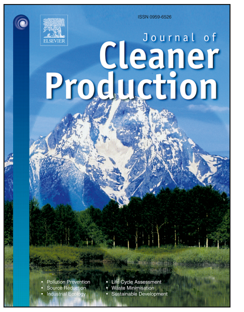

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From Farm to Fork - A Life Cycle Assessment of Fresh Austrian Pork

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Abstract

With 7.5% total nutritional value, pork is a staple food for many members of the Austrian population. Among members of the general public, little is known about the environmental impacts "from farm to fork" in the production of pork. This paper identifies three main impact categories for the environmental profile of Austrian pork using the Life Cycle Assessment (LCA) method. In a transparent and comprehensive manner, this LCA studied environmental impacts occurring throughout the production chain of pork, also including the transport and consumption stages. The results are expressed in terms of the global warming potential (GWP), soil acidification and eutrophication, specifically in CO_2-equivalents, SO_2-equivalents and NO_3-equivalents normalized to one kg of fresh Austrian pork (carcass weight) as the functional unit. The main results of the study indicated that the environmental burden is primarily related to the farming stage: 92.3% of GWP, 98.4% of soil acidification and 95.4% of eutrophication. The processes taking place after the agriculture stage (i.e., during the slaughtering stage, retail market and consumption) play a minor role, except for the relative impact of eutrophication during the slaughtering stage. The transportation that took place between the different life cycle stages only marginally influenced the emissions analysed, with private transport from the retail market to the household contributing most of the emissions considered in this part of the life cycle. These results point to the farming stage as the main focus for future improvements. Due to its high contribution to the GWP, soil acidification and eutrophication potential, enhancing the efficiency and environmental protection measures implemented during the farming stage (or improving the choice of commodities used from feed production) could generate the highest reductions in impacts on soil acidification, eutrophication and potentially on the global climate.

Keywords

Life cycle assessment; pork; agriculture; environmental profile; GHG emissions; eutrophication; acidification

1 Introduction

As one of the fastest growing subsectors of the agricultural economy, the production of livestock is a major contributor to global environmental problems (e.g., through its impact on the world's water, land and biodiversity resources). Moreover, livestock production contributes significantly to climate change and is responsible for about 18% of global anthropogenic greenhouse gas (GHG) emissions. When considering not only direct, but also indirect, effects such as grazing and the production of feed-crops, the livestock sector occupies approximately 30% of the ice-free terrestrial surface of the Earth (Steinfeld et al. 2006).

In global livestock production, meat production is an important element. In 2010, 37% of meat was produced from pigs and 24%, from chickens. The global annual production in 2010 of the three pig systems (backyard, intermediate and industrial) resulted in emissions of 668 million tonnes CO_2-equivalents (eq). The rising population and escalating demand for pig meat, which is projected to grow by 32% between 2005 and 2030, is predicted to result in further increases in the corresponding environmental problems (MacLeod et al. 2013).

Many scientific studies have dealt with the environmental effects of nutrition. One approach taken in these studies is from the context of "footprints", or the assessment of the environmental consequences of certain actions beyond the specific process in question. The "nutritional footprint" and "nutrient footprint" have been analysed in this way recently (Lukas et al. 2015, Grönman et al. 2015). Another approach is through life cycle assessment (LCA). LCA is a holistic approach that supports the detection of environmental "hotspots" and allows the analysis of the most environmentally-friendly methods of the various life cycle stages from the production phase of a certain commodity to the treatment of its remains after use. In this way, the LCA approach can be used to detect and, as a consequence, avoid problem-shifting between life cycle phases, different environmental effects or regions (Finnveden et al. 2009).

LCA has been previously applied to the agricultural sector, and several LCA studies and reviews have been undertaken with regard to the context of this paper, livestock production in general, or specifically pork production (cf. Dallegaard et al. 2007, de Vries and de Boer 2010, González-García et al. 2015, Kool et al. 2009, Kral 2011, MacLeod et al. 2013, Nemecek et al. 2005, Nguyen et al. 2010, Nguyen et al. 2011, Roy et al. 2012, Weidema et al. 2008).

