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Evaluation of the environmental sustainability of different European pig production systems using life cycle assessment

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ABSTRACT

The environmental sustainability of 15 European pig production systems has been evaluated within the EU Q-PorkChains project, using life cycle assessment (LCA). One conventional and two differentiated systems were evaluated from each of five countries: Denmark, Netherlands, Spain, France and Germany. The information needed for the calculations was obtained from an enquiry conducted on 5 to 10 farms from each system. The different systems were categorized among conventional (C), adapted conventional (AC), traditional (T) and organic (O). Compared to conventional, the differentiation was rather limited for AC systems with only some changes in order to improve meat quality, animal welfare or environmental impact. The difference was much more marked for the traditional systems with the use of fat slow-growing traditional breeds and generally the outdoor raising of the fattening pigs. The environmental impacts were calculated at farm gate, including the inputs, and expressed per kg live pig and per ha land use. For the conventional systems, the impact per kg live pig on climate change, acidification, eutrophication, energy use, and land occupation were 2.25 kg CO₂-eq, 44.0 g SO₂-eq, 18.5 g PO₄-eq, 16.2 MJ and 4.13 m², respectively. Compared to C, the corresponding values were on average 13, 5, 0, 2 and 16% higher for AC; 54, 79, 23, 50 and 156% higher for T, and 4, -16, 29, 11 and 121% higher for O. Conversely, when expressed per ha of land use, the impacts were lower for T and O differentiated systems, by 10 to 60% on average, depending on the impact category. This was mainly due to larger land occupation per kg pig produced as well for feed production and for the outdoor raising of sows and/or fattening pigs. The use of litter bedding tended to increase climate change impact per kg pig. The use of traditional local breeds, with reduced productivity and feed efficiency, resulted in higher impacts per kg pig produced, for all categories. Differentiated T systems with extensive outdoor raising of pigs resulted in markedly reduced impact per ha land use. Eutrophication potential per ha was substantially lower for O systems. Conventional systems were generally better for global impacts, expressed per kg pig, whereas differentiated systems were better for local impacts, expressed per ha land use.

Keywords: pig production, systems, environment, Life Cycle Assessment

1. Introduction

World livestock production has major impacts on the environment, because of its emissions to the environment which affect air, water and soil quality, and the use of limited or non renewable resources (Steinfeld et al., 2006). In this context the EU pork production system is facing major challenges. There is increasing societal concern regarding the currently prevailing intensive production systems (Petit and van der Werf, 2003), mainly because of environmental and animal welfare shortcomings. Although, non conventional production systems are often believed to be more sustainable, their real benefits for the environment may be controversial (Basset-Mens and van der Werf, 2005). An inventory at farm level of pig production systems, mainly from EU countries, has recently been performed within the Q-PorkChains EU project (Bonneau et al., 2011). This inventory was used as a basis for selecting contrasting systems that were evaluated in the present study. This evaluation was performed using a toolbox developed from the literature (Edwards et al., 2008) with life cycle assessment (LCA) as the method for the evaluation of the environmental sustainability.

2. Methods

2.1. Goal definition, system description and collection of data

Fifteen EU pig production systems were chosen among the 84 systems available in the inventory of pig production systems (Bonneau et al., 2011). One conventional and two differentiated systems were evaluated from each of five countries: Denmark, Netherlands, Spain, France and Germany. The different systems were categorized according to the typology defined by Bonneau et al., (2011) among conventional (C, n=5), adapted conventional (AC, n=5), and differentiated, including traditional (T, n=3) and organic (O, n=2). The information needed for LCA calculations was obtained from an enquiry conducted on about 10 farms from each system. Data collected concerned: (i) animal performance, including sows productivity, mortality rates, pig growth and feed intake during post-weaning and fattening periods, slaughter characteristics, (ii) feed

composition including metabolisable energy (ME), protein and phosphorus contents, (iii) animal housing including type of housing (indoor, outdoor, free range...), type of floor (litter bedding, complete of partially slatted floor...) and (iv) manure handling, including management in the building (liquid, solid, frequency of removal...) and during storage (type and duration of storage), manure treatment (composting, anaerobic or aerobic digestion) and type and distance of spreading. From the collected data, an "average" system was built for each production system. Performance and nutrient flows and emissions were calculated for each production stage, *i.e.* the sows and their piglets until weaning, the post-weaning piglets and the fattening pigs. In this way it was easy to aggregate the whole production systems, considering number of piglets weaned per sow per year, and mortality rates of pigs during post weaning and fattening periods.

