5. Results for chicken supply chains

5.1 GLOBAL PRODUCTION AND EMISSIONS

Chicken production is geographically widespread, with particularly high meat production in Latin America and the Caribbean, North America, and East and Southeast Asia, reflecting the size of the broiler flocks in these regions (see Figure 26 and Maps 4 to 6). The East and Southeast Asia region dominates egg production, accounting for 42 percent (by mass) of eggs from layers and 35 percent of backyard eggs. Annual production and emissions by system are shown in Figure 27. At a global level, broilers and layers account for the bulk of protein production and associated emissions. Backyard production accounts for 8 to 9 percent of production and emissions. However, these figures should not detract from backyard production's importance as a source of protein and emissions in developing countries.

The categories of emissions used in this study are outlined in Section 2. Feed production makes up 57 percent of emissions, with an additional 18 percent related to LUC caused by crop expansion (Figure 28). Feed N_2O emissions are caused by fertilization (both synthetic fertilizers and manure); whereas feed CO_2 emissions arise from fertilizer production, use of machinery in field operations, transport and processing of crops, feed blending and production of non-crop feed materials i.e. fishmeal, lime and synthetic additives.

Emissions related to manure storage and processing represent the next largest category of emissions, at 11 percent, followed by postfarm emissions and on-farm energy use, predominantly arising from broiler production.

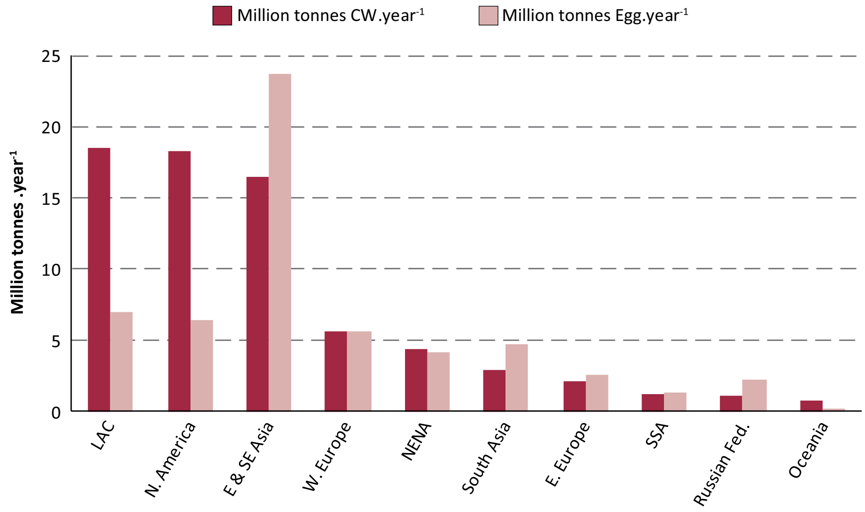
5.2 EMISSIONS INTENSITY

5.2.1 Variation in emission intensity between broiler meat and layer eggs

Overall, the emission intensity of broiler meat (per kg CW) is 45 percent higher than that of layer eggs (per kg eggs), see Figures 29 and 30. One of the main reasons for this value is that the feed conversion ratio of broilers is 22 percent higher than that of layers. Thus 22 percent more feed is required to produce one kg of meat compared to one kg of eggs so that, all things being equal, the feed emissions should be 22 percent higher for broiler meat. However, it should be noted that the broiler FCR is only nine percent higher when measured in terms of protein, and lower when measured in terms of LW (see Table 22). It is not, therefore, an inherent physiological inefficiency in feed conversion that leads to higher emissions (broilers are, in fact, highly efficient converters), but rather that a smaller proportion of what is produced is eaten, when compared to egg laying hens.

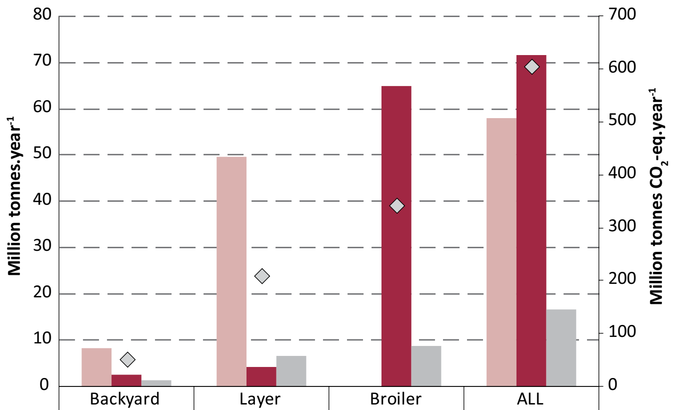
The dietary crude protein requirements of chickens depend on factors such as their age, size, growth rates and rate of egg production. Broilers typically have crude protein requirements ranging from 20 to 23 percent (Petri *et al.* 2007) while with laying hens the range is from 15 to 20 percent (Jeroch *et al.* 2011). Much of the crude protein is derived from soybean and soymeal, which explains why broiler meat is associated with higher LUC emissions than layer eggs. For a discussion on approaches and methods about emissions from LUC, refer to Appendix C of this report.

Figure 26.
Total chicken meat and egg production by region



Source: GLEAM.

Figure 27.
Global chicken production and emissions by system

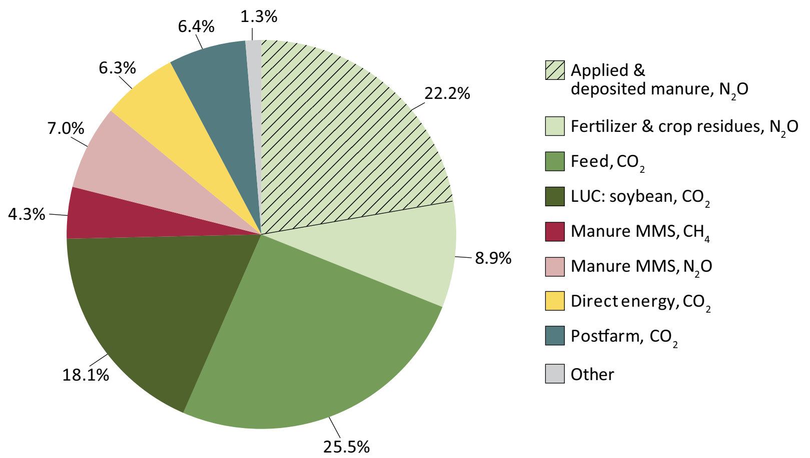


	Backyard	Layer	Broiler	ALL
Million tonnes EGG.year^{-1}	8.3	49.7	-	58.0
Million tonnes CW.year^{-1}	2.7	4.1	64.8	71.6
Million tonnes protein.year^{-1}	1.4	6.7	8.8	16.8
◇ Million tonnes CO_2-eq.year^{-1}	52.4	210.3	343.3	606.1

Source: GLEAM.

Emissions from direct energy use (i.e. on-farm heating, ventilation, but excluding feed production) are significantly higher for meat (4.5 MJ/kg CW) than for eggs (1.3 MJ/kg egg). This difference is largely due to the greater amount of heating needed in broiler production, where a much higher proportion of the flock consists of chicks.

Figure 28.
Breakdown of total global GHG emissions by category for chicken meat and egg supply chains



Source: GLEAM.

Most broilers are free housed on litter, so both the manure CH_4 and direct N_2O emissions tend to be low. By contrast, laying hens are kept in a variety of cage, barn and free-range housing systems, while the characteristics of the manure, and the way it is managed (often in warm anaerobic conditions suitable for CH_4 production) vary more within and between countries. As a result, eggs tend to be connected with higher (sometimes much higher) manure emissions than broiler meat.

5.2.2 Variation in emission intensity between backyard and commercial systems

Total feed emission intensity per kg of CW or eggs (not including LUC) for backyard meat and eggs is similar to that of layers and broilers (see Figure 29 and Figure 30), despite the much higher backyard FCR. This situation occurs because a significant part of the backyard ration consists of scavenged materials, swill and second grade crops, which have low or no emissions. This factor leads to a low emission intensity per kg of feed, which compensates for the high FCR. Unlike commercial systems, some backyard chickens have a significant amount of rice in the ration, and associated rice CH_4 emissions. However, these additional emissions are more than offset by the absence of emissions from LUC, as backyard chickens are assumed not to consume feed soybean or soymeal associated with LUC.

Manure N_2O

The most striking difference between backyard and commercial systems is in terms of their manure N_2O emissions, which are much higher for backyard chickens when compared to commercial chickens. There are several reasons for this difference.

Table 22. Global average feed conversion ratios for each system and commodity. Note that the values in this Table represent the averages over the whole flock, including parent birds: chickens

	FCR - kg of feed intake (DM) per kg of		
	EGG or LW	EGG or CW	Protein
Layers - eggs	2.3	2.3	19.0
Layers - meat	2.3	4.2	23.3
Broilers - meat	2.0	2.8	20.7
Backyard - eggs	9.2	9.2	77.2
Backyard - meat	9.7	14.6	108.0

Source: GLEAM.

