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Comparative life cycle assessment (LCA) of pork using different protein sources in pig feed

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SUPPORTING INFORMATION

1 Data inventory of the pork production system in Northern Germany

The data inventory necessary for the LCA of pork production is presented in the following. It represented the average pork production in the north of Germany in the marketing year 2011/2012. Most of the data presented was described in Reckmann et al. (2013) in detail. The pig production at farm level was considered as 'landless', as described in Nguyen et al. (2011). Therefore, feed and other resources were imported which reflected common practice for conventional pig farms.

Life cycle inventory: crop and feed production

The main components of typical conventional feed mixtures were wheat, barley and soybean meal of which the wheat and barley were mainly produced in Germany. We assumed a distance between the field in which the crop was grown and the feed company to be 100 km on average. The distance between the feed factory and the pig farm was estimated at 97 km. According to statistical data, the soy was imported from Brazil (Faostat, 2011). This resulted in a shipping distance of 9700 km from Brazil to Rotterdam harbour in the Netherlands. The following transport by lorry to the feed factory in Germany was 412 km.

The inventory of feed encompassed the crop cultivation, including use of fertilisers, fossil-fuels and other resources. Data of resources used and emission data due to the transformation of crop products into feed ingredients as well as the production of feed (e.g. electricity, heat and water consumption) were also supplied by the feed company. Additional data were included in databases of the software used, i.e. SimaPro 7.3.3 (Pré Consultants, 2009). More information is given in the manuscript.

Life cycle inventory: pig production system

The data inventory of the pig production (using standard feed) is listed in Table S1, related to the production of 1000 kg live weight at the farm gate. The chemical composition of the different diets considered is given in Table S2. The inventory started with the calculation of the amount of feed needed to raise the pigs. The housing of the animals consumed electricity for light, ventilation, feeding etc., heat for piglets and finisher pigs as well as water for animals and cleaning. Additionally, the animals needed to be transported between the different housing stages. Therefore, we assumed that piglets were transported 60 km from the piglet production to the weaning. The distance to the finisher stable was 32 km. The carcasses of lost animals also had to be disposed (40 km).

In all housing stages, pigs produced certain amounts of manure. A scheme of the manure management factors included in this study is illustrated in Figure S1. Manure could be used as fertiliser for crops, thereby replacing synthetic fertilisers. While having positive effects, the application of manure was also accompanied by emissions. Thereby, N_2O, nitrate and NH_3 were the most harmful substances from manure of the pollutants emitted. The emission of NH_3 arose out of the N in the manure, which could be easily volatised in in-house and outside storage. Phosphate was the only P substance affecting the environment. We considered that 3 % of the P in the manure was leached as phosphate. All environmental impacts related to manure management, including in-house storage, outside storage and field application, were allocated to the pork production. The calculations related to manure characteristics were based on those described in Nguyen et al. (2011).

The slaughtering process is describes in the manuscript. A data inventory of the slaughtering process is presented in Table S3.

2 Pig farm model

The implemented deterministic model of the pig farm reflected processes within a farrow-to-finishing farm. The computer simulation used farm data as presented in Table 2 while being combined with emission factors (IPCC, 2006) and different estimating equations (e.g. Dämmgen and Hutchings, 2008; Rigolot et al., 2010; Sommer et al., 2008). A schematic overview of the calculation procedure is given in Figure S3. In general, the pig farm model included an integrated production chain with vertical linkages between the four stages: farrowing, weaning, finishing and slaughtering of pigs. Thereby, the pig farm model was divided into five essentials: general farm information, biological performances, basic feed data, manure management and resource use & emissions, as shown in Figure S2. Each of these categories was divided further with regard to the stages farrowing, weaning and finishing. The general farm information described production parameters reflected in the model. Examples of input data are number of sows on the farm, number of piglet places per farm and finisher pigs produced per farm. The data for this area mainly originated from the extension service (SSB, 2011). The biological performance of the farm was handled in the second step of the pig farm model, considering biological coherencies. Number of piglets born alive per litter, piglet losses, weights of the sows, number of piglets produced per sow, N retention of the animals and daily weight gains of the finisher pigs were some of the parameters dealt with in this step. The third bullet point included basic feed data, such as feed intake of the pigs in the different stages, protein content of the feed mixtures and amount of feed needed per farm. The data of this step were provided by the feed company and the extension service. Up to this point, the model was mainly based on Krieter (1994, 2001) and de Vries (1989), but updated with current production parameters and expanded using new aspects. Manure management was described in the fourth step of the pig farm model. A simplified scheme of manure management included in the pig farm model is shown in Figure S1 and described above. The consumption of different resources (e.g. heat, electricity, water and transports) as well as emissions (e.g. CH_4 from enteric fermentation) were calculated in the last step of the pig farm model. Data sources are listed in Table S1. The model was based on a deterministic approach using fixed probability distributions (e.g. different culling rates for sows within cycle, varying litter sizes for sows during longevity), according to Krieter (1994, 2001). Interactions between farm parameters were accounted for since most of the calculations in the pig farm model were interactive. The procedure of a model run is amplified in Krieter (2001) and Reckmann and Krieter (2014).

