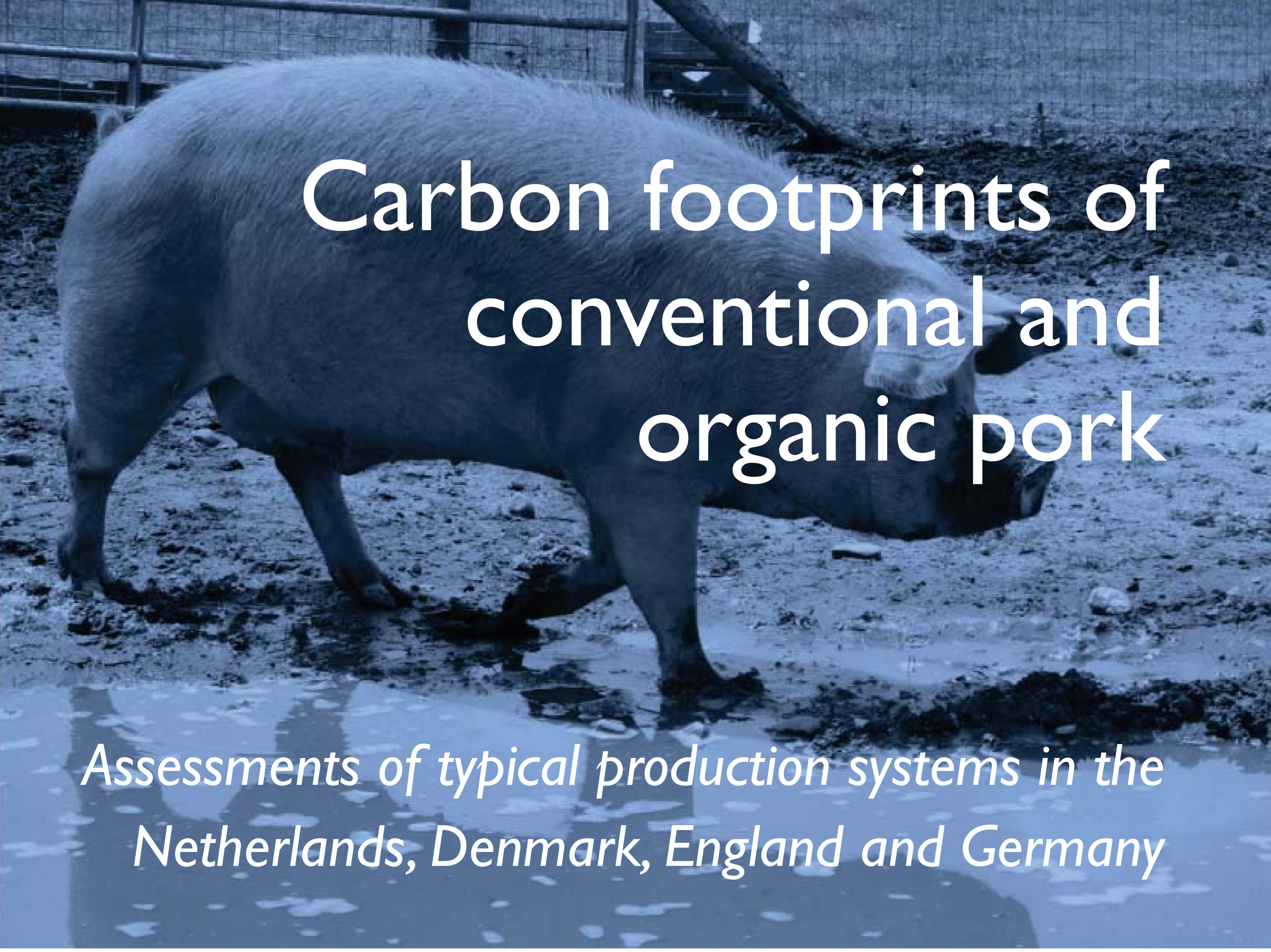

Carbon footprints of conventional and organic pork

Assessments of typical production systems in the Netherlands, Denmark, England and Germany

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Carbon footprints of conventional and organic pork

Assessment of typical production systems in the Netherlands, Denmark, England and Germany

November 2009

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Summary

The contribution of the animal production chain to the worldwide anthropogenic greenhouse gas emissions has become an important issue in the Netherlands and internationally. This report is the result of a study that responds to the demand for more insight in the contribution of greenhouse gas emissions from processes and activities in the animal production chain, by focusing on conventional and organic pork from Denmark, England, Germany and the Netherlands. The objectives of the study were: 1) to gain insight in the contribution of typical production systems to greenhouse gas emissions and the contribution of each process and activity within the chains by means of an explorative carbon footprint assessment; 2) to make an inventory of possible reduction options for the Dutch conventional and organic production chains; and 3) to make a starting point for further methodology and protocol development of carbon footprint assessments of animal products. The report gives an overview of existing methods for assessing carbon footprints of agricultural products and basic information on the methods that were used in this study, including descriptions of the functional unit, the pork production chain, methods for allocating upstream emissions to co-products, and statistical uncertainty analysis. The report also describes several scenarios for possible improvements of the carbon footprints

The carbon footprint of conventional pork was estimated between 3.5 and 3.7 kg CO_2eq per kg pork (fresh meat after the gate of the slaughterhouse). None of the differences between the studied typical farming systems in countries was within the statistical certainty range of more than 90%. The carbon footprint of organic pork was estimated between 4.0 and 5.0 kg CO_2eq per kg pork (Denmark and Germany, respectively). The difference between conventional and organic was within a certainty range of more than 90% for the Netherlands and Germany. The greenhouse gas emissions from land use and land use change (LULUC) was calculated separately from the other greenhouse gas emissions that are attributed to pork, because of methodological uncertainty. Nevertheless, the LULUC related emissions are about 50% compared to the carbon footprints. So, besides competing for land use and the pressure on biodiversity, the use of land for production of pork also has a major effect on greenhouse gas emissions. Production of feed (crop growing, transport of crop products, processing crop products, transport of raw materials and feed mixing) contributes roughly 50% - 60% to the carbon footprints of conventional and organic pork. For most systems, the second most important source is methane emissions from manure storage (12% to 17%). In systems with a substantial share of grazing (organic systems in Denmark and England), the emissions from grazing are the second most important source.

In order of magnitude and certainty the most obvious reduction options for the carbon footprint of conventional and organic pork are as follows: a) Digestion of manure, which reduces methane emissions from manure storage and avoids greenhouse gas emissions from fossil fuels by generating energy; b) Lowering the feed conversion rate, which reduces the amount of feed and nitrogen intake per produced amount of pork, and hence the emissions from feed production, manure management and application are reduced; c) The use of wet co-products in pigs' rations; d) Improving slaughtering efficiency and upgrading of pork co-products reduces the carbon footprint of pork, but increases the carbon footprint of the co-products; e) Some alternative activities have a smaller effect on the carbon footprint of pork, but can be certain reductions of greenhouse gas emissions; for example: covering uncovered liquid manure silos; pumping liquid manure directly after production in a pig house to the storage outside (silo); closing the cycle of raw material production; feed utilization, manure production and manure application as much as possible; and adding value to the manure exported from the pig farm. f) Setting limits on the carbon footprint when optimizing feed composition might realize a considerable reduction of a particular feed but it is uncertain whether it causes a reduction on a world scale.

To enable comparison between results of different studies on carbon footprints of pork and to stimulate methodology discussions and exchange of data, it is recommended to develop guidelines for carbon footprint assessment of pork (and other animal products) with international partners to eventually make an international protocol. As part of methodology development, it is recommend to analyze determining issues for the ratio between pork and co-products at the slaughter house more detailed. Besides development of methodology, effort should be put into obtaining representative data.

To increase the insight in the carbon footprints of pork from different pork production systems and the possibilities for reducing the greenhouse gas emissions, it is recommended to assess the carbon footprints of pork from real case pork production. Especially more insight is needed for feed composition, origin and production of feedstuffs and pig production on farm level, because of their large impact on the carbon footprint. The report closes by emphasizing that when assessing the sustainability of pork production, the attention should not only be focussed on carbon footprints of pork, but other aspects of sustainable pork production, for instance animal welfare and socio-economic aspects, should be taken into account.

Content

1 Introduction

The contribution of the animal production chain to the worldwide anthropogenic greenhouse gas emissions has become an important issue in the Netherlands and internationally. The FAO publication "World's Livestock Long Shadow" (Steinfeld e.a., 2006) made many people aware of the scale of the current contribution and the consequences of an expected doubling of meat and dairy consumption. Also the industry realizes the importance of reducing the greenhouse gas emission from food production chains. English retail started in 2007 with claiming information about greenhouse gas emissions from suppliers for labelling products. This growing awareness was a motivation for this study on the carbon footprint of pork produced in different countries in different systems. Another motivation was the question which share transport has in the carbon footprint of meat in the discussions about foodmiles. The report on greenhouse gas emissions from protein rich product chains that was commissioned by the Dutch Ministries of Environment and Agriculture (Blonk e.a., 2008) gave insight in the contribution of Dutch consumption of animal products. The present report is the result of a study that responds to the demand for more insight in the contribution of greenhouse gas emissions from processes and activities in the animal production chain, by focusing on conventional and organic pork from Denmark, England, Germany and the Netherlands.

A carbon footprint is a popular expression for a lifecycle assessment of greenhouse gas emissions that can be attributed to a product and has become a powerful tool for assessing the contribution of products to greenhouse gas emissions. However, the assessment of carbon footprints is not straightforward and several methodological choices that have large effects on the outcome need to be made. The PAS2050 (BSI, 2008) is the most practical protocol for assessing carbon footprints at this moment and will be an anchor point in the further development of a worldwide standard on assessing carbon footprints. It gives a framework and directions on how to deal with methodological choices in assessing carbon footprints. However, for agricultural products it is not specific enough. On several methodological issues a further specification is required to enable consistent carbon footprints assessments of animal products.

Because of these methodological issues and the increasing attention for the contribution of the animal production to greenhouse gas emissions, the Dutch company VION De Groene Weg and organizations Biologica and the Dutch Southern Agriculture and Horticulture Organisation (ZLTO) joined efforts to gain more insight in the carbon footprint of conventional and organic pork production. Eventually, a consortium was initiated consisting of the Dutch public and private parties VION De Groene Weg, Biologica, ZLTO, the Dutch Ministry for Agriculture, Nature and Food Safety (LNV), and Cehave Landbouwbelang ua to commission the present project. The project's research was done by Blonk Milieu Advies (project management), Wageningen UR Livestock Research, Wageningen UR LEI, and Wageningen UR Applied Plant Research.

1.1 Objectives

The objectives of the study were:

- To gain insight in the contribution of typical Dutch, Danish, German and English conventional and organic pork production systems to greenhouse gas emissions and the contribution of each process and activity within the chains by means of explorative carbon footprint assessment.
- To make a rough (or first) inventory of possible reduction options for the Dutch conventional and organic production chains.
- To make a starting point for further methodological and protocol development of carbon footprinting for animal production.

In recent years some studies compared the carbon footprints of pork between countries (Dalgaard, 2007) and between organic and conventional production (Blonk e.a., 2007a, Bos e.a., 2007, Williams e.a, 2006). The results pointed in several directions, while the underlying factors determining the differences in greenhouse gas emissions were not fully clear. So, the motivation for the first objective is the need for more insight in the differences between several production systems. It must be emphasized here that the aim of this study was not to quantify the total contribution of greenhouse gas emissions from all pork production systems in the four countries. We believe this is not yet possible, because methodologies still need to be developed and because of the lack of country specific data on averages and variation of parameters. This study only sets a starting point for coming to answers by defining practically applicable calculation rules and methods for assessing carbon footprints of pork, based on the most recent scientific and practical insights. By applying these calculation rules on realistic scenario’s for pork production systems a better understanding of differences is gained.

As part of methodology development, we also investigated the question how to determine significant differences between the carbon footprint of pig production systems. The result must be considered as an examination in understanding differences and not as the answer on ranking the carbon footprint of production systems. To do that, better data on production systems are required.

The results of this study give a starting point for further development in several directions. First, a foundation was constructed for further international methodology development. The results can be implemented in a protocol for assessing carbon footprints, similar to the PAS2050. Second, the developed calculation rules and selection of default data can be applied for assessing carbon footprints of existing pork production chains.

1.2 Outline of the report

This report consists of six chapters (including this introductory chapter). Chapter 2 starts with giving an overview of existing methodology for assessing carbon footprints of agricultural products and basic information on the methods that were used in this study. This information includes descriptions of the functional unit that was used, the pork production chain, allocation to co-products, and the uncertainty analysis. Detailed description of those methods and background data can be found in the annexes of this report.

Chapter 3 describes the production systems in the chains of conventional and organic pork from Denmark, Germany, the Netherlands, and England. This chapter was divided into four parts: feed production, animal production, slaughtering, and transport.

The results of the case studies are presented in the first part of Chapter 4. It continues with a more detailed description of important sources of greenhouse gas emissions in terms of contribution to the carbon footprint of pork. Chapter 4 also presents the results of a comprehensive sensitivity analysis, including uncertainty analysis. More detailed results are included in the annexes of this report.

Chapter 5 describes several scenarios for possible improvements of the carbon footprints and presents the resulting carbon footprints of pork in those scenarios. The scenarios are presented in three parts: the first focuses on possibilities to reduce the contribution of greenhouse gas emissions from the animal feed production chain; the second discusses methane emissions reduction options from manure management; and the third part explores ways to reduce the carbon footprint of pork through different strategies of manure application.

In chapter 6 the conclusions and recommendations that can be drawn from this study are stated. The conclusions refer as much as possible to the objectives of this study.

2 Methodology

2.1 Derived methodology in relation to standards

2.1.1 *General outline*

The methodology that was used in this study for assessing carbon footprints of pork is based on a framework that includes LCA protocols (PAS 2050 protocol and the recently published protocol for Dutch horticulture produce) and IPCC guidelines for National Inventories. (Figure 2.1). The protocols and guidelines allow some flexibility to adapt to data availability; so, where more detailed data is available, more detailed calculation rules are possible. The following sections give a brief description of the different sources.

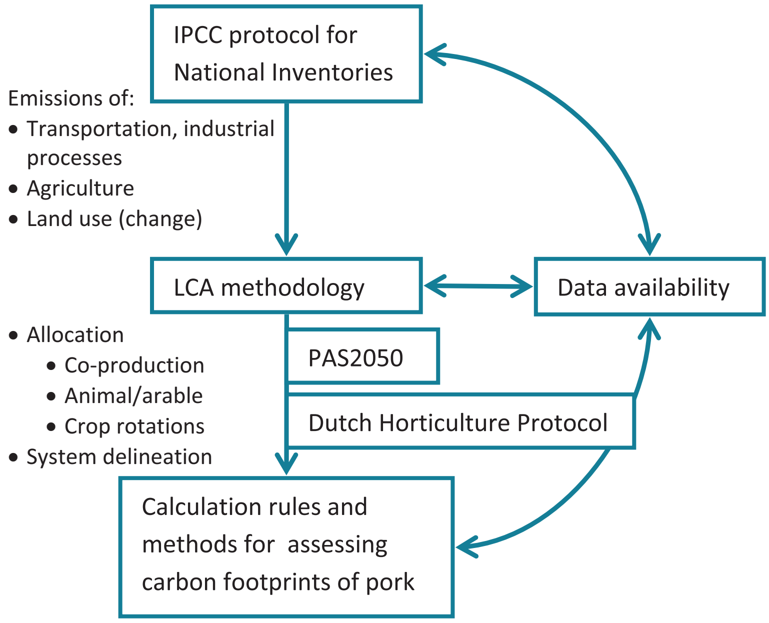

Figure 2.1 Carbon footprint assessment framework for the pork production chain

2.1.2 *IPCC guidelines for national inventories*

The IPCC publishes guidelines for performing national inventories on greenhouse gasses. The most recent IPCC guidelines were published in 2006. Volume 4 of the 2006 IPCC guidelines contains guidelines for calculating the emissions due to agricultural, forestry and other land use activities. To this protocol, the chapters 5 (cropland), 6 (grassland), 10 (livestock and manure management) and 11 (managed soils) of Volume 4 of the 2006 IPCC guidelines are most relevant to our project (Table 2.1).

Table 2.1 Chapters of Volume 4 of the 2006 IPCC guidelines that are most relevant to this study.

Chapter in IPCC 2006		Subject
5	Cropland	GHG emissions related to growing of feed crops in relation to changes in soil carbon stocks and conversion of nature to agricultural land
6	Grassland	GHG emissions related to grazing
10	Livestock and manure management*	Methane and nitrous oxide emissions in relation to pig house systems, manure storage and manure application
11	Managed soils	Nitrous oxide emissions from managed soils, and CO_2 emissions from lime and urea application

The IPCC guidelines provide three methodological tiers, varying in complexity, to be chosen on the basis of national circumstances:

- Tier 1 Simple first order approach: use coarse activity data from global datasets, simplifying assumptions, IPCC default parameters, large uncertainties
- Tier 2 A more accurate approach: more disaggregated activity data, country specific parameter values, smaller uncertainties
- Tier 3 Higher order methods: detailed modelling and/or inventory measurement systems driven by data at higher resolution and much lower uncertainties

The higher tier methods (Tier 2 and 3) are required for key source categories, source or sink categories that contribute substantially to the overall national inventory level, trend or uncertainty (Srivastava, 2009).

One of the objectives of our project was to make an explorative assessment for carbon footprints of organic and conventional pork in four north-western European countries. Important greenhouse gas emission sources to be calculated for this purpose are the nitrous oxide and methane emissions from crop growing and animal husbandry. Therefore, we compared the Tier 2 and 3 methodologies for calculating these emissions according to the National Inventory Reports of Denmark, England, Germany and the Netherlands. An important conclusion was that the used methodologies were not always comparable which implies that a sound comparison between the different pork production systems based on the respective NIRs is not possible.

In this study we use IPCC calculation rules and emission factors based on the Dutch NIR (which mainly uses IPCC methodology and default from guidelines tm 2004) and the most recent guidelines van IPCC (2006 en 2007). For some emissions the calculations are more detailed than the Dutch NIR, for instance:

- Nitrous oxide emissions related to nitrogen excretion on the pig farm
- Methane emissions due to manure storage
- Methane emissions due to loss of soil organic matter

In paragraph 2.6 and 2.7 we outline the used calculation rules and emission factors from IPCC and Dutch NIR compared to emissions factors used in German, English and Danish NIR's. The methodology is described in details in Annex 1 and 2.

2.1.3 Lifecycle Assessment

The IPCC (2006) gives guidelines on how to calculate greenhouse gas emissions of processes and activities, but do not give guidelines on how to attribute those emissions to a product. Lifecycle assessment (LCA) methodologies are developed to assess the contribution of a products lifecycle to environmental indicators, such as greenhouse gas emissions. Important questions for assessing the contribution of a product's lifecycle to greenhouse gas emissions are:

1. what is the scope and the functional unit of the study ?
2. which processes and activities need to be included in the system regarding the scope and functional unit?
3. how do we deal with multiple input and output processes (allocation)?
4. what data are appropriate regarding the scope of the study?

There are several life cycle assessment protocols, such as the ISO standards and guidelines for practitioners that give directions for how to solve these questions. Important life cycle assessment publications for our project are:

- The ILCD working draft on main guidance document for all applications and scope situations(European Platform on LCA, 2008)
- The ISO 14040 series
- The Dutch LCA guide (Guinee e.a., 2002)

We used these publications to define a coherent method for allocating greenhouse gas emissions to co-products and for setting system boundaries.

2.1.4 PAS2050

The PAS2050 (BSI 2008) is a recently published protocol for calculating greenhouse gas emissions due to the production of many products. However, it is not very specific for agricultural products. We consider the PAS2050 protocol at this moment and for this topic to be the best suitable basis on which we can build further specifications for several product categories, such as pork. The PAS2050 sets directions on how to deal with system boundaries, allocation, data quality and data acquisition. We have followed many of the PAS2050 directions in the methodology for agricultural products. However, further development for agricultural specifications were necessary.

2.1.5 Horticulture protocol

Recently a protocol for calculating the carbon footprint of horticulture (Blonk e.a., 2009a) has been developed. This protocol is the first refinement of the PAS 2050 for a (Dutch) agriculture production sector The horticulture protocol gives further specifications on calculating greenhouse gas emissions of arable crop products. The protocol involves:

- calculation rules for crop rotation schemes,
- delineation criteria for arable and animal farming with regard to manure application,
- allocation rules in case of coproduction and
- default data sets for specific products like fertilisers.

In this report we followed the directions of the horticulture protocol, especially for crop production, transport and allocation rules, unless it is not practical due to data limitations or significance considerations.

2.2 Functional unit

The functional unit of the carbon footprints (greenhouse gas emission lifecycle assessments) is usually kilogram carbon dioxide equivalents (CO_2eq) per kilogram or metric tonnes product. The most important greenhouse gasses in the pork production chain are carbon dioxide, methane and nitrous oxide. Other greenhouse gasses were not considered in this study. The IPCC 2006 guidelines GWP100 values (Global Warming Potential over a period of 100 years) were used, where 1 kg of emitted methane (CH_4) is equivalent to 25 kg CO_2eq and 1 kg of emitted nitrous oxide (N_2O) is equal to 298 kg CO_2eq

After pigs are slaughtered, the carcass is divided into many co-products. The number of co-products differ between slaughterhouses and there are many different uses of the co-products after they leave the slaughterhouse. Therefore, the functional unit was based on fresh meat cut of the pig that is not processed any further other than proportioning and packaging. The non fresh meat fraction consists of co-products from slaughtering that are not used as a (processed) meat product itself but are used as raw materials or ingredients in processed meat, food, feed and technical appliances. The greenhouse gas emissions from pork meat production is divided over fresh and non fresh meat based on the relative revenue of the products (economic allocation; see Section 2.3). For the production of fresh meat, carcasses from fattening pigs are the main input. Besides that producing fattening pigs involves the production of piglets by sows which on his turn gives a inevitable production of sows for slaughter. In this study we include the carcass production from slaughter sows in the carcass production from fattening pigs in a ratio which is based on the amount of sows needed to produce fattening pigs.

Different fresh meat parts of the pig or different meat qualities are not considered and all non-processed fresh meat is assumed to have the same value for the consumer. This is plausible when comparing different pig production systems, as far as there is no inherent difference between quality of organic and conventional meat. There might be some differences between meat quality that are partly related to differences in protein/fat ratios of the cut off fresh meat; here, such differences are not considered. So, the functional unit in this study is kg CO_2eq per tonne slaughtered fresh meat weight.

2.3 Production chain

The production chain of pork can be described in three parts (Figure 2.1). The first part consists of activities for the production of animal feed, such as crop growing, transport, processing of crop products, and mixing of (processed) crop products. The second part consists of pig husbandry activities, which includes transport of feed to the animal farm, the production of sows, piglets and slaughter pigs. The third part includes transport of slaughter pigs to the slaughter house, slaughtering, and processing until the meat leaves the gate of the slaughter house.

Conform the PAS2050 protocol, all greenhouse gas emission sources that are expected to contribute at least 1% to the processes or activities in Figure 2.1 are included in the lifecycle assessment. If the sum of the sources is expected to be less than 95%, also sources that contribute less than 1% are included so that the sum is at least 95%. In this study, based on experience from several other inventories (Blonk e.a, 2007a, Blonk e.a., 2008 en Blonk e.a., 2009a), the following sources are not included in the lifecycle assessment: production of capital goods (pig houses, machinery etc.), pesticides, transport and nutrition of employees.

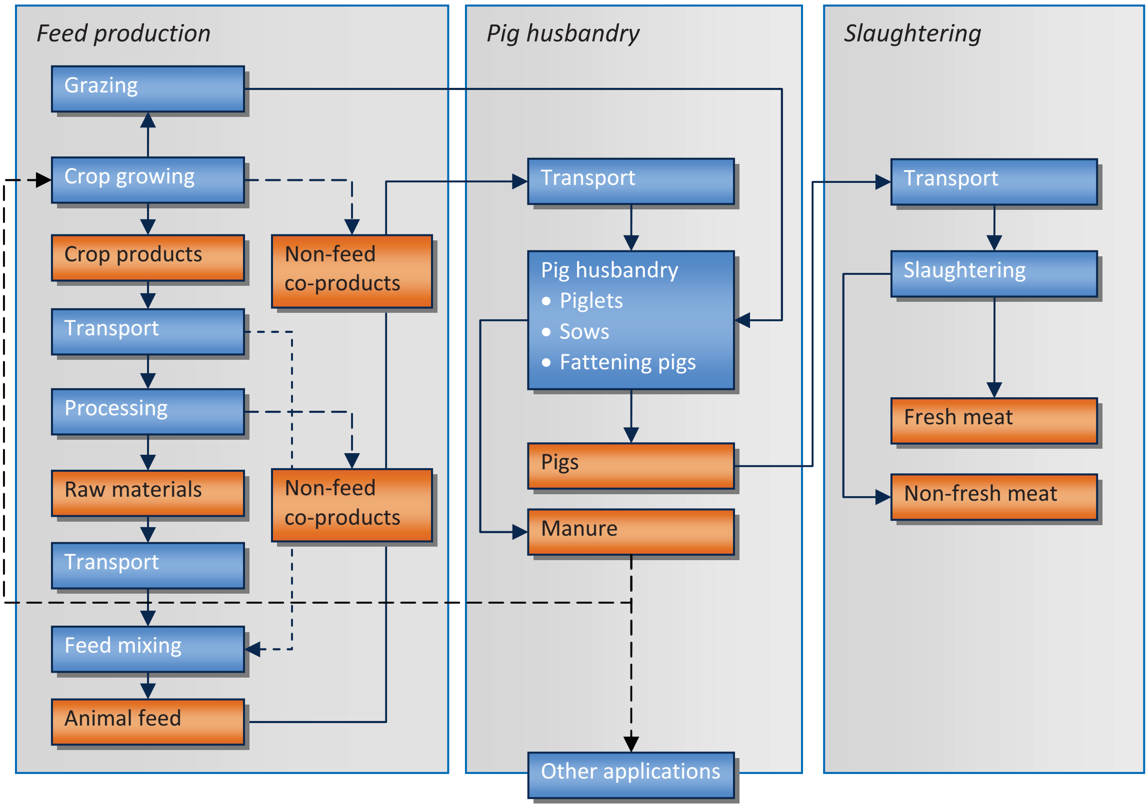

Figure 2.2 Overview of the pork production chain (the blue boxes are the most important processes and activities and the orange boxes are the products and important co-products in the production chain).

2.4 Allocation to co-products

Four different activities in the pork production chain result in co-production:

(1) crop growing (for example: straw, bagasse);
(2) processing of crop products (for example: oil and meal, wheat and maize milling products);
(3) pig husbandry (piglets, sows and fattening pigs for slaughter pigs and manure); and
(4) slaughtering (fresh meat and non fresh meat such as fats, meals, blood).

Because of the large number of co-production activities, the methods and data for allocation of greenhouse gas emissions to co-products has a large effect on the carbon footprint of pork.

Allocation in lifecycle assessments can be based on the mass (kg) of the co-products per unit area (hectare) in case of crop growing, per mass unit (kg) of the main ingoing product in case of processing, or per farm in case of animal husbandry. However, the mass does not always represent the (societal) value to produce a co-product. For example, crushing soybeans results in a small mass fraction of oil and a large meal fraction, while soybean oil has characteristics that are valuable for food and fuel production and meal is only used as feed for animal production. From a bio-fuel perspective, the energy content (combustion) of vegetable oil is the most important indicator for its value. However, the energy content is not the motivating characteristic for producing soybean meal. Therefore, the relative revenue of the co-products is often used in lifecycle assessments, where co-products have different uses, such as feed, food and fuel.

The use of relative revenues is referred to as economic allocation. The economic allocation fractions (the shares of upstream greenhouse gas emissions that are allocated to the co-products) are calculated by multiplying the mass of each co-product per production unit (area, mass or farm) by the value of the co-products as they are when leaving the production system (field, factory, farm), resulting in the co-products' revenues. The allocation fractions are the revenues divided by the sum of the revenues. Table 2.2 shows an example of how the economic allocation fractions of soybean oil and expeller can be calculated.

Table 2.2 Example of how the economic allocation fractions of soybean oil and expeller can be calculated.

		Oil	Expeller	Sum
Output	kg/kg input	0.175	0.800	0.975[a]
Mass allocation fraction	-	0.179	0.821	1.000
Price of co-products	US$/kg output	700	230	-
Revenue (price of co-products x output)	US$/kg input	122.5	184	306.5
Economic allocation fraction	-	0.400	0.600	1.000

[a] 0.025 kg water evaporates in the oil extraction process

However, in cases where the producer has to pay for the disposal of a co-product, the price co-product's price can be negative. In the Netherlands, Germany, Denmark and England, manure from conventional animal production has a negative value. Therefore, the greenhouse gas emissions from the use of manure in cropping systems should be allocated to the animal production system. Theoretically this is correct, but it does not take into account that manure has an intrinsic value due to the minerals that fertilize the plant. For nitrogen in manure, the part that is of value for the crop farmer is equal to the active nitrogen content: the efficiency of nitrogen uptake by the crop relative to the chemical fertilizer uptake efficiency (in the Netherlands referred to as the working coefficient).

Therefore, the emissions due to application are allocated to the cropping system equal to the active nitrogen content. The remaining emissions (equal to 1 minus the active nitrogen content) are allocated to the pig production system. For instance if the active nitrogen content of pig manure is 60%, 60% of the emissions due to application (dinitrous oxide emissions and emissions due to diesel used for transport and application) are allocated to the cropping system, 40% of those emissions are allocated to the pig production system. Although manure from organic animal production does not have any value in most northwest European countries, we use the same allocation method in the case of organic manure.