As one common key result of these LCAs, the environmental burden of the agricultural stage has been identified because it generates the highest share of relevant emissions along the meat supply chain. However, the majority of pork LCAs only considered the agricultural, slaughtering and transport stages; an exception was Woitowitz (2007), who also took the trade stage into account. In our "farm-to-fork" approach, we extend this concept to include the consumer stage on a national level (including such aspects as packaging materials and electricity for cooling). Along with literature reviews, the environmental effects of meat production and consumption need to be assessed in a "bottom-up" manner and, thus, regional and sectoral quantification is necessary. A number of country-specific pork LCAs have been published. Most of them have dealt with specific European countries, namely Denmark (Dallegaard et al. 2007, Kool et al. 2009, Nguyen et al. 2011), Germany (de Vries and de Boer 2010, Weidema et al. 2008), Portugal (González-García et al. 2015), Switzerland (Nemecek et al. 2005) and Austria (Kral 2011). In this paper, the focus is on Austria and on fresh pork. In 2009, 63% of the meat consumed in Austria was pork, and represented a total consumption of 40 kg per capita (Statistik Austria 2013). To analyse the environmental impacts of the production of Austrian pork, an LCA was performed that covered the life cycle stages from "farm to fork", including the consumer stage as mentioned above, as well as the impacts from soy bean importation from Latin America. This considerably extends the work of Kral (2011), which was thus far the only pork LCA undertaken for Austria.

While most of the LCAs mentioned focussed on the climatic impacts of meat production, other impact categories are also important. Because they were included in some other studies, soil acidification and eutrophication were also considered during the current study. One chemical element, nitrogen, seems to be an important contributor to all of these impact categories, and measures on nitrogen abatement could be generally beneficial (Sutton et al. 2011). The formation of particulate matter from livestock NH_3 emissions is another, additional nitrogen-related aspect. Indeed, the abatement of agricultural NH_3 emissions has recently been described as an important and cost-efficient way to reduce pollution with regard to particulate matter in Europe (Amann et al. 2014). Nitrogen (N) *per se* is not considered an impact category in an LCA, however, because N is an important factor in food production, it was also of interest to investigate this parameter in detail (see also Pierer et al. 2014, 2015).

This paper describes and discusses the first comprehensive LCA of Austrian fresh pork by covering the three key impact categories, global warming potential (GWP), soil acidification and eutrophication, which have also been considered by comparable LCAs conducted outside Austria. In order to identify, analyse and describe the main environmental problems over the entire life cycle of the pork (production, consumption and distribution), the goal and scope of the LCA are presented first (section 2), followed by a depiction of the life cycle inventory analysis (LCI) in section 3. Afterwards, the life cycle impact assessment (LCIA) is described in section 4 and, subsequently, the results are described (section 5) and discussed using a comparative delineation (section 6). Finally, conclusions are drawn in section 7.

2 Definition of Goal and Scope

2.1 Goal of the Study

The goal of this study was to identify the environmental profile "from farm to fork" of fresh Austrian pork. Pork represents 7.5% of the total amount of food consumed in an average Austrian household (Friedl et al. 2007). The analysis of the process chain was performed using LCA methodology according to the ISO standards 14040 and 14044 (ISO 2009; ISO 2006), with the aim to generate results that can help identify system parts with high levels of environmental impact. Therefore, the product life cycle was separated into five modules, namely (i) agriculture, including the feed production, (ii) slaughterhouse, (iii) trade, (iv) consumption and (v) transport.

2.2 System Boundaries

The system boundaries determined which processes were included in the life cycle assessment (ISO 2009). An overview of the production chain of Austrian pork and the included process is presented in Figure 1.

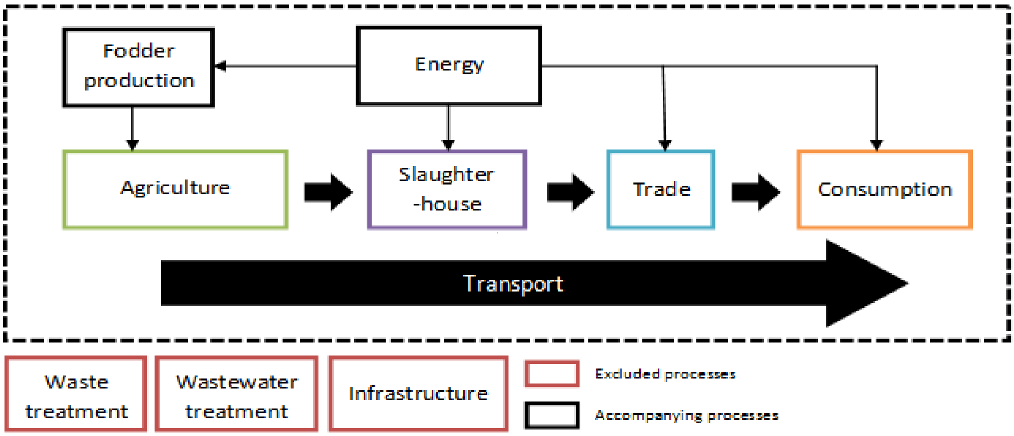

Figure 1: System boundaries of the production chain of Austrian pork

The study included environmental impacts caused by the provision of energy, raw materials and operating resources as well as transport emissions and waste and wastewater directly generated as a result of these processes. Not included were the emissions related to waste/wastewater treatment beyond the consumer stage or emissions caused by setting up infrastructure. Furthermore, the provision, maintenance and disposal of capital goods were not considered.

