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# Impact of organic pig production systems on $CO_2$ emission, C sequestration and nitrate pollution

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## Abstract

Organic rules for grazing and access to outdoor area in pig production may be met in different ways, which express compromises between considerations for animal welfare, feed self-reliance and negative environmental impact such as greeehouse gas emissions and nitrate pollution. This article compares environmental impact of the main organic pig systems in Denmark. Normally sows are kept in huts on grassland and finishing pigs are being raised in stables with access to an outdoor run. One alternative practised is rearing also the fattening pigs on grassland all year round. The third method investigated was a one-unit pen system mainly consisting of a deep litter area under a climate tent and with restricted access to a grazing area. Using life cycle assessment (LCA) methodology, the emissions of greenhouse gasses of the all free range system was estimated to be 3.3 kg $CO_2$-equivalents $kg^{-1}$ liveweight pig, which was significantly higher than the indoor fattening system and the tent system yeilding 2.9 and 2.8 kg $CO_2$-

eq. $kg^{-1}$ pig respectively. This was 7-22% higher compared with Danish conventional pig production but, due to the integration of grass-clover in the organic crop rotations these had an estimated net soil carbon sequestration. When carbon sequestration was included in the LCA then the organic systems had lower green house gas emissions compared with the conventional pig production. Eutrophication in nitrate equivalents per kg pig was 21-65% higher in the organic pig systems and acidification was 35-45% higher per kg organic pig compared with the conventional system. We conclude that even though the all free range system theoretically has agro-ecological advantages over the indoor fattening system and the tent system due to a larger grass-clover area this potential is difficult to implement in practice due to problems with leaching on sandy soil. Only if forage can contribute a larger proportion of the pigfeed-uptake may the free range system be economically and environmentally competitive. Improvement of nitrogen cycling and efficiency is the most important factor for reducing the overall environmental load from organic pig meat. Presently a system with pig fattening in stables and concrete covered outdoor runs seems to be the best solution from an environmental point of view.

*Keywords:* Agroecology, Life cycle assessment, Nutrient losses, Organic, Pig production.

## 1. Introduction

A large part of the European pig production is carried out in very intensive systems with the animals confined indoors in capital demanding stables, being fed optimised diets with supplementation of – among others –- synthetic amino acids (Dourmad et al., 1999). A high proportion of the feed is imported rather than grown on the farm and many large pig farms do not have sufficient land for the utilisation of manure and depend on export of slurry (De Clercq et al., 2001). Although the biological productivity of these systems is often high, the externalities in terms of reduced animal welfare and environmental impact through losses of nutrients have been questioned by society (Fernández & Fuller, 1999; Tamminga, 2003). Organic pig production has emerged as an alternative with the multiple aims of improving animal welfare by supporting to a higher extent the pig's natural behaviour (Hermansen et al., 2003), and improve soil fertility by better linking crop and livestock production from an agro-ecological point of view. The latter perspective has become even more interesting as a potential way to contribute to carbon mitigation by increasing soil organic matter. Moreover, some organic systems aim at reducing the need for resources and capital for investment in stables and other infrastructure. The European Commission uses *"The area under organic farming"* in general as an indicator for the development of environment – friendly farming practices (EEA, 2005).

The differences between organic and conventional pig production is more fundamental than for example differences between dairy production systems, which may be why the percentage of organic pig herds is considerably lower than the percentage of organic dairy herds compared with conventional herds in both the UK (Defra, 2009), Germany (Willer, et al., 2002) and Denmark (Plant Directorate, 2007). However, the recent development has seen a dramatic increase in demand for organic pig meat in both Denmark, Germany and the UK and present production in Europe cannot meet demand (Alrøe & Halberg, 2008; Padel et al., 2009). Approximately 80000 organic pigs were produced yearly in Denmark in 2007 and 2008, 60% of which was exported mainly to UK, Germany and France, making Denmark the largest exporter of organic pig products globally. Besides regulation on use of feedstuffs, the organic pig production has a major challenge in the regulation for housing. The sows need access to grazing in the summer time, and growing pigs need as a minimum requirement access to an outdoor run. In addition, the area requirements for indoor housing is higher than for conventional production.

These requirements have a major impact on what systems to consider, both from economical and agro-ecological points of view. Therefore, efforts to improve organic pig production should focus on the integration of livestock production and land use, but considering environmental impacts on local and global scales.

The most commonly used system in Denmark is to combine an outdoor sow production all year round with rearing growing pigs in barns with an outdoor run (Hermansen & Jakobsen, 2004). The type of stable most commonly used by full time producers in Denmark is a system with deep litter in the entire indoor area or deep litter/straw bed in half the area (Figure 1a). The outdoor consists of a concrete area (Figure 1b) from which the manure can be collected, as a way to comply with the environmental regulations aiming at preventing leaching.

