ENVIRONMENTAL ASSESSMENT OF DANISH PORK

REPORT NO. 103 · APRIL 2011
THU LAN T. NGUYEN, JOHN E. HERMANSEN, LISBETH MOGENSEN

AARHUS UNIVERSITY

Environmental assessment of Danish Pork

Supplementary information and clarifications (October 2019)

In an effort to ensure that this report complies with Aarhus University's guidelines for transparency and open declaration of external cooperation, the following supplementary information and clarifications have been prepared in collaboration between the researcher (s) and the faculty management at Science and Technology:

The report does not have a preface which is not in accordance with Aarhus University´s present guidelines for reports.

The preface of the report should contain the following information:

- The report is an update of a previous report from 2007, Danish Pork Production. An environmental assessment (DJF nr. 82, 2007), based on new data for farming and revised emission-coefficients and with the aim to illustrate the importance of using the PAS 2050 methodology instead of previously used consequential approach
- The aim of the report was to present an environmental profile of Danish pork through life cycle assessment and to illustrate the importance of using the PAS 2050 methodology instead of previously used consequential approach
- The report was partly financed by the Danish Agriculture and Food Council and partly by Aarhus University
- The report was established in cooperation between Aarhus University, Danish Agriculture and Food Council and Danish Crown. The two external parties have participated in project meetings with the researchers from Aarhus University and have contributed with data on typical pig production, feed and energy use, and housing systems in Denmark as well as resource use and outputs from the slaughterhouse to the report (declared at page 8 and 11 in the report).
- Aarhus University was solely responsible for performing the two types of LCA-analysis
- The report was sent to Danish Agriculture and Food Council and Danish Crown at the end of 2010 to serve as an internal report there. The report was published as an internal report no. 103 at DJF in april 2011.

SCIENCE AND TECHNOLOGY

ENVIRONMENTAL ASSESSMENT OF DANISH PORK

Thu Lan T. Nguyen
John E. Hermansen
Lisbeth Mogensen
Aarhus University
Department of Agroecology
Research Centre Foulum
P.O. Box 50
DK-8830 Tjele, Denmark

The reports can be downloaded at www.agrsci.au.dk

Print: www.digisource.dk
ISBN: 978-87-91949-54-8

Executive summary

The aim of this report is to present an environmental profile of Danish pork through a life cycle assessment (LCA). In LCA two different approaches are often used: an attributional approach and a consequential approach. Basically, the attributional approach describes the resources used and emissions engendered to produce the product in question (here one kg of pork), whereas the consequential approach accounts for the resources used and associated emissions when producing one kg of pork more. This choice of methodologies impacts on the results, since the attributional approach uses information of impacts related to e.g. the specific feed production, whereas the consequential approach relies on data on e.g. the environmental cost to produce the feed necessary for the production of one extra kg of pork. Both methods are being used and a previous life cycle assessment of Danish pork used the consequential methodology. However, the Publicly Available Specification for documenting the global warming potential or the carbon footprint of a product, (PAS 2050), requires the attributional approach to be used. In the present report, therefore, the assessment used both methods. The PAS 2050 in addition has the option of including the impact on the global warming potential of land use changes following the production of feed. The basis for doing this is, however, not sufficiently developed, and therefore this aspect was not included in the present work for any of the methods. If included, the global warming impact would be higher.

The environmental assessment was performed using data representing the typical Danish pork production in 2010 on the one hand, and on the other using data from the 25% of Danish pig herds with highest technical efficiency in terms of piglets per sow and feed use per kg pork produced. Based on the historical development, these herds will in a few years time be representative of the typical Danish pig production. The assessment was performed as if the pig production were a landless business where all feeds etc. need to be imported and all manure exported. The methodology used ensures that the results will not differ from a situation where the farmer produces part of the feed and uses part of the manure for this purpose on his own farm.

The environmental impact was expressed per 'one kg Danish pork (carcass weight) delivered from the slaughterhouse'. Five impact categories were considered: Global warming potential, Acidification, Eutrophication, Non-renewable energy use, and Land use. Table S1 summarizes the environmental performance with respect to the five impact categories expressed in equivalents ($_e$) of the respective impact category.

Table S1. The environmental impact per kg Danish pork from slaughterhouse (carcass weight).

	Typical 2010 production		25% of herds with higher efficiency	
	Attributional (PAS 2050)	Consequential	Attributional (PAS 2050)	Consequential
Global warming (GWP), kg CO_2e	3.1	3.4	2.8	3.1
Acidification (AP), g SO_2e	56	61	51	55
Eutrophication (EP), g NO_3e	243	321	220	292
Non-renewable energy, MJ primary	21	22	20	21
Land use, m^2a	5.8	8.5	5.3	7.9

As shown in the table, the estimated environmental impact is higher when using the consequential approach than when using the PAS 2050. This reflects primarily that the average feed cereals produced under Danish conditions are estimated to have a lower environmental impact than what is estimated for the marginal production of cereals on the world market, partly due to higher yields per ha and partly due to stricter environmental regulations in Denmark, which in particular decrease eutrophication and global warming impacts as well as land use requirements.

Compared to earlier results for Danish pork based on 2006 data and using the consequential approach, this work is based on updated emission coefficients and housing conditions, which makes a comparison difficult. Nevertheless, the global warming impact was slightly lower in the present work (0.2 kg CO_2e per kg pork) probably reflecting the improvements that have taken place in cereal production and pig rearing in the period.

The environmental burden of the pork is primarily related to the farming stage and less so to the slaughtering stage product. Thus, less than 0.2 kg CO_2e per kg pork (or 6%) is related to the slaughtering stage. Therefore, increased efficiency in the primary stage impacts considerably on the total environmental impact of the pork. This is illustrated also in Table S1, which shows that the pork from the 25% of pig herds with highest technical efficiency has an 8-10% lower environmental impact than the average.

Table S2 shows the contribution of different key elements to the different environmental impact categories at the farming stage expressed per kg live weight of pig leaving the farm. Total impact per kg live weight is estimated at 2.2 kg CO_2e for the typical Danish production after the PAS 2050 model. As the table shows, “feed use” and “on-farm emissions” are the two major contributors at approximately 60 and 30%, respectively, of the total impact, whereas “Transport of feed” and “on-farm energy use” are minor contributors. The major contributor to feed use impact is cereal, which illustrates the importance of having a very environmentally efficient cereal production. The main contribution to ‘On farm-emissions’ is from methane emissions from the manure and - to a lesser extent - N_2O emissions. These emissions can be reduced by manure management procedures and represent as such an improvement potential. For acidification approximately 1/3 of the total impact is related to the on farm emission of NH_3 illustrating the importance of efforts to reduce this.

The manure produced results in emissions at the farm, but it also has a value as a fertilizer, thus substituting synthetic fertilizer. Danish regulations stipulate that 75% of fertilizer N has to come from manure on a total N basis. Even though there are higher transport costs related to manure handling and that field emissions are relatively higher using manure, because the substitution rate is not 100%, the net effect is a saving due to saved CO_2e emissions related to fertilizer production. In the typical case the net effect is a saving of 0.03 kg CO_2e per kg pork produced.

A recent literature review arrived at a reference value of the climate impact associated with the primary production of 1 kg pork of approximately 3.3 kg CO_2e per kg carcass weight leaving the pig farm. In this assessment of typical Danish pork, we arrived at a value from 2.9 to 3.3 kg CO_2e per kg carcass weight leaving the farm, lowest with the attributional approach, which is the approach mostly widely used in different studies, thus well below the reference value given in literature.

Table S3 shows that total emission of pork after transport in 3 situations based on the PAS 2050 approach. It appears that the cooled transport situations hardly changes the total impact compared to Table S1. The freezing followed by intercontinental transport mainly increase energy use (27%), followed by global warming (16%) and acidification (14%).

Table S2. Breakdown of contributing factors to different impact categories using PAS 2050 methodology for typical 2010 production, per kg live-weight of pig leaving farms.

Item	Global warming g CO_2	Acidification g SO_2e	Eutrophication g NO_3e	Non-renewable MJ
Feed use	**1281**	**15.3**	**109.7**	**11.5**
Wheat, production	460	6.1	33.6	3.6
Barley, production	409	5.6	45.3	3.2
Soybean meal, production	160	1.1	16.8	1.4
Other feeds	247	2.4	14.0	3.2
Mineral feed P	5	0.1	0.1	0.07
Transport of feed	**130**	**1.8**	**1.7**	**1.9**
By truck	93	0.8	1.2	1.4
By ship	37	1.0	0.6	0.5
On-farm energy use	**148**	**0.2**	**0.3**	**2**
On-farm emissions	**662**	**15.0**	**28.4**	
CH_4	497	-		
NH_3 emission	-	14.3	27.6	
NO_x emission	-	0.7	0.8	
N_2O (in-house and outside storage)	165	-		
Manure utilization for fertilizer	**-37**	**10.4**	**44.6**	**-1.8**
Transport to fields	22	0.2	0.2	0.3
Farm traction	17	0.2	0.3	0.2
NH_3 emission	-	15.9	30.7	-
NO_x emission	-	0.1	0.2	-
NO_3	-	-	16.6	-
PO_4	-	-	7.6	-
N_2O emissions	222	-	-	
Avoided fertilizer production	-157	-1.3	-1.9	-2.3
Avoided fertilizer application	-142	-4.6	-9.0	-0.02
Sum	2184	42.5	185	13.6

Table S3. Total environmental impact of Danish pork following different transportations, per kg pork.

Transport	Global warming (GWP), kg CO_2e	Acidification (AP), g SO_2e	Non-renewable energy, MJ primary
600 km truck, cooled	3.2	57	23
130 km truck, 600 km ship, cooled	3.1	57	21
Freezing, 50 km truck, 21000 km ship	3.6	64	28

1. Introduction

Life cycle assessment (LCA) is a holistic environmental assessment tool, providing a systematic way to quantify the environmental impacts of individual products or services from cradle to grave. At the same time this tool can efficiently be used to evaluate improvement options to reduce the environmental impacts throughout the product life cycle.

