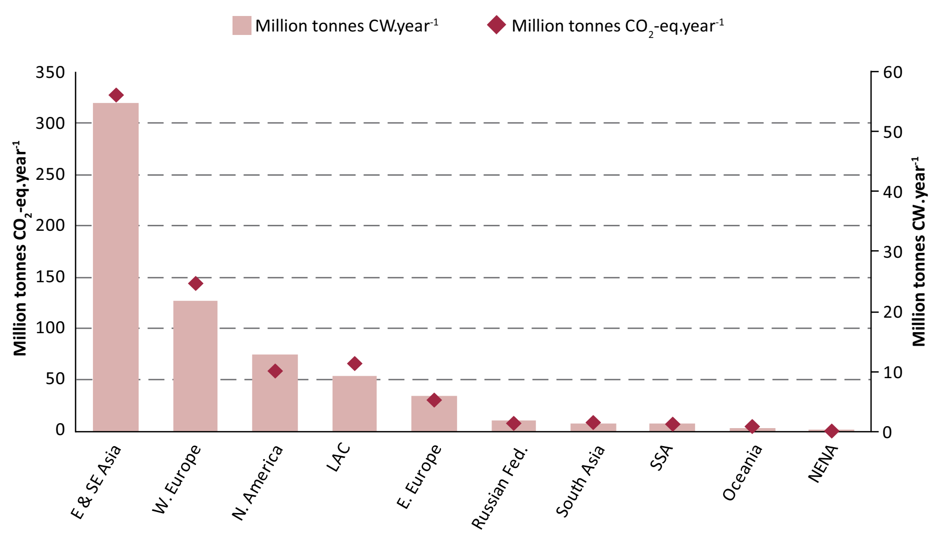
4. Results for pig supply chains

4.1 GLOBAL PRODUCTION AND EMISSIONS

The annual production and emissions for each of the pig systems is shown in Figures 4 and 5. The combined production for all three systems is 152 million tonnes live weight (LW) or 110 million tonnes CW[11], which causes emissions of 668 million tonnes CO_2-eq. Figure 23 shows the amount of the total global pig meat produced in each combination of AEZ and system. Temperate areas account for 56 percent of production and industrial systems for 61 percent, with industrial pigs in temperate areas accounting for 37 percent. There is a marked geographical concentration of pigs, with 95 percent of production taking place in East and Southeast Asia, Europe and the Americas (see Figure 4 and Map 1 to 3). This concentration reflects both cultural preferences and the fact that industrial systems and, to a lesser extent, intermediate systems, have limited connection to the local land resource base or physical conditions. Their location is more influenced by factors such as cost of land, proximity to output markets, and availability of infrastructure and storage facilities (FAO, 2011 p. 44).

The categories of emissions used in this study are outlined in Table 2. Feed production contributes 47 percent of emissions, with an additional 13 percent related to land-use change caused by crop expansion (Figure 6). 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,

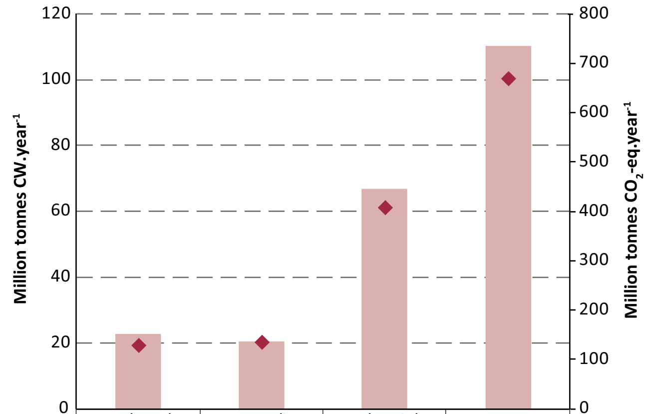
Figure 4.
Global pig production and emissions by region



Source: GLEAM.

[11] No emissions allocated to slaughterhouse by-products –cf. Appendix F.

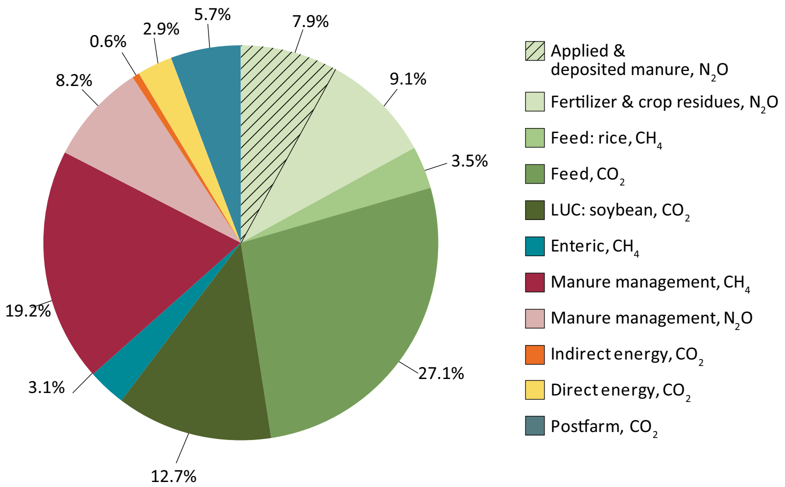
Figure 5.
Global pig production and emissions by system



	Backyard	Intermediate	Industrial	ALL
Million tonnes CW.year[-1]	22.9	20.5	66.8	110.2
Million tonnes CO_2-eq.year[-1]	127.5	133.9	406.6	667.9

Source: GLEAM.

Figure 6.
Breakdown of total global GHG emissions by category for pig supply chains



Source: GLEAM.

transport and processing of crops, feed blending and production of non-crop feed materials i.e. fishmeal and synthetic additives.

Emissions related to manure storage and processing, at 27 percent of the total, represent the next largest category. Most manure emissions are in the form of CH_4 (19 percent, predominantly from anaerobic storage systems in warm climates) while the rest is in the form of N_2O (8 percent).

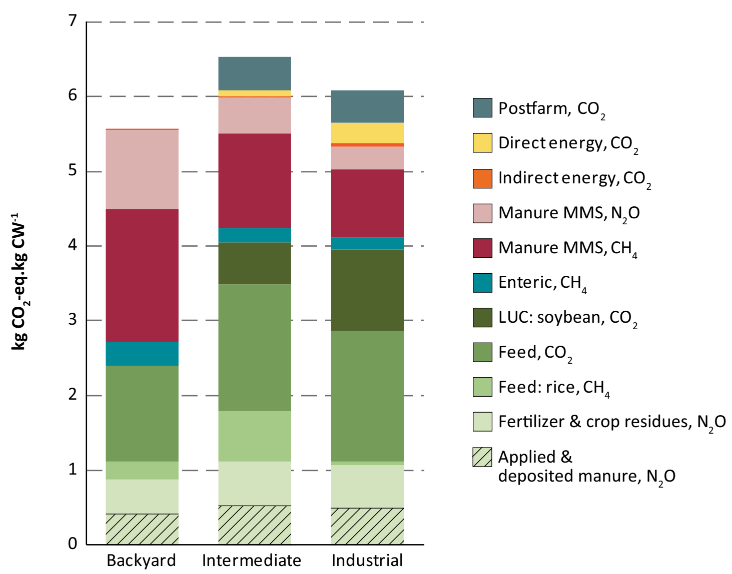
4.2 EMISSIONS INTENSITY

4.2.1 Variation in emission intensity between backyard, intermediate and industrial pig systems

The average emission intensity for each of the systems is shown in Figure 7. Overall emission intensity arising from feed production (coloured green) account for 60 percent and manure management (coloured brown) account for 27 percent. The total manure and feed emissions for backyard systems are 5.3 kg CO_2-eq/kg CW, which compares with 5.8 kg CO_2-eq/kg CW for intermediate systems and 5.2 kg CO_2-eq/kg CW for industrial systems. However, backyard systems are assumed to have negligible emissions arising from postfarm processing, on-farm energy use or manufacture of equipment and buildings, which means that overall they have the lowest emission intensity of the three systems.

Backyard systems have the highest manure emissions, reflecting their higher FCR and lower digestibility of the ration (the global average ration digestibility for backyard is 67 percent compared to 76 percent for intermediate and 81 percent for industrial; see Appendix B) which combine to produce significantly higher rates of volatile solid (VS) and N excretion per kg of protein produced (see Table 5).

Figure 7.
Global pig emission intensity by system



Source: GLEAM.