2.2. System boundaries and functional units

This is a cradle-to-farm-gate study over the whole pig production system including the reproducing sows and their piglets until weaning, the post-weaning piglets and the fattening pigs. The definition of system and subsystem boundaries was mainly derived from Basset-Mens and van der Werf (2005) and Nguyen et al., (2010). The main sub-system is the pig unit which includes the production of piglets and their raising until slaughter weight. This unit is considered to be landless as assumed by Nguyen et al., (2010) but it interacts with land use through the import of feed and the deposition/use of manure produced by the animals. The land used in case of outdoor pig raising is also considered within the system. The studied system includes the production and delivery of feed produced off-farm, herd management, and emissions from the animals and manure storage. The environmental consequences of manure utilisation are evaluated using system expansion as described by Nguyen et al., (2010). The transport and slaughter of animals leaving the system are not included. Veterinary medicines and hygiene products are not included because of lack of data in the enquiries. The functional units were 1 kg of live weight pig leaving the pig unit, including culled sows and slaughter pigs, and 1 ha of land occupied for the production of feed and the raising of animals.

2.3. Life cycle inventory analysis

The amount of complete feed used by the different categories of pigs was obtained from the enquiry, as well as their nutrient contents. However, no information was generally available on ingredients content. It is why these contents were estimated in a similar way as performed by Nguyen et al., (2010), assuming that the complete feed resulted from a mixture of cereals (wheat, barley and maize), protein rich ingredients (soybean meal, rapeseed meal and peas) and minerals (phosphate and calcium carbonate). This calculation was performed for all diets used by the different categories of pigs. A detailed description of the methodology used for the evaluation of impacts of production of non organic feed ingredients is given by Mosnier et al., (2011). Values for organic feed ingredients used in organic pig production systems were estimated from LCA food Database (2007).

Emissions to air were estimated for NH_3 , N_2O , NO_x and CH_4 . Emission of CH_4 from enteric fermentation and manure management were calculated from Rigolot et al., (2010a,b) and IPCC (2006). Direct N_2O emissions from manure during in-house and outdoor storage and during field application were calculated from IPCC (2006) and emissions of NO_x were estimated according to Nemecek and Kägi (2007). NH_3 emission during in-house storage, outside storage and field application of manure were calculated from Rigolot et al., (2010a,b) according to type of effluent (slurry, solid manure) duration and type of storage and method of spreading. A description of the CML 2001 and CED methods can be found in Frischknecht et al., (2007).

2.4. Life Cycle impact assessment

The following impact categories were considered: climate change (CC), eutrophication potential (EP), acidification potential (AP), cumulative energy demand (CED), and land occupation (LO). The indicator result for each impact category was determined by multiplying the aggregated resources used and the aggregated emissions of each individual substance with a characterisation factor for each impact category to which it may potentially contribute. CC, EP, AP CED and LO were calculated using the CML2 "baseline" and "all categories" 2001 characterisation methods as implemented in the Ecoinvent v2.0 database. CC was calculated according to the 100-year global warming potential factors expressed in kg CO_2 equivalent (eq). EP was calculated using the generic EP factors in kg PO_4 (Guinée et al., 2002). AP was calculated using the average European AP factors in kg SO_2 eq (Guinée et al., 2002). Cumulative energy demand (CED, MJ) was

calculated according to its version 1.05 as implemented in the Ecoinvent v2.0 database. Land occupation (m².yr) refers to on farm and off-farm area used for the production of feed or for the outdoor raising of pigs.

3. Results

3.1. Animal performance and system description

On average there were 310 sows per farm with sows, and farms with fattening pigs produced on average 3260 pigs per year (Table 1). The variability in average farm size per system (± 270 sows, CV= 85% and ± 1960 fattening pigs, CV=60%) was high with large differences between systems. Herd size was the highest for C and AC systems and the lowest for traditional systems, O systems being intermediate (Table 1). On average sows weaned 22.6 piglets per year. The highest performances were measured in C systems (26.9). Performances were slightly lower in AC systems (24.2) and the lowest in O and T systems (18.9 and 15.1, respectively). Consumption of feed per sows and per year was higher in T and O systems and this feed tended to be more concentrated in protein and phosphorus, compared to C and AC systems.

