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An environmental assessment

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Faculty of Agricultural Sciences

DJF ANIMAL SCIENCE NO. 82 • NOVEMBER 2007

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ISBN: 87-91949-26-2

Preface and acknowledgements

The environmental impact of our consumption of all goods and services is of increasing concern to consumers and - in turn – retailers and suppliers. Not least the effect on greenhouse gas emission is considered important by the public and policy makers. This is also true for food products, and there is a growing need to establish ways for retailers and consumers to make informed choices in this respect. Therefore, it is important for suppliers of food to be able to provide robust information to assist these choices.

In this study, the environmental load of Danish pork delivered for export (in this case, Great Britain) was investigated through a life-cycle assessment. This included the anticipated contribution of 1 kg of pork, delivered in Great Britain, to global warming, eutrophication and acidification and covered the entire product chain from production of feed, via pig production at the farm and the slaughtering process to the transport of the pork to the final destination. The study also examined at what stages in the chain, the most important environmental load were created. The work thus documents the environmental load of pork and also gives insights into where best to improve the environmental profile of pork.

The work was partly funded by the Danish Meat Association and data was kindly made available to us from a range of sources (the Danish Meat Research Institute, Meat and Livestock Commission in Great Britain, Danish Crown, DAKA, LEI (Agricultural Economics Research Institute) in the Netherlands and IGER (Institute of Grassland and Environmental Research) in Great Britain). This help and support was highly appreciated.

John E. Hermansen

Foulum, November 2007

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Summary

The primary aim of this report is to present data for the environmental profile of pork and to identify the most polluting parts in the product chain of Danish pork by use of the Life Cycle Assessment (LCA) methodology. The functional unit was ‘1 kg of Danish pork (carcass weight) delivered at the Port of Harwich’, and the environmental impact categories considered were global warming, eutrophication, acidification and photochemical smog. The global warming potential was 3.6 kg CO_2 equivalents per functional unit, which corresponds to the emissions from a 10 km drive in a typical passenger car.

It was found, that the environmental ‘hot spots’ in the production chain of Danish pork occur in the stages before the pigs’ arrival at the slaughterhouse. The highest contributions to global warming, eutrophication and acidification arise from production of feed and handling of manure in the pig housing and under storage. However, the manure/slurry applied to the fields also made a significant contribution to eutrophication potential. The transport of the pork to the Port of Harwich was not an environmental hot spot and contributed less than 1% of the total amount of greenhouse gasses emitted during the production. This result highlights, that ‘Food miles’ are a misleading environmental indicator.

The environmental profile of pork established was based on data from 2005, and it was found, that the environmental impact (global warming, eutrophication and acidification potentials) has been reduced since 1995. These environmental improvements were mainly obtained by lower feed (and protein) consumption and improved handling of manure/slurry. A potential exist for improving the environmental profile further. In particular, the greenhouse gas emission per kg pork can be reduced, if the manure/slurry is anaerobically digested, and the biogas is used for heat and power production.

The environmental impact of Danish pork was compared with the environmental impact of British and Dutch pork. This comparison showed, that the global warming potentials were equal, whereas the eutrophication and acidification potential was highest for British pork. Dutch pork had slightly lower eutrophication and acidification potential compared to that of Danish pork.

Dansk sammendrag

Det primære mål med denne rapport er at præsentere dansk svinekøds miljøprofil og at identificere de mest forurenende dele af dansk svinekøds produktkæde ved brug af LCA (livescyklusvurdering). Den funktionelle enhed var 'Ét kg dansk svinekød leveret til Harwich Havn i England', og global opvarmning, eutrofiering, forsuring samt fotokemisk smog var de valgte miljøpåvirkningskategorier. Det globale opvarmningspotentiale var 3,6 kg CO_2 ækvivalenter per funktionel enhed, hvilket svarer til drivhusgasudledningen fra 10 km's kørsel i personbil.

Det blev konkluderet, at de miljømæssige 'hot spots' i dansk svinekøds produktkæde er leddene før svinets ankomst til slagteriet. De højeste bidrag til global opvarmning, eutrofiering og forsuring kom fra foderproduktion samt fra gylle i stald og lager. Yderligere bidrog gylle tilført markerne betragteligt til eutrofiering. Transporten fra slagteriet til Harwich Havn i England var ikke et miljømæssigt 'hot spots' og bidrog således med mindre end 1% af den samlede drivhusgasudledning fra svinekødets produktkæde. Dette tydeliggør, at 'Food miles' er en misvisende miljøindikator.

Miljøprofilen for dansk svinekød var baseret på data fra 2005, og det blev konkluderet, at miljøpåvirkningen (global opvarmning, eutrofiering og forsuring) per kg svinekød var reduceret siden 1995. De miljømæssige forbedringer blev primært opnået pga. lavere foder- og proteinforbrug samt forbedret håndtering af gylle. Den miljømæssige profil kan forbedres yderligere. Især drivhusgasudledningen per kg svinekød kan reduceres, hvis gyllen bioforgases, og den producerede gas anvendes til el og varme.

Dansk svinekøds miljøpåvirkning blev sammenlignet med miljøpåvirkningen fra produktion af engelsk og hollandsk kød. Sammenligningen viste, at de globale opvarmningspotentialer var ens, hvorimod britisk svinekød havde det højeste eutrofierings- og forsuringspotentiale. Hollandsk svinekød havde lidt lavere eutrofierings- og forsuringspotentiale sammenlignet med dansk svinekød.

Introduction

When a kilogramme of pork arrives for sale at the refrigerated counter in the supermarket, it has completed a long journey. Firstly, feed for the pigs is grown, harvested and transported to the place of production. The pigs are then fed, and the excreted by-products, in the form of manure/slurry, are applied to the fields. The pigs are then transported to the abattoir for slaughter, the carcase is then cut into primals, and the pork is processed and packaged for delivery to the supermarket, whence it is purchased and taken home of the buyer and finally consumed. In each of these steps, energy is used and pollutants are emitted. For example, artificial fertiliser is applied to the field, where the crops for feed are grown, and energy is used in their production. In addition, different pollutants, e.g. nitrate and nitrous oxide, are emitted, when the crops for feed are grown, or when manure is excreted from the pig. Transport of fertiliser, feed and the pigs themselves, result in emission of CO_2 and other substances. All in all, many different kinds of pollutants in different amounts are emitted, before the pork is ready for consumption. These pollutants contribute to climate change, eutrophication (excess of nutrients) or increased acidity in the aquatic environment.

During the last two years, the debate on the impact of greenhouse gases on climate change has increased considerably, and the starting point for this report was an attempt to find an answer to the followings questions: Which area of the pork production chain emits the largest amount of greenhouse gases? Denmark is the largest exporter of pork in the world, and large amounts of Danish pork are transported to Japan, Great Britain, Germany, Russia and other markets. It is well known, that transport results in CO_2 emissions. But how significant is transport compared to other stages of the production chain? And which gases contribute most to the total greenhouse gas emission per kg of pork produced and consumed?

The primary aim of this report was, however, to present data for the environmental profile of Danish pork. The Life Cycle Assessment (LCA) methodology is used, and therefore the results are calculated per kg pork. The impact categories considered in this report are global warming, eutrophication, acidification, ozone depletion and photochemical smog. Some of the pollutants are emitted in large amounts, and some have a very significant effect, although released in small quantities. But, where should one start, if the goal is to reduce the environmental impact of the pork production? Firstly the environmental ‘hot spots’ of the production chain must be identified, in order to know which areas are the most polluting, and where the largest potential for improvement lies.