2.5 Uncertainty analysis

Carbon footprint lifecycle assessments are subject to many uncertainties because the input data originates from very different sources, some more reliable than others. Moreover, it is practically impossible to validate results of carbon footprint assessments with measured data, especially those of agricultural products. For example, nitrous oxide emissions in crop fields over the entire crop season (from sowing to harvest) are impossible to measure without disturbing the system. A common method for analysing the uncertainty of the results is the Monte Carlo simulation, named after the casino in Monaco.

A Monte Carlo simulation is done by repeating the calculations many times, for example 100,000, with random numbers for the input parameters within defined distributions. To keep it simple, a normal distribution can be assumed for each input parameter; so, only the averages and the standard deviations need to be known. If the standard deviation of a parameter cannot be derived from data, it was estimated.

This can be done by assuming the most probable range is equal to two times the standard deviation below and above the average value.

The results of each repetition can be analysed in distribution histograms, but in most cases the distribution is very similar to a normal distribution. So, the average and standard deviation of the repeated results are good indicators of the output uncertainty. The repeated results can also be used for comparing different carbon footprints; for example, between the carbon footprint of conventional and organic products or between the same products manufactured in different countries. The probability of whether the difference between two carbon footprints is positive (the first is higher than the second) can be expressed in percentage of the repetitions with a positive difference. This percentage can also be presented visually as a graph in which the share of results for the equation A – B is stated (see Figure 2.3). The surface below the graph left from the vertical axis represents the share of differences that are negative and right from the axis the share of differences that are positive. As an example in Figure 2.3 can be seen that the surface below the graph for the negative difference is much bigger (92.5%) than the positive surface (7.5%). This indicates that the probability of a negative difference is much bigger than a positive difference, meaning that the probability that result B is bigger than result A is much higher than the opposite.

The fraction of repeated differences between results of two products in a Monte Carlo simulation that need to be lower or higher than zero to determine whether a difference between two carbon footprints is "significant" is arbitrary. If all results are negative or positive, this is clearly significant. But what is 70% or 80% is positive? In this project, we drew the line at 90%. If the probability of a difference is above this limit, in this study this difference is stated as within the statistical certainty range (> 90%). Future research should make clear whether this threshold value could be changed.

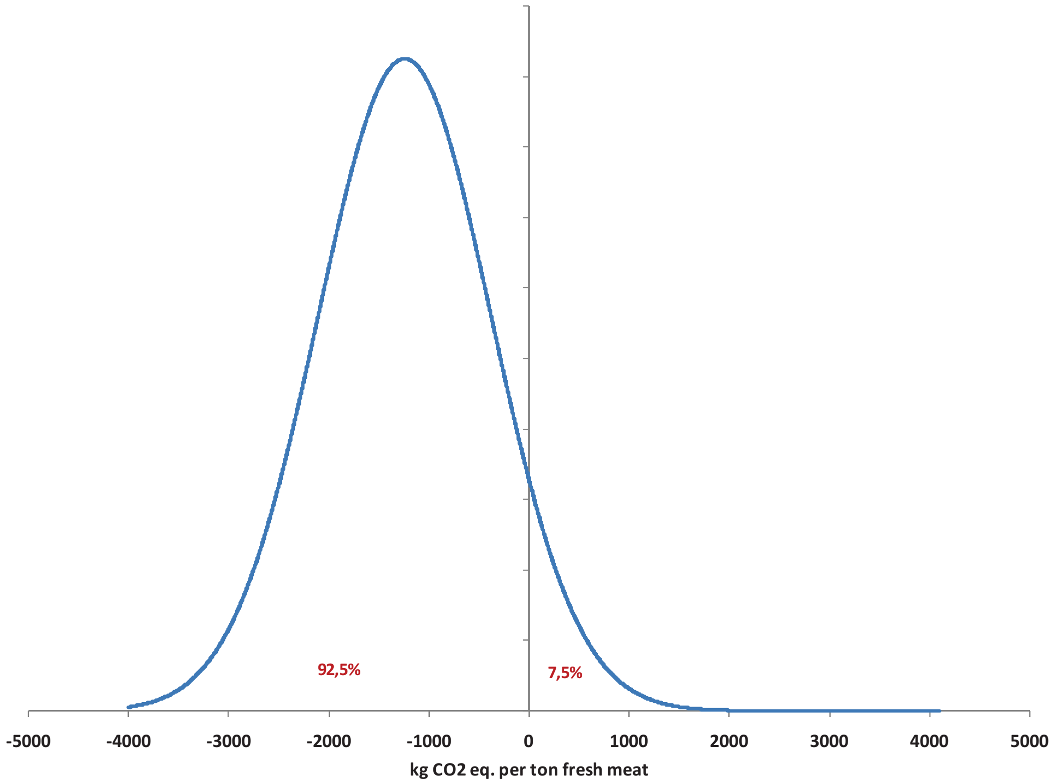

Figure 2.3 The partition of outcomes for the difference between two results (result A – result B), in red the portion of the surface below the graph which represents the share of 100.000 runs with a negative (left from vertical axes) and a positive (right from vertical axes) difference.

2.6 Calculation rules and emission factors for feed production

In this paragraph a brief description is given of calculation rules and emissions factors concerning feed production. Calculation rules and emission factors concerning transport and processing of feed ingredients are described in resp. paragraph 2.8 and 2.9. In Annex 1 a more detailed overview is given of values and references.

2.6.1 *Inputs used for cultivating crops*

The production of products used in crop growing like planting material, fertilizer and energy involves greenhouse gas emissions. For planting material, a fraction of the yield is assumed, where the carbon footprints of planting material is assumed equal to the carbon footprint of the marketed crop product. The assumed values (4 – 5%) are based on own estimates and KWIN (2007) values.

For most fertilizers, their production results in CO_2 emission. Production of CAN also results in a substantial amount of nitrous oxide emissions. Based on Kongshaug (1998), urea gives a CO_2 emission of 4.7 kg CO_2 per kg N, CAN gives N_2O and CO_2 emissions of 7.5 kg CO_2eq per kg N.

Emissions from electricity production are based on national estimates for the Netherlands (Groot & Vreede, 2008). For the other countries, national estimates are used based on OECD information (OECD 2007). For production, transport and combustion of diesel, gas and combustion oil, we use the same values as in horticulture proposal (Blonk e.a., 2009a)

Table 2.3 The emission factors for the use of products, energy and transport.

Sources	Emission factor	
	Unit	Value
CAN (Calcium Ammonium Nitrate) production and transport	kg CO_2eq/kg N	7.5[a]
Urea and other nitrogen fertiliser production and transport	kg CO_2eq/kg N	4.7[a]
Phosphorus (P_2O_5) production and use	kg CO_2eq/kg P2O5	0.6[a]
Potassium (K_2O) production and use	kg CO_2eq/kg K2O	0.4[a]
Diesel production and transport (including combustion)	kg CO_2eq/kg	3.51[b]
Electricity production and transport different countries	kg CO_2eq/kWh	0.339 – 0.514[c]
Natural gas production and transport (including combustion)	kg CO_2eq/m^3	1.99[d]
Transport by bulk carrier	kg CO_2eq/1000 km	6.3[d]
Transport by train	kg CO_2eq/1000 km	56[d]
Transport by boat	kg CO_2eq/1000 km	59[d]
Transport by truck	kg CO_2eq/1000 km	115[d]

[a] Kongshaug (1998), [b] Blonk e.a., (2008), [c] Groot & Vreede (2008), OECD (2007), [d] see Annex

2.6.2 *Crop growing*

Greenhouse gas emissions during crop growing are mainly nitrous oxide emissions from nitrogen sources, such as fertilizers, crop residues and biological nitrogen fixation. Part of these nitrous oxide emissions is direct emissions from the nitrogen sources and the other part is indirect emissions via ammonia emissions and nitrate leaching. Besides the use of peat soils that result in large volumes of greenhouse gas emissions, the carbon dioxide and nitrous oxide emissions from the use of Histosols are also considered. Emissions are calculated conform the basic IPCC calculation rule: the amount of nitrogen supplied multiplied by an emission factor.

Direct nitrous oxide emissions are calculated as the amount of nitrogen input multiplied by an emission factor. For crop growing we use the emissions factors in Table 2.4, conform the Dutch NIR (VROM 2009, protocol 4D, direct N_2O emissions). The nitrogen sources crop residues and biological nitrogen fixation are calculated based on the crop characteristics yield, yield-crop biomass ratio, crop residue fraction, nitrogen content and nitrogen fixation-uptake ratio. We use a nitrate leaching fraction of 0.30 kg NO_2-N/kg N, conform the IPCC 1996 and 2006 and the Dutch NIR (VROM 2009, protocol 4D, indirect N2O emissions). The fraction of N applied that is volatilized as ammonia depends on application method, type of fertilizer (liquid or solid manure, fertilizer) and region (climate and soil) (see Annex 1 for further details). The ammonia emission is based on available national references.

As explained in Paragraph 2.4, the application of manure and related emissions are allocated to the receiving crop by the fraction of active nitrogen in manure. The fraction active nitrogen in manure is calculated according to Dekker (2009) based on the fraction mineral nitrogen, the fraction of mineral nitrogen that is volatilized as ammonia and the fraction of Ne[1] that is available in the first year after application for uptake by the plant.

In the case that a crop results in more products, for example in the case of wheat or barley grain and straw production, the emissions from crop growing and former processes are allocated between the co-products based on economic shares.

For the Monte Carlo simulations, we assumed standard deviations of 25% of the above described emission factors for nitrous oxide emissions. For the ammonia emission and active nitrogen content in manure, we assumed standard deviations of respectively 25% and 10%.

Peat oxidation is only relevant in the case of growing oil palm in Malaysia for which we calculated the related N_2O and CO_2 emissions (see Annex 1, A1.3.2)

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[1] Ne is the fraction of organic N in manure that is mineralized in the first year after application

Table 2.4 The emission factors (with distinction between general and specific factors) for nitrous oxide and methane emissions from sources in crop growing and animal husbandry in this study compared to different NIR's. (Netherlands NIR 2009, VROM 2009, England NIR 2006 Choudrie e.a., 2008, Germany NIR 2006 , Strogies & Gniffke, 2008 , Denmark NIR 2008, Nielsen e.a, 2008).

Source	Unit	This study[a]	NIR Neth.	NIR Eng.	NIR Ger.	NIR Den.
Direct nitrous oxide						
General: Application of synthetic fertilizer	kgN-N_2O/kg N			0.0125	0.0125	0.0125
Specific: Ammonium fertiliser (no nitrate)	kgN-N_2O/kg N	0.005	0.005			
Specific: Other types of fertiliser	kgN-N_2O/kg N	0.01	0.01			
General:Application of animal manure	kgN-N_2O/kg N			0.0125	0.0125	0.0125
Specific: Manure, surface spreading	kgN-N_2O/kg N	0.01	0.01			
Specific: Manure, low-ammonia application	kgN-N_2O/kg N	0.02	0.02			
General: Animal manure excreted during grazing	kgN-N_2O/kg N			0.02	0.02	0.02
Specific: Faeces excreted during grazing	kgN-N_2O/kg N	0.01	0.01			
Specific: Urine excreted during grazing	kgN-N_2O/kg N	0.02	0.02			
Nitrogen fixation	kgN-N_2O/kg N	0.01	0.01	0.0125	0.0125	0.0125
Crop residues	kgN-N_2O/kg N	0.01	0.01	0.0125	0.0125	0.0125
Direct nitrous oxide	kgN-N_2O/kg N					
General: Solid manure management	kgN-N_2O/kg N		0.02	0.02	0.02	0.02
Specific: Solid manure stored in pig house	kgN-N_2O/kg N	0.02[b]				
General: Liquid manure management	kgN-N_2O/kg N		0.001	0.001	0.001	0.001
Specific: Liquid manure stored in pig house	kgN-N_2O/kg N	0.002[b]				
Specific: Solid and liquid manure stored in outside silo with cover	kgN-N_2O/kg N	0.005[b]				
Specific: Liquid manure stored in outside silo without cover	kgN-N_2O/kg N	0[b]				
Indirect nitrous oxide	kgN-N_2O/kg N					
Ammonia volatilization	kgN-N_2O/kg N	0.01	0.01	0.01	0.01	0.01
Nitrate leaching	kgN-N_2O/kg N	0.025	0.025	0.025	0.025	0.025
Nitrate leached	% of applied N	30%	30%	30%	30%	33%
Methane						
General: Manure management	kg CH_4/animal	n.a.[c]				
Specific: Sows including piglets	kg CH_4/animal		3.89	3	10	6.7
Specific: Fattening pigs	kg CH_4/animal		5.51	3	10	3.9
General: Enteric fermentation	kg CH_4/animal	1.5	1.5	1.5		
Specific: Sows including piglets	kg CH_4/animal				1.8	2.8
Specific: Fattening pigs	kg CH_4/animal				1.45	1.45

[a] emission factor for direct nitrous oxide emission relevant for mineral soils, for organic soils see Annex 1, [b]IPCC 2006, [c] Calculated based on VS excretion and MCF

2.6.3 Land use and land use change

Growing crops involves land use and land use change, which result in greenhouse gas emissions. The magnitude of these emissions can be substantial compared to other greenhouse gas emissions related to crop growing. However, methods and data for calculating the effects of land use and land use change are uncertain. Because of the uncertainty and the different order of magnitude, the emissions from land use and land use change are presented separate from the other emission sources.

In this study, three different effects on greenhouse gas emissions because of land use and land use change are considered:

- **Loss of soil organic matter (land use)**. Loss of soil organic matter occurs for a large period from the moment land conversion from nature to agriculture takes place. In this study, we assumed a constant yearly loss that results in 1650 kg CO_2eq per hectare in conventional cropping systems and 1100 kg CO_2eq per hectare in organic cropping systems (Blonk e.a., 2008)
- **Loss of sink function *(disc*ontinuing fossilization under natural ecosystems)**. Fossilization under natural ecosystems is stopped when converting nature to agriculture and this absence of carbon dioxide capture and long term storage is equal to an emission of 403 kg CO_2eq per hectare per year as an average for Europe (Nabuurs & Schelhaas, 2002). Due to lack of data, this value is also used for crop growing in other regions (which illustrates the uncertainty in these calculations).
- **Loss of natural biomass (deforestation/land conversion)**. Loss of natural biomass occurs when a natural ecosystem is converted to an agricultural system. The loss of biomass is based on trends in land conversion for separate countries (based on FAO information), which is allocated proportionally to crops with increasing area Ponsioen and Blonk, to be published).

2.7 Calculation rules and emission factors for pig production

Producing pigs in farms causes: a) methane emissions from manure management and enteric fermentation, b) nitrous oxide emission from manure management and manure application, and c) carbon dioxide emissions from energy use and transport. A detailed and complete description of methodology for calculating emissions from pig production is given in Annex 2.

For methane emission from manure management, we used the specific Tier 2 methodology, which calculates methane emissions based on manure and manure management characteristics. Concerning manure, the excretion of volatile solids is the determining factor. This excretion is calculated relative to feed characteristics, like energy intake and digestibility (see Annex 2). The manure management system determines which fraction of the potentially formed methane is being emitted. This methane conversion factor (MCF) is determined for each individual pork production system. For a separate pork production system more than one manure management system can be relevant. For instance the Dutch organic pork production involves manure storage inside the pig house in a pit, in a silo and also no manure storage at all for manure which is produced on the field by grazing sows. For each manure management system the MCF is calculated, taking into account the use of different manure management systems, average temperature, duration of storage, inoculation and coverage (for details see Annex 2). For each pork production system an average MCF can be calculated as the sum of the fractions of manure in a manure management system is multiplied with the specific MCF (Table 2.5). Annex 2 gives an overview of the MCF values for specific manure management systems in the different pork production systems.

Table 2.5 The average MCF calculated as the sum of the fractions of manure in a manure management system is multiplied with the specific MCF for organic and conventional pork production.

	Conventional Sows	Conventional Fattening pigs	Organic Sows	Organic Fattening pigs
Netherlands	10.6%	10.6%	8.0%	8.4%
England	14.5%	14.5%	1.0%	1.0%
Germany	10.2%	10.2%	9.6%	9.3%
Denmark	10.3%	10.3%	2.8%	7.8%

Manure management results in direct and indirect nitrous oxide emission. Both are calculated from the nitrogen excretion, which is calculated as a result from nitrogen intake and nitrogen retention in animal growth (see Annex 2). Indirect nitrous oxide emission originates from the ammonia volatilization from pig houses and manure storage. The ammonia emission from pig houses and manure storage are determined by Wageningen UR Livestock Research based on animal housing and manure management data (see Annex 2). For direct and indirect nitrous oxide emission the emission factors from the IPCC 2006 Guidelines are used (Table 2.4). These are more specified than emission factors used in the different NIR's.

Nitrous oxide emissions from manure application are calculated according the methodology used for crop production (the emission factors are presented in Table 2.4). An essential aspect is the allocation of emissions due to manure application. As earlier described in Section 2.4, emissions from manure application are allocated to the arable farmer equal to the active nitrogen content. The other part (1 – active nitrogen content) is allocated to the pig farmer. This method is also applied for manure that is applied on home grown feed crops.

Greenhouse gas emissions from energy used and transport on the pig farm are calculated according to the methodology and emission factors described for feed production (the emission factors are presented in Table 2.3).

2.8 Transport

Transport occurs in and between different parts of the pork production chain: transport of crops from the field to processing plant, feed ingredients to the feed manufacturer, feed to the pig farmer, manure from pig farm to arable farm, and animals to the slaughterhouse. Transport can take place in different ways: by ocean bulk carrier, by train, by inland waterways carriers and by road truck. The greenhouse gas emissions for the different ways of transport are derived from regression analysis between loading capacity, load factor, distance (including distance without load) and fuel use (Annex 1 and 2). Table 2.3 gives an overview of the greenhouse gas emissions per 1000 km for the different transport types, assuming a default value for loading capacity, load factor and fuel use.

2.9 Processing

Processing occurs in different parts of the pork production chain: feed ingredients production, feed manufacturing, and pig slaughtering. For processing, no specific calculation rules are used. The main issue for processing is the ratio between input and output (for instance input of live weight and output of pork) and economic allocation fraction for the different co-products. The emissions factors for energy carriers (natural gas, electricity and diesel) that are used for the processes are shown in Table 2.3.

3 System description

3.1 Feed production

The production of 1 tonne live pig weight requires between 2.6 and 3.8 tonne feed (88% dry matter)[2]. Feed can be compound concentrates, roughage, wet co-products, single crops and feed raw materials. In some biological systems, pigs graze in the field, which reduces the feed requirements. For growing feed crops, material and energy inputs are required. The main contributing sources of greenhouse gas emissions from feed crop growing are nitrogen in applied fertilizers and (in case of legume crops) nitrogen from biological nitrogen fixation. Furthermore, a certain amount of land is managed, which results in greenhouse gas emissions from organic matter mineralization and in some cases the land was converted from nature to agriculture. Feed crop production and land use/land conversion are activities that considerably contribute to the carbon footprint of pork.

The most important raw materials for pig concentrates are:

- cereal grains (wheat, barley, rye and triticale),
- maize and wheat milling co-products (maize gluten feed meal, wheat middlings, bread meal),
- oilseed meal and oil (rapeseed meal, palm kernel meal, soybean meal and oil, and sunflower seed meal),
- sugar milling co-products (molasses, beet pulp),
- tapioca (cassava meal),
- peas,
- animal products (animal fats, fish meal)

Tables 3.1 and 3.2 show the mass shares of each raw material group in conventional and organic pig concentrates, respectively, as assumed for the four countries. These shares are based on studies (Dalgaard e.a., 2006, Dalgaard 2007, Halberg e.a.) national statistics (Raamsdonk e.a., 2004), information from some feed producing companies (Tijssens, 2009 and Rossel, 2009), and information from Blonk Milieu Advies. The assumed Dutch concentrates compositions deviate the most from the other countries' compositions, where the shares of cereal grains are much smaller and the shares of co-products are much larger. Also, tapioca and animal fats are only used in conventional Dutch pig concentrates and peas are only used in Dutch organic pig concentrates. Unlike the other countries' compositions of organic concentrates, the Dutch organic concentrates does not contain animal products. In England, Germany and Denmark, part of the cereal grains were assumed to be grown in the same farm as the pig farm or very near to it. The assumed share of these grains are higher in organic concentrates and slightly higher in German and yet higher in English concentrates (Table 3.1 and 3.2). For the Monte Carlo simulations, we assumed coefficients of variation of 10% of the mass fraction (the fractions are corrected so that the sum is always equal to one). We assumed that the emissions from the other category is equal to the average of the other groups.

Table 3.3 shows the most important parameters for calculating the greenhouse gas emissions from crop production for conventional and organic pork concentrate feed production in the four countries. We assumed the yield of the organic crops was 30% lower than the conventional crops. For organic rapeseed and barley we assumed a 50% lower use of nitrogen compared to conventional due to a lower yield and more available nitrogen in the soil from N-fixation and crop residues from crops grown earlier in the

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[2] Range of Feed Conversion Rate is derived from the typical systems defined in this study, see also section 4.2.1 .

rotation. For wheat we assumed a 60% lower use of nitrogen compared to conventional because in organic systems mostly spring wheat is used with lower yields compared to winterwheat in conventional systems. For the input off nitrogen from N-fixation and crop residues in organic systems we assumed a figure of resp. 20 and 10 kg N/ha. This was incorporated in the model as an extra input.

Table 3.1 Mass share of each raw material group in conventional pig concentrates as assumed for the four countries.

Raw material group	Netherlands	England	Germany	Denmark
Cereal grains	40%	40%	45%	50%
Cereal grains (home grown)	0%	30%	25%	20%
Maize and wheat milling co-products	18%	0%	0%	0%
Oilseed meal and oil	24%	25%	26%	25%
Sugar milling co-products	5%	4%	3%	4%
Tapioca	10%	0%	0%	0%
Peas	0%	0%	0%	0%
Animal products (animal fat)	1.5%	0%	0%	0%
Other	2%	1%	1%	1%

Table 3.2 Mass share of each raw material group in organic pig concentrates[a] as assumed for the four countries.

Raw material group	Netherlands	England	Germany	Denmark
Cereal grains	50%	22.5%	32.5%	37.5%
Cereal grains (home grown)	0%	47.5%	42.5%	37.5%
Maize and wheat milling co-products	8%	0%	0%	0%
Oilseed meal and oil	23%	14%	14%	14%
Sugar milling co-products	3%	0%	0%	0%
Tapioca	0%	0%	0%	0%
Peas	13%	0%	0%	0%
Animal products (fishmeal)	0%	7.5%	7.5%	7.5%
Other	5%	4%	4%	4%

[a] Conform EU legislation in these organic feeds a maximum of 10% conventional feedstuffs is being applied. EU legislation prescribes a maximum of conventional feedstuffs in organic feeds on a complete ration bases of 10% till 31-12-2009, after that date this norm is reduced till 5% and after 2011 it is reduced till 0%.

In most cases, the nitrogen application rate contributes for about 50% of all greenhouse gas emission in cropping systems. Because of large differences between the yield and the nitrogen use and the types of fertiliser used, the greenhouse gas emissions from crop production can be very different for the crops.

Other important sources of greenhouse gas emissions in cropping systems are nitrogen from crop residues and biological nitrogen fixation. For most crops, the nitrogen in crop residues is between 25 and 50 kg N per hectare (based on estimates for crop dry matter content, yield/biomass ratio, crop residue/biomass ratio, and crop residue nitrogen mass fraction, which are partly from IPCC 2006). For oil palm, on the other hand, this is about 170 kg N per hectare (based on Schmidt 2008). Biological nitrogen fixation occurs in oil palm fields, because leguminous crops are planted to cover the fields in the first years before the canopies close. Averaged per year, this amounts to about 25 kg N per hectare. In soybean fields, about 100 to 150 kg N per hectare is fixed (based on Schmidt 2008). We assumed that this is higher in South America than in North America.

For most crops, we assumed that about 100 kWh electricity is used per hectare for various activities, such as irrigation, and 80 kg diesel per hectare for machinery and short distance transport of inputs and outputs, based on KWIN (2007). Only for cassava, sugarcane and oil palm, diesel use was assumed to be about 50 kg per hectare and (almost) no use of electricity.

Table 3.3 Crop yield and fertilizer use in crop production for conventional and organic pork concentrate feed production in the four countries. For organic rapeseed, barley and wheat an extra input of 30 kg N is assumed for crop residues and N-fixation due to the organic rotation.

		Yield conventional (t/ha)	Animal manure (kg N/ha)	Chemical fertilizer (kg N/ha)	Yield organic (t/ha)	Animal manure (kg N/ha)
Netherlands	Wheat	8.3	0	220	5.8	126
	Barley	6.0	150	0	4.2	71
	Beet	62	0	100	45	100
Germany	Wheat	7.5	0	200	5.2	114
	Barley	6.0	0	90	4.2	64
	Rapeseed	3.8	0	150	2.6	107
Denmark	Wheat	7.0	84	140	4.9	114
	Barley	5.1	84	30	3.5	64
	Rapeseed	3.3	0	150	2.3	107
England	Wheat	7.8	0	220	5.4	126
	Barley	5.8	0	100	4.1	71
	Rapeseed	3.2	0	150	2.2	107
France	Wheat	7.1	0	200	5.0	114
	Barley	6.3	0	90	4.4	64
	Rapeseed	3.3	0	150	2.3	107
	Peas	-	-	-	3.5	42
Thailand	Tapioca	18.3	0	65	-	-
Argentina	Soybean	2.6	0	0	-	-
Malaysia	Oil palm	19.4	0	106	-	-
Pakistan	Molasses	48	0	125	-	-

The use of peat land only applies to oil palm in Malaysia and Indonesia. We assumed that 25% of the oil palm was grown on peat land (based on estimates of Wetlands International).

Land conversion does not apply to European and North American crops, because no increase in agricultural area occurred in the recent past or can be expected in the near future. The most important crops concerning land conversion are oil palm in Malaysia and Indonesia and soybean in Argentina and Brazil. Table 3.4 shows the results of calculating greenhouse gas emission from land conversion using trend analysis with Faostat data between 1988 and 2007 (20 years).

Table 3.4 Results of calculating greenhouse gas emission from land conversion using trend analysis with Faostat data between 1988 and 2007 (20 years).

Result	Unit	Soybeans Argentina	Soybeans Brazil	Cassava Thailand	Oil palm Indonesia	Oil palm Malaysia
Sum of all trends	10^6 ha	241	1277	-115	348	45
Sum of negative trends	10^6 ha	-515	-459	-274	-226	-88
Sum of positive trends	10^6 ha	757	1736	158	575	134
Fraction from forest	ha/ha	32%	74%	-73%	61%	34%
Relative crop expansion	ha/ha	3.7%	3.0%	-2.7%	4.4%	3.3%
Forest biomass	tonne/ha	211	281	232	333	341
Emission factor	kg CO_2eq/kg biomass	1.77	1.77	1.77	1.77	1.77
GHG emission	tonne CO_2eq/ha	4.43	10.85	0.00	15.81	6.74
Emissions per ton product	tonne CO2eq/tonne	1.70	4.34	0.00	0.91	0.35

3.2 Animal production

This section gives a brief description of the different animal production systems studied. Annex 2 gives a more detailed overview of these systems. A starting point for the definition of pig farms in the calculations must be a representative farm for that specific country and sector (conventional or organic). So, the data in this report do not represent average farms, but typical farms for their country and sector. The definitions are based on Hoste & Puister (2009), InterPIG/LEI (2009) (both for conventional pig production), Hoste (2009b) (organic pig production in the Netherlands), Oosterkamp e.a., (2009) (for organic pig production in England, Germany and Denmark) and expert judgements from Vermeer (2009), Hoste (2009a) and Weismann (2009).

3.2.1 Typical pig farms in the Netherlands

Pig farming in the Netherlands is characterized by intensive farms with no arable land. Even the majority of organic pig farms do not have arable land. This means that feed production takes place outside the pig farm and manure is transported from the pig farm to arable farms. Most conventional farms use only concentrate feed. For describing a typical conventional pig farm, we use average values: 263 sows and 1733 finishing pigs on different sow and finishing pig farm. Conventional pig farming in the Netherlands is completely indoor. Housing in groups occurs in dry sows group housing. Lactating sows are kept in traditional farrowing crates. Piglets and fattening pigs are grown in groups, held on respectively fully and partially slatted floors. No straw is used; so, all manure is produced as liquid manure. By law, pig farms must take measurements to reduce ammonia emissions in pig houses. We assume the Dutch pig farms reduce the ammonia emission in accordance with this legislation. The main part of manure produced (75%) is stored in an outside covered silo ; the remaining 25% is stored in the pit below the pig house. Manure is stored for a period of six months during the autumn-winter season.

For organic pig farming we use average values: 143 sows and a finishing pig farm of 889 pigs. Organic pig farming in the Netherlands is partly indoor and partly outdoor. All pigs (lactating , dry sows, piglets and fattening pigs) have an outdoor run and an indoor pig house. Dry sows also have a paddock. For all pigs in the indoor part, straw is used as bedding material. A part of the manure is produced as solid manure (10-15%) that is stored outside. Solid manure is applied once a year so solid manure storage duration has a maximum of 1 year. The rest is liquid manure that is produced mainly on the outdoor run and ends up in the pit below the outdoor run. Storage of the liquid manure is partly in a pit below outdoor run (50%) and partly in an outside silo (50%). Liquid manure is stored for a maximum period of six months during autumn-winter season.