Table 5. Values of selected explanatory parameters: pigs

Parameter	System	Range of values		
		10th percentile*	50th percentile*	90th percentile*
FCR *(kg DM intake/ kg LW output)*	Backyard	4.8	4.9	5.2
	Intermediate	3.3	3.4	3.6
	Industrial	2.6	2.7	2.9
Ration digestible energy *(MJ/kg)*	Backyard	11.7	12.6	13.1
	Intermediate	13.6	14.4	14.8
	Industrial	14.6	15.9	15.9
Ration N content *(g N/kg DM)*	Backyard	28.0	37.8	38.9
	Intermediate	29.0	32.4	36.8
	Industrial	27.2	32.4	38.6
N excretion *(g N/head/day)*	Backyard	32.2	43.3	53.7
	Intermediate	33.5	38.7	46.3
	Industrial	29.3	38.0	55.3
N excretion *(kg N/kg protein output)*	Backyard	1.6	2.0	2.1
	Intermediate	0.8	1.0	1.1
	Industrial	0.5	0.7	1.0
N retention *(kg N retained/ kg N intake)*	Backyard	0.14	0.15	0.18
	Intermediate	0.20	0.23	0.25
	Industrial	0.22	0.30	0.35
Rate of conversion of excreted N to N_2O-N *(percentage)*	Backyard	1.0	1.0	1.0
	Intermediate	0.6	0.6	1.6
	Industrial	0.5	0.6	0.9
Volatile solids excretion *(kg VSx/head/day)*	Backyard	0.35	0.39	0.48
	Intermediate	0.30	0.32	0.37
	Industrial	0.24	0.26	0.37
Volatile solids excretion *(kg VSx/kg protein output)*	Backyard	16.7	18.4	21.7
	Intermediate	7.6	8.0	9.7
	Industrial	4.4	4.6	6.4
MCF *(percentage)*	Backyard	12	14	28
	Intermediate	6	27	31
	Industrial	11	27	31

* 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.

Note: The values in this table represent the averages over the whole herd, rather than just the growing pigs.
Source: GLEAM.

In backyard systems, higher manure emissions are offset by lower feed emissions. Despite higher average FCR in backyard systems, emissions per kg of feed are typically less than half those of other systems. This situation results from the following factors:

- Soybean and soymeal in backyard systems is assumed to be not associated with LUC.
- There is greater use of swill, which is not allocated emissions.
- There is a greater use of low-quality second grade crops, which have a lower economic value and are consequently allocated a lower proportion of the emissions.
- There is greater use of locally-produced feeds, which have lower emissions associated with transport.

The emission intensity of intermediate systems is higher than industrial systems as a result of three factors:

- higher FCR;
- lower digestibility of ration;
- higher rice CH_4 emissions because a greater proportion of the intermediate herd is in locations where there is flooded rice production (see Table 5 and Map 1 to 3).

4.2.2 Geographical variation in emissions intensity

The emission intensity for each system is shown by region in Figures 9 to 12. A brief qualitative overview of the drivers of variation is given below.

Animal performance and herd structure

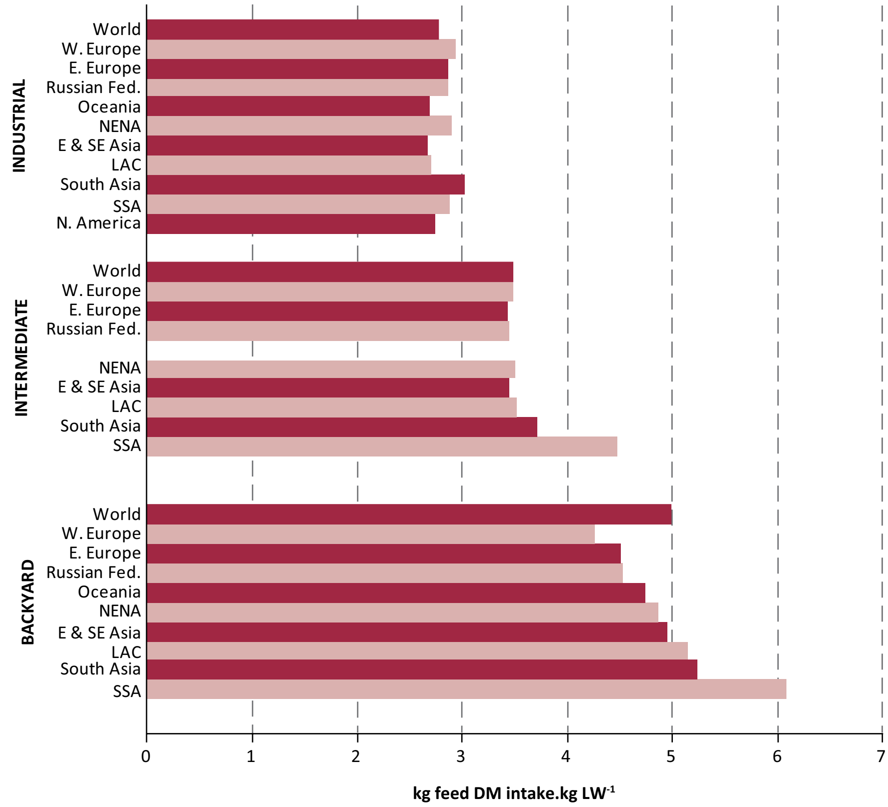
The physical performance of pigs can vary depending on a wide range of factors, such as genetics, diet, housing and management. These factors produce marked differences in growth rates, fertility rates and death rates which, in turn, produce significant variation in both individual animal performance and the overall herd structure. These variations can affect emissions per kg in all categories — aside from postfarm emissions — by:

- changing the proportion of the total energy intake devoted to growth of pigs, rather than unproductive activities such as maintenance;
- changing the relative proportions of each animal type within the herd. For example, increasing the sow fertility rate will lead to a reduction in the ratio of breeding/growing animals;
- reducing losses through mortality.

The efficiency with which the herd (rather than the individual pig) converts feed into LW can be used to measure the relative efficiency of different pig herds. Figure 8 shows the average regional FCR for the three pig systems calculated in GLEAM.

The FCRs in Figure 8 are expressed in terms of the herd feed intake divided by the herd LW output. In other words, they include the feed consumed by mature breeding animals that are not growing (or are growing slowly). FCR is usually expressed for the growing animal. In order for a comparison to be made with other studies, the average FCRs for meat pigs during the rearing and finishing periods are given in Table 6. There appears to be good agreement between the FCRs used in this study and those in other studies.

Figure 8.
Average feed conversion ratio of the pig herd, by region and system



Source: GLEAM.

Some of the main drivers of variation in FCR in growing pigs were outlined by Varley (2009) and are summarized below:

- age at slaughter: FCR increases with age as the pig deposits more fat as it get older, which has a higher feed energy cost than protein;
- genetics: FCR has a high heritability (see also Kyriazakis 2011);
- health status: according to Varley (2009) "sub-clinically sick pigs will return FCRs of four or five" and "high gut health is inextricably linked to a very low FCR index";
- nutrition: matching nutrient supply to requirements by phase feeding and/or monitoring feed quality helps to achieve an optimum lysine to energy ratio.

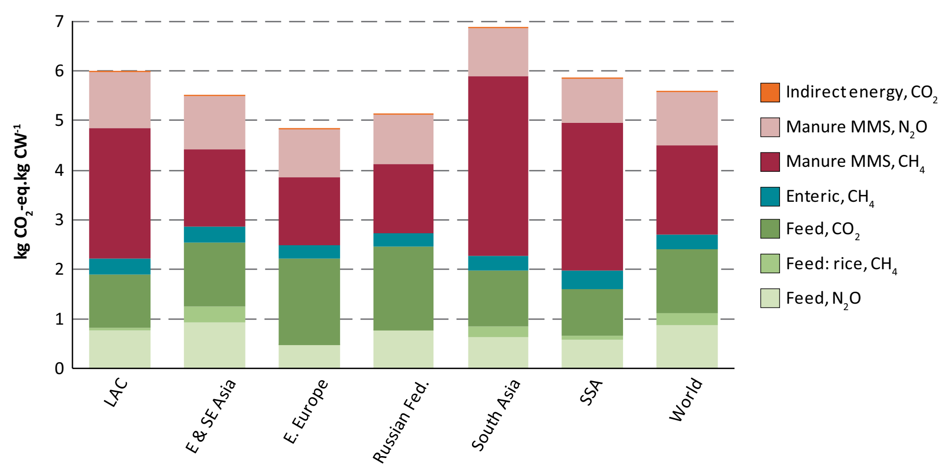
At the herd level, FCR is also influenced by the proportion of breeding animals in the herd. Breeding pigs have higher FCRs than growing pigs, so the herd FCR will increase as the proportion of breeding animals in the herd increases. The proportions of breeding to growing animals are determined primarily by sow fertility and replacement rates and by piglet/weaner death and growth rates. In addition, the herd FCR in Table 6 only includes the LW of pigs that enter the human food chain. Higher death rates will increase the FCR.

Table 6. Feed conversion ratios for industrial systems for the herd and for the growing pig

Industrial	Herd FCR*	Growing pig FCR*	
	This study (GLEAM)	This study (GLEAM)	BPEX (2010, p19)
LAC	2.71	2.44	2.47[a]
E & SE Asia	2.66	2.40	
E. Europe	2.85	2.58	
N. America	2.73	2.47	
Oceania	2.69	2.42	2.58[b]
Russian Fed.	2.87	2.59	
South Asia	3.01	2.72	
SSA	2.87	2.59	
NENA	2.90	2.62	
W. Europe	2.93	2.65	2.54[c]

* The average FCR during rearing and finishing.
[a] Value for Brazil.
[b] Value for Australia.
[c] European Union (EU) average value.