Energy requirement and intake. Backyard chickens tend to be smaller, slower growing and tend to lay fewer eggs. However, they are also more physically active as they spend more time scavenging for food, so their total energy requirement is similar to that of the higher yielding commercial chickens. As a result, a smaller proportion of the backyard chicken's energy intake is converted into edible protein, leading to a higher FCR (see Table 22). This result is compounded by the lower digestibility of the backyard ration (see Table B6) which means that the backyard chicken has to eat a greater mass of feed to meet a given energy requirement.

N intake and excretion. The average N contents of the backyard ration tends not to be lower than the broiler or layer ration (although the N content of the backyard ration is more variable, due to the reliance on locally produced feed materials). Consequently, the backyard chicken will have a higher intake of N per MJ of energy consumed (as it is consuming more kg DM for every MJ of energy). The N retention of backyard chickens is significantly lower than that in commercial systems. Backyard chickens have a median N retention of only 0.07, while layers have 0.31, and broilers 0.39 (see Table 23: the values for layers and broilers are consistent with the IPCC [2006, p. 10–60] default values for poultry of 0.30+/-50 percent). The low backyard N retention is due to the low growth and egg laying rates of animals, and the losses at flock level due to higher death rates. The higher N intake and lower N retention combine to give backyard chickens higher N excretion (Nx) rates per kg of protein produced, even though the Nx per animal per day is similar to the commercial systems.

Conversion of Nitrogen excreted into N_2O. For backyard chickens it was assumed that the birds spend 50 percent of their time scavenging and that 50 percent of manure was deposited directly on the ground (and not collected) while the other 50 percent was collected and applied to crops. Manure emissions were calculated using the pasture EF for the uncollected manure and the daily spread EF for the collected manure. Subsequent emissions from the application of manure to crops were allocated to the crops, rather than to manure management. This calculation leads to a median rate of conversion of Nx to N_2O of 1.17 percent compared to 0.9 percent for layers and 0.53 percent for broilers.

Animal versus flock FCR. The herd structures for backyard chickens are quite different from those of commercial systems. Backyard systems have much higher death rates

Table 23. Values of selected explanatory parameters: chickens

Parameter	System	Range of values		
		10th percentile*	50th percentile*	90th percentile*
FCR *(kg intake/kg protein)*	Backyard	45.1	76.0	130.8
	Layer	17.3	19.4	20.2
	Broiler	16.9	21.6	23.2
Ration metabolizable energy *(MJ/kg)*	Backyard	11.1	11.6	12.1
	Layer	12.6	13.6	14.2
	Broiler	13.6	13.8	13.9
Ration N content *(g N/g)*	Backyard	27.9	35.8	49.8
	Layer	24.7	28.1	31.5
	Broiler	33.7	35.3	39.3
N excretion *(g N/head/day)*	Backyard	1.2	2.1	2.9
	Layer	1.2	1.4	1.8
	Broiler	1.7	2.1	2.9
N excretion *(kg Nx/kg protein output)*	Backyard	1.60	2.90	9.60
	Layer	0.28	0.39	0.50
	Broiler	0.33	0.50	0.54
N retention *(kg Nretained/kg Nintake)*	Backyard	0.04	0.07	0.12
	Layer	0.26	0.31	0.35
	Broiler	0.36	0.39	0.42
Rate of conversion of excreted N to N_2O -N *(percentage)*	Backyard	1.1	1.2	1.2
	Layer	0.8	0.9	1.0
	Broiler	0.5	0.5	0.6
MCF *(percentage)*	Backyard	0.6	1.0	1.3
	Layer	4.1	22.7	39.5
	Broiler	1.5	1.5	1.5

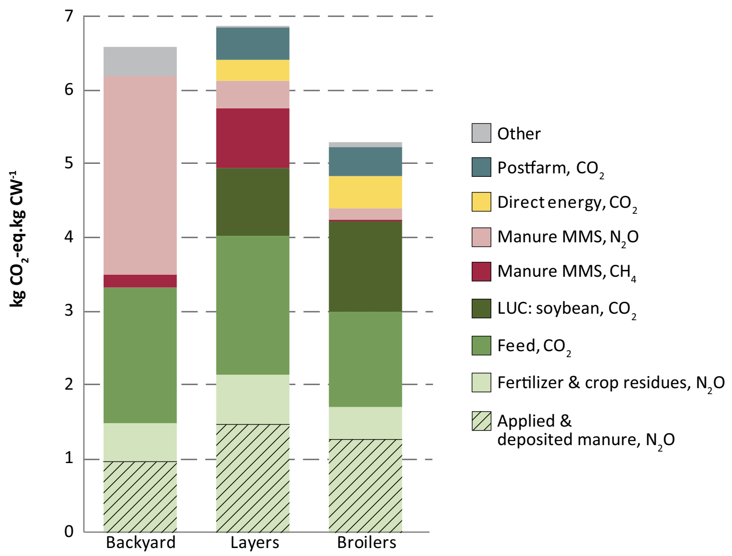
* Percentiles are by production and country, i.e. the tenth percentile is the value for the country that corresponds to the bottom ten percent of global production.
Source: GLEAM.

(due largely to disease and predation) and lower fertility rates, which means that breeding animals which are unproductive (in terms of producing edible protein) make up a larger proportion of the flock. Typically, they account for around 10 percent of the backyard flock, compared to 4 percent of the broiler flock and 1 percent of the layer flock. Therefore, there is a marked increase between the feed conversion ratio of the individual productive animals and the flock as a whole, in backyard systems when compared to commercial systems.

In summary, compared to a commercial flock with similar energy requirements, the backyard flock will:

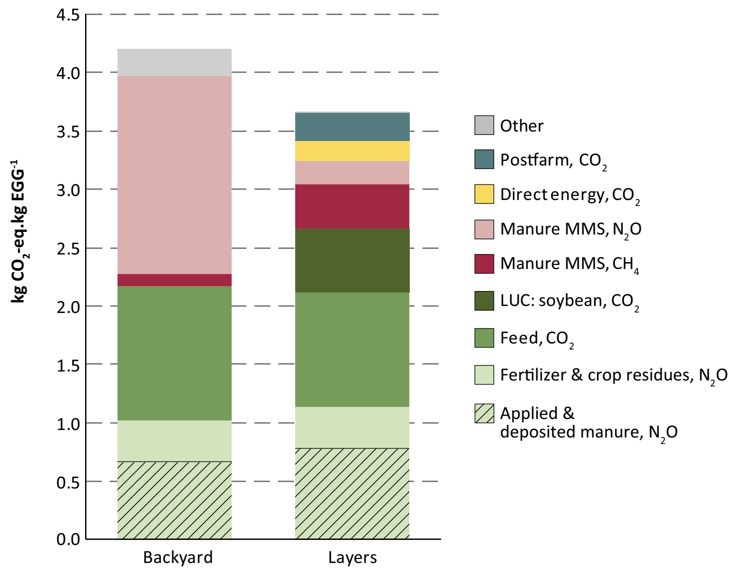
- have a higher dry matter (DM) intake for every MJ of metabolizable energy (ME) required, due to the lower energy content of the feed, and therefore a higher N intake for each MJ of ME consumed;
- convert less of the N intake into edible protein, due to the low yields of individual animals and the greater proportion of unproductive animals in the flock, and will excrete more N (and VS) per unit of edible protein produced;
- convert more of the Nx to N_2O.

Figure 29.
Chicken meat emission intensity ("Other" is rice CH_4 in backyard systems and indirect energy CO_2 in layers and broilers)



Source: GLEAM.

Figure 30.
Chicken eggs emission intensity ("Other" is rice CH_4 in backyard systems and indirect energy CO_2 in layers and broilers)



Source: GLEAM.

5.2.3 Geographical variation in emission intensity

Flock feed conversion efficiency

As Table 24 and Figure 31 show, the efficiency with which feed is converted into meat and eggs is much lower in the backyard systems. Figure 31 also shows that there is considerable regional variation in FCR within the backyard system, compared to layers or broilers, reflecting the wider ranges for key parameters in the backyard systems, notably: death rates, growth rates and egg yields. These ranges, in turn, reflect variability in the genetic potential of the animals and in the extent to which the underlying conditions of production (e.g. housing, exposure to disease and predators, ration and nutritional status) enable this potential to be achieved. As the FCR is expressed in terms of the kg of feed intake, it is also a function of the energy density of the ration. Thus, the lower the MJ/kg DM the larger the amount that needs to be eaten to meet a given ME requirement, and the higher the FCR.

Feed emissions

Feed emissions per kg of egg or meat are a function of (a) the emissions per kg of feed and (b) the efficiency with which the feed is converted into eggs or meat. The reasons why conversion efficiency varies are outlined above. The ways in which the FCR and emissions per kg of feed combine to produce the ranges of feed emissions per kg of egg or meat observed in Figures 32 to 37 are explored briefly below.