The production chain of pig meat "from farm to fork" is complex, and so is the environmental assessment of the product. This study is based on LCA methodology to assess the environmental impacts of Danish pork using updated data collected from pig farms (e.g. number of piglets per sow, growth rate, feed conversion ratio, manure management) and the slaughterhouse with the focus on use of resources and reuse of by-products. Environmental data on the production of major feed components like wheat, barley, and soybean meal are also updated in three aspects (1) new estimates of current crop yields and fertilizer inputs, (2) implementation of new technology to reduce the carbon footprint of nitrogen fertilizers, and (3) inclusion of the 2006 IPCC guidelines to estimate on-farm emissions. In our analysis, we adopt both a consequential and an attributional approach since both methods are used in the past and since the PAS 2050 requires an attributional approach. In addition to the typical pig production performance in 2010, we considered the situation that represents the 25% of the pig herds with highest technical efficiency in the pig production in terms of piglets per sow and feed conversion.

2. Materials and life cycle impact assessment method

2.1. Life cycle impact assessment (LCA) method

The LCA methodology often used to assess the environmental impact of agricultural products is ISO standardized (ISO 14044, 2006). The PAS 2050 (BSI, 2008) methodology has recently emerged as a standard to document the carbon footprint (i.e. the impact on the environment in terms of the amount of greenhouse gases produced) of a product so that the consumer can compare one product to another to make their green choice. This methodology does not totally comply with the ISO standard which will be addressed later.

In applying life cycle impact assessment, it is common to distinguish between attributional and consequential modelling (for convenience abbreviated as ALCA and CLCA, respectively). An attributional approach describes the resource flows and emissions within a chosen system attributed to the delivery of the functional unit, and in the PAS 2050 methodology, it is recommended to use that approach.

In contrast, a consequential approach estimates how resource flows and emission within a system change in response to the change in output of the functional unit, here one unit of pork (Ekvall and Weidema, 2004). It can also be rephrased as follows: while the attributional approach describes the resource use and emissions that have occurred to produce the product in question, the consequential approach accounts for the resource use and associated emissions that arise to replenish stocks of the product that have been used. Attributional LCA is argued by some practitioners to be more appropriate for identifying environmental hotspots and for developing market claims, such as environmental product declarations (Tillman, 2000). Consequential LCA, seeking to capture environmental consequences of decisions, is considered by others to generate the most relevant information through which the LCA supports decision making (Wenzel, 1998). While the tendency is that more and more LCA studies use consequential LCA, attributional LCA remains the common approach that most studies to date have used (Dalgaard et al., 2008).
In food production (in particular livestock production), it is common that more than one product is produced. There is a need in these cases to allocate the environmental burden between different products.

In principle, the ISO standard (ISO 14044, 2006) recommends that allocation should be avoided, if possible, by dividing the unit process to be allocated into sub-processes, or expanding the product system to include the additional functions of the co-products. Otherwise, allocation for the system can be done in such a way that it reflects the physical properties or the relative economic values of co-products. There is a relationship between the choice of method, allocation or system expansion, and the choice of LCA approach, attributional or consequential (Nielsen et al., 2003). The consequential approach, seeking to capture change in environmental impact as a consequence of actions, avoids co-product allocation by system expansion. The attributional approach deals with co-product allocation by partitioning the environmental impact related to the product using allocation factors based on mass, energy or economic value. Among the three ways of allocation, the PAS 2050 specifies that economic allocation should be the first option.

In our analysis, we apply both attributional and consequential LCA. The former is applied as per recommendation of the PAS 2050, which for the moment is widely adopted as the most appropriate standard for product footprint, whereas the latter is for illustrating the applicability of the novel approach.

2.2. Pig meat production in Denmark: System description

An overview of the production chain of pork is presented in Figure 1. For the sake of simplicity and data availability, we choose to consider the pig production at farm level as a ‘landless’ production system which imports its feed and other resources. Such assumption would not have a major effect on the results of the analysis since a typical conventional pig farm usually relies entirely on external protein feed resources and often partly on external energy feed (i.e. grain) resources.

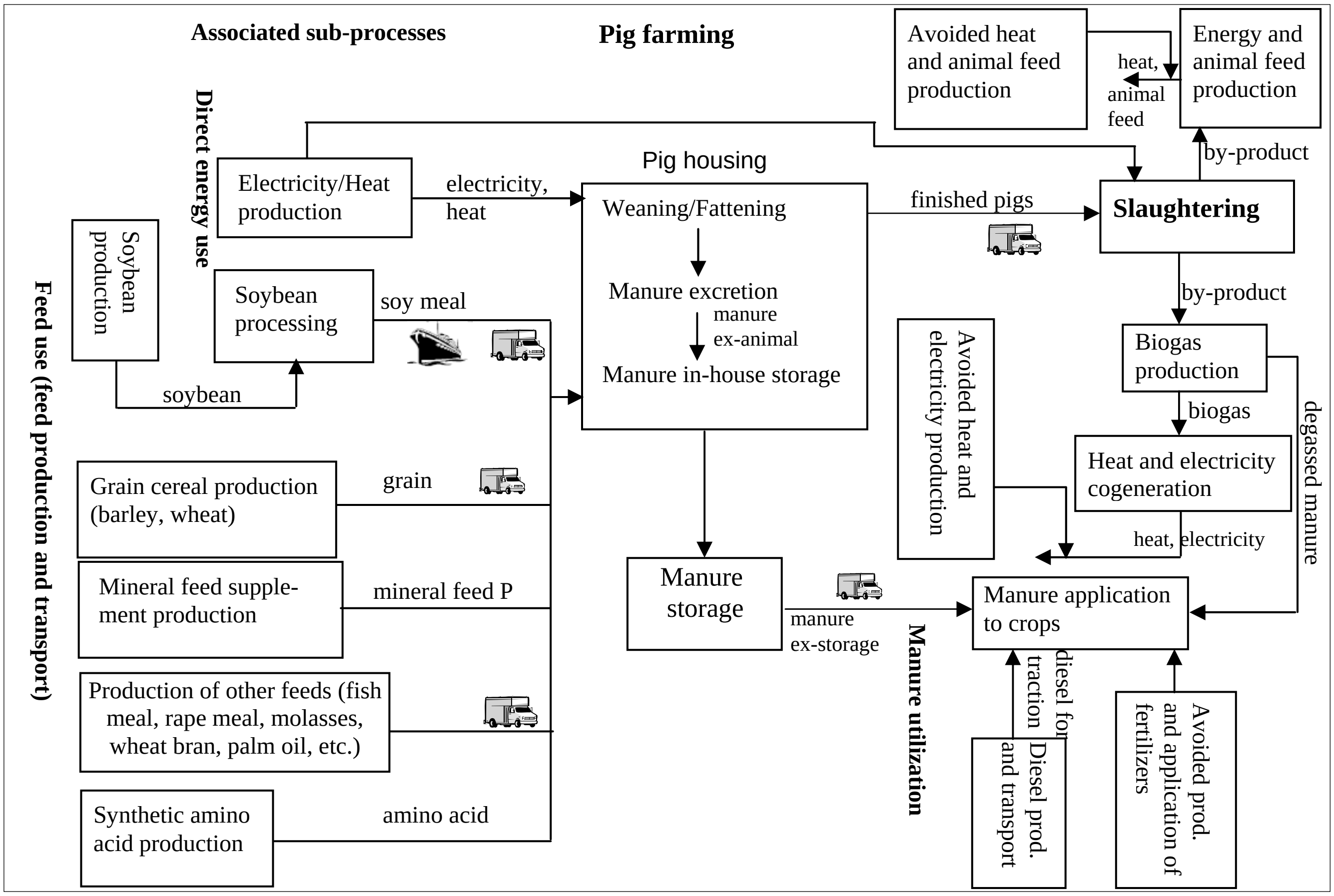

Fig. 1. Overview of the product chain of Danish pork (adapted from Nguyen et al., 2010).

The pig feed in real life is complex in terms of ingredients of difference sources. First, grain and oilseed meal (e.g. soybean meal, rapeseed meal, fish meal, sunflower meal) are the two main components of the feed. Besides these two components, mineral phosphorous is also included in the pig's diet as a feed supplement. Synthetic amino acids are added in a small amount to balance protein intake avoiding overfeeding with unnecessary proteins. Pig rearing consumes heat for piglets and weaners and electricity for ventilation, light, etc.

The manure excreted by the animals in the form of slurry i.e. a mixture of liquid and solid particles is first stored in the pit beneath the slats for a short interval and then pumped to the external storage tank where it is ready for field application. Regular (e.g. monthly) removal of manure from storage pits inside the building and proper storage of manure in outdoor slurry tanks with a natural crust cover are essential to environmentally friendly manure management in livestock production.

The manure after storage, considered as a resource, is expected to be used as fertilizers elsewhere outside the farm. This manure will substitute synthetic fertilizers to some extent depending on the actual availability for crops. The substitution rate for N, the most important nutrient element in manure, as per assumption in Plantedirektoratet (2010), is 75%. The substitution rate for P and K in manure is assumed in most cases to be 100% (Sommer et al., 2008). In relation to manure P, the substitution rate considered in this study is adjusted to 97%, taking into account the potential phosphorous leaching from crop farms (Dalgaard et al. 2006). We argue that all environmental impacts related to manure during in-house storage, outside storage, and field application should be allocated to the pork production (independently of whether it appears on the particular pig farm or not), while deducting reduction in environmental impacts associated with the avoided production of fertilizer nutrients.

At the end of the fattening period, the pigs are brought to the abattoir where they are slaughtered for meat.

2.3. Life cycle inventory: Farming process

The inventory for pig farming starts with the calculation of the amount of feed (SFU-Scandinavian Feed Units, protein, phosphorous), as well as the amount of energy used in the stable. The primary data for this calculation was supplied by Danish Agriculture and Food Council as given in Appendix table A1. Based on this is in appendix table A2 documented how use of total feed, protein use, phosphorous, and direct energy is calculated for one sow with offspring, and also how much meat that is produced from this .

For the PAS 2050 evaluation (the attributional modelling), the information about feed composition for sows, piglets and slaughter pigs (given in appendix table A3) was used to calculate the “actual” amount of each feed item consumed per 100 kg meat live weight produced. The three most important feed components are wheat, barley and soybean meal, with a share of 39.5, 30.4 and 12.1%, respectively, in the feed mixture. With a consequential approach, it is generalized that the pork production is global and draw on global feed resources. Thus producing an extra pig will ultimately draw on a protein source (e.g. oilseed meal) and cereals (Bouwman et al, 2006). The theoretical amount of the marginal energy feed (spring barley, according to Schmidt and Weidema, 2008) and protein feed (soybean meal as argued by Dalgaard et al., 2008) was calculated based on the amount of protein and energy supplied by the two feed ingredients to satisfy the protein and energy requirements of the pigs.