Output

Despite other output values, the pig farm model generated the amount of meat produced, electricity and water use, the amount of manure produced, transportation distances, feed use and on-farm emissions (see Figure S2). The output data were used to estimate the environmental impacts of the pork supply chain for the different scenarios via an LCA.

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Table S1. Data inventory per 1000 kg pig live weight at farm gate using standard feed.

In- / Output	**Unit**	**Amount**	**Data sources,** adapted or directly taken from
Feed			
Wheat	kg	1064	
Barley	kg	1120	Feed company and extension service
Soybean meal	kg	479	
Others	kg	169	
Energy and transports			
Heat (oil)	kWh	98	(KTBL, 2005)
Electricity mix	kWh	121	(KTBL, 2005) & (AEL)
Transport			
Ship	tkm	3375	Feed company
Truck 28 t	tkm	842	Various sources
Tractor and trailer	tkm	130	Farmers
Water (tap)	m^3	397	(EC, 2003)
Farm traction	MJ	249	(Dalgaard et al., 2001)
Emissions to air			
Methane	kg	28.1	(Rigolot et al., 2010) & (IPCC, 2006)
Dinitrogen monoxide	kg	1.2	(IPCC, 2006)
Nitrogen dioxide	kg	-3.2	See Nguyen et al., 2011
Ammonia	kg	24.9	
Emissions to water			
Nitrate	kg	1.4	Nutrient balance
Phosphate	kg	0.6	
Avoided fertiliser production			
N fertiliser	kg	59	
P fertiliser	kg	36	See text
K fertiliser	kg	18	

Table S2. Chemical composition of standard (ST) and alternative (LOW, LEG, AA) diets for sows and fattening pigs.

Contents [%]	**Gestating sows**				**Lactating sows**				**Growing pigs**				**Finishing pigs**			
	ST	**LOW**	**LEG**	**AA**	**ST**	**LOW**	**LEG**	**AA**	**ST**	**LOW**	**LEG**	**AA**	**ST**	**LOW**	**LEG**	**AA**
Energy [MJ ME]	*12.1*	*11.9*	*12.0*	*12.0*	*13.2*	*13.2*	*13.2*	*13.2*	*13.1*	*13.1*	*13.1*	*13.1*	*13.0*	*13.0*	*13.1*	*13.0*
Protein	*13.7*	*12.8*	*12.6*	*12.6*	*18.1*	*15.7*	*16.7*	*15.3*	*18.8*	*16.0*	*15.9*	*16.0*	*17.4*	*14.9*	*14.8*	*14.0*
Lysine	*0.67*	*0.61*	*0.60*	*0.63*	*1.00*	*0.95*	*0.97*	*0.95*	*1.08*	*1.06*	*1.07*	*1.08*	*0.91*	*0.91*	*0.90*	*0.91*
Methionine	*0.24*	*0.22*	*0.21*	*0.22*	*0.32*	*0.34*	*0.32*	*0.33*	*0.33*	*0.34*	*0.41*	*0.39*	*0.28*	*0.25*	*0.31*	*0.28*
Met + Cys	*0.50*	*0.48*	*0.45*	*0.47*	*0.64*	*0.64*	*0.61*	*0.61*	*0.66*	*0.64*	*0.68*	*0.68*	*0.59*	*0.54*	*0.57*	*0.55*
Threonine	*0.46*	*0.41*	*0.41*	*0.41*	*0.68*	*0.66*	*0.66*	*0.60*	*0.71*	*0.71*	*0.70*	*0.71*	*0.62*	*0.59*	*0.59*	*0.61*
Tryptophan	*0.18*	*0.16*	*0.16*	*0.16*	*0.23*	*0.18*	*0.19*	*0.19*	*0.24*	*0.23*	*0.22*	*0.19*	*0.22*	*0.17*	*0.16*	*0.17*
Fibre	*5.90*	*6.27*	*6.15*	*5.95*	*3.88*	*4.56*	*4.16*	*3.92*	*3.37*	*4.15*	*3.99*	*3.27*	*3.49*	*4.28*	*4.13*	*3.39*
Fat	*3.09*	*3.22*	*3.10*	*3.12*	*3.32*	*5.06*	*3.21*	*3.88*	*1.77*	*3.57*	*2.77*	*1.82*	*1.84*	*3.63*	*2.83*	*1.89*
Calcium	*0.87*	*0.87*	*0.86*	*0.86*	*0.79*	*0.80*	*0.77*	*0.77*	*0.76*	*0.77*	*0.74*	*0.74*	*0.72*	*0.73*	*0.70*	*0.70*
Phosphor, digestible	*0.35*	*0.36*	*0.34*	*0.35*	*0.38*	*0.39*	*0.35*	*0.37*	*0.31*	*0.32*	*0.29*	*0.29*	*0.28*	*0.29*	*0.25*	*0.25*