Feed conversion ratio during the post weaning period was 1.96 (± 0.44) on average. It was the lowest for C systems and the highest for T ones (Table 1). Mortality rate (2.9% on average of systems) was markedly higher for T systems, with small differences among the others systems. Dietary crude protein content of post-weaning diets, 174 g/kg on average of systems, was lower in T systems (162 g/kg) and higher in O systems (193 g/kg). Total dietary phosphorus content was the highest in O systems with no marked difference among the other systems.

Table 1. Description of the pig production systems: performance of sows, piglets and fattening pigs, and average composition of diets.

	All systems		Conven- tional	Adapted conventional	Traditional	Organic
	Average	Std ¹				
Number of systems	15	15	5	5	3	2
Number of sows / farm ²	310	270	395	475	59	128
Fattening pigs year ⁻¹ farm ⁻¹	3260	1960	4910	3570	510	2510
Sows						
piglets weaned / year	22.6	5.7	26.9	24.2	15.1	18.9
weaning weight / kg	8.4	1.8	7.3	7.4	9.3	12.1
feed per sow, kg/year	1390	312	1330	1340	1460	1590
crude protein, g/kg	138	14	134	134	137	158
total P, g/kg	5.0	0.6	4.7	4.9	5.2	6.0
Post-weaning						
final weight, kg	27.7	4.2	28.1	27.8	25.4	29.7
feed conversion ratio, kg/kg	1.96	0.44	1.67	1.90	2.42	2.20
mortality rate, %	2.9%	3.8%	1.9%	1.8%	7.0%	2.1%
crude protein, g/kg	174	19	175	173	162	193
total P, g/kg	5.6	0.5	5.5	5.6	5.5	6.4
Fattening pigs						
slaughter weight, kg	122	16.2	113	124	140	109
feed conversion ratio, kg/kg	3.44	1.37	2.74	3.18	5.29	3.03
mortality rate, %	3.5%	1.5%	3.4%	2.9%	4.5%	3.5%
crude protein, g/kg	155	14	157	153	145	174
total P, g/kg	4.7	0.475	4.7	4.5	4.8	5.1
Live weight / sow, kg/year	2570	555	2930	2840	1900	1990

¹ Standard deviation, ² average for farms with sows

Average pig slaughter weight was 113 kg in C systems, rather close to O systems (109 kg). It was higher in AC and T systems, by 11 and 27 kg, respectively. Feed conversion ratio during fattening period was 3.44 (± 1.37) on average. It was the lowest for C systems and the highest for T ones. Mortality rate (3.5% on average) was higher for T systems, with small differences among the others systems. Dietary crude protein content of fattening diets, 155 g/kg on average of systems, was lower in T systems (145 g/kg) and higher in O systems (174 g/kg). Total dietary phosphorus content was the highest in O and T systems with no marked difference between C and AC. Live weight pig produced per sow per year amounted 2570 kg on average of systems. It was higher in C and AC systems (2880 kg) and lower in T and O systems (1950 kg).

Conventional pigs were all housed indoor, on slatted floor and their manure was handled as slurry, only a small percentage of the slurry being treated. In AC systems slatted floor was also the most frequent but in

some cases sows and/or fattening pigs were raised on straw bedding with the production of solid manure. In O systems animals were raised outdoor or indoor with outdoor access or in open buildings. The use of slatted floor was the most frequent for fattening pigs. In T systems sows might be raised outdoor or indoor, whereas fattening pigs were most often raised outdoor.

3.2. Environmental impacts of pig production

The environmental impacts of the different systems are presented per kg of pig produced and per ha of land occupied during a year (Table 2). There were large differences between systems for all impact categories expressed per kg pig produced. On average, CC, EP, AP, CE and LO amounted 2.61 ($\pm 27\%$; mean \pm CV) kg eq CO₂, 0.022 ($\pm 41\%$) kg eq PO₄, 0.047 ($\pm 23\%$) kg eq SO₂, 18.2 ($\pm 26\%$) MJ, and 6.60 ($\pm 56\%$) m² per kg pig, respectively. There were substantial differences between extremes values for all impacts (up to x4). On average, CC per kg pig was the lowest for C and the highest for T (+54% compared to C), AC and O systems being intermediate. EP per kg pig was similar for C and AC systems; it was higher for T systems (+79%) and lower O systems (-16%). In the same way, AC per kg pig was similar for C and AC systems, whereas higher values were calculated for T and O systems (+23 and +29%, respectively). Energy demand per kg pig was the lowest for C and AC systems and was higher for O (+11%) and T (+50%) systems. Marked differences were found for LO, between C and AC systems, on one hand (4.5 m²/kg pig), and T and O systems, on the other hand (9.9 m²/kg pig).