In order to explore the potential for further improvements from the current status i.e. the typical 2010 production, we defined an alternative scenario representing the 25% of the pig herds with the best production performance. In this alternative scenario, we consider a potential 7-8% increase in feed efficiency and 10% increase in the number of piglets weaned per sow per year.

The calculated amount of feed input, manure output, and direct on-farm emissions per 1000 kg meat produced in the base case and the alternative scenario under the two LCA approaches are summarized in Table 1. The calculations related to manure characteristics are presented in Table 2. In most cases, livestock emissions cannot be measured with reasonable accuracy or cost-effectiveness, so they are often obtained by using some modeling technique. This is described in detail in Table 3. Key assumptions in relation to feed which is an important input in pig production are presented below.

Table 1. Life cycle inventory per 1000 kg pig meat live weight (at farm gate).

Item	Unit	Baseline: typical 2010 production		Alternative scenario: 25% herds with higher efficiency	
		Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
Feed use	**Kg**				
Wheat		0	1112	0	1028
Barley		2564	855	2369	788
Soybean meal		485	341	449	316
Others			497		459
Mineral feed P		1.9	1.8	1.8	1.6
Transport of feed [a]	**Tkm**				
By truck		541	411	500	380
By ship		5824	4094	5389	3791
On-farm energy use [b]					
Electricity	kWh	148	148	145	145
Heat	MJ	541	541	524	524
Manure flow [c]					
Mass					
ex-animal/ex-housing/ex-storage	T	6.9/6.9/7.4	6.9/6.9/7.4	6.0/6.0/6.5	6.0/6.0/6.5
DM (Dry Matter)					
ex-animal/ex-housing/ex-storage	Kg	528/502/477	528/502/477	464/441/419	464/441/419
VS (Volatile solids)					
ex-animal/ex-housing/ex-storage	Kg	433/406/381	433/406/381	381/357/335	381/357/335
N (Nitrogen)					
ex-animal/ex-housing/ex-storage	Kg	45.3/39.0/37.5	45.3/39.0/37.5	39.8/34.3/32.9	39.8/34.3/32.9
P (Phosphorous)	Kg	7.9	7.9	6.9	6.9
K (Potassium)	Kg	21.7	20.6	19.9	18.9
On-farm emissions [d]					
CH_4	Kg				
(Enteric fermentation)		(4.0)	(3.7)	(3.7)	(3.5)
(Manure management)		(16.2)	(16.2)	(14.2)	(14.2)
N_2O (in-house and outside storage)	G	553	553	486	486
NH_3	Kg	7.6	7.6	6.7	6.7
NO_x	G	612	612	538	538
Manure utilization for fertilizers					
Transport to fields [a]	Tkm	75	75	65	65
Farm traction [b]	MJ	157	157	138	138
N_2O emissions [d]	G	744	744	654	654
NH_3 [d]	Kg	8.4	8.4	7.4	7.4
NO_x [d]	G	123	123	108	108
NO_3 [d]	Kg	16.6	16.6	14.6	14.6
PO_4 [d]	Kg	0.7	0.7	0.6	0.6
Avoided fertilizer production [e]	Kg				
from manure N		28	28	24.7	24.7
from manure P		7.7	7.7	6.7	6.7
from manure K		21.7	20.6	19.9	18.9
Avoided fertilizer application					
Farm traction [b]	MJ	11	11	9.6	9.6
N_2O emissions [d]	G	473	473	416	416
NH_3 [d]	Kg	2.2	2.2	2.0	2.0
NO_x	G	646	646	568	568

Assumptions

[a] Soybean meal used in Denmark is produced in Argentina. It is first transported from Rosario Harbour to Rotterdam Harbour, the Netherlands (12000 km) by ship, and then to livestock feed factories and farms (totally 850 km) by truck

- Locally produced grain is transported over 50 km by truck
- Manure is transported over 10 km from outside storage to fields by tractor and trailer

[b] Energy use in housing is calculated from Table A2

Manure application (loading and spreading) consumes 21 MJ per tonne slurry ex-storage, and fertilizer application consumes 0.4 MJ per kg fertilizer N. These values are estimated from Dalgaard et al. (2001)

[c] Relevant calculations related to manure characteristics are shown in Table 2

[d] Factors for estimating emissions are summarized in Table 3

[e] The substitution rate for nitrogen, phosphorous and potassium in manure is 75, 97, and 100%, respectively (see text).

Table 2. Calculations related to manure characteristics.

Manure composition kg	Ex-animal	Ex-housing	Ex-storage
Nitrogen	[Feed weight × N content of feed (Møller et al., 2005)] – Nitrogen in meat (Poulsen et al., 2001: 25 g/kg LW for sow and 27 g/kg for slaughter pig) = G	G – Nitrogen loss in 'in-house storage' (see Table 3) = H	H – Nitrogen loss in 'outside storage' (see Table 3)
Phosphorous	[Feed weight × P content of feed (Møller et al., 2005)] – P in meat (Poulsen et al., 2001: 5.5 g/kg LW)		
Potassium	[Feed weight × K content of feed (Møller et al., 2005)] – K in meat (Poulsen et al., 2001: 2.2 g/kg LW)		
Mass	Manure N (kg) × 1000 ÷ 6.6 = A	A	A × 1.086 = B
Comments	Based on DJF (2008a): 3.1 kg N in 0.47 t manure	a small DM loss is considered ignorable	Based on DJF (2008a): 8.6% rain water coming during ex-storage
DM	D ÷ 0.95 = E Backward calculation from DM ex-housing	C ÷ 0.95 = D Backward calculation from DM ex-storage	B × 0.061 = C
Comments	Based on DJF (2008b) and Poulsen et al. (2001): DM ex-housing/DM ex-animal = 0.90 (more than one month in housing units); DM ex-storage/DM ex-housing = 0.95 DM loss when manure is stored in housing units for less than one month is assumed to be 5%		Adapted from DJF (2008a): dry matter content of manure ex-storage = 6.4%
VS	G + (E – D) Backward calculation from VS ex-housing	F + (D – C) = G Backward calculation from VS ex-storage	C × 0.8 = F
Comments	Assumption: the loss of DM is originated primarily from the loss of VS		Sommer et al. (2008): VS content of DM ex-storage = 80%

Table 3. Modeling of emissions from the pig farm [a] (related to the study).

Pollutant kg	Emission calculation (per 10 pigs or 1000 kg meat live weight)	Reference/guideline
CH_4		
Enteric fermentation	Sows: kg feed × 100 g ResD/kg feed × 1340 J/g ResD/(55.65 MJ/kg CH_4 × 10^6 J/MJ) Weaners and slaughter pigs: kg feed × 90 g ResD/kg feed × 670 J/(55.65 MJ/kg CH_4 × 10^6 J/MJ)	Rigolot et al. (2010)
Manure management	kg manure VS per pig × 0.45 m^3 CH_4/kg VS × 0.67 kg/m^3 CH_4 × methane emission factor for typical manure management e.g. 3% for slurry in-house storage less than one month, 10% for slurry outside storage with natural crust cover (cool climatic condition)	IPCC (2006)
Direct N_2O-N		
Manure management		IPCC (2006)
In-house storage	0.002 × kg manure N ex-animal	
Outside storage with natural crust cover	0.005 × kg manure N ex-housing	
Field application	0.01 × kg manure N ex-storage	
Fertilizer application	0.01 × kg fertilizer N	
N_2-N (sandy soil)		
Manure management		
In-house storage	0.006 × kg manure N ex-animal	Dämmgen and Hutchings (2008)
Outside storage	0.015 × kg manure N ex-housing	
Field application	0.047 × kg manure N ex-storage	
Fertilizer application	0.047 × kg fertilizer N	Vinther (2005)
NO_x-N		
Manure management		
In-house storage	0.002 × kg manure N ex-animal	Dämmgen and Hutchings (2008)
Outside storage	0.005 × kg manure N ex-housing	
Field application	0.001 × kg manure N ex-storage	Nemecek and Kägi (2007)
Fertilizer application	0.007 × kg fertilizer N	EEA (2007)
NH_3-N		
Manure management		
In-house storage	0.13 × kg manure N ex-animal	} Factors calculated from data in Table A1
Outside storage	0.02 × kg manure N ex-housing	
Field application	0.07 × kg manure N ex-storage	Andersen et al. (2001)
After application	0.117 × kg manure N ex-storage	Hansen et al. (2008)
Fertilizer application	0.065 × kg fertilizer N	Estimated from FAO (2001)
NO_3-N leaching (pot.)	kg N ex-animal – kg total N loss – kg fertilizer N substitution	Nutrient balance
PO_4-P leaching (pot.)	kg P ex-animal – kg fertilizer P substitution	
Indirect N_2O-N	0.01 × kg (NH_3-N + NO_x-N) loss + 0.0075 × kg NO_3-N leaching	IPCC (2006)

[a] Emissions from on-farm energy use are accounted for separately; they are calculated in SimaPro, using LCA food database (see Table 4)
ResD: digested fibre ingested

2.4. Life cycle inventory: Slaughtering process

According to the 2010 data supplied by Danish Crown, a carcass weight of about 81 kg is obtained from the live weight of one pig at slaughter, 107 kg. It is also shown that on average the process consumes 12 kWh electricity and 14 kWh heat per slaughter pig. By-products from the slaughterhouse that can be reused are categorized into two major groups depending on whether they are reused for (1) biogas, or (2) energy (e.g. heat) and animal feed.

By-products for biogas consist primarily of slurry from the stables at the slaughterhouse plus contents of casings and stomach as well as sawdust from lorry transport of the pigs. The materials are digested to produce biogas for production of heat and electricity and the degassed materials are returned to agriculture and applied to crops as fertilizer. By-products for energy and animal feed include bones, blood, fat, meat, and other scraps. Information from the Green Accounts (Horsens Slaughterhouse, 2007; DAKA, 2007) allows for the assumption that 1 tonne of by-products in this group can substitute 124 kWh district heat and 211 kg barley. The avoided products with associated environmental burdens are taken into account in quantifying the environmental footprint of pork.

2.5. Functional unit, assessment parameters and data inventory for certain system components

The functional unit used to report results of the analysis is one kg meat (carcass weight) delivered from the slaughterhouse.

Five impact categories was considered; Global warming potential (GWP), Acidification potential (AP), Eutrophication potential (EP), Non-renewable energy and Land use (LU). These impact categories are commonly used to provide a comprehensive picture of the environmental profile of agricultural products. For the first four categories, the EDIP method (Wenzel et al., 1997) was used to calculate the results with the update of the 100-year Global warming potential of CH_4 and N_2O to 25 and 298, respectively, following IPCC guidelines (IPCC, 2007). Since the EDIP method does not include the impact category ‘non-renewable energy use’, the Impact 2002+ method (Jolliet et al., 2003) was used as a substitute to calculate the results. All calculations for the analysis were performed in SimaPro where both methods, EDIP and Impact 2002+, are available.

