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## 5. Discussion

This section discusses the key drivers of variation in emissions from major processes in the ruminant supply chain that contribute significantly to the carbon footprint of ruminant species, highlighting differences among species and world regions. The section also discusses some of the parameters and assumptions that could strongly influence the results.

### 5.1 METHANE EMISSIONS FROM ENTERIC FERMENTATION

Regardless of the species, the largest source of GHG emissions in ruminant production is CH<sub>4</sub>, with more than 90 percent originating from enteric fermentation and the rest from manure. Globally, enteric fermentation from cattle, buffalo, and small ruminants contributes 2 448 million tonnes CO<sub>2</sub>-eq, of which 76 percent is emitted by cattle and 14 percent and 10 percent by buffalo and small ruminants, respectively. The production of enteric CH<sub>4</sub> from ruminants is mainly affected by feed intake and feed quality which, in turn, defines the total energy and nutrient intake and consequently animal performance.

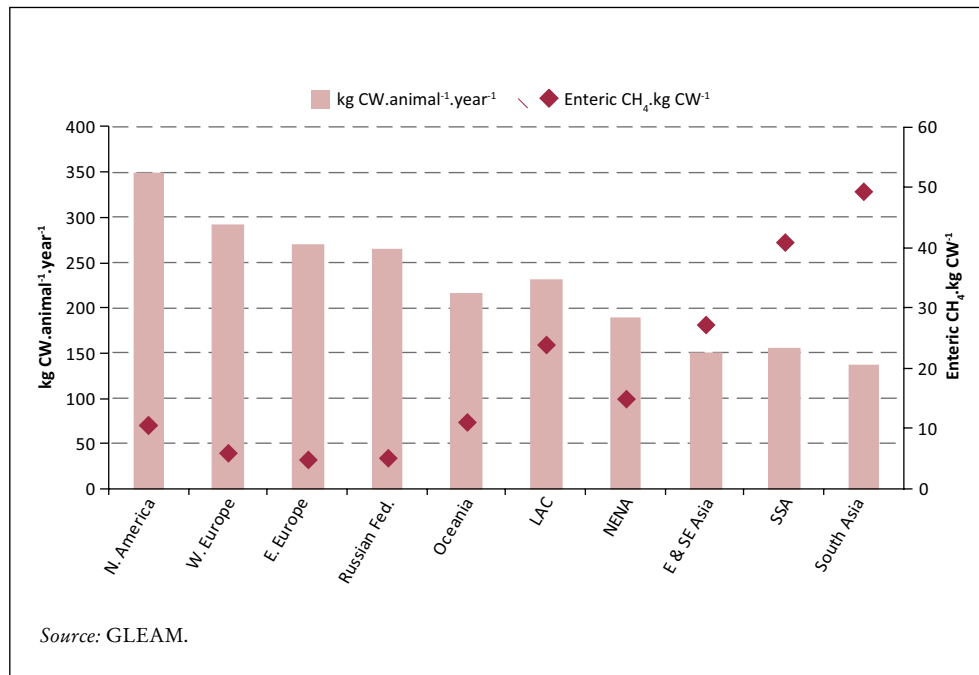
Many of these factors are interrelated, some of which affect net emissions and others emission intensity. At animal level, net emissions are influenced by feed intake and digestibility, while emission intensity is a function of net emissions, yield per animal, health and genetics. At herd level, factors affecting net emissions are similar to those cited above, while emission intensity is determined by issues such as reproductive and mortality rates, herd structure, management, etc. The following sections discuss some of the important factors that drive the variation in enteric CH<sub>4</sub>.

*Productivity.* Productivity is an important factor in explaining the variation of emissions among different production typologies. Studies show a close correlation between carbon footprint and yield per animal (Capper *et al.*, 2008; Gerber *et al.*, 2011; Cederberg and Flysjo, 2004), highlighting the trend of decreasing emission intensity with increasing productivity. Regions and production systems with greater productivity have lower emission intensity partly because high yields shift the distribution of feed towards less feed for maintenance functions and more for production. As productivity per animal increases, CH<sub>4</sub> emissions per animal are typically higher because of higher feed intake. However, as the productivity of each animal increases, the farmer can reduce the herd size to produce the same amount of output.

Figure 25a illustrates the differences in emission efficiency among the regions; the main reason for the differences is to be found in low productivity of the herd, which is in turn caused by low fertility, high mortality rates, low growth rates and low feed digestibility (see Appendix B). Gerber *et al.* (2011) have demonstrated the relationship between the carbon footprint of dairy cattle milk and productivity, and a similar trend has been established for small ruminants (Figure 25b). Lower-producing dairy animals tend to lose more feed energy as CH<sub>4</sub> per unit of milk produced. The benefits of improving animal productivity on CH<sub>4</sub> emissions results from the *dilution effect* of fixed maintenance where increasing productivity

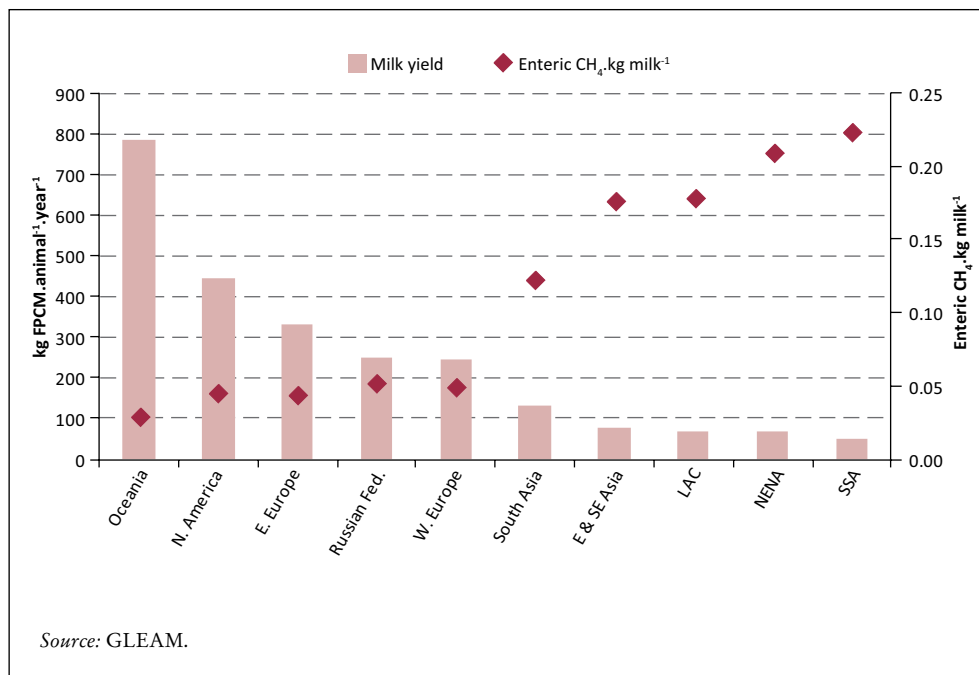
**Figure 25a.**

Regional variation in productivity and CH<sub>4</sub> emissions from enteric fermentation for beef herds



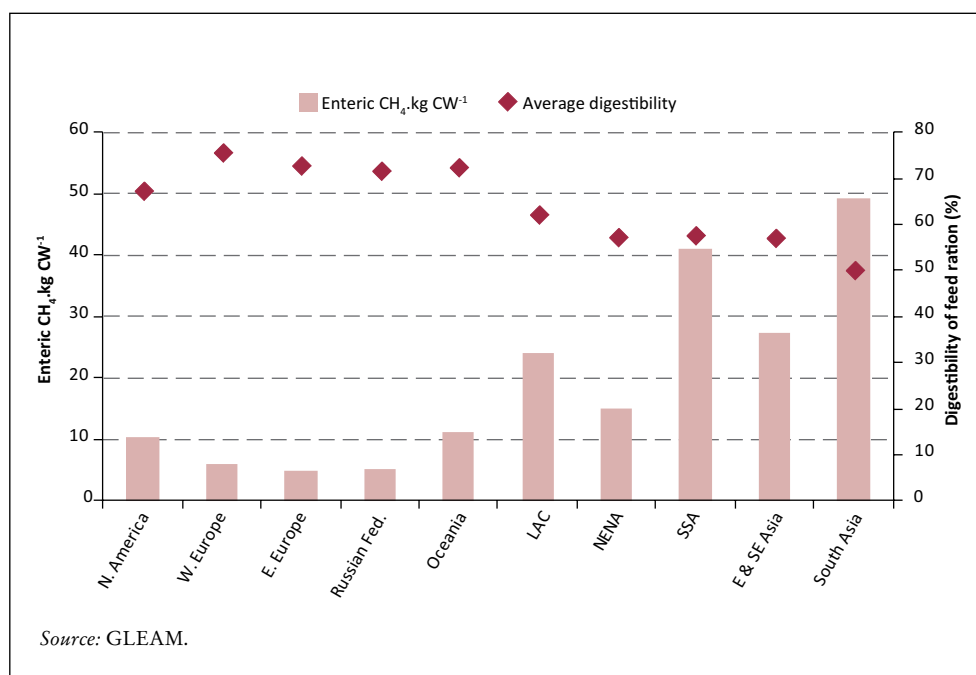
**Figure 25b.**

Regional variation in productivity and CH<sub>4</sub> emissions from enteric fermentation for dairy goats



**Figure 26.**

Regional variation in digestibility of the feed ration and CH<sub>4</sub> emissions from enteric fermentation for beef cattle



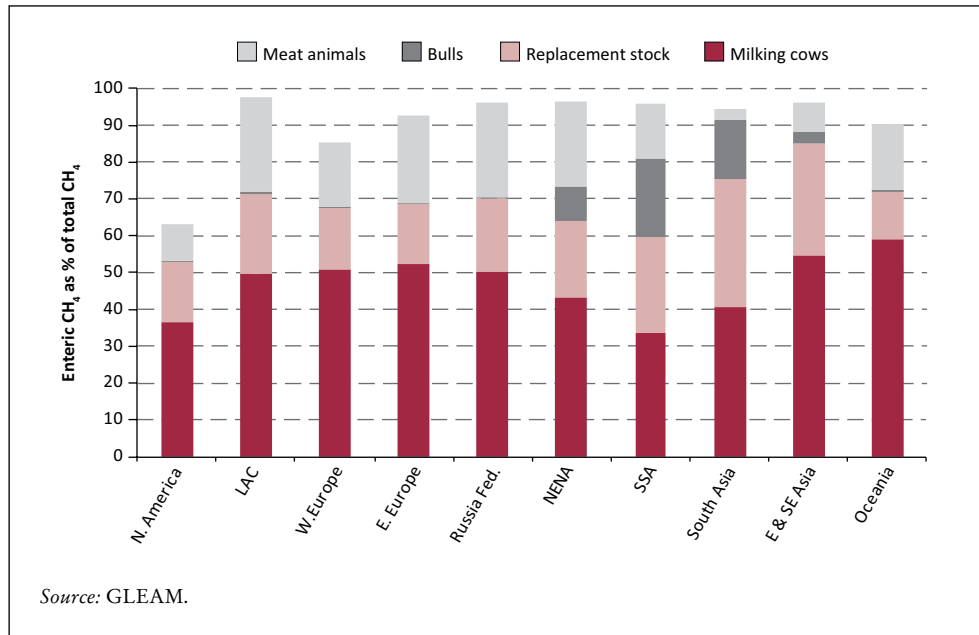
decreases the amount of CH<sub>4</sub> emitted per unit of product because emissions that arise from energy requirements for maintenance are spread over a larger output.

*Feed digestibility.* Enteric CH<sub>4</sub> emissions are also determined by feed properties, particularly the digestibility of the feed ration. The energy content of feed also affects the amount of CH<sub>4</sub> produced in enteric fermentation, with lower quality of feed causing greater CH<sub>4</sub> emissions (Figure 26). Regions with higher feed digestibility also often have higher proportion of high quality roughages, feed crops and concentrates in their diets, often an indication of higher quality ration (see Tables B7-B12 in Appendix B). As the digestibility of the feed ration increases, the amount of energy available to the animal also increases per kg of feed intake. With an increase in per kg of feed intake, more production can be realized and therefore CH<sub>4</sub> produced per kg of production decreases.