When expressed per ha of land occupied, there were also large differences between systems for all impact categories (Table 2). On average, CC, EP, AP, CE and PP per ha, amounted 4680 ($\pm 26\%$) kg eq CO₂, 38.6 ($\pm 28\%$) kg eq PO₄, 86.3 ($\pm 30\%$) kg eq SO₂, 32.5 ($\pm 25\%$) TJ, and 1925 ($\pm 36\%$) kg pig per ha, respectively. There were marked differences between extreme values for all impacts. On average, CC per ha was the lowest for O and the highest for C and AC (+100% compared to O), T systems being intermediate. Eutrophication potential per ha was substantially lower for O systems; it was the highest for C systems (+170%) followed by AC and T. Acidification potential per ha was similar for O and T systems, whereas higher values were obtained for C and AC systems (+70 and +45%, respectively). In the same way, CED per ha was the lowest for O and T systems, and was higher for C (+98%) and AC (+75%) systems. Substantial differences were found for pig produced per ha land occupation, between C and AC systems, on one and (2300 kg/ha), and T and O systems, on the other hand (1170 kg/ha).

Table 2. Potential environmental impact expressed per kg pig produced or per ha of land use

	All systems		Conventional	Adapted conventional	Traditional	Organic
	Average	Std [†]				
Number of systems	15	15	5	5	3	2
Impact per kg live weight						
Climate change, kg eq CO ₂	2.61	0.70	2.25	2.55	3.47	2.35
Eutrophication, kg eq PO ₄	0.022	0.009	0.019	0.020	0.034	0.016
Acidification, kg eq SO ₂	0.047	0.011	0.044	0.044	0.054	0.057
Energy demand, MJ	18.2	4.6	16.2	16.5	24.3	18.1
Land occupation, m ²	6.30	3.52	4.13	4.78	10.6	9.14
Impact per ha land use						
Climate change, kg eq CO ₂	4680	1220	5470	5320	3670	2610
Eutrophication, kg eq PO ₄	38.6	10.7	46.3	41.4	35.3	17.3
Acidification, kg eq SO ₂	86.3	26.2	106.1	89.9	63.8	61.6
Energy demand, MJ (x 1000)	32.5	8.0	39.4	34.8	25.7	19.98
Pig produced, kg LW	1925	684	2429	2162	1229	1114

[†] Standard deviation

4. Discussion

Results on environmental impacts of pig production evaluated with LCA were recently reviewed by de Vries and de Boer (2010). For CC the values obtained in the present study (2.25 to 3.47 kg eq CO₂ / kg pig) are within the large range of values (2.3 to 5.0 kg eq CO₂ / kg live pig) reviewed in that study. For conventional systems the observed average value (2.25 kg eq CO₂) is close to those reported by Basset-Mens and van der Werf (2005) and Nguyen et al., (2011): 2.3 and 2.2 kg eq CO₂, respectively. The value obtained for O systems (2.4 kg eq CO₂ / kg pig) is lower than those published for the same system by Halberg et al., (2010; 2.8 to 3.3 kg eq CO₂ / kg pig) and Basset-Mens and van der Werf (2005; 4.0 kg eq CO₂ / kg pig). The main reason for that difference is likely the higher animal performance in our study, both in terms of sow

productivity and feed efficiency, and the higher N₂O emission in the study from Basset-Mens and van der Werf (2005) due to the use of straw bedding. Traditional systems have higher CC impact per kg pig. This is mainly due to the lower feed efficiency in these systems, in connection with the raising of traditional breeds. This results in a higher CC impact due to the production of feed, only partially compensated by decreased CH₄ emission due to the outdoor raising of animals. AC systems have a slightly higher CC impact than C systems, mainly because of reduced animal performance and the more frequent use of straw bedding with increased N₂O emission.