The study focused on Austrian pork. Therefore, the geographic border reflects the Austrian border, and imports and exports of livestock or pig meat were excluded from the life cycle assessment. This assumption seemed reasonable at a national level of self-sufficiency of 106 % (Statistik Austria 2013). Data derived refer to an Austrian production system, characterized by a "model pig farm" (see section 3).

The reference period for the process data covered the time period from 2007 to 2010, as data from different sources were not always available for identical years.

2.3 Functional Unit

A life cycle assessment for the analysis of the environmental impact of a product involved an evaluation of all resource flows and emissions within a system that were related to the production and delivery of an entity of a given magnitude, the “functional unit” (ISO 2006).

The functional unit chosen to best represent the pork production system was “1 kg fresh Austrian pork (carcass weight)”, which is a common tare weight used in the retail trade. Only fresh pork, directly cut up at the slaughterhouse, was taken into account. Therefore, a carcass weight of 78% of the live weight of the pigs (ca. 120 kg), which equals an average 94 kg per animal (average value, cp. González-García et al. 2015, Jungbluth 2000, Walter et al. 2008), was used in this study. About 80% of the carcass weight is sold as packaged meat (Oklahoma State University, n.d., USDA, 2015).

3 Life Cycle Inventory Analysis

A life cycle inventory analysis involves data collection and calculation to quantify the relevant input and outputs of a product system (ISO 2009). Thus, the first step taken was to identify all appreciable material and energy flows, following the concept illustrated in Figure 1. For the analysis, MS Excel software was used and all data was derived from the published literature. All details about the relevant flows within the production chain of Austrian pork can be found in the supplementary material.

For each of the five modules of the life cycle, an inventory analysis was created and filled with primary and secondary data. The data was extracted from statistical databases, environmental databases and the scientific and technical literature.

3.1 Agriculture

We analysed a “model farm” for Austria, rather than integrating a multitude of different individual farms with their respective differences, in order to hold complexity to a reasonable level. For this purpose, we attempted to mimic the real situation of farms in Austria as closely as possible. Thus, the reference farm used in this study contained more than 400 animals, because this reflects the actual situation of 60% of all pigs in Austria (VÖS 2011).This model farm also was considered to use conventional production (as is used on the majority of pig farms in Austria), and no specific investigation of organic farming was conducted. The characteristics for the assessment are summarized in Table 1.

Table 1: Characteristics of the model pig farm

	Characteristics	Reference
Size of the farm	more than 400 animals[1)]	according to VÖS (2011), also using their classification scheme
Type of production	Conventional[2)]	according to Anderl et al. (2013)
Type of housing	Heated cot[3)]	as suggested by AMA (2013)
Livestock breeding	Combined upbringing of piglets, feeding pigs and breeding animals; Fully slatted floor[4)]	according to Statistik Austria (2012)
Feed use	90.5 % on-farm produced feed (feed supplements get purchased)	according to AGT (2009)
Manure management	Slurry based system with external storage tanks[5)]	according to Amon et al. (2007) & Anderl et al. (2013)
Manure utilization	On-farm utilization	Authors' assumption
Manure application	Traction engine >80 kW, diesel	according to Wieser & Kurzweil (2004)
Observation period	1 year[6)]	according to AMA (2013)
Average live weight	120 kg[7)]	VÖS (2011)

1) 60% of all pigs in Austria are kept on farms in herds of 400 to 3000 animals

2) Conventional farming, as opposed to organic farming.

3) Heated cots provide optimal and constant temperatures due to heating and ventilation systems. This is required because of the low winter temperatures in Austria.

4) Slatted floors are floors with slots through which excrement and urine flows. In cots with fully slatted floors, all surface areas have slots.

5) The manure excreted by the animals in the form of slurry (mixture of liquid and solid particles) is first stored in a pit beneath the slatted floors for a short interval. Then, the slurry is pumped to an external storage tank, where it is stored for use in field applications (BMLFUW, 2006).

6) The agriculture database referred to the above-mentioned observation period. Due to the fact that the annual amount of extracted manure (Pöllinger et al. 2011) and the total feed use (AGT 2009) considers the needs of piglets, feeding pigs and breeding animals, the observation period includes the following phases: fertilization, gestation period (16-17 weeks), lactation period (3-6 weeks), rearing period (6-8 weeks) and fattening period (17-18) weeks.