The environmental footprint of various feeds used in pig production is summarized in Table 4 together with that of other inputs, avoided products and emissions. In relation to feed production, our following discussion concentrates on the three most important feed ingredients: wheat, barley and soybean meal.

2.5.1. Life cycle inventory of barley and wheat

The life cycle inventory of barley and wheat in both attributional and consequential modeling is built on the LCA food database (Nielsen et al., 2003) but modified in three aspects which are described as follows.

Table 4. Environmental footprint of major inputs, outputs (by-products) and emissions associated with the system.

Item	unit	GWP, g CO_2e	AP, g SO_2e	EP, g NO_3e	Non-renewable energy, MJ primary	LU, m^2a	Data sources, adapted or taken directly from
Consequential LCA	**kg**						
Barley		507	6.6	53	3.76	2.1	LCAfood.dk (Nielsen et al., 2003)
Soybean meal		369	3.1	66.6	4.44	2.2	Dalgaard et al. (2008)
Fertilizer N		5440	33.2	59	61.4		Ecoinvent Centre (2010)
Attributional LCA	**kg**						
Wheat		414	5.5	30.2	3.23	1.4	LCAfood.dk
Barley		478	6.6	53	3.76	2.1	LCAfood.dk
Soybean meal		470	3.1	49.2	4.17	1.7	Dalgaard et al. (2008)
Rapeseed meal		316	4.7	35.2	2.7	1.1	LCAfood.dk
Fish meal		1170	8.9	16	16.2		LCAfood.dk
Palm oil		617	6.8	41	7.9	1.7	Ecoinvent centre (2010)
Molasses		108	0.9	5.7	1.4	0.2	Ecoinvent centre (2010)
Sunflower cake		750	6.2	54.3	6.5	2.5	van der Werf et al. (2005)
Wheat bran		186	1.2	14.6	0.9	0.3	LCAfood.dk
Amino acid		3600	41	9	86		Strid-Eriksson et al. (2004)
Calcium carbonate		6.5	0.03	0.02	0.105		LCAfood.dk
Fertilizer N		4250	33.2	58.9	61.4		Ecoinvent Centre (2010)
Consequential and attributional LCA							
Mineral feed P	kg	2690	41	26.4	39.6		LCAfood.dk
Fertilizer P		2690	41	26.4	39.6		LCAfood.dk
Fertilizer K		804	1.4	1.9	12.5		LCAfood.dk
Heat (oil)	MJ	94	0.2	0.15	1.3		LCAfood.dk
Heat (gas)	kWh	248	0.27	0.24	4.13		LCAfood.dk
Heat (slaughterh.)		269	0.42	0.34	4.18		LCAfood.dk
District heat	kWh	13.7	0.20	0.32	0.17		LCAfood.dk
Electricity (gas)		655	0.6	1.2	8.5		LCAfood.dk
Electricity (coal)	kWh	987	2.84	2.26	11		ETH-ESU (1996)
Traction		109	0.9	1.6	1.4		LCAfood.dk
Transport	kWh						
Ship		9	0.2	0.14	0.12		
Truck 28t	kWh	227	1.9	2.81	3.51		
Truck 16t		375	2.5	3.7	6.03		
Tractor and trailer	MJ	306	2.0	5.25	4.91		Ecoinvent centre (2010)
WW treatment	tkm						LCAfood.dk
Nitrogen		2620	2.6	4.8	34.2		
COD		721	0.7	1.3	9.4		
Methane	g	25					IPCC (2007)
Nitrous oxide		298					IPCC (2007)
Ammonia			1.88	3.64			Wenzel et al. (1997)
Nitric oxide			1.07				
Nitrogen dioxide			0.7				
Nitrogen oxides				1.35			
Phosphate				10.45			
Nitrogen (total)				4.43			
Phosphorous (total)				32.03			

(1) *New estimates of current crop yields (Statistics Denmark, 2010) and fertilizer inputs (Plantedirektoratet, 2010).* Compared to the LCA food database which is based mainly on data collected in 1999, the updated data show a 7% increase in wheat yield and a 19 and 5% reduction in fertilizer N input per hectare of wheat and barley, respectively.

(2) *The potential of reducing the carbon footprint of nitrogen fertilizers*. According to the LCA food database (Nielsen et al., 2003), the specific nitrogen fertilizer used in cereal production is calcium ammonium nitrate which has a relatively high carbon footprint of about 9.2 kg CO_2e per kg N. The use rate of 0.03 kg fertilizer N per kg conventional wheat thus adds about 276 g CO_2e to the carbon footprint per kg wheat produced. Nowadays advanced technology e.g. catalytic abatement technology in ammonium nitrate based fertilizer production helps reduce N_2O emissions and thus the carbon footprint by a factor of about 2, i.e. from 9.2 to about 4.3 kg CO_2e per kg N (YARA, 2010). This complies with the carbon footprint standard for fertilizers produced and delivered to Nordic countries like Finland, Denmark, Sweden and Norway. In the attributional modeling, we thus replace the original process "fertilizer N" in the cereal (wheat and barley) production process with the adjusted process considering the implementation of advanced technology to reduce up to 50% GHG emissions. Jenssen and Kongshaug (2003) found that the marginal nitrogen fertilizer (i.e. the one affected by a change in demand) would have a carbon footprint of about 5.4 kg CO_2e per kg N. This value is adopted in calculating the carbon footprint of the marginal energy crop (barley) in the consequential modeling.

(3) *The new IPCC guidelines (IPCC, 2006) to estimate on-farm emissions.* In current LCA studies on livestock products, the IPCC Guidelines are commonly used to obtain default factors to estimate methane and nitrous oxide emissions. Recently IPCC (2006) has revised and updated the 1996 revised IPCC Guidelines to provide more accurate methods and updated emission factors (EFs) for estimating emissions. For example, IPCC (2006) has changed the default EF from 0.0125 to 0.1 for direct N_2O emissions from nitrogen inputs as mineral fertilizers, organic amendments and crop residues, as compared to the 1996 IPCC guidelines. In relation to the first two nitrogen inputs, the amounts of nitrogen are no longer adjusted for the amounts of NH_3 and NO_x volatilization after application. The default EFs for indirect soil N_2O emissions from leaching has been also changed from 0.025 to 0.0075 kg N_2O-N/kg N leached.

2.5.2. Life cycle inventory of soybean meal

The LCA of soybean meal has been conducted and published (Dalgaard et al., 2008). Soybean meal is a product of soybean production. The production of soybean meal also results in the co-production of soy oil. This raises the need to distribute the environmental loads from soybean farming and processing between the two co-products, using either allocation or system expansion as mentioned earlier.

In the attributional modeling, economic allocation factors of 66.3 and 33.7% based on the 2005-2009 average market price of the meal and the oil, respectively (FAO, 2010), were applied to distribute the environmental burden between the two co-products. Economic allocation, as per recommendation of the PAS 2050, should be used if allocation cannot be avoided. The reasoning behind the selection of this method among others like allocation based on physical characteristics of co-products is that it reflects the underlying economic reasons for production (Jonasson, 2004) which is more or less in line with the consequential approach.

In the consequential modeling using system expansion to avoid allocation, the soybean product system is expanded to reflect that the soy oil produced together with the soybean meal will substitute other vegetables oil production. Thus, as a results there will typically be a lower need for palm oil production. As shown in Dalgaard et al. (2008), an increased demand for 1000g soybean meal causes a production of 1005 g of soybean meal itself, and results in a saved demand for palm fruit bunches (856 g) and an increased need for spring barley (12g). In this analysis, we updated the LCA of soybean meal by adopting the inventory for 'soybean cultivation' and 'oil palm cultivation' available in Ecoinvent database (Ecoinvent centre, 2010). Since the impacts of land use and land use change are outside the scope of our analysis, the unit process 'provision, stubbed land' and the emissions of 'CO_2 from land transformation' were excluded from these two system boundaries. The impacts are potentially included in future analyses. The 'spring barley' process was taken from the LCA food database with adjustments made for consequential modeling as mentioned earlier.

A comparison of the environmental footprint between 'consequential soybean meal' and 'attributional soybean meal' (see Table 4) shows that the impacts related to 'acidification potential' and 'non-renewable energy' are very similar. 'Eutrophication', 'land use' and 'global warming' from attributional soybean meal are 26% lower, 23% lower, and 27% higher than that from consequential soybean meal. The differences are attributed to different modelling methodologies chosen to account for the environmental impacts of products e.g. soybean meal.

3. Results and discussion

3.1. Environmental impact per kg pig meat live weight at farms

Table 5 summarizes the environmental performance in five impact categories considered per kg pig meat live weight at farms for both the base case and alternative scenario. Detailed presentation and discussion for each impact category are given in the following subsections.

Table 5. Environmental impact per kg pig meat live weight (LW) at farms using both consequential and attributional LCA.

	Typical 2010 production		25% herds with higher efficiency	
	Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
GWP, kg CO_2e	2.4	2.2	2.2	2.0
AP, g SO_2e	46.3	42.5	41.6	38.2
EP, g NO_3e	244	185	222	167
Non-renewable energy, MJ primary	14.7	13.6	13.8	12.8
Land use, m^2a	6.5	4.4	6.0	4.1

Global warming potential

The GWP per kg pig meat live weight produced at farms ranged from 2.0 to 2.4 kg CO_2e depending on systems (base case or alternative scenario) and the type of LCA modeling (attributional or consequential). A breakdown of contributions to the GWP from different components of the chain is presented in Table 6. As seen, the leading contributor to GWP in all cases is "feed use" (62 and 59% in the consequential and attributional modeling, respectively). At the second position is "on-farm emissions" (28-30%), with CH_4 being the main contributor responsible for 75% of the total CH_4 and N_2O emissions. "Transport of feed" and "on-farm energy use" are minor contributors accounting for around 6-7% of the total GWP per kg pig meat at farms. Manure utilization for crop fertilization results in a negative contribution, meaning that the practice effectively reduces some GHG emissions attributable to the pig meat product. As compared to the base case, the alternative scenario provides an 8% reduction in the impact category.