Research shows that very good production results can be obtained in such systems in terms of litter size, daily gain, feed consumption and health (Hermansen et al., 2003). However, two possible drawbacks exist. First, the space requirement per growing pig in housing facilities is considerable and, thus, capital demanding. For fattening pigs of 85-100 kg live weight, the indoor space required is equivalent to 1.3 $m^2$/pig (of which at least 0.65 $m^2$ must consists of a solid floor) and 1.0 $m^2$ outdoors run (Council

Regulation, 1999). In addition, each lying zone, i.e. straw bedding area, must be able to accommodate all pigs at a time. This put a heavy burden on costs of buildings and at the same time it can be questioned if such rearing systems comply with the consumer expectations. Second, the outdoor sow production has been connected with high environmental burden in the form of N losses (Larsen et al., 2000; Eriksen et al., 2001).

This made us consider two alternatives to the organic pig system most often used presently. A system where all pigs were reared outdoors on grassland (and saving buildings, Figure 2) and a system where sows and growing pigs were kept in a tent system placed upon a deep litter area in order to reduce risk for N leaching (Figure 3). Both systems have been used under commercial conditions. In order to assess the possible trade-offs between environmental impacts on the one hand and the assumed advantages of these alternative systems (animal welfare, low investment) on the other hand an Environmental Impact Assessment was needed. Environmental assessment of livestock farming systems can be done on an area basis (e.g. nutrient losses per ha; Eriksen et al., 2006) or on a product basis (e.g. Green House Gas emission per kg meat or milk; Haas et al., 2001; van der Werf & Petit, 2002; De Boer, 2003; Halberg et al., 2005; Dalgaard, 2008). The area based assessment is relevant for locally important emissions such as nitrate leaching but a product based assessment is more relevant for emissions, which have a less localised impact (acidification) or even a global character (green house gasses (Halberg et al., 2005)). Moreover, since the organic production is often considered a more sustainable alternative to conventional intensive pig production, from a consumer point of view it might be interesting to compare the emissions per kg meat produced from different organic and compared to conventional systems.

Basset-Mens and van der Werf (2005) compared three models of pig production, conventional, organic and an intermediate “label rouge”, and found that the organic scenario had lower emissions *per ha*. However, organic production had higher land use and green house gas emission *per kg pig* compared with conventional and similar eutrophication and acidification. Only one type of organic production system was modelled in this comparison. Degré et al. (2007) compared environmental impact from pig production on seven mixed organic respectively free range farms with seven specialised conventional pig farms and found that differences within each of the three groups were equally important as differences between the three systems. The objectives of this paper are 1. to compare the environmental impact of organic pig production systems with different levels of integration of livestock and land use and 2. to assess the relative importance of land use strategies and carbon sequestration for the environmental profile of the pork.

## 2. Materials and methods

Three models of organic pig production systems were established based on a synthesis of empirical data from on-farm studies and experimental production systems as explained in detail below. The emissions per ha from each farm type were modelled using state-of-the-art methodology for nutrient balances, ammonia volatilisation and green house gasses. Finally, the environmental impact per kg pork produced was assessed using standard Life Cycle Assessment methodology.

*2.1. Models of organic pig production*

Three different systems were considered. The point of departure was the most commonly used system today in Denmark, where the sow herd is kept on grassland with access to small huts for protection, and the fattening pigs are kept in indoor facilities (system "indoor fattening", Figure 1a + b). The construction of indoor facilities consisted of a house with natural ventilation; a deep bedded indoors area; a slatted floor area indoor, a slatted floor area outdoor; and a concrete area outdoors (Møller, 2000). The system allows collection of a part of the manure in liquid form.

As one alternative, fattening pigs were reared on grassland all year round, i.e. reducing housing facilities to movable steel huts, no collection of manure, but moving pigs in the crop rotation from year to year (system "all free range", Figure 2). The other alternative considered was a one unit pen system as described in principle by Andersen et al. (2000) and Jensen & Andersen (2005) (system "tent", Figure 3). In this system climate tents – containing 4 pens- are placed upon a deep litter area on a floor of seashells on the soil surface. From this area pigs have access to grazing when suitable. Walls are made of wood and polyethylene besides straw, and the tent is made of polyethylene as well. Four sows farrows at a time. At weaning sows are moved to another tent facility and the fattening pigs stay in the facility until slaughter. At that time the deep litter is removed and utilised as fertiliser.

*2.2 Bio-technical results in different organic pig production systems*

Very few baseline data from commercial organic pig production have been published. Whereas litter size is not expected to be different in organic systems from conventional systems, number of farrowing per sow and year are reduced due to the longer lactation period in organic systems, and this affects the number of weaned piglets per sow and year. Lauridsen et al. (2000) observed 1.9 litters per sow a year in organic production compared with 2.26 in conventional pig production. This, in combination with data on a number of piglets weaned per sow in commercial organic pig farms (Larsen & Kongsted, 2000; Strudsholm, 2004; Jensen & Andersen, 2005) made us conclude, that a reasonable estimate would be weaning of 19 piglets per sow and year with no differences between the organic systems.

Regarding efficiency in finisher production both a higher (Millet et al., 2004), or a lower daily gain (Hansen et al., 2001) has been observed compared with conventional production. In both references feed conversion was slightly poorer in the organic systems. This probably reflects a two-sided effect, where the more space in the organic housing system stimulates growth compared to conventional production, but the poorer possibilities to adjust feed composition in the organic system results in a higher feed consumption per kg gain.