*Herd structure.* A key factor that explains the variations in emissions across regions is the structure of the herd. Breeding populations are required to maintain the herd and thus reproductive performance is important because the cost of maintaining and replacing breeding stock also affects feed efficiency. In regions where the composition of the herd is skewed towards higher number of animals in the breeding herd, overall CH<sub>4</sub> emissions and emission intensities are most likely high because demand is placed on feed (with a large share of feed energy used for maintenance requirements rather than production). Figures 27a and 27b present the percentage contribution of enteric fermentation to total CH<sub>4</sub> from beef and dairy cattle by cohort groups. A breakdown of enteric CH<sub>4</sub> emissions by source not only illus-

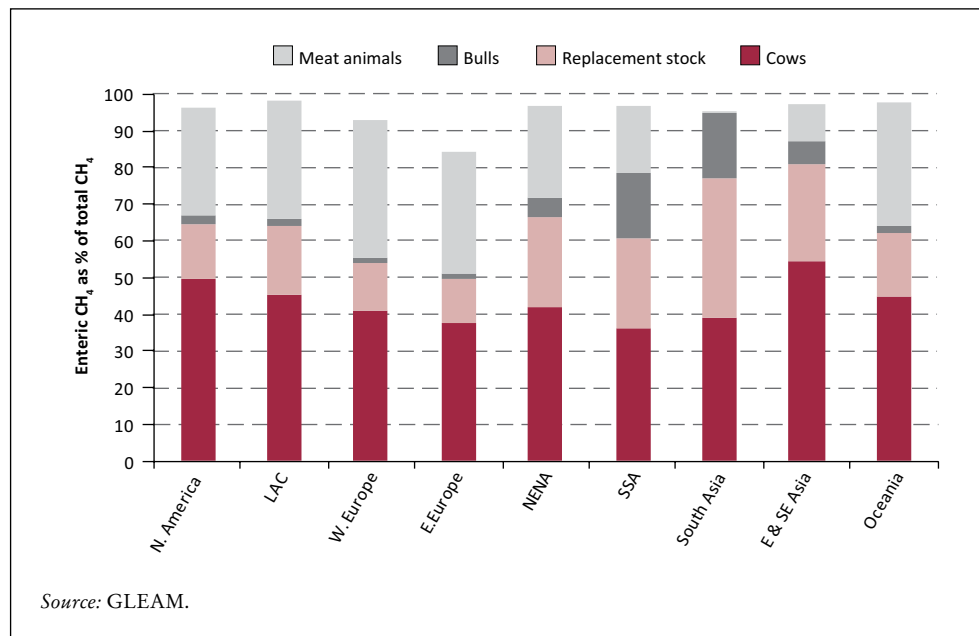
**Figure 27a.**

Regional variation in the relative contribution of animal cohorts to enteric CH<sub>4</sub> – dairy herds



**Figure 27b.**

Regional variation in the relative contribution of animal cohorts to enteric CH<sub>4</sub> – beef herds



trates the key hotspots of CH<sub>4</sub> emissions but also explains the variation in emission intensity among regions.

Figure 27a illustrates regional differences in dairy herd structure. Non-milk producing animals in dairy herds typically include replacement animals and adult bulls; these categories of animals are significant contributors to the CH<sub>4</sub> costs of producing milk at the herd level. While CH<sub>4</sub> from enteric fermentation is the main contributor to GHG emissions in all regions, there are major differences in the sources of emissions. Generally, in regions such as sub-Saharan Africa and South Asia, a large proportion of enteric CH<sub>4</sub> (approximately 50 percent) originates from the breeding herd and replacement stock, in combination with a low milk production per cow; hence a large proportion of the resources are used for other purposes such as maintenance and draught power. In these regions, non-milk productive functions contribute substantially to the maintenance energy requirement of the herd because they represent a significant use of energy and resources with no production of usable edible product produced.

In contrast, in Western and Eastern Europe, Oceania, Russian Federation, and East & Southeast Asia, more than 50 percent of the enteric CH<sub>4</sub> is from milking cows, pointing to increased use of feed for productivity purposes and thus explaining the lower emission intensity in these regions.

In typical beef systems, mature cows are kept for only calf production and have to be maintained along with bulls and replacement stock, which increases emissions per unit of carcass produced. The breeding stock in beef production systems (cows, replacement stock and bulls) accounts for 55-99 percent of the total feed requirements of the beef herd, and 52-97 percent of total CH<sub>4</sub> emissions. A higher slaughter generation (meat animals for fattening) is an indication of higher reproductive performance of the breeding herd and specialization of production such as in Oceania, Europe, North America and Latin America.

For small ruminants, there is no systematic difference in herd structure among regions, largely attributable to the greater fecundity in small ruminants and faster growth rates compared with cattle. The absence of draught power also reduces the gap among regions.

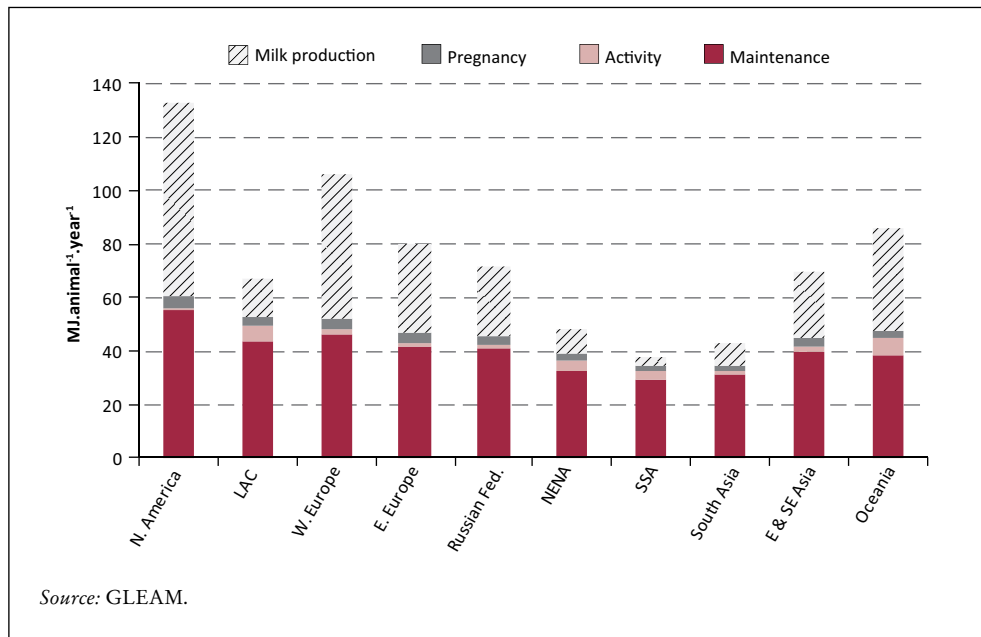
*Energy partitioning and utilization.* Methane is produced in the process of feed energy utilization within the animal. Changes in the efficiency of feed energy utilization therefore influence CH<sub>4</sub> emissions of animals. The efficiency of feed energy utilization depends on the type of animal, the type or quality and quantity of feed, environmental conditions, etc.

The way energy is partitioned between the different body functions (maintenance and production) also helps explain the variation in emission intensity. All animals have a necessary maintenance requirement that must be met and results in no production, yet are still associated with CH<sub>4</sub> losses. Ruminants partition feed energy over the following functions: maintenance, growth, lactation and reproduction; and in all cases, maintenance has priority. In situations where feed quality is low, relatively less energy is left for (re)productive functions.

The proportion of feed energy expended on animal maintenance as opposed to productive purposes is higher in those regions with low production rates at both animal (Figures 28a, 28b and 28c) and herd (Figures 29a and 29b) level. Figures 28a, 28b and 28c present the partitioning of energy requirements across the world regions for

**Figure 28a.**

Regional comparison of energy partitioning across the different functions in milking cows



**Figure 28b.**

Regional comparison of energy partitioning across the different functions in milking ewes

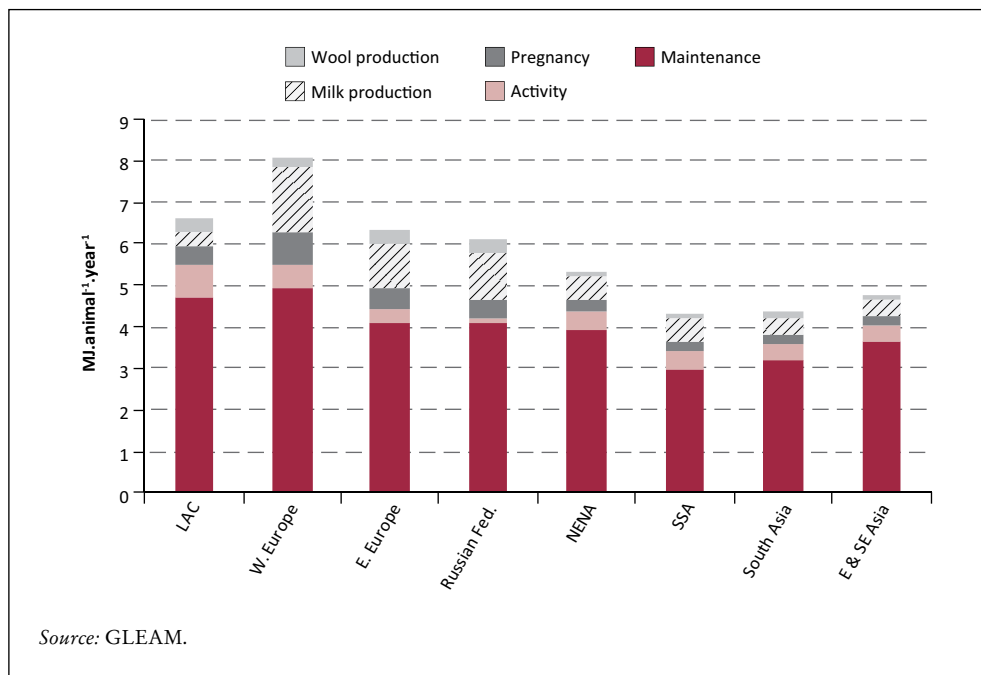


Figure 28c.

Regional comparison of energy partitioning across the different functions in adult female goats

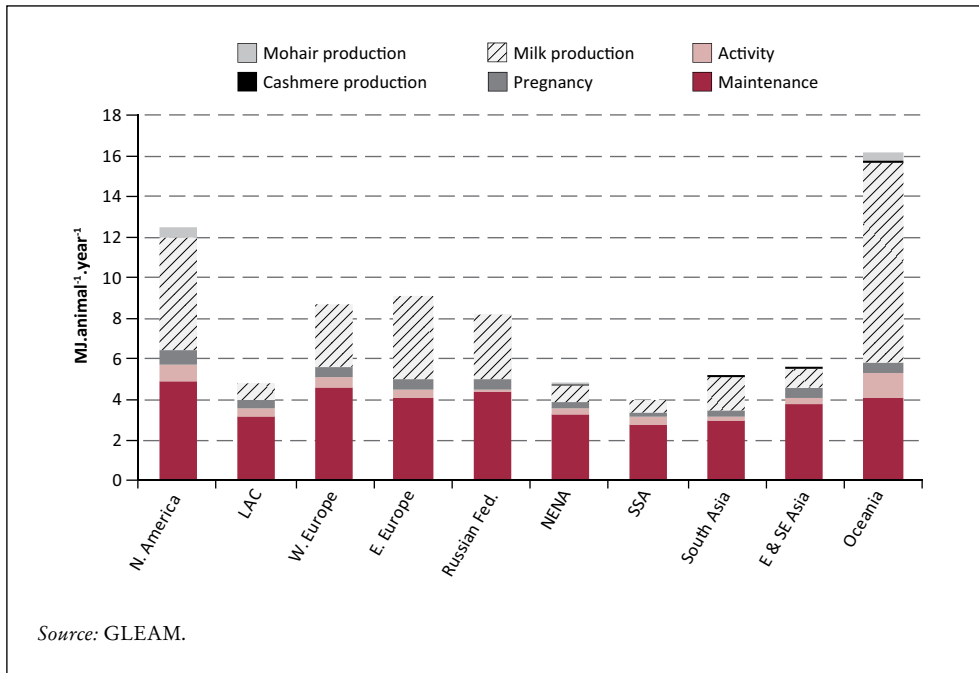
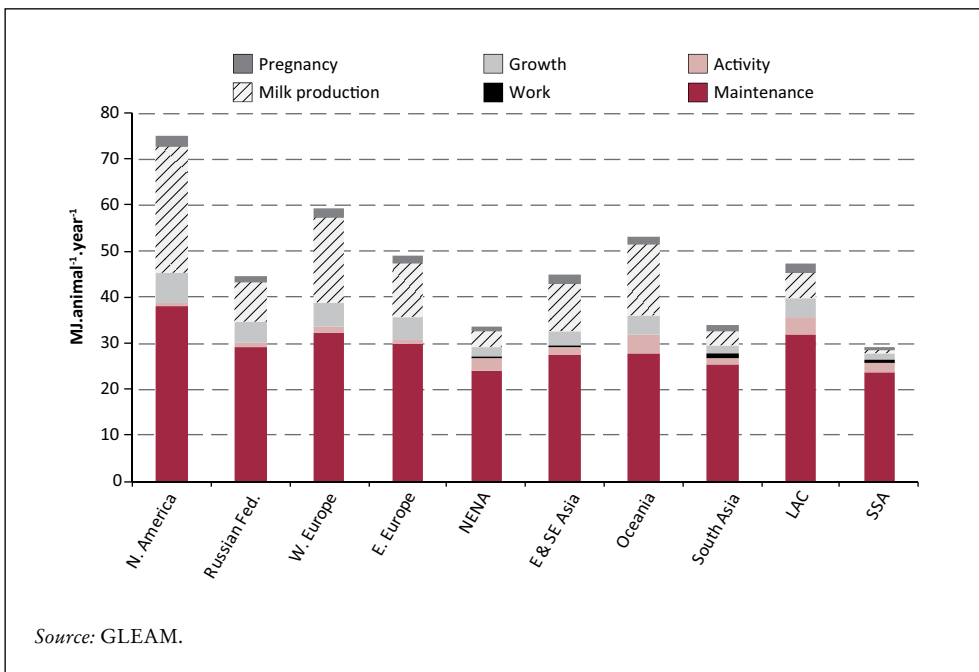


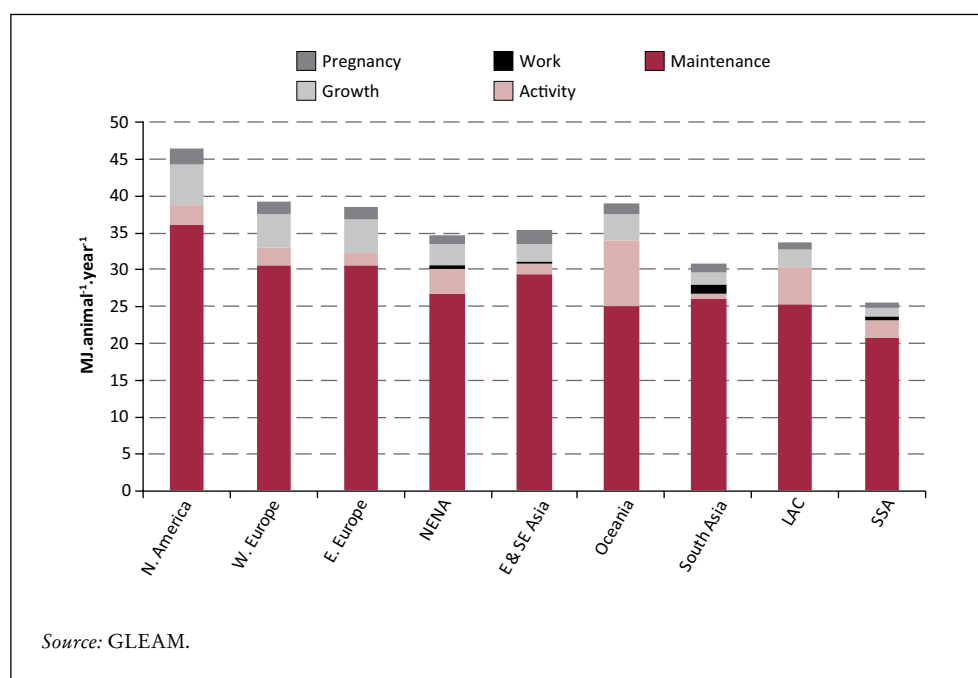
Figure 29a.

