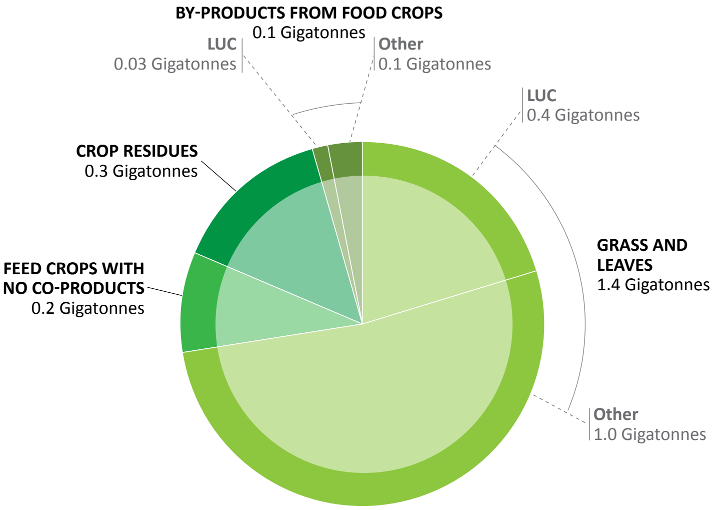


GHG EMISSIONS FROM GLOBAL LIVESTOCK SUPPLY CHAINS, BY PRODUCTION ACTIVITIES AND PRODUCTS

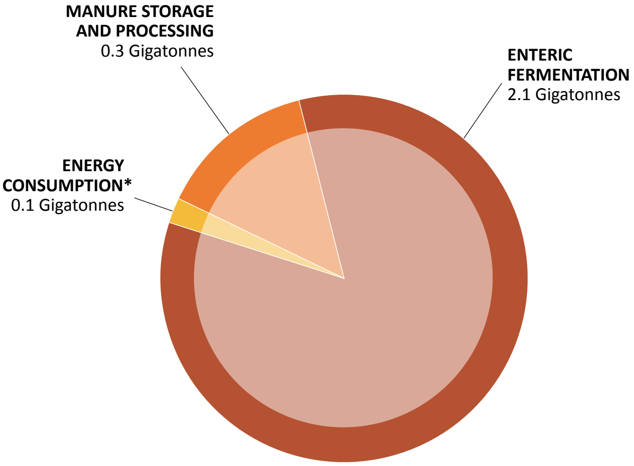
Different types of feed crops are identified: second grade crops (food crops that do not match quality standards for human consumption and that are fed to livestock), feed crops with no co-products (crops cultivated as feed, e.g. maize, barley), crop residues (residues from food of feed crops, e.g. maize, stover, straw), and by-products from food crops (by-products from food production and processing, e.g. soybean cakes, bran). The arrow "non-feed products" reminds us that the emissions from the production of feed are shared with other sectors. For example, household food wastes used to feed pigs in backyard systems are estimated to have an emission intensity of zero because emissions are entirely attributed to household food. In the same way, emissions related to crop residues (e.g. maize stover) are low because most of the emissions are attributed to the main product (maize grain).

No emissions could be allocated to slaughterhouse by-products (e.g. offal, skins, blood). Case studies show that by-products can add about 5 to 10 percent to the total revenue at slaughterhouse gate; for example, for beef and pork in OECD countries (FAO, 2013a and 2013b).

A FEED PRODUCTION



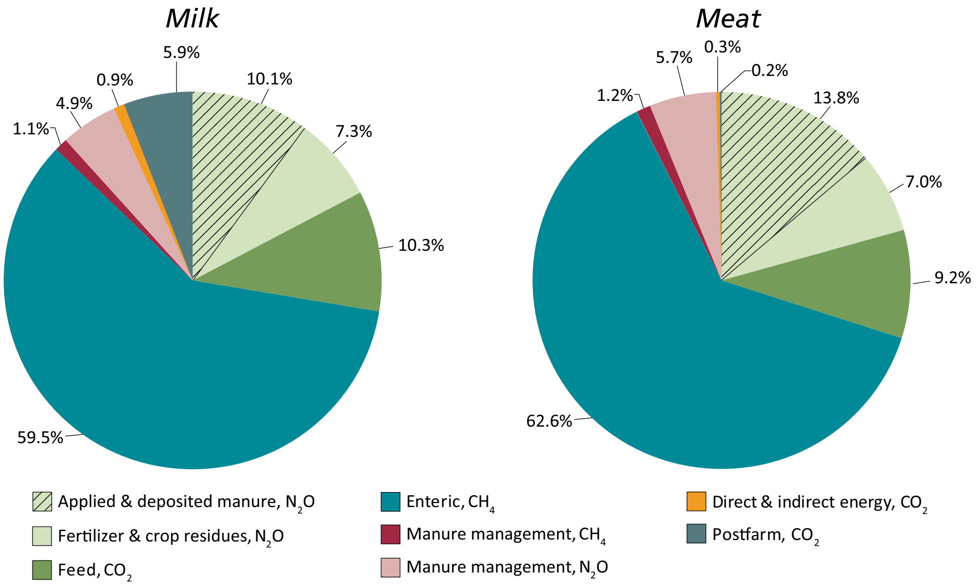
B LIVESTOCK PRODUCTION



*Embedded energy related to the manufacture of on-farm buildings and equipment is included in this category.

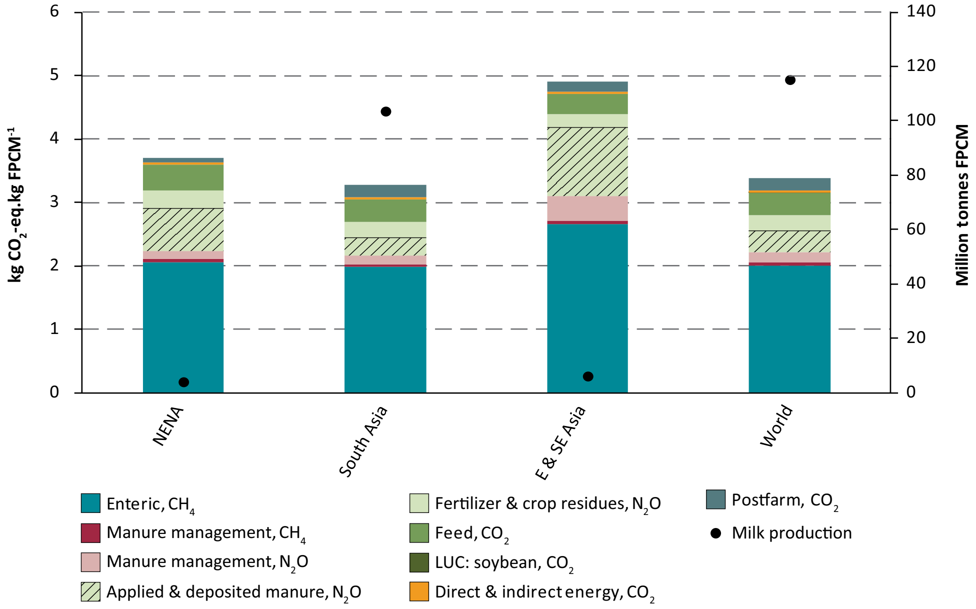
Source: GLEAM.