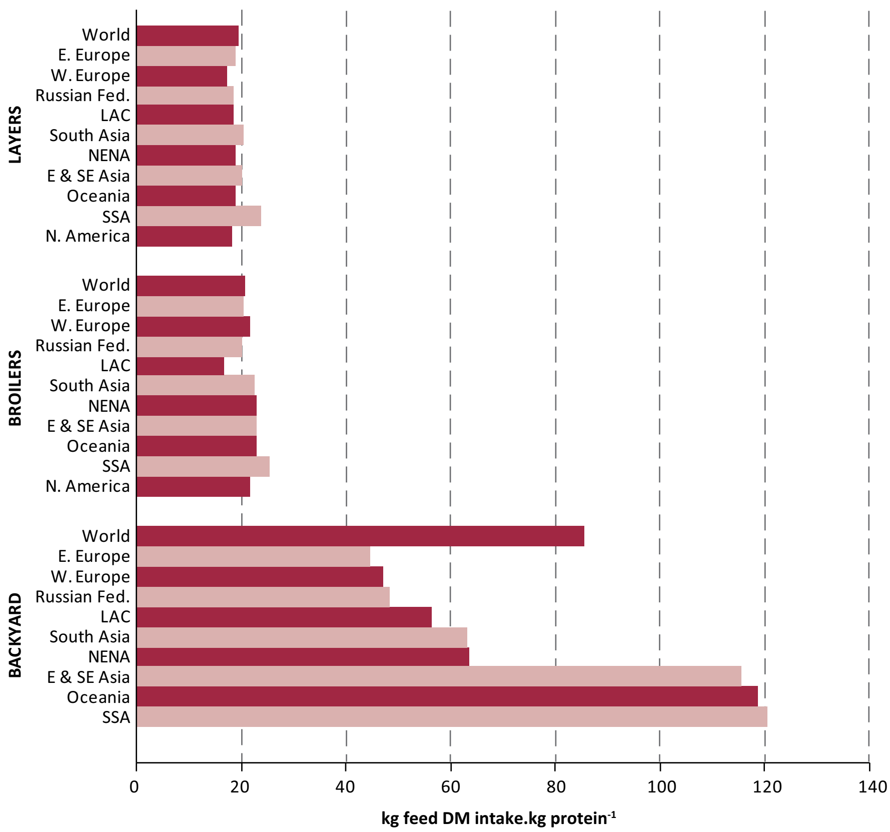
Backyard. East and Southeast Asia has the highest emissions per kg of egg production, due to a combination of moderate feed emission intensity and high FCR (see Figure 32). Feed N_2O and CO_2 are moderate, in part, because of the presence of rice in the ration, which has a relatively high yield per ha, but this also leads to significant rice CH_4 emissions. High FCR leads to Sub-Saharan Africa having high emissions per kg of egg, despite having low feed emissions. Near East and North Africa (NENA) have the highest feed emission intensity (per kg of DM) (see Figure 33), but are more efficient in terms of converting feed to eggs, and so have moderate emissions per kg of eggs. South Asia has the lowest feed emission intensity for backyard production, due to below average feed emission intensity and moderate FCR. The Russian Federation and Eastern Europe also have high feed emissions per kg of DM, due to the lower fraction of swill in the ration, but they have relatively efficient conversion rates, which lead to low emissions per kg of eggs.

Layers and broilers. In general, the level of emissions per kg of eggs or meat closely mirrors the emissions per kg of feed, as there is much less variation in the FCR for these systems compared to backyard chickens. One exception is broilers in Latin America and the Caribbean, which have high feed emission intensity, as a result of the soybean LUC emissions (see Figures 36 and 37). However, the high emissions per kg of feed combine with a lower FCR to produce an emission intensity per kg of meat that is only slightly above the global average. The feed emissions in Western Europe are also dominated by LUC, though the FCR for this region is close to the global average, leading to high emissions per kg of meat and eggs. For layers, the LUC emissions per kg of feed are higher in Western Europe than in Latin America and the Caribbean because of the higher amount of soybean in the ration and the greater proportion of the soybean imported from Brazil (some major egg producing countries in Latin America and the Caribbean, such as Mexico, import relatively small amounts of their soybean from Brazil) (see Figure 35).

North America has high N_2O emissions per kg of feed, meat and eggs, due to the spatially concentrated nature of chicken production (which means that the amount of nutrient excreted is often high compared to the local crop requirement). However, the absence of LUC emissions (there is limited LUC in North America) results in emission intensities which are below the global average for both broilers and layers.

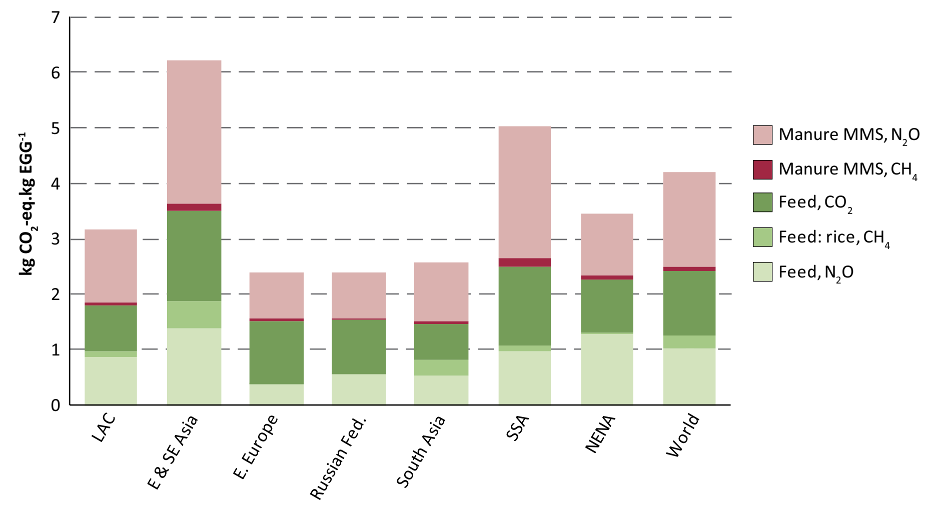
Eastern Europe and the Russian Federation have the lowest emissions per kg of feed for both broilers and layers, as they import small amounts of soybean from Brazil and Argentina, while the rate of manure N production is, on average, below the local crop requirement, making it easier to match the manure N applied to the crop requirement.

Figure 31.
Average feed conversion ratio by system and region (the values in this Figure represent the averages over the whole regional flock, rather than just the growing/laying chickens)



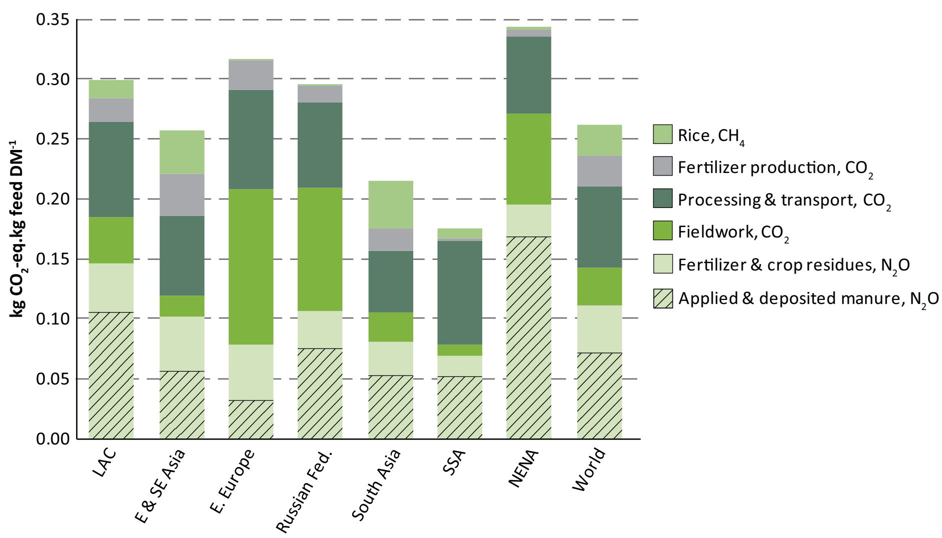
Source: GLEAM.

Figure 32.
Average backyard eggs emission intensity by region (regions with less than two percent of backyard production are omitted)



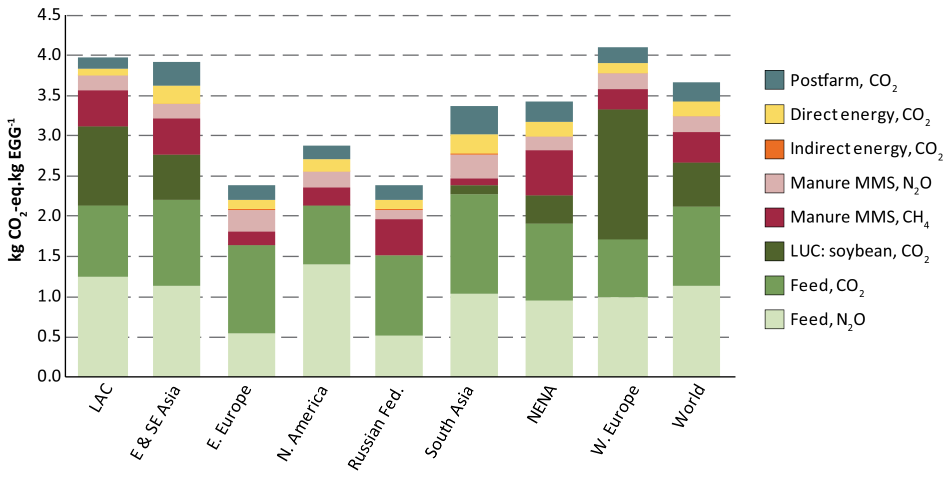
Source: GLEAM.