7) Average life weight of fully-grown pigs at the farm gate

Feed use. Pig production is closely linked to the feed supply. An optimal nutritional diet is hypothesized to lead to a higher production in fresh meat. The energy and protein contents of the feed are particularly important. Supplements such as vitamins or minerals can be given to support the pig's immune system. Therefore, a balanced diet should include feed rich in energy (e.g., corn and crop), protein (e.g., soy, rapeseed and sunflower) and minerals, which supplies vitamins and minerals as well as additional amino-acids as required (AMA 2013). Based on data published by the study group “Gesunde Tierernährung” (AGT 2009), a feed ration of 4 kg is calculated per functional unit. This ration consists of around 38.0 % corn, 19.0 % wheat, 19.0 % barley, 7.2 % soy meal, 3.6 % rapeseed meal, 3.6 % sunflower meal and 9.5 % mineral feed. Furthermore, a water consumption of 12 litres per functional unit has been proposed (Schafzahl 1999).

Energy use. Pig rearing in heated cots results in heat consummation and the expenditure of electricity for ventilation and light. Furthermore, energy is needed to pump raw sewage to the plant as part of the manure management system. Altogether, the production requires 0.35 kWh of electricity and 0.19 kWh of thermal energy per functional unit (KTBL 2005). Moreover, 1.21 kWh of mechanical energy is generally used for field manipulation and on-farm transportation (BMU 2012). This data, originally gathered in Germany, is considered relevant for Austria due to the many similarities in general conditions (e.g., outside temperatures and technologies used in animal husbandry).

Enteric fermentation. Enteric fermentation refers to processes in the animals’ intestines that lead to the emission of methane. To calculate the amount of these emissions, the “Tier 1-Method” developed by the International Panel on Climate Change (IPCC 2006) has been applied for animals in Austria (Anderl et al. 2013) and the results are 16.03 g CH_4 per functional unit.

Manure management. Regular (e.g., weekly) removal of manure from the storage pits beneath the slatted floor and proper storage of manure in outdoor tanks are essential points to support environmentally-friendly manure management in livestock production. A valuable resource, manure is destined to be used eventually as fertilizer on the farm. Therefore, it can act as a substitute for synthetic fertilizers to some extent. In this study, the substitution rates for N, P and K were assumed to be 75 %, 97 % and 100 %. Following the methods in Nguyen et al. (2011), we allocated all environmental impacts that were related to manure storage and application to pig production (instead of to the crops produced from manure-fertilized fields), and we specifically accounted for the reduction in environmental impacts associated with the avoidance of synthetic fertilizers. Calculations were based on the total amount of manure excreted by the animals in the form of slurry in 2008 (Pöllinger et al. 2011), and allowed us to estimate 10.3 kg slurry ex-animal per functional unit. Further estimates provided the dry matter and volatile solids content, as well as the emissions (N, P, K, CH_4, NH_3, direct and indirect N_2O) involved. The results and references are shown under manure management in Table 2.

The calculated amount of feed and energy input, manure output and on-farm emissions per functional unit are summarized in Table 2.

Table 2: Inventory analysis of the agricultural process, normalized to the functional unit (1 kg fresh Austrian pork (carcass weight))

Input	Unit	Data	Source
Mineral feed[1)]	kg	0.38	
Corn	kg	1.52	
Wheat	kg	0.76	
Barley	kg	0.76	See AGT (2009)
Soy meal	kg	0.29	
Rapeseed meal	kg	0.15	
Sunflower meal	kg	0.15	
Water	l	12.02	See Schafzahl (1999)
Electricity	kWh	0.35	See KTBL (2005)
Heat	kWh	0.19	
Mechanical energy	kWh	1.21	See BMU (2012)
Output	**Unit**	**Data**	**Source**
Livestock (1 kg carcass weight)	kg	1.28[2)]	
Enteric Fermentation	**Unit**	**Data**	**Source**
CH_4	g	16.03	See IPCC (2006) & Anderl et al. (2013)
Manure Management	**Unit**	**Data**	**Source**
Slurry ex-animal	kg	10.32	
Slurry ex-cot	kg	10.32	
Slurry ex-storage	kg	11.20	
Dry matter ex-animal	kg	0.79	
Dry matter ex-cot	kg	0.75	
Dry matter ex-storage	kg	0.72	See Nguyen et al. (2011) & Resch et al. (2006)
Volatile solids ex-animal	kg	0.65	
Volatile solids ex-cot	kg	0.61	
Volatile solids ex-storage	kg	0.57	
N	g	41.22	
P	g	5.16	
K	g	23.52	
CH_4	g	17.10	derived from IPCC (2006) & Anderl et al. (2013)
NH_3	g	15.99	See Nguyen et al. (2011) & Resch

			et al. (2006)
N_2O (direct and indirect; in-cot and outside storage)	g	0.07	See IPCC (2006) & Anderl et al. (2013)