FIGURE 11. Global emissions from buffalo milk and meat supply chains, by category of emissions



Source: GLEAM.

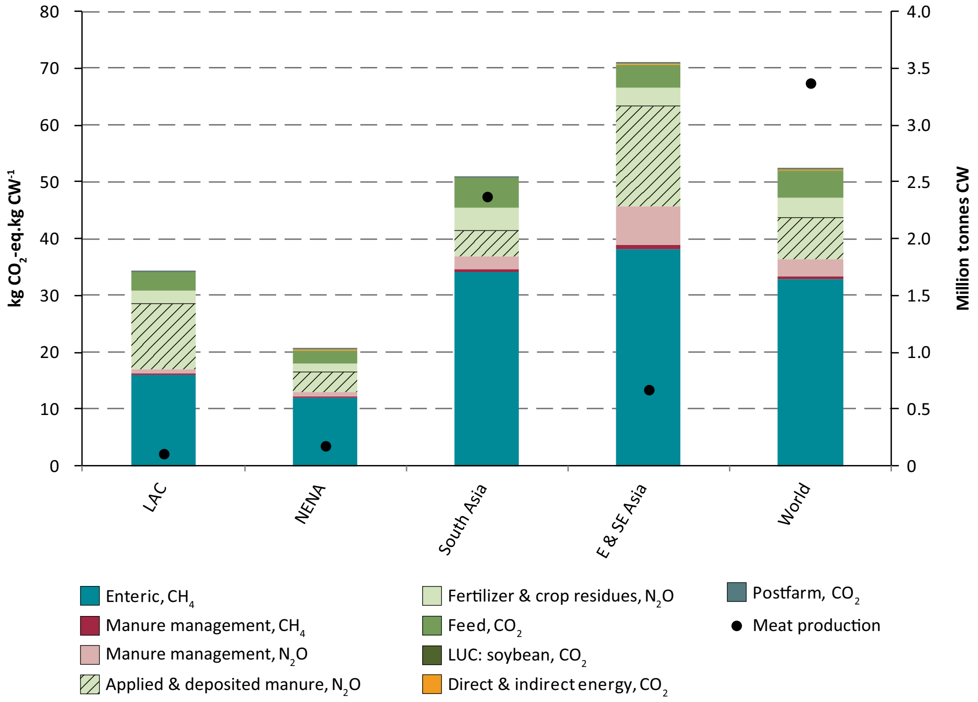
FIGURE 12. Regional variation in buffalo milk production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

FIGURE 13. Regional variation in buffalo meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

Meat production

Seventy percent of all buffalo meat originates from both grazing and mixed systems in the arid zones, which also have the lowest emission intensities.

Emission intensity of buffalo meat production at regional level ranges from 21 kg CO_2-eq/kg CW in NENA to 70.2 kg CO_2-eq/kg CW in East and Southeast Asia. Emission intensity of buffalo meat production is particularly high in East and Southeast Asia because productivity of the animals is low due to poor feed resources and low reproductive efficiency.

4.3 SMALL RUMINANTS (SHEEP AND GOATS)

Representing about 6.5 percent of the sector's global emissions, emissions from small ruminants amount to 475 million tonnes CO_2-eq , of which 299 million tonnes are allocated to meat production, 130 million tonnes to milk production and 46 million tonnes CO_2-eq to other goods and services.

Goat milk has a lower milk emission intensity compared with sheep (Table 7), due to higher yields.[14] Average emission intensity for small ruminant meat is 23.8 kg CO_2-eq/kg CW, with no large differences between sheep and goat meat.

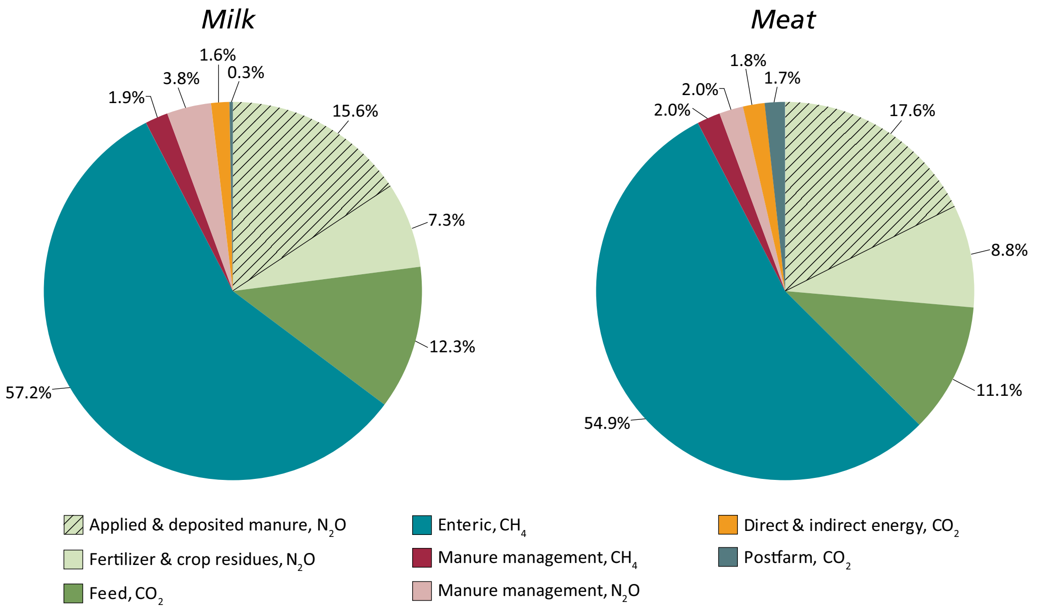
Main emission sources: enteric fermentation and feed fertilization

Similar to buffalo, over 55 percent of emissions from small ruminant meat and milk production come from enteric fermentation (Figure 14). Slightly more than 35 percent of emissions are from feed production. Compared with buffalo

---

[14] Fat and protein corrected milk.