From the table, it is also clear that the difference in the results due to the use of different LCA modeling approaches (consequential or attributional) is attributed mainly to how 'feed use' for the pigs is modeled and how the environmental footprint of major feeds is accounted for. In the consequential modeling, barley represents a major feed component with up to 84% contribution to the total feed use of 3.05 kg per kg meat LW. In Table 4, it shows that "consequential barley" has a relatively high GHG footprint compared to the three major feed ingredients in the attributional modeling: wheat, barley and soybean meal.

The comparison between Danish pork (at farm gate) and pork from existing literature with respect to climate impact has been made to put this study in perspective. In a recent paper (Stephenson, 2010) published by the Round Table on Sustainable Development at the OECD, it was shown that pork has the climate impact of 3.3 kg CO_2e/kg. The climate impact of Danish pork according to our estimate under the attributional approach is 2.9 kg CO_2e/kg carcass weight (assuming a dressing percentage of 76), which is 12% lower than the reference.

In a similar study, Dalgaard et al. (2007) arrived at 3.4 kg CO_2e/kg carcass weight as the climate impact of Danish pork in 2005, based on a consequential approach. The finding in this study, 3.2 kg CO_2e/kg under the same LCA approach, shows an improvement of 0.2 kg CO_2e/kg which is relatively minor.

Land use

Land use refers to the area of land that is being occupied and thus temporarily unavailable for other purposes. The results in Table 6 show that producing 1 kg pig meat in Denmark requires 4.1-6.5 m^2year. The highest range (6.0-6.5 m^2year) is obtained when the consequential LCA modeling is used, due to the lower yield per ha assumed for 'marginal' barley production than for Danish cereal production. From the land use range as presented in the base case, the alternative scenario offers the possibility of 7-8% savings.

Acidification potential

In terms of acidification potential, a range of 38.2 to 46.3 g SO_2e per kg pig meat live weight is found (Table 5). The attributional LCA modeling gives a slightly lower result in acidification (8%) than the consequential one. As seen in Table 7, the main contributors to acidification potential of the pig meat product at farms are feed use, "on-farm NH_3 emissions" and manure utilization. In contrast to global warming, the contribution from manure application to acidification is positive (i.e. addition of the impact) at 22-25% which is balanced between field emission impacts (mainly from ammonia) and avoided impacts from the production and application of artificial fertilizers. "Feed transport" and especially "on-farm energy use" again represent two minor contributors to acidification potential. As compared to the base case, the alternative scenario provides a 10% reduction in the impact category.

Eutrophication potential

In the baseline scenario, the eutrophication potential calculated by the attributional LCA modelling is 185 g NO_3e per kg pig meat produced at farms which is 24% lower than that calculated by the consequential LCA. This can be explained in the same manner as that described for "land use". As seen in Table 8, the highest contribution to eutrophication is made by "feed use" (60 and 69% in the attributional and consequential modelling, respectively) followed by "manure application" (24 and 18%) and "on-farm ammonia emissions" (14.9 and 11.3%). The other two relatively minor contributors are "feed transport" and "on-farm energy use". The improvement in eutrophication offered by the alternative scenario versus the base case is a 9% reduction, approximately.

Fossil (non-renewable) energy use

The 'Non-renewable energy' category is another important indicator of the sustainability of food production systems, given that it comes from finite resources which will eventually be exhausted beyond the level that can be economically extracted. As shown, one kg pig meat leaving the farm for slaughter consumed 13-15 MJ non-renewable energy (Table 5). The attributional LCA modeling gives a slightly lower result in this impact category (7.5%) than the consequential one. A further breakdown of the results presented in Table 5 (Table 9) shows that the largest contributor to 'non-renewable energy' is "feed use", accounting for 85 and 81% in the attributional and consequential modeling, respectively. Manure utilization for crop fertilization results in a negative contribution, that is, a deduction from the total energy used to produce the meat. As compared to the base case, the alternative scenario provides a 6% reduction in the impact category.

Table 6. Global warming impact potential (GWP, g CO_2e) and land use (LU, m^2a) per kg meat LW at farms.

Item	Typical 2010 production				25% herd with higher efficiency			
	Consequential		Attributional PAS 2050		Consequential		Attributional PAS 2050	
	GWP	LU	GWP	LU	GWP	LU	GWP	LU
Feed use	**1484**	**6.5**	**1281**	**4.4**	**1372**	**6.0**	**1183**	**4.1**
Wheat, production	0		460	1.5	0		426	1.4
Barley, production	1300	5.46	409	1.8	1201	5.1	377	1.7
Soybean meal, production	179	1.06	160	0.6	166	1.0	148	0.5
Other feeds	0		247	0.5	0		228	0.5
Mineral feed P	5		5		4.7		4.4	
Transport of feed	**175**		**130**		**162**		**120**	
By truck	123		93		114		86	
By ship	52		37		48		34	
On-farm energy use	**148**		**148**		**144**		**144**	
On-farm emissions	**670**		**662**		**593**		**587**	
CH_4	505		497		448		442	
(Enteric fermentation)	(101)		93		93		87	
(Manure management)	(404)		404		355		355	
N_2O (in-house and outside storage)	165		165		145		145	
Manure utilization for fertilizer	**-71**		**-37**		**-63**		**-33**	
Transport to fields	22		22		20		20	
Farm traction	17		17		15		15	
N_2O emissions	222		222		195		195	
Avoided fertilizer production	-191		-157		-169		-140	
(from manure N)	(-153)		(-119)		(-134)		(-105)	
(from manure P)	(-21)		(-21)		(-18.0)		(-18.0)	
(from manure K)	(-17)		(-17)		(-15.6)		(-15.6)	
Avoided fertilizer application	-142		-142		-125		-125	
(Traction)	(-1)				-1		-1	
(N_2O)	-(141)				-124		-124	
Sum	2406	6.5	2184	4.4	2208	6.0	2002	4.1

Table 7. Acidification potential (AP, g SO_2e) per kg meat LW at farms.

Item	Typical 2010 production		25% herd with higher efficiency	
	Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
Feed use	**18.4**	**15.3**	**17.0**	**14.1**
Wheat, production		6.1		5.6
Barley, production	16.8	5.6	15.5	5.2
Soybean meal, production	1.5	1.1	1.4	1.0
Other feeds		2.4		2.2
Mineral feed P	0.1	0.1	0.1	0.1
Transport of feed	**2.4**	**1.8**	**2.3**	**1.7**
By truck	1.0	0.8	1	0.7
By ship	1.4	1.0	1.3	0.9
On-farm energy use	**0.2**	**0.2**	**0.2**	**0.2**
On-farm emissions	**15.0**	**15.0**	**13.1**	**13.1**
NH_3	14.3	14.3	12.5	12.5
NO_x	0.7	0.7	0.6	0.6
Manure utilization for fertilizer	**10.4**	**10.4**	**9.1**	**9.1**
Transport to fields	0.15	0.15	0.13	0.13
Farm traction	0.15	0.15	0.13	0.13
NH_3 emissions	15.9	15.9	14.0	14.0
NO_x emissions	0.09	0.09	0.08	0.08
Avoided fertilizer production	-1.3	-1.3	-1.1	-1.1
from manure N	(-0.93)	(-0.93)	(-0.82)	(-0.82)
from manure P	(-0.32)	(-0.32)	(-0.28)	(-0.28)
from manure K	(-0.03)	(-0.03)	(-0.03)	(-0.03)
Avoided fertilizer application	-4.6	-4.6	-4.1	-4.1
Traction	(-0.01)	(-0.01)	(-0.01)	(-0.01)
NH_3	(-4.2)	(-4.2)	(-3.7)	(-3.7)
NO_x	(-0.45)	(-0.45)	(-0.4)	(-0.4)
Sum	46.3	42.5	41.6	38.2

Table 8. Eutrophication potential (EP, g NO_3e) per kg meat live weight (at farms).

Item	Typical 2010 production		25% herd with higher efficiency	
	Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
Feed use	**168**	**109.7**	**155.5**	**101.3**
Wheat, production		33.6		31.05
Barley, production	136	45.3	125.5	41.8
Soybean meal, production	32	16.8	30	15.5
Other feeds		13.95		12.9
Mineral feed P	0.05	0.05	0.05	0.04
Transport of feed	**2.3**	**1.7**	**2.2**	**1.6**
By truck	1.5	1.2	1.4	1.1
By ship	0.8	0.6	0.8	0.5
On-farm energy use	**0.3**	**0.3**	**0.3**	**0.3**
On-farm emissions	**28.4**	**28.4**	**25.0**	**25.0**
NH_3	27.6	27.6	24.3	24.3
NO_x	0.8	0.8	0.7	0.7
Manure utilization for fertilizer	**44.6**	**44.6**	**39.1**	**39.1**
Transport to fields	0.2	0.2	0.2	0.2
Farm traction	0.26	0.26	0.22	0.22
NH_3 emissions	30.7	30.7	27	27
NO_x emissions	0.17	0.17	0.15	0.15
NO_3	16.6	16.6	14.6	14.6
PO_4	7.6	7.6	6.6	6.6
Avoided fertilizer production	-1.9	-1.9	-1.7	-1.7
from manure N	(-1.7)	(-1.7)	(-1.5)	(-1.5)
from manure P	(-0.2)	(-0.2)	(-0.29	(-0.29
from manure K	(-0.04)	(-0.04)	(-0.04)	(-0.04)
Avoided fertilizer application	-9.0	-9.0	-7.9	-7.9
Traction	(-0.02)	(-0.02)	(-0.02)	(-0.02)
NH_3	(-8.1)	(-8.1)	(-7.1)	(-7.1)
NO_x	(-0.87)	(-0.87)	(-0.77)	(-0.77)
Sum	244	185	222	167

Table 9. Non-renewable energy use (MJ primary) per kg meat LW at farms.