Manure distribution on field	Unit	Data	Source
Transport to fields	Wh	175.3	
Application	Wh	55.9	
N_2O	g	0.4	
NH_3	g	1.1	
Avoided fertilizer production (emission credit)			
N	g	-30.9	See Nguyen et al. (2011)
P	g	-5	
K	g	-23.5	
Avoided fertilizer application (emission credit)			
Application	Wh	-3.90	
N_2O	g	-0. 6	
NH_3	g	-2.8	

1) a mixture of vitamins, minerals and additional protein- and energy-rich fodder
2) It is assumed that the carcass weight is 78% of the animal's live weight and, therefore, 1 kg of carcass weight equals 1.28 kg live weight.

At the end of the fattening period, the pigs are brought to the slaughterhouse. Detailed information on transport emissions is shown in section 3.5.

3.2 Slaughterhouse

A carcass weight of about 93.6 kg is obtained from the live weight of one pig at the time of slaughter, which is 120 kg. In the present study, we assumed that the whole fresh meat was packed and cooled directly after slaughter and dismembering, without considering further processing steps such as curing or mincing. Different packaging materials were considered – Expanded Polystyrene (EPS), High Density Polyethylene (HDPE), Polypropylene (PP) and packaging paper and cardboard. Further details of the slaughtering process are listed in Table 3.

Table 3: Inventory analysis of the slaughtering process, normalized to the functional unit (1 kg fresh Austrian pork (carcass weight))

Input	Unit	Data	Source
Pig (live weight)	kg	1.28	
Water	l	2.56	
Liquid CO_2	g	2.6	
Solid CO_2	g	3.1	See Nguyen et al. (2011)
Electricity	kWh	0.14	
Heat	kWh	0.17	

EPS	g	4.20	
HDPE	g	3.60	
PP	g	4.70	See Jungbluth (2000)
Packaging paper	g	18.00	
Packaging cardboard	g	25.00	
Output	**Unit**	Data	**Source**
Fresh Austrian pork (packaged meat)	kg	0.80[1]	
Waste	**Unit**	Data	**Source**
Organic waste (bones, bristles, etc.)	kg	0.20	See Jungbluth (2000)
Wastewater	**Unit**	Data	**Source**
Wastewater	l	2.56	See Nguyen et al. (2011)

[1] 80% of the dressed weight are retail cuts and can be sold in the store (this non-functional unit was used for certain parameters) (Oklahoma State University n.d., USDA ERS 2015)

3.3 Trade

The module "Trade" represents the process of keeping packed fresh pork cool in a retail store. This study acts on the assumption that the meat in shops is offered in open refrigerated units. The consumed amount of electricity is calculated according Nielsen et al (2003a) and accounted for 0.04 kWh per functional unit.

3.4 Consumption

The module "Consumption" covers the cooling and cooking processes that take place in households, including the production of emissions and waste. To arrive at the amount of electric energy required for cooling, 0.08 kWh per functional unit, we employed an equation developed by Nielsen et al (2003b). It was assumed that electric kitchen stoves are used to cook the fresh pig meat. Pursuant to Jungbluth (2000), the households need 0.20 kWh per functional unit for the cooking processes. Other commodities required (40.15 l of water for cooking and cleaning, BMLFUW 2012) or waste streams produced (64 g of organic waste and 56 g of packaging waste) were not considered in this study.

3.5 Transport

This module includes the transportation connections between the four steps of the life cycle discussed above (i.e., from "Agriculture" to "Slaughterhouse", from "Slaughterhouse" to "Trade" and from "Trade" to "Consumption") plus the feed transport from Latin America (Brazil and Argentina) to the Austrian farm. The overseas transport of soy was considered to include transport by ship, train and truck to Europe and accounted for 243 g CO_2-eq/t. For one kg of pork, an estimated 290 g of soy is fed to the animals, resulting in 65.25 g CO_2-eq/kg of pork (Castanheira and Freire 2013). In addition, the transport of soy from the harbour to the Austrian farm needs to be considered. Given the geographical location of Austria we assume a transport distance of about

1000 km to the farm (Nguyen et al. 2011 assume that soy is transported for about 500 km by trucks to Denmark, incl. transport in Latin America). When all soy is transported by trucks (worst case), emissions from this action would add up to 2.4 g CO_2/kg of pork resulting in an overall impact from feed transportation of 70.05 g CO_2-eq/kg of pork. We are aware of a certain acidification and eutrophication potential of feed transportation from Latin America to Austria, e.g. regarding the emissions of cross-Atlantic ship transport. However, it is not considered in this paper due to difficulties in quantifying those data. The main impact from the transport of livestock and meat is related to energy use expended during the transportation itself and as part of cooling processes that are necessary during transport. The carcass is cooled from the point it leaves the slaughterhouse or the retail store.