FIGURE 14. Global emissions from small ruminant milk and meat supply chains, by category of emissions



Source: GLEAM.

TABLE 7. Global production, emissions and emission intensity for small ruminants

Species	System	Production *(Million tonnes)*		Emissions *(Million tonnes CO_2-eq)*		Emission intensity *(kg CO_2-eq/kg product)*	
		Milk[1]	**Meat[2]**	**Milk**	**Meat**	**Milk[1]**	**Meat[2]**
Sheep	Grazing	3.1	2.8	29.9	67.3	9.8[3]	23.8[3]
	Mixed	5.0	4.9	37.1	115.0	7.5[3]	23.2[3]
	Total sheep	**8.0**	**7.8**	**67.1**	**182.4**	**8.4[3]**	**23.4[3]**
Post-harvest emissions[4]				0.3	4.1		
Goats	Grazing	2.9	1.1	17.7	27.2	6.1[3]	24.2[3]
	Mixed	9.0	3.7	44.3	84.5	4.9[3]	23.1[3]
	Total goats	**11.9**	**4.8**	**62.0**	**111.7**	**5.2[3]**	**23.3 [3]**
Post-harvest emissions[4]				0.4	1.0		
Totals		**20.0**	**12.6**	**129.8**	**299.2**	**6.5[5]**	**23.8[5]**

[1] Product: FPCM.

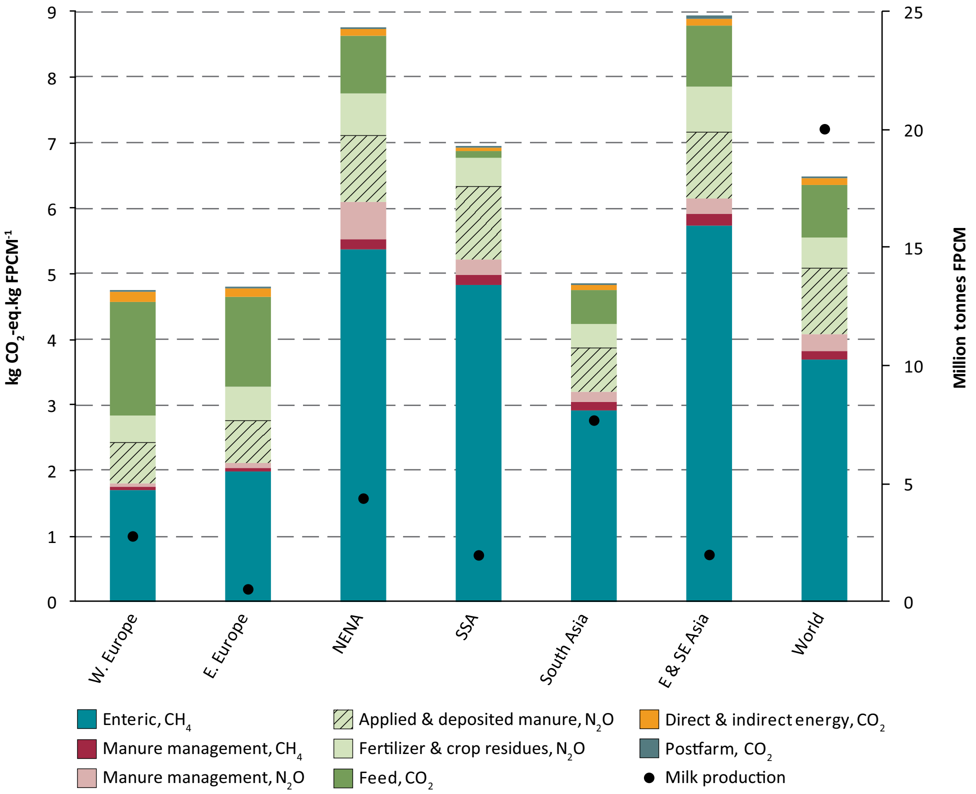
[2] Product: CW.

[3] Does not include post-harvest emissions.

[4] Computed at commodity and country level.

[5] Includes post-harvest emissions.

FIGURE 15. Regional variation in small ruminant milk production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.
Source: GLEAM.

and cattle, post-harvest energy consumption is lower due to less processing. Manure emissions are also lower because manure is mainly deposited on pasture (Figure 15).

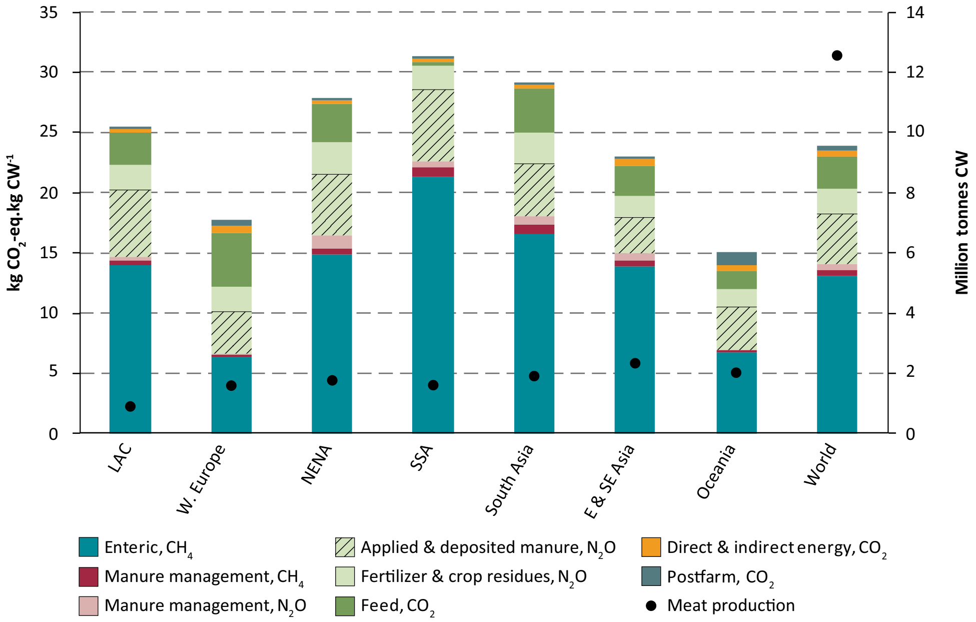
Production mainly in least affluent regions, with higher emission intensities

With the exception of milk in Western Europe and lamb and mutton meat in Oceania and Western Europe, small ruminant production is generally more important in less affluent regions (Figures 15 and 16).