Figure 33.
Average backyard chicken feed emission intensity by region
(regions with less than two percent of backyard production are omitted)



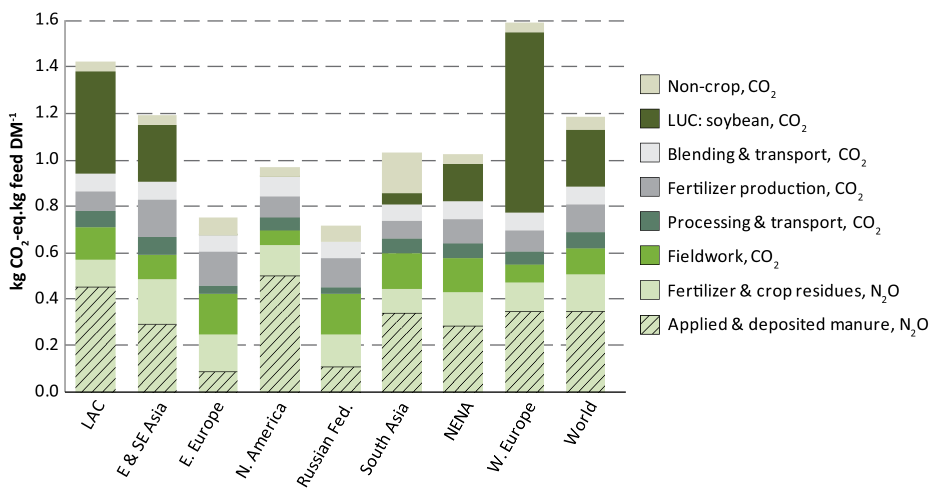
Source: GLEAM.

Figure 34.
Average layers eggs emission intensity by region (regions with less than two percent of layer production are omitted)



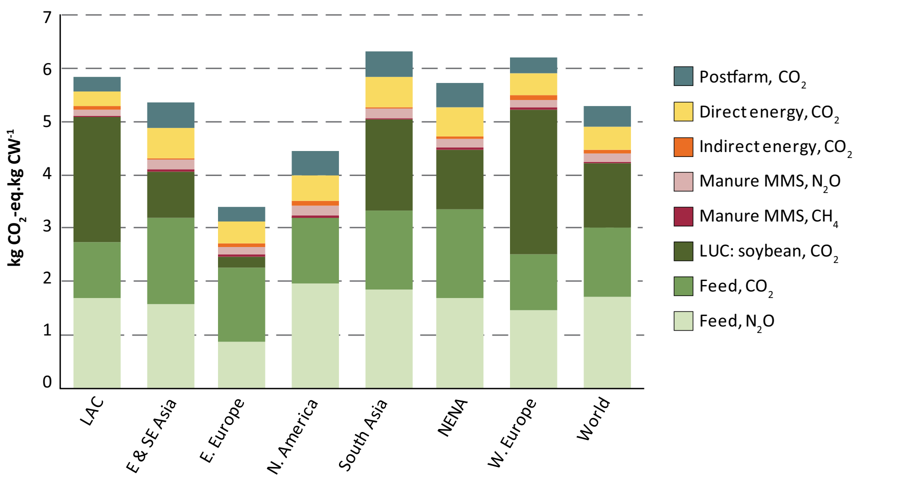
Source: GLEAM.

Figure 35.
Average layers feed emission intensity by region (regions with less than two percent of layer production are omitted)



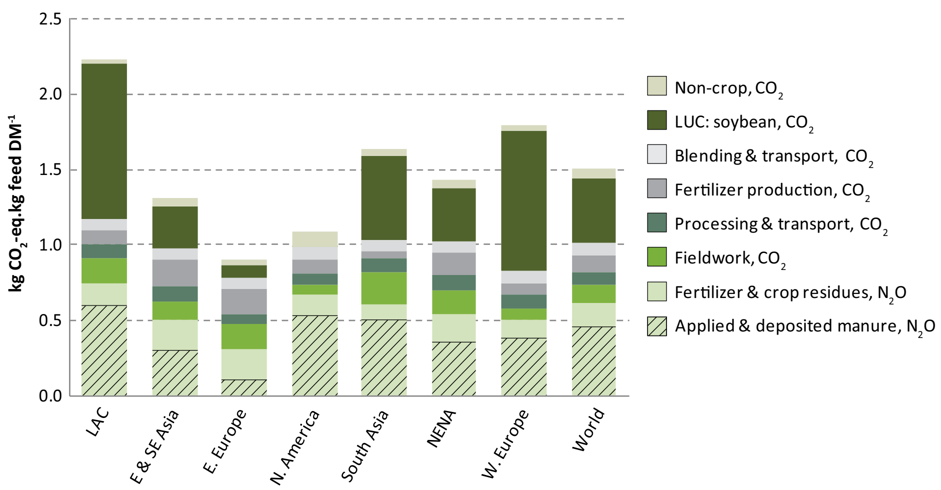
Source: GLEAM.

Figure 36.
Average broilers emission intensity by region (regions with less than two percent of broiler production are omitted)



Source: GLEAM.

Figure 37.
Average broilers feed emission intensity by region (regions with less than two percent of broiler production are omitted)



Source: GLEAM.

Regional variation in emission intensity of individual feed materials

Many of the chicken feed materials are similar to those in the pig ration, and the emission intensity of individual feedstuffs is influenced by the same factors, such as:

- crops yields;
- the rate at which manure and synthetic N are applied, relative to the crop requirement;
- allocation of emissions to crop residues and processing by-products;
- mechanization rates and crop transport distances;
- whether or not soybean production induces LUC;
- the rice cultivation system.

The challenge of assessing the rate at which manure N is applied to crops is, if anything, more complex with chickens than it is for pigs. Commercial chicken units often produce very high amounts of manure N, in forms that have significantly higher DM contents than pig excreta, which means it can be economically feasible to transport the manure significant distances. The extent to which this happens, and the resulting N application rates, are potentially an important source of variation in feed N_2O emissions, but are difficult to represent accurately at the global scale.

Regional variation in manure emissions

As with pigs, the emissions of N_2O and CH_4 from manure depends on: (a) the amount of VS or N excreted per kg of egg or meat produced and (b) the rate at which the VS or N are converted to CH_4 and N_2O (see Table 24).

The amount of VS excreted per unit of protein produced is a function of feed digestibility and the feed conversion ratio (high digestibility and low FCR produce low VSx rates and vice versa). However, feed digestibility is relatively consistent in commercial systems (see Appendix B) so the VSx is more influenced by the FCR. The subsequent rate at which the VSx are converted to CH_4 depends on how the manure is managed and the ambient temperature. It is assumed that the manure from both broilers and backyard chickens is managed in dry aerobic conditions, which leads to minimal CH_4 emissions. However, in Latin America and the Caribbean, and East and Southeast Asia, manure from laying hens is often managed in liquid systems, while long-term pit storage is common in other regions, such as the Near East and North Africa. Here, the resulting anaerobic conditions combine with the high ambient temperatures to produce high MCFs (see Map 8).

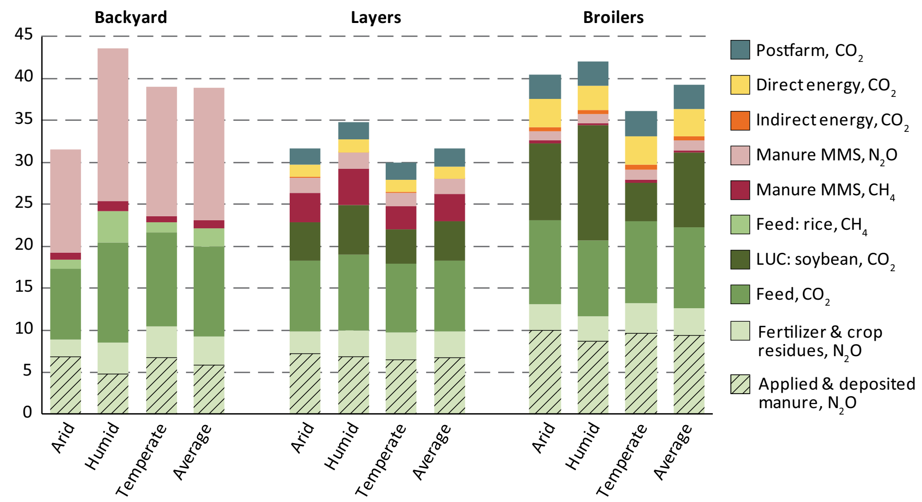
The amount of N excreted per unit of protein produced depends on how well-matched the intake is to the chickens' requirements, and the feed conversion ratio. There should be better matching in commercial systems where animal nutrition is better understood and there is greater scope for adjusting the ration to meet the chickens' changing nutritional requirements. Manure N_2O emissions are higher for backyard systems, for the reasons explained in Section 4.2.2. The manure N_2O emissions in backyard systems are greater in East and Southeast Asia, and Sub-Saharan Africa, where the feed conversion ratios are highest.

Direct energy and postfarm emissions

The main direct on-farm energy uses are heating, lighting and ventilation for broilers, and ventilation and lighting for layers (see Appendix E).