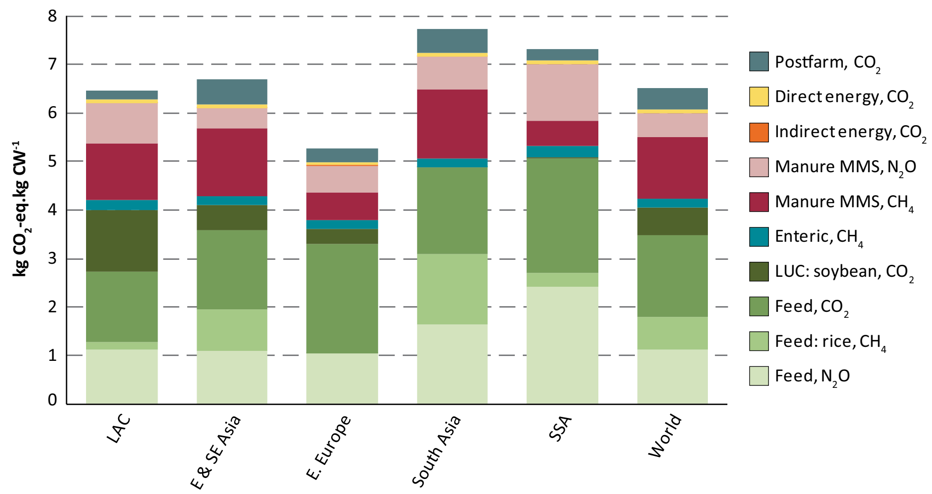
Figure 9.
Backyard pigs emission intensities (regions with less than one percent of backyard production are omitted)



Source: GLEAM.

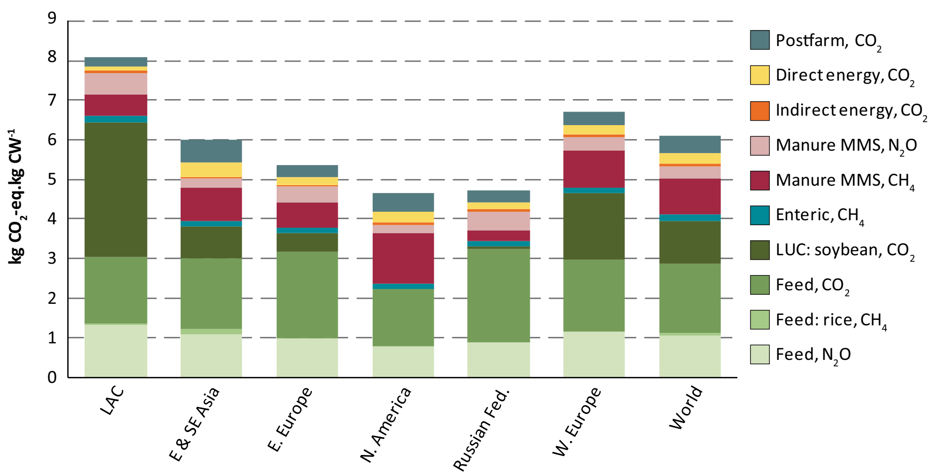
Overall, industrial systems have significantly lower FCRs than the backyard or intermediate systems, which is to be expected given the faster growth rates, higher fertility rates and lower death rates in these systems. At the regional scale, FCR varies most in the backyard systems, where there is a greater variety in genetic potential, health status and nutrition. National differences in FCR can be significant within all three systems; for example, Italian pigs tend to be slower growing and longer lived than those of other European countries, which leads to a higher FCR than the EU average. Figure 9 to 12 show the emission intensity for pigs by system.

Figure 10.
Intermediate pigs emission intensities (regions with less than one percent of intermediate production are omitted)



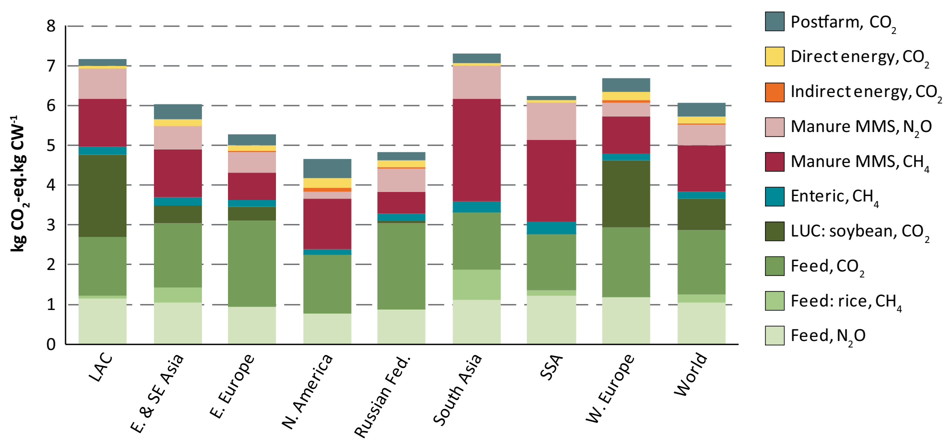
Source: GLEAM.

Figure 11.
Industrial pigs emission intensities (regions with less than one percent of industrial production are omitted)



Source: GLEAM.

Figure 12.
All pigs emission intensities (regions with less than one percent of total production are omitted)



Source: GLEAM.

Feed emissions

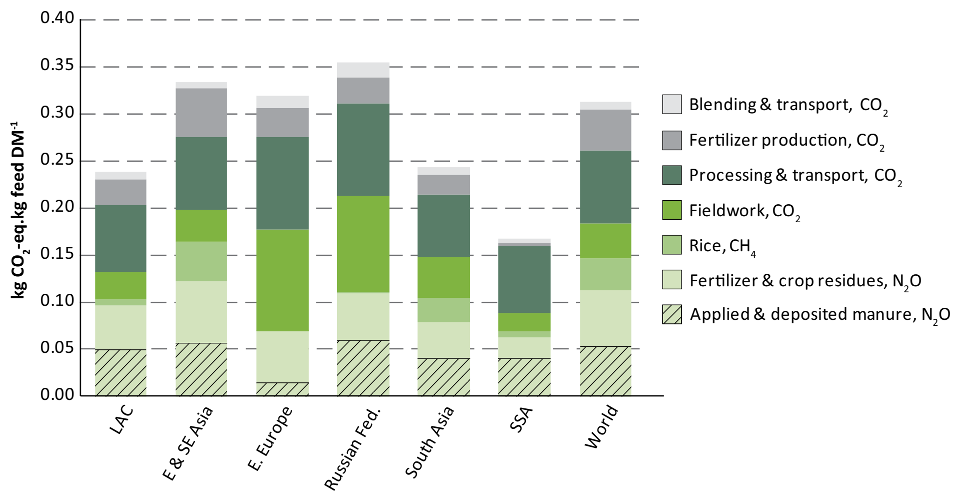
Feed emissions per kg of meat are a function of (a) the feed conversion efficiency (see the previous section) and (b) the emissions per kg of feed.

Influence of FCR on regional feed emissions. FCR does not vary greatly between regions, with the exception of Sub-Saharan Africa (SSA), where the high FCR increases the feed emissions per kg of CW for both the backyard and intermediate systems.

Influence of ration composition. Emissions per kg of feed vary depending on the proportion of each feed material in the ration, and the emission intensity of each individual feed material. Local feeds tend to have lower emissions per kg than non-local concentrate feeds, because (a) many of them are swill or second grade crops which are allocated lower emissions in proportion to their reduced value; (b) they have lower transport emissions and feed blending emissions; and (c) they are less likely to be associated with LUC. The proportion of non-local feeds in the ration is therefore a key determinant of the overall emission intensity from rations. That some rations include a higher proportion of local feed (e.g. backyard rations in Latin America and the Caribbean (LAC), South Asia and, in particular, Sub-Saharan Africa) explains why these regions have lower feed emissions (see Figure 13).

Industrial pigs' rations are comprised primarily of commercially produced compound feeds, which leads to more homogenous rations and feed emissions, *except in regions where soybean is sourced from areas associated with LUC*. For a discussion on approaches and methods about emissions from LUC, refer to Appendix C of this report.

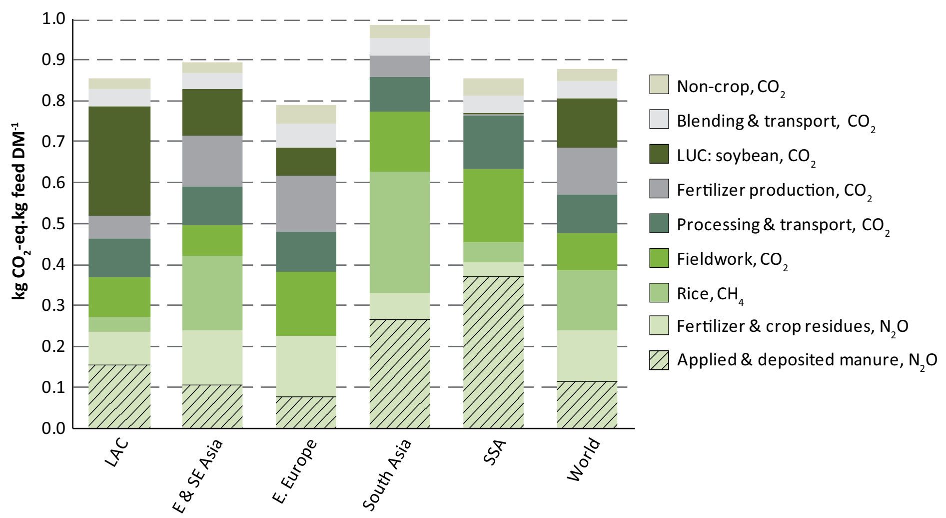
Figure 13.
Backyard pigs feed emissions (regions with less than one percent of backyard production are omitted)



Source: GLEAM.