3.2.2 Typical pig farms in England

Conventional pig farming in England differs from Dutch pig farming, because arable land is present on farms and no measurements are taken for ammonia emission. The size of conventional pig farms (376 sows on sow farms and 1876 finishing pigs) do not differ much from Dutch farms. On conventional farms, pigs are kept completely indoor. Dry sows are housed in groups. Lactating sows are kept in traditional farrowing crate. Piglets and fattening pigs are grown in groups, held on fully slatted floors. No straw is used; so, all manure is produced as liquid manure. All manure storage is in the pit below the pig house. Manure is stored for a period of six months during autumn-winter season.

For organic pig farming we use average values for a sow farm of 150 sows and a finishing pig farm of 753 pigs. Organic pig farming in England is completely outdoor. All pigs (lactating, dry sows, piglets and fattening pigs) are held in outdoor shed on the paddock. In these sheds straw is used as bedding material.

The main part of the manure is directly spread on the paddock after excretion. Manure remaining in the outdoor hut is spread on the paddock.

3.2.3 Typical pig farms in Germany

Conventional pig farming in Germany is comparable with Dutch conventional pig farming. However, average German pig farm size is smaller: sow farm 170 sows and finishing pig farm 1241 pigs. It is completely indoor and dry sows are housed in groups. Lactating sows are kept in traditional farrowing crate. Piglets and fattening pigs are grown in groups, held on respectively fully and partially slatted floors. No straw is used; so, all manure is produced as liquid manure. Manure storage is mainly (75%) in an outside covered silo, the remaining 25% is stored in the pit below the pig house. Manure is stored for a max period of six months during autumn-winter season.

For organic pig farming we use average values for a sow farm of 47 sows and a finishing pig farm of 308 pigs. Organic pig farming in Germany is comparable with Dutch organic pig farming with the exception that the pigs do not have any access to paddocks. Only outdoor runs are used. For all pigs in the indoor part straw is used as bedding material. Part of the manure is produced as solid manure (10-15%) that is stored outside. Solid manure is applied once per year; so, solid manure storage duration has a maximum of one year. The rest is liquid manure, which is produced mainly on the outdoor run and ends up in the pit below the outdoor run. Storage of the liquid manure is partly in the pit below outdoor run (50%) and partly in an outside non-covered silo (50%). Liquid manure is stored for a period of six months during autumn-winter season.

3.2.4 Typical pig farms in Denmark

Conventional pig farming in Denmark is comparable with Dutch conventional pig farming, except for the presence of arable land on Danish pig farms. Due to legislation, pig farming is coupled to a certain amount of arable land on farm level. For conventional Danish pig farms, we use a sow farm with 338 sows and a pig farm with 2204 finishing pigs.

Danish conventional pig farming is completely indoor and dry sows are housed in groups. Lactating sows are kept in traditional farrowing crate. Piglets and fattening pigs are grown in groups, held on partially slatted floors. No straw is used. So, all manure is produced as liquid manure. Manure storage is mainly (75%) in an outside covered silo. The remaining 25% is stored in the pit below the pig house. Manure is stored for a period of maximally six months during autumn-winter season. Conventional pig farms do have land so manure is applied on own land.

For organic pig farming we use average values for a sow farm of 160 sows and a finishing pig farm of 832 pigs. Organic pig farming in Denmark is comparable with England organic pig farming, because in both countries sows are kept in outdoor huts on the paddock. Piglets and fattening pigs are kept indoor in combination with outdoor run. For all pigs in the indoor part, straw is used as bedding material. A part of the manure is produced as solid manure (10-15%) that is stored outside. Solid manure is applied once per year; so, solid manure storage duration has a maximum of one year. The rest is liquid manure, which is produced mainly on the outdoor run and ends up in the pit below the outdoor run. Storage of the liquid manure is partly in pit below outdoor run (50%) and partly in an outside silo(50%). Liquid manure is stored for a period of maximally six months during autumn-winter season.

3.2.5 Technical results

The technical results for the different systems are derived from Hoste and Puister (2009). An overview is given in Table 3.5 and Table 3.6.

Table 3.5 Technical results for conventional pig farming in the different cases, based on Hoste and Puister (2009), InterPIG/LEI (2009) and Hoste (2009a).

		Netherlands	England	Germany	Denmark
Feed intake sows	kg/aps[1]	1953	2483	2081	2466
piglets	#/aps	26.4	26.4	21.7	25.6
weight piglets	kg	25.4	35.4	30.1	30
price piglets	€/animal	45	60	51	44
sows for slaughter	kg LW[2]	92	93	87	124
price LW sows slaughter	€/kg	0.85	0.89	0.90	0.80
Feed intake fattening pigs	kg/app[3]	782	686	773	847
pigs per year	#	3.12	4.03	2.94	4.04
slaughter weight	kg LW	117	99	120	109
LW production	kg LW/app	364	398	353	438
price LW	€/kg LW	1.17	1.22	1.20	1.04
FCR per 1000 LW[4]		2.7	2.6	2.9	2.7
N excretion per 1000 kg growth [4]		43.0	42.2	50.6	46.6

[1] aps= average present sow (including piglets), [2] LW = live weight, [3] app= average present fattening pig, [4] 1000 kg LW or growth pig production (fattening pigs and sows for slaughter, see also paragraph 2.2)

Table 3.6 Technical results for organic pig farming in the different cases, based on Oosterkamp e.a., (2009) and Hoste, (2009b).

		Netherlands	England	Germany	Denmark
Feed intake sows[1]	kg/aps[2]	2498	2447	2210	2941
piglets	#/aps	19.9	17.5	15.8	21.2
weight piglets	kg	29	32	28.5	30
price piglets	€/animal	102	100	92	94
sows for slaughter	kg LW[3]	76	92	92	104
price LW sows slaughter	€/kg	0.85	0.89	0.90	0.80
Feed intake fattening pigs	kg/app[4]	784	894	808	815
pigs per year	#	2.88	3.72	2.38	3.71
slaughter weight	kg LW	115	100	117	104
LW production	kg LW/app	332	372	279	386
price LW	€/kg LW	2.34	2.22	2.32	1.91
FCR per 1000 LW[5]		3.3	3.5	3.8	3.3
N excretion per 1000 kg growth [5,6]		68.9	79.9	91.7	71.5

[1] for all cases including 183 kg DM fodder (Vermeer, 2009),[2] aps= average present sow (including piglets), [3] LW = live weight [4] app = average present fattening pig, [5] 1000 kg LW or growth pig production (fattening pigs and sows for slaughter, see also paragraph 2.2), [6] Includes N in manure from straw used as bedding

3.3 Slaughtering

At the slaughterhouse, pig carcasses are divided in many fractions. First, there is a wide range of meat products of which part is sold and packed as fresh meat products and part is processed further in meat products. Despite the great variety in meat products and product values, meat is considered as one category in this study. Besides the meat products, slaughter co-products are used in many applications. Table 3.7 presents an overview of the Dutch situation for average conventional pigs based on data from the largest pork producing slaughterhouse (VION) and processer (Sonac) in the Netherlands (Luske & Blonk, 2009). Many prices of meat products and slaughter co-products are not publically available.

Furthermore the prices of slaughter co-products at the slaughterhouse do not adequately represent the economic value. Therefore, we calculated prices from the prices of the main commodities produced from the slaughter co-products by correcting for the processing costs and the dry matter content of the end product related to the slaughter co-product used as an input. By doing this we consider slaughtering and producing commodities from the animal as one multi input output process. For the upgrading of slaughter co-products an extra energy input is required and needs to be taken into account as part of the energy use for slaughtering (Blonk & Luske, 2008, Luske & Blonk, 2009).

Table 3.7 Average mass and price balance for the Dutch production of fresh meat and other commodities from a conventional pig

Slaughter product → commodity	Mass distribution of conventional pig use in the Netherlands	Estimated commodity price Euro/kg	Turn over distribution based on estimated commodity prices
Fresh meat			
Fresh meat → fresh meat products and input for processed meat	55%	1.85	88.0%
Food grade & gelatine grade			
Food grade fat → edible fats	3%	0.500	1.4%
Food grade rind → gelatine	3%	1.000	2.4%
Food grade bones → gelatine, bone meal	11%	0.240	2.3%
Food grade organs & entrails → products for meat processing and food industry	4%	0.800	2.5%
Food grade blood → blood meal for food industry	2%	0.250	0.4%
Feed grade Cat 3. by products			
Cat. 3 organs & entrails	4%	0.400	1.2%
Cat. 3 large intestine and other parts → flesh meal	5%	0.140	0.6%
Cat. 3 bones → bone meal	3%	0.240	0.6%
Cat. 3 head → fresh meal	2%	0.100	0.1%
Cat. 3 fat → fats for feed	1%	0.250	0.3%
Cat. 3 blood → blood meal for feed and fertilizer	2%	0.080	0.2%
Cat. 3 hair → fertilizer	1%	0.060	0.0%
Energy use Cat. 2 en 1			
Cat 2/1 → Electricity production	5%	0.000	0.0%

Table 3.7 shows that 88% of the carbon footprint of the upstream greenhouse gas emissions and the energy use of slaughtering and upgrading slaughter co-products is allocated to fresh meat production. The input/output balance is 1/0.55 = 1.82 which means that 0.88*1.82 = 1.6 times the live weight production of pigs is needed for the calculation of the carbon footprint of one kg of fresh meat.

To come to an estimation for organic production and for the other countries, three assumptions are made. First it is assumed that the division between fresh meat products and slaughter co-products is linear to the carcass weight. Then the carcass weight from live weight is calculated using the following formula (KWIN veehouderij, 2007), assuming that this formula is also correct for organic pigs and the pigs in other countries.

Carcass weight [kg] = (1.5075/0.005)-((√(2.2726-0.01*Live weight [kg]))/0.005)

Table 3.8 shows that by doing this the fresh meat part of a pig becomes slightly higher when the live weight increases.

Table 3.8 Live weight at slaughter and the share of fresh meat.

	live weight at slaughter	Fresh meat as % of live weight
Netherlands conventional	116.8	55.7%
Netherlands organic	115.2	55.5%
Denmark conventional	108.5	54.9%
Denmark organic	104.1	54.4%
Germany conventional	120.0	56.0%
Germany organic	117.1	55.7%
England conventional	98.8	53.9%
England organic	100.0	54.1%

Second, we assumed that for slaughtering and upgrading of slaughter co-products of conventional pigs the Dutch situation of value creation by upgrading slaughter by products is also realized in other countries.

Third, we also assumed that for slaughtering and upgrading of slaughter co-products of organic pigs the Dutch situation of value creation by upgrading slaughter by products is realized in other countries. In the Netherlands specific organic outlets are created for a part of the slaughter by-products which is favourable in relation to economic allocation because of the relatively high prize of organic fresh meat. We obtained price information of VION De Groene Weg (Leijen, 2009). When no added value is realized on the organic slaughter co-products, a higher proportion of the carbon footprint is allocated to organic fresh meat. This might be the case in Denmark, England and Germany. Table 3.9 shows the final results of the slaughter process mass ratio between input of live weight and output of fresh meat and the economic allocation fraction.

Table 3.9 The Input/output ration and economic allocation factor for pork at the slaughterhouse.

	Conventional Input/output	Conventional Allocation fraction	Organic Input/output	Organic Allocation fraction
Netherlands	1.82	88.0%	1.80	89.3%
England	1.82	87.9%	1.84	88.9%
Germany	1.79	88.4%	1.79	89.4%
Denmark	1.85	87.5%	1.85	88.8%

3.4 Transport

Transport occurs in and between the different stages of the pork production chain. After harvest the crop is transported directly to a processing plant or a collection centre. Feed ingredients are transported to the feed processing plants and after processing, the feed is transported to the pig farm. If piglets are raised on a farm that is separate from the fattening pig farm, live piglets are transported. In some cases, manure is transported from the pig farm to a crop farm. Finally, pigs are transported to the slaughterhouse .

Data about transport are mainly assumptions that are based on distances between countries and private information from the industry (for example, average distance between producer and farmer, loading fraction, type of transport, number of animals per truck). For cereal grains, a distinction is made between grains grown at the pig farm ('home grown'), grains grown outside the pig farm, but in the same country, and imported grains.

Transport of fresh meat from slaughterhouse to retail is not included in this study but in the sensitivity analyzes the extra emissions due to this transport are given if meat is transported to retail in the Netherlands from the different countries.

4 Results and discussion

The first section (4.1) of this chapter presents the general results of the carbon footprint assessments for typical conventional and organic pork that is produced in Denmark, Germany, England and the Netherlands. The general results consists of the emissions from sources as described in previous chapters. The emissions due to land use and land use change are presented separately. The general results are presented in the first section in four parts: 1) the carbon footprints of conventional pork, 2) the carbon footprints of organic pork, 3) the carbon footprints of conventional and organic pork compared, and 4) the contribution of the important sources of greenhouse gas emissions to the carbon footprints. In the last part of this section, the emissions due to land use and land use change are presented. The second section (4.2) explains the general results in detail, starting with animal feed, manure management, nitrogen excretion, energy use in the pig farm, and ending with typical aspects of the carbon footprint of organic pork. Section 4.3 presents the results of the sensitivity analysis.

4.1 Total carbon footprint of pork

4.1.1 Conventional pork

The carbon footprints of conventional pork from Denmark, Germany, the Netherlands and England are between 3.5 and 3.7 kg CO_2eq per kg pork (Figure 4.1 and Table 4.1). Pork from typical conventional systems in Denmark and England has the lowest and pork from typical conventional systems in Germany the highest carbon footprint. The differences between the production systems for pork are relatively small and uncertain. The probability of whether the difference between the carbon footprints for conventional pork production in two countries is positive or negative (calculated as the difference between the means in Table 4.1) is between 51% and 63% for all possible comparisons. This percentage expresses the share of 100,000 repetitions in the Monte Carlo simulations with comparable (positive or negative) difference. For instance, the difference between the mean results for pork from England and Germany is 0.2 kg CO_2eq/ton (3.5 minus 3.7). From the 100,000 repetitions in the Monte Carlo simulations, 54% gives a negative difference (meaning the German carbon footprint for pork is higher than the English pork) and 46% a positive difference. The probability of these differences that are presented in Figure 4.2 shows that the peaks of all graphs are very close to the vertical axis, which means that negative and positive differences between conventional pork production in the four northwest European countries have a comparable and low probability (far below the certainty limit of 90%, see Section 2.5) of being a certain difference. This is also indicated by the overlap of error bars in Figure 4.1, which indicates the standard deviation in the results.

Table 4.1 Carbon footprint in kg CO_2eq per kg fresh meat at the slaughterhouse, for conventional and organic produced pork (standard deviations from Monte Carlo simulations between parenthesis)

	Conventional	Organic
Netherlands	3.6 (±0.4)	4.3 (±0.4)
England	3.5 (±0.4)	4.4 (±0.4)
Germany	3.7 (±0.4)	5.0 (±0.5)
Denmark	3.5 (±0.4)	4.0 (±0.4)

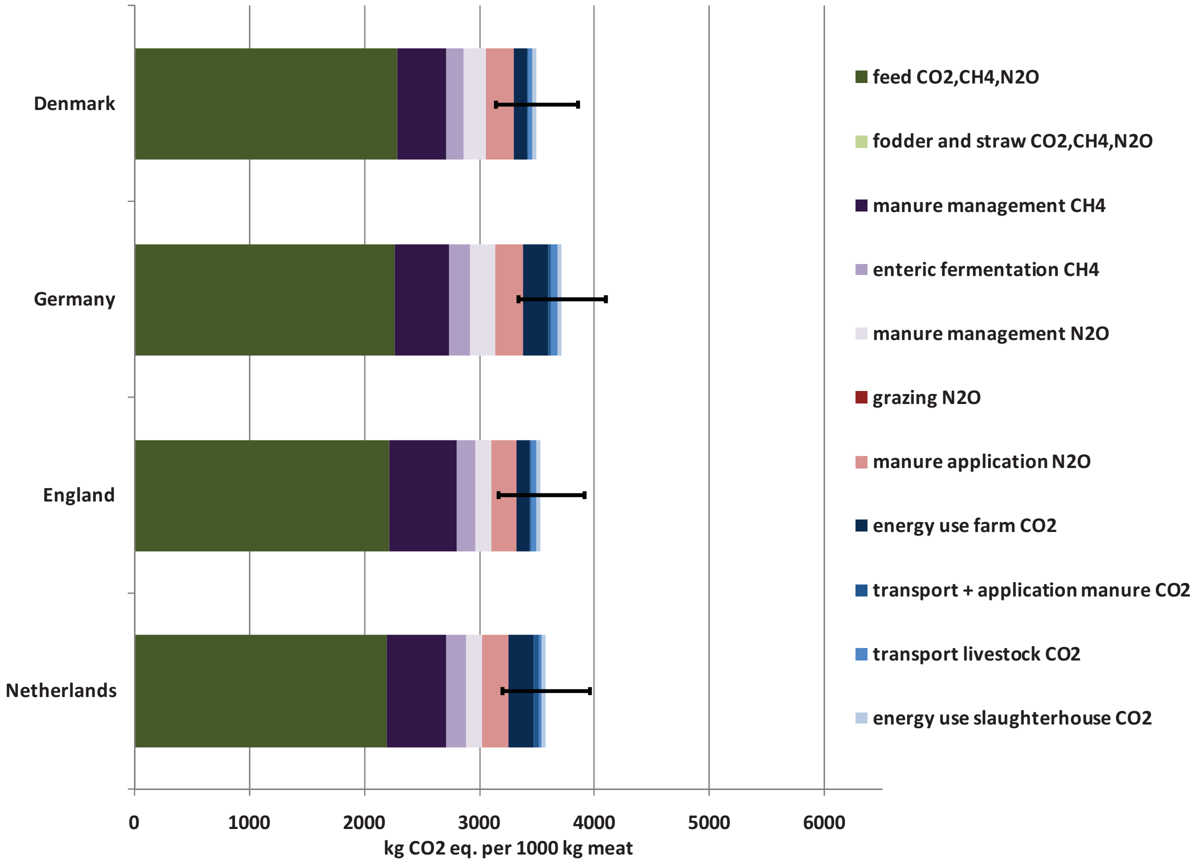

Figure 4.1 Carbon footprint of 1000 kg conventional pork (fresh meat at slaughterhouse).

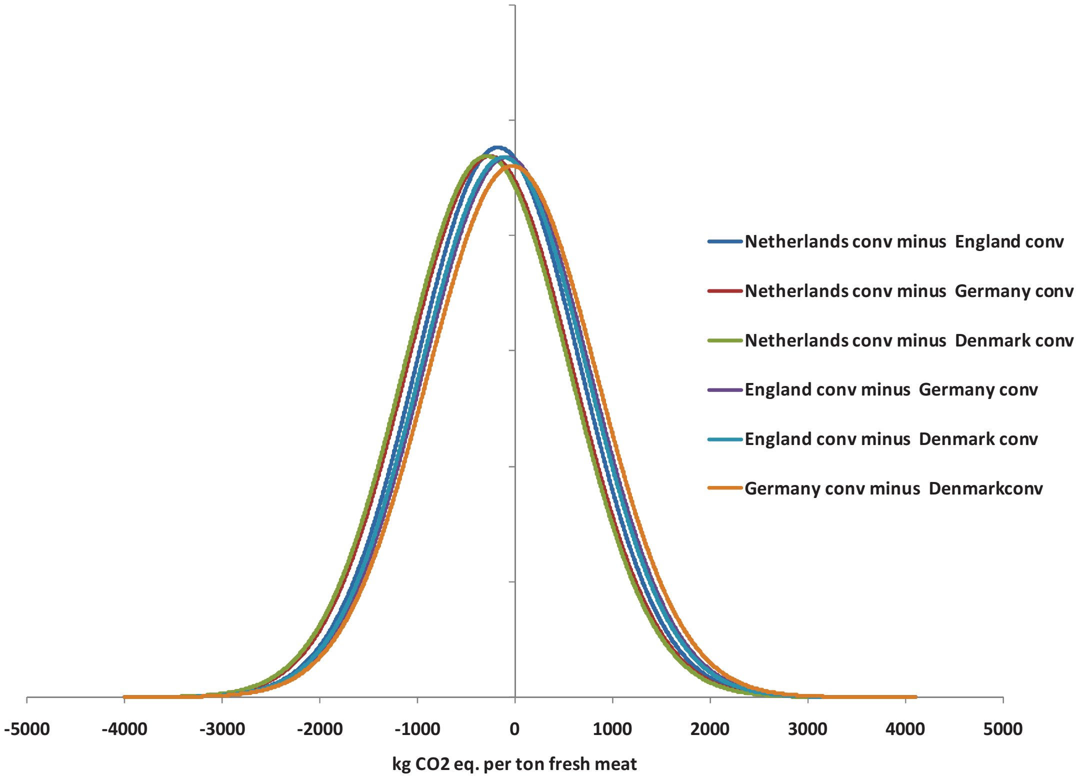

Figure 4.2 The partition of outcomes for the difference between the carbon footprint for conventional pork in different countries (conv = conventional pork production).

4.1.2 Organic pork

The carbon footprints of organic pork are between 4.0 and 5.0 kg CO_2eq per kg pork (Figure 4.3 and Table 4.1). Similar to the results with conventional pork, the carbon footprints of organic pork from Denmark was the lowest and from Germany was the highest. There are larger and more certain differences between the carbon footprints of pork from typical organic systems in the four countries than in case of pork from typical conventional systems. From the 100,000 repetitions in the Monte Carlo simulations, 85% (orange line on the rightmost side in Figure 4.4) give a positive difference between German and Danish organic pork (meaning German organic pork has a higher carbon footprint than Danish organic pork). This share is below the statistical certainty range (> 90%) that was assumed in this study, but still high enough to be marked as fairly certain. Compared to Dutch and English organic pork, German organic pork also has a higher carbon footprint, but with a lower frequency in the Monte Carlo simulations (respectively 72% and 73%, respectively the red and purple lines on the leftmost side in Figure 4.4).

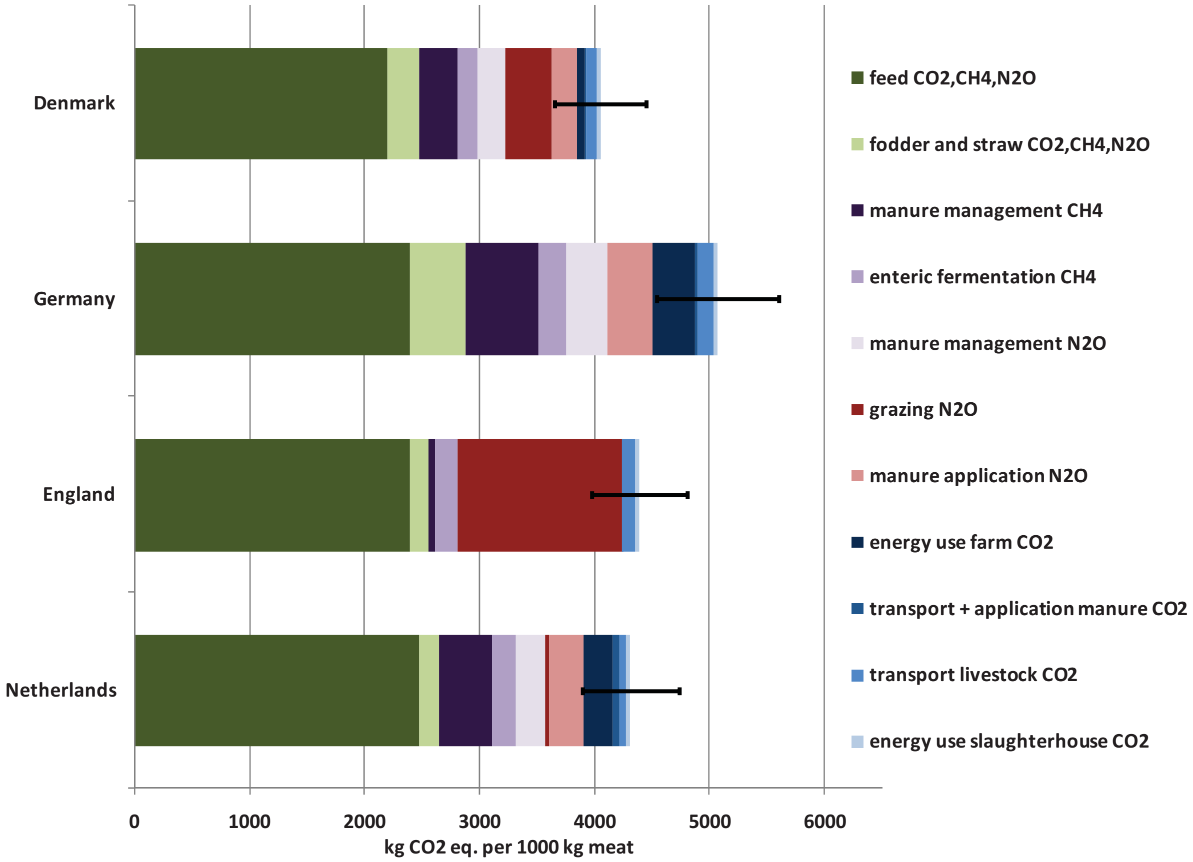

Figure 4.3 Carbon footprint of 1000 kg organic pork (fresh meat at slaughterhouse).

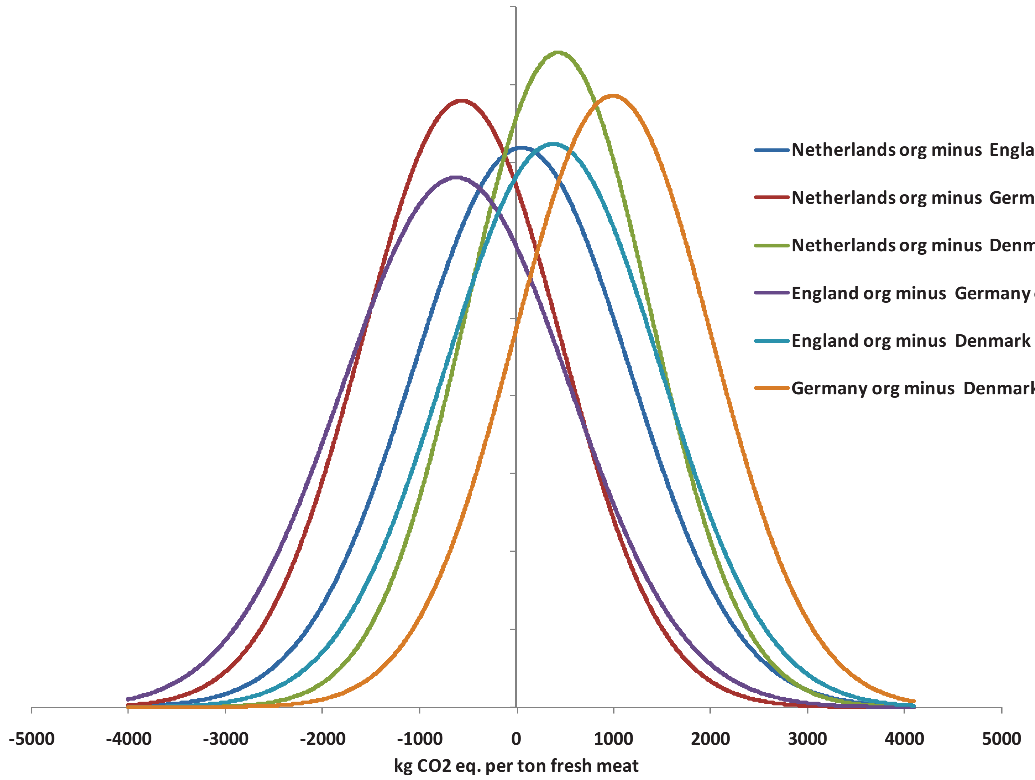

Figure 4.4 The partition of outcomes for the difference between the carbon footprint for organic pork in different countries (org = organic pork production).

4.1.3 Conventional and organic production compared

For the four countries, the carbon footprints of organic pork is higher than the conventional pork (Figure 4.5 and Table 4.1). The difference between organic and conventional pork production is within the statistical certainty range (> 90%) for the Netherlands and Germany (respectively 92% and 94%, Figure 4.6). For England and Denmark, these differences are lower than this range with respectively 83% and 72% . The main reason for the higher carbon footprint of organic pork compared to conventional pork is the higher use of feed per kg pork produced. This is explained more in detail in Paragraph 4.2.1.

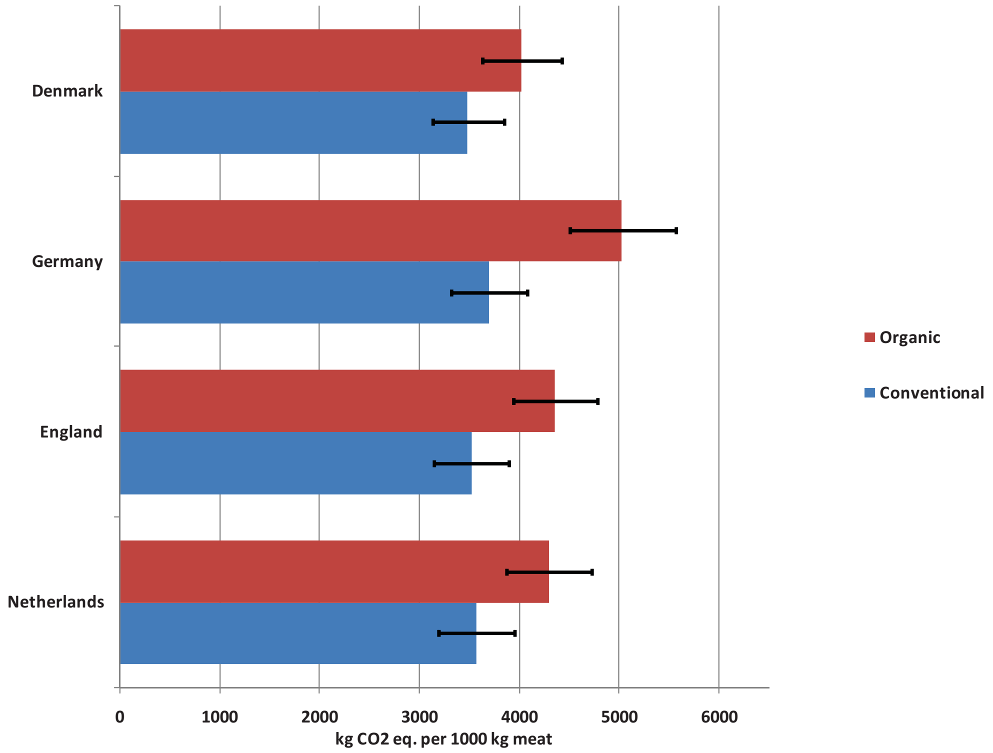

Figure 4.5 Carbon footprint of 1000 kg organic and conventional pork (fresh meat at slaughterhouse) compared.