Item	Typical 2010 production		25% herd with higher efficiency	
	Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
Feed use	**11.9**	**11.5**	**11.0**	**10.6**
Wheat, production		3.6		3.3
Barley, production	9.6	3.2	8.9	3.0
Soybean meal, production	2.2	1.4	2.0	1.3
Other feeds		3.2		2.9
Mineral feed P	0.07	0.07	0.07	0.07
Transport of feed	**2.6**	**1.9**	**2.4**	**1.8**
By truck	1.9	1.4	1.8	1.3
By ship	0.7	0.5	0.6	0.5
On-farm energy use	**2**	**2**	**1.9**	**1.9**
Manure utilization for fertilizer	**-1.8**	**-1.8**	**-1.5**	**-1.5**
Transport to fields	0.3	0.3	0.3	0.3
Farm traction	0.22	0.22	0.20	0.20
Avoided fertilizer production	-2.3	-2.3	-2.0	-2.0
from manure N	(-1.7)	(-1.7)	(-1.52)	(-1.52)
from manure P	(-0.3)	(-0.3)	(-0.27)	(-0.27)
from manure K	(-0.3)	(-0.3)	(-0.25)	(-0.25)
Avoided fertilizer application (traction)	-0.02	-0.02	-0.01	-0.01
Sum	14.7	13.6	13.8	12.8

3.2. Environmental impact associated with slaughtering process

Table 10 presents results on the environmental impact associated with slaughtering process. The table clearly shows the benefits from the recovery and reuse of the two groups of by-products. The use of by-products for biogas reduces the environmental impact in two impact categories, global warming and non-renewable energy whereas the use of by-products for energy (district heat) and animal feed reduces the impact in almost all impact categories considered except non-renewable energy. Detailed calculations to get characterized results for the two groups of by-product from slaughterhouse are presented in Tables 11 and 12. The net impact (i.e. balancing the costs of inputs e.g. energy, transport of the pig, wastewater treatment and the benefits of utilizing by-products) as seen in Table 10 is an increase in global warming, acidification, non-renewable energy (i.e. addition of the impact) and a decrease in eutrophication and land use (i.e. deduction of the impact).

Table 10. The environmental impact associated with slaughtering process.

	unit	amount [a]	GWP g CO_2e	AP g SO_2e	EP g NO_3e	Non-renew. energy MJ primary	LU m^2a	Comments
Inputs								
1 living pig	kg	107						
Electricity (gas)	kWh	12	7865	7.7	14.3	102.9		
Heat (slaughterhouse)	kWh	14	3775	5.8	4.8	58.5		
Transport 80 km (lorry, 16 t)	tkm	8.56	3216	21	31.8	51.6		
Outputs	kg							
Pork		81						
Materials for biogas		5.6	-736	0.06	1.64	-6.3		cf. Table 11
Bone, blood and meat meal prod.		15.6	-374 *(CLCA)* -281 (*ALCA*)	-20.6	-170	5.5	-7.0	cf. Table 12
WW treatment	kg							
COD		0.83	599	0.59	.09	7.8		
N		0.04	105	0.103	0.19	1.4		
SUM			14450 *(CLCA)* 14543 (*ALCA*)	15	-116	221	-7.0	

[a] Data source: Danish Crown

Table 11. The environmental impact per tonne of by-product[a] from slaughterhouse for biogas.

		amount	GWP kg CO_2e	AP kg SO_2e	EP kg NO_3e	Non-renewable energy MJ primary
Inputs [b]						
Electricity (gas)	kWh	2	1.3	0.0013	0.0024	17.1
Heat (oil)	kWh	13	4.4	0.0098	0.0071	60.4
Outputs [c]						
Electricity (avoided product: coal-based electricity)	kWh	70.7	-69.8	-0.2	-0.16	-776
Heat (avoided product: oil-based heat)	kWh	91.5	-31.1	-0.07	-0.05	-424
Emissions [d]						
from biogas plant						
CH_4	g	530	13.25			
from biogas combustion						
CH_4	g	218.5	5.46			
N_2O	g	0.34	0.1			
SO_2	g	13		0.013		
NO_x		365.3		0.256	0.493	
Avoided N_2O emissions from appl.: 50% reduction	g	50	-14.9			
Avoided CH_4 emissions from storage: 90% reduction	kg	1.6	-40.2			
Sum			-131.5	0.011	0.292	-1122

[a] Assuming VS content of this material ≈ 6.3%
[b] Data source for input of electricity and heat: Nielsen et al. (2003)
Transport distance to biogas plants is assumed to be 5 km
[c] Energy yield from biogas: 1.12 kWh as electricity/kg VS and 1.45 kWh as heat/kg VS (Nguyen et al., 2010)
[d] CH_4 emissions from biogas plant: 8.4 kg/t manure VS (Sommer et al., 2004)
Emissions from biogas combustion for energy: see Table A4, appendix
Avoided N_2O and CH_4 emissions: cf. Sommer et al. (2004)

Table 12. The environmental impact per tonne by-product for energy and animal feed.

		amount	GWP kg CO_2e	AP kg SO_2e	EP kg NO_3e	Non-renewable energy MJ primary	Land use m^2a
Inputs							
Electricity (gas)	kWh	87	57	0.056	0.104	743	
Heat (gas)	kWh	69	17	0.0185	0.0168	285	
Outputs: avoided production of							
District heat	kWh	124	-1.7	-0.0253	-0.0395	-20.7	
Barley, from farm	Kg	211	-97 *(CLCA)* -91 *(ALCA)*	-1.37	-11.2	-659	-443
Emissions	G						
Nitrogen (total)		29			0.13		
Phosphorous (total)		1			0.03		
SUM			-24 *(CLCA)* -18 *(ALCA)*	-1.32	-10.9	348	-443

3.3. Environmental impact per kg Danish pork

The environmental performance in the five impact categories considered per kg Danish pork for both the base case and alternative scenario is presented in Table 13. The table shows that a major share of the environmental burden of the pork product is related to the primary production on the farm: 87-88% in the impact category “non-renewable energy”, 94-95% in “global warming”, 99.7% in “acidification”, and over 100% in “eutrophication” and “land use”. In the latter case, the contribution to the two environmental impacts from the farm is slightly offset by the negative contribution from the slaughterhouse as discussed earlier. The improvement offered by the alternative scenario versus the base case is a reduced impact of as much as 5-10% depending on impact category. The characterized results calculated by the consequential LCA modelling are always higher than those by the attributional LCA and the increment ranges from 7 to 47% depending on impact category. The smallest increment is found for the impact category “non-renewable energy” and the largest one is for “land use”.

3.4. Contribution from transport of slaughtered pork

The main impact from transport of meat is related to energy use for the transport itself and for the necessary cooling and freezing connected to storage during the transport. Assumptions and data sources used for the assessment are given in appendix A.5. The carcass is cooled when it leaves the slaughter house, so the costs for cooling is included in the slaughtering process. However, when freezing is required, there is a need to add costs for the freezing process itself.

In table 14 is given the environmental impact in three examples of transport: i) cooled transport by truck (600 km; 32 t truck), ii) cooled transport by truck (130 km) followed by ship (600 km), and iii) Freezing followed by 50 km truck transport and followed by ship (21000 km). The example i) is equivalent to transport from Horsens to Mid Sweden or Mid Germany, example ii) from Horsens to UK, and example iii) from Horsens to Asia. Considering global warming, the transport to UK as a combined truck and ship transport amounts only to 1/3 of the transport in a similar distance by truck. Freezing and frozen transport to Asia amounts to 0.5 kg CO_2e.

Table 13. Characterized results on the environmental impact per kg Danish pork.

	Typical 2010 production		25% herds with higher efficiency	
	Consequential	Attributional PAS 2050	Consequential	Attributional PAS 2050
GWP, kg CO_2e				
Pigs from farm 107 kg	257.4	233.6	236.2	214.2
Slaughtering (Table 10)	14.5	14.5	14.5	14.5
SUM	271.8	248.2	250.7	228.7
Per kg pork produced	**3.4**	**3.1**	**3.1**	**2.8**
AP, g SO_2e				
Pigs from farm 107 kg	4952	4550	4455	4084
Slaughtering (Table 10)	15	15	15	15
SUM	4967	4565	4470	4099
Per kg pork produced	**61**	**56**	**55**	**51**
EP, g NO_3e				
Pigs from farm 107 kg	26129	19780	23786	17914
Slaughtering (Table 10)	-116	-116	-116	-116
SUM	26013	19664	23760	17798
Per kg pork produced	**321**	**243**	**292**	**220**
Non-renewable energy, MJ primary				
Pigs from farm 107 kg	1574	1459	1473	1367
Slaughtering (Table 10)	221	221	221	221
SUM	1795	1681	1694	1588
Per kg pork produced	**22**	**21**	**21**	**20**
Land use, m^2a				
Pigs from farm 107 kg	698	478	644.6	440
Slaughtering (Table 10)	-7	-7	-7	-7
SUM	691	469	637.6	433
Per kg pork produced	**8.5**	**5.8**	**7.9**	**5.3**

Table 14. Environmental costs associated with transport after slaughtering (reference flow: 1 kg product).

Case	Freezing	Road transport (by lorry)		See transport (by refrigerated container)		SUM per kg pork
		Chilled	Frozen	Chilled	Frozen	
Global warming, g CO_2e						
600 km truck		149				149
130 km truck and 600 km ship		32.4		13.9		46
50 km truck and 21000 km ship	82		10		422	514
Energy, MJ primary						
600 km truck		2.2				2.2
130 km truck and 600 km ship		0.5		0.2		0.7
50 km truck and 21000 km ship	0.85		0.15		6.11	7.1
Acidification, g SO_2e						
600 km truck		1.0				1.0
130 km truck and 600 km ship		0.21		0.22		0.4
50 km truck and 21000 km ship	0.06		0.06		7.06	7.2
Eutrophication, g NO_3e						
600 km truck		1.5				1.5
130 km truck and 600 km ship		0.33		0.26		0.6
50 km truck and 21000 km ship	0.12		0.1		7.9	8.1

Results on the environmental impacts associated with the entire chain of pork for both the base case and alternative scenario – are provided in Table 15. Breakdown into three process stages: farm gate, slaughtering and transport is also presented which show how significant their contribution to the entire chain.

Table 15. Environmental impact per kg Danish pork after transport to different destinations (breakdown into three process stages and based on attributional approach).