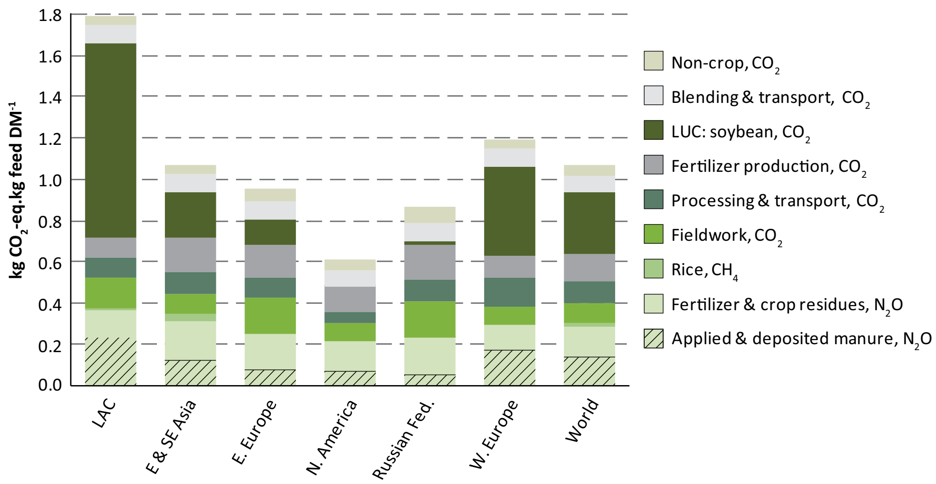
The feed emission intensity (excluding LUC emissions) for industrial pigs is in the range 0.7-0.8 kg CO_2-eq/kg DM for all regions except North America (see Figure 15) and 0.6-1.0 kg CO_2-eq/kg DM for intermediate pigs (see Figure 14). In this region, emissions are lower due to the presence of a relatively large proportion of (high yielding) maize, and shorter transport distances for soybean, most of which is produced within the region, rather than imported.

Figure 14.
Intermediate pigs feed emissions (regions with less than one percent of intermediate production are omitted)



Source: GLEAM.

Figure 15.
Industrial pigs feed emissions (regions with less than one percent of industrial production are omitted)



Source: GLEAM.

Influence of variation in individual feed material emission intensity. The main factors leading to spatial variation in the emission intensity of individual feed materials captured in this study are summarized in Table 7.

Local differences can lead to complex patterns of variation in emission intensity of feed materials. Full exploration of this matter is beyond the scope of this report. However, the following general observations can be made:

- The average yield per ha of the ration across all feed materials is important. Commercial pig units often produce amounts of manure N in excess of local crop requirements, so higher yields will permit greater uptake of the excreted N and lower N_2O emissions per kg of yield. Ultimately, the N_2O per kg of DM is determined by how well matched the N application is to the crop, rather than the yield *per se*. It should also be noted that some high yielding crops (e.g. maize, sugarcane tops) have low N contents, which may necessitate the addition of (high emissions per kg) protein feeds (protein crops, animal meals or synthetic additives). Emissions per megajoule (MJ) and/or per kg of N can therefore be useful ancillary measures of feed material emissions.
- Higher yields also tend to result in lower CO_2 emissions per kg for fieldwork (but not for subsequent processing and transport).
- The use of (and allocation of emissions to) crop residues (e.g. straw) or by-products (e.g. meals) should result in lower crop emissions, provided that emissions from processing are not greater than the reduction achieved through allocation.
- Emission intensity of soybean feeds are more variable than other crops, depending on the extent to which soybean cultivation is associated with LUC.
- Rice has the extra burden of CH_4, which will lead to higher emission intensity in areas where flooded rice cultivation is common.

Table 7. Factors leading to spatial variation in the emission intensity of individual feed materials: pigs

Emission category	Source of spatial variation
N_2O	Manure N application rate Synthetic N application rate Crop yields Use of crop residues
CO_2 (not LUC)	Synthetic N application rate Crop yields Use of crop residues Mechanization rates
LUC	LUC associated with soybean cultivation
Rice CH_4	Mode of rice cultivation

Source: Authors.

Enteric fermentation

Emissions from enteric fermentation were calculated using the IPCC (2006) Tier 2 approach (see Appendix A). The enteric emission intensity per kg of CW varies inversely with ration digestibility (the lower the digestibility, the more gross energy (GE) is consumed to satisfy the pig's energy needs) and directly with the FCR (the higher the FCR the more feed, and so the more MJ of GE, that needs to be consumed per kg of CW). At the regional scale, the only observable effect of variation in these parameters is in Sub-Saharan Africa, where the higher FCR leads to significantly higher enteric emissions.

Manure emissions

Emissions of N_2O and CH_4 from manure depend upon: (a) the amount of VS or N excreted per kg of meat produced, and (b) the rate at which the VS or N are converted to CH_4 and N_2O during manure management (see Table 8).

Manure CH_4. The amount of VS excreted per kg of CW produced depends on how many kg of feed the animal requires to produce one kg of food (i.e. the feed conversion ratio) and the proportion of the feed organic content that is utilized by the animal, i.e. the digestibility of the feed.

The rate at which excreted VS are converted to CH_4 depends on the manure storage system. Systems that provide the anaerobic conditions suitable for methanogenesis, such as lagoons, slurry systems and deep pits with longer residence times, have much higher methane conversion factors than aerobic systems. In addition, the MCF increases with temperature, particularly for slurry and pit systems. One of the advantages of the GIS approach was that it allowed the calculation of manure emissions to take local biophysical conditions into account. Maps 7 and 8 illustrate the way in which the MCF varies between cells in response to variations in temperature and between countries, according to different manure management practices (although, as Lory *et al.* 2009 argue, the relationship between temperature and MCF can diverge from the IPCC formulae).

In backyard systems, South Asia, Sub-Saharan Africa, and Latin America and the Caribbean have the highest levels of manure CH_4 due to the combination of higher average temperatures and lower digestibility of rations (MMSs are assumed to be

Table 8. Factors influencing the rate of manure CH_4 and N_2O production: pigs

	Manure production	Conversion of VSx > CH_4 or Nx > N_2O
CH_4	kg VSx/kg protein output	Manure management Bo Temperature
N_2O	kg Nx/kg protein output	Manure management Leaching rate

Source: Authors.

the same for all backyard systems). These are reflected in higher than average MCF and VS excretion rates (see Figure 16). Trends are quite different for intermediate systems. In South Asia, levels of manure CH_4 are high as liquid manure systems and high temperatures result in a high MCF, while the ration has lower than average digestibility, leading to increased VS excretion (see Figure 17). East and Southeast Asia also have high manure CH_4 emissions, primarily due to the use of anaerobic liquid manure systems and high temperatures.

Emission levels in Sub-Saharan Africa, however, are low due to the predominance of drylot-type manure management. Eastern Europe, too, has low manure CH_4 emissions, due to low temperatures and the preference for solid storage and pits with short retention times. Finally, in industrial systems (see Figure 18), North America and East and Southeast Asia have high MCF, reflecting the widespread use of lagoons, slurry systems and pits with long residence times. The manure CH_4 per kg of CW (see Figure 11) is higher in North America due to the combination of high MCF and high biodegradability of manure; Bo = 0.48m^3 CH_4/kg VSx, IPCC (2006, Table 10A-7).

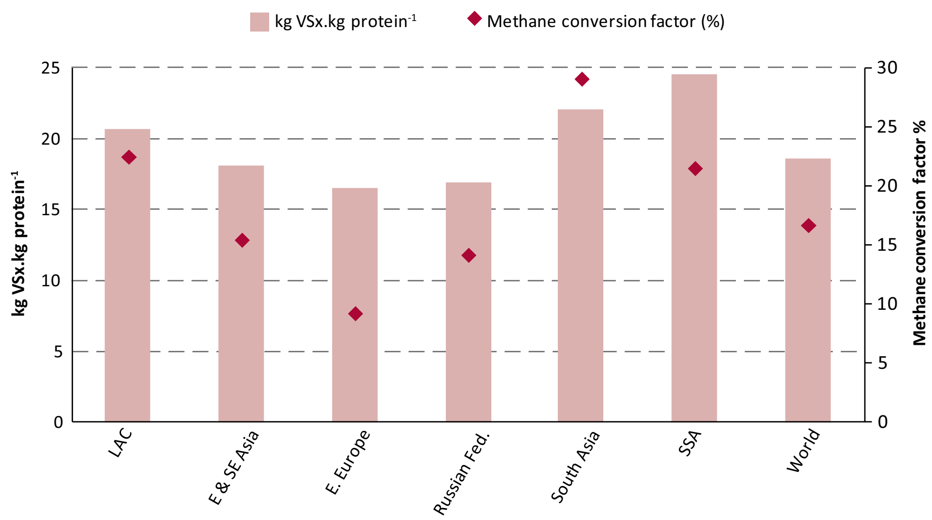
Manure N_2O. Once the N is excreted, the rate at which it is converted to N_2O depends primarily on the MMS. Emissions arise (a) from the direct conversion of manure N to N_2O; (b) indirectly, through volatilization of NH_3 and nitrogen oxides (NOx) and (c) from leached N. Systems that provide the conditions required for direct N_2O emissions via nitrification and denitrification (such as drylot and solid storage) tend to have the highest emissions.