However, growth rates and feed use seems to be comparable in indoor and outdoor housing (Lee et al., 1995; Sather et al., 1997; Strudsholm & Hermansen, 2005) and therefore, results observed under commercial Danish conditions by Strudsholm (2004) – daily gain 740 g/d and feed consumption per kg gain 3.0 SFU (Scandinavian Feed Units = Barley equivalents) – was used in the three models.

Based on these bio-technical results we established three models of different organic pig production systems. All three systems had the same total production of 1800 fattening pigs (100 kg live weight) per year from a total of 100 sows with own replacement and a total land area of 84 ha. In the indoor fattening system and the all free range system, sows were kept in simple, movable semi-isolated huts in grassland, while the fattening pigs were either moved to stables with access to outdoor concrete area (system "indoor fattening") or also raised in (separate) huts (system "all free range"). In the tent system all animals were housed in tents on deep litter straw bedding on a layer of blue shells and with access to a limited grazing area.

The feed use per sow including recruitment was 2200 SFU year$^{-1}$, 30 SFU was used per piglet from 18-30 kg weight and 217 SFU per grown from 30-100 kg weight in all three systems. Cereals contributed 57% of feed rations, protein rich feed 33% and silage/grass-clover the remaining 10%.

The area with grassland for outdoor keeping of livestock was calculated according to Danish public rules for free range organic pig production (European Commission, 2000; Ministry of Environment, 2002), which allow a stocking rate expected to deposit 280 kg N/ha every second year. This determined the crop rotation to a large extent and – as a consequence – grassland accumulated to 48% of the area in system II (Table 1). Next, crops were chosen in order to best fulfil the feed requirements of the herd under the restrictions of maximum 15% of the total land grown with rapeseed and peas – respectively – in the crop rotation due risks of soil borne pathogens. The rest of the feed requirements for the herd were assumed imported from outside the farm, which resulted in the all free range system importing a higher percentage of feed due to the limited area with cereals.

Table 1. Land use and crop yields in three modelled types of organic pig production

| Characteristic of system | Free range sows | All free range | Tent system |
|---|---|---|---|
| Area use, ha | 84 | 84 | 84 |
| - grain cereals, % | 52 | 39 | 55 |
| - pea and lupine, % | 14 | 6 | 15 |
| - winter rape, % | 14 | 7 | 13 |
| - grass/clover/alphalpha, % | 20 | 48 | 18 |
| Manure on crops, kg N ha$^{-1}$ | | | |
| - grain cereals | 116 | 0 | 142 |
| - pea and lupine | 0 | 0 | 70 |
| - winter rape | 230 | 0 | 240 |
| - grass/clover/alphalpha | 195 | 260 | 214 |
| Average over all crops | 132 | 124 | 157 |
| Crop yields | | | |
| - grain cereals, kg ha$^{-1}$ | 4343 | 3625 | 4592 |
| - pea and lupine, kg ha$^{-1}$ | 2592 | 2770 | 2642 |
| - winter rape, kg ha$^{-1}$ | 2610 | 1482 | 2922 |
| - grass/clover/alphalpha, SFU ha$^{-1}$ | 4088 | 1707 | 4491 |
| Average over all crops, SFU ha$^{-1}$ | 3856 | 2381 | 4053 |

*2.3 Estimation of crop yield in the system*

In Denmark 598 organic arable farmers reported their cash crop yields with economic accounts during the period of 1999-2002 (Anonymous, 2002). The characteristics of the farms are given by Kristensen (2005). The recorded grain yield per ha on farms with sandy soils (less than 10% clay, corresponding to USDA (1990) soil texture classes loamy sand and sandy loam) and mostly no irrigation was in average 3410 kg cereal (*Avena Sativa L., Hordeum vulgare L., Triticum aestivum L.*), 1890 kg winterrape (*Brassica napus L.*) and 2770 kg peas (*Pisum sativum L.*). These yields were achieved with an average input of 70 kg N per ha of animal manure. The grass/clover fields consisted of a mixture of mainly *Lolium perenne L., Poa pratensis L., Festuca Pratensis L.* and *Trifolium repens L.* or alphalpha (*Medicago sativa L.*) in pure stand. It was assumed that all the area with grass/clover was ploughed each year, and that the N left over and mineralised from crop and root residuals equalled 70 kg N per ha available for a following cereal crop (Anonymous, 2005). The resulting expected crop yields per ha used in the three farm models are given in Table 1.

In the tent system the manure production available for redistribution was 23% higher than in the indoor fattening system, due to high straw import for bedding in the deep litter in the one-unit pen system, and the fact that a higher proportion of manure deposited by sows were collected. This resulted in slightly higher yield of cereals in the tent system. The average net yield in grass/clover was determined in each system as a combination of the grazing area needed to comply with regulations in minimum area per grazing animal and the assumed roughage uptake by the sows and pigs. This resulted in relatively low estimated net yields in the all free range system because of a need for a large grass-clover area, which cannot be used effectively as feed by the pigs under the current feeding practices.