In order to reduce stress on the animals, the route of transport between the farm and the slaughterhouse should be as short as possible. Considering the location of the agricultural and meat-processing businesses, a distance of 50 km was assumed (VÖS 2011), considering that the pigs need to be shipped by a truck with a capacity of 20 t. This allowed us to estimate the amount of fuel needed per functional unit. Because emission factors are available for specific distances, we allocated a certain distance to each functional unit, which was mathematically identical, even if physically less plausible. By doing so, we obtained a distance of 59 m per functional unit for the transport distance between the farm and the slaughterhouse.

Refrigerated transport is needed between the slaughterhouse and the retail store. We estimated that a typical travel distance would be 110 km. Again, at a capacity of 20 t, this results in a calculated distance of 117 m per functional unit. In order to additionally account for the energy costs related to refrigeration, we used an incremental factor of 10.4 % based on that published by Nguyen et al. (2011).

Assuming that the average distance covered during daily shopping is 11.55 km (BMVIT 2007), and assuming that pork represented 7.5% of the total average food consumption in Austria (7.5 %) (Statistik Austria 2013), we estimated that a distance of 400 m was travelled by car per functional unit. Thus, this aspect represented the highest environmental burden, relatively speaking, within the transport stage of this LCA. Furthermore, we calculated a distance of 6.72 m per functional unit, when public transportation (bus) was used.

4 Life Cycle Impact Assessment

In its LCIA phase, the LCA considered only the impact categories “global warming potential (GWP)”, “acidification potential (AP)” and “eutrophication potential (EP)”, the choice of which can be justified as follows:

(i) The three chosen impact categories are commonly used to draw a picture of the environmental profile of agricultural products, which is considered to be comprehensive(cf. Perrin et al. (2014), who considered GWP, AP and EP to be the three crucial impact categories in an analysis of 72 cropping systems in the field of the LCA of vegetable products).

(ii) Six other relevant studies in the field of life cycle assessment for pork have been conducted, namely Kral (2011), Nguyen et al. (2011), Kool et al. (2009), Hirschfeld et al. (2008), Koerber et al. (2007) and Woitowitz (2007) (cf. Table 9 in the discussion (in section 6)). All authors included GWP as an impact category and, thus, a comparison with the results of this paper is possible. However, only Nguyen et al. (2011) additionally considered AP and EP. On the other hand, Nguyen et al. (2011) did not consider trade and consumption within the life cycle. Therefore, this paper is a more comprehensive pork LCA with regard to both life cycle stages and impact categories.

(iii) Other impact categories, such as land-use change (LUC) or use of energy, which this paper did not take into account, are indirectly considered because the energy use (e.g., electricity used for cooling, emissions from transport) is closely related to the emission of CO_2. The emissions of CH_4 and N_2O that are needed to determine the impact category GWP also cover land-use to a certain extent. However, it is very difficult to include emissions from LUC in a LCA, as noted by Nemecek et al. (2014): there is a lack of “[…] international consensus on how to consistently and systematically address LUC in life cycle inventory, despite significant research in the LCA community.”

In order to assess GWP, data from the latest IPCC assessment report (IPCC 2013) were used to quantify the respective contributions of CH_4 and N_2O with respect to CO_2. This yielded the factors of 36 and 298, respectively, which could be converted into CO_2-eq for a 100-year time horizon. For the last two categories, AP, and EP, emission equivalents according to Klöpffer & Grahl (2011) were used to estimate the environmental impacts. These characteristic factors reflect stoichiometric relationships between nitrogen and sulphur (AP), and nitrogen and phosphorous (EP), and their respective derivatives.

The respective emission factors needed for the impact assessment were taken from different databases or the literature. For the input factor, electricity, the Austrian mix according to “ProBas” was used (BMU 2013). The factors for heat, which were different in the farming and slaughtering stages, were extracted from the literature (Pölz 2007; Wieser & Kurzweil 2004). The emission factors of wastewater from the slaughtering and consumption phases also differed, as well as those appearing in the associated literature (Nguyen et al. 2011; Antranikian 2006). Wieser & Kurzweil (2004) provided emission factors for the different various means of transportation.