As with pigs, emissions arising from direct on-farm energy use and postfarm processing vary regionally, depending on the ways by which electricity is generated and transmitted.

Figure 38.
Effect of agro-ecological zone on emission intensity



Source: GLEAM.

Postfarm emissions vary between regions, depending on the nature of the supply chains within each country (i.e. the proportion that is sold directly versus the proportion that enters the retail supply chain) and on postprocessing transport emissions. Regions that export a significant proportion of their production (such as Europe, North America and Latin America) will have higher transport emissions than regions where most production is consumed domestically.

Influence of agro-ecological zones on emission intensity

Backyard chickens in arid areas have lower emissions for all categories (see Figure 38). This is because these arid areas are predominantly in India, which has a relatively efficient backyard flock (i.e. lower death rates and higher fertility rates) compared with other countries. In addition, emission intensity in humid areas is increased by CH_4 from rice, which forms a larger part of rations in these areas.

For layers, the main differences between AEZs are the higher manure CH_4 in arid and humid areas (reflecting the relationship between ambient temperature and CH_4 conversion factor) and also the higher emissions from LUC in humid areas, as these include countries, such as Brazil, Thailand and Indonesia, where rations contain significant proportions of soybean associated with LUC. The effect of soybean LUC emissions is even more marked for broilers than for layers and is the main cause of variation between the three AEZs.

5.3 ANALYSIS OF UNCERTAINTY FOR CHICKENS

This analysis is also based on the Monte Carlo simulation approach. For a brief explanation of how it was undertaken, see the analysis of uncertainty for pigs in Section 4.3.

Table 24. Emissions categories contributing more than 10 percent of total global emissions: chickens

	Backyard	Layers	Broilers	ALL
Feed CO_2	Y	Y	Y	Y
Manure CH_4	N	Y	N	N
Feed N_2O	Y	Y	Y	Y
Feed LUC CO_2	N	Y	Y	Y
Manure N_2O	Y	N	N	N

Source: GLEAM.

Table 25. Approaches used for varying CH_4 conversion factor (MCF): chickens

System/species	Approach	Basis
ALL	MCF CV[1]=10%	Assuming IPCC (2006, 10.48) uncertainty range of +/-20% is for 5th/95th percentiles

[1] The 95 percent confidence interval is approximately equal to the standard deviation, or coefficient of variation, multiplied by two, e.g. if the mean is 20 and the standard deviation is 4, then the coefficient of variation is 4/20*100 percent = 20 percent, and the range at the 95 percent confidence interval is 20 percent*2, i.e. +/-40 percent.

5.3.1 Identification of main emissions categories

In order to focus analysis of uncertainty, parameters were identified that (a) were likely to have a significant influence on the most important emissions categories (i.e. emissions categories contributing more than ten percent of the total emissions) and (b) had a high degree of uncertainty or inherent variability (see Table 24).

Countries with significantly sized sectors and systems, where data availability was expected to be better than average (for the given species and systems) were chosen for the Monte Carlo analysis: layers and broilers in the United Kingdom and backyard chickens in Viet Nam.

5.3.2 Selection of parameters for inclusion in the analysis and their ranges

Manure CH_4

The two main drivers of manure CH_4 are (a) the amount of volatile solids excreted per kg of protein and (b) the rate at which the VS are converted to CH_4. The underlying parameter of feed digestibility was tested instead of VSx (see Section 4.3 for further explanation and Tables 25 and 26 for variation of parameters).

Feed land-use change CO_2

The increase of emissions that results from LUC to grow soybean is subject to uncertainty in terms of both the percentage of soybean in the ration, and the EF of the soybean (see Tables 27 and Appendix C).

N_2O and CO_2 arising from feed production

Feed N_2O has high degrees of uncertainty regarding (a) the rates at which organic and synthetic N are applied to crops and (b) the rate at which the applied N is converted to N_2O.

Table 26. Approaches used for varying the digestibility of the ration: chickens

System/species	Range	Basis
Layers: *United Kingdom*	Ration digestibility CV = 5%	Based on ranges of ME given by Jeroch *et al.* (2011)
Broilers: *United Kingdom*	Ration digestibility CV = 5%	Based on ranges of ME given by Petri and Lemme (2007)
Backyard chickens: *Viet Nam*	Swill digestibility CV = 5%	Sonaiya and Swan (2004, p15)
	Vary % of swill in ration	Assumption that proportion of swill and local rice will (inversely) co-vary

Table 27. Approaches used for varying soybean percent and emission factors: chickens

System/species	Range	Basis
Layers: *United Kingdom*	Soybean % in the ration CV = 30% EFs = see Appendix C	Expert opinion
Broilers: *United Kingdom*	Soybean % in the ration CV = 30% EFs: see Appendix C	Expert opinion
Backyard chickens: *Viet Nam*	NA – no LUC	

NA: Not Applicable.

Characterizing the uncertainty of feed CO_2 (not including soybean LUC) is challenging as it requires some knowledge of where the feed materials are sourced, and also of the uncertainty of ranges of the relevant input parameters in the countries where the feed is produced.

For more explanation on parameters chosen for these two categories, refer to Section 4.3 of this report.

Herd/flock parameters

Herd/flock parameters have a significant impact on emission intensity, by altering the FCR of the individual animal, and the ratio of productive to unproductive animals in the herd or flock. These parameters are particularly difficult to define with precision in backyard systems, where data is scarce and parameters can vary considerably in response to variations, such as health status, ration, growth rates and slaughter weights. The ranges for key parameters are given in Table 28.

Where possible, the most fundamental parameters were selected for inclusion in the uncertainty analysis. Some parameters were excluded as they were thought to have limited influence on emission intensity. For example, the layer death rate makes little difference to the emission intensity, as the breeding overhead is less than one percent of the laying flock, while increasing the death rate simply increases the size of the (very small) breeding flock.

In GLEAM, not all the herd parameters require ranges, as some are dependent on others. Thus, varying the number of eggs will automatically vary the feed intake and the FCR. As Leinonen *et al.* (2012b) note, varying underlying parameters within a Tier 2-type model has the advantage that it provides a way of accounting for correlation between different parameters, as “these relationships (between parameters) are automatically built into results”. However, not all relationships may be built in, so care should be taken to avoid inconsistent combinations of values of parameters arising during the simulation.

Table 28. Ranges for key herd parameters: chickens

System/species	Coefficient of variation *(percentage)*	Basis
Layers: *United Kingdom*	Eggs per bird = 4	Leinonen (2012a)
Broilers: *United Kingdom*	Feed intake = 6 Juvenile chickens mortality = 15 Killing out % = 5	Teeter (2011) Leinonen (2012b) Leinonen (2012b)
Backyard chickens: *Viet Nam*	Eggs per year = 10 Egg weight = 8 Mortality = 17	Sonaiya and Swan (2004)

5.3.3 Results of the Monte Carlo analysis for chickens

As with pigs, the distributions of results are Lognormal (Table 29) and asymmetric.

The variance in the two industrial systems (layers and broilers) is comparable, and for both systems variation in the EF for direct N_2O (EF1), the digestibility of the ration (i.e. ME) and the percentage of soybean in the ration are important. Variation in the feed intake and killing out percentage (the CW as a percentage of LW) are also important for broilers. The backyard system has higher variance, which results from quite different drivers from the industrial systems. It is assumed that half of the manure from backyard chickens is deposited directly on the ground by scavenging birds, which leads to high manure N_2O emissions. As a consequence, variation in EF3 (the N_2O emissions factor for N deposited on pasture, range or paddock) is the main driver of variation in the emission intensity of the backyard chickens in this example.

5.4 COMPARISON OF THE CHICKEN RESULTS WITH OTHER STUDIES

The results from this study for broilers tend to be higher than previous studies, while there is no systematic difference between the results for layers in this study and other studies (see Table 30). Common reasons for the differences are described briefly below.

5.4.1 Scope

Although efforts were made to normalize the scope of the studies, this was not always possible, due to lack of disaggregation or information.

5.4.2 Ration

Differences in the proportions of feed material making up the ration can lead to significant differences in the feed and (to a lesser extent) the manure emissions. Rations vary over time and space and are, therefore, something of a moving target. The rations used in this study were based as far as possible on empirical evidence, and key parameters (digestibility and protein content) were checked. While there is no guarantee that these parameters will be the same as in other studies, it is believed that they are a reasonable reflection of typical rations.

5.4.3 Soybean and soymeal LUC

The total emission intensity is particularly sensitive to the assumptions made about soybean and soymeal. In addition to the amount of soybean in the ration, differences in either of the following parameters can lead to significant differences in the overall emission intensity:

- the country of origin of the soybean/soymeal
- the emissions per ha of soybean/soymeal

Table 29. Summary of the results of the Monte Carlo analysis for chickens

	Backyard *Viet Nam*	**Broilers** *United Kingdom*	**Layers** *United Kingdom*
Mean emission intensity *(kg CO_2-eq/kg protein)*	40.3	45.6	30.4
Emission intensity coefficient of variation *(percentage)*	16.6	13.8	13.2
Distribution	Lognormal	Lognormal	Lognormal
Contribution to variability of key parameters (excluding parameters contributing <5% to variance) *(percentage)*	EF3 (PRP N_2O): 72.6 Swill: 8.9 Eggs laid: -6.6	EF1 (direct N_2O): 21.4 Feed intake: 20.2 Soymeal %: 18.9 Feed ME: -12.4 Killing out %: -12.2 Soybean EF: 7.1	EF1 (direct N_2O): 45.2 Feed ME: -19.5 Soymeal %: 10.0

Source: Authors' calculations.