*2.4 Estimating emissions from the pig production model farms*

Based on the import of feed and straw and the export of live pigs and cash crops, farm gate Nitrogen (N) and Phosphorus (P) balances were established following methods described in Halberg et al. (1995) and Kristensen et al. (2005). The farm gate balance included deposition (estimated to 16 kg N $ha^{-1}$ in Denmark) and Biological Nitrogen Fixation (BNF), which was assumed to be 75 kg N $ha^{-1}$ grassland taking into account high levels of N returned from grazing livestock live all the systems. Subsequently partial nutrient balances for the herds, the manure stores and fields were established order to estimate partial losses of N in ammonia ($NH_3$) volatilisation and denitrification.

Sommer et al. (2001) have shown that $NH_3$ volatilization from grassland grazed by sows primarily depends on feed inputs. Therefore, $NH_3$ losses were estimated as 23% of the N surplus of the grazed area (Eriksen et al., 2002; Gustafson & Svennson, 2003; Williams et al., 2000).

Denitrification was estimated using the SimDen model (Vinther & Hansen, 2004) based on added N and soil type and this model also estimated the proportion of Dinitrogen monooxide ($N_2O$) in total denitrification ($N_2O$+$N_2$). SimDen does not account for the $N_2O$ emissions from manure management and storage and the indirect $N_2O$ emissions in recipients of the ammonia and nitrate emissions from the farm. This was estimated according to IPCC principles using the fractions 0.025 and 0.01 of

Nitrate-N ($NO_3$-N) leached respectively $NH_3$-N volatilised (IPCC, 2000). In the indoor fattening system and the tent system emission factors of 0.001 and 0.1 of N in slurry and deep litter straw bedding respectively were used (IPCC, 2000).

Ammonia loss from indoor growing pigs were estimated using Danish standards: Loss of 15% $NH_3$-N in slurry and 10% in deep litter (Poulsen et al., 2001). In the tent system the total gaseous N-losses was estimated to be 25% of deposited manure N. Partial estimates of nitrate leaching from grasslands and cereal crops following the first year after ploughing grass clover swards were estimated following Eriken (2001).

The farm level nitrate emission was estimated from the soil balance after deducting airborne emissions and soil N change and checked against the field level estimates. Changes in soil-N were calculated on the basis of the C-inputs from manure and crop residues and the current soil C/N, using a dynamic model, (C-tool) which is outlined in Gyldenkærne et al. (2007). The change in soil-N used here is that which is predicted to occur after 10 years.

*2.5 Product based environmental assessment of pork from 3 model farm types*

In order to calculate the aggregated resource use and environmental impact through the production chain for organic pigs in the three systems consequential Life Cycle Assessment methodology was applied (Wenzel et al., 1997; Anonymous, 2001; Ekwall and Weidema, 2004). The functional unit was defined as one kg of live weight pig delivered from the farm. The system was defined as the production on farm (herd and crops), the off farm production and transport of feed off farm and the production of the building material for housing and of energy for electricity and traction.

For each farm type a process was established in the Life Cycle Assessment tool Simapro Version 7.01 (Anonymous, 2006) using the databases LCAfood (Nielsen et al., 2003; Dalgaard et al., 2006) and EcoInvent (EcoInvent Centre, 2004) with purchased feed and diesel for traction as the main input from the "techno sphere" to the pig production. The environmental impact categories considered were eutrophication, acidification, Global Warming Potential (emissions of greenhouse gasses), ozone depletion and land use following the principles of EDIP 97 (Wenzel et al., 1997, updated version 2.3).

### *2.6 Uncertainty analysis and Monte Carlo simulation*

An analysis of the influence of uncertainty on the comparative assessment of the emissions from the three pig systems was carried out using the Monte Carlo simulation tool in SimaPro (Anonymous, 2006). This involved running 300 pair wise comparisons were the LCA-tool randomly choses values for emissions and inputs according to the chosen distributions and counting the frequency of results where one system had a higher environmental impact than the other. Differences were considered significant if 95% of the iterations are in favour of one of the compared system following Huijbregts (1998). The uncertainty on the nutrient emissions was determined based on the aggregated coefficient of variation on the farm gate N-balance calculated from the coefficients of variation of the individual input and output items (Kristensen et al., 2004; Dalgaard et al., 2006).

## 3. Results and discussion

### *3.1 Farm level environmental impact*

Table 2 shows the N balances (kg N $ha^{-1}$ $year^{-1}$) on herd, land and farm level in a coherent set up, which accounts for the total internal and external N flows. The N balances of the three organic pig production systems differed mainly with respect to the amount of imported protein in feed due to the different land use. The indoor fattening system imported 140 kg N $ha^{-1}$ with cereals and concentrates, which accounted for 61% of the 229 kg N $ha^{-1}$ in total feed protein and straw supplied to the herd. The all free range system had a higher feed N import - 73% of total N to herd - due to a larger grassland area. In the tent system the feed import was comparable with system I, but due to the need for straw for the bedding the total N input from outside the farm was higher. The all free range system had the highest N surplus per ha (land and farm level) and the highest denitrification due to the dominant grazing area. The total emission of $NH_3$ per ha was at comparable levels in all systems but in system II, there was a relatively high emission of $NH_3$ from manure and urine excreted on the outdoor area. After deduction of gaseous losses and net soil N changes from the N-surplus the resulting $NO_3$ leaching was highest in the all free range system (III) and lowest in system I.