Fibre production can represent a substantial part of emissions

Small ruminants not only produce edible products, but also important co-products including wool, cashmere and mohair. The relative economic value was used to partition emissions between edible products (meat and milk) and non-edible products (natural fibre). In regions where natural fibre production is important and has high economic value, a substantial share of emissions can be attributed to these products, reducing the share of emissions attributed to milk and meat production. Globally, 45 million tonnes CO$_2$-eq are allocated to fibre production (Figure 17).

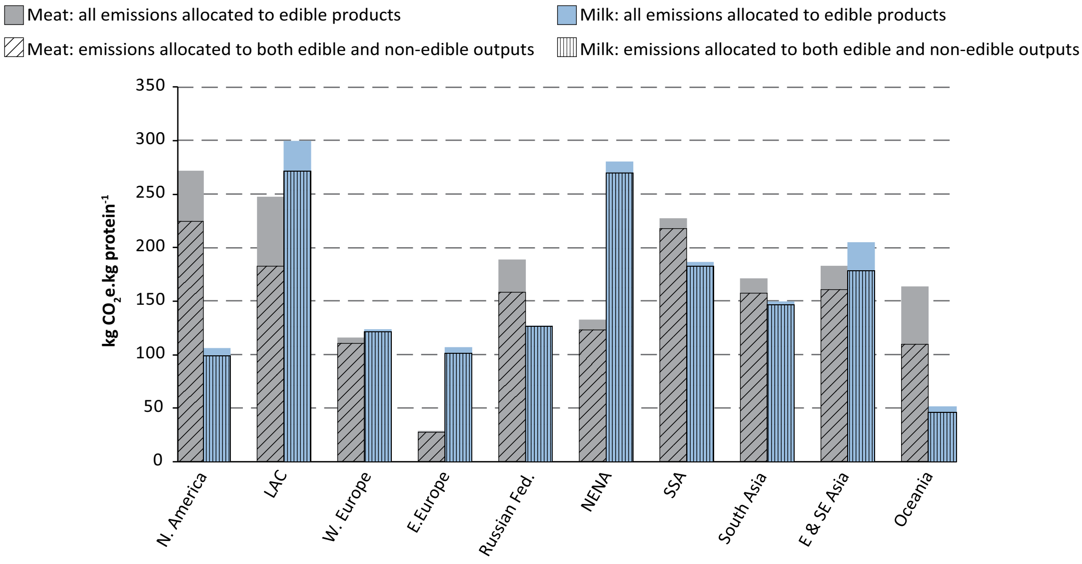
FIGURE 16. Regional variation in small ruminant meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

FIGURE 17. Emissions per kg meat and milk protein from small ruminants, with and without allocation of emissions to non-edible outputs



Source: GLEAM.

4.4 PIG

Globally, pork production is estimated to emit about 668 million tonnes CO_2-eq, representing 9 percent of the livestock sector emissions.

Main emission sources: feed production and manure

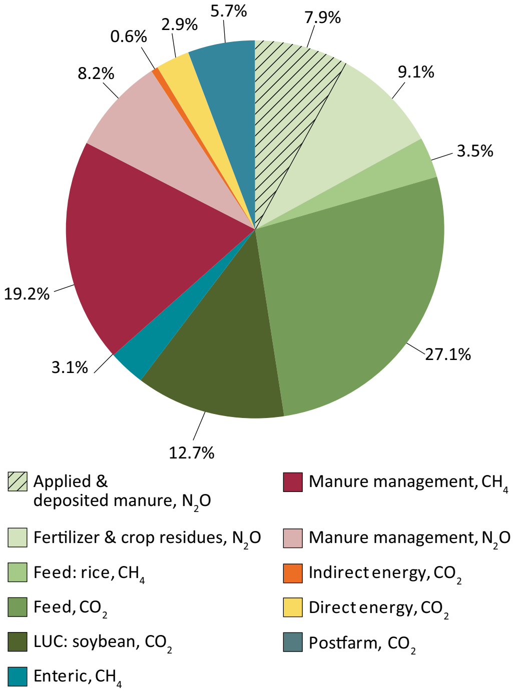
Feed production contributes to 48 percent of emissions. An additional 12.7 percent relate to land-use change caused by soybean expansion for feed production (Figure 18). About 27 percent of emissions are related to the production of fertilizers, the use of machinery and transport for feed production. About 17 percent of emissions are caused by fertilization (emitting N_2O) with both synthetic fertilizers and manure.

Manure storage and processing are the second largest source of emissions, representing 27.4 percent of emissions. Most manure emissions are in the form of CH_4 (19.2 percent, predominantly from anaerobic storage systems in warm climates); the rest is in the form of N_2O (8.2 percent).

Postfarm emissions from processing and transport contribute moderately to total GHG output (5.7 percent).

On-farm energy consumption represents only 3.5 percent of emissions; however, when other energy uses in postfarm activities and feed production are added, emissions from overall energy use amount to about one-third.

FIGURE 18. Global emissions from pig supply chains, by category of emissions



Source: GLEAM.

Lowest emission intensity in backyard systems

On a global scale, the difference in emission intensities between the various production systems is not substantial. Intermediate[15] systems have the highest average emission intensities, followed by industrial and backyard. Industrial systems do, however, account for the majority of both total production and emissions (Table 8).

Backyard systems have relatively high manure emissions, caused by larger amounts of volatile

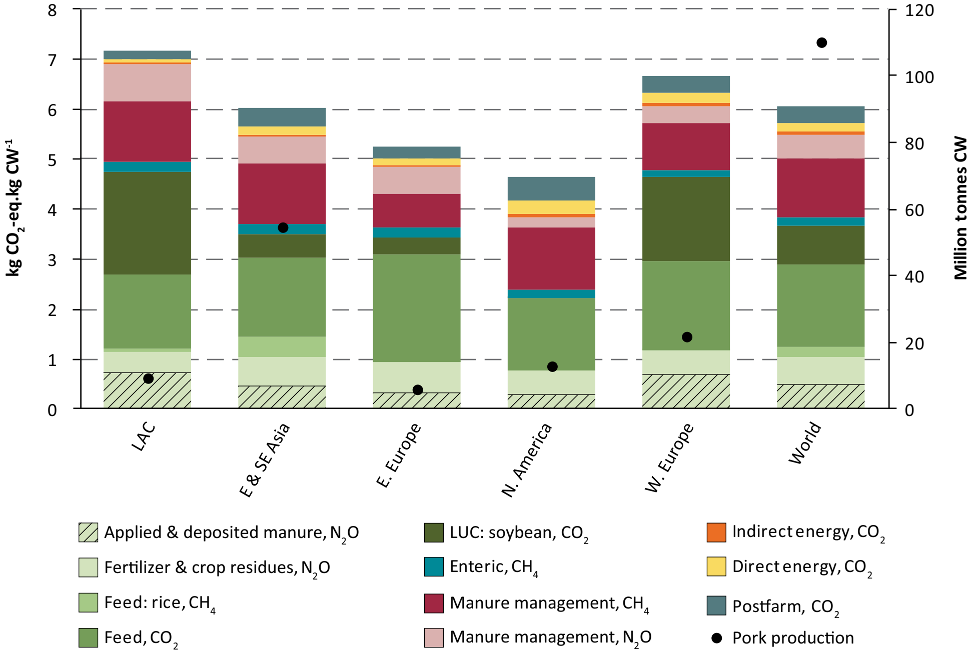
TABLE 8. Global production, emissions and emission intensity for pigs