For example, Wiedemann *et al.* (2012) assume that all of Australia's imported soymeal comes from the USA, and therefore has no LUC emissions, whereas this study assumes (based on FAO trade statistics) that about 75 percent of the soymeal used in Australia is imported from Brazil. This seeming inconsistency arises because the two studies were for different years, and the amount of soybean imported from Brazil was about five times higher in 2005 than in 2009. In order to avoid anomalous results, rolling five-year averages may be advisable for parameters with significant temporal variation.

Emissions per unit of soybean associated with LUC can also vary a great deal. For example, Prudencio da Silva *et al.* (2010a) calculated Brazilian soybean emissions using the assumptions set out in Prudencio da Silva *et al.* (2010b) i.e. that "one percent of land use for soybean production was transformed from rainforest". This produces an EF of 0.3 kg CO_2-eq/kg DM for soybean LUC, which is much lower than the value used in this study, of 8.5 kg CO_2-eq/kg DM (for further discussion of soybean emission intensity, see Appendix C).

Soybean emission factor also accounts for some of the difference between this study and Leinonen *et al.* (2012a). Using their EFs (5.3 and 1.6 kg CO_2-eq/kg DM for Brazil and Argentina, respectively) would give an emission intensity of 5.8 kg CO_2-eq/kg CW. The remaining difference is probably due to the use of system expansion to provide credit for avoided fertilizer emissions and different crop N_2O calculation methods.

5.4.4 Feed N_2O

Calculating feed N_2O emissions is complex and there are a variety of potential input values and methods from which to choose. The IPCC (2006) guidelines provide uncertainty ranges as well as default values for direct and indirect N_2O emission factors etc., so that even two studies using the same method can lead to quite different results. For example, both this study and Wiedemann *et al.* (2012) used EF for direct N_2O that are within the IPCC (2006) ranges, but are quite different.

One of the main causes of difference between this study and others is the way in which the calculation of N_2O emissions arising from manure applied to crops is approached. In this study, the excreted N is assumed to be applied to crops and grassland within the 0.05 decimal degrees square cell where it is produced. Consequently, in areas with high concentrations of imported feed for livestock (i.e. where there are landless systems) the N excreted and applied can be in excess of the crop requirement, leading to high N_2O emissions. In reality, in some locations it can be cost-effective (and sometimes legally necessary) to transport N (particularly poultry litter) for tens or even hundreds of kilometres (see Mkhabela, 2004, Cooper, 2010 and Dunkley *et al.*, 2011).

It is recognized that the assumptions made in this study have the disadvantage of overestimating N_2O emissions from manure application in areas where litter is traded and widespread efforts are made to balance nutrient applications. However, this study's approach has the advantage of accounting for all emissions that arise from manure N. Simply assuming that nutrients are applied at optimal levels, presents the problem of estimates that do not fully account for the N excreted by livestock.

Ultimately, N_2O emissions should be based on a sound understanding of the nutrient budgeting practices in each country. While such an understanding is challenging in a global study, it will be a priority for future work.

5.4.5 Feed CO_2

In this study, the feed CO_2 category includes emissions arising from the following activities:

- energy used in field operations;
- energy used processing crops;
- energy used transporting crops to feed mills;
- energy used blending feed and transporting it to the point of use;
- energy used manufacturing synthetic fertilizer;
- energy used producing non-crop feed materials i.e. fishmeal, lime and synthetic additives.

While not exhaustive, this is a relatively comprehensive approach and includes more sources of feed CO_2 than most studies. Wherever possible, the feed CO_2 scope was adjusted to match other studies, so comparisons could be made. However, where insufficient information was available to allow matching, we have erred on the side of caution and have used the more comprehensive estimate of feed CO_2, leading, in some cases, to higher emissions.

The results show that feed CO_2 is a consistently important source of emissions across all regions and systems, so improving the assessment of feed CO_2 will be a priority for future work.

5.4.6 Manure management

Manure management emissions per animal are influenced by the volatile solid excretion rates, ambient temperature and the way in which the manure is managed. Most broilers are free housed on litter so the manure emissions tend to be low. The manure from layers, on the other hand, can be managed in a variety of ways, and produces quite different amounts of CH_4 and N_2O as a result. The emission intensity of manure management is, therefore, highly sensitive to the assumptions made about how the manure is managed. Unfortunately, information on manure management is scarce and, in the absence of authoritative data sets, informed assumptions have to be made, which can lead to quite different estimates of manure emissions. When checked against the other studies, the manure emissions in this study, while sometimes quite different, do not exhibit any systematic bias.

5.4.7 Allocation

The allocation required at different stages of analysis can produce significantly divergent results. For example, Nielsen *et al.* (2011) used systems expansion to credit broilers with avoided emissions from reduced fertilizer manufacture (manure) and mink feed (slaughter by-products). So while the FAO emissions *per kg of CW* are 33 percent higher than in Nielsen's study, there is, in fact, very little difference between the emissions when measured *per broiler*. Allocation also leads to differences between the FAO results and those of:

- Pelletier (2008) – allocation of emissions to by-products on the basis of energy;
- Wiedemann *et al.* (2012) – credit given for avoided synthetic fertilizer manufacture and use, allocation of emissions to by-products;
- Leinonen *et al.* (2012b) – credit given for avoided synthetic fertilizer manufacture.

5.4.8 Summary

There are some significant differences between the results in this study (notably for broilers) and other studies, even when they have the same scope. However, most of these differences can be explained by the different methodologies and assumptions employed, in particular regarding:

- scope of the analysis
- composition of the ration
- LUC emissions associated with soybean and soymeal
- feed N_2O
- feed CO_2
- allocation to by-products
- manure management

Table 30. Comparison of the emission intensity for broilers with other studies

Study	Country	System	Scope								Emissions intensity *(kg CO_2-eq/kg CW)*	
			Feed N_2O	Feed CO_2	Feed LUC	Manure CH_4	Manure N_2O	Direct energy	Indirect energy	Postfarm	Study	FAO (adjusted to same scope as study)
Williams *et al.* (2006)	United Kingdom	Standard indoor	Y	Y	N	Y	Y	Y	Y	N	4.57 (no LUC)	3.81 (no LUC) 6.67 (LUC)
Pelletier (2008)	USA	Standard indoor	Y	Y	NA	Y	Y	Y	N	N	1.40 kg CO_2-eq/kg LW (no LUC)	2.76 kg CO_2-eq/kg LW (no LUC)
Prudencio da Silva *et al.* (2010)	Brazil	Indoor (Large Scale Central West)	Y	Y	Y	Y	Y	?	?	~~	2.01	2.81 (no LUC) 7.71 (LUC)
	France	Indoor (Standard System)	Y	Y	Y	Y	Y	?	?	~~	2.56	2.24 (no LUC) 6.26 (LUC)
Lesschen *et al.* (2011)	EU27	Mainly standard indoor[a]	Y	~~	Y	Y	Y	~~	N	N	3.11 (LUC, no LU)	4.70 (LUC, no LU)
Neilsen *et al.* (2011)	Denmark	Mixture	Y	Y	N	Y	Y	Y	~~	~~	2.31	3.08 (no LUC) 3.96 (LUC)
Weiss and Leip (2011)	EU27	Mainly standard indoor[a]	Y	Y	Y	Y	Y	Y	N	N	2.48 (no LULUC) 3.31 (LUC II, no LU) 5.04 (LUCIII, no LU)	5.29 (LUC, no LU)
Wiedemann *et al.* (2012)	Australia	Standard indoor	Y	Y	N	Y	Y	Y	Y	~~	2.38 (Q'land) 1.89 (SA)	5.00 (no LUC) 3.61 (no LUC)
Leinonen *et al.* (2012b)	United Kingdom	Standard indoor	Y	Y	Y	Y	Y	Y	Y	N	4.40 (LUC)	6.67 (LUC)
Mollenhorst *et al.* (2006)	Netherlands	Conventional cage	Y	Y	N	Y	Y	Y	N	N	3.90 (no LUC)	2.85 (no LUC)
Williams *et al.* (2006)	United Kingdom	Conventional cage	Y	Y	N	Y	Y	Y	Y	N	5.53 (no LUC)	2.45 (no LUC) 3.62 (LUC)

(Continued)