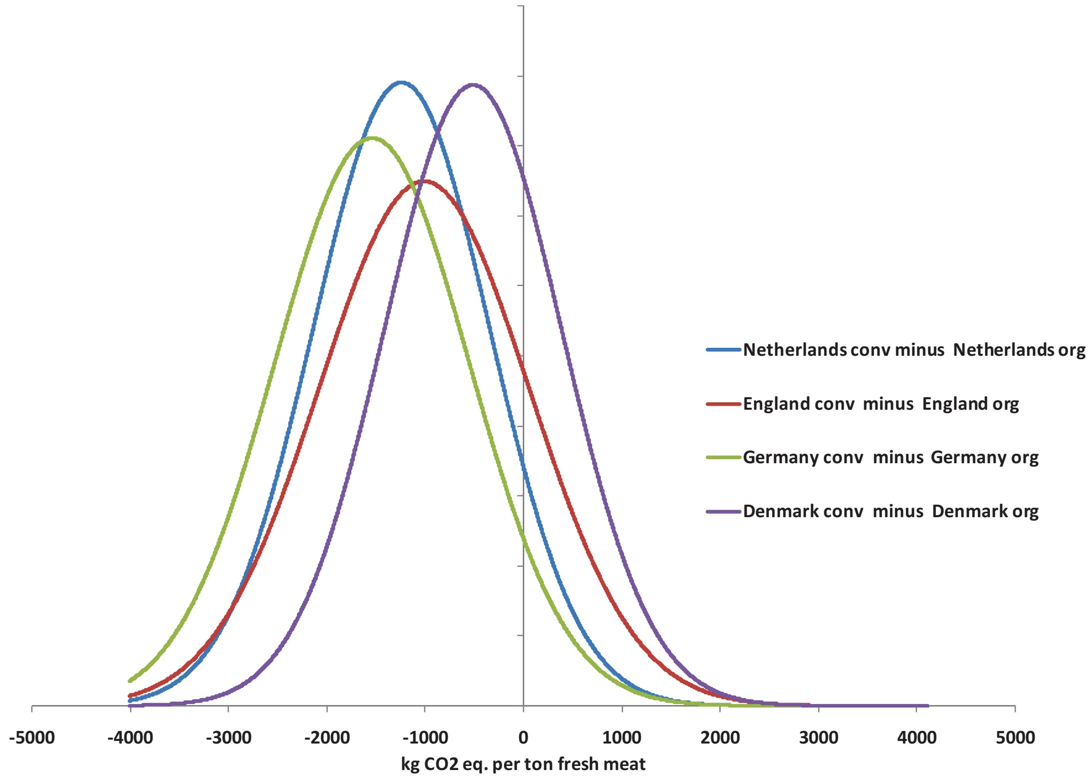

Figure 4.6 The partition of outcomes for the difference between the carbon footprint for conventional and organic pork in the same country (org = organic pork production, conv = conventional; production).

4.1.4 Sources of greenhouse gas emissions

Production of feed (crop growing, transport of crop products, processing crop products, transport of raw materials and feed mixing) is by far the most important source of greenhouse gas emissions in the carbon footprint of pork. Feed production contributes between 61% to 66% for conventional pork production and between 48% to 58% for organic pork production. Figure 4.7 shows the shares in the cases of typical Dutch organic and conventional pork. For conventional production, the second most important source is methane emissions from manure storage with a share that varies between 12% and 17% of total emissions.

With a larger share of grazing in organic production, this can be the second most important source of greenhouse gas emissions in the carbon footprint of organic pork. The share of grazing ranges from only the sows in Denmark to all pigs; and sows, piglets and fattening pigs in England. With these differences in rate of grazing, the share of emissions from grazing ranges from 10 to 33% (Figure 4.8). A higher share of grazing and related emissions results in lower greenhouse gas emissions from manure management (CH_4 and N_2O) and manure application.

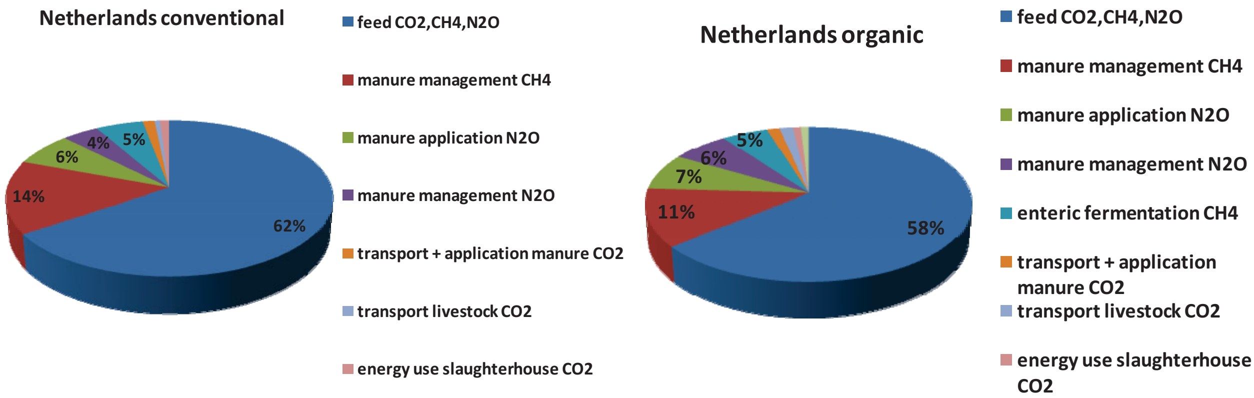

Figure 4.7 The contribution of different sources to the carbon footprint of 1000 kg Dutch conventional and organic pork (fresh meat at slaughterhouse).

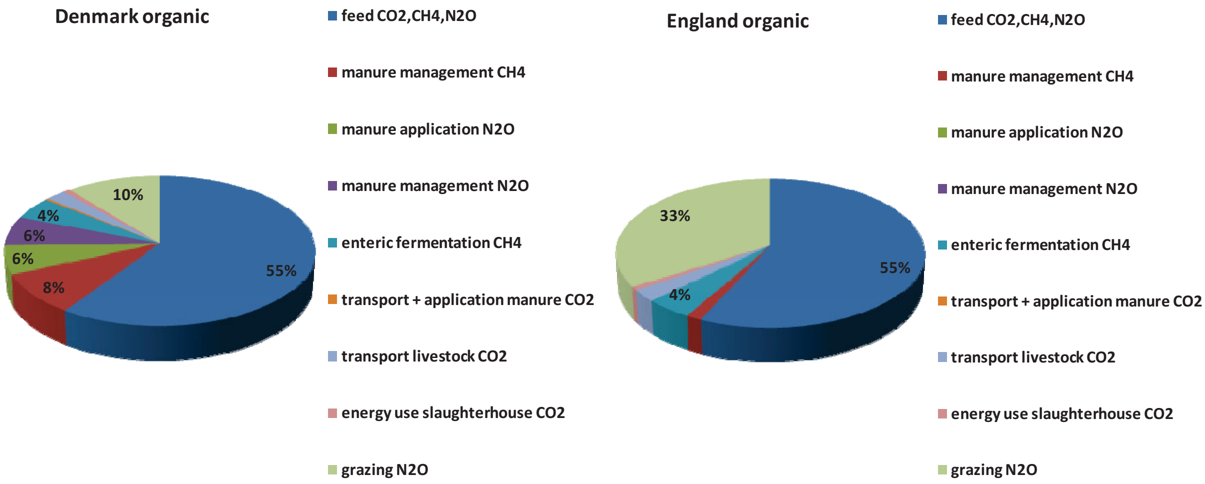

Figure 4.8 The contribution of different sources to the carbon footprint of 1000 kg Danish and English organic pork (fresh meat at slaughterhouse).

The carbon footprint of pork production can be divided into four different stages of the production chain: (1) feed production (growing crops, processing and transport feed ingredients); (2) husbandry of piglets and sows; (3) husbandry of fattening pigs; and (4) the slaughterhouse. In this division, the importance of feed production is also comprehensive. For conventional pork, the emissions from crop growing is about 50%, except for Dutch pork where this share is 41% (Figure 4.9). The relatively low share for feed production in the Netherlands is because of the higher amount of co-products that are used in the feed. That is also the reason for the relatively high share of feed transport (12%). Feed ingredients in Dutch pig feed that have a relative high share of emission from transport are, for instance, tapioca, palm kernel meal and beet pulp. The share of emissions from crop product processing and transport is in general between 5% and 10%. Emissions on farm level contribute for 9-13% and 22-27% for sows (including piglets) and fattening pig production, respectively. The contribution of the emissions from transport of manure and livestock leaving the farm and energy use at the slaughterhouse are negligible with about 1%. The contribution of fattening pig production is 22% in Denmark and England and 26%-27% in the Netherlands and Germany. This difference is because of the lower weight at slaughter for Danish and English pork. A relatively lower weight at slaughter requires relative more sows per kg slaughtered fattening pig.

The contribution of the different production stages for organic pork is comparable with the conventional pork production (Figure 4.10), except the slightly higher contribution of piglet production (14-17%). The German organic pork has a relatively high share for fattening pig production of 32% compared to 24% - 28% for the other countries.

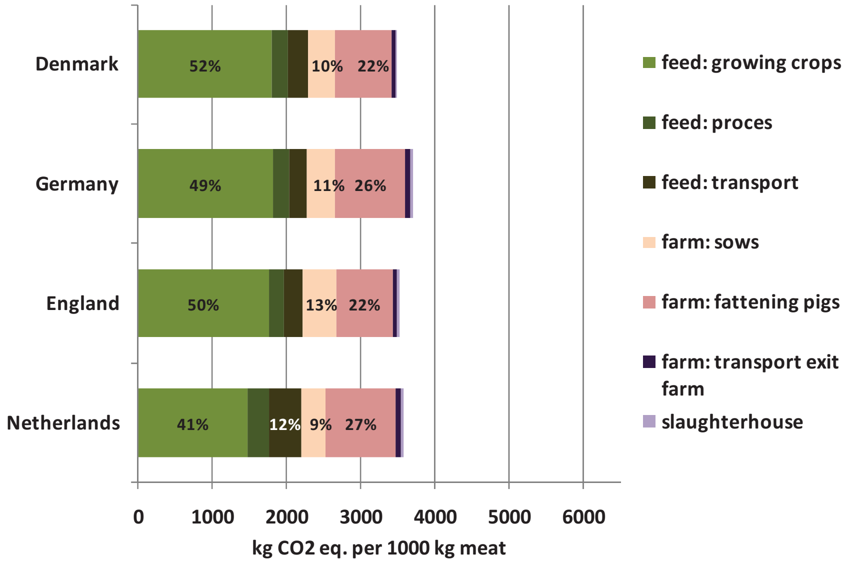

Figure 4.9 Carbon footprint of 1000 kg conventional pork (fresh meat at slaughterhouse) divided by the different stages of pork production.

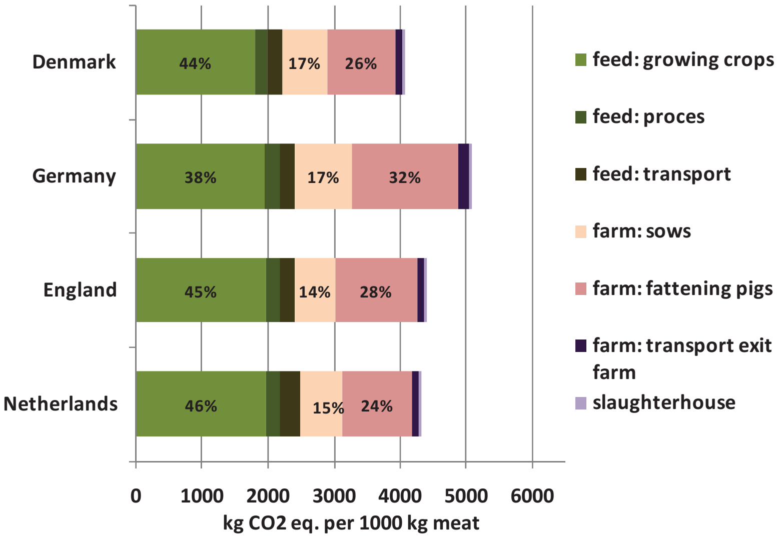

Figure 4.10 Carbon footprint of 1000 kg organic pork (fresh meat at slaughterhouse) divided by the different stages of pork production.

4.1.5 Land use and land use change

The greenhouse gas emissions from land use and land use change (LULUC) are about 50% compared to the carbon footprint as described before (expressed as the purple bars in Figure 4.11 and 4.12 compared to the carbon footprint due to feed use and other main sources without LULUC). The carbon footprint that only includes emissions sources from loss of soil organic matter, loss of carbon sink function and land use change is comparable to the contribution of feed production to the carbon footprint that includes all emissions sources except for LULUC related sources. For conventional pork, the size of the LULUC related carbon footprint is between 80% and 86% of the carbon footprint of feed production and use. For organic, this is even higher with 82% - 95%. So, this means that if LULUC sources would be included in the carbon footprint, the contribution of feed would be almost double.

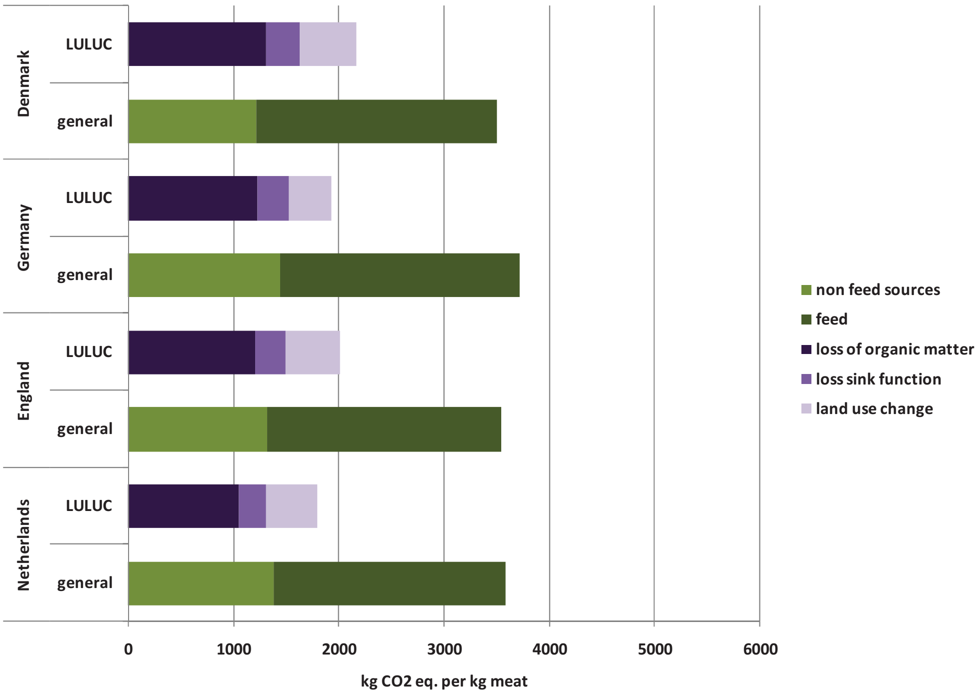

Figure 4.11 Carbon footprint of 1000 kg conventional pork (fresh meat at slaughterhouse) from general sources compared to emissions from Land Use and Land Use Change (LULUC).

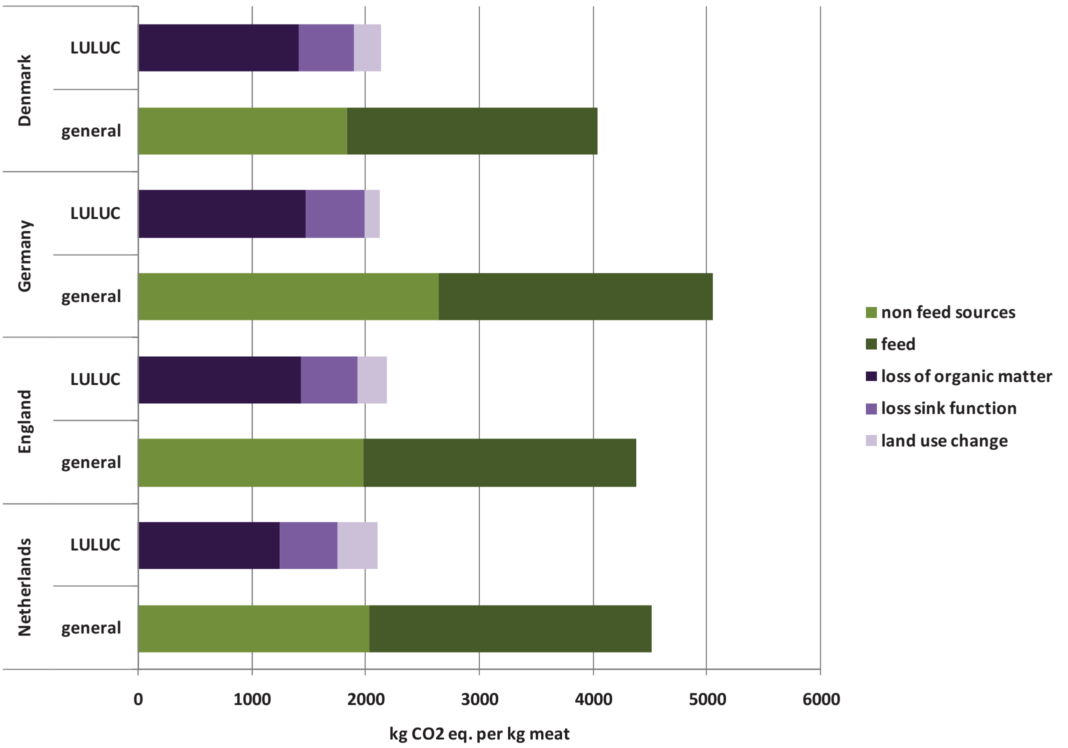

Figure 4.12 Carbon footprint of 1000 kg organic pork (fresh meat at slaughterhouse) from general sources compared to emissions from Land Use and Land Use Change (LULUC).

4.2 Results explained

4.2.1 Animal feed

The differences in greenhouse gas emissions from feed use between cases can be explained by differences in production, processing and transport of feed ingredients, feed composition and feed use per kg pork produced. The carbon footprint of conventional feed used to produce conventional pork in the different countries is about 500 kg CO_2eq per ton feed (Figure 4.13 and Table 4.2). Organically produced feeds have lower carbon footprints compared to conventional feeds. This difference has a high certainty (90% for the Netherlands and more than 99% for the other countries).

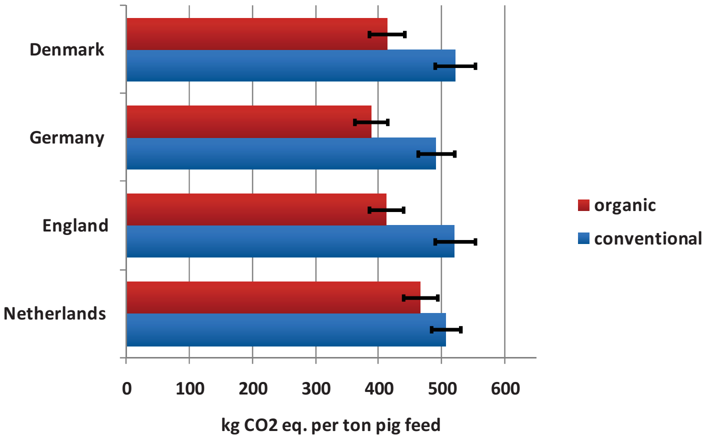

Figure 4.13 Carbon footprint for conventional and organic pig feed (kg CO_2eq per ton feed) used to produce pork in the different countries.

Table 4.2 Carbon footprint (kg CO_2eq per ton pig feed) of conventional and organic pig feed in different countries used (standard deviations between parenthesis)

	Conventional (kg CO_2eq/ton)	Organic (kg CO_2eq/ton)
Netherlands	505 (± 23)	465 (± 27)
England	520 (± 31)	412 (± 27)
Germany	491 (± 29)	388 (± 26)
Denmark	521 (± 32)	413 (± 28)

Annex 1 gives details for the carbon footprint per feedstuff and contribution of different feedstuffs in the carbon footprint of the different feeds. The feed used per kg produced pork varies between the different cases. For conventional pork in England, 2.6 kg is used to produce 1 kg of pork, in Germany this is 2.9 kg (Table 4.3). This difference can be explained by a difference in efficiency of pork production. Also, characteristics of pork production in different countries, like the weight at slaughter, influences the use of feed per kg live weight produced. For instance, fattening pigs are slaughtered in England at a relative low weight of 99 kg. In Germany, the slaughter pigs are older and heavier with 120 kg. This higher slaughter weight gives relatively higher feed conversion rates because the growth between 99 and 120 kg require more feed than the stage up to 99 kg.

Table 4.3 The feed conversion factor (kg feed per 1000 kg live weight pork)

	Conventional (kg CO_2eq/ton)	Organic (kg CO_2eq/ton)
Netherlands	2.7	3.3
England	2.6	3.5
Germany	2.9	3.8
Denmark	2.7	3.3

Producing organic pork requires between 20% (for The Netherlands and Denmark) and 30% (Germany and England) more feed per kg pork. This accounts for the largest share in the carbon footprint of organic pork compared to that of conventional pork.

4.2.2 Methane from manure management

As shown in Figure 4.1 and 4.2, methane emissions per 1000 kg pork differ between the cases. Table 4.4 shows the differences in the contribution of methane emissions from manure management. The variation in methane emissions from manure management originates from differences in feed composition and manure management system (length of storage, temperature and inoculation).

Table 4.4 The methane emission from manure management (kg CH_4 per 1000 kg live weight)

	Conventional Sows (kg CH_4/1000 kg)	Conventional Fattening pigs (kg CH_4/1000 kg)	Organic Sows (kg CH_4/1000 kg)	Organic Fattening pigs (kg CH_4/1000 kg)
Netherlands	73	243	94	197
England	132	228	15	24
Germany	103	273	129	278
Denmark	87	181	41	168

Feed composition determines the excretion of organic matter (volatile solids, VS) in manure. Table 4.5 gives an overview of the amount of organic matter produced from feed[3] in manure per average present animal.

Table 4.5 The excretion of organic matter (volatile solids, VS) per average present sow or fattening pig (kg VS per average present animal per year) for organic and conventional pork production

	Conventional Sows (kg VS/apa/y)	Conventional Fattening pigs (kg VS/apa/y)	Organic Sows (kg VS/apa/y)	Organic Fattening pigs (kg VS/apa/y)
Netherlands	381	152	466	141
England	415	114	467	165
Germany	366	136	429	151
Denmark	412	141	558	150

The VS excretion explains part of the differences in methane emissions from manure management. Another part is explained by differences in *methane conversion factor* (MCF) as shown in Table 2.5 (Chapter 2). The MCF for conventional pig farming varies between 10% and 11%, except for England, where due to the use of an uncovered silo the MCF is about 14%. For organic pig farming the MCFs are lower due to the partial production of solid manure with lower MCFs and because (part of) the manure is produced in the field with a MCF of 1%.

The calculated VS excretion and MCF can be compared with default values used in IPCC methodologies or National Inventory Reports (NIRs). For the excretion of VS, the Dutch NIR uses a value of 179 kg per average sow and 66 kg per average fattening pig. These values are reasonably lower than calculated with this model. The Danish NIR uses a value for the Danish pig farming of 146 kg per average fattening pig, which is comparable with the value calculated in this study. For sows, the Danish NIR divides it into 259 kg for sows including pigs with less than 7 kg live weight and 55 kg for piglets between 7 and 30 kg. This combined (assuming 2.5 piglets places per sow per year), gives a value of 396, which only differs 4% from the calculated value in this study. The German NIR calculates the excretion of VS identically to the used methodology in this study. Differences can obtain due to differences in GE and DE percentage. In England, the Tier 1 approach is followed, which means that a default value is used for methane from manure management of 3 kg CH_4 per head per year.

The calculated average MCFs are much lower than the default value used in the Dutch NIR of 34%. For both the conventional and organic system, this is because 50% of the manure is stored for a period less than one month in summertime with a MCF of only 3%. The assumption is that manure in summertime is applied soon after production. Besides that a reasonable share of the liquid manure is assumed to be stored outside in a silo with a MCF of 13.7%. The organic MCF is lower than the MCF for conventional because part of the manure is produced directly on the pasture with a MCF of 1% . This is especially relevant for English organic pork where 100% of the manure is produced on the paddock. However, this is also relevant for Danish and Dutch organic pork, where a part of the manure is produced on the paddock. The Danish NIR uses a value of 10% for the MCF, which is the same as the calculated MCF in this study. The German NIR uses specific MCF's for the different manure management systems which are used in Germany

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[3] Note that in these figures only VS from feed is included. VS in manure from other sources like straw used as bedding is not included.

The average MCF for English and German conventional pork is relatively high because the manure stored outside in a silo is not covered, which gives a higher MCF of 20% compared to a covered silo in the Netherlands and Denmark, which have a MCF of 12% - 13%. The organic matter excretion and MCF combined determines the specific methane emissions from manure management. In Table 4.6 these specific methane emissions are given as kg methane per kg manure.

Table 4.6 The methane emission from manure management (kg CH_4/ ton manure).

	Conventional Sows (kg CH_4/ton)	Conventional Fattening pigs (kg CH_4/ton)	Organic Sows (kg CH_4/ton)	Organic Fattening pigs (kg CH_4/ton)
Netherlands	1.79	3.32	1.44	1.98
England	2.65	3.40	0.19	0.26
Germany	2.10	3.61	1.53	2.04
Denmark	1.87	2.98	0.61	1.73

In the Dutch NIR, the default values of 2.68 and 4.59 kg CH_4 per kg manure for sows and fattening pigs are used. For the conventional system, the calculated values in this study are about 25% to 33% lower. For the organic system the calculated values are about 50% of the defaults from the NIR.

4.2.3 N-excretion and N_2O emissions

The N-excretion determines the N-related greenhouse gas emissions from the farm, which are direct N_2O and ammonia and nitrate losses (which results in indirect N_2O emissions) from manure management, grazing and manure application. These nitrogen related greenhouse gas emissions from the farm contribute 10-14% in conventional pork production. In organic pork production, this share increases with the amount of grazing. In German and Dutch organic pork production, where no or very few grazing occurs, the share is 12-15%, whereas in Danish and English organic pork production, this share increases to respectively 20% and 29%. The nitrogen excretion is the result of nitrogen input, which is determined by feed and fodder intake and nitrogen content minus nitrogen retention in animals (meat). In this study, also nitrogen input in manure from straw, which is used as bedding is taken into account.

Table 4.7 The nitrogen excretion per 1000 kg live weight (fattening pigs and slaughter sows) produced (kg N/1000 kg live weight), including N from straw used as bedding (between parenthesis: the nitrogen excretion that can be related to fodder and straw)

	Conventional (kg N/1000 kg)	Organic (kg N/1000 kg)
Netherlands	43.0	68.9 (3.8)
England	42.2	79.9 (4.5)
Germany	50.6	91.7 (8.7)
Denmark	46.6	71.5 (5.3)

The nitrogen excretion has a direct and linear effect on direct nitrous oxide (N_2O) emissions from manure management, application and grazing. Also indirect emissions will increase with a higher nitrogen excretion because ammonia volatilization from manure management and manure application and nitrate leaching from manure application will increase.

4.2.4 Energy use at the pig farm

Energy at the pig farm is mostly used for heating and ventilation. The share in total carbon footprint is about 6% for Dutch and German conventional and organic pig farming. In Danish and English pig production, where pig houses are less heated, the share is about 3% (except for English organic production, where almost no energy is used). However, the figures about energy use might not be representative for all cases. Especially for organic pork production, it was not possible to find sound figures for energy use; so, assumptions were made (See Annex2).

4.2.5 Transport

The share of transport in the carbon footprint is relatively limited with about 10% in conventional production systems and about 8% in organic systems (Table 4.8). An exception is the Dutch conventional and organic system, where the share is respectively 14% and 10%. This is mainly due to a higher share of transport with feed, because relatively more co-products are used as feedstuff, of which transport has a higher share in the carbon footprint. Moreover, because all the manure has to be exported from the pig farm to an arable farm, emissions from manure transport has a bigger share. Transport of feed (which includes transport of feedstuffs to feed manufacturer and feed to the pig farm) is the largest contributor to the carbon footprint from transport. For organic pig production the share of livestock transport is relatively larger compared to conventional pig production, because fewer animals per truck are transported (due to smaller scaled farms) and the distance to slaughter house is assumed to be longer (see Annex 2 for details).