The aim of this report is threefold:

- To estimate the potential environmental impact (global warming, eutrophication and acidification, ozone depletion, photochemical smog) per kg of Danish pork
- To clarify to what extent transport of pork from Denmark to Great Britain contributes to global warming potential

- To compare the current environmental impact of Danish pork with that produced in 1995 and consider different scenarios for the year 2015, and also to compare the Danish results with those of pork produced in Great Britain and the Netherlands

The functional unit is: ‘1 kg of Danish pork (carcass weight) delivered to the Port of Harwich’. This unit must be considered as ‘average’ with no distinction between the different types of pork (e.g., chop, bacon, tenderloin).

Methodology and data sources

Life Cycle Assessment (LCA) methodology applied to pig production

The LCA methodology is used to establish the environmental profile of Danish pork, and therefore all results are presented per kg pork. Because one of the aims of the report was to reveal environmental impact of food transport and distribution, and because Great Britain is one of the most important markets for Danish pork products, the Port of Harwich is used as the end point of the LCA. Thus the so-called functional unit is: '1 kg of Danish pork (carcass weight) delivered to the Port of Harwich'. No distinction is made between different types of pork (e.g. bacon, chops), and thus the single kg of pork must be considered as 'average'. In Figure 1, an overview of the production chain of Danish pork is presented. Soybean meal and grain are the main components of the feed. When the feed is produced, there are emissions from the fields, the processing and transport of the grain and soybean meal. The feed is consumed by the pig, which excretes manure/slurry during its growth. The manure/slurry is stored and applied to fields as a fertiliser. The pig is brought to the abattoir, where it is slaughtered and the resulting meat is transported to the Port of Harwich in Great Britain by lorry and ship. The pork in this assessment represents Danish pork produced at an average Danish pig farm during 2005.

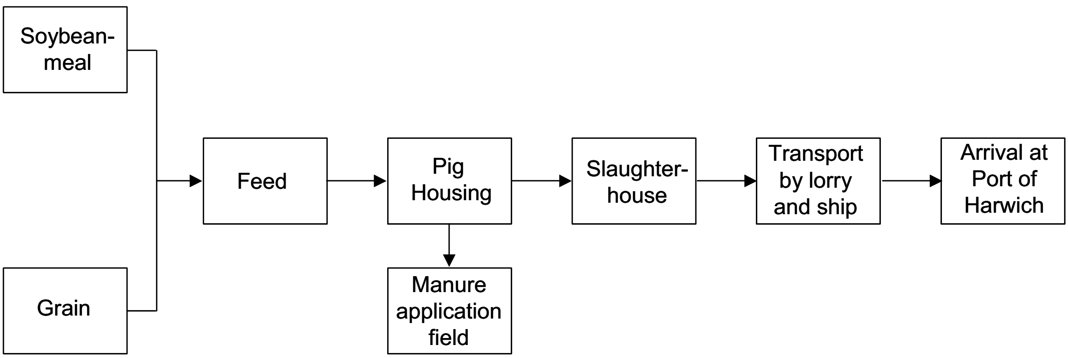

Figure 1 Overview of the product chain of Danish pork delivered to the Port of Harwich in Great Britain. This represents a simplified view, where only the most important stages of the production chain are shown

The LCA methodology is ISO Standardized (ISO 140 44) and has often been used to assess the environmental impact of agricultural products (e.g., Cederberg & Flysjö, 2004; Basset Mens & van der Werf, 2005; Williams et al., 2006; Dalgaard et al., 2007). The consequential modelling used is as described by, for example, Weidema (2003) and Dalgaard et al., (2007, p. 2-3).

The impact categories considered in this study are: Global warming, eutrophication and acidification. Global warming is an increase in temperature induced by emissions of greenhouse gases, as for example CO_2 or methane. Eutrophication appears when nutrients (e.g., nitrate and phosphate from manure/slurry) are leached to the aquatic environment, where it causes algae bloom, which may again result in oxygen deficiency. Eutrophication also affects biodiversity negatively. Acidification appears when acidifying substances (e.g., ammonia from manure/slurry or sulphur dioxide from combustion of fossil fuel) result in a reduction of pH in natural habitats (e.g., lakes) and thereby change the biodiversity. The environmental impact category of 'toxicity' is excluded from this study due to methodological limitations.

For the Life Cycle Impact Assessment (LCIA), the EDIP method (Wenzel et al., 1997. Version. 2.03) is used, but the characterization factors for methane (CH_4), and nitrous oxide (N_2O) have been updated according to IPCC (2001) to 23 kg CO_2 eq. per kg methane and 296 kg CO_2 eq. per kg nitrous oxide respectively. The calculations have been carried out in LCA software SimaPro (www.pre.nl), where the EDIP method also is available. In the following sections, data sources for each stage of the production chain are described. The most important data is presented in the appendix.

Feed

The total amount of feed consumed by the pig during its life is calculated on basis of data from BPEX (British Pig Executive) (Sloyan et al. 2006), as explained in the section 'Pig housing'. The content of the feed is based on recipes of feed mixtures from the Danish feed company, DLG. Three different kinds of feed are considered: feed for sows, weaners and finishers. The protein content is 12.8% for sow feed, 18.6% for weaner feed, and 16.8% for finisher feed. Phosphorus and energy content in the feed mixtures are presented in appendix (Table A1). Feed mixtures for pigs contain several ingredients, e.g. soybean meal, wheat, palm oil, fish meal etc. An increased production of pigs implies an increased demand for feed. The feed mixtures used in this study contain several ingredients (e.g. soybean meal, wheat, barley, wheat, fish meal, sunflower meal), but using the consequential LCA approach, it is sufficient to have LCA data on those crops, which are affected by an increased demand for feed. When a pig farm purchases - for example - rape seed meal, there will be an increased demand for rape seed meal in the market. But, because the most competitive protein meal on the world market is soybean meal, and not rape seed meal as argued by Dalgaard et al. (2007) and Weidema (2003), the increased demand for rape seed meal will result in an increased production of soybean meal. Consequently, it is only necessary to have LCA data on soybean meal, but not on rape seed meal and other 'non-affected crops'. Because soybean meal has too high a protein content to meet both the protein and energy demand of pigs, grain production is also affected by an increased demand for feed. Thus, even though several feed ingredients are purchased by a pig farm, only LCA data on soybean meal and grain need to be considered in this context. The amounts of soybean meal and grain are calculated on the basis of energy and protein content of the feed ingredients needed to satisfy the protein and energy requirements of the pigs.

LCA-data on barley and soybean meal are presented in Table 1. The data on barley is from the LCAfood database (www.LCAfood.dk (Link1)). The dry matter content is 85%, and the protein content is 12.6% of dry matter. The data on soybean meal from Argentina is from Dalgaard et al. (2007), but with the addition of transport from the Port of Rotterdam in the Netherlands to Denmark. The global warming potential is highest for soybean meal, primarily because of the longer transport by lorry. Although the transport by ship is much longer, the contribution to global warming is not as high, because considerably less greenhouse gases are emitted per km compared to transport by lorry. The eutrophication and acidification potential is lower for soybean meal compared to barley. The very low eutrophication per kg soybean meal is because the nitrate emission from the soybean cultivation in general is very low (Austin et al. 2006; Dalgaard et al. 2007), as more N is removed from the field, than is applied as fertiliser and fixed by the soybeans.