Table 2. Nitrogen balances at herd, land and farm level in three modelled, organic pig production systems

| System | Herd level | | | Land level[1)] | | | Farm gate | | |
|---|---|---|---|---|---|---|---|---|---|
| I = Free range sows II = | I | II | III | I | II | III | I | II | III |
| All free range III = Tent system | (Kg Nitrogen ha$^{-1}$ year$^{-1}$) | | | (Kg Nitrogen ha$^{-1}$ year$^{-1}$) | | | (Kg Nitrogen ha$^{-1}$ year$^{-1}$) | | |
| Inputs | | | | | | | | | |
| Imported cereals | 99 | 124 | 96 | | | | 99 | 124 | 96 |
| Concentrates | 41 | 41 | 41 | | | | 41 | 41 | 41 |
| Straw-bedding | 5 | 5 | 28 | | | | | | 23 |
| Seeds | | | | 2 | 1 | 1 | 2 | 1 | 1 |
| Biological fixation | | | | 40 | 45 | 39 | 40 | 45 | 39 |
| Deposition | | | | 16 | 16 | 16 | 16 | 16 | 16 |
| Home-grown cereals and legumes | 53 | 29 | 57 | | | | | | |
| Home-grown forages | 21 | 10 | 27 | | | | | | |
| Grazing | 9 | 18 | 2 | | | | | | |
| Collected manure | | | | 97 | | 122 | | | |
| Deposited manure[2)] | | | | 51 | 167 | 27 | | | |
| Total input[3)] | 229 | 227 | 251 | 205 | 229 | 206 | 197 | 228 | 216 |
| Outputs | | | | | | | | | |
| Home-grown cereals | | | | 53 | 29 | 57 | | | |
| Home-grown forages | | | | 30 | 28 | 29 | | | |
| Cash crops | | | | 12 | 3 | 12 | 12 | 3 | 12 |
| Live pigs | 60 | 60 | 60 | | | | 60 | 60 | 60 |
| Straw | | | | 5 | 5 | 5 | | | |
| Total output | 60 | 60 | 60 | 100 | 65 | 103[4)] | 72 | 64 | 72 |
| Balance | 169 | 167 | 190 | 105 | 164 | 102[4)] | 125 | 164 | 144 |
| Losses | | | | | | | | | |
| Denitrification | 2 | | 7 | 12 | 17 | 10 | 14 | 17 | 17 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $NH_3$ losses | | | | | | | | |
| Stable and storage | 19 | 18 | | | | 19 | | 18 |
| Grazing | | | 12 | 37 | 6 | 12 | 37 | 6 |
| Spreading and crops | | | 11 | 4 | 11 | 11 | 4 | 11 |
| Soil change | | | 24 | 25 | 38 | 24 | 25 | 38 |
| Leaching | | 16[5)] | 46 | 80 | 37 | 46 | 80 | 53 |

1. Balance covering all farmland used on farm including grass-clover, cereals, pulses and cash crops
2. Manure deposited directly by livestock during grazing
3. Total herd input of feed protein is equal in all systems because protein norms were identical in the three models
4. Rounding off errors give small inconsistencies of 1 kg $ha^{-1}$
5. Leaching from the deep litter bedding outside tents in average of total farm area (equals 1440 by N total from tent area)

Table 3 shows the aggregated emissions of $NH_3$ and the $NO_3$ and $PO_3$ leaching and denitrification in kg substance at farm level used as input to the LCA models. The different models of pig production represents trade offs between emissions. The tent system (III) had lower ammonia loss compared with the indoor fattening system but higher denitrification loss and nitrate leaching. The all free range system had highest N losses and the higher nitrate leaching from grazed swards in this system may be considered as the major environmental cost of keeping free range fattening pigs.

This is because the potentially improved nutrient cycling from increased grass-clover area is difficult to establish in reality on sandy soils which are prone to leaching. The higher proportion of grass-clover in the rotation increases BNF and could improve the cereal yields. But the average effect on farm level was lower cereal and rapeseed yields per ha (Table 1) due to lack of manure for the second year cereal crops. This resulted in a higher feed import, which together with high BNF increased the surplus of the farm gate N balance. (Table 2 and 3). However, most of this extra N-input was lost through leaching and $N_2O$-emissions according to experience documented in the methods section. Therefore, the relatively high nitrate leaching from free range pig fattening would have to be reduced considerably for this system to be environmentally sustainable. One possible way for this could be to reduce the purchased feed and increase the pigs' forage uptake (which presently accounts for only 10% of feed intake, thus equal to the two systems "indoor fattening system" and "tent system), and hereby increasing the immediate nutrient recycling during the grazing period. However, it remains to be documented that this in fact can be obtained and it can be foreseen that other crops than grass, i.e. root crops then need to be included in the crop rotation. Another way of reducing N-leaching could be to only keep fattening pigs on grassland in the plants growing season (Eriksen et al., 2006), but this is difficult from an economic point of view.