Regional comparison of energy partitioning across the different functions in dairy cattle herds



**Figure 29b.**

Regional comparison of energy partitioning across the different functions in beef cattle herds



milk production from cattle and small ruminants. For example, in dairy cattle in sub-Saharan Africa, NENA, South Asia and Latin America & Caribbean, energy intake is low and, as a consequence, a large proportion of energy is used for maintenance (78 percent, 67 percent, 72 percent and 67 percent, respectively) while in industrialized regions a greater share is used for lactation as illustrated in Figure 28a.

*Key assumptions and uncertainties.* Given that enteric CH<sub>4</sub> is the single largest contributor to GHG emissions in ruminant production, the method and EFs used for calculating CH<sub>4</sub> from enteric fermentation are fundamental for assessing the carbon footprint of ruminant species. Enteric CH<sub>4</sub> emissions were calculated on the basis of the IPCC Tier 2 approach (IPCC, 2006 Volume 4, Chapter 10), where CH<sub>4</sub> emissions are estimated for different animal categories in the herd as a direct function of gross energy requirements and the CH<sub>4</sub> conversion rate (see Appendix A).

Uncertainties in Tier 2 estimates may be associated with population data, production practices and performance data, including feeding strategy. The use of Tier 2 methodology requires a detailed characterization of the livestock population. Uncertainty in livestock population depends on the extent and reliability of livestock population data. In addition, different accounting conventions for animals, particularly for those that do not live for a whole year such as small ruminants, also add to the uncertainty. Furthermore, total animal numbers are often reported as single values and composition of the different cohorts in herds is not reported separately, making it difficult to characterize these populations.

To overcome this problem in this study, the population was modelled on the basis of a number of herd parameters (see Tables B2-B6 in Appendix B) obtained through



data collection and literature reviews. In addition, there is a scarcity of published data on production practices, dietary information, dry matter intake (DMI) and animal performance, which may contribute to the uncertainty of model prediction. While the feed rations used in this assessment represent the general diet characteristics within each region/country, there may be some uncertainty associated with local variation in feed as well as management practices which may also affect the ultimate energy requirements of the animal and consequently CH<sub>4</sub> emissions.

## 5.2 EMISSIONS FROM FEED PRODUCTION

Feed production constitutes 36 percent, 36 percent and 28 percent of the total emissions for cattle, small ruminants and buffalo, respectively. Emissions related to feed are a function of several factors:

- *Feed ration* (i.e. specific feed materials in the ration). Feed materials have different emission intensities because they are produced in different modes. Generally, rations with higher proportions of by-products and concentrates tend to have higher emission intensities. The regional average feed composition for ruminant species is presented in Appendix B.
- *Mode of feed production*: whether feed production utilizes additional production inputs such as fertilizers, pesticides, etc.
- *Source of feed materials*: reliance on off-farm produced feed or imported feed also has an impact on the emission intensity of the feed-crop.
- *Feed associated with LUC adds additional emissions* (see Appendix C on land use and LUC).

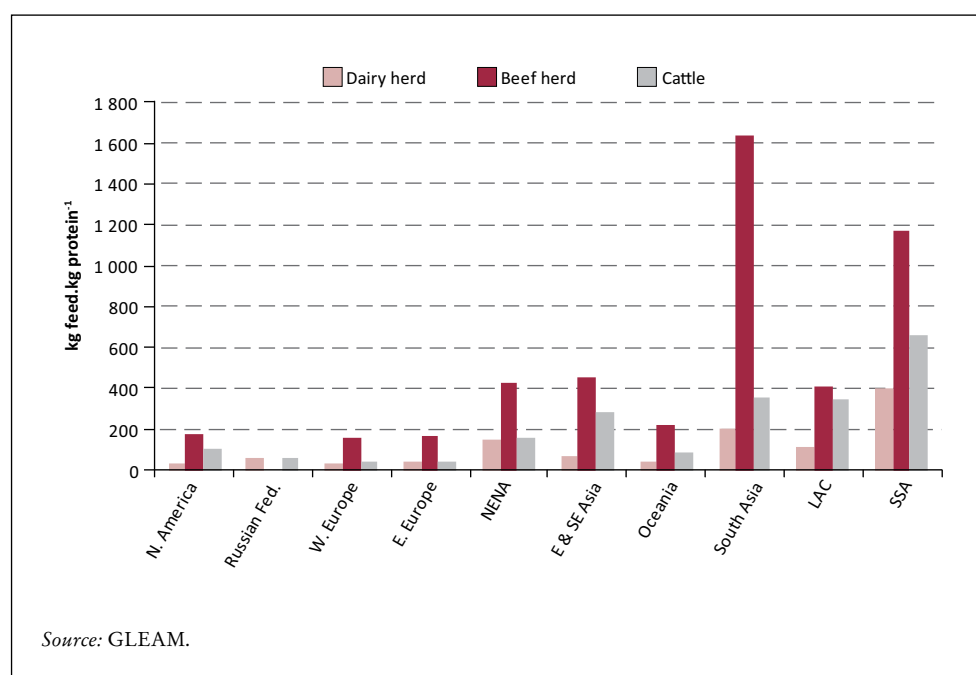
Feed conversion is a measure of the efficiency with which animals convert feed into a gain in body weight or usable product. There are large differences in feed conversions among the various species. The feed conversion of ruminants is usually much lower than that of non-ruminants. High feed consumption per kilogram of protein is partly due to the biological time-lag that it takes for an animal to reach slaughter weight or to calve, and partly due to the amount of feed required by the breeding stock. For example, a suckler cow gives birth to one calf per year. This calf needs between one to four years to reach slaughter weight, depending on production conditions.

Feed conversion also varies among regions for the following reasons:

- animals need a certain amount of feed as their maintenance energy requirement;
- the proportion of breeding stock in the herd – these animals also need to be fed even though they are unproductive;
- regions that rely on dairy herds for their meat supply have a higher feed conversion ratio (FCR) because they produce two products; and
- the characteristics of the production system are also important; aspects such as mortality rates (when animals die or are culled before they reach slaughter weight or first lactation represents significant loss of feed resources), growth rates, age at first calving (lower age at first calving reduces feed requirements during the growth period), etc. influence feed requirements.

Figure 30 compares feed utilization efficiency for dairy and beef herds by region expressed as DMI per unit of protein produced. Increased animal performance due to improved genetics, nutrition and management results in improved feed use efficiency. This improvement is largely a function of dilution of the growing animal's

**Figure 30.**  
Regional variation in feed conversion ratio for the cattle sector



maintenance requirements in respect to their total feed requirements. A higher proportion of feed is used for growth and production while a lower proportion for maintenance.

In cattle production, emissions of  $N_2O$  are the predominant emissions in feed production in all regions (Figure 31a). This trend is similar for small ruminants, with the exception of North America and Western Europe where both  $N_2O$  and  $CO_2$  emissions contribute equal shares of emissions, while in Eastern Europe  $CO_2$  emissions per kg of feed intake are higher (Figure 31b). In cattle production, South Asia has the lowest emission intensity per kg of DMI, a consequence of the large proportion of crop residues used as feed material which make up more than 60 per cent of the feed ration (see Tables B7 and B8, Appendix B).

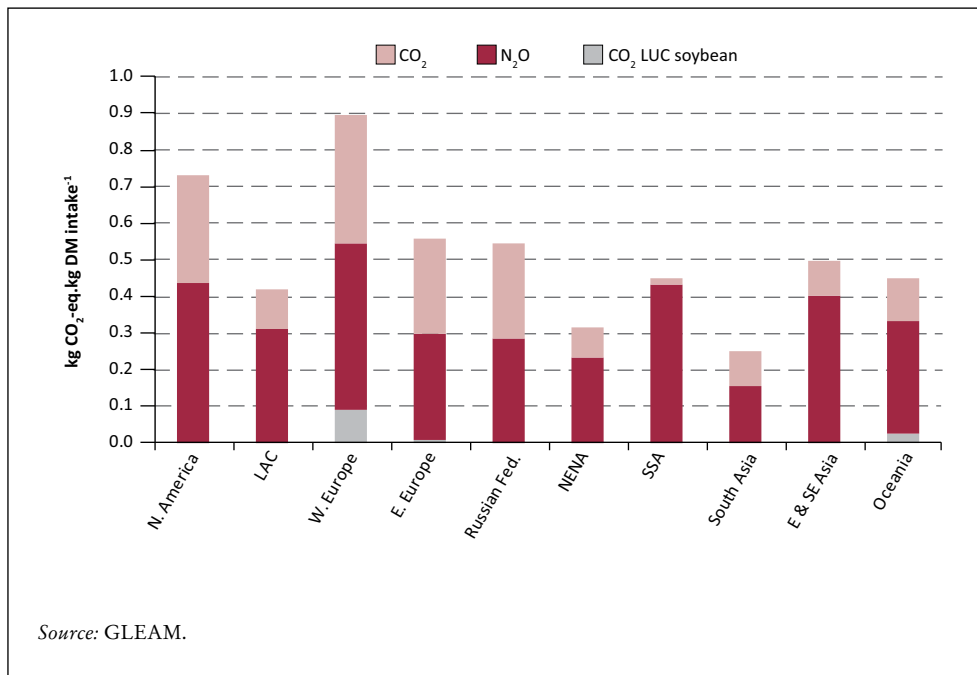
### 5.2.1 Nitrous oxide from feed production

Nitrous oxide emissions associated with feed production are related to the use of N fertilizer in feed production,  $N_2O$  arising from the deposition of manure on grazing land, N from crop residues returned to soils, and  $N_2O$  emissions from the application of manure to land.

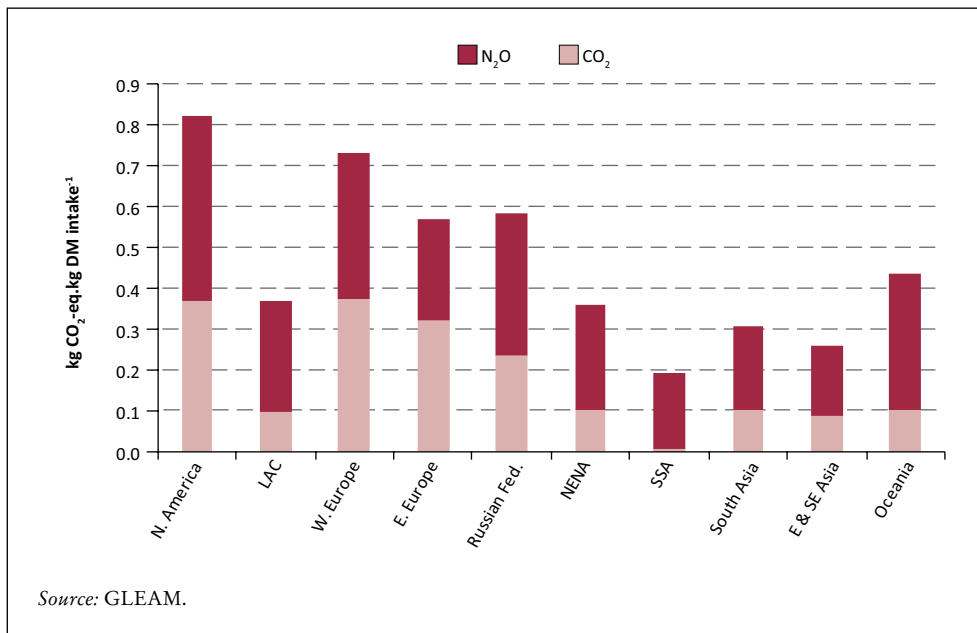
Manure is an important source of  $N_2O$  emissions, and in ruminant production systems manure  $N_2O$  emissions from feed production result from manure deposited directly by animals on pasture as well as the manure applied to crops. In the latter case, manure applied to land comprises of all manure that is handled in MMS and includes manure from other species.