Table 4.8 The share of transport due to feed (transport of feedstuffs and feed to farm), exporting manure from farm and carrying away pigs to slaughterhouse in the carbon footprint

	Conventional feed	Conventional manure	Conventional livestock	Organic feed	Organic manure	Organic livestock
Netherlands	12%	0,9%	0,6%	8%	1,0%	1,4%
England	7%	0,1%	1,2%	6%	0%	2,5%
Germany	6%	0,1%	1,5%	5%	0%	2,9%
Denmark	8%	0,1%	0,9%	6%	0%	2,1%

4.2.6 Typical organic aspects

Grazing

In the different countries a different rate of grazing is applied. In the Netherlands, only the dry sows have access to the paddock; whereas in Denmark, all sows are kept in outdoor huts on the paddock. Organic pig farming in England is completely outdoor, where all pigs from sows to fattening pigs are kept in outdoor huts. In German organic pig farming, the pigs do not have any access to the paddock, because of the risk of being infected with the swine fever from wild pigs.

Grazing results in greenhouse gas emissions from the excretion of dung and urine on the pasture, leaching of nitrate and ammonia emission. On the other hand, manure that is produced on the paddock is not produced in the pig house and cannot result in greenhouse gas emissions from manure management and application. In Table 4.9, the greenhouse gas emissions per kg excreted nitrogen on the paddock and in the pig house are compared, assuming that other parameters will be equal. The results in Table 4.9 shows that each kg excreted nitrogen on the paddock results in more greenhouse gas emissions, but depends strongly on the MCF for manure management. In this example, we used the MCF for Dutch organic sows with a value of 8.1%. This value may be as high as 17.5% in a worst case scenario. In that case, the greenhouse gases per kg excreted nitrogen in the pig house are higher than excreted on the paddock.

Table 4.9 The greenhouse gas emissions (kg CO_2eq per kg N) per kg excreted nitrogen 100% in the pig house and 100% on the paddock

	100% pig house (kg CO_2eq/kg N)	100% paddock (kg CO_2eq/kg N)
Grazing	0	11.2
Manure management N_2O	1.8	0
Manure management CH_4, (MCF = 8.1%)	3.9	0.5
Manure application	2.8	0
Manure transport	0.5	0
TOTAL	9.0	11.7

Use of fodder and straw

In organic pig farming different amounts of fodder and straw are used (see Annex 2). The production of fodder and straw results in a non negligible share of 3% - 9% in the carbon footprint of organic pork. The use of fodder contributes for about 1% and straw contributes for the remaining 2%-7%. Besides the emissions due to production, the use of fodder and straw results in more nitrogen (Table 4.11) and VS excreted in manure, which in turn results in more methane and nitrous oxide emissions from manure management and application.

Table 4.10 The greenhouse gas emissions from the use of fodder and straw in organic pork production in kg CO_2eq per kg organic pork and in %

	GHG emissions (kg CO_2eq/kg pork)	Contribution (%)
Netherlands	0.2	4%
England	0.2	3%
Germany	0.5	9%
Denmark	0.3	6%

Table 4.11 The total nitrogen excretion and nitrogen excretion from use of fodder and straw per 1000 kg live weight (fattening pigs and slaughter sows) produced (kg N/1000 kg live weight) for organic pig farming

	Total N excretion (kg N/1000 kg)	Fodder and straw (kg N/1000 kg)
Netherlands	68.9	3.8 (6%)
England	79.9	4.5 (6%)
Germany	91.7	8.7 (9%)
Denmark	71.5	5.3 (7%)

4.3 Sensitivity analysis

4.3.1 Feed

Feed determines a significant part of the carbon footprint of pork. If the amount of feed used to produce pork is decreased by 10% and animal production and feed composition remains equal, the carbon footprint decreases within the range of 8.5% - 10%. This decrease is more than expected when focussing on the share of the emissions that are related to feed production. The share of feed in the carbon footprint is 50% to 67%, so a decrease of 10% will cause a decrease of 50% * 10% = 5% to 67% * 10% = 6.7%. The larger decrease is because a lower feed intake will also cause a lower manure production and nitrogen excretion. This results in lower methane and nitrous oxide emissions from manure storage and application.

Table 4.12 Change in carbon footprint (kg CO_2eq/kg fresh meat at slaughterhouse) when feed use is reduced by 10%.

	Conventional (Excluding LULUC) (kg CO_2eq/kg)	Organic (Excluding LULUC) (kg CO_2eq/kg)	Conventional (Including LULUC) (kg CO_2eq/kg)	Organic (Including LULUC) (kg CO_2eq/kg)
Netherlands	-9.4%	-8.8%	-9.6%	-9.2%
England	-9.6%	-9.7%	-9.7%	-9.8%
Germany	-9.3%	-8.0%	-9.6%	-8.6%
Denmark	-9.8%	-9.2%	-9.8%	-9.5%

A reduced use of feed and realizing the same production is not expected without changing the composition of the feed. If we assume a 10% lower nitrogen content in the feed, the carbon footprint will reduce 2% – 7% (Table 4.13). In this scenario, the change in feed composition to realize this reduced nitrogen content is not included. Changing the feed composition to reduce the nitrogen content will probably affect the carbon footprint of feed. Probably the carbon footprint per ton feed will also reduce if the nitrogen content is reduced, because generally the feed ingredients with relatively high concentration protein and nitrogen also have relatively high carbon footprints.

Reducing the nitrogen content in feed (with the same technical results) results in a more stronger reduced nitrogen excretion. For conventional systems, the nitrogen excretion decreases by about 30%, for organic systems, it decreases by 20%-25%. This is because the nitrogen retention in animal growth is assumed to be equal. The difference between organic and conventional is because in conventional systems all the nitrogen input is from feed; in biological systems, a major part of the nitrogen input is also from fodder and straw (which is not affected).

A reduction in nitrogen excretion linear influences the nitrous oxide emissions from manure management and manure application in the same magnitude. So, the emissions from these sources decline with 25 to 30% and, because of the relative small share in total carbon footprint of these sources, the total carbon footprint changes by a relative small part. The effect on total carbon footprint is higher where more grazing is applied (England and Denmark organic). In those cases the nitrous oxide emissions from grazing are a relatively large part of the carbon footprint and these emissions are directly affected by the nitrogen excretion.

Table 4.13 Change in carbon footprint (kg CO_2eq per kg fresh meat at slaughterhouse) when nitrogen excretion is reduced by 10%

	Conventional (Excluding LULUC) (kg CO_2eq/kg)	Organic (Excluding LULUC) (kg CO_2eq/kg)	Conventional (Including LULUC) (kg CO_2eq/kg)	Organic (Including LULUC) (kg CO_2eq/kg)
Netherlands	-3.1%	-3.1%	-2.0%	-2.0%
England	-3.2%	-6.5%	-2.1%	-4.1%
Germany	-3.4%	-3.3%	-2.2%	-2.4%
Denmark	-4.1%	-4.5%	-2.7%	-3.0%

Feed composition also affects the methane emissions from manure management. Energy content and digestibility determines the amount of organic matter produced in manure and the amount of organic matter determines the methane emission from stored manure.

The gross energy content (expressed by GE) has a linear effect on organic matter production in manure and the methane emissions from manure management. This means that a 5% higher GE content (assuming no reduction in feed intake) in feed causes a 5% higher methane emission from manure management. The effect is smaller when the ration is not only feed, but also fodder is used as in the organic systems. With a share of 10 to 15% of the total carbon footprint, a decrease of methane emissions from manure management will result in a less than 1% higher total carbon footprint of pork.

The content of digestible energy has a stronger effect on methane emissions from manure management. An increase of 5% in DE% will result in a about 20% reduction of the amount of organic matter production in manure. Subsequently, this linearly effects the methane emissions from manure management. With a share of 10 to 15% of the total carbon footprint, a decrease of methane emissions from manure management will result in a 1 to 3% lower total carbon footprint of pork.

4.3.2 Animal housing

The type of animal housing and manure storage determines ammonia, nitrous oxide and methane emissions. The sensitivity of manure storage type can be illustrated by an example for the German organic case. In the original case, it was assumed that liquid manure stored outside the pig house is stored in a non covered silo. What will be the effect if this silo would be covered? First of all the methane conversion factor (MCF) of this manure management system will decrease from 20% to 12.5%. This reduction of 37.5% will reduce the methane emission from manure management with the same amount. With a share of 10 to 15% of the total carbon footprint, a decrease of methane emissions from manure management will result in a 4 to 6% lower total carbon footprint of pork.

Besides the effect on methane emissions, covering a silo reduces the ammonia emissions even stronger with a reduction of about 90%. Because of the very small part of indirect nitrous oxide emissions via ammonia emissions of the total carbon footprint (less than 1%), this reduction barely affects the total carbon footprint.

4.3.3 Manure

In this study, we have chosen to allocate the emissions due to application of manure to the user (crop farmer/plant production system) and producer (pig farmer/animal production system) by using the active nitrogen content in manure. That means that the part equal to the active nitrogen content is allocated to the user and the other part is allocated to the producer. This is well considered and argued; however, it can still be doubted if it is the best solution. Another possibility is to allocate all emissions due to manure application (and transport) to the producer. An argument for this is that, in general, the producer has to pay for exporting the manure. Using economic allocation, this means that all emissions have to be allocated to the producer. This way, emissions from manure application in the production chain of animal production will be higher; on the other hand, the emissions from manure application for cultivating crops in the production chain of feed will be lower.

The increase in emissions from manure application are comparable for all cases. On the other hand, the decrease in carbon footprint from feed use differs a lot. For conventional feed, the ingredients are cultivated with only a very small amount of animal manure. For organic feed, this amount is, in general, much higher. Therefore, the carbon footprint of conventional feed declines most steeply with 6%. For organic feed the decline is about 20 to 25%.

For the total carbon footprint of conventional pork, the increase in emissions from manure application is only partly compensated by a lower carbon footprint of feed. For organic systems, the compensation is higher and, for organic pork production, there is another effect: the manure applied on the paddock due to grazing is not affected by this change, that was already 100% allocated to pork production. In that case, only a reduced carbon footprint of feed results in the reduction of the total carbon footprint

Table 4.14 Change in carbon footprint (kg CO_2eq per kg fresh meat at slaughterhouse) when all emissions due to application and transport of manure are allocated to pork production

	Conventional (Excluding LULUC) (kg CO_2eq/kg)	Organic (Excluding LULUC) (kg CO_2eq/kg)	Conventional (Including LULUC) (kg CO_2eq/kg)	Organic (Including LULUC) (kg CO_2eq/kg)
Netherlands	18%	6%	127%	4%
England	9%	-17%	6%	-11%
Germany	11%	-2%	7%	-1%
Denmark	9%	-1%	6%	-1%

4.3.4 Transport

Transport contributes to the total carbon footprint of pork for about 10 to 15% (Paragraph 4.2.5). Most transport related greenhouse gas emissions of the carbon footprint are related to the feed production chain. Transport distances of food products (food miles) receive a lot of attention as an indicator of environmental burden. However, if all land transport distances (road and rail) would increase by 100%, the total carbon footprint would increase by only 7 to 9.5% (Table 4.15).

Table 4.15 Change in carbon footprint (kg CO_2eq per kg fresh meat at slaughterhouse) when all transport on land is increased by 100%

	Conventional (Excluding LULUC) (kg CO_2eq/kg)	Organic (Excluding LULUC) (kg CO_2eq/kg)	Conventional (Including LULUC) (kg CO_2eq/kg)	Organic (Including LULUC) (kg CO_2eq/kg)
Netherlands	9.3%	8.3%	6.2%	5.5%
England	6.8%	7.0%	4.4%	4.8%
Germany	7.1%	6.8%	4.8%	4.9%
Denmark	7.7%	7.4%	4.8%	4.9%

The system boundary of the pork production system is defined here as fresh meat at the gate of the slaughterhouse. After slaughter, the fresh meat is transported to retail. In Table 4.16, the additional greenhouse gas emissions from this transport are given when fresh meat is transported to the Netherlands from the neighbouring countries. The total carbon footprint of pork increases with 1, 2 and 3% if pork is transported from respectively Germany, England and Denmark.

Table 4.16 Additional greenhouse gas emissions from transport from slaughterhouse in neighbouring countries to retail in the Netherlands

	Distance (km)	Additional emissions (kg CO_2eq/kg meat)	% of total carbon footprint
Netherlands	100	0.014	0.4%
England	500	0.071	2%
Germany	300	0.042	1%
Denmark	750	0.105	3%

4.3.5 Slaughtering

At the slaughterhouse, pork is separated from co-products that are not used as a (processed) pork product itself, but are used as raw materials or ingredients in processed meat, food, feed and technical appliances. The relative revenue from pork in relation to the revenue from all co-products (prices multiplied by the mass outputs per unit ingoing product) determines the fraction of upstream greenhouse gas emissions that is allocated to pork. A change in this fraction linearly affects the total carbon footprint of pork. So, if this fraction decreases by 5% for pork (meaning that the co-products give higher turnover), the carbon footprint of pork decreases by 5%. Two issues with a considerable effect on the allocation fraction are mentioned here:

- The definition pork and the co-products is not always obvious, for instance: blood is separated at first, but later it is added in processed meat; is blood part of meat or is it a separate co-product?
- The economic value (price) of co-products is usually lower than the economic value of pork. However, after processing, the economic value of some co-products can increase considerably because of specific product properties. The question is: how should this added value of processed co-products be taken into account in relation to the economic revenues from meat in case of economic allocation, especially in cases where the processing takes place in the slaughter house?

5 Options to reduce the carbon footprint

In this chapter, options to reduce the greenhouse gas emissions that are related to the pork production chain are discussed. The options are related to the different stages of the production chain; for instance, production of feedstuffs or animal production on the pig farm. Notice that these options are only considered from the perspective of reducing greenhouse gas emissions. The options may have effects on other sustainability indicators for pork production, such as animal welfare, acidification and economic aspects. To analyse those effects was not within the scope of this study, but we recommend that before implementing the described options, an integral analysis of important sustainability aspects is done.

The reduction options described in this chapter are divided in those related to pig feed, manure management and manure application. In separate sections, different options are described. This chapter ends with an overview of potential, certainty and critical factors of the different options.

5.1 Pig feed

5.1.1 Feed composition

The carbon footprints of raw materials in pig feed determine the carbon footprint of pork for a large part. Optimisation of feed compositions focussed on greenhouse gas emissions could therefore have a large effect on the carbon footprint of pork. However, reduction of carbon footprint by optimisation is limited because of nutritional limits and changes in nutritional characteristics of feed could increase the emission during feed utilization. On the other hand, a recent study by Blonk Milieu Advies (Kool, 2008 and Blonk e.a., 2009b) shows that concerning dairy compound feed, a reduction of 10 to 15% in greenhouse gas emissions per ton feed is possible with only a minor increase in ingredients costs and without a decline in feeding value. If this would hold for pork production, with a share of about 50% in total carbon footprint, a reduction of 10 to 15% would give a 5 to 7.5% reduction in carbon footprint of pork. An uncertainty about setting limits on the carbon footprint when optimizing feed composition, is the effect on feed production and feed composition on a world scale. Reduction of the use of feedstuffs with a high carbon footprint in a certain production chain or country may stimulate the use of that feedstuff in another production chain or country. This means that on world scale the total use of that feedstuff might not be affected. These risks for averting environmental burdens to other production chains should be taken into account. From the scope of this study and involved researchers, no source is know where this analysis is being made.

Besides the choice between raw materials, the production of each individual feedstuff can be optimized. As can be seen from the crop growing characteristics and greenhouse gas emissions profile for cereal grains (calculated in this study), there are differences of about 5 to 15% in greenhouse gas emissions for the same crop grown in different systems (Figure 5.1). This suggest that optimizing greenhouse gas emissions per ton product is possible. Besides that, a choice can be made between different sources of the same feedstuff. For the Netherlands, where wheat for feed is mostly imported, replacing French wheat by German wheat gives a 1% lower emission profile for conventional pig feed.

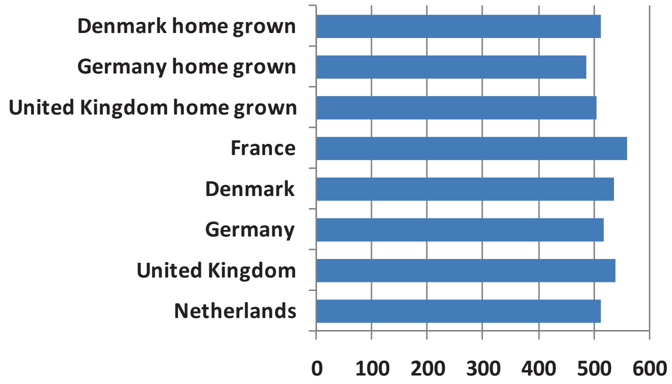

Figure 5.1 The greenhouse gas emission of conventional wheat grown in different countries

5.1.2 Feed use

Besides feed composition, feed use per kg produced pork can be optimized. A recently developed pig feed by the Dutch feed producer Cehave Landbouwbelang ua (Airline 2.0) shows that feed used per kg produced pork can be reduced significant. Another positive effect is the reduction of nitrogen excretion, which reduces the nitrogen related greenhouse gas emission (nitrous oxide emissions from manure management and application). Blonk Milieu Advies calculated that using this particular feed can reduce greenhouse gas emissions with about 10% (Kool & Blonk 2008). This includes the reduction in feed conversion rate (kg feed per kg live weight) and nitrogen excretion.

5.1.3 Wet co-products

In the Netherlands, a major part of (mostly conventional) pig farmers use wet co-products besides compound feed. Wet co-products result from production of mainly human food (such as sugar) and bio-fuels (such as wheat ethanol). Concerning greenhouse gas profile, the wet co-products mostly have a low economic value compared to the feed or fuel co-products, which results in relatively low allocation of upstream greenhouse gas emissions to the wet co-products. A potential negative effect of using wet co-products on the carbon footprint of pork can be transport. Transport of wet co-products by truck causes a relatively high emission profile, because of the large share of water in wet co-products (dry matter content varies between 5% for whey to about 28% for distillers grains). When distances are short enough, calculations by Blonk Milieu Advies indicates that using wet co-products can reduce the greenhouse gas emissions from feed use by about 10% (Blonk, 2005; Kool e.a., 2008; and Kool, 2009). This may reduce the total carbon footprint of pork with 5%. However, these results are based on a rough approach. To define a more founded reduction potential, more research is needed on the greenhouse gas emission related to the use of wet co-products.

5.1.4 Closing the cycle

An interesting direction that can be explored when searching for greenhouse gas emission reduction options, is the concept of closing the cycle of raw material production, feed utilization, manure production and manure application as much as possible. The core of this concept is that a part of the chemical fertilizers in cropping systems is replaced by animal manure and that the transport distance of animal manure is as short as possible. The results in Figure 5.1 shows that for wheat, the carbon footprint of home grown wheat is lower than for wheat grown outside the pig farm. We defined a scenario where the transport of wheat and barley grains in the animal ration is reduced to zero and part of the crops' chemical nitrogen fertilizers are replaced by manure from the pig production farm. For the Dutch situation, it is not a realistic scenario, because most grains are imported from France and Germany.

The difference between the carbon footprint results and the "closing the cycle" scenario is about 6 to 8% for Danish, German and English grains and 1 to 3% for French and Dutch grains, where the carbon footprints in the scenario are always lower[4]. The difference for French and Dutch grains is smaller because less chemical fertilisers were replaced by manure. The differences are not as large as expected, because more manure is needed in terms of nitrogen mass per hectare than chemical nitrogen fertiliser. Some difference can be accounted to reductions in transport. The difference between the carbon footprints results and the scenario is at the most 3% for the pig feed, resulting in a difference of 1 to 2% for pork. If the nitrogen use efficiency of manure could be increased considerably, this could probably have some effect on the difference between the carbon footprints of pork as assessed in this study and in the "closing the cycle" scenario.

5.1.5 Fodder

In this study, we assumed that, in organic pig farming, fodder is included in the ration. Due to the lack of data, we assumed 0.5 kg dry matter is used per sow per day. The amount given per day, nitrogen content and GE and DE% content influences the carbon footprint of (organic) pork. Fodder results in a relatively large amount of methane emission from manure management due to the relatively low DE% content. In this study, we assumed DE% of 60.6%. If this can be increased to 70%, the methane emissions from manure management for sows reduces by 4%. With a share of 4% for methane emissions from manure management from sows in the total carbon footprint of pork, the total carbon footprint reduces by 0.2%.

5.2 Methane from manure management:

5.2.1 Covering storage

For conventional pork production in England and organic pork production in Germany, we assumed (based on expert judgement) that silos for liquid manure storage where not covered. This results in a significant higher methane conversion factor (MCF) (19 to 20%) compared to manure stored in covered silos assumed for the Netherlands and Denmark (12 to 13%). For conventional English pork this results in a 12% lower methane emission from manure management. For organic German pork, methane emission from manure management reduces by 14%. In English organic pork production, no manure is stored because we assumed all manure is produced on the paddock. The total carbon footprint of German organic pork reduces by 1.5% when the silo for liquid manure storage is covered. The total carbon footprint of English conventional pork reduces by 2% in this case.

5.2.2 Optimizing storage

Temperature affects methane emissions from manure storage. The average temperature in a pit below a pig house is higher than in a separate silo. Storage of liquid manure in a pit below a pig house therefore results in more methane emissions compared to a silo. So, an option to reduce greenhouse gas emissions

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[4] Although the impact on the carbon footprint may be relatively low, closing the cycle may have a relatively high impact on other sustainability aspects.

is maximizing the amount of manure stored in an outside covered silo. For instance, in the Dutch conventional and organic pig production, we assumed that during winter respectively 25 and 50% of the liquid manure is stored in a pit below the pig house or, in case of organic pig production, below the outdoor run. If we assume that this fraction of liquid manure is stored in a silo shortly after excreted, then the methane emissions from manure management reduces by 21.5 and 15% for conventional and organic pork production. The reduction for conventional pork is larger because of the larger reduction in MCF when manure is stored in a silo compared to the pit (reduction from 32 to 13% for conventional and from 18 to 13% for organic). A reduction of 21.5% in methane emissions from manure storage results in a 3% reduction of the carbon footprint of conventional pork. A reduction of 15% in methane emissions from manure storage results in a 1.5% reduction of the carbon footprint of organic pork.

5.2.3 *Solid versus liquid manure for organic pork*

In organic pig farming, straw is used as bedding material for welfare reasons and results in solid manure. The methane emissions from manure management and nitrous oxide emissions from manure application are for solid manure lower compared to liquid manure. On the other hand, nitrous oxide emissions from manure management for solid manure is higher than for liquid manure (2 to 0.2%). Table 5.1 shows that a change to 100% solid manure results in more greenhouse gas emissions. This is excluding the additional emissions from production of straw and from nitrogen input from straw; so, changing to a more straw based husbandry does not reduce greenhouse gas emissions.

Table 5.1 The greenhouse gas emissions from manure management and application (kg CO_2eq per ton fresh meat) for the traditional Dutch organic farming and the situation that more straw used as bedding and all manure is produced as solid manure

	Mainly liquid (kg CO_2eq/ton)	100% solid (kg CO_2eq/ton)
Manure management CH_4	471	160
Manure management N_2O	241	547
Manure application	305	360
TOTAL	1016	1067

5.2.4 *Manure digestion*

In Germany, Denmark and, recently, the Netherlands, biogas production from manure to produce energy (heat and electricity) is applied in an increasing part of the pig farms. Manure digestion increases the methane emissions from manure. However, because this 'biogas' is used as a fuel to produce energy, it is not emitted to the air. Besides this, the produced energy replaces greenhouse gas emissions from energy produced by fossil fuels.

For the production of energy from manure digestion, we use the following values. From the volatile solids (VS) in pig manure, 350 m^3 biogas (per ton VS) is produced (Zwart e.a., 2006). Per m^3 biogas, 1.8 kWh electricity is produced (Kool e.a., 2005) and is delivered to the national electricity grid. We assume that only electricity can be exported and replaces electricity that is produced with fossil fuels. The heat produced with manure digestion is mostly used for a significant part for continuation of the digestion process and if any heat remains it is mostly not profitable to export it outside the farm. For the reduction of methane emissions from manure management we use a method similar to the Danish NIR (Nielsen e.a., 2008), which assumes a 50% reduction in methane emissions from manure management if manure is digested.

Besides these reductions, we take the leak of methane from combustion in the combined heat and power (CHP) installation into account. From research done with CHP installations in horticulture, an average value of 2.3% leak is assumed and reported in a study by Blonk Milieu Advies (Blonk e.a., 2009a). If these values are analysed for the Dutch conventional pork production, the total carbon footprint can be reduced by about 500 kg CO_2eq per ton pork (Table 5.2 shows detailed values for this estimation). This is a reduction of 13%. The estimated reduction is a rather conservative assessment: the reduction of methane emissions from manure management could be more than was assumed here and heat from the CHP can be used to replace gas for heat production on farm level.

Table 5.2 The greenhouse gas emissions from manure management for the traditional conventional pig farming and the extra and avoided emission for the situation with digestion of manure (kg CO_2eq per ton fresh meat)

	Without digestion (kg CO_2eq/ton)	With digestion (kg CO_2eq/ton)	Difference (kg CO_2eq/ton)
Manure management CH_4	512	256	- 256
Avoided electricity production	0	-298	-298
Leak methane CHP	0	71	71
TOTAL			-483

5.3 Manure application

In organic farming manure is the main source of fertilizer. In this study, we assumed (based on expert judgment) that organic manure has no market value for pig farmers. The question is: what happens if manure can be sold by the pig farmer to the crop farmer? We assume that the organic pig farmer can sell the manure for 5 euro per ton. The economic allocation for the different products will change because an extra economic revenue (manure) is generated (Table 5.3). This means that if a crop farmer applies manure, part of the emissions from animal production is allocated to manure (about 1.5% for sows and 0.8% for fattening pigs).

Table 5.3 The economic allocation between piglets, live weight for slaughter and manure if manure is sold for 5euro per ton

Netherlands	95.6%	3.1%	1.3%	99.2%	0.8%
England	94.2%	4.4%	1.4%	99.2%	0.8%
Germany	92.9%	5.3%	1.8%	99.0%	1.0%
Denmark	94.7%	4.0%	1.3%	99.1%	0.9%

This implies that more greenhouse gas emissions are attributed to feedstuffs cultivated with pig manure, because a part of the greenhouse gas emissions from production of animal manure is taken into account and 100% of the emissions from application are allocated to the crop product. In the original case, only the part equal to the amount of active nitrogen was allocated to the crop product. This gives a 11 to 12% increase in carbon footprint of feed for organic pork production. The emissions on pig farm level reduces, because of the lower economic allocation to piglets and live weight and emissions from manure application are reduced to zero.

These effects combined results in a different outcome per case (Table 5.4). For the Netherlands and Germany, it results in a reduction of the carbon footprint. For the Netherlands, no emissions of manure application are allocated to the pig farmer. The increase in carbon footprint of feed is relatively low compared to other countries, because of the use of more co-products, where no animal manure is used.

The carbon footprint of Danish pork increases because the increase in carbon footprint of feed is only partly compensated with less emissions from manure application, because not all manure is sold and part of the manure is produced on the paddock.

Table 5.4 The effect on carbon footprint of organic pork if manure from organic pig production can be sold for a value of 5 euro per ton (in England this situation is not relevant, because all manure is produced on the paddock and cannot be sold)

	Relative change in carbon footprint of pork
Netherlands	- 1.0%
England	Non relevant
Germany	- 0.3%
Denmark	+0.8%

5.4 Overview

Table 5.5 gives an overview of the reduction potential, certainty of that reduction potential and limitations and other side effects for the most important reduction options.

Table 5.5 The reduction potential, certainty of that reduction potential and limitations and other side effects for the most important reduction options concerning feed production and feed use in pork production

Feed composition	5 to 7.5%	The greenhouse gas emissions per ton feed has a uncertainty due to variance in input data. Moreover, changing feed composition will result in a change of demand in raw materials. The effects of these changes are not assessed in an attributional LCA on which the carbon footprint is based	Nutritional limits
Feed use	In a recent case study for Cehave a reduction of 10% appeared to be possible. This reduction is the result of reduction of FCR and a (lower) increase of CF of the feed	Relatively high, because feed use can be measured.	Reducing feed use is often related to a change in feed composition and may cause a change in greenhouse gas emissions. This effect has to be taken into account.
Wet co-products	First proxy is 5%. Based on detailed inputs of a pig farmer	More research is needed to analyze this reduction option in more detail	The effect on feed use and changes in composition of concentrates has to be taken into account
Closing the cycle	A negligible 1 to 2%	Low, mainly because of the small effect in relation to the tot carbon footprint	
Fodder use	Less than 1%	Unless a small effect on total emissions, lowering the input of N and improving DE will give a certain reduction of emissions. The exact effect depends on the modelling of N emissions and CH4 emissions.	Only relevant for organic pork
Covering storage	2%	High, because covering silo will give a certain reduction of MCF for manure management	non
Optimizing storage	1 to 3%		Only possible if outside storage is available
Manure digestion	Calculated for Dutch conventional pork: 13%	High uncertainty in the reduction of methane emissions from manure management In this study we assumed a 50% reduction (according to Danish NIR).	The reduction is calculated using the method of system expansion (according to PAS 2050). Using another methodology for allocation (for instance economic allocation) will affect the outcome
Manure application: value for manure	Depends on pork production chain, reduction for Dutch pork 1%, increase for Danish pork 1%	The effect depends on how the production of pork is organized and will vary between countries.	