Table 3. Farm level emissions of ammonia, dinitrogen monooxide, nitrate, methane and phosphate in kg year-1 from three modelled types of organic pig production

| System<br>Emissions | Free range sows | All free range | Tent system | Estimated CV, %[1)] |
|---|---|---|---|---|
| Ammonia | 4164 | 4183 | 3548 | 22 |
| Dinitrogen monooxide | 692 | 843 | 793 | 29 |
| Nitrate | 17183 | 29767 | 19785 | 15 |
| Phosphate | 74 | 122 | 109 | 50 |
| Methane | 2174 | 506 | 490 | 50 |

1) See methods for explanation

Methane emissions in the indoor fattening system were four times higher than in the all free range system and the tent system due to losses during storage of the slurry (Table 3).

*3.2 Environmental impact per kg pig*

Results of the LCA combining the farm level emissions and traction with emissions from production and transport of imported feeds and construction of sow and pig housing are presented in Table 4. The contribution to Global Warming in kg $CO_2$ equivalents per kg pig was significantly higher (according to the Monte Carlo simulations) in the all free range system compared with the indoor fattening system and the tent system mainly due to the higher emission of $N_2O$ in the free range system (Table 3) and the higher feed import (due to lower cereal and pulse areas, table 1). The production and transport of imported feed accounted for 33% of total greenhouse gas emission in the all free range system compared with 27 and 26% in the indoor fattening system and the tent system respectively (Figure 4). Traction for crop production and fodder handling on the farm accounted for 12% of greenhouse gas in all systems while emissions from housing and electricity were relatively small. In all systems $N_2O$ linked to the N-cycling on the farm and in production of imported feed contributed by far the larger part of the total greenhouse gas.

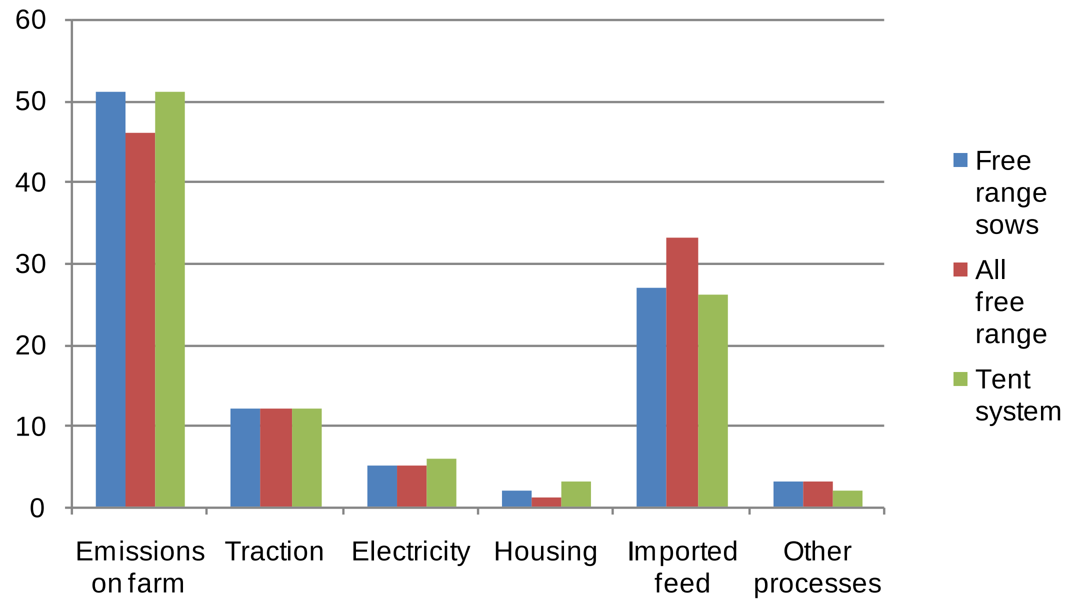
The all free range system caused approximately 30% higher eutrophication per kg pig compared with the indoor fattening system and the tent system (significant with 100% Monte Carlo runs higher for the all free range system) primarily because of higher nitrate leaching from the grazed swards. Approximately 1/3 of the total eutrophication per kg pig was linked with the production of imported feeds (28-31%, not shown), while emissions on the farm accounted for almost all the rest. Acidification was mainly caused by $NH_3$ volatilisation in all systems. Diesel use for traction and transport contributed 5-10% of total Acidification. The all free range system had higher acidification than the tent system, but the difference between acidification in the indoor fattening system and the all range system was not significant.