$N_2O$  emissions may arise directly as a result of application of the N sources mentioned above. In addition to the direct emissions, N inputs may also lead to indirect formation of  $N_2O$  after leaching or following gaseous losses and deposition of ammonia and nitric oxides. In ruminant production, the main source of  $N_2O$

**Figure 31a.**  
Regional difference in N<sub>2</sub>O and CO<sub>2</sub> emission intensity of feed – cattle



**Figure 31b.**  
Regional difference in N<sub>2</sub>O and CO<sub>2</sub> emission intensity of feed – small ruminants



emissions is manure, with most of the N<sub>2</sub>O losses originating from manure that has been deposited or applied.

Figures 32a and 32b present emission intensities for feed for cattle and small ruminants illustrated by region and source of N. In all developing regions, as well as in Oceania and Western Europe, the predominant source of N<sub>2</sub>O emissions associated with both cattle and small ruminant species is manure deposited during grazing and applied manure. On the contrary, N<sub>2</sub>O emissions from fertilizer application (N fertilizer) are important in North America and to a lesser extent in Europe.

The composition of the feed ration is a key factor in explaining the variation in N<sub>2</sub>O emissions because of the vast differences in feed production (see Tables B7-B12, Appendix B, for detailed feed basket composition). For example, in regions where fresh grass is the dominant source of feed, N inputs within the system are more likely to come from manure. However, in intensive grazing systems, N<sub>2</sub>O emissions are also likely to be important due to the use of N chemical fertilizer to maintain the productivity of pastures. High N<sub>2</sub>O emissions from grazing in regions such as Latin America and the Caribbean and sub-Saharan Africa are mainly a consequence of the importance of pasture as a source of feed. For small ruminants, N<sub>2</sub>O emissions from grazing are concentrated in Oceania, sub-Saharan Africa and Latin America.

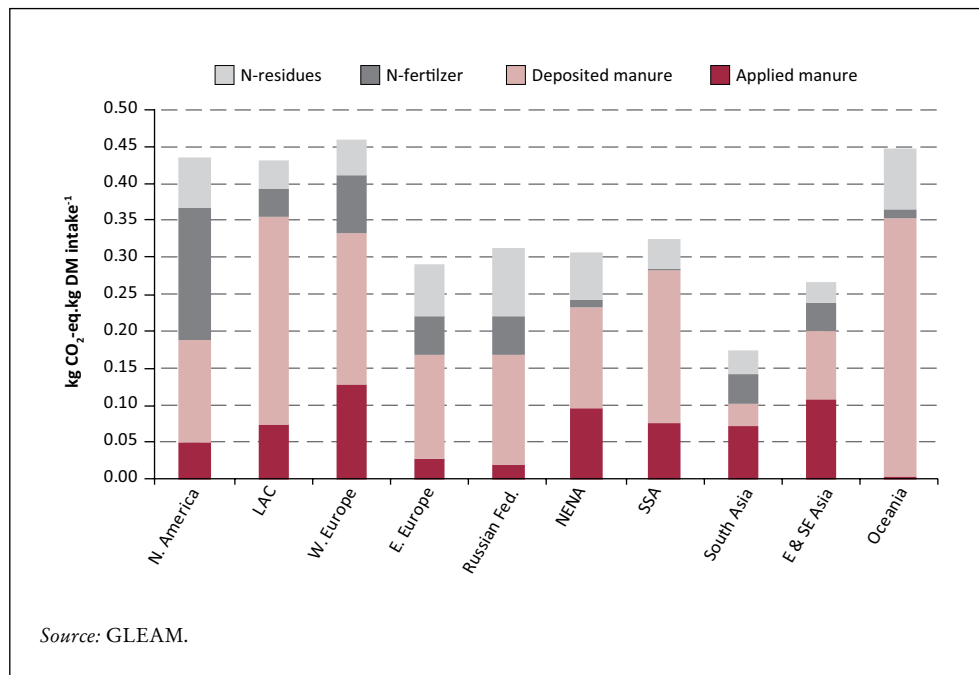
Regions with a high proportion of concentrates in the feed basket (and to a certain extent hay produced off-farm and silage), are likely to have a larger proportion of N<sub>2</sub>O emissions from nitrogen fertilizer. N<sub>2</sub>O emissions from fertilizer use in feed production for cattle are significant in North America, and Europe due to the high N application rates on feed in these regions. In the rest of the world's regions, use of fertilizer is negligible; in these regions, N nutrients for feed crop production are largely met from manure. It is also important to note that fertilizer input for other crops can be high in these regions as a consequence of large differences in crop yield and N fertilizer use. N<sub>2</sub>O emissions from feed production can be very different for the same feed crop in grown in different locations.

*Assumptions and uncertainties.* Determining N<sub>2</sub>O emissions is often difficult due to the high spatial and temporal variability of N<sub>2</sub>O fluxes. N<sub>2</sub>O emissions related to feed are based on the IPCC guidelines (2006) following the Tier 1 protocol, and in the modelling of N<sub>2</sub>O emissions we adopted a simplified approach that took into account only N additions from fertilizer, manure and biomass on pasture and feed crops. However, other factors also drive N<sub>2</sub>O emissions, such as local climatic conditions and soil properties (including water and N dynamics, soil type and structure), and management practices (tillage, irrigation, N application techniques, etc.), thus rendering the quantification of N<sub>2</sub>O emissions challenging, which also implies that the results may contain substantial uncertainty.

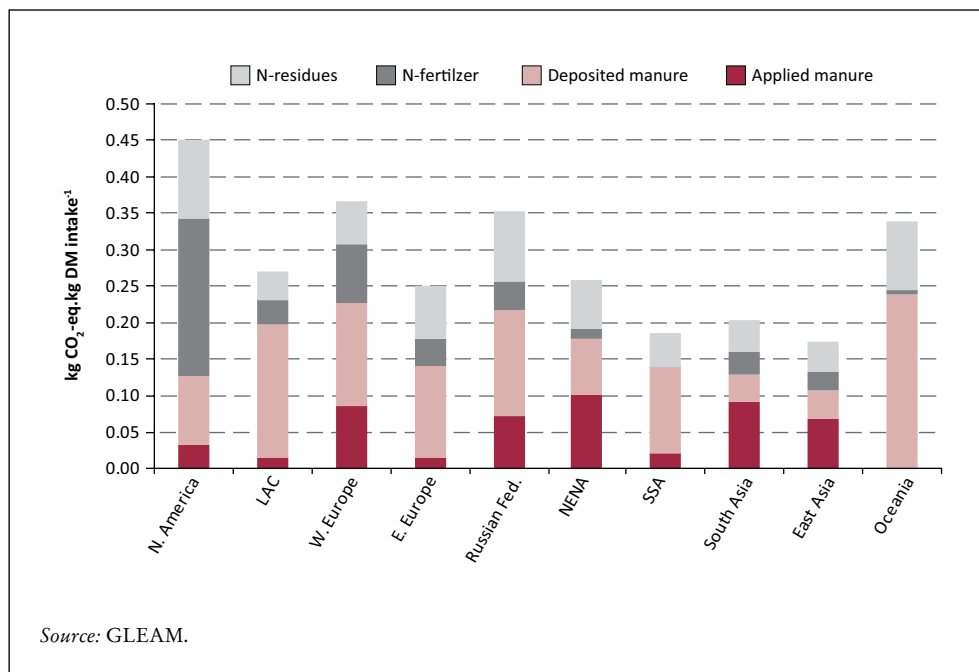
There are additional uncertainties related to N<sub>2</sub>O emissions, such as those related to N application rates coupled with limited information on manure application techniques and timing; the fate of manure and the lack of detailed estimates of the proportion of manure excreted at pasture; and how residues are managed (whether burned or incorporated). In addition, the N content in pasture and manure can vary during the year due to climatic conditions and stages of grass growth. All these aspects are difficult to capture given the scale of the analysis.

In this study, it is also assumed that all managed manure is applied to crops pro-

**Figure 32a.**  
Regional difference in N<sub>2</sub>O emission intensity of feed – cattle



**Figure 32b.**  
Regional difference in N<sub>2</sub>O emission intensity of feed – small ruminants



duced in the same location that production takes place. This may result in high N<sub>2</sub>O emissions from applied manure particularly in areas where crop yields are low.

Another important aspect that influences the emissions from feed production is the choice of feed material; for example, in regions where the use of crop residues and by-products is important, there will be a tendency towards lower emission intensities per kg of DM because part of those emissions have been allocated to the main crop while regions that rely on concentrate feed, cultivated pasture, grains as a source of feed are likely have to have higher emissions intensities.

### 5.2.2 Carbon dioxide emissions from fossil fuel use in feed production

Carbon dioxide emissions from feed production are related to the use of fossil fuels, particularly diesel in tractors and harvesting machinery, oil in dryers, and natural gas in the manufacture and application of synthetic fertilizer and LUC. In the post-farm stages of feed production, CO<sub>2</sub> is emitted in conjunction with various feed processes (with drying being important) and transport.

In general, CO<sub>2</sub> emissions from energy use in feed production, processing and transport are strongly correlated to the feed ration. Other factors that also explain the variation in emission intensity among world regions include: the level of mechanization, the rate of fertilizer application, dependence on imported feed and source of feed (a key determinant of emissions related to transport of feed) and the extent to which the feed in question is associated with LUC.

Figures illustrate the emission intensity of feed by different processes in feed production and by region for both cattle (Figure 33a) and small ruminants (Figure 33b). In both cases, CO<sub>2</sub> emissions from fossil fuel use in feed production are important in industrialized regions. In these regions, two key factors explain the high emission intensities: (i) high fertilizer application rates; and (ii) transport of feed due to the higher proportion of by-products, feed crops or imported hay in the feed ration.

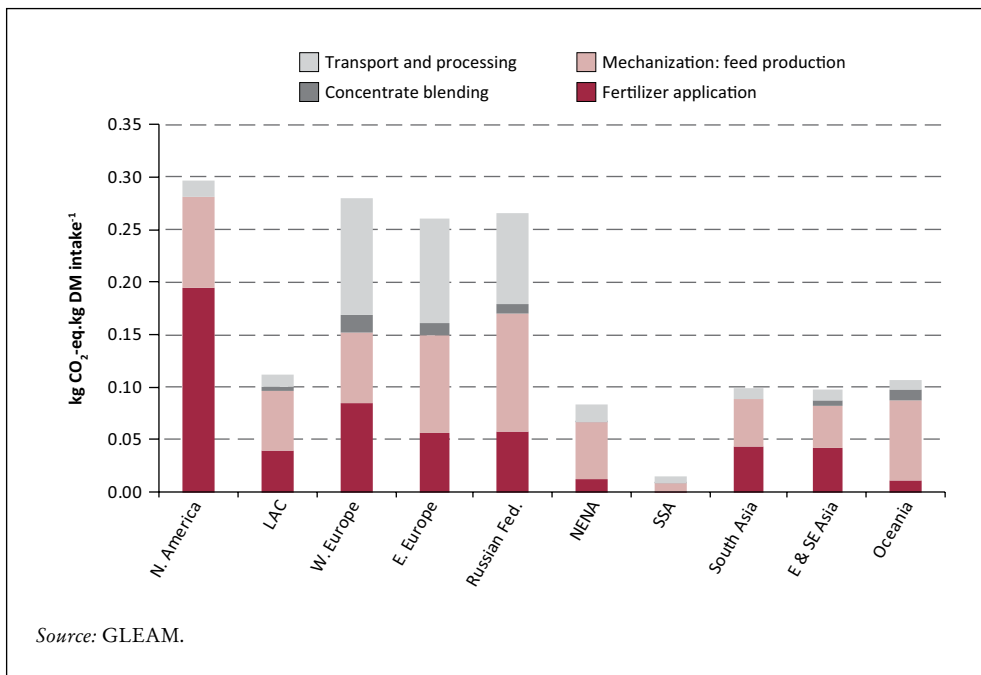
In other world regions, emission intensity is low and dominated by CO<sub>2</sub> emissions from energy use in field work. In both cattle and small ruminant production, sub-Saharan Africa has the lowest CO<sub>2</sub> feed emissions and there are several reasons for this: (i) reliance on natural pasture as a source of feed and low concentrate feed use; (ii) low use/negligible use of inputs such as fertilizer in the production of feed; and (iii) the low level of mechanization in the region.

*Assumptions and uncertainties.* The estimation of CO<sub>2</sub> emissions in this study are influenced by a number of assumptions and factors such as energy source and related emission coefficients used (see Table B14, Appendix B); level of mechanization (Table A1, Appendix A); and where feed is sourced and composition of the feed ration – both of which are variable.