System	**Production** *(Million tonnes CW)*	**Emissions** *(Million tonnes CO_2-eq)*	**Emission intensity** *(kg CO_2-eq/kg CW)*
Backyard	22.9	127.5	5.6
Intermediate	20.5	133.9	6.5
Industrial	66.8	406.6	6.1
Totals	**110.2**	**667.9**	**6.1**

---

[15] Farming systems defined on the basis of the animal ration and level of market integration – see Chapter 2.

FIGURE 19. Regional variation in pork production and GHG emission intensities*



* Regions accounting for less than 1 percent of world production are omitted.
Source: GLEAM.

solids (VS) and N excretion per kg of meat produced. This is caused by poor conversion[16] of low quality feed. Higher manure emissions in backyard systems are, however, offset by relatively low feed emissions, as the provision of low quality feed has low emissions.

Emission intensity in intermediate systems is generally higher than that in industrial systems. This is explained by a poorer feed conversion and a higher share of rice products in animal rations. A large share of intermediate production is located in rice-growing areas and uses rice by-products as feed material (East and Southeast Asia); the production of paddy rice emits CH_4 and has higher emission intensities than the production of other cereal products. Higher emission intensities are also linked to the storage of manure in anaerobic storage systems, leading to higher CH_4 emissions.

Feed emission intensity: driver of regional differences

Mainly due to cultural preferences, the global pig population is geographically concentrated. Ninety-five percent of production takes place in three regions: East Asia, Europe and the Americas (Figure 19). This geographical concentration close to consumption areas has been maintained over time by importing increasingly large amounts of feed.

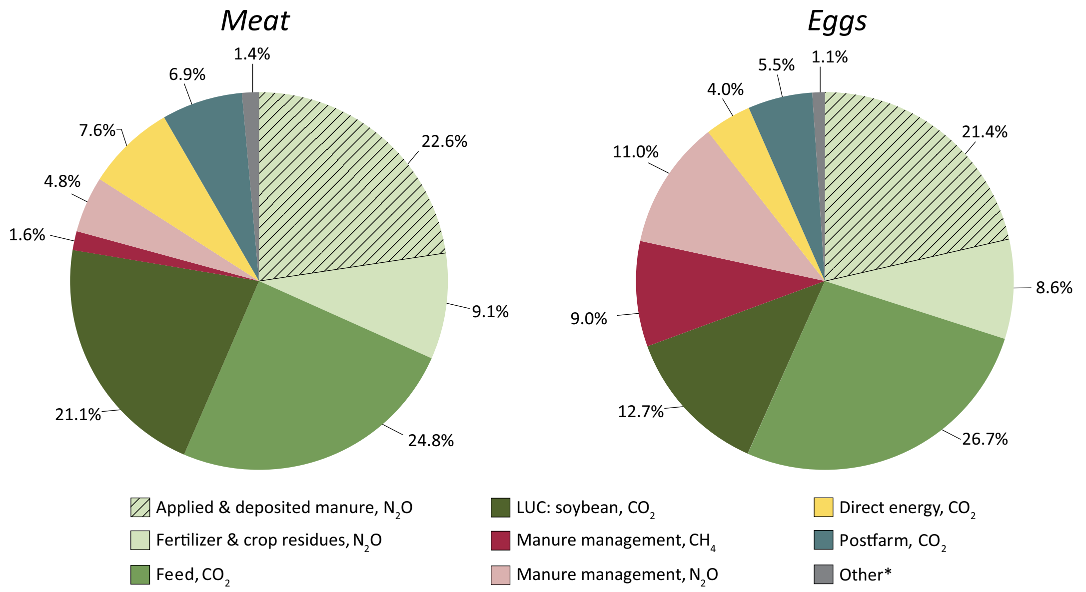
Emission intensities in the top-five producing regions range between 4.6 and 7.1 kg CO_2-eq per kg CW.

Regional differences are mostly explained by variation in feed material in the ration, animal

---

[16] The feed conversion ratio is kg of feed used per kg of meat produced. Feed conversion ratio is an indicator of feed-use efficiency and is mostly determined by feed quality, animal genetics, animal health and animal husbandry practices.

FIGURE 20. Global emissions from chicken meat and egg supply chains, by category of emissions



* Includes "Feed: rice, CH_4" and "Indirect energy, CO_2".

Source: GLEAM.

productivity and climate. In East and Southeast Asia, emissions from manure are comparatively more important, mainly due to the types of manure storage systems and climatic conditions. In Europe and Latin America and the Caribbean, high emission intensities are partly explained by feeding of soybean cake originating from areas where land-use change has occurred in the past 20 years.

4.5 CHICKEN

Globally, chicken supply chains emit GHG emissions of 606 million tonnes CO_2-eq, representing 8 percent of the sector's emissions.

Main emission source: feed production (fertilization, use of machinery and transport)

Feed production contributes about 57 percent of emissions from both chicken and egg supply chains, with an additional 21.1 percent related to the expansion of soybean cultivation in the case of meat and 12.7 percent in the case of eggs (Figure 20). Broiler rations are richer in protein and, on average, include a higher share of soybean sourced from areas where land-use conversion has taken place.

Manure emissions account for 20 percent of emissions in eggs but only 6 percent in broilers. This is due to different management systems; most of the manure from specialized meat production is managed in dry, aerobic conditions whereas that from hens is often managed in liquid systems with long-term pit storage.

Emissions from energy consumption, including direct energy, feed CO_2 and postfarm CO_2 are 35 to about 40 percent of total emissions.