Table 4. Comparative Life Cycle Assessment of three modelled systems of organic pig production. Environmental impacts per kg live weight pig delivered from the farm[1)]

| Impact category | Unit | Indoor fattening | All free range | Tent system |
|---|---|---|---|---|
| Global warming (greenhouse gas 100) | g $CO_2$-eg | 2920 b | 3320 a | 2830 b |
| Soil C sequestration | g $CO_{2\text{-eg}}$ | -398 | -413 | -623 n.a. |
| Ozone depletion | g $CFC_{11}$-eg | 6.9 E-4 b | 7.7 E-4 a | 6.8 E-4 b |
| Acidification | g $SO_2$-eg | 57.3 a | 61.4 a | 50.9 b |
| Eutrophication | g $NO_3$-eg | 269 b | 381 a | 270 b |
| Land use | $M^2$ year | 6.9 | 9.2 | 8.5 n.a. |

1) Differences interpreted significant based on pair wise Monte Carlo simulations giving one system a higher outcome in more than 95% of 300 runs are indicated with small letters. n.a. = not applicable

Figure 4. Relative contribution to emissions of green house gasses from different sources in three organic pig production systems (% of total emission of green house gasses per kg live weight pig from farm)




The greenhouse gas emission from construction and maintenance of housing was lowest in the free range system and 78% higher in the indoor fattening system with stables in concrete and steel and 180% higher in the tent system, (results not shown). Most of the greenhouse gas emissions and acidification from the construction and use of the tents were caused by transport of the blue shells (20 tonnes per tent every year). However, the different pig housing infrastructure contributed only small proportions of the total greenhouse gas (1-3%), acidification (0.2-1.8%) and eutrophication (0-0.7%) per kg pig (Figure 4). Erzinger et al. (2004) also showed that housing infrastructure itself was of minor importance for the LCA results of fattening pigs. However, they found that energy use in stables (mostly for ventilation) for intensive pig production accounted for almost 30% of the energy consumption and that differences in housing methods had a large impact on nutrient related emissions. This conclusion is supported by our study.

The environmental impacts per kg pig from the organic pig systems are higher than results from the comparable LCAs on conventional Danish pig production in the LCAfood database. Dalgaard et al. (2005) reported emissions from Danish conventional pig production corresponding to 2.7 kg $CO_2$-eq, 230 kg $NO_3$-eq and 43 kg $SO_2$-eg per kg liveweight pig at farm gate, which were comparable with the conventional pig scenario assessed by Basset Mens & van der Werf (2005). Thus, the greenhouse gas emission per kg live weight pig in the indoor fattening system was 7% higher compared with conventional pig production and the all free range system was 22% higher. This comparison, however, does not take into account the Carbon balances arising from differences in the crop rotations. The 24-38 kg N $ha^{-1}$ net soil accumulation per year (Table 2) corresponds to approximately 240-390 kg net C sequestration in the three systems given a C/N ratio of 10 in the "active" pools (Hansen et al., 1991). This C sequestration on the farm corresponds to approximately -0.4, -0.4 and -0.6 kg $CO_2$-eq per kg liveweight pigs in the three organic systems (table 4) or a reduction of approximately 11-18%. Thus, when including soil carbon sequestration the greenhouse gas emissions per ha and per kg pig from the organic indoor fattening system and the tent system were lower than from conventional pig systems where the net soil N and C changes were close to neutral (Dalgaard et al., 2006). The differences were larger for the eutrophication, where the indoor fattening system and the tent system had 35 and 21% higher emissions compared with the conventional system while the all free range system had 65% higher emission, mainly due to leaching from the grasslands. All organic systems had 18-43% higher acidification per kg pig compared with conventional due to larger ammonia losses from outdoor runs (the indoor fattening system) respectively grasslands (the all free range system) and the deep litter bedding (the tent system).

From previous studies (Dalgaard & Halberg, 2005) it was known that the main determinants of the impact categories greenhouse gas, eutrophication and acidification were the nutrient flows and emissions. Therefore, the uncertainty analysis focused on these emissions and used estimated variance parameters for the emissions rather than each input variable as suggested by Huijbregts (1998). The estimated CV's of P loss and Methane emissions were less precise, which was justified because of their smaller relative importance to the comparative results of the pig systems under Danish conditions.

### *3.3 Overall comparison of systems*

The three modelled organic pig systems are all realistic commercial pig production farms. Tvedegaard (2005) compared the three systems' economic performance and found that the indoor fattening system with outdoor sow herd and fattening pigs kept in indoor facilities is the most cost efficient system. The costs are slightly higher in the all free range system where also the fattening pigs are kept on grassland. Even though investment costs are lower in the all free range system the overall cost efficiency was better in the indoor fattening system due to lower labour costs. In the tent system the pig production is more expensive primarily due to the large amounts of straw to be imported from other organic farms.

Motives for free ranging the pigs include animal welfare, reduced environmental and economic costs from construction of stables and the - supposed - agro-ecological advantage of improved crop rotation with grass-clover leys (improved nutrient cycling, including BNF, increased soil fertility, higher crop diversity, reduction of cereal pests and diseases). However, as mentioned, the reduced investment costs in the all free range system and the tent system with no stables were offset by higher labour costs.