Table 1 LCA data for soybean meal and barley. Functional unit: 1 kg from feed factory

	Soybean meal	Barley
Data source	Dalgaard et al. (2007)	www.LCAfood.dk (Link 1)
Reference year	2005	1999
Country of origin	Argentina	Denmark
Transport	Ship: 9,980 km Lorry: 850 km	Lorry: 50 km
Global warming potential, g CO_2 eq.	934	694
Eutrophication potential, g NO_3 eq.	0.7	53.4
Acidification potential, g SO_2 eq.	4.8	5.9
Photochemical smog potential, g ethene eq.	0.4	0.2
Ozone depletion, mg CFC11 eq.	0.3	0.1

Pig housing

'Pig housing' takes account of the production of pigs and the storage of manure/slurry. Hence methane emission from enteric fermentation, nitrous oxides, methane and ammonia emissions from manure/slurry are included in 'Pig housing'. Emissions related to the transport and application of manure to the field are included in the 'Manure/slurry application field' section.

The 'Pig housing' includes all life stages of the pig, i.e the sow with the piglets, the weaner (7-30 kg) and the finisher (30-105 kg). When pigs are produced, a quantity of feed and other inputs are needed. In Table 2, these inputs, together with outputs (pigs and manure/slurry) and emissions are presented. All values in the table are per 100 kg pig (live weight). The amount of feed consumed is calculated using data on physical performance (e.g., 'pig weaned per sow per year', 'finishing feed conversion ratio') from Sloyan et al. (2006). This data represents the year 2005, and is presented in the Appendix (Table A2). For production of 100 kg pig meat (live weight), 43 kg feed is needed for the sow, 38 kg for the weaner and 183 kg for the finisher (appendix, Table A4). This results in total feed consumption of 264 kg feed per 100 kg pig (live weight) produced (see Table 2), and from the overall total of 100 kg meat produced-pig (live weight) 3.9 kg is derived from the culled sow, while the rest is accounted for by the finished pig. The feed conversion ratios are 1.81 kg and 2.67 feed per kg live weight gain for weaners and finishers respectively, and the feed consumption per sow per year is 1,318 kg (Sloyan et al., 2006).

Table 2 Inventory for pig housing. Inputs, outputs and emissions per 100 kg pig (live weight)

Inputs	
Feed, kg	264
Heat (oil), MJ	23.9
Electricity, kWh	19.5
Outputs	
Pigs (live weight), kg	100
Manure/slurry, kg N	3.43
Emissions	
Ammonia, kg NH_3	0.98
Nitrous oxide, g N_2O	46.0
Methane, kg CH_4	2.5

The nitrogen (N) and phosphorus (P) content in the manure/slurry excreted by the pigs is calculated by subtracting the N and P content in 100 kg pig from the N and P content in the consumed feed. This procedure is a mass balance approach per animal produced, where it is assumed, that all N (or P), which enters the pig by feed, leaves the pig as either N (or P) in the pig meat (live weight, including bone, blood etc) or as N (or P) in the manure/slurry. N content per kg sow and finisher is 25 g and 27 g respectively, whereas the P content per kg pig is 5.5 g (Poulsen et al. 2001).

Pigs emit methane, which is a by-product of enteric fermentation. The amount of methane from enteric fermentation is low (0.5 kg per 100 kg pig (live weight)) compared to the amounts of methane from the manure/slurry (1.9 kg per 100 kg pig (live weight)). The amount of methane emitted due to enteric fermentation and from manure/slurry is calculated according to IPCC (2006). Nitrous oxide emissions from manure/slurry are also calculated according to IPCC (2006), and as it is shown, in Table 2, 46 g of nitrous oxide is emitted per 100 kg pig (live weight). Although nitrous oxide is a much stronger greenhouse gas (296 g CO_2 eq. per g nitrous oxide) than methane (23 g CO_2 eq. per g methane), methane emissions from the housing make a higher contribution because a larger quantity is emitted.

N in manure/slurry is easily volatilized, therefore ammonia is emitted from the manure/slurry both in the housing itself, and when it is stored subsequently. The level of emission depends on temperature, type and amount f N in the manure/slurry, the production system, type of storage etc. Andersen et al. (2001) calculated the yearly amount of ammonia emitted from pig production in Denmark for the period 1985 to 1999. According to this, 14% and 5% of the N excreted by pigs is lost in the housing and from the storage respectively. These values are based on the types of pig production systems used in 1999 and may therefore be lower today, because less ammonia is emitted from the newer generation of housing systems. However, as it has not been possible to find more updated information on production systems, the ammonia loss percentages from 1999 are used.

At the pig farm, heat is used for the piglets, and the weaners and electricity is used for ventilation, light etc. Per 100 kg pig produced (live weight) 24 MJ heat (based on oil) and 19 kWh electricity (based on natural gas) is used. These values are taken from the National Agricultural Model (Dalgaard et al., 2006), where farm types representing Danish agriculture as a whole are modelled by use of Farm Accountancy Data. The LCA data on heat and electricity is taken from www.LCAfood.dk (Link 2), and the greenhouse gas emissions are 94 g CO_2 eq. per MJ heat and 654 g CO_2 eq. per kWh.

Manure/slurry application field

Manure/slurry contains N and P, which is used by plants for growth, emitted to the environment or incorporated into the soil. So, on the one hand manure/slurry contributes positively to the environment because it substitutes artificial fertiliser, but on the other hand it causes emissions of pollutants, because it is not used as efficiently by the plants as is the case with artificial fertilisers.

From an environmental perspective, the most harmful N substances from manure/slurry are nitrous oxide (contributing to global warming), nitrate (contributing to eutrophication) and ammonia (contributing to eutrophication and acidification). Phosphate (contributing to eutrophication) is the only P substance from the manure/slurry which affects the environment negatively. In an LCA of pork, it is essential to include both the positive and negative consequences of the resulting manure/slurry (Dalgaard & Halberg, 2007) and this has been carried in accordance with the methodology used in the LCAfood database, as described by Dalgaard & Halberg (2007). The amount of substituted artificial fertiliser is 0.7 kg artificial fertiliser N per kg N in pig manure/slurry applied to the fields according to Danish Legislation on the use of nutrients in the agricultural sector (Plantedirektoratet, 2005). Ammonia emission from the manure/slurry applied is calculated according the ammonia emission coefficients given in the Appendix, Table A5. LCA-data for manure/slurry application to field are presented in the Appendix, Table A6.

Slaughterhouse

It is assumed, that the fatteners are transported 80 km from the farm to the slaughterhouse. The average liveweight at slaughter and carcass weight is 105 kg and 79.2 kg respectively (Sloyan et al., 2006). Data on energy use and disposal of animal by-products are taken from the Green Accounts from Horsens Slaughterhouse (2007) and DAKA (2007) (processor of animal by-products), and both data sets represent the year 2005. Manure/slurry from the slaughterhouse is anaerobically digested in a joint scale plant, where the biogas is used for heating and electricity. The substituted energy is included in the calculations. For further details on LCA-data for the process of anaerobic digestion, see www.LCAfood.dk (Link 3). The animal by-products are used for energy and animal feed production, and based on information from the Green Accounts, it is assumed, that 211 kg barley and 124 kWh district heat is substituted per ton animal by-product from the slaughterhouse. 10.4 kg animal by-product is delivered to DAKA per finisher (size: 105 kg).