Lower emission intensity for industrial systems

Three types of chicken production systems exist: backyard layers and industrial layers, producing both meat and eggs, and industrial broilers, producing only meat.[17]

---

[17] Farming systems defined on the basis of the animal ration and level of market integration (Chapter 2).

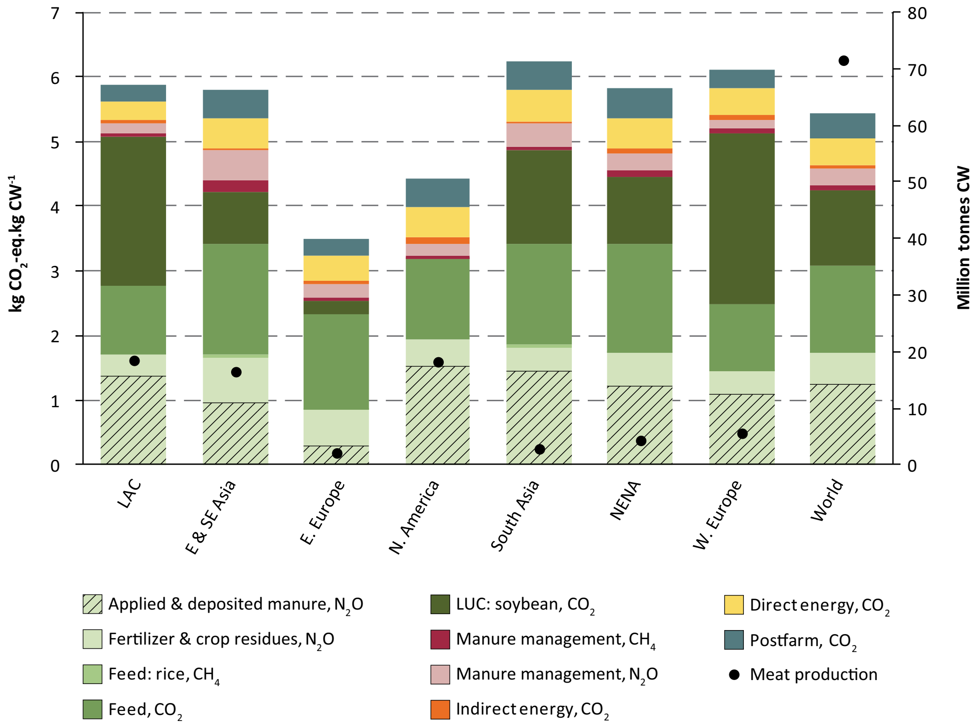
Making up over 90 percent of meat production, industrial broilers have the lowest emission intensity (Table 9). Likewise, the production of eggs from intensively-managed laying hens represents over 85 percent of output and has a lower emission intensity than the production of eggs from backyard systems. Backyard systems have higher emission intensities but they represent less than 10 percent of GHG emissions. Backyard production occurs in small units, with slow growing animals

TABLE 9. Global production, emissions and emission intensity for chickens

System	Production (Million tonnes)		Emissions (Million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Eggs	**Meat**[1]	**Eggs**	**Meat**	**Eggs**	**Meat**[1]
Backyard	8.3	2.7	35.0	17.5	4.2	6.6
Layers	49.7	4.1	182.1	28.2	3.7	6.9
Broilers		64.8		343.3		5.3
Totals	**58.0**	**71.6**	**217.0**	**389.0**	**3.7**	**5.4**

[1] Product: CW.

FIGURE 21. Regional variation in chicken meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

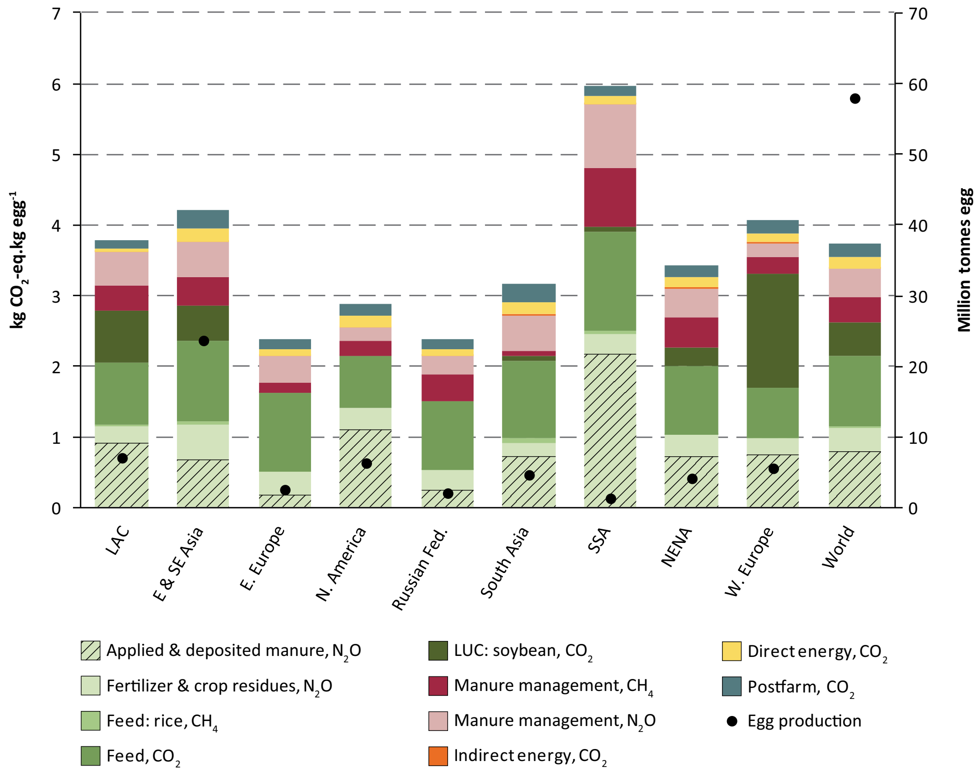
and lower egg production per hen than industrial systems.

Several factors explain the higher emission intensities of backyard systems. First, hens in backyard systems have poor feed conversion ratios because of the relatively low quality of feed and because birds spend energy scavenging for feed. Second, backyard systems have a higher proportion of unproductive animals (around 10 percent of the backyard flock, compared with 4 percent of the broiler flock and 1 percent of the layer flock). This is due to much higher death rates (largely through disease and predation) and lower fertility rates. In backyard systems, manure N_2O emission intensity is also higher due to poor feed conversion (higher rates of transformation of feed N into N_2O emissions).