As explained, the results confirmed and have quantified the trade off between objectives for free range, outdoor pig production systems and the objectives of reducing emission with negative environmental impact. But the study also suggests that another compromise between these different objectives might be found. Thus, the emissions per kg live weight pig delivered from the tent system were on the same level – or possibly lower -compared with the indoor fattening system. This demonstrates that it has been possible under practical conditions to reduce the N-related emissions (from the tent system) compared with the all free range system by proper management of the deep litter bedding under the tent, ample supply of straw and a layer of blue shells beneath. The pigs in the tent system have only access to a limited grass-clover area, though these are larger than the outdoor runs in the indoor fattening system. But the integration of pig rearing and land use and the resulting crop rotation in the tent system might not seem different from the indoor fattening system from an agro-ecological perspective (Table 1). The feed import was slightly lower in the tent system compared with other systems. The most problematical aspects of the tent system are imports of straw and high labour costs. The indoor fattening system, combining stables with outdoor runs for fattening pigs in combination with free ranging sows seems to be the most competitive system. And the 20% grass-clover in this systems crop rotation still has an agro-ecological advantage over crop rotations with cash crops and cereals only and contributes to carbon sequestration.

Compared with conventional systems there is a trade off between lower eutrophication and acidification in conventional system and better animal welfare and agro-ecological advantages of better crop rotation in the organic systems. It should be noted that important environmental impacts such as pesticide toxicity was not included in this comparison. Organic agriculture differs from conventional in this respect but due to methodological limitations this impact was not quantified. Degrè et al. (2007) suggested to solve such dilemmas by multi criteria analysis using expert evaluations and prioritisation. They concluded that on average the Belgium organic and free range pig production ranked higher than conventional farms but also that "the best conventional farms were close to the best organic and free range farms". In reality, the prioritisation rests with individual farmers based on their criteria and assessment of economic prospect vis-à-vis their existing farm structure and market opportunities.

Currently there is an under supply of organic pork in Denmark and better economic return compared with conventional but still a limited growth in the organic pig production (Halberg & Alrøe, 2008). The number of organic pigs in the UK increased by 41% in 2008, but still comprise only 1.5% of total pig production (Defra, 2009). This might be explained by the large changes in management options and production facilities when converting from a conventional system.

Even though the systems were modelled specifically under Danish conditions they may also represent typical organic pig production forms in other European countries. Basset-Mens & van der Werf (2005) compared two non-organic pig systems with a modelled organic pig production scenario consisting of an outdoor piglet production in farrowing huts and fattening pigs on deep litter straw bedding in a building. Our indoor fattening system resemble the French organic pig production modelled by Basset-Mens

& van der Werf (2005) in terms of land use and pig housing. The French model assumed 20.3 weaned piglets $sow^{-1}$ $year^{-1}$ compared with 18 in our model and a comparable feed to gain ratio in fattening pigs (3.2 kg feed per kg live weight gain compared to our 3.1, Table 1). The French organic model showed higher greenhouse gas emission per kg pig and lower acidification and eutrophication compared with the Danish organic indoor fattening system. However, methodological differences makes a direct comparison between the two studies problematic. The French study also found that organic pig production had a better environmental performance compared with conventional when calculated per ha but worse when calculated per kg pig product. But they did not include differences in the soil carbon sequestration as in our study.

Stern et al. (2005) compared three non-organic pig production systems using LCA and showed that a so-called ”environmentally friendly” system with closed stables and slatted floors had approximately 10% lower greenhouse gas emission and nutrient surplus compared with an “animal welfare” system with housing similar to our indoor fattening system. The greenhouse gas emissions per kg meat was comparable with the results of our study (though methodological differences does not allow precise comparisons) but the N and P surpluses were much lower.

## 4. Conclusion

Of the systems considered the indoor fattening system with only grazing sows and fattening pigs in stables had a better economic and environmental performance compared with systems with all pigs on grassland and housed in huts (all free range system) or a tent with deep litter straw (tent system). The all free range system can be considered an attempt to minimise investment costs and the environmental burden of building concrete stables, to enhance animal welfare and to benefit from agro-ecological advantages of increased grass-clover area in the rotation. However, the present relations between feed uptake pig production and crop rotation did not ensure an efficient recycling on the sandy soils in the all-grazing system and the nitrate leaching was therefore 50-60% higher compared with the other systems. If the grass-clover could contribute a larger proportion of feed uptake this would reduce the need for purchased feed and improve farm gate nutrient efficiency. The tent system might be a compromise between all grazing systems and the use of stables because it allows the pigs a more natural behaviour and access to grazing. But the present version is disadvantaged by higher labour costs, and the yearly import of large amounts of straw and shells, which increases transport related emissions.

Greenhouse gas emissions per kg pig were lower in organic systems compared with conventional when carbon sequestration in soils was included in the life cycle assessment. Eutrophication and acidification per pig was 21-65% higher in the organic systems compared with conventional. The reduction of environmental burdens from organic pig production should focus on improved nutrient cycling at the farm level. Presently a system with pig fattening in stables and concrete covered outdoor runs seams to be the best organic pig system from a combined economic and environmental of view.

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Figure 1a + b. Stable for organic pig fattening, deep litter with partly concrete floor and access to outdoor run covered with concrete.

Figure 2. Fattening pigs outdoors in fenced grass-clover paddocks as part of crop rotation

Figure 3. One unit pen tent system for outdoor pig production from piglet to slaughter weight on deep litter straw bedding and access to small grazing plots.