Transport by road and sea to Great Britain

The pork (carcass) is transported 126 km by lorry from Horsens Slaughterhouse to the Port of Esbjerg on the west coast of Denmark and 619 km by ship to the Port of Harwich on the east coast of England. LCA-data for transport is taken from Ecoinvent Centre (2004), and the greenhouse gas emissions are 168 g CO_2 eq. per ton per km transported by lorry (size: 32 tons lorry) and 10.6 g CO_2 eq. per ton per km transported by ship. Accordingly, transport by lorry emits 15 times as much greenhouse gas as transport by ship. The data on transport includes emissions from combustion of fuel but also maintenance of the ship and lorry, port and road facilities etc.

Other scenarios

Additional scenarios have been established to explore, whether the environmental profile of pork has improved during the last decade and to clarify the potential for further improvements in future. Furthermore, two scenarios for production of British and Dutch pork have been considered. The data, sources used for the various scenarios are described, and the 'base scenario' refers to the Danish pork scenario as presented above.

In the 1995 scenario, 'weaned piglets per sow' is 20.6, and the 'finishing feed conversion ratio' is 3.04 kg. The crude protein content in feed is higher compared to the base scenarios: 14.4% for sows, 22.5% for weaners and 18.9% for finishers. All data is provided by the Danish Meat Association. 0.4 kg artificial fertiliser N is substituted per kg N in manure/slurry in accordance with the Danish Legislation on the use of nutrients in the agricultural sector (Plantedirektoratet, 1995).

In the 2015 scenario, it is assumed, that ‘weaned piglets per sow’ will increase by 10% from 26.09 in 2015 to 28.7 in 2005, and the ‘finishing feed conversion ratio’ will decrease by 10% from 2.67 in 2005 to 2.40 in 2015. These improvements are smaller than the improvements achieved by the Danish pig sector from 1995 to 2005 and are therefore may be considered rather conservative. Furthermore, it is assumed, that the use of electricity and heat in pig housing is reduced by 10%. All other data is the same as for the base scenario. Regarding anaerobic digestion, it is assumed, that all manure/slurry is processed in this manner and the energy produced from the biogas substitutes fossil energy. The inventory data for anaerobic digestion is presented in the Appendix (Table A3).

For the scenarios with British and Dutch pork production, country specific data has been used wherever possible. Data on physical performance of the pigs is taken from Sloyan at al. (2006), and is presented in appendix (Table 1A). The British feed data is representative of the overall British pig sector and was provided by Meat and Livestock Commission (MLC). The Dutch feed data was provided by Danish Meat Association and is representative of the overall Dutch pig sector. Feed data is presented in appendix, Table A1. Inventory for manure/slurry applied to the field is presented in appendix (Table A6). The amount of substituted artificial fertiliser is 0.5 kg N per kg N in manure/slurry applied to the field for Great Britain in accordance with Williams et al. (2006; p. 52), and 0.7 in the Netherlands. The ammonia losses from housing, storage and field are presented in appendix (Table A5). Coefficients on ammonia losses from Great Britain and the Netherlands are based on Misselbrook et al. (2004) and Luesink & Kruseman (2007) respectively. The British and Dutch pork is transported 126 km by lorry, and 0 km and 228 km by ship respectively.

Beef and poultry

LCA results on beef (from suckler cows) and poultry from the LCAfood database are also presented. The inventories for beef and poultry farms are based on Dalgaard et al. (2006), as described at www.LCAfood.dk (Link 4). The EDIP method was used in the Life Cycle Assessment but updated with the characterization factors from IPCC (2001), and are thereby directly comparable with the LCA of pork in the present study. For further details see www.LCAfood.dk (Link 4).

Results

Environmental impact per kg of Danish pork

The environmental profile in terms of global warming, eutrophication, acidification and photochemical smog potentials per kg Danish pork delivered to the Port of Harwich is presented in Table 3. More detailed results on global warming, eutrophication and acidification potential are presented in the following section.

Table 3 Characterized results showing the environmental impact per functional unit

Impact category, unit	
Global warming potential, kg CO_2 eq.	3.6
Eutrophication potential, g NO_3 eq.	232
Acidification potential, g SO_2 eq.	45
Photochemical smog potential, g ethene eq.	1.3
Ozone depletion, mg CFC11 eq.	0.7

Global warming potential

The greenhouse gas emission per functional unit is 3.6 kg CO_2 eq, which equals the amount of greenhouse gas emitted from a 10 km car drive (LCA-data ETH-ESU (1996). The most significant contributors to global warming potential are nitrous oxide, methane and CO_2, and they are responsible for 44%, 32% and 20% of the greenhouse gas emissions respectively. In Figure 2 the contribution to global warming potential from the different stages of the product chain of Danish pork are presented.

The feed consumed by the pigs **('Soybean meal'** and **'Grain')** contributes more than 2.4 kg CO_2 eq. and is therefore more significant than any other areas of the production chain. The greenhouse gas emission per kg barley is 0.694 kg CO_2 eq. (Table 1), and thus, with feed usage of 2.3 kg barley per kg pig live weight (see appendix, Table A3) and 79.2 kg carcass weight per 105 kg live weight, it is not surprising that greenhouse gas emission form '**Grain**' amounts to approximately 2 kg CO_2 eq. per functional unit (=0.694*2.3*105/79.2).

From the housing and storage stages, 81% of the global warming potential is methane and 19% is nitrous oxide. 78% of the emitted methane in the housing is from the manure/slurry, and only 22% is from the enteric fermentation from the pigs themselves. The nitrous oxide comes exclusively from the manure/slurry.

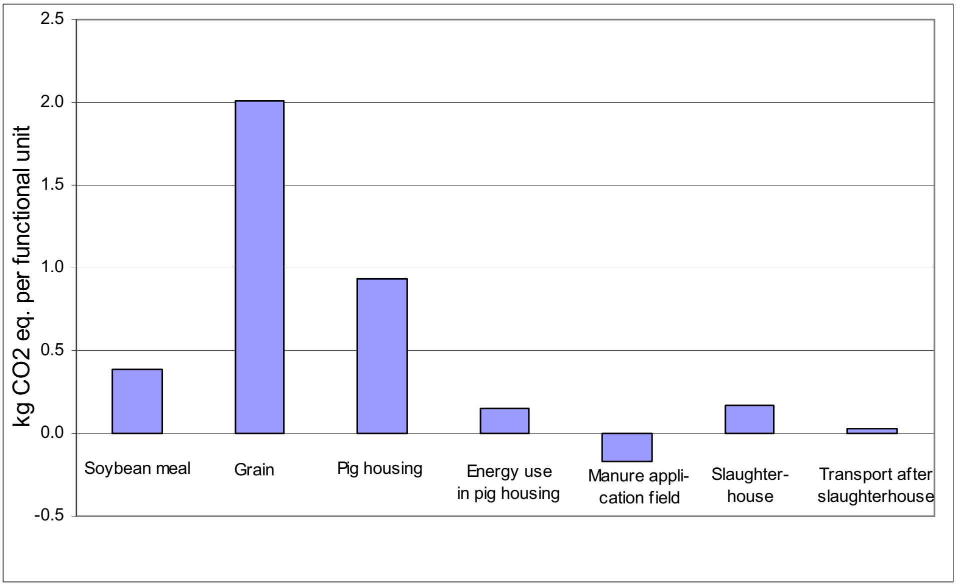

Figure 2 Contribution to global warming potential from the different stages of the production chain

The contribution from **'Energy use in pig housing'** is both CO_2 emission from the production and distribution of electricity, and the CO_2 emitted from oil combusted for heat production at the farm. CO_2 is responsible for more than 98% of the greenhouse gases emitted. The contribution is 0.15 kg per functional unit and out of this 85% is from the use of electricity, while the remainder is related to the heat production from oil.