For the input factors feed, synthetic fertilizers and packaging materials, the calculated CO_2-, SO_2- and NO_3-eq were used (shown in Table 4). The emission factors for feed were based on a study using the SALCA (Swiss agricultural life cycle assessment) method by Nemecek et al. (2005) and implicitly included GHG emissions such as N_2O. Due to similarities between Swiss and Austrian agriculture, these parameters could be directly transferred. It is important to consider that these emission factors are much higher than those estimated from different studies (e.g., Denmark - compare with Nguyen et al. 2011). It can be argued that emission factors from soy meal are higher in landlocked countries, which have a suboptimal climate for soy planting, than in coastal lands characterized by soy imports. Furthermore, improved techniques of manure application may result in different levels of NH_3 release (see Bittmann et al. 2014), which may also further explain discrepancies observed.

Table 4: Emission factors per kg feed, kg synthetic fertilizer and kg packaging material, expressed as Global Warming Potential (g CO_2-eq), Acidification Potential (g SO_2-eq) and Eutrophication Potential (g NO_3-eq)

Feed	**g CO_2-eq**	**g SO_2-eq**	**g NO_3-eq**	**References**
Corn	565	6.44	12.50	
Wheat	692	5.10	17.40	
Barley	605	4.80	19.40	
Soy meal	1,532	8.60	25.90	Nemecek et al. (2005)
Rapeseed meal	1,304	14.40	19.70	
Sunflower meal	1,123	7.29	20.31	
Mineral feed	729	6.34	4.43	
Fertilizer	**g CO_2-eq**	**g SO_2-eq**	**g NO_3-eq**	**References**
Nitrogen fertiliser	4,250	33.20	58.90	
Phosphorous fertiliser	2,690	41.00	26.40	Nguyen et al. (2011)
Potassium fertiliser	804	1.40	1.90	
Packaging material	**g CO_2-eq**	**g SO_2-eq**	**g NO_3-eq**	**References**
HDPE	1,960	6.39	4.36	
EPS	3,672	10.44	6.53	Plastics Europe (2013)
PP	2,000	6.13	4.44	

Paper	1,172	6.32	6.93	BUWAL (1996)
Cardboard	745	11.42	2.89	

5 Results

Table 5 summarizes the environmental performance of the five modules in the three impact categories considered per kg fresh Austrian pork (carcass weight).

Table 5: The total environmental impact per kg fresh Austrian pork (carcass weight)

Life cycle module	GWP g CO_2-eq	AP g SO_2-eq	EP g NO_3-eq
Agriculture	4,383	60.48	363.82
Slaughterhouse	142	0.61	16.96
Trade	8	0.01	0.02
Consumption	50	0.10	0.13
Transport	168	0.28*	0.50*

* does not include feed transport from Latin America to the Austrian farm

The total impact per functional unit (including credits from manure management) is estimated at 4,751 g CO_2-eq, 61.5 g SO_2-eq and 381.4 g NO_3-eq for the typical Austrian pork production. Table 5 shows that the environmental impacts are notably related to the agricultural production stage (with a contribution of 92.36% contribution to GWP, 98.4% to soil acidification and 95.4% to eutrophication) and much less so to the subsequent modules. The high contribution of agriculture to GHG emissions of Austrian pork production is in line with the results of similar studies (slightly higher value for Austria: Kral 2011; slightly lower value for Portugal: González-García 2015). The impact of eutrophication during the slaughtering stage is considerable, contributing to 4.4% of the total eutrophication, whereas the remaining values in Table 5 represent less than 0.01%. Eutrophication during the slaughtering stage originates from organic pollutants, nitrogenous and phosphorous compounds in the wastewater. However, the prominent role of agriculture with regard to its environmental effects is striking and, thus, it is worthwhile to consider this farming stage in more detail.

Table 6: Environmental profile of the agricultural stage per kg fresh Austrian pork (carcass weight)

Life cycle module for the agricultural stage	GWP g CO_2-eq	AP g SO_2-eq	EP g NO_3-eq
Feed	2,923	25.41	295.66
Energy use	519	8.01	15.30
Enteric fermentation	545	0.00	0.00
Manure management	602	30.06	58,20

Credits (mineral fertilizer savings)	-206	-3.00	-5.36

As Table 6 shows, “Feed” is the major contributor during the farming stage (see Nguyen et al. 2011 for comparable results) when considering all three impact categories analysed, whereas “Manure management” turns out to be a major contributor in terms of acidification and eutrophication. Energy use and enteric fermentation are minor contributors with reference to eutrophication and acidification, but along with manure management are each responsible for 11-12.5% of the GWP. The credits gained due to the substitution of synthetic fertilizers only slightly alleviated the environmental impacts of the agricultural stage with regard to GHG emissions, acidification and eutrophication.