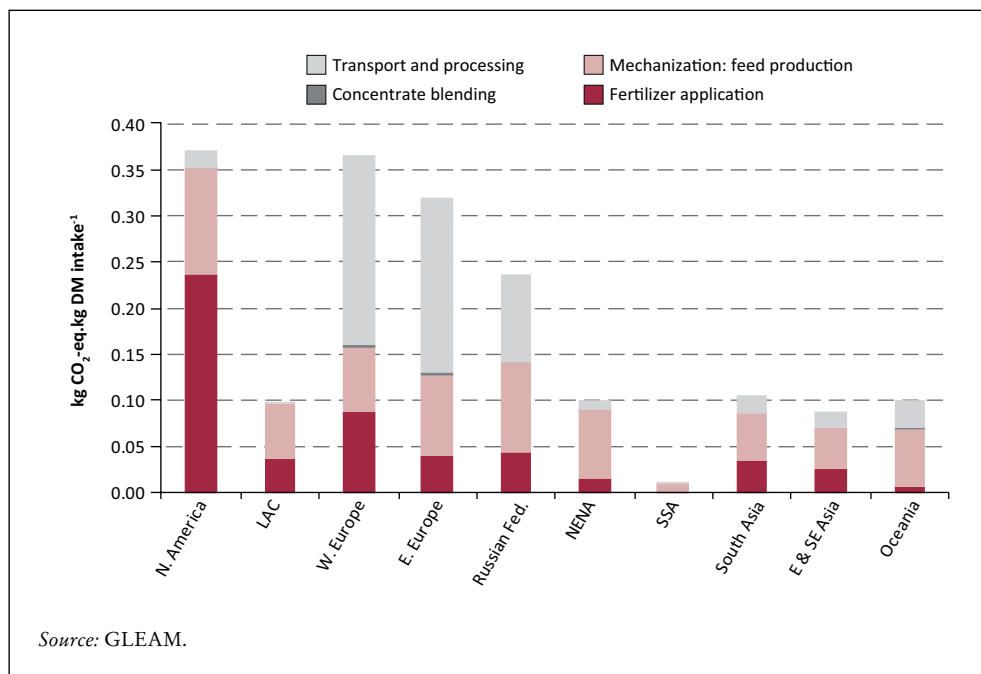
### 5.2.3 Carbon dioxide emissions from land-use change

Emissions from LUC attributable to the ruminant sector amount to 450 million tonnes CO<sub>2</sub>-eq, the bulk of these emissions (93 percent) are related to pasture expansion into forest areas for beef production in Latin America. The use of soybean produced on previously forested land as feed especially for dairy production contributes another 30 million tonnes CO<sub>2</sub>-eq. The approach used in this assessment for estimating emissions from C stock changes associated with livestock induced LUC is further elaborated in Appendix C.

**Figure 33a.** Regional variation in CO<sub>2</sub> (fossil fuel-related) emission intensity of feed – cattle



**Figure 33b.** Regional variation in CO<sub>2</sub> (fossil fuel-related) emission intensity of feed – small ruminants



**Table 10.** Regional sources of soybean and soybean cakes in 2005

	Brazil		Argentina		Other	
	Soybean	Soybean Cake	Soybean	Soybean Cake	Soybean	Soybean Cake
	<i>percentage</i>					
LAC	42	49	41	15	17	36
E & SE Asia	17	7	14	10	68	83
E. Europe	0	9	0	27	100	63
N. America	0	0	0	0	100	100
Oceania	0	60	0	0	100	40
Russian Fed.	5	5	0	37	95	57
South Asia	6	2	1	0	93	98
SSA	0	0	1	60	99	39
NENA	12	7	19	23	69	69
W. Europe	61	34	0	38	38	28

Source: FAOSTAT (2013).

**Table 11.** Main exporters of soybean and soybean cakes in 2005

	Soybean		Soybean cake	
	Exports (million tonnes)	Share of global exports	Exports (million tonnes)	Share of global exports
Argentina	20.8	37%	10.0	15%
Brazil	14.4	26%	22.4	34%
United States of America	5.1	9%	25.7	39%
India	4.8	8%	0.0	0%
Paraguay	0.8	1%	3.0	5%

Source: FAOSTAT (2013).

*Soybean expansion.* In quantifying total emissions associated with the transformation of forest for soybean cultivation, LUC emissions are attributed to only those countries supplied by Brazil and Argentina with soybean and soybean cake. Tables 10 and 11 present the regional share of soybean and soybean cake sourced from Brazil and Argentina and main exporting countries, respectively.

This analysis shows that about 224 million tonnes CO<sub>2</sub>-eq are emitted *per annum* from the expansion of soybean production in Brazil and Argentina to meet global demand for pigs, chickens and cattle feed. The bulk of these emissions arise in response to soybean demand in Europe, East Asia and LAC (Table 12) which source large quantities of their soybean feed from Argentina and Brazil. The emissions estimated for the livestock sector in Western Europe are particularly high, which not only indicates a high reliance on imported soybean and soybean cake for feed, but also use of soybean with a high emission intensity, particularly because a large share is sourced from Brazil (see Table 10).

On a species level, the largest share of these emissions is attributed to the non-ruminant sector, equivalent to 195 million tonnes CO<sub>2</sub>-eq (87 percent). This is not



**Table 12.** Regional comparison of land-use change emissions associated with soybean production

Region	Cattle	Pigs	Chicken
	<i>(million tonnes CO<sub>2</sub>-eq)</i>		
Latin America	5.2	19.3	47.9
East and Southeast Asia	0.9	25.3	25.1
East Europe	0.6	2.1	0.4
North America	0.5	0.0	0.1
Oceania	2.4	1.5	1.6
Russian Federation	0.1	0.1	0.1
South Asia	0.0	0.0	4.5
Sub-Saharan Africa	0.0	0.0	0.5
Near East and North Africa	0.2	0.0	5.6
Western Europe	19.6	36.7	23.9
<b>World</b>	<b>29.6</b>	<b>85.0</b>	<b>109.6</b>

Source: GLEAM.

surprising because of the high share of soybean in diets of non-ruminants. Regarding the cattle sector, LUC emissions from soybean are important in Europe where it is utilized in dairy production. The results suggest that emissions are largely influenced by: (i) the quantity of soybeans and soybean cake imported from the two countries; and (ii) the share of soybean in the ration of the diet.

*Pasture expansion.* According to our estimations, about 13 million hectares of forest land in Latin America were converted to pasture land between 1990 and 2006. Deforestation for pasture establishment in the region emitted about 420 million tonnes CO<sub>2</sub>-eq per year, releasing on average 32 tonnes CO<sub>2</sub>-eq ha<sup>-1</sup> yr<sup>-1</sup>. At country level, changes in C stocks range between 30 and 35 tonnes CO<sub>2</sub>-eq ha<sup>-1</sup> yr<sup>-1</sup> (Table 13). The estimates of GHG emissions due to pasture-driven LUC presented here represent a first step towards an estimation of LUC emissions. The analysis is consistent with the Tier 1 methodology outlined in the IPCC guidelines (IPCC, 2006). In order to progress towards better methodologies, certain gaps in data, methods, and in scientific understanding need to be addressed.

These preliminary estimates indicate that the inclusion of CO<sub>2</sub> emissions from land-use change have a significant influence on the carbon footprint of livestock products. However, changes in soil carbon sequestration due to land use are important and need to be considered.

*Assumptions and uncertainties.* Due to the uncertainty in the methods and data for calculating the impacts of LUC, we recognize the high level of uncertainty associated with this estimation. There is much uncertainty regarding the magnitude of LUC emissions due to (a) uncertainty in the estimates of deforestation rates; (b) uncertainty in the carbon storage capacity of different forests, (c) the modes of C release, and (d) uncertainties in the dynamics of land use, thus limiting the accuracy of the estimated carbon loss (Houghton and Goodale, 2004; Ramankutty *et al.*, 2006).

**Table 13.** Annual carbon stock changes and emissions from pasture expansion in Latin America

Countries	Average emissions		Total carbon losses
	tonnes CO <sub>2</sub> /ha	tonnes CO <sub>2</sub> /ha/yr	million tonnes CO <sub>2</sub> -eq
Brazil	- 509.7	- 31.9	-325.3
Chile	- 510.7	- 31.9	-36.7
Paraguay	- 488.1	- 30.5	-31.7
Nicaragua	- 485.3	- 30.3	-13.8

Source: Authors' calculations.

This analysis also relies on a Tier 1 approach and use of IPCC default values and is therefore subject to high levels of uncertainty. We test other existing methods and assumptions in Appendix C to illustrate the range of uncertainty that exists.

The way in which the LUC emissions should be allocated over beef production is a question for further research. Within this analysis, we allocate emissions to total beef produced within the country; however, not all beef production is carried out on deforested land. A related methodological issue is the debate on the allocation of emission related to LUC because of the complexity in ascertaining the key driver of land-use change. In addition, the calculated emission intensity is highly sensitive to the time period selected over which emissions from the initial deforestation are annualized. Appendix C explores alternative approaches to estimating emissions related to LUC, incorporating some of the issues discussed here.

## 5.3 EMISSIONS FROM MANURE MANAGEMENT

### 5.3.1 Methane from manure management

Animal manure emits CH<sub>4</sub> depending on the way it is produced and managed. Ruminants (cattle, buffalo and small ruminants) contribute 109 million tonnes of CH<sub>4</sub> from manure (2 percent of total emissions from ruminants), of which 86 percent is from cattle. Three primary factors affect the quantity of CH<sub>4</sub> emitted from manure management operations: type of treatment or storage facility, climate and composition of the manure.

Storage and treatment of manure in liquid systems such as lagoons or ponds leads to the development of anaerobic conditions which result in high CH<sub>4</sub> emissions. In addition, higher ambient temperature and moisture content also favour CH<sub>4</sub> production. The composition of manure is directly related to animal types and diets.

Manure CH<sub>4</sub> emissions are lower in regions where manure is handled in dry systems. In dairy and beef cattle production, where liquid MMS (lagoons, liquid/slurry systems) are common, the proportion of manure CH<sub>4</sub> emissions in total CH<sub>4</sub> emissions is considerable, and particularly in regions where animals are confined for a part of the year, such as Europe and North America. For dairy, this ranges from 5 percent in Eastern Europe to 35 percent in North America; on the other hand, in beef production the use of liquid systems is confined to Western Europe and Eastern Europe where 6 percent and 14 percent of CH<sub>4</sub> emissions originate from manure, respectively. The anaerobic nature of liquid manure systems increases the potential for CH<sub>4</sub> production and reduces N<sub>2</sub>O production.

In the other world regions, a large fraction of the manure from cattle is handled in dry systems, while in small ruminant production manure is managed in dry systems, including drylots and solid systems, or deposited on pastures and ranges.

Maps 9 and 10 in Appendix G present the CH<sub>4</sub> conversion factor that defines the portion of CH<sub>4</sub> producing potential achieved by each manure management system. Methane conversion factor is higher in North America and Europe, which explains the higher CH<sub>4</sub> emissions. The high CH<sub>4</sub> conversion factor in North America and Europe is due to the use of liquid MMS.

*Assumptions and uncertainties.* In this study, CH<sub>4</sub> emissions from manure management are calculated using the IPCC Tier 2 approach. This approach uses country-specific inputs of volatile solids estimated from DMI, feed digestibility and ash content of manure, a CH<sub>4</sub> conversion factor based on climate and type of manure management and storage system, and the maximum CH<sub>4</sub> potential (Bo) of manure based on species and diet.

Uncertainties related to estimation of CH<sub>4</sub> from manure management derive from: limited activity data on manure management; differences in manure management practices; and the effect of time-related aspects such as storage periods, as well as seasonal temperature variations in emission rates which are not explicitly accounted for in the calculations.

### 5.3.2 Nitrous oxide from manure management

Nitrous oxide is produced directly and indirectly during storage and treatment of manure before it is applied to land. Indirect N<sub>2</sub>O emissions result from volatile N losses that occur mainly from ammonia (NH<sub>3</sub>) and NO<sub>x</sub> and leaching of nitrate. Key important variables that influence N<sub>2</sub>O emissions from manure management include the amount of N excreted and the way in which manure is managed. A considerable amount of N entering the livestock food chain through feed is wasted; ruminants excrete between 75 percent and 95 percent of the N they ingest (Castillo *et al.*, 2000; Eckard *et al.*, 2007). Maps 11 and 12 in Appendix G compare the proportion of feed nitrogen retained by dairy and beef herds.

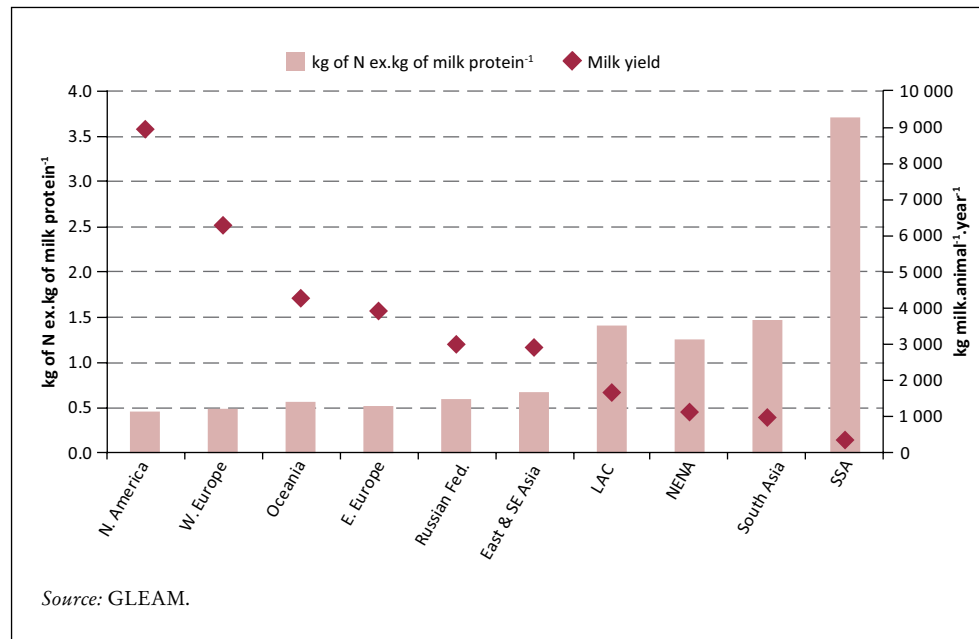
Animal productivity is important for N excretion; as more milk or meat is produced per animal, the maintenance requirement of protein per unit of production is reduced. Thus, the animal product can be produced with less N consumed and excreted. Figure 34 illustrates the relationship between animal performance and N excretion per kg of milk protein; a comparison among regions reveals that, on average, high-producing animals excrete less N per unit of protein produced because more nutrients are directed towards production.