The contribution from **'Manure application field'** is negative, because less artificial fertiliser is used, when the manure/slurry is applied to the fields for fertilization of the crops. The production and transport of artificial fertiliser emits greenhouse gases, and thus, when artificial fertiliser is substituted by manure/slurry, greenhouse gas emissions will be reduced. On the other hand, when manure/slurry is used for fertilization instead of artificial fertiliser, more nitrous oxide is emitted, and more diesel for tractor driving is used. However, this factor is more than counterbalanced by the saved artificial fertiliser.

The contribution from **'Slaughterhouse'** is 0.17 kg CO_2 eq. per functional unit and is thus the second smallest contributor to the global warming potential. The major contributor from **'Slaughterhouse'** is use of electricity at the slaughterhouse and the transport of the pigs from the farm to the slaughterhouse (distance 80 km). However some of the by-products from the slaughterhouse result in saved emissions of greenhouse gases. Manure/slurry from the pigs is transported to a biogas plant, where it is anaerobically digested, and the gas is used for heat and electricity production. The energy produced from manure/slurry substitutes fossil energy and this results in a reduced emission of greenhouse gases. Also some animal by-products (bone, blood etc) are used as bone and blood meal for animals or energy production. Nevertheless, the total of avoided emission of greenhouse gases resulting from use of manure/slurry and animal by-products is low, and, in total, adds up to just -0.013 kg CO_2 eq. per functional unit.

‘**Transport from slaughterhouse’** to the Port of Harwich is the stage of the product chain, which emits the smallest amount of greenhouse gases. 0.021 kg CO_2 eq. per functional unit is emitted from the transport by lorry, and 0.007 kg CO_2 eq. is emitted from the transport by ship. So, even though transport by lorry only is 126 km, whereas the transport by ship is 619 km, the emission from lorry transport is 3 times higher. Less than 1% of the greenhouse gas emitted during the production of Danish pork can be ascribed to transport from the slaughterhouse to the Port of Harwich in Great Britain.

The environmental ‘hot spots’ in the production chain of Danish pork, relating to global warming, occur in the stages, before the pigs arrival at the slaughterhouse. A key parameter in reducing the global warming potential is farm management. If the protein consumption, per pig produced, is decreased, less N in manure/slurry will be excreted, and thereby less nitrous oxide will be emitted from the pig housing. In addition less protein consumption will result in a decreased use of soybean meal and a small increase in grain use. But because the greenhouse gas emission is lower per kg grain compared to soybean meal, a net decrease in greenhouse gas emission from the feed production will appear. In conclusion, a reduction in protein consumption creates a ‘win-win’ situation. Less greenhouse gases are emitted from the feed production and less from the manure/slurry. In addition, if the farmer can reduce the amount of protein purchased but maintain a similar level of pig production, his financial outlay will also be reduced.

In the debate on climate change, the focus is predominantly on CO_2 emissions and the use of energy by the industry and the transport sector. However, when considering food products, and in particular livestock products, methane and nitrous oxide are more important than CO_2 for the total impact on global warming. This conclusion is in accordance with the results presented above, where the transport and the slaughterhouse stages are less significant, but the emissions from feed production and housing can be seen to have a far greater impact.

But what results occur if Danish pork is transported, for example, to Munich in southern Germany or Tokyo in Japan? To answer this question, two additional transport scenarios were established. Firstly, where pork is transported 1075 km by lorry (size: 32 tons), which equals the distance from Horsens Slaughterhouse to Munich, and a second scenario, where pork is transported 21,153 km, which equals the distance from the Port of Esbjerg to the Port of Tokyo in Japan. These longer transport distances increase the emissions from 3.6 kg CO_2 eq. per functional unit (base scenario, se Table 3) to 3.7 and 3.8 kg CO_2 eq. for the Munich and the

Tokyo scenario respectively. So, even though the transport is much longer, the increased contribution to global warming potential is limited.

Eutrophication potential

The most important contributor to eutrophication potential is nitrate (62%), followed by ammonia (32%), nitrogen oxides (4%) and phosphate (2%). As Figure 3 shows, the contribution from **'Soybean meal'** is very low, because nitrate in general is not leached during the cultivation of soybeans in Argentina (Dalgaard et al., 2007; Austin et al., 2006). The highest contribution to eutrophication potential comes from **'Grain'** (122 g NO_3 eq. per functional unit), with nitrate and ammonia emitted during the cultivation of the grain being the major contributors. The only contributing substance from **'Pig housing'** is ammonia, which equals 47 g NO_3 eq. per functional unit. The ammonia comes from the manure/slurry excreted in the housing and during storage. The contribution from **'Energy use in pig housing'** is very low. The second highest contributor is **'Manure application field'**, which contributes with 62 g NO_3 eq. per functional unit. A major part of this is N in the manure, which is leached, because it not is assimilated into the crops. **'Slaughterhouse'** contributes -0.4 g NO_3 eq. per FU and is negative, because animal by-products, to some extent, are used as animal feed and thereby substitute the use of grain in feed. From **'Transport after slaughterhouse',** small amounts of nitrogen oxides are emitted due to fossil fuel combustion, but the contribution per functional unit is very low. The key element regarding eutrophication potential is N in the form of nitrate leached from fields and ammonia emitted from the manure/slurry. The contribution from P is less than 2% per functional unit.

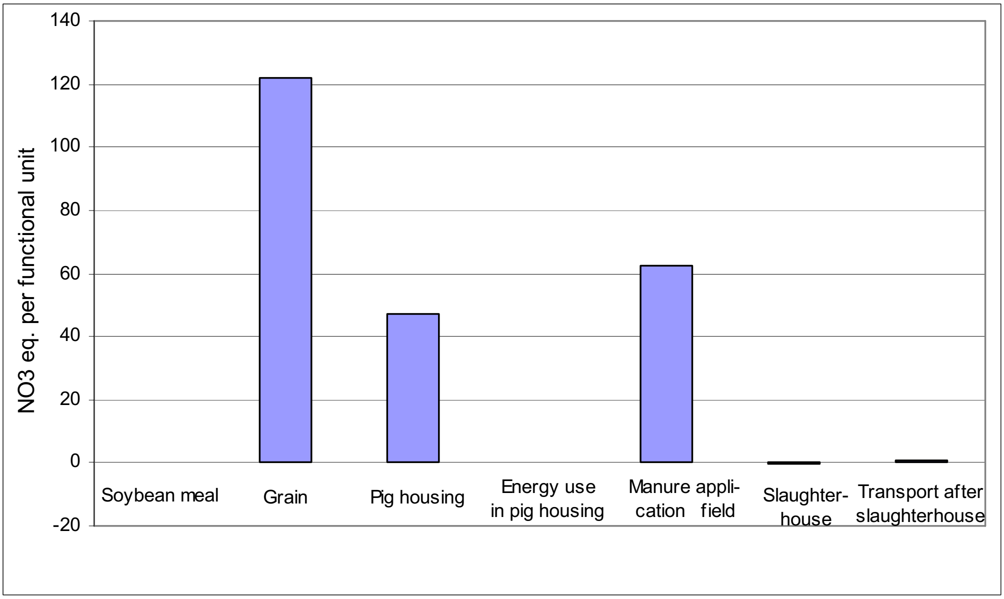

Figure 3 Contribution to eutrophication potential from the different stages of the production chain