	Typical 2010 production			25% herds with higher efficiency		
Transport case	600 km truck	130 km truck and 600 km ship	50 km truck and 21000 km ship	600 km truck	130 km truck and 600 km ship	50 km truck and 21000 km ship
GWP, kg CO_2e	**3.21**	**3.11**	**3.58**	**2.97**	**2.87**	**3.34**
% Contribution						
Farm gate	89.8	92.7	80.6	88.9	92.1	79.2
Slaughtering	5.6	5.8	5.0	6.1	6.3	5.4
Transport	4.7	1.5	14.4	5.0	1.6	15.4
AP, g SO_2e	**57.3**	**56.8**	**63.5**	**51.6**	**51.0**	**57.8**
% Contribution						
Farm gate	98.0	98.9	88.4	97.8	98.8	87.3
Slaughtering	0.3	0.3	0.3	0.4	0.4	0.3
Transport	1.7	0.8	11.3	1.9	0.8	12.4
EP, g NO_3e	**244**	**243**	**251**	**221**	**220**	**228**
% Contribution						
Farm gate	100	100.4	97.3	100	100.4	97.1
Slaughtering	-0.6	-0.6	-0.6	-0.7	-0.7	-0.6
Transport	0.6	0.2	3.2	0.7	0.3	3.6
Energy, MJ primary	**22.9**	**21.4**	**27.9**	**21.8**	**20.3**	**26.7**
% Contribution						
Farm gate	78.6	84.1	64.7	77.5	83.2	63.2
Slaughtering	11.9	12.8	9.8	12.6	13.5	10.2
Transport	9.5	3.1	25.5	10.0	3.3	26.6

4. Conclusion

Using the attributional approach as prescribed in the PAS 2050 the environmental impact per kg Danish pork leaving the slaughterhouse is estimated to 3.1 kg CO_2e in global warming, 243 g NO_3e in eutrophication, 56g SO_2e in acidification, 21 MJ primary non-renewable energy, and 5.8 m^2a in land use. By far the major part of the environmental impact occurs at the farming stage being responsible for more than 95 % of the total impacts, except for use of non-renewable energy, where the slaughtering stage and related transport account for 12-13 %. The low impact related to the slaughtering stage is due to an efficient use of residues and by-products for energy production and feed.

The 25% of herds with the highest technical efficiency in the pig production produce pork with a 10 % lower environmental impact. This is assumed to be the situation for the average pig production in a few years taken the current development in efficiency at the pig farms into consideration.

The environmental impact estimated by use of the consequential approach is considerable higher regarding eutrophication and land use. This is related to the relative lower environmental impact of the Danish cereals as compared to the marginal cereal source on the global market, reflecting both higher yields per ha and a strong environmental regulation regarding N fertilization in the Danish situation.

References

Andersen, J.M., Poulsen, H.D., Børsting, C.F., Rom, H.B., Sommer, S.G., Hutchings, N.J., 2001. Ammoniakemission fra landbruget siden midten af 80'erne. Faglig rapport fra DMU 353, pp. 1–48.

Bouwman, L., van der Hoek, K., van Drecht, G., Eickhout, B., 2006. World Livestock and Crop Production Systems, Land Use and Environment between 1970 and 2030. In: F. Brouwer and B.A. McCarl (eds.), Agriculture and Climate Beyond 2015, 75-89.

BSI, 2008. PAS 2050:2008 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. British Standards, UK.

Broeze, J., van den Broek W., 2009. Agrotechnology & Food Sciences Group, Wageningen (personal communication)

CSSC, 2011. Refrigerated Containers – Usage and Dimensions. CS Shipping Containers, Battisford, Nr. Stowmarket, Suffolk, UK. http://www.csshippingcontainers.co.uk/refrigerated-containers/refrigerated-containers-usage-and-dimensions

DAKA, 2007. Grønt regnskab. 2005/2006. Daka a.m.b.a. www.daka.dk.

Dalgaard, R., Halberg, N., Hermansen, J.E., 2007. Danish pork production. An environmental assessment. DJF Animal Science No. 82.

Dalgaard, R., Halberg, N. Kristensen, I.S., Larsen, I., 2006. Modelling representative and coherent Danish farm types based on farm accountancy data for use in environmental assessments. In: Agriculture Ecosystems and Environment 117, 223-237.

Dalgaard, R., Schmidt, J.,Halberg, N.,Christensen, P.,Thrane, M., Pengue,W.A., 2008. LCA of soybean meal. International Journal of Life Cycle Assessment 13 (3), 240–254.

Dalgaard, T., Halberg, N., Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems and Environment 87(1), 51-65.

Danish Agriculture and Food Council, Pig Research Centre, 2010. Annual report 2009. http://eng.vsp.lf.dk/About%20us/~/media/Files/PDF%20-%20Aarsberetning%20VSP%20English/DSP_AnnualReport_2009.ashx

Dämmgen, U., Hutchings, N.J., 2008. Emissions of gaseous nitrogen species from manure management - a new approach. Environmental Pollution 154, 488-497.

DJF (Danmarks Jordbrugs Forskning), 2008a. Normtal 2008. Gældende pr. 1. august 2008. (Normtal for kvælstof, fosfor og kalium i husdyrgødning). http://www.agrsci.dk/var/agrsci/storage/original/application/13edd10b464e09c220a7c705d1c40bce

DJF (Danmarks Jordbrugs Forskning), 2008b. Baggrundstal 2008. (Baggrundstal for normtal for kvælstof, fosfor og kalium i husdyrgødning). (ændret den30-06-08)

Ecoinvent Centre, 2010. Ecoinvent Data v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland. http://www.ecoinvent.ch

EEA, 2007. EMEP/CORINAIR Emission inventory guidebook – 3rd edition. 2007 Update. Technical report No. 30. Environmental European Agency, Copenhagen, Denmark, 2374 pp.

Ekvall, T., Weidema, B.P., 2004. System Boundaries and Input Data in Consequential 18 Life Inventory Analysis. Int. J. LCA 9, 161-171.

ETH-ESU, 1996. SimaPro Database Manual. The ETH-ESU 96 libraries. http://www.pre.nl/download/manuals/DatabaseManualETH-ESU96.pdf.

FAO, 2001. Chapter 5: Global estimates. In: Global estimates of gaseous emissions of NH_3, NO and N_2O from agricultural land. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2010. Monthly Price and Policy Update; (No. 14) . http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Oilcrops/Documents/MPPU_Apr10.pdf

Hansen, M.N., Sommer, S. G., Hutchings, N., Sørensen, P., 2008. Emissionsfaktorer til beregning af ammoniakfordampning ved lagring og udbringning af husdyrgødning. Det Jordbrugsvidenskabelige Fakultet, Aarhus Universitet. DJF rapport nr. xx, 39 pp. (under trykning)

Heun, J.C, Schotanus, T.D, De Groen, M.M., Werner, M., 2002. Simulation Tool for River Management, Final report, Executive summary, Delft. http://www.irmasponge.org/publications/irma-irma-sponge-1011614035.pdf

Horsens Slaughterhouse, 2007. Grønt Regnskab 2005/2006. Danish Crown. Available online at: http://www.datagraf.dk/pageviewerx/index.dsp?issue_id=268.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (eds). Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

IPCC, 2007. IPCC Fourth Assessment Report (AR4) – Climate Change 2007. Intergovernmental Panel on Climate Change, 2007. Available online at: www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

ISO 14044, 2006. Environmental management - Life cycle assessment - Requirements and guidelines. Geneva, Switzerland, International Organization for Standardization, Geneva, Switzerland.

Jenssen, T.K., Kongshaug, G., 2003. Energy Consumption and Greenhouse Gas Emissions in Fertiliser Production. The International Fertiliser Society, York, UK, Proceedings No. 509.

Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., Rosenbaum, R., 2003. IMPACT 2002+: A New Life Cycle Impact Assessment Methodology. International Journal of Life Cycle Assessment 8(6), 324-330.

Jonasson, K., Sanden, B., 2004. Time and Scale Aspects in Life Cycle Assessment of Emerging Technologies - Case Study on Alternative Transport Fuels-, CPM-report, ISSN 1403-2694

Møller, J., Thøgersen, R., Kjeldsen, A.M., Weisbjer, M.R., Søegaard, K., Hvelplund, T., Børsting, C.F., 2005. Fodermiddeltabel. Sammensætning og foderværdi af fodermidler til kvæg. Rapport nr. 91. Landbrugets Rådgivningscenter.

Nemecek, T., Kägi, T., 2007. Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent v2.0 No. 15, Swiss Centre for Life Cycle Inventories, Duebendorf, CH.

Nguyen. T.L.T., Hermansen, J., Mogensen, L., 2010. Fossil energy and GHG saving potentials of pig farming in the EU, Energy Policy 38, 2561-2871

Nielsen, P., Nielsen, A., Weidema, B., Dalgaard, R., Halberg, N., 2003. LCA Food Data Base. In: Denmark. http://www.lcafood.dk.

Plantedirektoratet, 2010. Vejledning om gødskning- og harmoniregler. Planperioden 1. August 2010 til 31 juli 2011. Ministeriet for Fødevarer, Landbrug og Fiskeri. 96 pp.

Poulsen, H.D., Børsting, C.F., Rom, H.B. & Sommer, S.G., 2001. Kvælstof, fosfor og kalium i husdyrgødning - normtal 2000. DJF rapport Husdyrbrug 36, 152 pp; ISSN 1397–9892.

Rigolot, C., Espagnol, S., Pomar, C., Dourmad, J.Y., 2010. Modelling of manure production by pigs and NH3, N2O and CH4 emissions. Part I: animal excretion and enteric CH4, effect of feeding and performance. Animal 4, 1401-1412.

Schmidt, J., Weidema, B.P., 2008. Shift in the marginal supply of vegetable oil. Int J LCA 13(3), 235–239

Sommer, S.G., Maahn, M., Poulsen, H.D, Hjorth, M., Sehested, J., 2008. Interactions between phophorus feeding strategies for pig and dairy cows and sepraparation efficiency of slurry. Environmental Technologies. 29, 75-80.

Sommer, S.G., Petersen, S.O., Møller, H.B., 2004. Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutrient Cycling Agroecosystems 69,143–154.

Statistics Denmark, 2010. HST7: Høstresultat efter område, afgrøde og enhed (afsluttet). www.statistikbanken.dk

Stephenson, J., 2010. Livestock And Climate Policy: Less Meat Or Less Carbon? Round Table on Sustainable Development. OECD, Paris. http://www.oecd.org/dataoecd/54/37/44682539.pdf

Strid-Eriksson, I., Elmquist, H., Stern, S., Nybrant, T., 2004. Environmental system analysis of pig production-the impact of feed choice. Int. J. LCA. 1-12.

Tillman, A.-M., 2000. Significance of decision-making for LCA methodology, Environmental Impact Assessment Review 20 (1) 113-123

Van der Werf, H.M.G, Petit, J., Sanders, J., 2005. The environmental impacts of the production of concentrated feed: The case of pig feed in Bretagne. Agric Sys 83, 153–177

Vinther, F.P., 2005. SIMDEN – A simple model for quantifying denitrification and N_2O emission. In: Stensberg, M., Nilsson, H., Brynjolfsson, R., Kapuinen, P., Morken, J. & Birkmose, T.S. (eds.). Manure – an agronomic and environmental challenge. NJFseminar no. 372, 5-6 September 2005, Nils Holgerssongymnasiet, Skurup, Sweden.