N_2O emissions can also vary significantly for the same manure storage system between different regions due to the variation in the proportion of N leached (particularly in liquid storage systems). However, this does not necessarily translate into significant regional variations in N_2O emissions, as only a small proportion of the leached N (0.8 percent) is converted into N_2O.

It is assumed that manure is managed in the same way in all backyard systems, so they show little variation in manure N_2O, as regional variation in N excretion is small, and N leaching has a limited effect on total N_2O emissions (see Figure 19). For intermediate pigs, emissions are highest in Sub-Saharan Africa where drylots are more common, which leads to a higher rate of conversion of excreted N to N_2O (see Figure 20). The manure N_2O emissions vary more between regions in the industrial systems due to differences in regional average N excretion rates as well as the rates of conversion to N_2O (see Figure 21).

The emission intensity of N_2O from manure is similar to that of CH_4 from manure, in that it depends on (a) the N excretion rate and (b) the proportion of the

Figure 16.
Regional averages for key parameters influencing manure management CH_4 emissions in backyard pig systems (regions with less than one percent of backyard production are omitted)



Source: GLEAM.

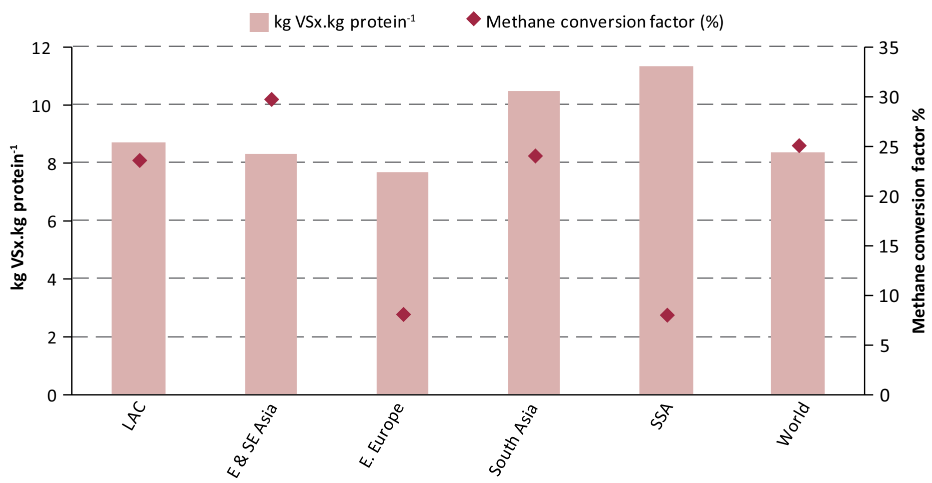
excreted N that is converted to N_2O during manure storage, either directly or indirectly.

The N excretion rate depends on the balance between the animal's feed N intake and its N retention in tissue. Different categories of animals (e.g. adult females, adult males and growing pigs) can have quite different N requirements depending on, for example, their growth rates, lactation rates and yields. In theory, the ration should be adjusted to reflect the N requirements of different categories and ages of animals. Phase feeding, where the ration is altered to suit the changing N requirements of growing animals, may be possible in industrial systems. However matching the N intake to the animals' needs is more difficult in intermediate and backyard systems, where the composition of the ration is based, in part, on what is locally available, rather than the physiological needs of the animals. Map 9 shows the spatial variation in N retention for all pigs; N retention is inversely correlated with the proportion of the herd within a cell that consists of backyard pigs.

N_2O arising from manure storage and application to land

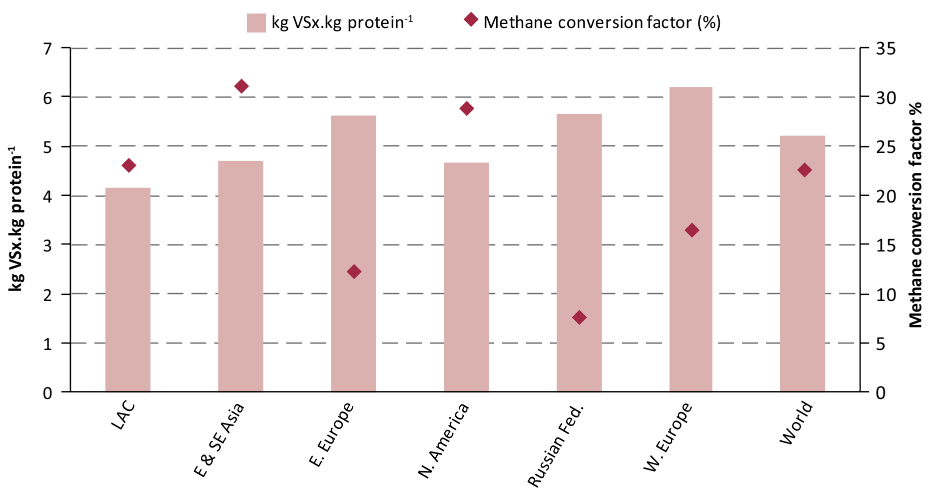
N_2O emissions arising during manure storage are accounted for under manure management, while emissions arising during subsequent application to land are accounted for under feed N_2O. An exception is made for the manure N deposited by backyard pigs and chickens while they are scavenging. These emissions are added to the manure management N_2O rather than the feed N_2O, because it is assumed that little of the manure is actually applied to feed crops.

Figure 17.
Regional averages for key parameters influencing manure management CH_4 emissions in intermediate pig systems (regions with less than one percent of intermediate production are omitted)



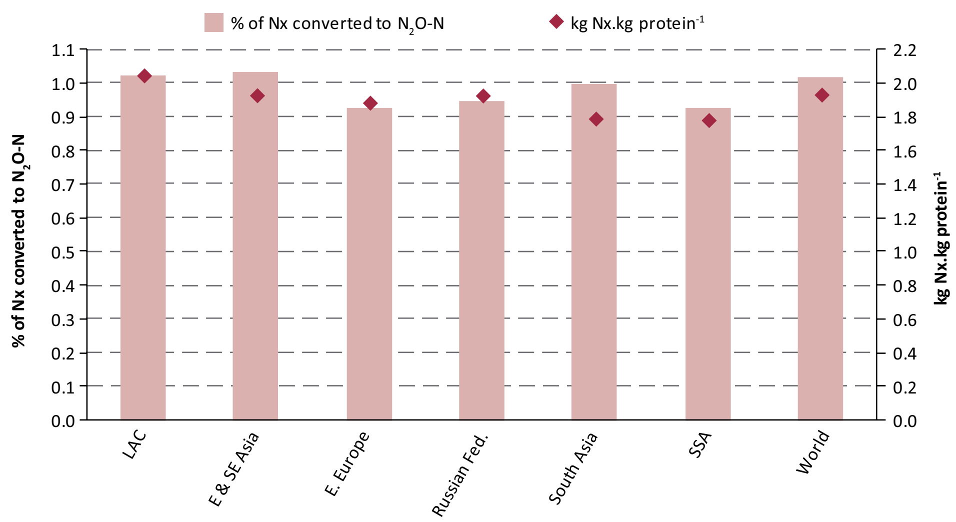
Source: GLEAM.

Figure 18.
Regional averages for key parameters influencing manure management CH_4 emissions in industrial pigs systems (regions with less than one percent of industrial production are omitted)



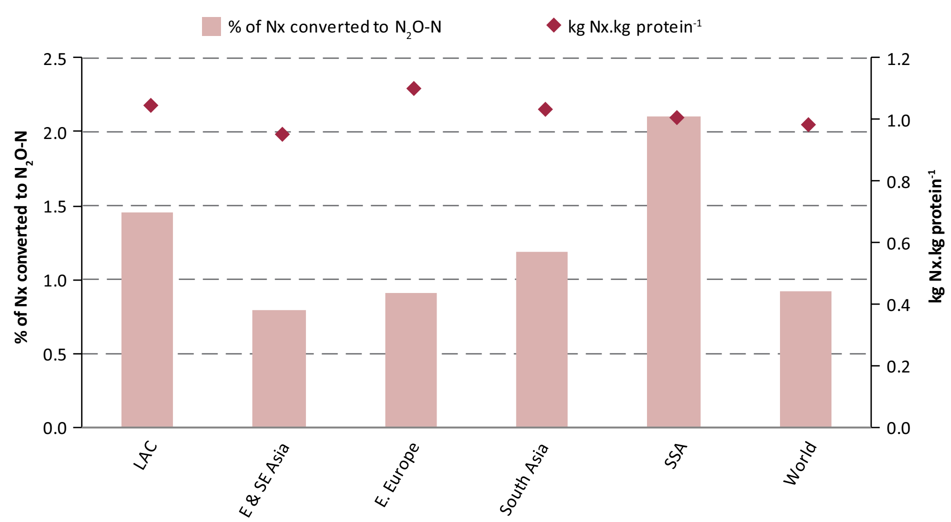
Source: GLEAM.