Manure handling and storage also influence N<sub>2</sub>O emissions from manure. A large proportion of N<sub>2</sub>O from manure management is released as direct N<sub>2</sub>O, the bulk of which originates from dry systems (with approximately 60 percent and 65 percent from drylot systems in beef and dairy cattle production). All manure from small ruminants and buffalo is managed in dry systems (drylot and solid systems). Nitrous oxide emissions are most likely to occur in dry manure handling systems that have aerobic conditions (in the presence of oxygen), but that also contain pockets of anaerobic (in the absence of oxygen) conditions.

For dairy and beef cattle, most N<sub>2</sub>O emissions from manure management are found in developing regions. Oceania is the only region without N<sub>2</sub>O emissions

**Figure 34.**

Nitrogen excretion per kg milk protein versus average regional milk yield – dairy cattle



associated with manure management because all manure from beef and small ruminants in Oceania is assumed to be deposited on pasture. The proportion of N<sub>2</sub>O from leaching is insignificant and has a limited impact on total N<sub>2</sub>O from manure management because only a small proportion of leached N is converted to N<sub>2</sub>O.

*Assumptions and uncertainties.* The basis for the estimation of N emissions is the total mass of N excreted. Excretion is determined as the difference between crude protein intake and retention within the animal. N<sub>2</sub>O emissions associated with manure deposited on pasture, ranges and paddocks are not included in these estimates but considered as part of the feed production component (cf. Appendix A), because they are considered as a source of N fertilizer in feed production.

#### 5.4 COMPARISON WITH OTHER STUDIES

A direct comparison with literature values from other LCAs is often complicated by the use of differing boundaries, functional units, disparate assumptions and algorithms in calculating emissions. Nevertheless, comparisons can be useful to provide an indication of the validity of results and contribute to drawing conclusions. Tables 14 and 15 compare existing studies for beef cattle and small ruminants with the current study. While several studies have focused on the cattle sector and to a limited extent small ruminants, many of these estimates are at a much smaller scale and are often specific to regions or production systems within countries (e.g. Verge *et al.*, 2008; Peters *et al.*, 2009; Biswas *et al.*, 2010; Beauchemin *et al.*, 2010; Pelletier *et al.*, 2010; Nguyen *et al.*, 2010; Kanyarushoki *et al.*, 2010; Zhou *et al.*, 2007, Zervas and Tsiplakou, 2012; Edwards-Jones *et al.*, 2009). For purposes of this comparison, only those studies with a national or regional scope were selected.

Table 14. Comparison of emission intensities for beef cattle

Study	Country	System	Scope							Emission Intensities/Emissions			
			Enteric CH <sub>4</sub>	Manure CH <sub>4</sub>	Manure N <sub>2</sub> O	Feed N <sub>2</sub> O	Feed CO <sub>2</sub>	Energy	Post farmgate				
Foley <i>et al.</i> (2011)	Ireland	Pastoral suckler (National average farm scenario)	Y	Y	Y	Y	Y	Y	N	N	23.1 kg CO <sub>2</sub> -eq/kg CW	27.7 kg CO <sub>2</sub> -eq/kg CW	GLEAM
Leip <i>et al.</i> (2010)	EU27	Beef	Y	Y	Y	Y	Y	Y	Y	N	22.2 kg CO <sub>2</sub> -eq/kg CW	24.1 kg CO <sub>2</sub> -eq/kg CW	
Cederberg <i>et al.</i> (2009)	Brazil		Y	Y	Y	Y	Y	Y	Y	N	28 kg CO <sub>2</sub> -eq/kg CW (without LUC)	32.4 kg CO <sub>2</sub> -eq/kg CW (without LUC)	
Williams <i>et al.</i> (2006)	Brazil		Y	Y	Y	Y	Y	Y	Y	Y	32.2 kg CO <sub>2</sub> -eq/kg CW (without LUC)	32.4 kg CO <sub>2</sub> -eq/kg CW (without LUC)	
Casey and Holden (2006)	Ireland	Typical Irish beef	Y	Y	Y	Y	Y	Y	Y	N	11.26 kg CO <sub>2</sub> -eq/kg LW	19.1 kg CO <sub>2</sub> -eq/kg LW	
Ogino <i>et al.</i> (2007)	Japan		Y	Y	Y	Y	Y	Y	N	N	32.1 kg CO <sub>2</sub> -eq/kg CW	39.0 kg CO <sub>2</sub> -eq/kg CW	
Ominski <i>et al.</i> (2003)	Canada		Y	N	N	N	N	N	N	N	16.1 million tonnes CO <sub>2</sub>	17.5 million tonnes CO <sub>2</sub>	

Y: emission category included; N: emission category excluded.

Table 15. Comparison of emission intensities for small ruminants

Study	Country	Species	System	Scope						Study	Emission Intensity		
				Enteric CH <sub>4</sub>	Manure CH <sub>4</sub>	Manure N <sub>2</sub> O	Feed N <sub>2</sub> O	Feed CO <sub>2</sub>	Energy			Post farmgate	
Leip <i>et al.</i> (2010)	EU27	Small ruminant meat		Y	Y	Y	Y	Y	Y	N	20.3 kg CO <sub>2</sub> -eq/kg CW	18.1 kg CO <sub>2</sub> -eq/kg CW	GLEAM
Leip <i>et al.</i> (2010)	EU27	Small ruminant milk		Y	Y	Y	Y	Y	Y	N	2.9 kg CO <sub>2</sub> -eq/kg milk	4.7 kg CO <sub>2</sub> -eq/kg milk	
Ledgard <i>et al.</i> (2011)	New Zealand	Lamb		Y	Y	Y	Y	Y	Y	Y	19 kg CO <sub>2</sub> -eq/kg CW	14.8 kg CO <sub>2</sub> -eq/kg CW (with allocation to wool) 19.0 kg CO <sub>2</sub> -eq/kg CW (without allocation to wool)	
Ripoli-Bosch <i>et al.</i> (2010)	Spain	Lamb	Grazing Mixed Zero-grazing	Y	Y	Y	Y	Y	Y	N	Grazing: 56.7 Mixed: 48.5 kg CO <sub>2</sub> -eq/kg CW	25.9 kg CO <sub>2</sub> -eq/kg CW	
Yamaji <i>et al.</i> (2003)	China	Goats		Y	Y	N	N	N	N	N	869 gigagrams CH <sub>4</sub>	641 gigagrams CH <sub>4</sub>	
Yamaji <i>et al.</i> (2003)	China	Sheep		Y	Y	N	N	N	N	N	760 gigagrams CH <sub>4</sub>	925 gigagrams CH <sub>4</sub>	

Y: emission category included; N: emission category excluded.

The following factors have been identified as potential reasons for the deviation in results.

*Scope.* Studies can: (a) have different system boundaries; (b) include different emissions categories within the same system boundaries; (c) have different functional units; or (d) include different emission sources within an emission category.

*Input data/assumptions.* Quantifying emissions requires input data on key parameters such as livestock population numbers and distributions, herd structures and crop yields. Ideally, validated empirical data sets should be used, but there are often gaps in the data on key parameters, which necessitate assumptions. In many cases, key input data have been found to vary; for example a comparison of small ruminant population numbers in the 27 Member States of the European Union (EU27) revealed that the small ruminant population for these countries used in this current study are 30 percent higher than those used by Leip *et al.* (2010). The authors also noted that there was an observed difference between the small ruminant inventory that they utilized and national inventory reports. The animal inventory utilized in this study was, however, found to be consistent with those reported by the countries.

*Calculation methods.* A review of the studies revealed the major differences in methodology across all studies particularly in the use of different approaches such as use of Tier 1 vs. Tier 2 approaches, and differences in allocation technique applied. Generally, due to the importance of enteric fermentation, most recent studies apply a Tier 2 approach, particularly for cattle. While the approach may be similar, studies may obtain different results which may largely depend on data inputs such as animal weights, feed digestibility and feed composition, all of which are important in assessing emissions from enteric fermentation. On the other hand, the assessment of enteric fermentation in small ruminants in the few studies conducted (Leip *et al.*, 2010; Yamaiji *et al.*, 2003; Edward-Jones *et al.*, 2009) has largely been based on the Tier 1 approach using the IPCC default value of 8 kg CH<sub>4</sub> per head.

The allocation technique applied may also explain variations in emission intensity. Significant differences were found between this study and the EU27 study (Leip *et al.*, 2010) for small ruminant milk production (cf. Table 14), which is also explained by the differences in allocation techniques. The authors allocate emissions between three outputs: milk, meat and lamb/kids based on the nitrogen content of the products, and emissions related to the raising of young animals during pregnancy are allocated to meat. In contrast, this study allocates emissions between milk, meat and wool based on economic value of the products and subsequently utilizes protein content of products to allocate emissions among the edible products (see allocation technique in Appendix A). A key explanation of the deviation between the current study and EU27 study is related to the fact that a large part of the total dairy herd emissions (i.e. emissions associated with the adult females and male animals and replacement animals) in our study are allocated to milk, while only emissions of the dairy activity (time from the first lactation to the slaughtering of the animal) are allocated to milk in the EU27 study (Weiss and Leip, 2012).

The overlying issues with comparison lie in the lack transparency of information and a standardized methodology or protocol for conducting LCAs and reporting results. The variability among studies in methods used places emphasis on the need to clearly define and agree on methodologies for estimating GHG emissions from the ruminant sector.

## 5.5 ANALYSIS OF UNCERTAINTY

Estimates of GHG emissions are subject to large uncertainties. Fundamentally, uncertainties are associated with the variables used in the calculation of EFs, in estimates of activity data (e.g. animal populations and herd parameters) and assumptions made. This section presents a partial analysis of uncertainty, based on the Monte Carlo (MC) Simulation approach.

In order to focus the analysis of uncertainty, parameters that had the greatest influence on emission intensity were identified. Key contributors to emissions were defined as those emissions categories contributing more than 10 percent of the emissions and with a high degree of uncertainty arising from either the lack of data or inherent

**Table 16.** Summary of parameters and uncertainty distributions used in the Monte Carlo simulation runs for dairy and beef in France

Parameters and emission factors	Distribution	CV <sup>1</sup>	Min	Max	Reference and basis for uncertainty estimates
<b>Parameters</b>					
Feed digestibility	Normal	0.10			Assuming IPCC uncertainty range of $\pm 20\%$ (IPCC, 2006 – Volume 4, Chapter 10, Section 10.2.3)
Dairy: Milk yield	Normal	0.2			Institut de l'Élevage, 2011
Dairy: Age at first calving	Normal	0.19			Institut de l'Élevage, 2011
Beef: Age at slaughter	Normal	0.23			Institut de l'Élevage, 2011
Beef: Age at first calving	Normal	0.17			Institut de l'Élevage, 2011
<b>Emission factors</b>					
Enteric CH <sub>4</sub> emission factor	Normal	0.10			Assuming IPCC (2006, Volume 4, Chapter 10, Section 10.3.4) uncertainty range of $\pm 20\%$
EF1: N <sub>2</sub> O emission factor, synthetic and organic N	Beta Pert		0.003	0.03	IPCC (2006, Table 11.1)
EF3: N <sub>2</sub> O emission factor, pasture, rangeland and paddock	Beta Pert		0.007	0.06	IPCC (2006, Table 11.1)
EF4: Emission factor, N volatilization	Beta Pert		0.002	0.05	IPCC (2006, Table 11.3)
EF5: Emission factor, leaching	Beta Pert		0.0005	0.025	IPCC (2006, Table 11.3)
Fraction of applied synthetic N to volatilization NH <sub>3</sub> , No <sub>x</sub>	Beta Pert		0.03	0.3	IPCC (2006, Table 11.3)
Fraction of applied organic N to volatilization NH <sub>3</sub> , No <sub>x</sub>	Beta Pert		0.05	0.5	IPCC (2006, Table 11.3)
Ammonium Nitrate manufacture EF	Normal	0.27			Based on values for fertilizer CO <sub>2</sub> EFs in Wood and Cowie (2004)
Soybean scenario 1: GLEAM	Normal	0.08			See Appendix C on LULUC
Soybean scenario 2: PAS 2050-1:2012	Normal	0.15			See Appendix C on LULUC
Soybean scenario 3: One-Soy	Normal	-			See Appendix C on LULUC
Soybean scenario 4: Reduced time-frame	Normal	0.08			See Appendix C on LULUC

<sup>1</sup> CV – Coefficient of Variation is the ratio of the standard deviation to the mean. The 95 percent confidence interval is approximately equal to the standard deviation or coefficient multiplied by two.



variability or assumptions made. For the ruminant sector, emission categories that contribute more than 10 percent include CH<sub>4</sub> from enteric fermentation, CO<sub>2</sub> from land-use change, and N<sub>2</sub>O from feed production (see Section 4). Section 5.4 highlighted some of the important factors that are likely to influence emissions. The MC simulation was applied to two countries, France and Paraguay. In France, uncertainties in both mixed dairy and beef production systems were assessed, while in Paraguay the focus was on grazing systems. The choice of countries was based on criteria such as the availability of statistics for inventory data [standard deviation (SD), confidence interval or ranges], and relative importance of production in these countries.