Table 30. *(Continued)*

Study	Country	System	Scope								Emissions intensity *(kg CO_2-eq/kg EGG)*	
			Feed N_2O	Feed CO_2	Feed LUC	Manure CH_4	Manure N_2O	Direct energy	Indirect energy	Postfarm	Study	FAO (adjusted to same scope as study)
Dekker *et al.* (2008)	Netherlands	Organic	Y	Y	N	Y	Y	N	N	N	4.04	3.12 (no LUC) 4.35 (LUC)
Cederberg *et al.* (2009)	Sweden	38% cage 56% free range 6% organic FR	Y	Y	N	Y	Y	Y	N	N	1.42	1.92 (no LUC) 1.93 (LUC)
Verge *et al.* (2009)	Canada	Conventional cage	Y	~~	NA	Y	Y	Y	N	N	2.65 (no LUC)	3.27 (no LUC)
Weiss and Leip (2011)	EU27	Mainly conventional cage[b]	Y	Y	Y	Y	Y	Y	N	N	1.57 (no LULUC) 1.79 (LUC II, no LU) 2.15 (LUC III, no LU)	2.27 (no LULUC) 3.61 (LUC, no LU)
Lesschen *et al.* (2011)	EU27	Mainly conventional cage[b]	Y	~~	Y	Y	Y	~~	N	N	1.34 (no LUC or LU) 2.40 (LUC, no LU)	1.89 (no LULUC) 3.23 (LUC, no LU)
Wiedemann and McGahan (2011)	Australia	Conventional cage	Y	Y	N	Y	Y	Y	Y	~~	1.30 (no LUC)	3.36 (no LUC)
Leinonen *et al.* (2012a)	United Kingdom	Conventional cage Barn	Y	Y	Y	Y	Y	Y	Y	N	2.92 3.45	3.62 (LUC) 3.26[c]

Y: included; N: not included; NA: not applicable (soybean used in this country not associated with LUC); ~~ = partially included.
? = it is uncertain whether or not this emissions category is included.
[a] For proportions of flock in different housing, see Van Horne and Achterbosch (2008).
[b] See Van Horne and Achterbosch (2008).
[c] Using same soybean LUC EF.

6. Summary of production and emission intensities

The total production and emissions for pig meat, chicken meat and eggs are summarized in Table 31. A brief explanation of why the differences between the emission intensity of chicken and pig production arise is provided below, along with a summary of key explanatory parameters in Table 32.

6.1 COMMERCIAL SYSTEMS (LAYERS, BROILERS, INDUSTRIAL AND INTERMEDIATE PIGS)

Chicken meat and eggs have lower emissions per kg of protein than pigs for a number of reasons:

- Due primarily to physiological differences, the individual broiler or laying hen tends to be a more efficient converter of feed into edible protein than the growing pig.
- Chickens have higher fertility rates than pigs, which means that the proportion of the animals required to maintain the flock/herd size rather than to produce food (the "breeding overhead") is smaller for chickens than it is for pigs.
- The smaller breeding overhead in chicken flocks leads to a proportionate reduction in the FCR at the flock/herd scale compared to pigs. While chickens tend to have higher feed emissions per *kg of feed* (due in part to greater use of soybean and high spatial concentrations of N excretion), their lower FCR compensates to produce lower feed emissions per *kg of protein* produced.
- The smaller breeding overhead in chicken flocks also leads to a proportionate reduction in the amount of manure excreted per kg of protein produced. Furthermore, the rate of conversion of excreted volatile solids to CH_4 during manure management is lower for egg layers and (in particular) broilers than for pigs, due to the greater use of anaerobic manure management systems in pig production.
- Chickens are assumed to produce negligible enteric CH_4 emissions.

6.2 BACKYARD SYSTEMS

Feed emissions per kg of protein produced are similar for both pigs and chickens, as the higher chicken FCR is offset by lower emissions per kg of feed. Most of the differences between the species is due to manure management, specifically the greater use of liquid systems in backyard pig systems, which leads to much higher manure CH_4 emissions, and higher manure emissions overall (despite the lower N_2O emissions from backyard pigs' manure). In addition, enteric fermentation contributes another 2.7 kg CO_2-eq/kg protein to the emission intensity of backyard pigs.

6.3 GAPS IN EMISSION INTENSITY WITHIN SYSTEMS AND REGIONS

Average emission intensities for every combination of system, region and AEZ are presented in Tables 33 and 34, as well as the lowest and highest emission intensity of pixels accounting for 10 percent of the production in the same system-region-

Table 31. Summary of total global production and emissions for pig meat, chicken meat and eggs

	Production *(Million tonnes product*/year)*	Production *(Million tonnes protein/year)*	Emissions *(Million tonnes CO_2-eq/year)*	Emission intensity *(kg CO_2-eq/kg product*)*	Emission intensity *(kg CO_2-eq/ kg protein)*
Pig meat	110	13	668	6.1	51.8
Chicken meat	72	10	389	5.4	39.5
Chicken eggs	58	7	217	3.7	31.5
Total	**240**	**30**	**1 274**	**5.3**	**43.0**

* Carcass weight or eggs.

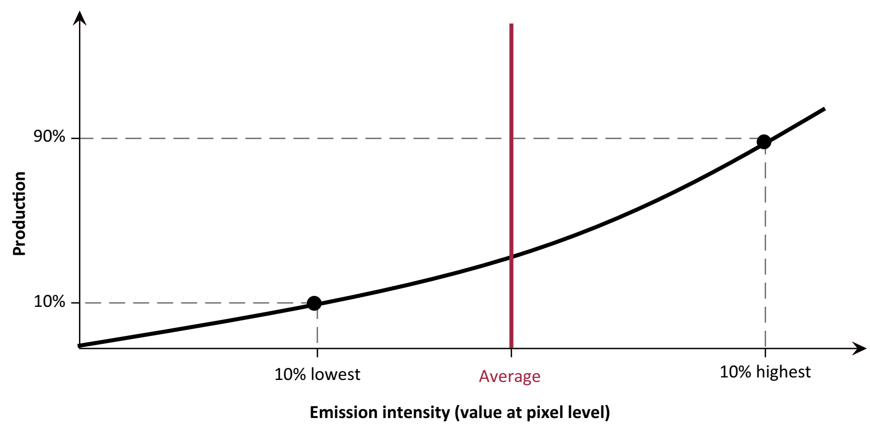
Source: GLEAM.

Table 32. Comparison of key parameters for pigs and chickens

	Pigs			Chickens		
	Backyard	**Intermediate**	**Industrial**	**Backyard**	**Broilers**	**Layers**
Total emission intensity *(kg CO_2-eq/kg protein)*	48.4	56.3	51.7	38.9	39.2	31.6
Feed emission intensity *(kg CO_2-eq/kg protein output)*	20.9	35.0	33.6	22.2	31.2	23.0
Feed emission intensity *(kg CO_2-eq/kg DM)*	0.31	0.88	1.07	0.26	1.50	1.18
Feed conversion ratio *(kg intake/kg protein)*	66.7	39.9	31.5	85.4	20.7	19.4
Volatile solids excreted *(kg VSx/kg protein output)*	18.6	8.4	5.2	22.5	4.0	3.6
CH_4 conversion factor *(percentage)*	17.2	26.1	23.3	1.0	1.5	21.0

Source: GLEAM.

Figure 39.
Schematic representation of emission intensity gap, for a given commodity, within a region, and farming system



Source: Authors.

AEZ (see Figure 39 for calculation method). The gaps between these low and high emission intensity are substantial for pigs and chickens. For example, in pig industrial systems of East and South East Asia in humid agro-ecological conditions, the average emission intensity is 6.15 kg CO_2-eq/kg CW, whereas the lowest is 5.37 and the highest 7.94. This means that there is a potential for improvement between producers in the same region and production system. This mitigation potential doesn't require changes in farming systems and can be based on already existing technologies and practices. It is estimated to 30% of the sector's total emissions and further explored in the overview report published in parallel of this one (FAO, 2013a). This situation is completed by case study analysis to explore regional dimensions of mitigation in the sector.

The "Average" value is calculated at regional-climatic zone level, by dividing total emissions by total output. The "10% lowest" value is the upper bound of lowest emission intensities up to 10% of production. The "10% highest" value is the lower bound of highest emission intensities down to 90% of production.

Table 33. Variation of pigs emission intensity within regions, systems and agro-ecological zone, in kg CO_2-eq/kg CW (regions representing less than 1% of global production within systems are not included)

	Arid			Temperate			Humid		
	10% lowest	Average	10% highest	10% lowest	Average	10% highest	10% lowest	Average	10% highest
Backyard									
LAC	4.17	5.73	6.97	3.78	4.69	5.43	5.38	6.40	7.47
E & SE Asia	4.90	5.54	6.56	4.49	5.15	5.79	5.32	5.99	7.05
E. Europe	5.14	5.24	5.45	4.16	4.81	5.32	NA	NA	NA
Russian Fed	6.25	6.62	7.83	4.64	5.10	5.19	6.01	7.81	8.55
South Asia	6.20	6.98	7.46	3.43	4.47	5.90	5.57	6.69	7.57
SSA	0.86	5.41	8.30	3.64	4.47	5.49	5.07	6.76	7.94
Intermediate									
LAC	4.11	5.53	8.08	4.18	5.01	6.34	4.91	7.11	9.40
E & SE Asia	6.02	6.63	8.22	5.16	6.27	8.80	6.28	7.09	8.42
E. Europe	4.71	4.86	5.01	4.84	5.27	6.43	4.67	4.74	4.83
South Asia	6.49	7.40	8.18	5.18	7.47	12.62	6.77	8.18	10.92
SSA	4.75	7.29	9.96	4.49	5.75	8.15	5.06	7.55	12.67
Industrial									
LAC	4.09	6.74	9.47	4.15	5.81	10.34	4.67	9.05	11.28
E & SE Asia	5.31	5.78	7.03	5.1	5.88	6.91	5.37	6.15	7.94
E. Europe	4.40	4.57	4.67	4.40	5.37	6.41	4.39	4.47	4.52
N. America	4.41	4.87	5.30	4.13	4.53	4.77	4.87	5.26	5.80
Russian Fed	4.56	4.82	5.14	4.52	4.71	4.71	4.75	5.00	5.19
W. Europe	4.63	8.36	10.40	4.44	6.02	7.13	4.85	7.03	10.22

Note: Some regions may not have data for a combination of system and AEZ or production is insignificant within the system and AEZ. The ´average' is calculated at regional-climatic zone level. "10% lowest" is the upper bound of lowest emission intensities up to 10% of production. "10% highest" is the lower bound of highest emission intensities down to 90% of production.