Wenzel, H., 1998. Application Dependency of LCA Methodology: Key Variables and Their Mode of Influencing the Method. International Journal of Life cycle Assessment 3 (5) 281-288

Wenzel, H., Hauschild, M., Alting, L., 1997. Environmental Assessments of products – Vol 1: Methodology, tools and case studies in product development. London. Chapman & Hall.

Wilting, H.C., Benders, R.M.J., Kok, R., Biesiot, W., Moll, H.C., 2004. Energy Analysis Program Manual, Version 3.5. IVEM research report no. 98, 2nd revisited edition. Groningen, June 2004.

YARA, 2010. Calculation of Carbon Footprint of Fertilizer Production. http://www.yara.com/doc/29293_2010_Carbon%20footprint%20of%20AN%20-%20Method%20of%20calculation.pdf

Table A1. Basic technical assumptions regarding pig production[1)].

Sows		
27.2 piglet á 7.4 kg produced per sow year		
Feed use 1,500 SFU[2)] with 138 g crude protein and 4.6 g P		
Farrowing stage:	80% on partly slatted floor:	(13% NH_3-emission)
	20% on fully slatted floor:	(2% NH_3-emission)
Pregnancy stage:	50% on partly slatted floor, box:	(13% NH_3-emission)
	50% on partly slatted floor, free:	(16% NH_3-emission)
Piglets 7.4 – 32 kg		
1.92 SFU per kg gain with 161 g protein and 5 g P		
Floor:	Partly slatted:	69% (10% NH_3-emission)
	Drained rest area:	7% (21% NH_3-emission)
	Fully slatted:	24% (24% NH_3-emission)
Finisher 31 – 107 kg		
2.82 SFU per kg gain with 151 g protein		
Floor:	Partly slatted (50-75%):	8% (13% NH_3-emission)
	Partly slatted (25-49%):	29% (17% NH_3-emission)
	Drained rest area:	7% (21% NH_3-emission)
	Fully slatted:	56% (24% NH_3-emission)

1) Source: Danish Agriculture and Food Council
2) SFU: Scandinavian Feed Unit for Pigs.

Table A2. Feed use (SFU, N, P), direct energy use, and meat produced per sow with offspring.

Calculation	Result
Feed use SFU	
1 sow: (1050 + 450) SFU	1500
1 piglet (alive): 1.92 SFU/kg gain × (32 – 7.4) kg gain = 47.23 SFU	
1 piglet (dead): 47.23/2 SFU	
No of piglet dead: 27.2 × 2.6% = 0.707	
Feed use: 0.707 × 47.23/2 SFU	16.7
No of piglet alive: 27.2 – 0.707 = 26.5	
Feed use: 26.5 × 47.23 SFU	1251.3
1 slaughter pig (alive): 2.82 SFU/kg gain × (107 – 32) kg gain = 211.5 SFU	
1 slaughter pig (dead): 211.5/2 SFU	
No of slaughter pig dead: 26.5 × 4.1% = 1.09	114.9
Feed use: 1.09 × 211.5/2 SFU	
No of slaughter pig alive: 26.5 – 1.09 = 25.41	
Feed use: 211.5 SFU × 25.41	5373.5
SUM	8256
Crude protein kg	
1 sow: 0.138 kg/SFU × 1500 SFU	207
1 piglet (alive): 0.161 kg/SFU × 47.23 SFU = 7.6 kg	
1 piglet (dead): 7.6/2 kg	
No of piglet dead: 27.2 × 2.6% = 0.707	
Protein use: 0.707 ×7.6/2 kg	2.7
No of piglet alive: 27.2 – 0.707 = 26.5	
Protein use: 26.5 × 7.6 kg	201.5
1 slaughter pig (alive): 0.151 kg/SFU× 211.5 SFU = 31.9 kg	
1 slaughter pig (dead): 31.9/2 kg protein	
No of slaughter pig dead: 26.5 × 4.1% = 1.09	
Protein use: 1.09 × 31.9/2 kg	17.3
No of slaughter pig alive: 26.5 – 1.09 = 25.41	
Protein use: 31.9 kg × 25.41	811.4
SUM	**1239.9**
Phosphorous kg (same calculation procedure)	36.8
Direct energy use	
Heat (oil) MJ	
540 MJ/sow + (28.8 MJ/piglet × 26.5 piglets/sow) + (7.2 MJ/slaughter pig × 25.41 slaughter pigs/sow)	1486
Electricity (natural gas) kWh	
100 kWh/sow + (2 kWh/piglet × 26.5 piglets/sow) + (10 kWh/slaughter pig × 25.41 slaughter pigs/sow)	407
Meat produced kg	
Slaughter pigs: 107 kg × (25.41 – 0.54 replacement for sow)	2661
Sow replacement: 180 kg × 0.54 × 0.9 alive	87.2
Total	2748

Attributional LCA (ALCA)
Conversion from feed use SFU to feed kg (per 100 kg meat produced):
Sow: 1500/1.05/27.48 = 51.99 kg
Piglets: (16.7 + 1251.3)/1.13/27.48 = 40.83 kg
Slaughter pigs: (114.9 + 5373.5)/1.06/27.48 = 188.42
SUM: 281.24 kg

Table A3. Feed use (kg) and ingredients per 100 kg meat live weight produced.

	Sow	Piglets	Slaughter pigs	sum	%
Wheat	51.99 × 0.32	40.83 × 0.47	188.42 × 0.4	111.2	39.5
Barley	51.99 × 0.4	40.83 × 0.2	188.42 × 0.3	85.5	30.4
Soybean meal	51.99 × 0.08	40.83 × 0.18	188.42 × 0.12	34.1	12.1
Sunflower cake	51.99 × 0.03	40.83 × 0	188.42 × 0.05	11	3.9
Rape meal	51.99 × 0.03	40.83 × 0	188.42 × 0.05	11	3.9
Wheat bran	51.99 × 0.05	40.83 × 0	188.42 × 0.02	6.4	2.3
Fish meal	51.99 × 0.01	40.83 × 0.04		2.2	0.8
Palm oil	51.99 × 0.03	40.83 × 0.04	188.42 × 0.015	6.0	2.1
Amino acid	51.99 × 0.002	40.83 × 0.008	188.42 × 0.005	1.37	0.5
Minerals (Calcium carbonate + Monocalcium phosphate)*	51.99 × 0.028	40.83 × 0.022	188.42 × 0.02	6.13	2.2
Beet molasses	51.99 × 0.02	40.83 × 0.01	188.42 × 0.02	5.2	1.9
Special protein		40.83 × 0.03		1.2	0.4

* -P supplied from wheat, barley, soybean meal, sunflower cake, rapeseed meal, wheat bran, fish meal, molasses = 1.16 kg
- Mineral feed P need = 1.34 – 1.16 = 0.18 kg P # 0.73 kg monocalcium phosphate
- Calcium carbonate need = 6.13 – 0.73 = 5.4 kg

Consequential LCA (CLCA)

Let *X* and *Y* be kg of soybean meal and barley (marginal protein and energy feed, respectively) that need to be used to satisfy the energy and protein (N) requirement of the pigs considering the production of 100 kg meat live weight. Composition and feeding value of the two feed ingredients are presented in the table below (Table A4).

Feed characteristic

	Moisture content %	kg dry matter/SFU	kg crude protein/100 kg DM	g P/kg DM
Soybean meal	87.6	0.73	48.7	7.6
Spring barley	85	0.9	11.2	3.8

From the table, the simultaneous equations with two unknowns *X* and *Y* are derived.

$$\begin{cases}(0.876\,X \div 0.73) + (0.85\,Y \div 0.9) = 8256*100/2748 = 300.4 \\ (0.876\,X \times 0.487/6.25) + (0.85\,Y \times 0.112/6.25) = 1239.9*100/2748/6.25 = 7.22\end{cases}$$

$$\Leftrightarrow$$

$$\begin{cases}1.2X + 0.9444Y = 300.4 \\ 0.06826X + 0.015232Y = 7.22\end{cases}$$

$X = 48.5$ kg; $Y = 256.4$ kg

From Table A4, P supplied from 48.5 kg soybean meal and 256.4 kg barley

$= 48.5 \times 0.876 \times 0.0076 + 256.4 \times 0.85 \times 0.0038$

$= 1.15$ kg

Extra P need (mineral feed) = 36.8*100/2748 – 1.15 = 1.34 – 1.15 = 0.19 kg

Table A4. Emissions from biogas combustion for energy.

Emissions	g/GJ [a]	g/m^3 biogas [b]	g/kg manure VS [c]
SO_2	19.2	0.4416	0.2058
NO_x	540	12.42	5.7877
NMVOC	14	0.322	0.1501
CH_4	323	7.429	3.4619
CO	273	6.279	2.9260
CO_2	83.6	1.9228	0.8960
N_2O	0.5	0.0115	0.00536
PM2.5	0.206	0.004738	0.00221
PM10	0.451	0.010373	0.00483

[a] Data source: (Nielsen et al., 2003)
[b] Energy value of biogas: 23 MJ/m^3
[c] Biogas yield: 466 m^3/t VS (Nguyen et al., 2010)

Table A5. Assumptions related to transport after slaughtering.

	Assumptions	Data source
Freezing	Energy use per kg product = 100 kWh/t	Broeze and van den Broek (2009)
	Electricity is derived from natural gas (NG)	
	Life cycle impacts of electricity (NG)	Nielsen et al. (2003)
	GHG emissions of refrigerants # 25% of those related to energy use	Broeze and van den Broek (2009)
Road transport	Transport mean: lorry 32 t	
	Life cycle impacts of lorry transport	Ecoinvent centre (2010)
Frozen	Energy use for 'cooling transport' is 8% higher than 'normal transport'	Wilting, et al. (2004)
Chilled	Energy use for cooling in 'chilled transport' is 1.3 times that in "frozen transport"	Estimated from CSSC (2011)
Sea transport	Transport mean: Transoceanic freight ship	
	Life cycle impacts of ship transport	Ecoinvent centre (2010)
Frozen	Extra fuel use for cooling = 0.063 kg diesel/t product/hr = 0.0024 kg diesel/tkm (assuming ship speed is 14 knots i.e. about 26 km/hr)	Broeze and van den Broek (2009)
Chilled	Energy use for cooling in 'chilled transport' is 1.3 times that in 'frozen transport'	Estimated from CSSC (2011)

Read about research, education and other activities on www.agrsci.au.dk from which You also can download publications and subscribe to the weekly newsletter