### 5.5.1 The approach

*Choice of probabilistic distributions of input variables.* Monte Carlo simulations enable an investigation into how input uncertainty propagates through the life-cycle emissions model. However, there is little data on probability distributions of the input data required to perform a MC simulation.

In this assessment, the probability distributions were defined using the SD from a number of sources and applying the coefficient of variation indicated in Tables 16 and 17, and normal distributions were assigned to technical parameters for which no choice of mode could be justified given available information.

**Table 17.** Summary of parameters and uncertainty distributions used in the Monte Carlo simulation runs for beef in Paraguay

Parameters and emission factors	Distribution	CV <sup>1</sup>	Min	Max	Reference and basis for uncertainty estimates
<b>Parameters</b>					
Feed digestibility	Normal	0.10			Assuming IPCC uncertainty range of $\pm 20\%$ (IPCC, 2006 – Volume 4, Chapter 10, Section 10.2.3)
Beef: Age at slaughter	Normal	0.24			Ferreira <i>et al.</i> (2007); Fréchou (2002)
Beef: Age at first calving	Normal	0.02			Ferreira <i>et al.</i> (2007); Fréchou (2002)
<b>Emission factors</b>					
Enteric CH <sub>4</sub> Emission factor	Normal	0.10			Assuming IPCC (2006, Volume 4, Chapter 10, Section 10.3.4) uncertainty range of $\pm 20\%$
EF1: N <sub>2</sub> O emission factor, synthetic and organic N	Beta Pert		0.003	0.03	IPCC (2006, Table 11.1)
EF3: N <sub>2</sub> O emission factor, pasture, rangeland and paddock	Beta Pert		0.007	0.06	IPCC (2006, Table 11.1)
EF4: Emission factor, N volatilization	Beta Pert		0.002	0.05	IPCC (2006, Table 11.3)
EF5: Emission factor, leaching	Beta Pert		0.0005	0.025	IPCC (2006, Table 11.3)
Fraction of applied synthetic N to volatilization NH <sub>3</sub> , NO <sub>x</sub>	Beta Pert		0.03	0.3	IPCC (2006, Table 11.3)
Fraction of applied organic N to volatilization NH <sub>3</sub> , NO <sub>x</sub>	Beta Pert		0.05	0.5	IPCC (2006, Table 11.3)
Ammonium Nitrate manufacture EF	Normal	0.27			Based on values for fertilizer CO <sub>2</sub> EFs in Wood and Cowie (2004)
Land-use change: Pasture expansion (combined scenario)	Normal	0.28			Combined uncertainty range calculated based on IPCC default uncertainty values for carbon pools and uncertainty in land area estimates

<sup>1</sup> CV – Coefficient of Variation is the ratio of the standard deviation to the mean. The 95 percent confidence interval is approximately equal to the standard deviation or coefficient multiplied by two.

**Table 18.** Emission intensity for imported soybean and soybean cake used in France

Approach	Soybean Cake	Soybean
	<i>kg CO<sub>2</sub>-eq/kg product</i>	
GLEAM	4.81	5.35
PAS 2050-1:2012	1.42	1.58
One-Soy	2.98	3.31
Reduced time-frame	2.31	2.56

Source: Authors' calculations.

**Table 19.** Default carbon stock values for Paraguay and uncertainty values of carbon pools

	Carbon stocks	Uncertainty of the carbon pool <sup>1</sup>
	<i>tonnes C/ha</i>	<i>percentage</i>
<b>Previous land: Forest</b>		
Biomass	260.4	±24%
Soil carbon	65	±95%
Dead organic matter (DOM)	2.8	±30%
<b>Total carbon stocks</b>	<b>328.2</b>	
<b>Land-use after conversion: Grassland</b>		
Biomass	0	0 <sup>2</sup>
Soil carbon	63	±95%
Dead organic matter	0	0 <sup>3</sup>
<b>Total Carbon stocks</b>	<b>63</b>	
<b>Carbon stock change</b>	<b>265.2</b>	

<sup>1</sup> Two standard deviation CI 95%.

<sup>2</sup> No uncertainty analysis is needed for Tier 1 since the default assumption is that all biomass is cleared and therefore the default biomass after conversion is zero.

<sup>3</sup> No uncertainty analysis is needed for Tier 1 since the default assumption is unchanging carbon stocks in DOM.

Source: Authors' calculations.

For the IPCC parameters, these are mainly provided with a potential range, often estimated by expert opinion or drawn from studies. The ranges for EF1, EF3, EF4, EF5 were taken from IPCC (2006) and beta-pert distributions were used to model parameters from IPCC based on the maximum and minimum value. These distributions and underlying data sources are also summarized in Tables 16 and 17.

We also employed MC simulation analysis to understand the uncertainty associated with LUC. The approaches described in Appendix C were used to generate parameter ranges used in the MC simulation. The three alternative soybean approaches were only applied to the French case study where imported soybean cake is used as feed. The soybean emission intensity calculated for the GLEAM and the three additional scenarios for soybean imported by France from Brazil and Argentina are presented in Table 18.

The approach for assessing the uncertainty related to changes in C stocks resulting from pasture expansion into forest areas takes into account the *uncertainty associated with carbon fluxes from carbon pools considered* and the *uncertainty as-*

sociated with the land area estimates. The two uncertainties were run separately and then combined. The IPCC guidelines (2006) indicate that, if using aggregate land use area statistics for activity data (e.g. FAO data on land area), as is the case in this study, a default level of uncertainty for the land area estimates of  $\pm 50$  percent may be applied.

Estimates of the carbon loss on land conversion include uncertainties in several underlying quantities: the carbon in the above-ground biomass, the carbon in the below-ground biomass (generally estimated as a percentage of the above-ground biomass), the carbon in the soil, and the fraction of all carbon lost upon conversion. The uncertainty associated with carbon fluxes from three carbon pools considered in this study are taken from IPCC guidelines (2006, Volume 4) and the “Good Practices Guidelines” for national GHG inventories (IPCC, 2003) and are presented in Table 19.

Total uncertainty combining uncertainty in carbon stock changes per hectare with the uncertainty in land area converted was calculated using the *error propagation approach* outlined in Chapter 6, IPCC Good Practice Guidance (2000, Chapter 6 equations 6.3 and 6.4) that combines different uncertainties to provide an uncertainty estimate for an inventory. The result of the combined uncertainty used as input in the Monte Carlo simulation is presented in Table 17.

*Uncertainty estimates and sensitivity analysis.* In this assessment, the number of simulations run was 10 000. For any analysis of this type, it is important to determine the sources of uncertainty and the impact that parameters and their embedded assumptions have on the results. A sensitivity analysis was therefore used to identify parameters that have a significant effect on the uncertainty estimates. Sensitivity analysis also identifies the most influential parameters indicating emissions sources that offer the opportunity to decrease the overall uncertainty associated with life-cycle of milk and beef production emissions. The relative sensitivity of input variables was assessed by Monte Carlo using the *Rank Correlation Coefficient (RCC)*<sup>8</sup> calculated between all inputs variables and the emission intensity as their contribution to the overall uncertainty.<sup>9</sup>

## 5.5.2 Results from the uncertainty analysis

### France

The mean emission intensity for milk production in mixed farming system in kg CO<sub>2</sub>-eq calculated on the basis of kg milk was estimated to be 1.9 kg CO<sub>2</sub>-eq/kg milk ( $\pm 0.95$  kg CO<sub>2</sub>-eq/kg milk at the CI<sub>95%</sub>). The range of values around the mean obtained with the uncertainty analysis was 0.9-2.8 kg CO<sub>2</sub>-eq/kg milk (Figure 35 and Table 20). The average emission intensity for beef is 15.6 kg CO<sub>2</sub>-eq/kg CW ( $\pm 8.0$  kg CO<sub>2</sub>-eq/kg CW) (Figure 36 and Table 20) The range of values was 7.5-23.6

<sup>8</sup> RCC is a measure of the strength and direction of association between input variables and output estimates. If an input parameter and an output estimate have a high correlation coefficient, it means that the input has a significant impact on the output; positive correlation coefficients indicate that an increase in the input is associated with an increase in the output estimate while negative coefficients indicate an inverse relationship. The larger the absolute value of the correlation coefficient, the stronger the relationship.

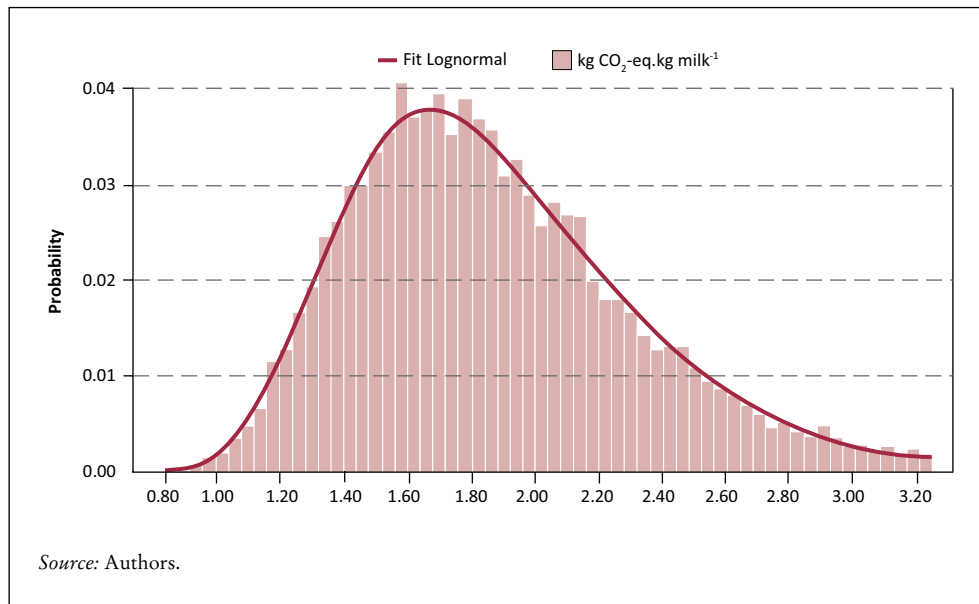
<sup>9</sup> Crystal ball computes the rank correlation between inputs and each output parameter then normalizes these to sum to 100 percent. This provides a measure of sensitivity, i.e. the contribution of each parameter to the overall uncertainty of emission intensity.

**Table 20.** Summary of results from Monte Carlo analysis for mixed dairy and beef production in France

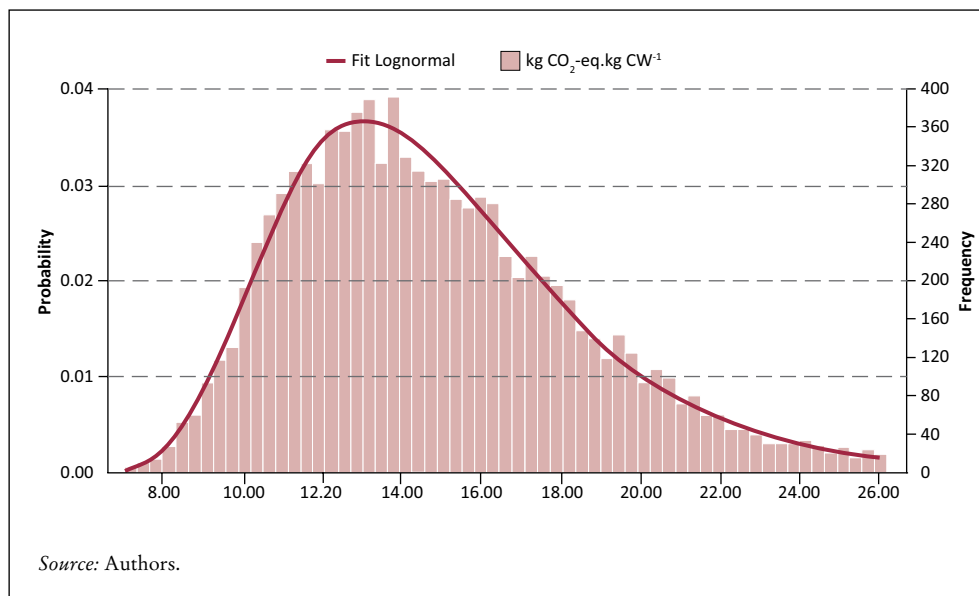
	Mixed dairy production	Mixed beef production
Mean emission intensity	1.89 kg CO <sub>2</sub> -eq/kg milk	15.6 kg CO <sub>2</sub> -eq/kg CW
EI standard deviation	0.49	4.10
Coefficient of Variation	26%	26%

Source: Authors' calculations.

**Figure 35.**  
Probability distribution for milk emission intensity in France



**Figure 36.**  
Probability distribution for beef emission intensity in France



**Table 21.** Impact of alternative soybean scenarios on emission intensity for dairy and beef in France

	GLEAM	PAS 2050-1:2012	One-Soy	Reduced time-frame
<b>Beef</b>				
Mean Emission intensity (kg CO <sub>2</sub> -eq/kg CW)	15.6	14.9	15.2	15.0
Contribution to variance	0%	0.1%	0%	0%
<b>Dairy</b>				
Mean Emission intensity (kg CO <sub>2</sub> -eq/kg milk)	1.89	1.78	1.82	1.81
Contribution to variance	0%	0%	0%	0%

Source: Authors' calculations.

kg CO<sub>2</sub>-eq/kg CW. Both probability distribution frequencies (PDFs) for France are positively skewed indicating that the distribution has a longer right tail (Figures 35 and 36).