6 Conclusions and recommendations

This chapter contains the conclusions in relation to the three main objectives of this study (Chapter 1). This concluding chapter ends with recommendations on follow up research.

6.1 Methodology for assessing carbon footprints of pork and international adjustment

From recent scientific insights, methods for calculating the carbon footprint of pork were defined. These methods are based on the IPCC guidelines, the National Inventory Reports (NIRs) from the involved countries, published research, practical insights, and the PAS2050 and Dutch horticulture carbon footprint protocols. The methods make a comparison possible between pork produced in different countries and different production systems (conventional/organic). To come to these methods, we had to make a further specification of life cycle assessment guidelines and the PAS2050 for agriculture and harmonize greenhouse gas emission factors for agricultural production. The greenhouse gas emission factors in the NIRs of the studied countries differ for several processes. Therefore, we made a selection of most appropriate emission factors and added some modelling for deriving consistent emission factors that can be applied for all studied countries and organic and conventional farming. Especially the feed composition based modelling of methane and nitrous oxide emissions at the farm is much more precise than the models in the NIRs.

In this study, Monte Carlo simulations were applied to assess impact of input data uncertainty, emission factors and defaults on the result. This results in standard deviations of the carbon footprints and the certainty of differences between carbon footprints of production systems, such as conventional and organic.

6.2 Insight in the carbon footprint of pork

The carbon footprints for conventional pork (at the gate of the slaughterhouse) from typical production systems in the Netherlands, England, Germany and Denmark are respectively 3.6, 3.5, 3.7 and 3.5 kg CO_2eq per kg pork. No certain differences occur between these results.

The carbon footprints of organic pork (at the gate of the slaughterhouse) from typical production systems in the Netherlands, England, Germany and Denmark are respectively 4.3, 4.4, 5.0 and 4.0 CO_2eq per kg fresh meat. Although differences between the typical systems of the four countries are larger compared to conventional pork, these differences are not within the statistical certainty range of more than 90%. Only the difference between the highest carbon footprint value (Germany) and the lowest (Denmark) can be considered as fairly certain with a probability of 85%.

For the Netherlands and Germany, the carbon footprint of organic pork is higher than conventional pork within the statistical certainty range of more than 90%. For English and Danish pork, this difference is not within this range, although the difference for English pork can be considered as fairly certain with a probability of 83%.

The greenhouse gas emissions from land use and land use change (LULUC) are about 50% compared to the carbon footprints. These emissions are calculated and presented separately from the other greenhouse gas emissions, because of methodological uncertainty. So, besides competing for land use and the pressure on biodiversity, the use of land for production of pork also has a major effect on greenhouse gas emissions.

Production of feed (crop growing, transport of crop products, processing crop products, transport of raw materials and feed mixing) is with a contribution of more than 60% for conventional and about 50% for organic pork, the most important source of greenhouse gas emissions in the carbon footprint of conventional and organic pork.. For conventional production, the second most important source is methane emissions from manure storage with a share that varies between 12% and 17% of total emissions. For organic systems with a substantial share of grazing (for instance Denmark and England in this study), the emissions from grazing can be the second most important source.

The greenhouse gas emissions per ton feed are lower (10 to 20%) for organic compared to conventional production systems for the different countries. Nevertheless, this advantage of organic production is compensated by more feed(20 to 30%) that is used to produce pork (feed conversion ration) for organic compared to conventional production systems.

Concerning different stages in the production chain, the feed production stage has the largest share in the carbon footprint (roughly between 40 and 50%). Producing fattening pigs and piglets are the second and third most important stages. For organic farming, the shares of the animal production stages are slightly larger than for conventional (because conventional pork is produced more efficiently).

The calculations of methane emission from manure management is based on the basis of nutritional feed values and types of manure storage. This results in a detailed assessment of this emission source, which in some cases deviate from less detailed approaches that are used in National Inventory Reports.

Calculating nitrogen excretion as the difference between nitrogen intake and retention in growth, results in detailed insight in differences between nitrogen excretion and related greenhouse gas emissions from pig farming (nitrous oxide from manure management and application) for the different cases. The differences in nitrogen excretion between conventional and organic pig farming are evident (50 to 80% higher in organic pig farming), which causes more nitrous oxide emissions.

A change in the mass balances and prices of pork and co-products at the slaughter house, has a strong effect on the carbon footprint of pork. The definition of which product can be defined as meat or other co-product and rating a representative value for co-products strongly affects the results.

6.3 Reduction options

In order of magnitude and certainty the most obvious reduction options for the carbon footprint of conventional and organic pork are as follows:

- Digestion of manure: digestion of manure reduces methane emissions from manure storage and avoids greenhouse gas emissions from generating energy with fossil fuels and results in a 13% reduction of the carbon footprint (this was calculated for Dutch conventional pork production);
- Reducing the feed conversion rate: less feed and nitrogen intake per produced amount of pork results in a reduced carbon footprint, because less greenhouse gas emission from feed production, manure management and application occur. A recently study by Blonk Milieu Advies

suggests a 10% reduction is possible for a concept in which a lower feed conversion rate and nitrogen excretion is obtained;

- Optimisation of feed: Setting limits on the carbon footprint when optimizing feed composition could realize a considerable reduction of a particular feed, but it is uncertain whether it causes a reduction on world scale. Blonk Milieu Advies found that a 10 to 15% reduction in greenhouse gas emissions per ton dairy compound feed is possible with only a minor increase in ingredients costs and without a decline in feeding value. A reduction of 10 to 15% will give a 5 to 7.5% reduction in carbon footprint of pork. More research is needed to confirm if these figures are also relevant for pig feed; Furthermore, it is necessary to make an examination of substitution effects due to a change in demand of feed (co-)products;
- Wet co-products: a rough approach points out that the use of wet co-products as a partial replacement of compound feed might reduce the greenhouse gas emissions from feed with about 10%. This might reduce the total carbon footprint with about 5%. To define a more founded reduction potential for wet co-products, more research is needed on the greenhouse gas emission related to the use of wet co-products;
- Although the contribution of slaughter process to the carbon footprint of pork is small, the mass balance of live weight pigs and output of fresh meat and the economic allocation fraction for fresh meat compared to co-products linearly affects the outcome of the carbon footprint. This means that improving the economic value of co-products derived from slaughtering reduces the carbon footprint of pork. On the other hand, the carbon footprint of these products increase.
- Relatively small reductions (about 1 to 3%) can be reached with options as covering uncovered liquid manure silos, pumping liquid manure directly after production in a pig house to storage outside (silo), closing the cycle of raw material production, feed utilization, manure production and manure application as much as possible and adding value to the manure exported from the pig farm.

6.4 Recommendations

There are several recommendations for further research and development that follow from the results of this report. First, it is recommended to initiate the development of an international standard or protocol for calculating the greenhouse gas emissions that can be attributed to pork production. This can be used as a standard for assessing the carbon footprints and can improve the comparability of results. The results of this study can be used as a starting point.

Besides development of methodology, effort must be put into obtaining representative data. In this study, it was difficult to obtain representative and reliable data.

More insight in the carbon footprints from real case pork production is needed to evaluate the differences that can occur in pork production and the possibilities for reducing the greenhouse gas emissions. Especially more insight is needed for feed composition, origin and production of feedstuffs and pig production on farm level because of the impact on the carbon footprint.

The issues defined as major determining factors, such as the mass balance and economic values of pork and co-products at the slaughter house, need to be analysed more in detail. Besides that, representative data has to be collected on the fresh meat share from live weight and value creation of co-products. To distinguish between pork and co-products, a sound definition has to be formulated and an answer has to be formulated for the question how to rate a co-product at its true value, considering the differences in economic value before and after processing these products.

When focussing on greenhouse gas emissions, other aspects concerning sustainable pork production (such as animal welfare, other environmental aspects and socio-economic aspects) should not be neglected. Therefore, with further development of the carbon footprint of pork, an integral approach of sustainability should be incorporated.

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Annex I: Animal feed production

A1.1 Processes, activities and emission sources

The production of animal feed starts with the production and transport of inputs for crop growing (Figure A1.1). This results in greenhouse gas emissions that can be attributed to the crop products. Crop growing itself and the application of inputs result in more emissions, especially the high impact nitrous oxide emissions from sources that contain nitrogen, such as fertilizers and manure. After ocean, railway, inland waterway and/or road transport, the crop products can be processed (grain or sugar milling, oil crushing, et cetera). For transport and processing, energy carriers, such as combustion oil, diesel, natural gas and electricity, need to be produced, transported and (in most cases) combusted, resulting in certain volumes of greenhouse gas emissions. In case the crop product is processed, the resulting raw materials are transported to the feed mixing factories, where the raw materials are mixed and processed. So, in the animal feed production chain, four different types of activities can be distinguished:

1. Production and transport of inputs
2. Crop growing
3. Transport of crop products and raw materials
4. Processing of crop products and feed mixing

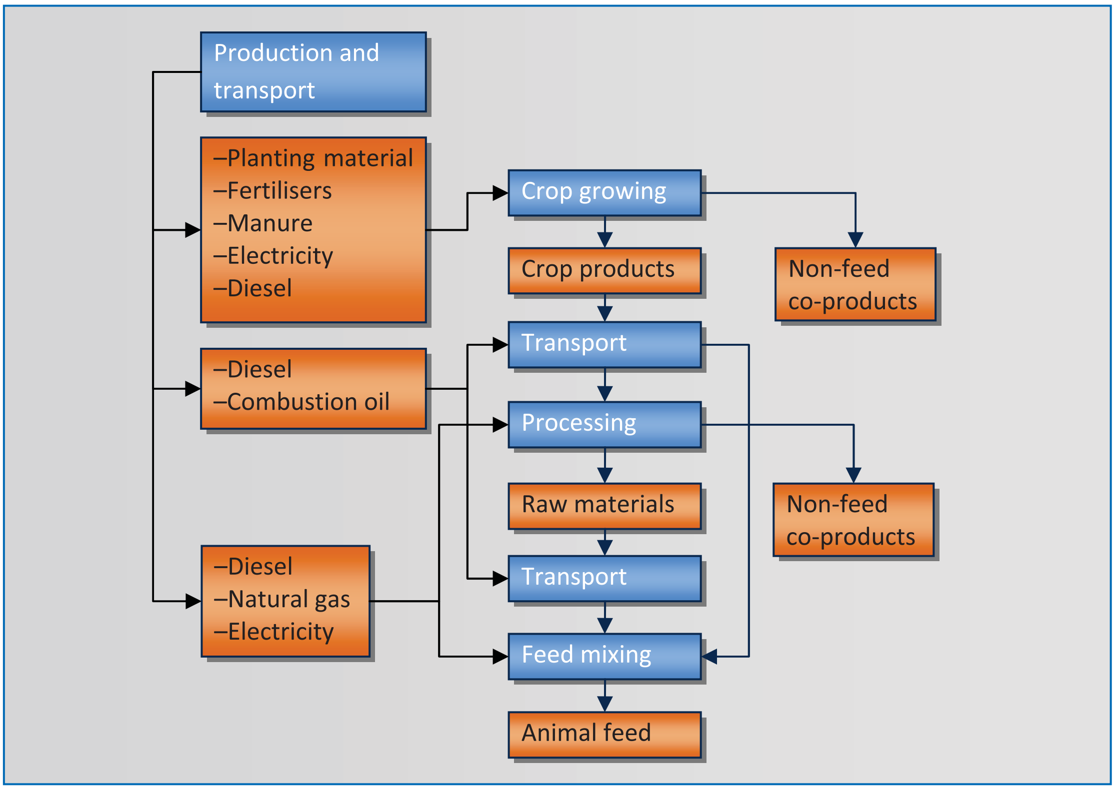

Figure A1.1 Processes and activities (blue boxes), inputs and products (orange boxes), and mass flows

A1.2 Production and transport of inputs

The emission sources from production and transport of inputs are:

- Planting material (CO_2 and N_2O)
- Fertilisers and manure (CO_2 and N_2O)
- Electricity (CO_2)
- Diesel (CO_2)
- Combustion oil (CO_2)
- Natural gas (CO_2)

Planting material is, in most cases, the same as the main crop product. Therefore, we assume that the amount of planting material is equal to a fraction of the yield mass. So, the emissions from planting material is equal to a fraction of the calculated carbon footprint of the crop product. In most cases, this fraction is 0.04 to 0.05 based on own estimates and KWIN (2007) values.

The emissions from production and transport of fertilisers depend on the type of fertiliser (Table A1.1). Although less carbon dioxide are emitted from the production and transport of CAN fertiliser (3.0 kg CO_2/kg N) than urea (4.7 kg CO_2/kg N), additionally nitrous oxide are emitted, resulting in a total of 7.5 kg CO_2eq/kg N from CAN. Because these nitrous oxide emissions from fertiliser production is unique to CAN, we assumed that the emissions from other chemical nitrogen fertilisers is equal to urea.

The emissions from electricity production and transport In the Netherlands was estimated by CE-Delft to 0.555 kg CO_2eq per kWh. According to the OECD (2004), the emissions from electricity production and transport in Germany, Denmark, England and France are resp. 0.498, 0.339, 0.514 and 0.096 kg CO_2eq per kWh. The carbon dioxide emissions from diesel combustion is 3.1 kg CO_2 per kg and the nitrous oxide emissions is 0.1 kg CO_2eq per kg, and the carbon dioxide and nitrous oxide emissions from diesel production and transport are 0.2 and 0.1 kg CO_2eq per kg, respectively. In total, this amounts to 3.5 kg CO_2eq per kg diesel. The emissions from combustion oil production and combustion are similar to those of diesel, resulting in the same rounded values. The production, transport and combustion of natural gas is 2.0 kg CO_2eq per m^3.

Table A1.1 Emissions sources as present in a crop production field per hectare that are included in the crop growing phase and the emission factors for each source

CAN (Calcium Ammonium Nitrate) production and transport	kg CO_2eq/kg N	7.5
Urea production and transport	kg CO_2eq/kg N	4.7
Other nitrogen fertiliser production and transport	kg CO_2eq/kg N	4.7
Manure production	kg CO_2eq/kg N	0
Phosphorus (P_2O_5) production and use	kg CO_2eq/kg P2O5	0.6
Potassium (K_2O) production and use	kg CO_2eq/kg K2O	0.4
Diesel production and transport (including combustion)	kg CO_2eq/kg	3.5
Electricity production and transport (Netherlands)	kg CO_2eq/kWh	0.555
Electricity production and transport (England)	kg CO_2eq/kWh	0.514
Electricity production and transport (Germany)	kg CO_2eq/kWh	0.498
Electricity production and transport (Denmark)	kg CO_2eq/kWh	0.339
Electricity production and transport (Argentina)	kg CO_2eq/kWh	0,35
Electricity production and transport (United States of America)	kg CO_2eq/kWh	0,58
Electricity production and transport (Rest of the World)	kg CO_2eq/kWh	0,88

A1.3 Crop growing

Emission sources from crop growing are:

- Fertilisers and manure (N_2O)
- Crop residues (N_2O)
- Biological nitrogen fixation (N_2O)
- Diesel combustion (CO_2; included in production and transport)
- Peat oxidation (CO_2 and N_2O)
- Land use and land use change (CO_2, CH_4 and N_2O)

A1.3.1 Fertilisers, manure, crop residues and biological nitrogen fixation

The calculation of nitrous oxide emissions from fertilizer, manure and biological nitrogen fixation in cropping systems is mostly in line with the IPCC guidelines (IPCC 1994 and 2006) and the specifications for the Dutch NIR. These guidelines and specification distinguish three types of nitrous oxide emissions from nitrogen sources in a cropping system:

1) Direct emission (fertilizers, manure, crop residues, and biological nitrogen fixation);
2) Indirect emission via leached nitrate (fertilizers, manure, and crop residues).
3) Indirect emission via volatized ammonia (fertilizers and manure); and

Direct nitrous oxide emissions

Direct nitrous oxide emissions are a result of de-nitrification, which is a microbial activity converting nitrate into nitrite and nitrous oxide gas. Table 7.2 shows the emission factors as used here. If the symbol N_{source} is the nitrogen source in kg nitrogen per hectare, EF_{dir} is the emission factor for direct nitrous oxide emission in kg N_2O-N per kg N, the nitrous oxide emissions (EM_{dir}) per hectare in kg CO_2eq per hectare can be expressed as:

$$EM_{dir} = N_{source} \times EF_{dir} \times 44/28 \times 298$$

Where 44/28 is the mass conversion from nitrogen to nitrous oxide and 298 is the global warming potential over 100 years of nitrous oxide, converting nitrous oxide into carbon dioxide equivalents. An emission factor of 0.01 kg/kg then results in 4.7 kg CO_2eq per kg N. As discussed in Section 2.3, the nitrous oxide emissions from manure application is allocated between crop growing and animal husbandry, based on the active nitrogen in manure (Table A1.3).

Table A1.2 Emission factors in kg N_2O-N per kg N for direct nitrous oxide emission from agricultural soils according to the Dutch emission registration of the Netherlands (NIR) (source: VROM 2008)

Source	Mineral soil (kg/kg)	Organic soil (kg/kg)
Ammonium fertiliser (no nitrate)	0.005	0.01
Other types of fertiliser	0.01	0.02
Manure (surface spreading)	0.01	0.02
Manure (low-ammonia emission application)	0.02	0.02
Faeces (grazing)	0.01	0.01
Urine (grazing)	0.02	0.02
Nitrogen fixation	0.01	-
Crop residues	0.01	-
Cultivation of Histosols	0.02	-

The amount of nitrogen in crop residues can be estimated by determining the mass ratio between the yield and crop residues and the nitrogen mass fraction of the crop residues. The amount of nitrogen from biological nitrogen fixation is more difficult to determine. First, the total nitrogen uptake can be determined by the mass ratio between the yield and the rest of the plant biomass and the nitrogen mass fractions of the yield and the rest of the plant. Then, the fraction of nitrogen that is taken up from biological nitrogen fixation needs to be known. According to estimations, this is between 0.5 to 0.7 kg/kg.

Indirect emission via leached nitrate

A considerable part of the nitrogen in fertilizers, manure, and crop residues leaches as nitrate into surface or groundwater. Although this fraction can be different depending on the nitrogen source, weather conditions, soil type, groundwater level, crop type, and crop management, we assumed an average fraction of 0.3 kg NO_3—N per kg N for all crops, countries and nitrogen sources (conform to the IPCC 1996 and 2006 and the Dutch NIR). A fraction of the leached nitrate becomes nitrous oxide gas because of microbial de-nitrification activity. This fraction is 0.025 kg N_2O-N per kg NO_3—N according to IPCC (1996) and the Dutch NIR. If F_{leach} is the leaching fraction, EF_{leach} is the emission factor of leached nitrate, the nitrous oxide emissions via leaching (EM_{leach}) per hectare in kg CO_2eq per hectare can be expressed as:

$$EM_{leach} = N_{source} \times F_{leach} \times EF_{leach} \times 44/28 \times 298$$

Because F_{leach} and EF_{leach} have fixed values, the nitrous oxide emissions via nitrate leaching are 3.5 kg CO_2eq per kg N. For manure, this emission is allocated between crop production and animal husbandry, based on the active nitrogen in manure (Table A1.3).

Indirect emission via volatized ammonia

A part of the nitrogen in fertilizers and manure volatizes as ammonia gas. This fraction depends on the type of fertilizer or manure, the way of application (in case of manure) and environmental conditions (Table A1.2). A fraction of the volatized ammonia deposits on the soil and becomes nitrous oxide gas because of biological nitrification (ammonia into nitrate) and de-nitrification (nitrate into nitrous oxide) activities. This fraction is 0.01 kg N_2O-N per kg NH_3—N according to IPCC (1996) and the Dutch NIR. If $F_{ammonia}$ is the ammonia emission fraction, $EF_{ammonia}$ is the emission factor of volitised ammonia, the nitrous oxide emissions via volatized ammonia (EM_{leach}) per hectare in kg CO_2eq per hectare can be expressed as:

$$EM_{ammonia} = N_{source} \times F_{ammonia} \times EF_{ammonia} \times 44/28 \times 298$$

For manure, this emission is allocated between crop production and animal husbandry, based on the active nitrogen in manure (Table A1.3).

The fraction active nitrogen in mnaure is calculated as fraction N-mineral minus volatalized ammonia plus 65% / 80% of N-organic easy degradable for resp. conventional and organic manure. This calculation rule and fractions used are based on Dekker (2009).

A1.3.2 Peat oxidation

Peat oxidation only in the case of part of the oil palm production in Malaysia. A rough estimation is that 25% of the land under oil palm in Malaysia is peat land. Assuming that each year 2 cm of peat soil is lost due to oxidation, the bulk density of peat soil is 0.14 tonne per m^3, the organic matter mass fraction is 0.3 kg per kg soil, and the carbon mass fraction is 0.5 kg/kg organic matter, the total carbon dioxide and nitrous oxide emissions would result in approximately 15.4 tonnes of carbon dioxide equivalents per hectare (0.02 m/year x 0.14 tonne/m^3 x 0.3 kg/kg x 0.5 kg/kg x 44/12 kg CO_2/kg C).

Table A1.3 Ammonia emission factor, working coefficient and greenhouse gas (GHG) emission factor for different types of fertiliser in the four different countries

Type of fertiliser (country)	Ammonia emission (kg N/kg N)	Reference	Active nitrogen (kg/kg)	Emission via ammonia (kg CO_2eq/kg N)	Emission factor (kg CO_2eq/kg N)
Liquid manure (Netherlands)	0.06	Hoek 2002	0.70	0.2	5.9
Liquid manure (Denmark)	0.12	Mikkelsen e.a. 2006	0.64	0.4	5.6
Liquid manure (Germany)	0.13	Idem as Denmark	0.64	0.4	5.6
Liquid manure (England)	0.13	Misselbrook e.a., 2006	0.64	0.4	5.6
Solid manure (Netherlands)	0.03	Dekker 2009	0.51	0.1	4.3
Solid manure (Denmark)	0.06	Mikkelsen e.a. 2006	0.48	0.1	4.1
Solid manure (Germany)	0.06	Idem as Denmark	0.48	0.1	4.2
Solid manure (England)	0.07	Choudrie e.a., 2008.	0.49	0.2	4.2
CAN fertiliser	0.02	Hoek 2002	1	0.1	8.3
Urea fertiliser	0.15	Hoek 2002	1	0.7	8.9
Other chemical N fertilisers	0.034		1	0.2	8.4

A1.3.3 Land use and land use change

Methods and data for calculating the effects of land use and land use change are uncertain and in some cases of a very different magnitude than other greenhouse gas emission sources in cropping systems. Here, three different sources are considered:

- Loss of soil organic matter (land use)
- Loss of sink function (discontinuing fossilization under natural ecosystems)
- Loss of natural biomass (deforestation/land conversion)

The loss of soil organic matter is a process that takes place after land conversion from nature to agriculture, but it takes a long time before the soil organic matter reaches a new equilibrium under agriculture. Here, we assumed a constant yearly loss that results in 1650 kg CO_2eq per hectare in conventional cropping systems and 1100 kg CO_2eq per hectare in organic cropping systems.

The loss of sink function is the discontinuation of fossilization under natural ecosystems after land conversion to crop growing; so, this is not an emission, but an absence of carbon dioxide capture. Nabuurs & Schelhaas (2002) estimated the average carbon sink function of natural forests between zero and three hundred years old in Europe at 110 kg carbon or 403 kg carbon dioxide per hectare per year. Therefore, the emission factor for loss of sink function was assumed to be 403 kg CO_2eq per hectare.

The loss of natural biomass is the conversion of natural ecosystems to agricultural systems. Because it is difficult to determine the exact location and the history of the location where a crop product was grown, the greenhouse gas emissions from yearly land conversion from forest to agriculture in a country is divided over agricultural land use activities that increase in area. This can be done by determining the most probable trends of yearly area change of all agricultural land use activities in that country using FAOSTAT data. The area that is converted per hectare of a crop is equal to the trend in hectare per year, corrected for area expansion from crops with contracting area and divided by the actual area under the crop. The correction factor is equal to one minus the absolute sum of activities with contracting area divided by the sum of activities with expanding area (1 – contracting area/expanding area). The greenhouse gas emissions per converted area is equal to the average aboveground forest biomass, multiplied by the emission factor of 1.8 kg CO_2eq/kg biomass (0.5 kg carbon per kg biomass and 44/12 kg CO_2 per kg carbon; burning part of the biomass results in the same rounded emission factor).

For the Monte Carlo simulations, we assumed standard deviations of 5% in the calculated figures for land use and land use change.

A1.4 Emission sources from transport

Here, four types of transport are distinguished: ocean, railway, inland waterways and road transport.

A1.4.1 Ocean

Ocean transport of bulk raw material products uses about 1.3 kg of combustion oil per 1000 km per tonne product. The emission factor of combustion oil is about 3.5 kg CO_2eq per kg. However, some distance needs to be travelled without load. We assumed that this is about 35% of the distance with load. So, the greenhouse gas emission from ocean transport is 6.3 kg CO_2eq per 1000 km per tonne (Table A1.4).

A1.4.2 Railway

Railway transport uses about 16 kg of diesel per 1000 km per tonne, assuming that the loading capacity is 700 tonnes, the load fraction is 0.8, and the diesel use per 1000 km is 9 kg/km (9/[700 x 0.8] = 16). The emission factor of diesel is about 3.5 kg CO_2eq per kg. So, the greenhouse gas emission from railway transport is 56 kg CO_2eq per 1000 km per tonne (Table A1.4).

A1.4.3 Inland waterway

Inland waterway transport uses about 17 kg of combustion oil per 1000 km per tonne, assuming that the loading capacity is 1000 tonnes, the load fraction is 0.8, and the combustion oil use per 1000 km is 13.5 kg/km (13.5/[1000 x 0.8] = 17). So, the greenhouse gas emission from railway transport is 59 kg CO_2eq per 1000 km per tonne (Table A1.4).

A1.4.4 Road

For road transport, the relation between diesel use and loading capacity is not linear (the equation was simplified for a loading fraction of 1):

EM_{road} = (0.0065 * [loading capacity]+ 0.22) * [total distance] * 0.84 * EF_{diesel} / [loading capacity]

Figure A1.2 shows this relation graphically. Assuming the additional distance without load 75%, and the loading capacity is 14 tonne, the greenhouse gas emission from road transport is 115 kg CO_2eq per 1000 km per tonne (Table A1.4).

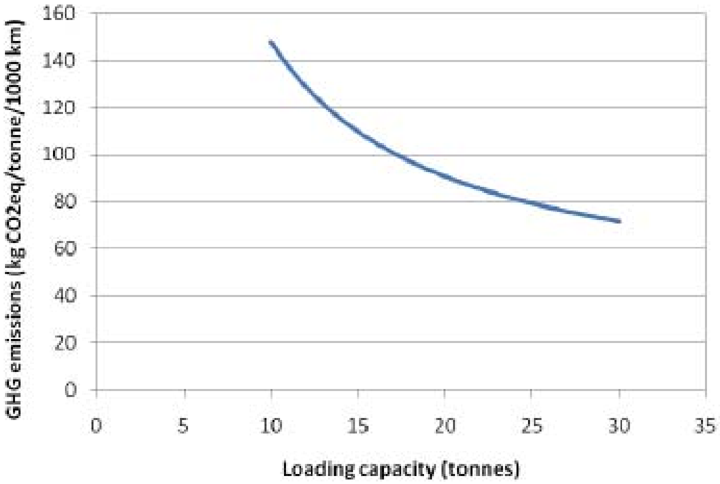

Figure A1.2 Relation between GHG emissions from road transport and loading capacity.

Table A1.4 Emission factors for ocean, rail, inland waterways, and road transport.

Transport mode	Emission factor (kg CO_2eq/1000 km)
Ocean	6.3
Railway	56
Inland waterways	59
Road	115

A1.5 Emission sources from processing

For processing of crop products, the emission from diesel, electricity and natural gas production and transport are considered. Table A1.5 shows the emission factors.