Table S3. Data inventory from a slaughterhouse, representing the slaughter process in the north of Germany in 2008.

	Unit	Amount
Inputs		
1 living pig	kg	120.0
Electricity mix	kWh	21.2
Water (tap)	m^3	0.2
Outputs		
Pork	kg	95.0
Carbon monoxide	g	0.3
Carbon dioxide	g	4537
Nitrogen oxides	g	3.0
Nitrogen dioxide	g	0.08
Methane	g	0.09
Waste (-water) treatment		
BOD5 [1)]	g	94.7
COD [2)]	g	2462
Nitrogen	g	322
Phosphorus	g	28.4
Biodegradable waste	kg	0.4

[1)] BOD5: Biochemical oxygen demand

[2)] COD: Chemical oxygen demand

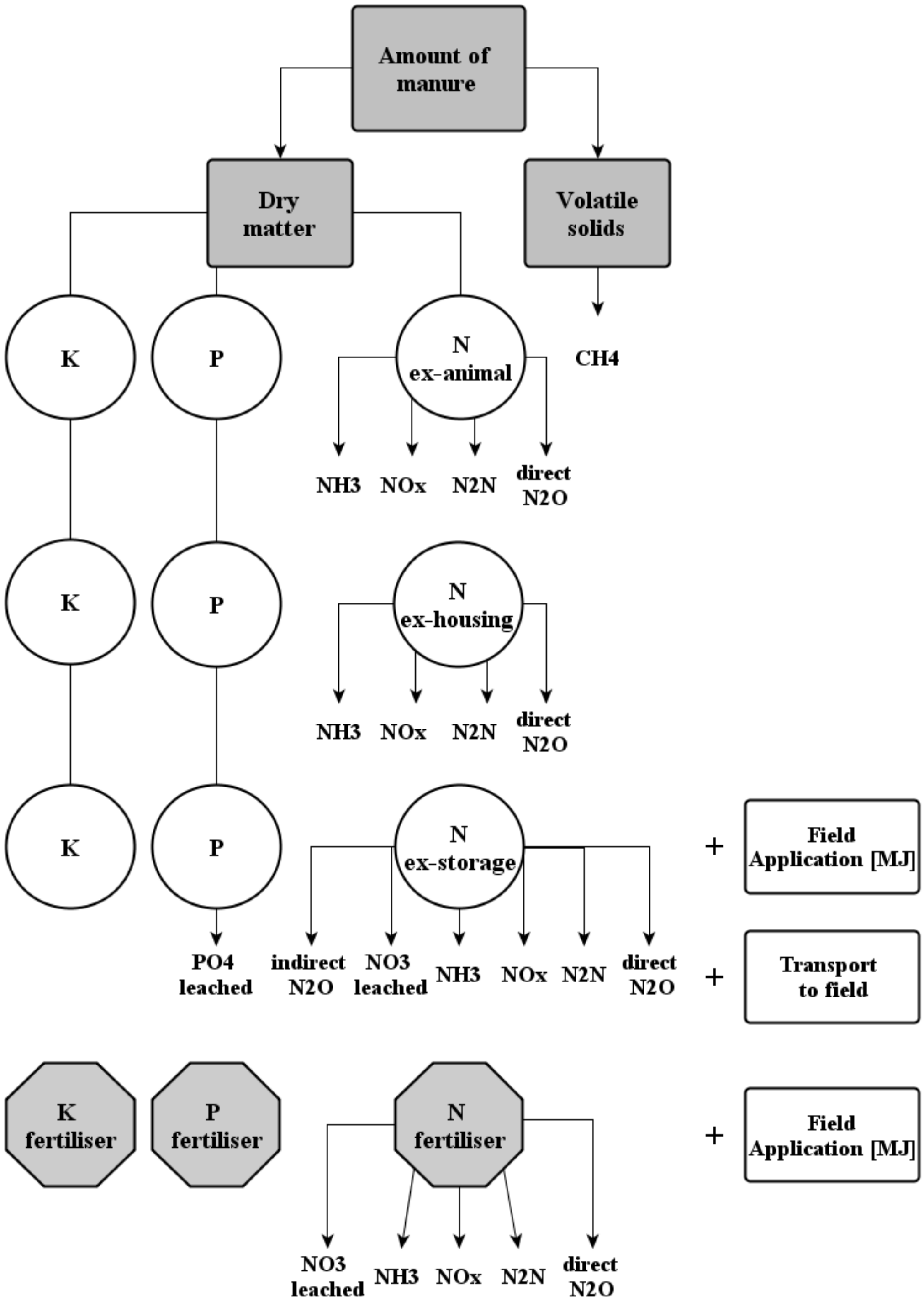

Figure S1. Simplified scheme of the calculation approach for manure management, including emissions and transports.

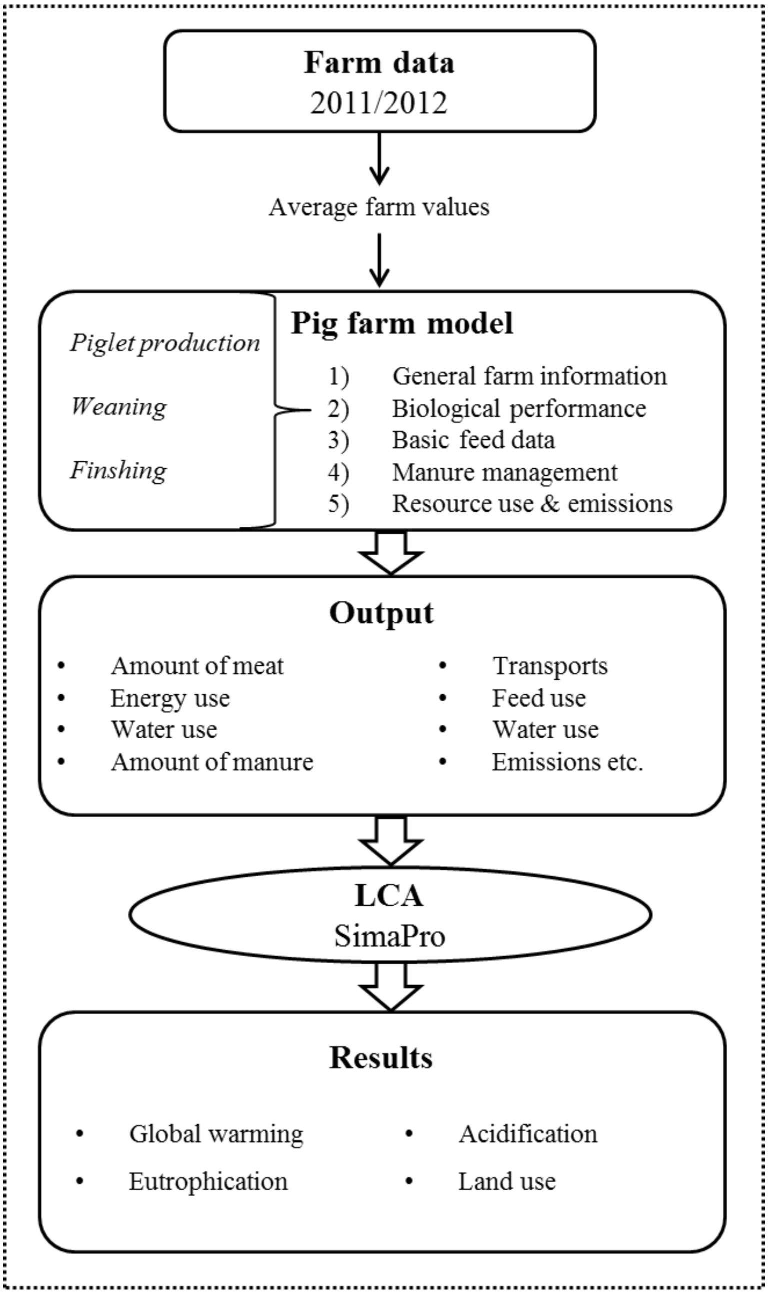

Figure S2. Calculation approach for the LCA of pork produced in Germany.