Acidification potential
Ammonia is responsible for 84% of the acidification potential. Nitrogen oxides, sulphur oxides and sulphur dioxides, which arise from the use of energy, are responsible for 16% of the acidification potential. The contribution from **'Soybean meal'** is low (see Figure 4) and almost exclusively related to the emissions of nitrogen oxides, sulphur oxides and sulphur dioxides emitted during the transport of soybean meal from Argentina to Denmark. **'Pig housing'** is the largest contributor to acidification potential, with ammonia as the only acidifying substance. Contributions from **'Energy use in pig housing'** and **'Slaughterhouse'** are very small. **'Manure application field'** contributes, because ammonia is emitted, when the manure/slurry is applied to the field. However, a significant part of that ammonia is counterbalanced, because the manure/slurry applied to the field substitutes artificial fertiliser, which again results in saved emission from the use of fossil fuel.

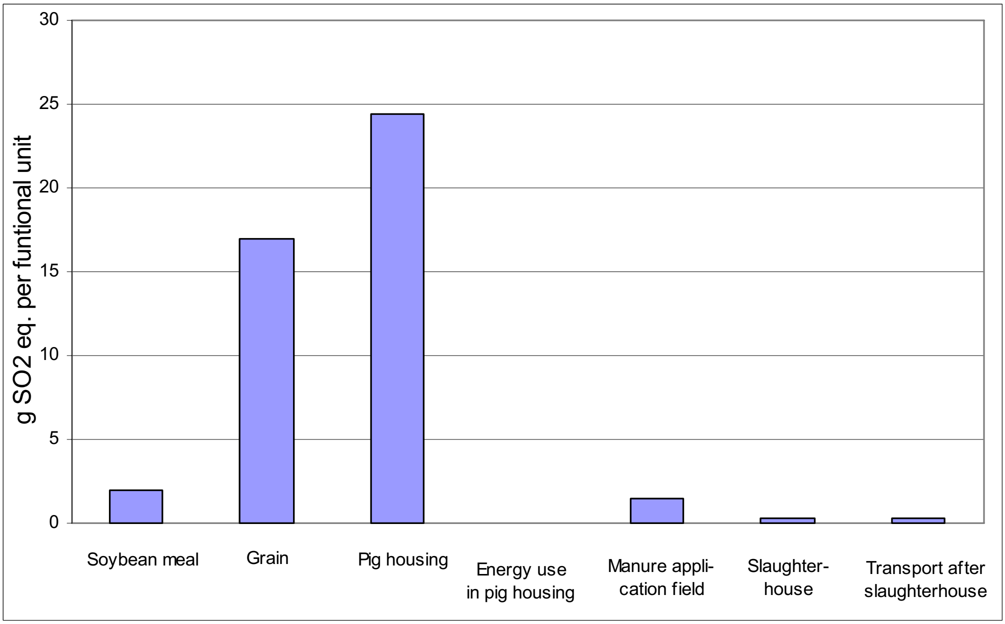

Figure 4 Contribution to acidification potential from the different stages of the production chain

Other scenarios
In Figure 5, global warming potential, eutrophication potential and acidification potential per functional unit are compared. The 'Base scenario' is based on the same results as presented in the previous section (see Table 3) and represents pork produced in 2005. 'Scenario 1995' is

Danish pork produced in 1995, where the numbers of pigs weaned per sow' and amount of feed consumed were lower. 'Scenario 2015' represents pork as it is assumed to be produced in 2015. In the 'Scenario anaerob.' it is assumed that all the manure/slurry from the pig farm is brought to a joint scale biogas plant, where it is anaerobically digested, and the biogas is used for energy production.

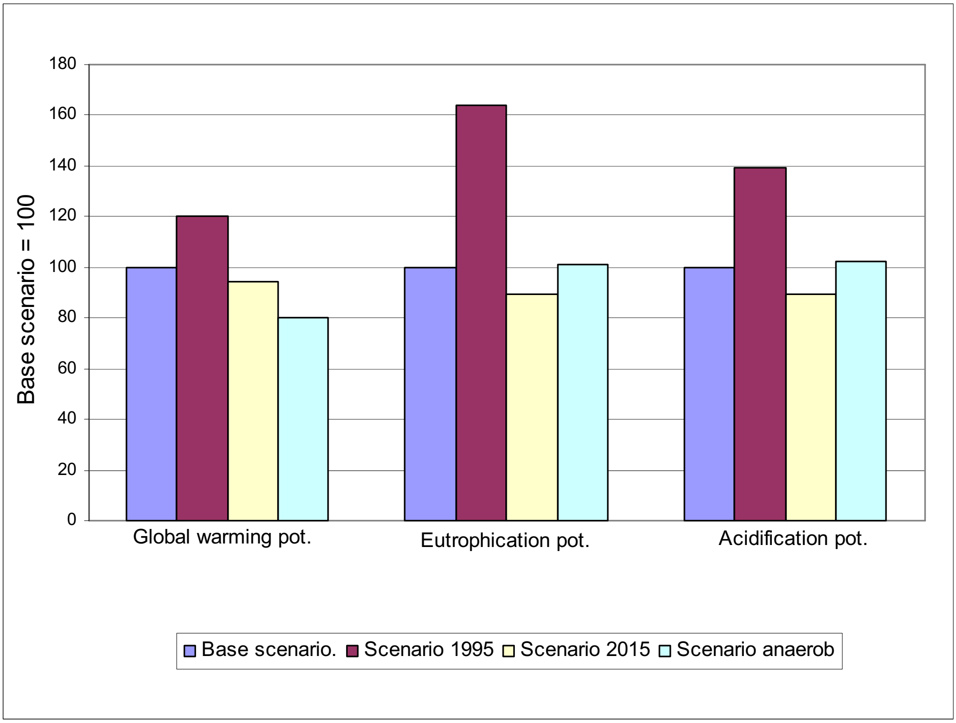

Figure 5 Comparison of the global warming, eutrophication and acidification potential for Danish pork produced in 2005 (Base scenario), 1995 (Scenario 1995), 2015 (Scenario 2015) and by anaerobic digestion of the manure/slurry (Scenario anaerob.). Base scenario corresponds to the results presented in Table 3

According to Figure 5, pork produced in 2005 ('Base scenario') has a lower environmental impact compared to that of pork produced in 1995 ('Scenario 1995'). This is mainly because of the lower feed (and protein) consumption and improved handling of manure/slurry, regarding the N emissions from housing, storage and field.

For the three impact categories under review, the emissions are up to 11% lower for the pork produced in 2015 ('Scenario 2015') compared to the 'Base scenario'. However, the highest reduction in greenhouse gas emissions can be obtained by anaerobic digestion of the manure/slurry, as shown in 'Scenario anaerob.', where the greenhouse gas emission is reduced by 20%. This high reduction potential is because, the biogas is used for energy production and thereby substitutes fossil energy.