Table A1.5 Emission factors for diesel, electricity and natural gas production and transport

Diesel production and transport (including combustion)	kg CO_2eq/kg	3.51
Electricity production and transport (Netherlands)	kg CO_2eq/kWh	0.555
Electricity production and transport (England)	kg CO_2eq/kWh	0.514
Electricity production and transport (Germany)	kg CO_2eq/kWh	0.498
Electricity production and transport (Denmark)	kg CO_2eq/kWh	0.339
Electricity production and transport (Argentina)	kg CO_2eq/kWh	0.351
Electricity production and transport (United States of America)	kg CO_2eq/kWh	0.576
Electricity production and transport (Rest of the World)	kg CO_2eq/kWh	0.876
Natural gas production and transport (including combustion)	kg CO_2eq/m^3	1.99

A1.6 Overview of input data and results

In the following tables an overview is given of inputdata concerning feed production

Table A16 Input data concerning crop production of conventional feedstuffs (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, TH = Thailand, AR = Argentina, ML = Malaysia, VS = United States of America , PK = Pakistan)

	Yield ton/ha	N-Fertilizer amm. kg N/ha	N-Fertilizer CAN kg N/ha	N-Fertilizer Urea kg N/ha	N-Fertilizer other kg N/ha	N-manure kg N/ha	P-fertilizer kg P2O5/ha	K-fertilizer kg K2O/ha	N-fixation kg N/ha	N-crop residues kg N/ha	Diesel kg/ha	Electricity kWh/ha	CO2 kg CO2/ha	CH4 kg CH4/ha	N2O kg N2O/ha	all factor field
wheat_NL	8.3	0	198	11	11	0	80	100	0	54	84	100	0	0	0	0.84
barley_NL	6.0	0	0	0	0	150	55	70	0	25	84	100	0	0	0	0.82
rye_NL	4.5	0	0	0	0	113	40	45	0	37	84	100	0	0	0	1
Triticale_NL	5.3	0	0	0	0	116	45	60	0	41	84	100	0	0	0	0.82
wheat_UK	7.8	0	198	11	11	0	75	90	0	51	84	100	0	0	0	0.84
barley_UK	5.8	0	90	5	5	0	55	70	0	31	84	100	0	0	0	0.82
rye_UK	5.9	0	91	5	5	0	50	65	0	48	84	100	0	0	0	1
Triticale_UK	4.9	0	76	4	4	0	40	50	0	37	84	100	0	0	0	0.82
wheat_DE	7.5	0	180	10	10	0	70	85	0	49	84	100	0	0	0	0.84
barley_DE	6.0	0	81	5	5	0	50	65	0	25	84	100	0	0	0	0.82
rye_DE	5.1	0	69	4	4	0	45	55	0	42	84	100	0	0	0	1
Triticale_DE	5.8	0	78	4	4	0	50	65	0	44	84	100	0	0	0	0.82
wheat_DK	7.0	0	127	7	7	84	65	85	0	46	84	100	0	0	0	0.84
barley_DK	5.1	0	28	2	2	84	40	50	0	21	84	100	0	0	0	0.82
rye_DK	5.1	0	28	2	2	84	40	50	0	41	84	100	0	0	0	1
Triticale_DK	5.1	0	28	2	2	84	40	50	0	39	84	100	0	0	0	0.82
wheat_FR	7.1	0	180	10	10	0	65	80	0	46	84	100	0	0	0	0.84
barley_FR	6.3	0	81	5	5	0	55	70	0	26	84	100	0	0	0	0.82
rye_FR	4.6	0	59	3	3	0	40	50	0	37	84	100	0	0	0	1
Triticale_FR	5.1	0	66	4	4	0	45	55	0	39	84	100	0	0	0	0.82
wheat_UK_conv_home	7.8	0	135	8	8	100	75	90	0	51	84	100	0	0	0	0.84
barley_UK_conv_home	5.8	0	27	2	2	100	55	70	0	31	84	100	0	0	0	0.82
rye_UK_conv_home	5.9	0	27	2	2	100	50	65	0	48	84	100	0	0	0	1
Triticale_UK_conv_home	4.9	0	23	1	1	100	40	50	0	37	84	100	0	0	0	0.82
wheat_DE_conv_home	7.5	0	117	7	7	100	70	85	0	49	84	100	0	0	0	0.84
barley_DE_conv_home	6.0	0	18	1	1	100	50	65	0	25	84	100	0	0	0	0.82
rye_DE_conv_home	5.1	0	15	1	1	100	45	55	0	42	84	100	0	0	0	1
Triticale_DE_conv_home	5.8	0	17	1	1	100	50	65	0	44	84	100	0	0	0	0.82
wheat_DK_conv_home	7.0	0	117	7	7	100	65	85	0	46	84	100	0	0	0	0.84
barley_DK_conv_home	5.1	0	18	1	1	100	40	50	0	21	84	100	0	0	0	0.82
rye_DK_conv_home	5.1	0	18	1	1	100	40	50	0	41	84	100	0	0	0	1
Triticale_DK_conv_home	5.1	0	18	1	1	100	40	50	0	39	84	100	0	0	0	0.82
Tapioca_TH	18.3	0	20	46	0	0	35	30	0	13	34	0	0	0	0	1
wheatmiddlings_FR	7.1	0.0	180	10	10	0	65	80	0	46	101	100	0	0	0	0.84
Maizeglutenfeed_FR	8.7	0	50	50	50	80	80	105	0	65	101	100	0	0	0	1
Bread meal_FR	7.1	0.0	180	10	10	0	65	80	0	46	101	100	0	0	0	0.84
Soybean meal_AR	2.6	0	0	0	0	0	15	20	133	48	67	100	0	0	0	1
Rapeseed meal_DE	3.8	0	135	38	38	0	25	35	0	38	92	100	0	0	0	0.9
Rapeseed meal_UK	3.2	0	116	32	32	0	25	30	0	32	92	100	0	0	0	0.9
Rapeseed meal_DK	3.7	0	135	38	38	0	30	35	0	37	92	100	0	0	0	0.9
Palm kernel extracted_ML	19.4	76	0	30	0	0	70	230	24	172	50	5	0	170	0	1
Palm kernel extracted_Mlpeat	19.4	36	0	50	0	0	90	300	24	172	50	5	21950	170	24	1
Soybean oil_VS_NL	2.6	0	18	12	0	0	60	95	99	48	67	100	0	0	0	1
Sugar canmolasses_PK	48.4	0	31	94	0	0	56	0	0	13	67	0	0	7	0	1
Sugar beet pulp_NL	61.6	0	81	27	0	0	50	70	0	128	101	100	0	0	0	1
wheatstraw_NL_conv_home	4.0	0	198	11	11	0	80	100	0	56	84	100	0	0	0	0.16
wheatstraw_UK_conv_home	4.0	0	198	11	11	67	75	90	0	52	84	100	0	0	0	0.16
wheatstraw_DE_conv_home	4.0	0	180	10	10	0	70	85	0	49	84	100	0	0	0	0.16
wheatstraw_DK_conv_home	4.0	0	127	7	7	84	65	85	0	47	84	100	0	0	0	0.16

Table A1.7 Input data concerning crop production of organic feedstuffs (for grain cereals and rapeseed figures off 20 and 10 kg N/ha for resp. N-fixation and crop residues are included as a estimate of the extra N-input from the organic rotation system) (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, AR = Argentina, VS = United States of America).

	yield ton/ha	N-manure solid kg N/ha	N-manure liquid kg N/ha	N-fixation kg N/ha	N-crop residues kg N/ha	Diesel kg/ha	Electricity kWh/ha	CO2 kg CO2/ha	CH4 kg CH4/ha	N2O kg N2O/ha	all factor field
wheat_NL	5.8	33	187	20	48	84	100	0	0	0	0.88
barley_NL	4.2	15	85	20	28	84	100	0	0	0	0.84
rye_NL	4.0	8	43	20	43	84	100	0	0	0	1
Triticale_NL	4.0	8	43	20	41	84	100	0	0	0	0.84
wheat_UK	5.4	33	187	20	45	84	100	0	0	0	0.88
barley_UK	4.1	15	85	20	32	84	100	0	0	0	0.84
rye_UK	4.0	10	57	20	43	84	100	0	0	0	1
Triticale_UK	4.0	10	57	20	41	84	100	0	0	0	0.84
Oats_UK	4.0	10	57	20	43	84	100	0	0	0	1
wheat_DE	5.2	30	170	20	44	84	100	0	0	0	0.88
barley_DE	4.2	14	77	20	28	84	100	0	0	0	0.84
rye_DE	4.0	10	57	20	43	84	100	0	0	0	1
Triticale_DE	4.0	10	57	20	41	84	100	0	0	0	0.84
Oats_DE	4.0	10	57	20	43	84	100	0	0	0	1
wheat_DK	4.9	30	170	20	42	84	100	0	0	0	0.88
barley_DK	3.5	14	77	20	25	84	100	0	0	0	0.84
rye_DK	4.3	8	43	20	45	84	100	0	0	0	1
Triticale_DK	4.3	8	43	20	43	84	100	0	0	0	0.84
Oats_DK	4.3	8	43	20	45	84	100	0	0	0	1
wheat_FR	4.4	30	170	20	39	84	100	0	0	0	0.88
barley_FR	2.3	14	77	20	20	84	100	0	0	0	0.84
rye_FR	2.1	8	43	20	27	84	100	0	0	0	1
Triticale_FR	2.1	8	43	20	26	84	100	0	0	0	0.84
wheat_UK_org_home	5.4	33	187	20	45	84	100	0	0	0	0.88
barley_UK_org_home	4.1	15	85	20	32	84	100	0	0	0	0.84
rye_UK_org_home	4.0	10	57	20	43	84	100	0	0	0	1
Triticale_UK_org_home	4.0	10	57	20	41	84	100	0	0	0	0.84
wheat_DE_org_home	5.2	30	170	20	44	84	100	0	0	0	0.88
barley_DE_org_home	4.2	14	77	20	28	84	100	0	0	0	0.84
rye_DE_org_home	4.0	10	57	20	43	84	100	0	0	0	1
Triticale_DE_org_home	4.0	10	57	20	41	84	100	0	0	0	0.84
wheat_DK_org_home	4.9	30	170	20	42	84	100	0	0	0	0.88
barley_DK_org_home	3.5	14	77	20	25	84	100	0	0	0	0.84
rye_DK_org_home	4.3	8	43	20	45	84	100	0	0	0	1
Triticale_DK_org_home	4.3	8	43	20	43	84	100	0	0	0	0.84
wheatmiddlings_FR	4.4	30	170	20	39	101	100	0	0	0	0.88
Maizeglutenfeed_FR	4.4	30	170	0	33	101	100	0	0	0	0.88
Bread meal_FR	4.4	30	170	0	29	101	100	0	0	0	0.88
Soybean expellar_AR	2.6	0	0	133	48	67	100	0	0	0	1
Rapeseed expellar_DE	2.6	23	128	20	36	92	100	0	0	0	0.9
Rapeseed expellar_UK	2.2	23	128	20	32	92	100	0	0	0	0.9
Rapeseed expellar_DK	2.3	23	128	20	33	92	100	0	0	0	0.9
Soybean oil_VS_NL	2.6	0	0	99	48	67	100	0	0	0	1
Sugar beet pulp_NL	45.0	15	85	0	93	101	100	0	0	0	1
wheatstraw_NL_org_home	2.0	33	187	0	56	84	100	0	0	0	0.12
wheatstraw_UK_org_home	2.0	33	187	0	52	84	100	0	0	0	0.12
wheatstraw_DE_org_home	2.0	30	170	0	49	84	100	0	0	0	0.12
wheatstraw_DK_org_home	2.0	30	170	0	47	84	100	0	0	0	0.12
sunflowerseed expellar	2.0	5	31	0	24	92	100	0	0	0	1
peas	3,5	6	36	150	42	92	100	0	0	0	1
soybean	2,6	0	0	133	48	67	100	0	0	0	1

Processing and transport

Grain cereals are used as feed ingredient without being processed. For inland produced cereals we assume 75, 75 and 125 km transport with resp. boat, train and truck. For homegrown cereals we assume a value of zero for transport distance. For producing pig feed we use a default value of 15 m3 gas per ton feed produced. For transport of pig feed from feed producer to pig farm we use a default transport distance of 50 km (truck).

Table A1.8 Input data concerning transport and processing of conventional feedstuffs (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, TH = Thailand, AR = Argentina, ML = Malaysia, VS = United States of America, PK = Pakistan)

	Transport field to process 1				Energy use process 1			All. process 1		Transport process 1 to process 2				Energy use process 2		All. process 2		Transport process 2 to feed producer		
	bulk carrier km	train km	ship km	truck km	diesel kg	electricity kWh	gas m3	in_out	all.fact	bulk carrier km	train km	ship km	truck km	electricity kWh	gas m3	in_out	all.fact	bulk carrier km	ship km	truck km
Tapioca_TH	0	0	0	200	5	0	0	2.4	1	17000	0	0	350	0	0	1	1	0	0	0
wheatmiddlings_FR	0	75	75	75	0	80	5	5.55	0.073	0	0	0	350	0	0	1	1	0	0	0
Maizeglutenfeed_FR	0	75	75	75	65	125	34	3.73	0.178	0	0	0	350	0	0	1	1	0	0	0
Bread meal_FR	0	75	75	75	0	80	5	1.43	0.791	0	0	0	350	0	0	1	1	0	0	0
Soybean meal_AR	0	0	0	300	0	35	45	1.39	0.588	12200	63	367	560	0	0	1	1	0	0	0
Rapeseed meal_DE	0	75	75	75	0	45	18	1.77	0.22	0	0	0	350	0	0	1	1	0	0	0
Rapeseed meal_UK	0	75	75	75	0	45	18	1.77	0.22	0	0	0	350	0	0	1	1	0	0	0
Rapeseed meal_DK	0	75	75	75	0	45	18	1.77	0.22	0	0	0	350	0	0	1	1	0	0	0
Palm kernel extracted_ML	0	0	0	5	0.6	0	0	18.8	0.137	0	0	0	80	94.13	0	1.919	0.1	15500	76	219
Palm kernel extracted_Mlpeat	0	0	0	5	0.6	0	0	18.8	0.137	0	0	0	80	94.13	0	1.919	0.1	15500	76	219
Soybean oil_VS_NL	8700	63	367	1360	0	35	45	5.7	0.385	0	0	0	350	0	0	1	1	0	0	0
Sugar canmolasses_PK	0	0	0	200	15	0	0	4.35	0.04	11500	0	60	350	0	0	1	1	0	0	0
Sugar beet pulp_NL	0	75	75	75	1.14	0.48	25.4	3.33	0.08	0	0	0	350	0	0	1	1	0	0	0

TableA1.9 Input data concerning transport and processing of organic feedstuffs (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, AR = Argentina, VS = United States of America).

	Transport field to process 1				Energy use process 1			All. process 1		Transport process 1 to process 2				Energy use process 2		All. process 2		Transport process 2 to feed producer		
	bulk carrier km	train km	ship km	truck km	diesel kg	electricity kWh	gas m3	in_out	all.fact	bulk carrier km	train km	ship km	truck km	electricity _2 kWh	Gas m3	in_out	all.fact	bulk carrier km	ship km	truck km
wheatmiddlings_FR	0	75	75	75	0	80	5	5.55	0.073	0	0	0	350	0	0	1	1	0	0	0
Maizeglutenfeed_FR	0	75	75	75	65	125	34	3.73	0.178	0	0	0	350	0	0	1	1	0	0	0
Bread meal_FR	0	75	75	75	0	80	5	1.43	0.791	0	0	0	350	0	0	1	1	0	0	0
Soybean expellar_AR	0	0	0	300	0	35	45	1.39	0.588	12200	63	367	560	0	0	1	1	0	0	0
Rapeseed expellar_DE	0	75	75	75	0	70	0	1.49	0.350	0	0	0	350	0	0	1	1	0	0	0
Rapeseed expellar_UK	0	75	75	75	0	70	0	1.49	0.350	0	0	0	350	0	0	1	1	0	0	0
Rapeseed expellar_DK	0	75	75	75	0	70	0	1.49	0.350	0	0	0	350	0	0	1	1	0	0	0
Soybean oil_VS_NL	8700	63	367	1360	0	35	45	5.70	0.385	0	0	0	350	0	0	1	1	0	0	0
Sugar beet pulp_NL	0	75	75	75	1.14	0	25	3.33	0.080	0	0	0	350	0	0	1	1	0	0	0
sunflowerseed expellar	0	75	75	75	0	0	0	1.00	1.000	0	0	0	350	0	0	1	1	0	0	0
peas	0	75	75	75	0	0	0	1.00	1.000	0	0	0	350	0	0	1	1	0	0	0
soybean	0	0	0	300	0	0	0	1.00	1.000	12200	63	367	560	0	0	1	1	0	0	0

Table A1.10 Feed composition[1] *(as percentage of concentrate) and feeding value* (NL = Netherlands, FR = France, TH = Thailand, AR = Argentina, ML = Malaysia, VS = United States of America, PK = Pakistan).

	Conventional feed				Organic feed			
	Netherl.	England	Germany	Denmark	Netherl.	England	Germany	Denmark
wheat inland	2.5%	15.0%	17.5%	20.0%	2.5%	15.0%	17.5%	20.0%
barley inland	2.5%	15.0%	17.5%	20.0%	2.5%	17.5%	20.0%	20.0%
rye inland		5.0%	5.0%	5.0%				
triticale inland		5.0%	5.0%	5.0%				
oats inland						10.0%	10.0%	10.0%
wheat inland_home		15.0%	12.5%	10.0%		15.0%	12.5%	10.0%
barley inland_home		15.0%	12.5%	10.0%		17.5%	15.0%	15.0%
wheat abroad	17.5%				22.5%			
barley abroad	17.5%				22.5%			
Tapioca_TH	10.0%							
wheatmiddlings_FR	10.0%				7.5%			
Maizeglutenfeed_FR	2.5%							
Bread meal_FR	5.0%							
Soybean meal_AR	12.5%	14.0%	10.0%	14.0%				
Soybean expellar_AR					7.5%	5.0%	2.5%	5.0%
Rapeseed meal_inland		7.5%	12.5%	7.5%				
Rapeseed meal_abroad	7.5%							
Rapeseed expellar_inland						7.5%	10.0%	7.5%
Rapeseed expellar_abroad					12.5%			
Palm kernel extracted_ML	1.9%	0.8%	0.8%	0.8%				
Palm kernel extracted_Mlpeat	0.6%	0.3%	0.3%	0.3%				
Soybean oil_VS_NL	1.5%	2.0%	2.0%	2.0%		1.5%	1.5%	1.5%
Sugar canmolasses_PK	4.0%	4.0%	3.0%	4.0%	2.5%			
Sugar beet pulp_NL	1.0%							
sunflowerseed expellar					2.5%			
peas					12.5%			
fish meal						7.5%	7.5%	7.5%
Gross Energy (GE) (MJ)	16.6	16.2	16.3	16.2	15.7	16.4	16.4	16.4
Digestible Energy (DE) (% from GE)	79.9%	82.6%	81.7%	82.6%	80.4%	80.8%	80.5%	80.8%
EW	1.08	1.08	1.08	1.08				
N-content	25.3	26.1	25.8	26.1	27.2	27.5	27.0	27.5

[1] The sum of ingredients is not 100% but 95% - 98%. Ingredients that complete the 100% are for instance minerals, salt, vitamins etc. The carbon footprint for feed is calculated for this fraction of ingredients and extrapolate for 100%.

Table A1.11 Carbon footprint (in kg CO2 eq per ton) of conventional feedstuffs (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, TH = Thailand, AR = Argentina, ML = Malaysia, VS = United States of America, PK = Pakistan).

	crop production excl LULUC	processing	transport	Sink	Landgebruik	Landconversie	total excl LULUC	total incl LULUC
wheat_NL	456	30	28	43	175	0	514	732
barley_NL	310	30	28	58	237	0	368	663
rye_NL	432	30	28	94	385	0	490	968
Triticale_NL	311	30	28	65	267	0	369	701
wheat_UK	481	30	28	46	187	0	539	771
barley_UK	328	30	28	60	245	0	386	691
rye_UK	423	30	28	72	295	0	480	847
Triticale_UK	353	30	28	71	292	0	411	774
wheat_DE	461	30	28	47	194	0	519	761
barley_DE	288	30	28	58	237	0	346	641
rye_DE	395	30	28	82	338	0	452	872
Triticale_DE	314	30	28	60	246	0	372	678
wheat_DK	479	30	28	51	208	0	537	796
barley_DK	317	30	28	68	279	0	375	721
rye_DK	420	30	28	83	340	0	478	901
Triticale_DK	341	30	28	68	279	0	399	746
wheat_FR	479	30	53	50	205	0	562	817
barley_FR	270	30	53	55	226	0	353	634
rye_FR	383	30	53	92	378	0	465	936
Triticale_FR	305	30	53	68	279	0	388	735
wheat_UK_conv_home	472	30	5	46	187	0	506	739
barley_UK_conv_home	317	30	5	60	245	0	352	657
rye_UK_conv_home	405	30	5	72	295	0	440	807
Triticale_UK_conv_home	370	30	5	71	292	0	404	767
wheat_DE_conv_home	452	30	5	47	194	0	486	728
barley_DE_conv_home	276	30	5	58	237	0	311	606
rye_DE_conv_home	410	30	5	82	337	0	445	865
Triticale_DE_conv_home	308	30	5	60	246	0	343	649
wheat_DK_conv_home	478	30	5	51	208	0	512	771
barley_DK_conv_home	315	30	5	68	279	0	349	696
rye_DK_conv_home	417	30	5	83	340	0	452	875
Triticale_DK_conv_home	339	30	5	68	279	0	374	721
Tapioca_TH	169	72	208	58	236	0	450	744
wheatmiddlings_FR	199	52	52	20	83	0	304	407
Maizeglutenfeed_FR	316	268	57	32	132	0	641	806
Bread meal_FR	557	91	65	57	232	0	713	1002
Soybean meal_AR	432	113	201	134	550	849	746	2280
Rapeseed meal_DE	371	53	52	39	160	0	475	674
Rapeseed meal_UK	384	53	52	46	190	0	489	725
Rapeseed meal_DK	381	52	52	40	164	0	485	690
Palm kernel extracted_ML	973	41	135	11	44	102	373	529
Palm kernel extracted_Mlpeat	1497	275	569	11	44	102	1149	1306
Soybean oil_VS_NL	196	30	68	361	1477	0	2341	4179
Sugar canmolasses_PK	9	39	126	2	6	0	173	181
Sugar beet pulp_NL	14	44	50	2	7	0	109	118

Table A1.12 Carbon footprint (in kg CO2 eq per ton) of organic feedstuffs (NL = Netherlands, UK = England, DE = Germany, DK = Denmark FR = France, AR = Argentina, VS = United States of America).

	crop production excl LULUC	processing	transport	Sink	Landgebruik	Landconversie	total excl LULUC	total incl LULUC
wheat_NL	336	30	28	64	184	0	393	641
barley_NL	292	30	28	85	242	0	350	676
rye_NL	340	30	28	106	302	0	398	806
Triticale_NL	282	30	28	89	254	0	340	683
wheat_UK	350	30	28	69	197	0	408	674
barley_UK	302	30	28	87	248	0	360	694
rye_UK	379	30	28	106	302	0	437	845
Triticale_UK	315	30	28	89	254	0	373	715
Oats_UK	379	30	28	106	302	0	437	845
wheat_DE	341	30	28	72	205	0	399	675
barley_DE	272	30	28	85	242	0	330	656
rye_DE	379	30	28	106	302	0	437	844
Triticale_DE	315	30	28	89	254	0	373	715
Oats_DE	379	30	28	106	302	0	436	844
wheat_DK	355	30	28	76	217	0	413	706
barley_DK	316	30	28	102	290	0	374	765
rye_DK	312	30	28	98	281	0	370	750
Triticale_DK	259	30	28	83	236	0	317	636
Oats_DK	312	30	28	99	281	0	370	749
wheat_FR	386	30	53	85	242	0	468	795
barley_FR	456	30	53	155	442	0	538	1135
rye_FR	555	30	53	202	575	0	638	1414
Triticale_FR	463	30	53	169	483	0	545	1197
wheat_UK_org_home	350	30	5	69	197	0	384	650
barley_UK_org_home	302	30	5	87	248	0	336	671
rye_UK_org_home	380	30	5	106	302	0	414	822
Triticale_UK_org_home	315	30	5	89	254	0	350	692
wheat_DE_org_home	341	30	5	72	205	0	375	651
barley_DE_org_home	272	30	5	85	242	0	306	633
rye_DE_org_home	379	30	5	106	302	0	413	822
Triticale_DE_org_home	315	30	5	89	254	0	350	693
wheat_DK_org_home	355	30	5	76	217	0	390	683
barley_DK_org_home	316	30	5	102	290	0	350	741
rye_DK_org_home	312	30	5	98	281	0	347	726
Triticale_DK_org_home	259	30	5	83	236	0	294	613
wheatmiddlings_FR	168	52	52	34	98	0	272	404
Maizeglutenfeed_FR	368	268	57	56	160	0	692	909
Bread meal_FR	633	91	65	96	273	0	790	1159
Soybean expellar_AR	425	113	201	134	384	855	739	2112
Rapeseed expellar_DE	344	48	54	76	219	0	447	742
Rapeseed expellar_UK	399	48	54	90	258	0	502	850
Rapeseed expellar_DK	384	48	54	86	247	0	486	819
Soybean oil_VS_NL	1028	275	569	361	1030	0	1872	3263
Sugar beet pulp_NL	14	44	50	3	7	0	108	118
wheatstraw_NL_org_home	191	30	5	25	73	0	225	323
wheatstraw_UK_org_home	184	30	5	25	72	0	219	317
wheatstraw_DE_org_home	170	30	5	25	73	0	205	303
wheatstraw_DK_org_home	168	30	5	25	72	0	203	301
sunflowerseed expellar	464	30	63	212	604	0	556	1373
peas	536	30	63	121	346	0	629	1095
soybean	521	30	207	164	469	1046	758	2437

Table A1.13 Carbon footprint (kg CO2 eq per ton) conventional pig feed.

	crop production excl LULUC	processing	transport	Sink	Landgebruik	Landconversie	total excl LULUC	total incl LULUC
Netherlands	340	64	102	60	112	244	506	922
England	414	47	59	69	123	285	520	997
Germany	394	45	52	65	88	268	491	913
Denmark	411	48	62	74	123	301	521	1018

Table A1.14 Carbon footprint (kg CO2 eq perton) organic pig feed.

	crop production excl LULUC	processing	transport	Sink	Landgebruik	Landconversie	total excl LULUC	total incl LULUC
Netherlands	369	39	58	96	68	273	466	902
England	335	37	40	87	44	248	412	791
Germany	314	36	38	84	22	240	388	735
Denmark	334	37	43	93	44	266	412	816

Table A1.15 The share of 100,000 (expressed as percentage) repetitions in the Monte Carlo simulations with a comparable (positive or negative) difference between the carbon footprint of organic pork production in the mentioned countries.

difference	Share of repetitions with same outcome
Germany < Netherlands	73%
Germany < England	78%
Germany < Denmark	77%
Denmark < Netherlands	69%
Denmark <England	67%

Table A1.16 The share of 100,000 (expressed as percentage) repetitions in the Monte Carlo simulations with a comparable (positive or negative) difference between the carbon footprint of organic and conventional pork production in the same country.

difference	Share of repetitions with same outcome
Netherlands organic < Netherlands conventional	90%
England organic < England conventional	> 99%
Germany organic < Germany conventional	> 99%
Denmark organic < Denmark conventional	> 99%

Annex 2: Pig production

A2.1 Introduction

A major part of the emissions of the pork production chain occurs on pig farms. The activities of animal production farms can be divided into animal production and feed production. Feed production, including compound feed supply and production of wet co-products from bio-fuel production, is modelled as external supplying activities to the animal production. In organic systems and in some conventional systems, animal production occurs partly inside animal housing facilities and partly in the field. The presence of animals inside or outside is an important factor for calculating greenhouse gas emissions. Greenhouse gas emissions from animal production can be calculated in relation to the number of animals in the farm, the growth rate of animals, the type of hardware that is used on the farm, and the excretion in the field and inside animal housing facilities. Figure A2.1 gives an overview of greenhouse gas emissions in the pork production system.

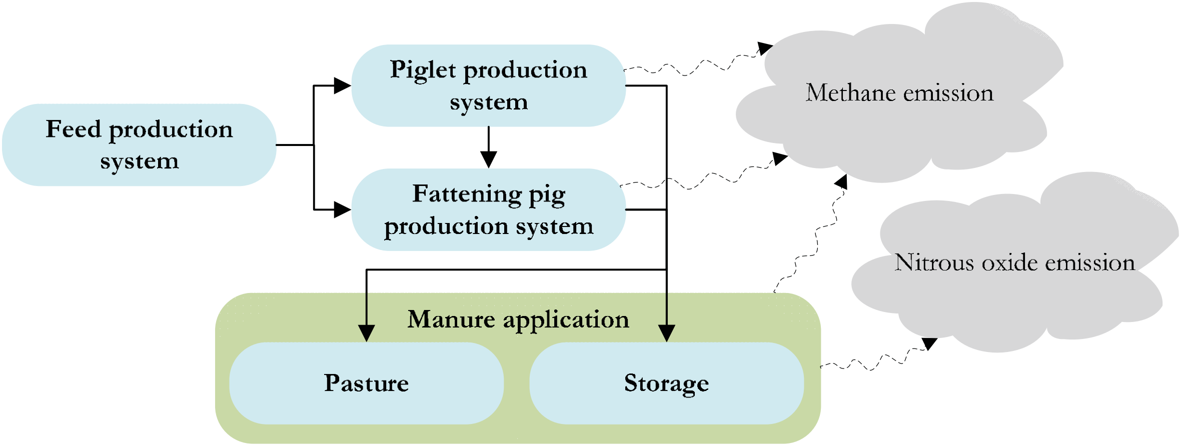

Figure A2.1 Overview of greenhouse gas emissions in the pork production system

A2.2 General system description

Raising piglets and pigs are activities that usually occur in separate systems. In some cases, piglet raising occurs in one country and pig fattening in another. Therefore, we model these systems separately. Closed pig farming systems, where the pigs are raised from birth to slaughtering, can be evaluated in the model by combining the results of raising piglets and pigs (for examples see Blonk 2004).

The greenhouse gas emissions of a livestock farm is the sum of all individual and relevant emissions in the livestock system including the emission from production of possible starting material. For example: the greenhouse gas emission from pork production systems is the sum of emissions from sources such as manure storage causing methane emission including the emission from production of piglets as starting material.

A2.3 Emission from feed use

The greenhouse gas emissions from feed use are the product of feed use (Table A2.11 and Table A2.12) multiplied with the greenhouse gas emission score per ton feed (see Annex 1 Table A1.11 and A1.12).