The coefficient of variation defines the standard deviation as a percentage of the mean and can be used to compare SDs with different means. Despite the markedly different means and SD for milk and beef, the coefficient of variation for both milk and beef in France is 26 percent of the mean.

*Impact of alternative soybean approaches on emission intensity.* Different scenarios to assess the impact of soybean-related LUC were tested for both dairy and beef production systems in France and the results are presented in Table 21. Soybean cake accounts for a small proportion of the feed ration (between 2-6 percent of the feed ration for both dairy and beef) and hence has a negligible impact on emission intensity.

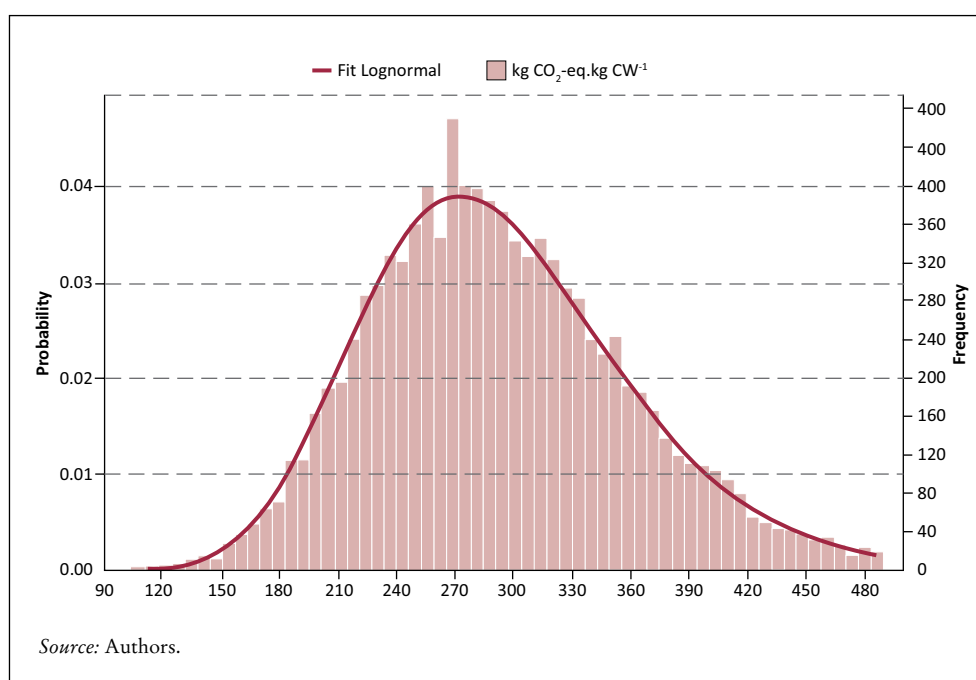
### **Paraguay**

Figure 37 presents the results from the Monte Carlo simulation for Paraguay. The mean value for the emission intensity of beef produced in grazing systems in Paraguay (including carbon losses from deforestation for pasture) is 294.2 kg CO<sub>2</sub>-eq/kg CW ( $\pm 136.3$  kg CO<sub>2</sub>-eq/kg CW), with the 95 percent certainty interval around the mean ranging from 157.8-430.6 kg CO<sub>2</sub>-eq/kg CW. The coefficient of variation (CV) is estimated at 24 percent of the mean.

*Impact of LUC uncertainty on emission intensity of beef in Paraguay.* Table 22 presents the results from the propagation of uncertainty associated with land area estimates, carbon stock losses per hectare as well as the combined scenario of the two uncertainties.

The assumptions and uncertainties in total land area converted and carbon stocks and their impact on the mean were about the same magnitude. The sensitivity analysis showed that uncertainty in the total land area converted is the single largest contributor to variance, accounting for 27 percent of the variance, while uncertainty in estimates of the carbon in soil and biomass accounts for nearly 9 percent of the variance.

**Figure 37.**  
Probability distribution for beef emission intensity in Paraguay



**Table 22.** Effects of alternative LUC uncertainty estimates on average emission intensity for beef production in Paraguay

	Emission intensity (kg CO <sub>2</sub> -eq/kg CW)		
	Mean	95% probability range	
		Low	High
Land area	292.1 (22%)*	163.7	420.6
Carbon stocks	293.4 (21%)*	173.0	413.7
Baseline (combined scenario)	294.2 (24%)*	157.9	430.6

\* Percentages in brackets relate to Coefficient of Variation (CV)

Source: Authors' calculations.

*Analysis of sensitivity.* Tables 23 and 24 illustrate the *contribution to variance* (CoV)<sup>10</sup> and the *RCC* for the uncertain input parameters (above a 1 percent threshold) and presents the most important factors affecting the total uncertainty measured by the absolute value of *RCC* between the parameters and the emission intensity. For milk production in mixed systems in France, three parameters contribute about 90 percent of the total variance in the emission intensity; feed digestibility is the largest contributor to variance, accounting for almost half of the total, and the uncertainty in N<sub>2</sub>O EF3 and milk yield contributing another 22 and 20 percent of the variance, respectively. In beef production, the N<sub>2</sub>O EF3 and feed digestibility parameters contribute 93 percent of the variance (Table 23).

<sup>10</sup> The contribution to variance (CoV) provides information on how much each variable contributed to the uncertainty of emission intensity relative to the contribution of other variables.

**Table 23.** Percent Contribution to Variance (CoV) and Rank Correlation Coefficient (RCC) in mixed dairy and beef systems in France

Parameter	Dairy		Beef	
	CoV	RCC	CoV	RCC
Feed digestibility	47%	-0.66	42.2%	-0.63
N <sub>2</sub> O EF3 Pasture, ranging and paddock	22.2%	0.45	51.5%	0.69
Milk yield	20.4%	-0.43	NA	NA
Age at first calving	5.4%	0.22	NS	NS
EF for enteric fermentation	1.7%	0.12	NS	NS
EF 1 for synthetic and organic N	1.0%	0.09	2.5%	0.15
EF 4 for N volatilization	NS	NS	1.5%	0.12
EF 5 for N leaching	NS	NS	1.2%	0.1

NA: Not Applicable; NS: Not Significant.

Source: Authors' calculations.

**Table 24.** Percent Contribution to Variance (CoV) and Rank Correlation Coefficient (RCC) for grazing beef systems in Paraguay

Parameter	Beef	
	CoV	RCC
N <sub>2</sub> O EF3 Pasture, ranging and paddock	44%	0.64
Land-use change pasture: combined scenario	34%	0.52
Feed digestibility	17%	-0.40
Age at slaughter	5%	0.21

Source: Authors' calculations.

The sensitivity analysis shows that the key parameters contributing to uncertainty for both the dairy and beef scenarios are:

- the feed digestibility variable plays a significant role in total emissions; 47 percent and 42 percent of the uncertainty in emission intensity of milk and beef is caused by the uncertainty in feed digestibility variable, respectively. Digestibility is a dominant factor in the calculations of a number of emission sources and hence its role in influencing the uncertainty in emission intensity.
- N<sub>2</sub>O EF3 for manure deposited on pasture due to the high degree of uncertainty i.e., wide distribution (large natural variability) of possible values.
- In dairy production, milk yield has an impact on the uncertainty of milk emission intensity due to the high variability in milk production.

For Paraguay, the sensitivity analysis shows that 4 parameters: N<sub>2</sub>O EF3 Pasture, ranging and paddock, feed digestibility and land-use change, and age at slaughter contribute 99 percent of the variance to the emission intensity of beef in Paraguay (Table 24).

The uncertainty in N<sub>2</sub>O EF3 is the largest contributor to variance (44 percent); the rate of emissions of N<sub>2</sub>O (per unit N applied/deposited) is perhaps the most uncertain effect in GHG emission profile. In addition to the wide distribution N<sub>2</sub>O EF3 (the N<sub>2</sub>O emissions factor for N deposited on pasture, range or paddock), it is assumed that 95 percent of the manure in this case is deposited directly on pasture

hence the high N<sub>2</sub>O emissions. The uncertainty in the estimates of LUC combined scenario (carbon stock losses per hectare and in the land area estimates) account for 34 percent of the variance.

In conclusion, the uncertainty performed for the two case studies show that relatively few parameters (N<sub>2</sub>O EF3 Pasture, ranging and paddock, feed digestibility and LUC) are responsible for most of the variance. Although the present analysis captures several important parameter uncertainties, significant model uncertainties still remain.

Point estimates from LCAs describe only an average situation and many scenarios may be equally plausible. Uncertainty analysis such as these offer the opportunity to understand and estimate the imprecision of the average result resulting from uncertainties in input data as well as deliver more meaningful results.



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## 6. Conclusion

Globally, ruminant supply chains are estimated to produce 5.7 gigatonnes CO<sub>2</sub>-eq *per annum* of which 81 percent, 11 percent and 8 percent is associated with cattle, buffalo and small ruminant production.

This report provides the first comprehensive and disaggregated global assessment of emissions from the ruminant sector, which enables the understanding of emission pathways and hotspots. This is a fundamental, initial step towards identification of mitigation strategies.

Average emission intensity for products from ruminants were estimated at 2.8, 3.4 and 6.5 kg CO<sub>2</sub>-eq/kg FPCM for cow milk, buffalo and small ruminant milk, respectively, and 46.2, 53.4, and 23.8 kg CO<sub>2</sub>-eq/kg CW for beef, buffalo and small ruminant meat, respectively. Although there is great heterogeneity among production systems, some commodities are associated with particularly high emission intensities. These emission profiles and the on-going growth in output call for the adoption of mitigation practices.

The ranges of emission intensity within supply chains suggest that there is room for improvement (Tables 7 to 9). This mitigation potential is further explored in an overview report published in parallel to this one (FAO, 2013a). It is estimated to reach 30% of the sector's global emissions. The overview report also explores regional mitigation potentials through case study analysis. When drawing any conclusions about scope for improvement, one must distinguish those production parameters that can be managed from those that are related to agro-ecological conditions and cannot be managed. This is particularly true for extensive production systems, where the environment cannot be controlled, or at prohibitive costs.

Regarding these systems, and those facing particularly harsh environments, mitigation practices should not be proposed at the cost of diminished resilience and food security. Bearing these caveats in mind, the results of this study indicate six areas of possible interventions to reduce the emission intensity from ruminant supply chains:

- Reducing LUCs arising from pasture expansion and feed crop cultivation;
- Improving feeding practices and digestibility of diets;
- Improving grazing and pasture management to increase soil organic carbon (SOC) stocks;
- Increasing yields, e.g. through genetics, feeding and animal health;
- Improving manure management – reducing the use of uncovered liquid MMS, particularly in dairy systems; and
- Increasing energy use efficiency, especially in postfarm part of the supply chain.

Comparison of this study with others shows that methods matter. Discrepancies in results are well explained by different system boundaries, allocation methods and computation of emissions, especially with regard to LUC, enteric CH<sub>4</sub> and feed N<sub>2</sub>O. The many different methods that are being used to measure and assess the emissions of animal rearing make it difficult to compare results and set priori-

ties for the continuous improvement of environmental performance along supply chains. This calls for an effort to harmonize approaches and data used in this kind of analysis.

This report presents an update and refinement of the previous assessment in *Livestock's long shadow* (FAO, 2006). It should be understood as one step in a series of assessments, to measure and guide progress in the sector's environmental performance.

Numerous hypothesis and methodological choices were made, introducing a degree of uncertainty in the results. Furthermore, data gaps forced the research team to rely on generalizations and projections. A partial sensitivity analysis was conducted in order to illustrate the effect of these approximations. Results were tested for methodological choices regarding land-use change emissions and input data uncertainty. This partial analysis showed that the emission intensity at 95% confidence interval is  $\pm 50\%$

Priorities for refinement of GLEAM include:

- Information about the feed rations, particularly the amount of roughage, by-products and concentrates in the ration;
- Information on manure management;
- Methods for allocation of emissions, especially for slaughter by-products;
- Quantification of the emissions associated with land use and LUC;
- Quantification of feed N<sub>2</sub>O that better reflect where and how manure N is applied to crops.

Methodological developments are being carried out by private and public sector organizations to improve the accuracy and comparability of results over time. LEAP – the Partnership on Livestock Environmental Assessment and Performance<sup>11</sup> will be instrumental to these developments; this multi-stakeholder initiative is facilitated by FAO and involves government representatives, private sector organizations and civil society in an effort to harmonize indicators and methods for the assessment of environmental performance in the livestock sector.

Although estimating GHG emissions from the sector provides an important starting point for understanding the sector's potential for mitigating emissions, identifying approaches to reduce emissions requires complementary analysis.

First, the private and public costs of mitigation, as well as the social dimensions associated with technology changes and the impact of mitigation efforts on food consumption trends, should be understood in order to identify viable and acceptable options. Several groups are addressing these questions, including FAO. There is also a need to broaden the scope of environmental performance assessment beyond GHG emissions, in order to avoid undesired policy outcomes. GLEAM will progressively be adapted to compute a wider set of metrics that enable several environmental parameters to be quantified. The model provides a consistent and transparent analytical framework within which to explore proposed mitigation methods, thereby providing an empirical basis for policy-making.

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<sup>11</sup> <http://www.fao.org/ag/againfo/livestock-benchmarking/en/>

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