Similar emission intensities in top three producing regions

Latin America and the Caribbean, North America and East and Southeast Asia dominate chicken meat production, and the latter region also dominates egg production (Figures 21 and 22). Average emission intensities are at similar levels in the top three production regions, reflecting the relative standardization of production systems and similar levels of technology. However, North American

FIGURE 22. Regional variation in chicken egg production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

systems generally have slightly lower emission intensities, as a result of good feed conversion and low emission intensity feed (about 1 kg CO_2-eq per kg feed dry matter). Higher emission intensity feed, related to sourcing feed from areas of deforestation, cause emission intensities to be higher in Western Europe and Latin America and the Caribbean. In East and Southeast Asia, poorer feed conversion ratios and more anaerobic storage of manure explain the higher emissions compared with North America.

4.6 CROSS-CUTTING OBSERVATIONS

GHG emissions and natural resource use efficiency

To the climatologist, CH_4, N_2O and CO_2 are GHGs released into the atmosphere. However, for the livestock producer, these emissions are losses of energy, nutrients and soil organic matter. Their emissions often reflect the non-efficient use of initial inputs and resources. These losses undermine the efficiency, and often the economic viability, of supply chains.

Methane

Enteric CH_4 emissions mean a loss of energy to the production system: part of the energy ingested as feed is lost in the form of CH_4 instead of being assimilated by animals and used for production. Livestock producers make substantial efforts to produce feed or bring animals to pastures; feed is typically the main production cost item in mixed and intensive systems. Wasting part of the feed energy in the form of CH_4 is, thus, not only a climate change issue but also damages production. Furthermore, feed production mobilizes natural resources, such as water, land, fossil fuels and rock phosphorus; its wastage is also detrimental to other dimensions of environmental sustainability.

Likewise, CH_4 emissions from manure are another form of energy loss that can be recovered when manure is fed into a biogas digester.

The total enteric CH_4 emissions of the sector are 2.7 gigatonnes CO_2-eq per year, or 144 million tonnes of oil equivalent per year - about the energy use of South Africa (World Bank, 2013). The total manure CH_4 emissions are 300 million tonnes CO_2-eq per year, or 16 million tonnes of oil equivalent per year - about the energy use of Ireland.

While manure CH_4 emissions could be largely recovered, enteric CH_4 losses can only be partially avoided given current knowledge. These figures nevertheless give an impression of the magnitude of the loss. This has not escaped producers and improving the energy efficiency of feed is now the main argument for the use of dietary lipids, with reduction of enteric emissions being seen as a co-benefit.

Nitrous oxide

Nitrous oxide emissions, either direct or indirect from NH_3 losses, are both forms of N loss. Nitrogen is a macronutrient of plants, key to improving yield. Supplying reactive N to plants (in the form of manure or synthetic fertilizers) and preserving N in soils through agronomic practices come at significant cost to producers. They also involve high levels of fossil fuel consumption.

Nitrous oxide emissions from manure storage and processing, and from the application of manure on crops and pasture, represent about 3 million tonnes of N. This is about 15 percent of the mineral N fertilizer use that can be ascribed to feed (crop and pasture) production for the livestock sector (FAO, 2006).

Additional losses of N take place in the form of NH_3 and NO_x emissions into the atmosphere and leaching of soluble forms of N into ground water. While the latter is not quantified in this assessment, it is estimated that NH_3 and NO_x emissions represent significant N losses: NH_3 and NO_x emissions from the application of manure on crops and pasture, and from manure storage and processing are estimated to represent 26 million tonnes of N and 17 million tonnes of N, respectively. While not contributing to climate change, these emissions pose other environmental problems such as the acidification and eutrophication of natural habitats.

Carbon dioxide

Carbon dioxide emissions are related to fossil fuel consumption and land use activities.

On-site energy consumption is generally marginal in production cost structure but can be high in some cases, for example in intensive milk production systems. Energy-use efficiency can be improved by the adoption of better management practices (e.g. maintenance of equipment and operating time) and energy saving devices (e.g. heat pumps and thermal isolation), reducing both emissions and energy costs for farms and processing plants.

Soil organic matter, the primary form of carbon in soils, serves several functions. From an agricultural standpoint, it is important as a "revolving nutrient fund", as well as an agent to improve soil structure, maintain tilth and minimize erosion. (FAO, 2005). When soil organic matter is lost, either through inadequate agricultural practices in feed production or pasture degradation, the productivity of land decreases over time.

Important but poorly understood contribution of land use and land-use change

Land-use change is estimated to contribute 9.2 percent to the sector's overall GHG emissions (6 percent from pasture expansion, with the rest from feed crop expansion).

While relatively limited when averaged globally and over all species, land-use change emissions are significantly higher for some specific supply chains and regions. They amount to 15 percent for beef production (linked to pasture expansion) and 21 percent in chicken meat production (linked to soybean expansion). Because soybean is largely traded internationally, emissions from soybean expansion in Latin America and the Caribbean are actually attributed to production units around the world using soybean cakes imported from that region. This is different for pasture expansion, where induced emissions are entirely attributed to local production. As a result, land-use change emissions amount to 24 kg CO_2-eq per kg CW of beef in Latin America and the Caribbean, 33 percent of total emissions.

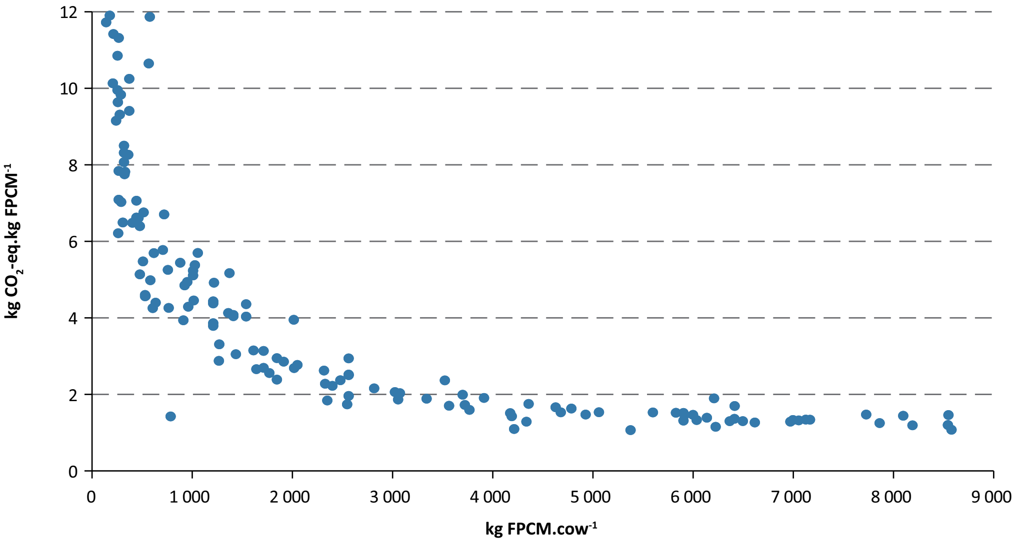
The drivers of land-use changes, and the attribution of the related emissions, as well as the methods available to compute land-use change emissions, are still highly debated.