Figure 19.
Regional averages for key parameters influencing manure management N_2O emissions in backyard pig systems (regions with less than one percent of backyard production are omitted)



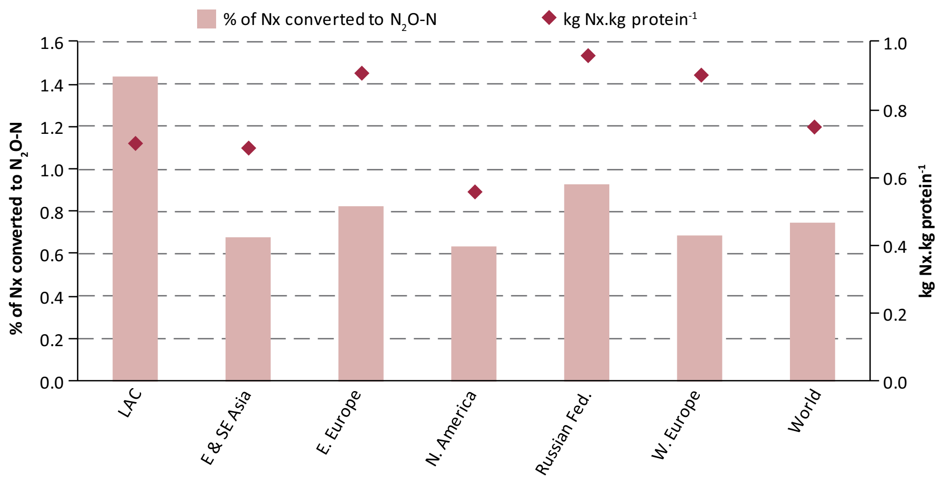
Source: GLEAM.

Figure 20.
Regional averages for key parameters influencing manure management N_2O emissions in intermediate pig systems (regions with less than one percent intermediate production are omitted)



Source: GLEAM.

Figure 21.
Regional averages for key parameters influencing manure management N_2O emissions in industrial pig systems (regions with less than one percent of industrial production are omitted)



Source: GLEAM.

Direct energy and postfarm emissions

A relatively small proportion of the total emissions arise from the direct use of energy on-farm, in intermediate and industrial systems, primarily for the purposes of ventilation, lighting and heating (see Appendix E).

Emissions arising from direct on-farm energy use and postfarm processing vary regionally as the emissions associated with the use of electricity vary, depending on the way it is generated and the efficiency of transmission. For example, the emissions per kWh are higher in North America and China compared to Western Europe or Brazil, where renewable energy accounts for a greater proportion of electricity generating capacity. This explains why direct energy emissions in Asia, North Africa and North America are higher than those in Latin America or Western Europe.

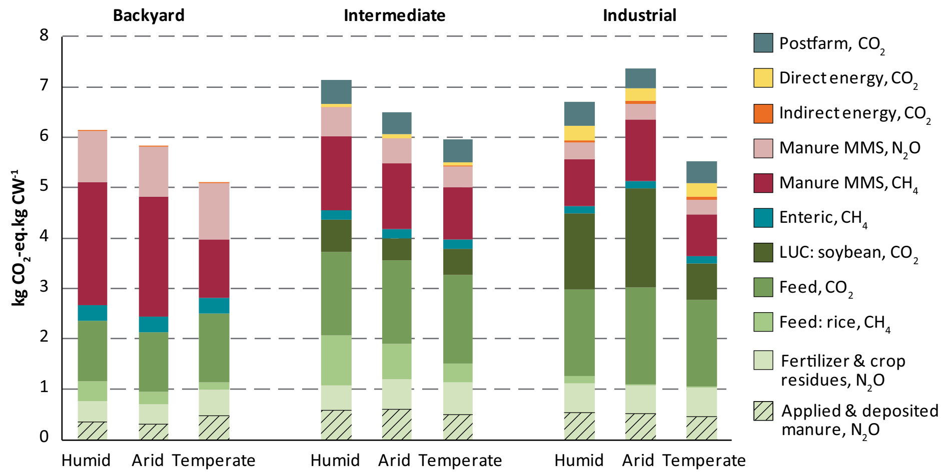
Postfarm emissions vary between regions, depending on the assumed distances from farm to processing plant and to retail point. In addition, regions which export a significant proportion of their production will have higher transport emissions than regions where most production is consumed domestically.

For intermediate systems, the proportion of the animals processed at commercial slaughterhouses is assumed to be 90 percent, except for Sub-Saharan Africa where the proportion is only 50 percent, reducing processing emissions in this region.

Variation between agro-ecological zones

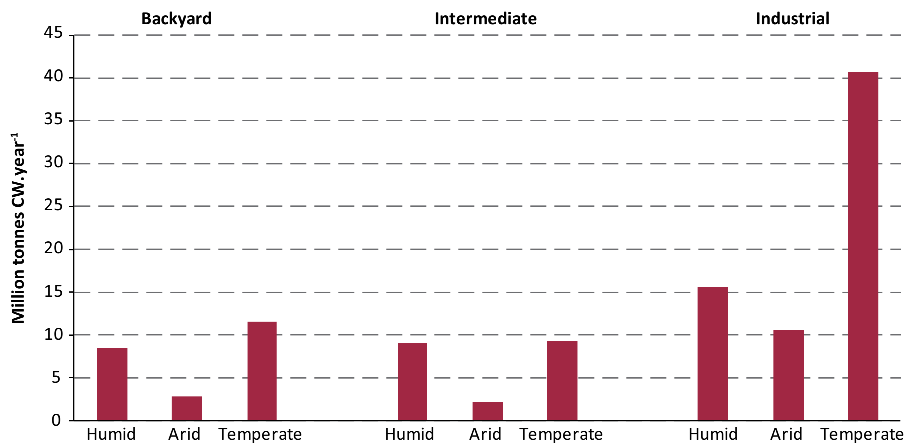
Figure 22 and 23 show the variation in emission intensity and production between different AEZ's. Across all three systems, manure CH_4 emissions are lower in temperate areas than in arid or humid areas, due to the lower average temperatures in temperate areas. Emissions of CH_4 from rice production are higher in humid areas, where more rice is grown and, consequently, where rice and rice by-products form a greater proportion of the pig ration. This effect is less marked in industrial systems where rice forms a relatively small proportion of the ration. Finally, there are

Figure 22.
Pig emission intensity by system and agro-ecological zone



Source: GLEAM.

Figure 23.
Pig production by system and agro-ecological zone



Source: GLEAM.

marked differences in the emissions from LUC between the AEZs for industrial systems. This difference is due to variations in the source countries from which each AEZ obtains its soybean and soymeal.

It is important to distinguish variation between AEZs that can be directly linked to differences in the agro-ecological conditions (for example, manure CH_4 emissions vary with temperature) from variation that arises due to intervening variables. For example, a greater proportion of the industrial pigs in temperate areas may be in countries that use soybean not associated with LUC.

4.3 ANALYSIS OF UNCERTAINTY IN PIG EMISSION INTENSITY

4.3.1 Identification of main emissions categories

Calculation of emission intensities in the LCA involves hundreds of parameters. The values of these parameters are subject to some degree of uncertainty, which can combine to have a significant impact on the results. Quantifying the uncertainty for the global results would require uncertainty ranges for many parameters, and is beyond the scope of this report. Instead, a partial uncertainty analysis, for selected countries and systems, is provided to illustrate the likely uncertainty ranges in the results and to highlight the parameters that make the greatest contribution to uncertainty. This partial analysis is based on the Monte Carlo simulation approach that uses repeated random sampling.

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, see Table 9) and (b) had a high degree of uncertainty or inherent variability.

Countries with significantly sized sectors and systems, where data availability was expected to be better than average (for the given species and system) were chosen for the Monte Carlo analysis (see Table 10).

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

Manure CH4

The parameters selected for testing were feed digestibility (the overall digestibility of the ration) and the MCF (see Tables 11 and 12). The two main drivers of manure CH_4 are (a) the amount of VSx 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

Table 9. Emissions categories contributing more than ten percent of total global emissions: pigs

	Backyard	Intermediate	Industrial	ALL
Feed CO_2	Y	Y	Y	Y
Manure CH_4	Y	Y	Y	Y
Feed N_2O	Y	Y	Y	Y
Feed LUC CO_2	N	N	Y	Y
Manure N_2O	Y	N	N	N

Source: GLEAM.

Table 10. Combinations of system and country chosen for the Monte Carlo analysis: pigs

System	Country
Industrial	United Kingdom
Intermediate	Viet Nam
Backyard	Viet Nam

Source: Authors.

Table 11. Approaches used for varying CH_4 conversion factor (MCF)

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.

Table 12. Approaches used for varying the digestibility of the ration: pigs

System/species	Range	Basis
Industrial pigs: *United Kingdom*	Ration digestibility CV = 3%	Based on ranges of DE given by Dammgen *et al.* (2011)
Intermediate pigs: *Viet Nam*	Vary % of locally produced grain and crop-residues	Assumption that proportions of grain and crop residues will (inversely) co-vary depending on availability and price
Backyard pigs: *Viet Nam*	As for intermediate	As for intermediate

instead of volatile solids excretion. This testing was done to make it easier to relate the changes in emission intensity resulting from changes in VSx to changes in feed digestibility, and thereby to actual changes in underlying ration composition. Furthermore, changes in feed digestibility are likely to lead to proportionately larger increases in VSx. For example, if digestibility increases by ten percent, from 80 percent to 88 percent, then the proportion of the feed intake excreted decreases from 20 percent to 12 percent, a reduction of 40 percent. The change in the VSx, therefore, depends on the initial DE. Simply varying VSx by ten percent for backyard, intermediate and industrial pigs ignores the initial DE of the ration and will obscure system-dependency of the effect.

Feed land-use change CO_2

The increase of emissions that results from LUC to grow soybean is an important emissions category. It is subject to uncertainty in terms of both the percentage of soybean in the ration, and the EF of the soybean (see Tables 13 and 14). The soybean LUC EF depends on where the soybean is imported from and how the LUC emissions are calculated (see Appendix C).