Environmental impact of pork produced in Great Britain and the Netherlands

In Figure 6, the environmental impact of pork produced in Denmark is compared to pork produced in the Great Britain (GB) and the Netherlands (NL). The functional unit for all three pork products is '1 kg pork (carcass weight) delivered to the Port of Harwich', and no distinction is made between different types of pork (e.g., minced meat, tenderloin etc.). Global warming potential is equal for all three countries. As explained previously, the amount of greenhouse gases emitted from transport of pork by lorry and ship is low, thus the longer transport distances for pork produced in DK and NL compared to GB, do not influence the results. The protein content in the GB feed is higher, as more soybean meal and less grain is used (Appendix, Table A3). Greenhouse gas emissions are higher for soybean meal than for barley (Table 1), consequently the greenhouse gas emissions from feed production and distribution become higher for the GB pork compared to the DK and NL pork. However, the global warming potential from housing and storage is lower for GB, because more of the manure/slurry is handled as solid and less as liquid. The methane conversion factor (MCF) is 17% for liquid and only 2% for solid (IPCC, 2006). Overall, the global warming potential ends up being equal for all three countries. Eutrophication and acidification potential is higher for GB compared to DK and NL. The reasons are, that more protein is consumed, and more N is excreted from the GB pigs. In addition, the manure/slurry is handled in a way that results in higher ammonia losses. Ammonia contributes to both eutrophication potential and acidification potential.

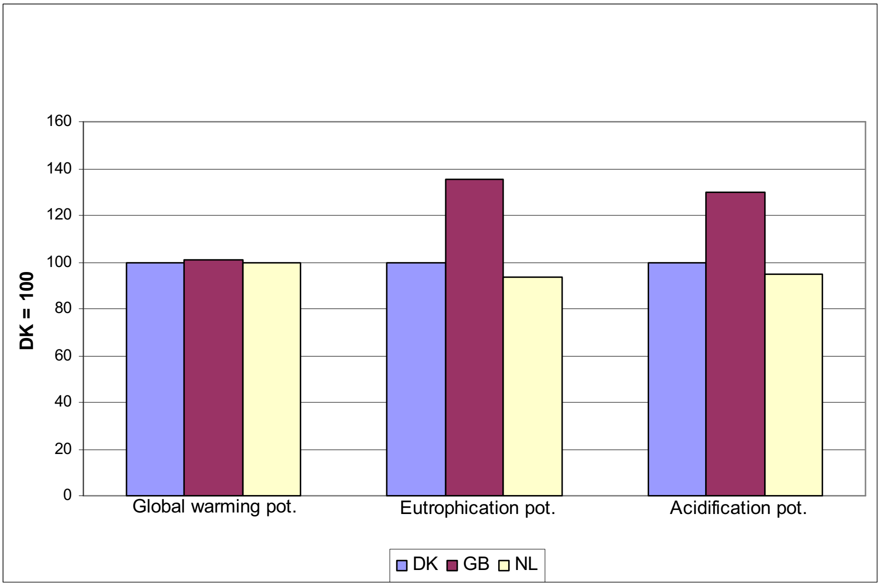

Figure 6 Comparison of the global warming, eutrophication and acidification potential for pork produced in Denmark (DK) (results from Table 3), Great Britain (GB) and the Netherlands (NL)

Environmental impact of beef and poultry produced in Denmark

In Table 4, the environmental impact of pork is compared to that of beef and poultry. The global warming per kg beef is only slightly higher, although considerably more methane from enteric fermentation is emitted from a cow than from a pig. But the greenhouse gas emitted from production of feed is lower for the cows, because they almost only consume grass and silage, which emit less greenhouse gases than grain and soybean meal.

Table 4 Characterized results for pork, beef and poultry

Impact category, unit	Pork	Beef	Poultry
Global warming potential, kg CO_2 eq.	3.6	3.7	3.6
Eutrophication potential, g NO_3 eq.	232	3190	195
Acidification potential, g SO_2 eq.	45	374	48
Photochemical smog potential, g ethene eq.	1.3	7	0.6
Ozone depletion, mg CFC11 eq.	0.7	3.0	0.5

Discussion

One of the important conclusions of this study is, that the transport of the pork only emits very small amounts of greenhouse gases compared to other areas of the production chain. Less than 1% of the greenhouse gases emitted from the production of pork can be related to the transport from the Danish slaughterhouse to the Port of Harwich in Great Britain. In the media, the global warming is frequently attributed to production in factories, energy use and transport, and these are indeed important contributors to global warming. But when considering agricultural products, one should not just focus on CO_2 emissions, as there are other greenhouse gases of greater potency. Nitrous oxide and methane, for example, have a 296 and 23 times higher global warming potential than the much publicised CO_2. Thus, if the intention is to reduce the emissions of greenhouse gases, it is more important to encourage farmers to use feed as efficiently as possible and to handle the manure/slurry in ways that minimises their impact, instead of focusing on issues such as 'Food miles'. If consumers in Great Britain are confronted with a choice of British, Danish or Dutch pork, they may well be tempted to conclude that, by choosing the 'home produce,' their choice may be a less environmentally damaging one in view of the shorter distance from farm to retail outlet. This report clearly demonstrates, that the overall greenhouse gas emissions per kg Danish or Dutch pork are not higher than those for British pork. The eutrophication and acidification potential is actually lower than that for the British pork, due to the higher productivity efficiencies in Denmark and the Netherlands. Another limitation regarding the concept of 'Food miles' is that the mode of transport (ship, aircraft or lorry) is often overlooked. For example, transport by lorry emits more than 15 times as much CO_2, than if the same commodity was transported by ship. So if 'Food miles' are to be used as an environmental indicator, it is crucial to divide it into mode of transport, for example, 'Food ship-miles' and 'Food lorry-miles'. 'Carbon footprint' is another environmental indicator, which has become used in various forms (Wiedmann & Minx, 2007), and it must be used with care if applied to food products. If emission of nitrous oxides and methane are not included in the environmental assessment, then the impact of a particular food on global warming may be underestimated and a misleading picture presented.

The greenhouse gas emission per functional unit ('1kg of Danish pork (carcass weight) delivered at the Port of Harwich') was 3.6 kg CO2 eq. and thereby equals the amount of greenhouse gases arising from a 10 km drive in a typical passenger car. Although it was stated in this study that the contribution from transport of pork by lorry and ship is low compared to the rest of the production chain, it should be emphasized that the contribution from the consumers' transport to the supermarket may increase the global warming potential per kg pork dramatically, if a long journey is involved.

The protein content in the feed has an impact on emissions at several life cycle stages. Higher protein content results in increased use of soybean meal and decreased use of grain, which again will increase the global warming potential per kg pork, but decrease the eutrophication potential and acidification potential, see Table 1 (soybean meal and barley). Higher protein content in the feed also results in increased emissions of nitrous oxides, ammonia and nitrate from housing, storage and field. The protein content in the sow and finisher feed mixtures from GB are higher than those typically used for the feed mixtures in DK (base scenario) and NL (Appendix, Table A1). A sensitivity analysis, where the protein content in the finisher feed mixtures from GB was decreased from 18% to 16%, was carried out, and it was shown, that the overall effect was limited. The global warming, eutrophication and acidification potentials decreased by 2%, 5% and 7% respectively. Thus, although a lower protein content was used in the modelling, the pork produced in GB still had higher eutrophication and acidification potential.