As noted above, this report follows IPCC guidelines (IPCC, 2006) and three alternative approaches were tested in the context of a partial sensitivity analysis of the results. Land-use change emissions computed for Argentina ranged between 0.3 and 4.2 kg CO_2-eq per kg soybean cake and between 3.0 and 7.7 kg CO_2-eq per kg soybean cake produced in Brazil (the values resulting from the IPCC method and used in this assessment are 0.9 and 7.7 for Argentina and Brazil, respectively).

This analysis could not estimate changes in soil carbon stocks under constant land use management practices because of the lack of global databases and models. The effect of this simplification was, however, tested in the case of the European Union, where data are available (Soussana *et al.*, 2010). Permanent grasslands in the European Union represent a sink of 3.1 ± 18.8 million tonnes C per year (or 11.4 ± 69.0 million tonnes CO_2-eq per year), equivalent to 3 percent (± 18 percent) of the yearly emissions of the ruminant sector in the European Union. Net sequestration/emission of C in permanent pasture under stable management practices may thus be significant but the uncertainty about calculation parameters is such that it cannot be said with certainty whether permanent pastures are a net sink or source of emissions. The relative importance of land use emissions may even be higher in other parts of the world where permanent pastures are much more common and C sequestration higher (e.g. Africa, Latin America and the Caribbean).

Better understanding of soil organic carbon dynamics in grasslands and the development of methods and models to monitor and predict changes in C stocks are, however, required for the inclusion of this emission category in global assessments (FAO, 2013b).

FIGURE 23. Relationship between productivity and emission intensity of milk (country averages)



Source: Gerber *et al.*, 2011.

Correlation between productivity and emission intensities

Ruminants

In ruminant production, there is a strong relationship between productivity and emission intensity – up to a relatively high level of productivity, emission intensity decreases as yield increases.

Gerber *et al.* (2011) demonstrate this relationship for milk, illustrating how differences in productivity explain the variation in emission intensity between countries. Figure 23 highlights the strong correlation between output per cow and emission intensity per unit of product produced.

High-yielding animals producing more milk per lactation generally exhibit lower emission intensities for three main reasons. First, because emissions are spread over more units of milk, thus diluting emissions relative to the maintenance requirements of the animals. Second, because productivity gains are often achieved through improved practices and technologies which also contribute to emissions reduction, such as high quality feed and high performance animal genetics. And third, because productivity gains are generally achieved through herd management, animal health and husbandry practices that increase the proportion of resources utilized for productive purposes rather than simply being used to maintain the animals. This results in a reduced standing biomass (both in lactating and in replacement herds) per unit of milk produced. The impact per unit of milk is therefore reduced at both the individual cow and dairy herd level.

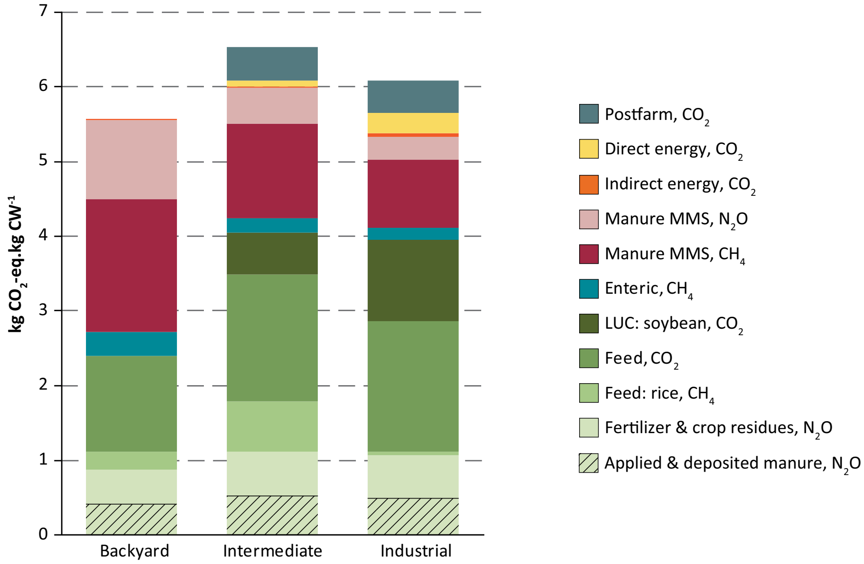
A large potential to mitigate emissions thus exists in low-yield ruminant production systems. Improved productivity at the animal and herd level can lead to a reduction of emission intensities while at the same time increasing milk output.

Monogastric species

The relation between productivity gains and emissions shows a different pattern for monogastric species.

In pig production, the relation between intensification and emission intensity follows a slight

FIGURE 24. Global emission intensity from pig supply chains, by main production systems



Source: GLEAM.

inverse U-shape relation (Figure 24). At the low end of the productivity spectrum, in backyard systems, emission intensity is low. The feed ration is mostly made up of wastes and by-products with low emission intensity which compensate for the high manure emissions per unit of product due to poor nutrient balancing and low digestibility. In contrast, industrial systems characterized by high productivity have slightly higher emission intensity on a global average than backyard systems. They have optimized feed conversion ratios but are penalized by the relatively high emission intensity of the feed materials they rely on (driven up by energy consumption and land-use change). Highest emission intensity is found among intermediate systems, which combine relatively high feed emission intensity with moderate feed conversion ratios. The diversity of manure emission intensities, not related to farming systems but rather to local manure management practices and climate, further blurs the relation between productivity and emission intensity.

The possibility to increase backyard production is limited by the availability of the feed materials these systems rely on. There is, however, a strong mitigation potential in upgrading intermediate systems to improve herd efficiency. Furthermore, independent of the production system, manure storage, processing and application practices can be altered to mitigate emissions.

For chicken, the broiler and layer systems display lower levels of emission intensity than backyard systems for meat and eggs. Feed represents about 75 percent of emissions in intensive systems, so the type and origin of feed materials explain most of the emission intensity variability within these systems.