N_2O arising from feed production

Feed N_2O is an important source of emissions, with 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.

In non-OECD countries manure N is assumed to be applied to land within a short distance (i.e. less 8 km) from where it is excreted by the animals. In the United Kingdom, where there is a suite of regulations designed to limit application of nutrients (such as the Nitrates Directive) it is assumed that a proportion of the manure will be exported and applied outside the cell (see Tables 15, 16 and 17 for ranges).

Table 13. Soybean LUC emission factors and ranges

LUC scenario	Emissions factor *(kg CO_2/kgDM)*			Coefficient of variation (percentage)
	Soybean	Soymeal	Soybean oil	
1. GLEAM	3.53	3.17	5.05	8%
2. PAS 2050-1:2012	1.47	1.32	2.10	46%
3. One-Soy	3.31	2.98	4.74	0%
4. Reduced time frame	1.68	1.51	2.40	9%

Source: Authors' calculations.

Table 14. Approaches used for varying soybean percentage: pigs

System/species	Range	Basis
Industrial pigs: *United Kingdom*	Soybean % in the ration CV = 30%	Expert opinion
Intermediate pigs: *Viet Nam*	Soybean % in the ration CV = 30%	Expert opinion
Backyard pigs: *Viet Nam*	NA – no LUC	

NA: Not Applicable.

Table 15. Ranges of N applied per ha

System/species	Range	Basis
Pigs and chickens: *United kingdom*	The CV of the total amount of N applied per ha varies from 10% to 25%	Range reflects the difference between N/ha when (a) all N is applied in cell and (b) N is matched to crop requirement.
Pigs and chickens: *Viet Nam*	NA	Assumed all manure is applied locally (i.e. within cell).

NA: Not Applicable.
Source: GLEAM.

Table 16. Ranges for feed N_2O emissions factors for all species/systems

Emission factor	Range	Basis
EF1 - emissions from organic and synthetic N application	0.003—0.03	Based on IPCC (2006, 11.11; 11.24) using an asymmetric distribution
EF3 - emissions from pasture, range, paddock	0.007—0.06	See above
EF4 - emissions from via NH_3 volatilisation	0.002—0.05	See above
EF5 - emissions from via leaching	0.0005—0.025	See above
FracGasF - fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x	0.03—0.3	See above
FracGasM - fraction of animal manure N that volatilizes as NH_3 and NO_x	0.05—0.5	See above

Table 17. Ranges for crop yields for all species/systems

	Range	Basis
Crop yields	CV = 5%	Based on FAO calculations of variation in yield over time, and Basset-Mens (2005)

Table 18. Ranges for fertilizer manufacture emissions factors for all species/systems

Emission factor	Range	Basis
Ammonium Nitrate manufacture EF	CV = 27%	Based on values for fertilizer CO_2 EFs in Wood and Cowie (2004)

CO_2 arising from feed production

Feed CO_2 (not including soybean LUC) is an important emissions category, but characterizing the uncertainty 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. This complex task is beyond the scope of this analysis. However, ranges for the single biggest source of feed CO_2 — the manufacture of fertilizer — are included, in order to gauge the potential effect of feed CO_2 (see Table 18).

Herd/flock parameters

Herd/flock parameters such as fertility, growth and mortality rates can have a profound impact on emission intensity, by altering the feed conversion ratio 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 19. 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.

4.3.3 Results of the Monte Carlo analysis

The analysis was undertaken for all combinations of species/system/country (six in total). Each run produced a probability distribution and sensitivity analysis (see Figures 24 and 25). The results of the Monte Carlo analysis for pigs are summarized in Table 20.

The distributions of results are, to a greater or lesser extent, asymmetric for all of the runs, reflecting the asymmetric distribution of the N_2O EF ranges. The variation in the FCR is similar in the industrial and intermediate systems. The greater variance in emission intensity in industrial systems compared to intermediate is due to a number of factors:

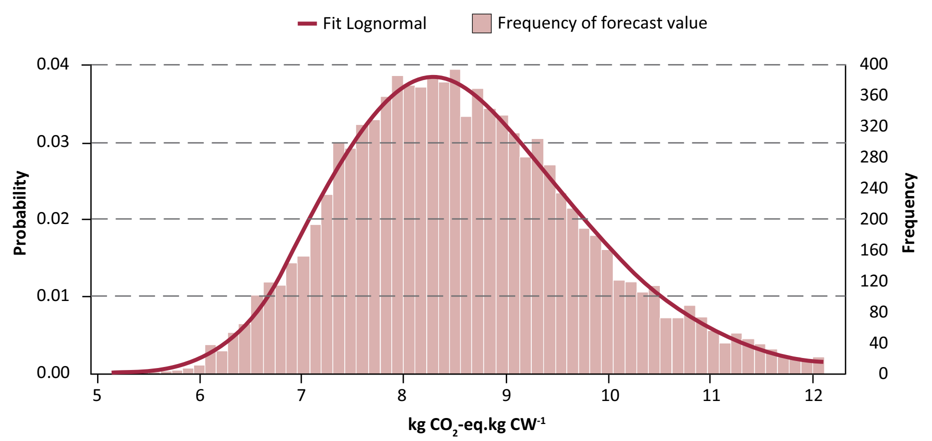
- feed N_2O (which tends to be more variable than other emission categories) accounts for a greater percent of emissions resulting from industrial pigs from the United Kingdom;
- greater variance in the amount of manure N applied per ha in the industrial example;
- higher percentage of soybean in the ration in the industrial example, and consequently greater variation arising from the variation in quantity of the ration consisting of soybean.

Variance in backyard pigs results predominantly from variation in daily weight gain, which, in turn, affects the FCR. Unlike the intermediate and industrial systems, EF1 has a relatively minor effect as feed N_2O forms a smaller proportion of emissions than in the other systems.

Table 19. Ranges for key herd parameters: pigs

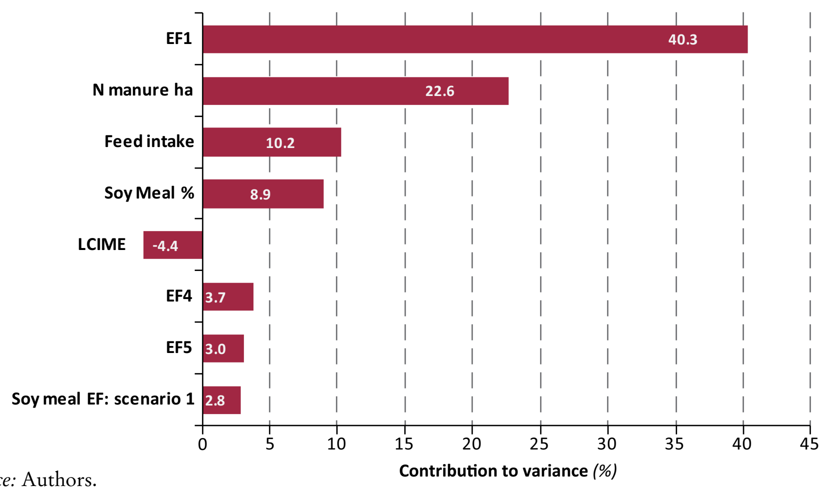
System/species	Coefficient of variation *(percentage)*	Basis
Industrial pigs: *United Kingdom*	FCR=5	Guy *et al.* (2002)
Intermediate pigs: *Viet Nam*	Daily weight gain=15 Litter size=7 Litters/year=5 Piglet mortality=20	Lemke (2006)
Backyard pigs: *Viet Nam*	Daily weight gain=20 Litter size=14 Litters/year=14 Piglet mortality=25	Lemke (2006)

Figure 24.
Distribution of results of the Monte Carlo simulation for industrial pigs in the United Kingdom (10 000 runs)



Source: Authors.

Figure 25.
Contribution to variance of the main input parameters varied in the Monte Carlo simulation for industrial pigs in the United Kingdom (10 000 runs)



Source: Authors.

Table 20. Summary of the results of the Monte Carlo analysis for pigs

	Backyard *Viet Nam*	Intermediate *Viet Nam*	Industrial *United Kingdom*
Mean emission intensity *(kg CO_2-eq/kg CW)*	6.8	5.6	8.0
Emission intensity coefficient of variation *(percentage)*	13.8	9.7	14.5
Distribution	Lognormal	Lognormal	Lognormal
Contribution to variance of key parameters (excluding parameters contributing <5% to variance) *(percentage)*	Daily weight gain: -66.8 MCF: 10.9 EF1 (direct N_2O): 10.6	Daily weight gain: -35.9 EF1 (direct N_2O): 30.5 EF4 (N_2O via vol): 10.6 MCF: 7.5 EF5 (N_2O via leach): 7.2	EF1 (direct N_2O): 40.3 N manure/ha: 22.6 Feed intake: 10.2 Soybean meal %: 8.9

Source: Authors' calculations.

4.4 COMPARISON OF THE PIG RESULTS WITH OTHER STUDIES

No LCA studies of backyard or intermediate systems could be found, so the comparison is limited to the industrial systems (see Table 21).