In Table 5, some of the results from this study are compared to the LCA results of pork produced in Denmark (Halberg et al., 2007), Sweden (Cederberg & Flysjö, 2004), France (Basset-Mens & van der Werf, 2005) and Great Britain (Williams et al. 2006). The functional unit is '1 kg pork' (carcass weight) delivered from farm gate, which means that some of the production stages (e.g., transport of live pigs, slaughtering etc.) not are included. The results from Halberg et al. (2007) represent organic production in Denmark and the results are presented as a range, because three different systems of organic production were studied. The environmental impact per kg organic pork is higher compared to conventional production for both global warming, eutrophication and acidification.

The results of this study are comparable to results of Cederberg & Flysjö, (2004) and Basset Mens & van der Werf, (2005). But the environmental impact per kg pig is considerably higher in the study of Williams et al. (2006). It seems as the main difference between the results of this study and those of Williams et al. is related to the method of calculation of nitrous oxides. In addition, much more ammonia is emitted per kg pig and presumably the nitrate leaching from the soybean used in the study of Williams et al. is higher than the equivalent results in this study.

Table 5 Comparison of pigs from different LCA-studies within Europe
Functional unit: 1 kg (carcass weight) pork from farm gate

Environmental impact	Global warming potential	Eutrophication potential	Acidification potential
Unit	Kg CO_2 eq.	g NO_3 eq.	g SO_2 eq.
Current study			
Pork produced in Denmark	3.3	232	45
Pork produced in Great Britain	3.4	301	61
Other studies			
Organic pork produced in Danmark (Halberg et al., 2007)	3.8-4.3	353-501	67-81
Pork produced in Sweden (Cederberg & Flysjö, 2004)	2.6	170	37
Pork produced in France (Basset Mens & van der Werf, 2005)	3.0	274	57
Pork produced in Great Britain (Williams et al. 2006)	5.6	760	290

Conclusion

The environmental impact per kg Danish pork is 3.6 kg CO_2 eq. for global warming potential; 232 g NO_3 eq. for eutrophication, 45 g SO_2 eq. for acidification potential and 1.3 g ethene eq. for photochemical smog potential. The environmental 'hot spots' in the production chain of Danish pork, in relation to global warming, occur in the stages before the pigs arrival at the slaughterhouse. The highest contributions come from production of feed and handling of manure in the housing and under storage. These environmental 'hot spots' are the same for eutrophication potential and acidification potential. But in addition, the manure/slurry applied to the fields also makes a significant contribution to eutrophication potential. The contribution to global warming potential from the transport of pork from the slaughterhouse in Denmark to the Port of Harwich in Great Britain is less than 1%. The most important contributors to the three environmental impact categories under review are nitrous oxide (44%) for global warming potential, nitrate (62%) for eutrophication potential and ammonia (84%) for acidification potential.

The environmental impact per kg pork has decreased over the last decade, primarily because of lower protein content in the feed, improved production efficiencies ('pigs weaned per sow per year', 'feed conversion ratio'), and more controlled and careful handling of manure. However, there is still scope for improvement. For example the results of this study indicate, that the global warming potential per kg pork could be reduced by up to 20%, if the manure/slurry is anaerobically digested.

Comparison of the environmental impact per kg Danish pork with the British and Dutch equivalent showed, that the global warming potentials were equal, whereas the eutrophication and acidification potential was highest for British pork. Dutch pork had slightly lower eutrophication and acidification potential compared to that of Danish pork.

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Appendix

Table A1 Characteristics of feed mixtures used for the modelling

	DK (Base scenario)	DK (Scenario 1995)	GB	NL
Crude protein, %				
Sows	12.8	14.4	14.2	16.7
Weaners	18.6	22.5	21.1	17.2
Finishers	16.8	18.9	18.0	15.5
P content, g/kg				
Sows	5.0	5.3	6.4	4.6
Weaners	6.2	7.7	6.0	4.7
Finishers	4.5	6.4	6.2	4.4
Energy, MJ ME/kg				
Sows	13.1	13.1	12.7	12.9
Weaners	15.2	15.2	13.5	13.6
Finishers	13.9	13.9	13.1	13.8

Table A2 Physical performance in 2005 (Sloyan et al., 2006)

	DK	GB	NL
Pigs weaned per sow per year	26.09	21.5	24.52
Sow feed (kg) per sow per year	1318	1339	1145
Average live weight at slaughter, kg	105.0	96.9	113.8
Finishing mortality, %	4.0	6.5	2.9
Sow mortality, %	14.1	4.7	5.0
Rearing feed conversion ratio	1.81	1.70	1.61
Finishing feed conversion ratio	2.67	2.74	2.66

Table A3 Inventory for production of 100 kg pig (live weight) at farm

	DK (base scenario)	DK Scenario 1995	DK Scenario 2015	DK Scenario anaerob	GB	NL
Products						
Pigmeat, kg	100	100	100	100	100	100
Manure ab storage, Kg N	3.4	5.0	3.0	3.4	3.8	3.2
Resource use						
Grain, kg	233	244	214	233	218	231
Soybean meal, kg	31	54	29	31	52	29
Heat (oil), MJ	24	24	22	24	24	24
Electricity, kWh	20	20	18	20	20	20
Emissions						
Ammonia, kg NH_3	1.0	1.4	0.9	1.0	1.4	0.8
Nitrous oxide, g N_2O	46.0	66.5	40.0	46.0	57.8	41.4
Methane, kg CH_4	2.5	2.5	2.5	2.5	1.5	2.6

Table A4 Feed consumption per 100 kg pig meat (live weight)

	DK	GB	NL
Before weaning, kg	43	56	38
Rearing herd, kg	38	50	24
Finishing, kg	183	164	198
Total, kg	264	270	260

Table A5 Ammonia emission from manure, % of N excreted

	DK	GB	NL
Housing	14%	16%	17%
Storage	5%	7%	0%
Land spreading	8%	15%	10%
Total	27%	38%	28%

Table A6 Inventory for application of 1 kg N in manure/slurry to field

	DK	GB	NL
Substituted artificial fertiliser			
Fertiliser (N), kg	0.7	0.5	0.7
Fertiliser (P), kg	0.1	0.1	0.1
Energy			
Traction, MJ	4.1	4.1	4.1
Lubricant oil, ml	10	10	10
Emissions			
Nitrous oxide, g N_2O	8.3	13.8	8.3
Ammonia, g NH_3	23.5	67.1	30.2
Nitrate, kg NO_3	1.2	2.0	1.2
Phosphate, g PO_4	4.5	10.0	4.2

Table A7 Characterized results for pork produced in Denmark (DK) (under different circumstances) and pork produced in Great Britain (GB) and the Netherlands (NL). Functional unit: 1 kg pork produced and delivered to the Port of Harwich in GB

	DK (base scenario)	DK Scenario 1995	DK Scenario 2015	DK Scenario anaerob	GB	NL
Global warming potential, kg CO_2 eq.	3.6	4.3	3.4	2.9	3.6	3.6
Eutrophication potential, g NO_3 eq.	232	380	208	234	301	219
Acidification potential, g SO_2 eq.	45	64	41	47	64	42
Photochemical smog potential, g ethene eq.	1.29	-	-	-	1.35	1.25
Ozone depletion, mg CFC11 eq.	0.7	-	-	-	0.9	0.8

SUMMARY

The primary aim of this report is to present data for the environmental profile of pork, and to identify the most polluting areas in the production chain of Danish pork, by use of the Life Cycle Assessment (LCA) methodology.

The functional unit is '1 kg of Danish pork (carcass weight) delivered at the Port of Harwich', and the environmental impact categories considered are global warming, eutrophication, acidification, ozone depletion and photochemical smog.

PLANT SCIENCE

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