For EP the values obtained in the present study (0.016 to 0.034 kg eq PO₄ / kg pig) are also within the range of values (0.012 to 0.038 kg eq PO₄ / kg live pig) reviewed by de Vries and de Boer (2010). For C systems the observed average value (0.019 kg eq PO₄) is close to those reported for similar systems by Basset-Mens and van der Werf (2005) and Nguyen et al., (2011): 0.021 and 0.018 kg eq PO₄, respectively. The value obtained for organic production (0.016 kg eq PO₄ / kg pig) is lower than those published for this system by Basset-Mens and van der Werf (2005; 0.022 kg eq PO₄ / kg pig) and by Halberg et al., (2010; 0.025 to 0.038 kg eq PO₄ / kg pig), mainly because of higher animal performance in the present study. Among the evaluated systems, O systems have the lowest EP impact in connection with a much lower EP impact of feed in that system. For the same reason as for CC, T systems have the highest EP impact.

For AP the values obtained in the present study (0.044 to 0.057 kg eq SO₂ / kg pig) are also within the large range of values (0.008 to 0.120 kg eq SO₂ / kg live pig) reviewed by de Vries and de Boer (2010). For AC and C systems the observed average value (0.044 kg eq SO₂) is close to those reported for similar systems by Basset-Mens and van der Werf (2005) and Nguyen et al., (2011): 0.044 and 0.043 kg eq SO₂, respectively. The value obtained for organic production (0.057 kg eq SO₂ / kg pig) is higher than that published for this system by Basset-Mens and van der Werf (2010; 0.037 kg eq SO₂ / kg pig) and similar to those reported by Halberg et al., (2010; 0.050 to 0.061 kg eq SO₂ / kg pig). This is mainly related to the production of solid manure with reduced NH₃ emission in the study of Basset-Mens and van der Werf (2005).

For CED the values obtained in the present study (16 to 24 MJ / kg pig) are within the large range of values (10 to 25 MJ / kg live pig) reviewed by de Vries and de Boer (2010). For C and AC systems the observed average value (16.3 MJ) is close to those reported for similar systems by Basset-Mens and van der Werf (2005) and Nguyen et al., (2011): 15.9 and 13.6 MJ, respectively. The observed value for organic production (18.1 MJ / kg pig) is slightly lower than that published (22.2 MJ / kg pig) for this system by Basset-Mens and van der Werf (2005). In relation with the use of larger amounts of feed, T systems have the highest CED impact per kg pig.

The values obtained for LO in the present study (4.1 to 10.6 m² / kg pig) are partly outside the range of values (4.2 to 6.9 m² / kg live pig) reviewed by de Vries and de Boer (2010). This is mainly related to T and O systems which obtained higher values for LO. For T systems the main reason is the outdoor raising of fattening pigs. In the case of O systems the larger LO is mainly related to the higher LO impact for feed production, due to reduced yield of organic crops. For C systems the observed value (4.13 m² / kg pig) is close to those reported for similar systems by Basset-Mens and van der Werf (2005) and Nguyen et al., (2011): 5.4 and 4.4 m² / kg pig, respectively. The value obtained for organic production, 9.1 m² / kg pig, is close to the values published for this system by Basset-Mens and van der Werf (2010; 9.9 m² / kg pig) and Halberg et al., (2010; 6.9 to 9.2 m²/kg pig).

When impacts are expressed per ha of land used, the ranking of systems is very different for most impacts. They are generally the lowest for O followed by T systems and the highest for C systems. The degree of intensification inversely correlates with the environmental impact per kg pig, whereas the opposite is found when the impact is expressed per ha. The same effect of the functional unit on the results was reported by Basset-Mens and van der Werf (2005). Our results clearly indicate that the choice of the functional unit has a major effect on the ranking of systems in terms of environmental impact in line with previous results (Basset-Mens and van der Werf, 2005). The use of plural functional units is rather common in the application of LCA in agriculture, but still under debate. As suggested by different authors this refers to two essential functions of agriculture: the production of food and land occupation. It is why some authors have suggested to adapt the choice of the functional unit to the category of impact, *i.e.* the kg of product for global impacts and ha of land occupation for local impacts (de Boer, 2003)

5. Conclusion

The diversity in production systems considered in the present study results in very large variations in all environmental impacts. However, the results depend on the functional unit. The degree of intensification inversely correlates with the environmental impact per kg pig, whereas the opposite is found when the impact is expressed per ha. According to the results from this study, LCA appears a suitable methodology for the

evaluation of the environmental sustainability of pig production systems and can contribute to the overall assessment of sustainability.

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