A2.4 Methane emission from manure management

For calculating methane emissions from manure management, the Tier 2 methodology that was proposed by IPCC is used. Manure production (VS and B0) and characteristics of the manure management system (MCF) determines the methane emissions. Based on the IPCC Guidelines 2006 and the Dutch NIR 2008, the following equation is used:

Methane emissions from manure management = VS * 365 * B0 * MCF * 0.662

Manure, VS and B0:
Excretion of volatile solid (VS) in manure is one of the determining factors for methane emissions from manure management and depends on feed characteristics. The amount of Gross Energy (GE) intake and Digestibility (DE) determines the excretion of volatile solid as follows:

VS = (GE * (1-DE) + (UE*GE))* ((1-ASH)/18,45)

GE and DE are known from the feeding values (see Table A1.8) UE stands for urinary energy and states the fraction of energy that is lost in urine. Corresponding IPCC (2006) we use the a default value of 0.02 MJ/MJ for swine. ASH is the mass fraction ash of manure for which we use a default value of 0.02 kg/kg according to the Danish NIR (Nielsen e.a., 2008). Besides VS that originates from feed, VS in manure can also originate from other sources like straw, which is used as bedding and ends up in manure. This source is not included in the calculations in this study, but we recommend to determine the possible attribution of this source to the VS content of manure and related methane emissions.

Another determining factor for methane emissions from manure is B0. B0 is the maximum methane producing capacity fraction for manure. This fraction is determined by the degradability of the organic matter in the manure; therefore, it depends on feed composition. In this study we use the value given by the Dutch Inventory Report (NIR 2008): 0.34 kg/kg for breeding and market swine.

Manure management, MCF:
The Methane Conversion Factor (MCF) is the fraction of the maximum potential of methane production that is produced. This fraction depends on manure management (type and length of storage, cover), temperature and the amount of inoculum, i.e., material including methanogenic bacteria.. The MCF's for manure management were determined for each manure compartment Two methane conversion factors were determined for summer and winter temperatures (Table 3) since considerable differences will occur in these time periods due to environmental temperature differences.

In order to distinguish between countries and systems, IPPC (2006) default values for MCF's were used and adjusted to reflect temperature differences between countries (see Table 3). This was done by using the model ANIPRO, available at Wageningen University. Inoculum amount was kept constant (15%), a storage time (depending on the system) was used as input, and average temperatures for each country were applied (van Ouwerkerk, 1999). ANIPRO is used to calculate the methane production under these conditions. This factor is used to calculate the deviation from the reference (Table A2.3 – A2.5). Results are presented in Table A2.1.

The MCFs for solid manure were IPCC defaults without adjustment for temperatures. Temperatures inside the heap is not affected considerably by outside temperature.

The MCF used to calculate methane emissions from manure management for a individual pig production system is the result of the sum of the individual fractions of manure in manure management multiplied by the specific MCF (as in table A2.1). For instance conventional sows in the Netherlands produce 50% of the manure in the pit in summer for short storage, 37.5% of the manure is stored for long time outside in silo and 12.5 % is stored in pit, the total MCF is 50% * 3% + 37.5% * 13.69% + 12.5% * 32% = 10.6%

Table A2.1 The MCF's for the different manure management systems in different countries

Type of manure	location	Length and season	Netherlands	England	Germany	Denmark
Liquid manure	Pit inside	Short storage[1], summer	3%	3%	3%	3%
		Long storage[2], winter	32%	32%	32%	32%
Liquid manure	Pit below outdoor run	Short storage, summer	2.75%	Non relevant	2.80%	2.6%
		Long storage, winter	18.2%	Non relevant	16.06%	16.6%
Liquid manure	Silo, incl inside pit	Long storage, winter (including short storage in inside pit before pumped into silo	13.7%	20%	12.47%[3] / 20%	12.77 %
	silo, incl outside pit	Long storage, winter (including short storage in outside pit before pumped into silo	13.0%	19.26%	11.65%[3] / 19.18%	11.98 %
Solid manure	Inside pig house	Long storage, whole year	5%	5%	5%	5%
Solid manure	outside	Long storage, whole year	2%	2%	2%	2%
Liquid/solid	Paddock/pasture	summer	1%	1%	Non relevant	1%

[1] Short storage is < 1 month. This is relevant for summer time when manure is applied regular and in winter when manure is pumped into silo. We assumed that in these cases storage time is on average 14 days.

[2] Long storage is > 1 month. This is relevant for winter time when manure has to be stored for application in next growth season. We assume a maximum storage time of 6 and 12 months for resp. liquid and solid manure for all countries.

[3] low / high value for resp. covered silo in conventional and uncovered silo in organic German pig production.

Table A2.2: Average outside temperatures per country for time periods March – August and September – February (UK = England, NL = Netherlands, GE = Germany and DK = Denmark).

		Average temp °C
UK	March - Aug	11.5
	Sept - Feb	7.3
NL	March - Aug	14.0
	Sept - Feb	8.0
GE	March - Aug	14.6
	Sept - Feb	6.4
DK	March - Aug	12.1
	Sept - Feb	6.8

Reference scenarios were created that set the basis for the temperature adjustments. Table A2.3 shows the reference scenario for 14 days storage at 17 degrees Celsius. The MCF is the amount of methane produced in pit storage below animal confinements at a storage time smaller than a month. A biogas production figure was calculated in ANIPRO according to these data.

Table A2.3: Reference data for 14 days storage at 17 degrees.

Reference 14 days storage at 17 deg			
temp	days	MCF	Anip
17	14	3.0	0.006729

Table A2.4 presents the reference data for the range storage of liquid slurry. The MCF is the default for storage under animal confinements longer than a month at lower than 10 degrees.

Table A2.4: Reference data for range in summer time.

Reference range (uitloop) summer			
temp	days	MCF	Anip
7.1	104	17	0.02036

Table A2.5 shows the reference for outside silo storage with an MCF for liquid slurry storage with natural crust cover. For England a default MCF was used (17%) considering no cover applied on the storage facilities.

Table A2.5: Reference data for outside silo storage.

Reference silo outside storage			
avg temp	days	MCF	Anip
7.1	90	10	0.01834

A2.4.1 Nitrous oxide emissions from manure management

Concerning nitrous oxide emission we distinguish direct and indirect emissions. Direct emission is the emission of nitrous oxide which is directly formed from nitrogen in manure stored. Indirect nitrous oxide emissions are caused by volatilization of ammonia and NO_x, which convert into nitrous oxide after deposition.

Nitrogen excretion

Both are linear related to the amount of nitrogen excreted in manure. The nitrogen excretion of pigs is calculated as the result of nitrogen ingested with feed subtracted whit nitrogen retention in growth or other animal products (like milk, wool and young animals). Nitrogen uptake is the result of nitrogen content in feed (Table A1.8) multiplied with feed intake (Table A2.11 and Table A2.12). The retention of nitrogen in growth of pigs depends on growth rate and nitrogen mass fraction in body mass (other animal products like milk or wool are not relevant for this study). For nitrogen mass fraction of body mass, we use a default value (assuming that pigs do not differ in average nitrogen content in body mass) (Table A2.6).

Table A2.6 The nitrogen content of body mass in pigs (Jongbloed e.a. 2002 and Jongbloed & Kemme 2002)

	fN_{body} (g N/kg body mass)
Dead piglets during rearing	23.1
Living piglets raised	24.8
Sows	25.0
Fattening pigs	25.0

A2.4.2 Direct nitrous oxide emissions from manure management

Based on the IPCC Guidelines 2006 and the Dutch NIR 2008 the direct nitrous oxide emissions from manure management is calculated as the result of N excreted in a specific manure management system multiplied with the specific emission factor for that system :

direct nitrous oxide emissions from manure management = N-excretion * EF mmN2O * 44/28

The emission factors for the direct nitrous oxide emissions from the different manure management systems are given in Table A2.7 according the IPCC Guidelines 2006..

Table A2.7 The emission factor (EF) for nitrous oxide emission from manure management (kg N-N_2O per kg N), according to the IPCC Guidelines 2006

	Emission factor (kg N-N_2O/kg N)
Solid manure, inside pig house	0.02
Solid manure, storage outside	0.005
Liquid manure, inside pig house	0.002
Liquid manure, storage outside with cover	0.005
Liquid manure, storage outside without cover	0

A2.4.3 Indirect nitrous oxide emissions from manure management

The volatilization of ammonia from the pig house and manure storage is calculated from the nitrogen excreted. For the ammonia volatilization from stored manure the amount of nitrogen stored is corrected for the volatilized nitrogen in a pig house. The volatilization of ammonia for the different cases are given in Table A2.8. Several sources were used as indicated below. For the Dutch conventional and ammonia reduction systems, factors during storage from (Steenvoorden e.a., 1999) were used. Main differences are observed between conventional and organic systems, with organic systems having higher nitrogen volatilization rates. For the conventional storage systems in England no nitrous oxide emits due to open tank storage. On the other hand high ammonia volatilization rates occur. To calculate the indirect nitrous oxide emissions from volatilized ammonia the volatilized nitrogen is multiplied with the emissions factor 0.01 (according to the IPCC Guidelines 2006).

TableA2.8.The fraction of nitrogen excreted in pig housing and stored in storage that emits as ammonia (kg N-NH_3 / kg N) (Steenvoorden e.a., 1999; Oenema e.a., 2000; Hutchings e.a., 2001; Webb e.a., 2004; Groenestein e.a., 2005; IPCC, 2006; Dämmgen, 2007)

	Pig house				Storage	
	Lactating sows	Dry sows	piglets	Finishing pigs	sows	Finishing pigs
Netherlands liquid	0.14	0.15	0.06	0.11	0.019	0.019
Netherlands solid	0.27	0.15	0.18	0.28	0.019	0.019
England liquid	0.27	0.25	0.18	0.28	0.094	0.087
England solid	0.17	0.17	0.08	0.18	Non relevant[1]	Non relevant[1]
Germany liquid	0.27	0.25	0.18	0.28	0.024[2]	0.017[2]
Germany solid	0.27	0.15	0.18	0.28	0.019	0.019
Denmark liquid	0.27	0.25	0.13	0.28	0.024	0.017
Denmark solid	0.17	0.17	0.18	0.28	0.019	0.019

[1] no solid manure storage because all the manure is excreted on the field

[2] for liquid manure stored in a non-covered silo in German organic pork production we assume the same emission factor as for liquid manure stored in a non-covered silo in England 0.094 and 0.087 for resp. sows and fattening pigs)

A2.5 Enteric fermentation

Enteric fermentation with formation of methane occurs in pigs, but is much less than in ruminants. Because enteric fermentation for swine is not a key source of greenhouse gas emissions, the IPCC Guidelines 2006 suggest the use of a fixed amount of methane emission due to enteric fermentation by sows and fattening pigs. The emission factor for sows includes the emission due to enteric fermentation of piglets. The emission of methane from enteric fermentation is 1.5 kg CH_4 per average present pig.

A2.6 Manure application and grazing

In some pork production systems animals (partly) spend time outside on pastures. In Denmark and especially in England sows stay outside for a large part of the year in biological systems. Also, in many cases part of the ration is grown on the same farm. Examples of feed grown on the farm is wheat and corn cob mix. When the pigs are on the pastures, faeces and urine are excreted there. Also, manure can be applied on cropping field on the same farm.

The greenhouse gas emissions from grazing and manure application are calculated as described in Section A1.3. For grazing the fraction of nitrogen excreted in faeces and urine is set as a default of respectively 29 and 71% from total nitrogen excretion (based on Aarnink, 1997). For swine, no specific ammonia volatilization fraction is quantified to our knowledge. Van der Hoek e.a. (2002) give a value of 0.08 kg/kg for nitrogen excreted by dairy cattle in pasture. This fraction is used for swine. No specific default for nitrate leaching due to manure deposited in pastures is given by IPCC. For swine, nitrate leaching in pastures is not quantified to our knowledge. Therefore, we used the IPCC-default of 0.3 kg nitrate nitrogen that is leached per kg nitrogen excreted in pasture or paddock.

As already mentioned in Annex 1, the emissions due to manure application and transport are allocated between producer and user analogues the active nitrogen content. The emissions due to application are allocated to the cropping system equal to the active nitrogen content. The remaining emissions (equal to 1 minus the active nitrogen content) are allocated to the pig farmer. This is applied for manure application outside the pig farm and for manure application at home grown crops.

A2.6 Energy use

The greenhouse gas emissions from energy used at the pig farm are calculated with the emission factors as described in Annex 1. Input data for energy use (see Table A2.9 and A2.10) were not available for all cases. For the missing cases, we assumed the same energy use as most related production system (see remarks at Table A2.9 and A2.10).

A2.7 Transport

For animal production transport of animals (piglets to fattening pig farm and pigs to slaughterhouse) and manure transport is relevant. For calculating emissions from this transport the same equations as described in Annex 1 are used. For animal transport by truck is relevant and the load was calculated as number of animals multiplied with weight per animal. For animal transport we assumed a loading capacity of 12 and 24 ton for respectively piglet and fattening pig transport. Manure is also only transported by truck with 80% loading fraction, additional distance of 100% and loading capacity of 20 and 30 ton for resp. solid and liquid manure.

A2.8 Overview of input data and results

In the following tables an overview is given of input data concerning pig production. Table A2.9a,b and Table A2.10a,b give an overview of the characteristics of the different conventional and organic pig production systems. On the basis of these data, emission factors for methane (MCF, Table A2.1) and ammonia are derived by Livestock Research, Wageningen UR (Table A2.8). The figures in these tables are based on expert judgments and verified by experts from the different countries. Table A2.11 and A2.12 gives the technical results for the different pork production systems. In Table A2.13 to 16, the values are given for energy use and transport used in this study. Tables A2.17 to 19 give an overview of the results for the calculations of the carbon footprint of pork in this study.

Table A2.9a overview of characteristics of housing at conventional pig farming

	Netherlands	England	Germany	Denmark
Lactating sows	Traditional farrowing crate	Traditional farrowing crate	Traditional farrowing crate	Traditional farrowing crate
Area per sow	4.5 m^2	4.5 m^2	4.5 m^2	4.5 m^2
Surface	Fully slatted	Fully slatted	Fully slatted	Fully slatted
NH3 reduction[1]	65%	no	no	no
Empty and dry sows and gilts:	Group housing,ESF (Electronic Sow Feeding); no straw	Group housing, straw as bedding	Group housing, no straw	Group housing, no straw
Area per sow/gilt	2.25m^2	2.0m^2	2.25m^2	2.25m^2
Surface indoor	Partly slatted (0.95 m^2 slatted 1.3m^2 solid)	Partly slatted (50% slatted 50% solid)	Partly slatted (50% slatted 50% solid)	Partly slatted (50% slatted 50% solid)
NH3 reduction	45%	no	no	no
Piglets:	Groups of 10-40 pigs	Groups of 20-50 pigs	Groups of 10-40 pigs	Groups of 10-40 pigs
Area per piglet	0.35 m^2	0.3 m^2	0.3 m^2	0.35 m^2
Surface indoor	Fully slatted	Fully slatted	Fully slatted	Partly slatted (2/3 slatted 1/3 solid)
NH3 reduction	69%	no	no	no
Growing / finishing Pigs:	Groups of 15 animals	Groups of 15 pigs	Groups of 15 pigs	Groups of 15 pigs
Area per pig	0.8 m^2	0.65 m^2	0.65 m^2	0.65 m^2
Surface indoor	Partly slatted (60% slatted 40% solid)	Fully slatted	Fully slatted	Fully slatted
NH3 reduction	60%	no	no	no

[1] compared to traditional housing

Table A2.9b overview of characteristics of manure management at conventional pig farming

	Netherlands	England	Germany	Denmark
Manure production indoor	100%	100%	100%	100%
Proportion solid manure vs. liquid manure (slurry)	100% liquid manure	100% liquid manure	100% liquid manure	100% liquid manure
Description liquid manure storage	75% Outside in covered silo 25% in indoor slurry pit	50% outside uncovered silo; 50% indoor slurry pit	75% Outside in covered silo 25% in indoor slurry pit	75% Outside in Non-covered silo with straw crust 25% in indoor slurry pit
Duration liquid manure storage	6 months	6 months	6 months	6 months

Table A2.10a overview of characteristics of housing at organic pig farming

	Netherlands	England	Germany	Denmark
Lactating sows	Farrowing pen	Outdoor hut	Farrowing pen	Outdoor hut
Indoor: Area per sow	7.5 m^2	No	7.5 m^2	No
Indoor: Surface	4.5 m^2 solid with straw, 3 m^2 fully slatted with scraper	No	4.5 m^2 solid with straw, 3 m^2 fully slatted + scraper	No
Outdoor run: Area per sow	4 m^2	No	4 m^2	No
Outdoor run: Surface	Partly slatted (50% slatted 50% solid)	No	Partly slatted (50% slatted 50% solid)	No
Paddock: Area per sow	No	1417 m^2 / av sow	No	833 m^2 / av sow
Empty and dry sows and gilts:	Group housing,ESF (Electronic Sow Feeding); straw	Outdoor hut	Group housing,ESF (Electronic Sow Feeding); straw	Outdoor hut
Indoor: Area per sow	2.5 m^2	No	2.5 m^2	No
Indoor: Surface	Partly slatted: 75% solid with straw as bedding material	No	Partly slatted: 75% solid with straw as bedding material	No
Outdoor run: Area / sow	2 m^2	No	2 m^2	No
Outdoor run: Surface	Partly slatted (50% slatted 50% solid)	No	Partly slatted (50% slatted 50% solid)	No
Paddock: Area per sow	158 m2	1417 m^2 / av sow	No	833 m^2 / av sow
Piglets:	Groups of 20-50 pigs	Outdoor hut	Groups 20-50 pigs	Groups 20-60 pigs
Indoor: Area per piglet	0.6 m^2	No	0.6 m^2	0.6 m^2
Indoor: Surface	0.4 m^2 solid, straw bedding, 0.2 m^2 slatted floor	No	0.4 m^2 solid straw bedding and 0.2 m^2 slatted floor	0.4 m^2 solid straw bedding and 0.2 m^2 slatted floor
Outdoor run: Area per piglet	0.4 m^2	No	0.4 m^2	0.4 m^2
Outdoor run: Surface	Partly slatted (50% slatted 50% solid)	No	Partly slatted (50% slatted 50% solid)	Partly slatted (50% slatted 50% solid)
Paddock: Area per piglet	No	1417 m^2 / av sow	No	No
Growing / finishing Pigs:		Outdoor hut		
Indoor: Area per pig	1.3 m^2	No	1.3 m^2	1.3 m^2
Indoor: Surface	Partly slatted (25% slatted 75% solid)	No	Partly slatted (25% slatted 75% solid)	Partly slatted (25% slatted 75% solid)
Outdoor run: Area per pig	1 m^2	No	1 m^2	1 m^2
Outdoor run: Surface	Partly slatted (50% slatted 50% solid)	No	Partly slatted (50% slatted 50% solid)	Partly slatted (50% slatted 50% solid)
Paddock: Area per pig	No	1417 m^2 / av sow	No	No

Table A2.10b overview of characteristics of manure management at organic pig farming

MANURE MANAGEMENT	Netherlands	England	Germany	Denmark
Lactating sows:				
Manure production indoor/outdoor/paddock	5% / 95% / 0%	0 / 0 / 100%	5% / 95% / 0%	0 / 0 / 100%
Proportion solid manure vs. liquid manure (slurry)	10% / 90%	100% solid	10% / 90%	100% solid
Empty and dry sows and gilts:				
Manure production indoor/outdoor/paddock	15% / 65% / 20%	0 / 0 / 100%	15% / 85% / 0%	0 / 0 / 100%
Proportion solid manure vs. liquid manure (slurry)	15% / 85%	100% solid	15% / 85%	100% solid
Piglets:				
Manure production indoor/outdoor/paddock	5% / 95% / 0%	0 / 0 / 100%	5% / 95% / 0%	5% / 95% / 0%
Proportion solid manure vs. liquid manure (slurry)	10% / 90%	100% solid	10% / 90%	10% / 90%
Growing / finishing Pigs:				
Manure production indoor/outdoor/paddock	5% / 95% / 0%	0 / 0 / 100%	5% / 95% / 0%	5% / 95% / 0%
Proportion solid manure vs. liquid manure (slurry)	10% / 90%	100% solid	15% / 85%	15% / 85%
Manure storage:				
Description liquid manure storage	50% Outside in covered silo 50% in pit below floor outdoor run	Non relevant	50% outside in covered silo 50% in outdoor slurry pit	50% Outside silo with straw crust 50% in outdoor slurry pit
Duration liquid manure storage	6 months	Non relevant	6 months	6 months
Description solid manure storage	75% Outside on concrete floor, not covered 25% inside pig house	No storage, manure is spread on field	75% Outside on concrete floor, not covered 25% inside pig house	75% Outside on concrete floor, not covered 25% inside pig house
Duration solid manure storage	12 months	Non relevant	12 months	12 months

Table A2.11 technical results of conventional sow and finishing pig production in different countries

sows		Netherlands	England	Germany	Denmark
compound feed	kg/apa[1]	1953	2483	2081	2466
fodder	kg DM/apa	0	0	0	0
straw	kg/apa	0	0	0	0
piglets	#/apa	26.4	26.4	21.7	25.6
weight piglets	kg	25.4	35.4	30.1	30
price piglets	€/animal	45	60	51	44
sows for slaughter	kg LW[2]	92	93	87	124
price LW sows slaughter	€/kg	0.85	0.89	0.90	0.80
liquid manure	kg/apa	5100	5100	5100	5100
price liquid manure	€/ton	-15.10	-1.86	-2.69	-2.63
solid manure	kg/apa	0	0	0	0
price solid manure	€/ton	0.00	0.00	0.00	0.00
N excretion	kg N/apa	29.8	38.7	34.5	41.4
VS excretion	Kg/dy/apa	1.04	1.14	1.00	1.13

Fattening pigs		Netherlands	England	Germany	Denmark
compound feed	kg/apa	782	686	773	847
fodder	kg DM/apa	0	0	0	0
straw	kg/apa	0	0	0	0
pigs per year	#	3.12	4.03	2.94	4.04
growth rate	g/day	781	700	724	869
slaughter weight	kg LW	117	99	120	109
LW production	kg LW/apa	364	398	353	438
price LW	€/kg LW	1.17	1.22	1.20	1.04
liquid manure	kg/apa	1100	1100	1100	1100
price liquid manure	€/ton	-15.10	-11.15	-5.88	-5.91
solid manure	kg/apa	0	0	0	0
price solid manure	€/ton	0	0	0	0
N excretion	kg N/apa	12.5	11.2	13.2	13.9
VS excretion	Kg/dy/apa	0.42	0.31	0.37	0.39
FCR per 1000 LW[3]		2.7	2.6	2.9	2.7
N excretion per 1000 kg growth [3]	kg N/1000 kg growth	43.0	42.2	50.6	46.6

[1] apa= average present animal (sow or fattening pig)

[2] LW = live weight

[3] 1000 kg LW or growth combined for fattening pig production and sow production

Table A2.12 technical results of organic sow and finishing pig production in different countries

Sow production:		Netherlands	England	Germany	Denmark
compound feed	kg/apa[1]	2315	2264	2027	2758
fodder	kg DM/apa	183	183	183	183
straw	kg/apa	440	0	660	295
piglets	#/apa	19.9	17.5	15.8	21.2
weight piglets	kg	29	32	28.5	30
price piglets	€/animal	102	0	92	94
sows for slaughter	kg LW	76	92	92	104
price LW sows slaughter	€/kg	0.85	0.89	0.90	0.80
liquid manure	kg/apa	5500	5500	5500	5500
price liquid manure	€/ton	-10.00	0.00	0.00	-0.19
solid manure	kg/apa	440	0	660	295
price solid manure	€/ton	0.00	0.00	0.00	0.00
N excretion	kg N/apa	54.7	51.8	50.7	64.7
VS excretion	Kg/dy/apa	1.28	1.28	1.17	1.53

finishing pigs		Netherlands	England	Germany	Denmark
compound feed	kg/apa	784	894	808	815
fodder	kg DM/apa	0	0	0	0
straw	kg/apa	62	150	238	241
pigs per year	#	2.88	3.72	2.38	3.71
growth rate	g/day	680	693	578	753
slaughter weight	kg LW	115	100	117	104
LW production	kg LW/apa	332	372	279	386
price LW	€/kg LW	2.34	0.00	2.34	1.91
liquid manure	kg/apa	1300	1300	1300	1300
price liquid manure	€/ton	-10.00	0.00	0.00	-10.33
solid manure	kg/apa	62	150	238	241
price solid manure	€/ton	0	0	0	0
N excretion	kg N/apa	15.3	19.1	18.0	16.7
VS excretion	Kg/dy/apa	0.39	0.45	0.41	0.41
FCR per 1000 LW[2]		3.3	3.5	3.8	3.3
N excretion per 1000 kg growth [2]	kg N/1000 kg growth	68.9	79.9	91.7	71.5

Table A2.13 Energy use in conventional and organic sow production in different countries

		Conventional pig production				Organic pig production			
		Netherlands	England[2]	Germany[1]	Denmark	Netherlands[1]	England	Germany	Denmark
electricity	kWh/apa	206	287.8	206	287.8	206	0	271.4	153
gas	m3/apa	39	0	39	0	39	0	0	0
oil	l/apa	1.79	0	1.79	0	1.79	0	44.47	0
diesel	l/apa	1	0	1	0	1	0.05[3]	0	0

[1] Due to lack of data energy use of conventional sows in Germany and organic sows in the Netherlands are assumed to be the same as conventional Dutch sows

[2] Due to lack of data energy use of conventional sows in England are assumed to be the same as conventional Danish sows because both have no use of gas.

[3] Use of diesel for organic sows includes the use of diesel for organic fattening pigs

Table A2.14 Energy use in conventional and organic fattening pig production in different countries

		Conv. Neth.	Conv. Eng.	Conv. Ger.[1]	Conv. Den.	Org. Neth.	Org. Eng.	Org. Ger.[1]	Org. Den.
electricity	kWh/apa	33.29	5.75	33.29	48.48	33.29	0	33.29	22.26
gas	m3/apa	2.13	0	2.13	0	2.13	0	2.13	0
oil	l/apa	0	0	0	0	0	0	0	0
diesel	l/apa	0.89	0	0.89	0	0.89	0	0.89	0

[1] Due to lack of data energy use of conventional and organic fattening pigs in Germany are assumed to be the same as conventional Dutch fattening pigs

Table A2.15 The fraction of manure that is transported out of the pig farm for application elsewhere and transport distance.

	Conventional pig production		Organic pig production			
	liquid manure		liquid manure		Solid manure	
	fraction transported	km	fraction transported	km	fraction transported	km
Netherlands	1	150	1	150	1	200
England	0.25	50	0	/	0	/
Germany	0.33	50	0	/	0	/
Denmark	0.4	50	0	/	0	/

Table A2.16 The number of animals transported in a truck and the transport distance.

	Conventional		Organic		Conventional		Organic	
	piglets	km	piglets	km	fattening pigs	km	fattening pigs	km
Netherlands	200	50	100	75	200	100	100	150
England	200	75	100	100	150	150	75	200
Germany	100	75	50	100	100	150	50	200
Denmark	200	75	100	100	200	150	100	200

Table A2.17 The greenhouse gas emissions (kg CO2 eq per kg fresh meat at slaughterhouse) for the different general sources.

		feed excl. LULUC CO2,CH4,N2O	fodder and straw CO2,CH4, N2O	manure management CH4	enteric fermentation CH4	manure management N2O	grazing N2O	manure application N2O	energy use farm CO2	transport + application manure CO2	transport livestock CO2	energy use slaughterhouse CO2
conven-tional	Netherlands	2.20	0.00	0.51	0.18	0.14	0.00	0.23	0.21	0.04	0.02	0.03
	England	2.22	0.00	0.58	0.17	0.14	0.00	0.22	0.10	0.02	0.04	0.03
	Germany	2.27	0.00	0.47	0.19	0.21	0.00	0.25	0.22	0.02	0.06	0.03
	Denmark	2.29	0.00	0.43	0.15	0.20	0.00	0.24	0.11	0.02	0.03	0.03
organic	Netherlands	2.48	0.17	0.46	0.20	0.25	0.03	0.30	0.26	0.06	0.06	0.03
	England	2.40	0.15	0.06	0.19	0.00	1.44	0.00	0.00	0.00	0.11	0.03
	Germany	2.40	0.48	0.64	0.24	0.36	0.00	0.40	0.36	0.02	0.15	0.03
	Denmark	2.20	0.27	0.33	0.18	0.23	0.40	0.23	0.07	0.01	0.09	0.03

Table A2.18 The greenhouse gas emissions (kg CO2 eq per kg fresh meat at slaughterhouse) for the LULUC sources

		Loss of organic matter	Loss sink function	Land use change
Netherlands	Conventional	1.07	0.26	0.49
	Organic	1.46	0.51	0.36
England	Conventional	1.21	0.30	0.52
	Organic	1.44	0.51	0.26
Germany	Conventional	1.24	0.30	0.41
	Organic	1.49	0.52	0.14
Denmark	Conventional	1.32	0.32	0.54
	Organic	1.42	0.50	0.24

Table A2.19 The probability that the difference between the outcome for A and B (A minus B) is negative (B > A) or positive (A>B) (conv = conventional and org = organic) .

A	B	positive	negative
Netherlands conv	Netherlands org	8%	92%
England conv	England org	17%	83%
Germany conv	Germany org	6%	94%
Denmark conv	Denmark org	28%	72%
Netherlands conv	England conv	42%	58%
Netherlands conv	Germany conv	38%	62%
Netherlands conv	Denmark conv	37%	63%
England conv	Germany conv	46%	54%
England conv	Denmark conv	45%	55%
Germany conv	Denmark conv	49%	51%
Netherlands org	England org	52%	48%
Netherlands org	Germany org	29%	71%
Netherlands org	Denmark org	68%	32%
England org	Germany org	30%	70%
England org	Denmark org	63%	37%
Germany org	Denmark org	84%	16%