Meaningful comparison is complicated by the variety of factors that can lead to different results, and the inevitable partial knowledge one has of how other studies were done. Even well-documented studies cannot disclose every assumption and calculation procedure, so one is often left reading between the lines. In general, the reasons for different results fall into three categories:

- scope
- input data/assumptions
- calculation methods

4.4.1 Scope

Studies can: (a) have different system boundaries, (b) include different emissions categories within the same system boundaries or (c) include different emissions sources within an emissions category. For example, when quantifying emissions from on-farm energy use, some studies only include electricity consumption, while others also include other fuels such as gas and petrol. Where possible, the scope of the results in this study has been adjusted to match the studies with which they are compared.

4.4.2 Input assumptions

Quantifying emissions requires input data on key parameters, such as livestock population numbers and distributions, herd structures and crop yields. Ideally, sets of validated empirical data should be used, but there are often gaps in the data on key parameters, requiring assumptions to be made. Where key parameters are reported, these are used to explain differences between results. In addition some of the parameters have a high degree of variability, so two studies can have precise, but quite different values for the same parameter. For example, the formulation of concentrate feed can vary significantly within a short period of time in response to changing prices of individual feed materials.

Some studies present difficulties of comparison. These difficulties may occur because the studies do not provide adequate detail on the method used to make a like-for-like comparison. Also, they may present results for subsystems (e.g. Eriksson *et* *al.* 2005) or for systems that are fundamentally different (e.g. Cederberg and Flysjö *et al.* 2004). Where comparison is possible, the results from this study appear to be broadly consistent with most other studies, once the results are adjusted to account for different scope and methods. Common reasons for the remaining differences are described briefly below.

4.4.3 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. 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 will be the same as in other studies, it is believed that they are a reasonable reflection of typical rations. The total emission intensity is particularly sensitive to the assumptions made about LUC emissions associated with soybean and soymeal. The results with and without LUC emissions are presented in Table 21 in order to facilitate comparison of the non-LUC emissions. Further details of the method used to quantify emissions from LUC are given in Appendix C.

Feed N_2O

The extent to which the rate of application of synthetic and manure N matches crop requirements varies between studies and can lead to significant differences in N_2O emissions (e.g. see Basset-Mens *et al.* 2004). This study assumes that all excreted N is applied to crops and grassland within the (0.05 decimal degree) cell. It is recognized that this assumption will lead to an overestimation of the rate of N applied in countries, such as Sweden, where the livestock numbers (and therefore manure N production) are more in balance with the available land resources. Even when the rates of N application and uptake are the same, different methods can be used to calculate N_2O emissions, which explains the discrepancy in results between this study and others, such as those conducted by Williams *et al.* (2006) and Wiedemann *et al.* (2010).

Feed CO_2

There is great variation in the scope of this category of feed CO_2. For instance, Vergé *et al.* (2009a) and Lesschen *et al.* (2011) include quite different subcategories of emissions from this study. However, these differences have been compensated for as far as possible. Differences also arise in terms of where crops are assumed to be grown and processed. Some studies assume that most crops are produced on the farm or within the country, leading to lower transport distances, and different electricity EFs. For example, in Cederberg and Flysjö (2004) and Eriksson *et al.* (2005) the crops in question were grown and processed in Sweden, which leads to different levels of emissions than those in this study.

Manure management

Some studies have different assumptions about how manure is managed. For example, this study assumes significant use of straw-based systems in England and Wales, while Kool *et al.* (2009, p24) assume that “all manure is produced as liquid manure” leading, for England and Wales, to a higher MCF (and lower N_2O emissions). Weiss and Leip (2011) assume a greater proportion of manure managed in

Table 21. Comparison of emission intensity for pigs with other studies

Study	Country	System	Scope									Emissions intensity *(kg CO_2-eq/kg CW)*	
			Feed N_2O	Feed CO_2	Feed LUC	Enteric CH_4	Manure CH_4	Manure N_2O	Direct energy	Indirect energy	Postfarm	Study	FAO (adjusted to same scope as study)
Cederberg and Flysjo (2004)	Sweden	Various, future farm types	Y	Y	N	Y	Y	Y	Y	N	N	2.14 – 2.61	4.74 (no LUC)[b, c]
Cederberg *et al.* (2009)	Sweden	Various, future farm types	Y	Y	N	Y	Y	Y	Y	N	N	3.39 (no LUC)	4.74 (no LUC)[b, c]
Eriksson *et al.* (2005)	Sweden	Standard indoor, soy-bean ration	Y	Y	N?	Y	Y	Y	Y	N	N	2.01 (no LUC)	3.92 (no LUC)[a, b, d]
Basset-Mens *et al.* (2004)	France	Standard indoor	Y	Y	N?	Y	Y	Y	Y	Y	N?	3.80 (no LUC)	3.50 (no LUC) 4.60 (LUC)
Williams *et al.* (2006)	United Kingdom	Standard indoor	Y	Y	N	Y?	Y	Y	Y	Y	N	6.36 (no LUC)	4.69 (no LUC) 7.17 (LUC)
Dalgaard (2007)	Denmark	Specialized pig farm	Y	Y	N?	Y	Y	Y	Y	Y	Y	3.77 (no LUC)	4.39 (no LUC) 5.43 (LUC)
Halberg *et al.* (2010)	Denmark	Organic: stables Organic: grass Organic: litter	Y	~~	N?	Y	Y	Y	Y	Y	N	3.89 (no LUC) 4.43 (no LUC) 3.77 (no LUC)	3.95 (no LUC)
Kool *et al.* (2009)	Denmark	Standard indoor	Y	Y	Y	Y	Y	Y	Y	N	Y	3.55 (no LUC) 4.09 (LUC)	3.80 (no LUC)[e] 4.71 (LUC)[e]
	England	Standard indoor	Y	Y	Y	Y	Y	Y	Y	N	Y	3.52 (no LUC) 4.04 (LUC)	4.33 (no LUC)[e] 6.51 (LUC)[e]
	Germany	Standard indoor	Y	Y	Y	Y	Y	Y	Y	N	Y	3.72 (no LUC) 4.13 (LUC)	4.01 (no LUC)[e] 5.21 (LUC)[e]
	Netherlands	Standard indoor	Y	Y	Y	Y	Y	Y	Y	N	Y	3.56 (no LUC) 4.05 (LUC)	4.69 (no LUC)[e] 5.61 (LUC)[e]

(Continued)

Table 21. *(Continued)*

Study	Country	System	Scope									Emissions intensity *(kg CO_2-eq/kg CW)*	
			Feed N_2O	Feed CO_2	Feed LUC	Enteric CH_4	Manure CH_4	Manure N_2O	Direct energy	Indirect energy	Postfarm	Study	FAO (adjusted to same scope as study)
Verge *et al.* (2009)	Canada	Mainly standard indoor	Y	~~	NA	Y	Y	Y	Y	Y	N	3.08 (no LUC)	4.05 (no LUC)[b]
Wiedemann *et al.* (2010)	Australia	Slatted floor Deep litter	Y	Y	N?	Y	Y	Y	Y	Y	Y	5.50 (no LUC) 3.10 (no LUC)	6.37 (no LUC) 9.85 (LUC)
Pelletier *et al.* (2010)	USA	Standard indoor Deep bedding	Y	Y	NA	Y	Y	Y	Y	N	N	3.29—4.07 (no LUC)[a] 3.36-4.44 (no LUC)[a]	3.98 (no LUC)[b]
Thoma *et al.* (2011)	USA	Aggregate of US production	Y	Y	NA	Y	Y	Y	Y	N?	Y	3.83 (no LUC)[f]	3.98 (no LUC)[b, f]
Lesschen *et al.* (2011)	EU27	Aggregate of EU27	Y	~~	Y	Y	Y	Y	~~	N	N	3.07 (no LUC) 5.37 (LUC)	3.34 (no LUC)[g] 4.94 (LUC)[g]
Weiss and Leip (2012)	EU27	Aggregate of EU27	Y	Y	Y	Y	Y	Y	Y	N	N	5.79 (LUC, no LU) 4.46 (no LULUC)	4.39 (no LULUC) 5.99 (LUC, no LU)

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] Assuming the ratio CW/LW = 0.75, and no allocation to slaughter by-products.
[b] Negligible LUC emissions due to very small percent of soybean imported from Brazil or Argentina.
[c] Assuming fat and bone free meat is 59 percent of carcass weight.
[d] Only growing/fattening animals.
[e] Using same allocation to slaughter by-products as Kool *et al.* (2009) i.e. 12 percent of emissions allocated to slaughter by-products.
[f] To farm gate only.
[g] Feed CO_2 adjusted to Lesschen *et al.*'s scope.

anaerobic conditions than does this study, which also leads to higher manure CH_4 and lower N_2O. Furthermore, not all studies have the same assumptions about the rate at which VS are converted to CH_4. For example, Cederberg and Flysjö (2004) use the evidence presented in Dustan (2002) to argue for a lower MCF than the IPCC (2006) value.

Allocation

Where possible, the results were adjusted to compensate for differences in allocation methods. For example, 12 percent of our emissions were allocated to slaughter by-products to enable comparison with Kool *et al.* (2009). However, adjustment was not always possible. Some studies (such as Dalgaard 2007) adopt a consequential rather than an attributional approach. Consequential LCAs use marginal analysis to estimate the emissions from an extra kg of pork, instead of the average emissions per kg of pork currently produced. While not directly comparable, these studies produce complementary results, which provide useful insights for policy.

In addition, system expansion is often used to provide credit for avoided emissions. For example, the production of manure N can lead to reduced manufacture and use of synthetic fertilizer (see Wiedemann *et al.* 2010).