Source: GLEAM.

NA: Not Applicable

Table 34. Variation of chickens emission intensity within regions, systems and agro-ecological zone in kg CO_2-eq/kg egg or meat CW (regions representing less than 2% of global production within systems are not included)

	Arid			Temperate			Humid		
	10% lowest	Average	10% highest	10% lowest	Average	10% highest	10% lowest	Average	10% highest
Backyard *(kg CO_2-eq/kg egg)*									
LAC	2.52	3.13	3.95	2.36	3.25	5.29	2.48	3.17	4.32
E & SE Asia	4.46	5.11	6.16	4.76	5.98	7.50	4.31	6.53	8.62
E. Europe	2.18	2.35	2.55	1.82	2.39	2.51	2.23	2.40	2.59
Russian Fed	3.65	4.41	6.07	1.89	2.39	2.47	2.79	4.05	4.61
South Asia	2.05	2.62	3.43	2.17	2.63	3.50	2.16	2.49	2.96
SSA	2.75	4.85	8.37	2.51	3.41	4.67	3.54	5.93	8.68
NENA	0.93	3.50	6.63	1.38	3.30	6.09	1.08	1.64	2.50
Layers *(kg CO_2-eq/kg egg)*									
LAC	2.19	3.43	5.82	2.06	3.00	3.48	2.31	4.65	7.14
E & SE Asia	3.26	3.73	4.43	3.14	3.96	5.40	3.26	3.81	5.34
E. Europe	1.89	2.03	2.39	2.26	2.38	2.60	1.89	1.96	2.04
N. America	1.92	3.21	4.81	1.82	2.98	3.37	1.99	2.41	2.91
Russian Fed	2.16	2.41	2.72	2.17	2.38	2.43	2.40	2.67	2.90
South Asia	2.58	3.27	3.67	2.67	3.44	4.00	2.78	3.54	4.71
NENA	2.35	3.60	4.77	1.66	2.49	3.09	2.94	3.20	3.28
W. Europe	3.63	4.73	5.41	2.33	3.71	4.96	3.71	5.15	5.88
Broilers *(kg CO_2-eq/kg CW)*									
LAC	2.36	4.59	7.61	2.43	4.24	7.54	2.47	6.51	9.24
E & SE Asia	4.04	4.99	6.51	4.41	5.54	7.74	4.19	5.18	6.84
E. Europe	2.60	2.85	3.27	2.90	3.41	3.87	2.59	2.72	2.79
N. America	3.04	4.89	7.02	3.04	4.66	5.25	3.09	3.71	4.44
South Asia	3.73	6.67	9.16	3.57	5.01	6.63	3.60	5.32	7.14
NENA	3.34	5.87	8.01	2.81	4.51	5.33	4.31	4.79	5.66
W. Europe	4.81	6.33	7.71	3.55	5.93	7.54	5.70	8.03	9.13

Note: Some regions may not have data for a combination of system and AEZ or production is insignificant within the system and AEZ. The ´average' is calculated at regional-climatic zone level. "10% lowest" is the upper bound of lowest emission intensities up to 10% of production. "10% highest" is the lower bound of highest emission intensities down to 90% of production.

Source: GLEAM.

7. Conclusions

Monogastrics are an increasingly important source of food. The contribution of chicken to diets is growing particularly rapidly, given their biological performance and social acceptability. While pig and chicken supply chains have relatively low emissions, the sectors' scale and rate of growth requires further reductions in emission intensity.

Globally, pig supply chains are estimated to produce 152 million tonnes LW or 110 million tonnes CW per annum and related GHG emissions of 668 million tonnes CO_2-eq. Industrial systems account for about two-thirds of the output, with backyard and intermediate each accounting for half of the rest. The average emission intensity of pig meat is 6.1 kg CO_2-eq/kg CW, with feed production and manure management representing the main categories of emission.

Globally, chicken supply chains are estimated to produce 58 million tonnes of eggs and 72 million tonnes CW per annum and the related GHG emissions of 606 million tonnes CO_2-eq. Industrial systems account for over 90 percent of the output on a protein basis. The average emission intensity of chicken is 5.4 kg CO_2-eq/kg CW for meat and 3.7 kg CO_2-eq/kg eggs. Feed production is the main source of emissions but manure emissions are also significant, especially in laying and backyard systems. When the CO_2 emissions arising from all energy use across the supply chain are aggregated, they amount to more than a third of emissions. Emission intensities are relatively homogeneous when compared to other species, reflecting the standardization of production. Variation in the emission intensity of feed, which is influenced by the type and origin of the feed materials that make up the ration, accounts for much of the regional differences in the emission intensity of chicken production.

The ranges of emission intensity within production systems suggest that there is room for improvement. 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, the following points should be borne in mind: (a) differences in emission intensity may reflect differences in production systems that have arisen over time to enable the system to perform better within a given context, e.g. to make them more profitable, or resilient; (b) focusing on a single measure of efficiency (in this case GHG emissions per kg of output) can lead to positive and negative side effects on, for instance, biodiversity, water quality and animal welfare; (c) reducing GHG emissions is not the only objective producers need to satisfy, as they also need to respond to changing economic and physical conditions. Bearing these caveats in mind, the results of this study indicate six target areas with high mitigation potential:

- reducing LUC arising from feed crop cultivation;
- improving the efficiency of crop production, particularly fertilization management, i.e. soil quality and balanced plant nutrition;

- improving the efficiency of energy generation and supply, and of energy use, both on-farm, in housing and fieldwork, and off-farm, in the manufacture of inputs and the transportation and processing of farm products;
- improving manure management – reducing the use of uncovered liquid manure management systems, particularly in warm climates;
- improving the feed conversion ratio at the animal level (e.g. through breeding) and at the herd/flock level (e.g. by reducing losses to disease and predation, particularly in backyard systems);
- providing balanced animal nutrition.

Caution should be exercised when drawing specific policy conclusions from what is essentially a static analysis. For example, the lower emission intensity of backyard systems in some regions does not imply that expansion of backyard production would be a viable mitigation strategy. There are several reasons for this. Firstly, the lower emission intensity of backyard systems is partly due to the assumed low economic value of second-grade crops, however the value of these crops is uncertain and variable. Secondly, an expansion in backyard production would lead to (or require) increased production of second-grade crops, i.e. increased waste in crop production. If demand for these crops increased more rapidly than supply, then the economic value of the second-grade crops, the emissions allocated to them and, consequently, the emission intensity of the backyard systems themselves, would also be likely to rise. Finally, there may be regulatory barriers to the use of swill, as use of food wastes as feed is banned for legitimate safety and animal health reasons in some countries. The extent to which backyard production could be expanded, and the effect of expansion on emission intensity, are complex questions that require future analysis.

Comparison of this study with others shows that methods matter. Discrepancies in results can often be explained with reference to methodological differences: system boundaries, allocation and emissions calculation (especially with regard to LUC, feed N_2O and feed CO_2). Such differences can make it difficult to compare results and set priorities for the continuous improvement of environmental performance along supply chains. Efforts are, therefore, needed to harmonize approaches and data used in this kind of analysis.

This report presents an update and refinement of the previous emission estimates given 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 coefficient of variation varies between 9.2 and 16.6 percent.

Priorities for refinement of GLEAM include improving:

- Information regarding the composition of feed rations, particularly the amount of the feed crop associated with land-use change in the ration;
- Information on manure management, especially for pigs;

- Quantification of the emissions and C sequestration associated with land use and land-use change;
- Methods for allocation of emissions, especially for slaughter by-products;
- Methods for quantifying feed N_2O that better reflect where and how manure N is applied to crops;
- Assessment of feed CO_2 that better reflects variations in tillage regimes, transport and manufacturing efficiency.

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[12] will be instrumental in furthering these developments. This multistakeholder initiative, facilitated by FAO, brings together 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. An important area of work will be the development of guidelines for the LCA of GHG emissions, to address questions such as allocation, functional units and changes in soil carbon stocks related to land use and LUC. The Partnership aims at developing metrics for other environmental dimensions, such as nutrient use efficiency, water and biodiversity.

While estimating GHG emissions from this 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 and the potential policies for achieving uptake of mitigation measures need to be better understood. 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 GLEAM model provides a consistent and transparent analytical framework with which to explore proposed mitigation methods, thereby providing an empirical basis for policy-making.

12 http://www.fao.org/ag/againfo/livestock-benchmarking/en/