Table 7: Environmental profile of the feed per kg fresh Austrian pork (carcass weight)

Feed	GWP g CO_2-eq	AP g SO_2-eq	EP g NO_3-eq
Mineral feed	278	2.42	28.16
Corn	861	9.81	84.34
Wheat	527	3.88	58.70
Barley	461	3.66	65.45
Soy meal	444	2.50	33.29
Rapeseed meal	189	2.09	12.66
Sunflower meal	163	1.06	13.05

The environmental burden of the total feed ration per functional unit is estimated at 2,920 g CO_2-eq, 25.41 g SO_2-eq and 295.66 g NO_3-eq. The major contributor was corn with reference to GWP and AP, and corn, barley and wheat, with reference to EP. We noted that the impact was derived from both the emission factor and the amount used. The amount of feed and its composition was similar to that described in a comprehensive EU study (Leip et al. 2010), which described a greater use of corn and soy meal, but less of rapeseed and sunflower meals. For example, corn has a lower emission factor than rapeseed, but plays a bigger role due to its higher consumption levels. Using a different recommendation for feed composition by the Austrian organisation of swine production (VÖS 2011) resulted in a calculated increase in GWP by 1.7%, acidification potential by 1.6% and eutrophication potential by 1.2% (cp. Table 8). In Austria, around 10% of the total amount of feed for pigs is not produced by the farmers (AGT 2009) and needs to be bought and/or imported from abroad. One way to reduce the impact on the environment would be to decrease the amount imported feed. Another way would be to alter the dietary composition, for example, by using phase feeding. For example, Pierer et al. (2015) demonstrated decreases in N-leakages by phase feeding.

Table 8: Comparison of different feed compositions (AGT 2009, VÖS 2011)

Feed	Assumption in this study (kg)	Recommendation by VÖS (2011) (kg)
Mineral feed	0.38	0.12
Corn	1.52	1.80
Wheat	0.76	0.00
Barley	0.76	1.24
Soy	0.29	0.42
Rapeseed	0.15	0.21
Sunflowers	0.15	0.21

When examining manure management during the agricultural LCA stage, the environmental impact was mainly caused by methane emissions from the manure and, to a lesser extent, by direct and indirect N_2O emissions. With reference to acidification, the environmental impact was related to the on-farm emission of NH_3, and the emissions in the category eutrophication could be attributed to the nitrogen and phosphorus derivatives released.

6 Discussion

The results of our analysis clearly demonstrated that the environmental burden of fresh Austrian pork is primarily associated with the agriculture stage. Environmental burdens associated with other stages such as trade, transport or slaughterhouse, have a relatively minor impact. During the agriculture stage, the foremost source of environmental impacts identified was the production of feed, which was shown to be more important than manure management or energy use on farms. The proper selection of feed, therefore, may also influence the environmental impact of pig farming. The result of this LCA allows us to provide recommendations to optimize the environmental performance of pig farming, especially when considering feed production.

When optimizing feed rations with regard to environmental aspects, animal requirements and animal welfare aspects cannot be neglected. It is necessary to optimize growth for economic reasons, but a waste of protein (generally an expensive commodity) should be avoided. Phase feeding allows animal requirements to be more specifically addressed, while avoiding the addition of excess protein and, at the same time, release of excess nitrogen into the manure of the animals (Amon et al. 2014).

When compared to other animals (see e.g., Steinfeld et al. 2006, Leip et al. 2010), pigs display similar environmental impacts as chickens, but clearly have a lower impact than cattle. The environmental impacts of enteric fermentation, which are rather low for pigs, play an important role in cattle farming. This fermentation is a result of symbiotic microbial processes in the rumen of cattle, which allow them to digest grass. The formation of methane is directly linked with the digestion of a commodity that is *per se* not accessible to humans: grass. Pigs, on the other hand, partly compete for the same resources as humans (e.g., corn or wheat). It is necessary to raise awareness about this fact and, therefore, an efficient mitigation option would be to adjust human diets to encourage lower meat consumption levels (Stehfest et al. 2009).

Most notably, pig rations in Austria are mostly based on the availability of local products (corn, wheat), in contrast to many other European countries, where pig production is based on the availability of soybeans, which are mostly imported from Latin America (see e.g., for Spain, Laselletta et al. 2014). While soybeans and soy meal are considered a significant cost factor in Austrian production, cheap ship transport allows their use in coastal regions of Europe. The different environmental footprints associated with soybean vs. other foodstuff have been discussed by Hörtenhuber et al. (2014), *inter alia*. The use of soy meal as feed has a significant impact on the environment as indicated in these LCA results. The range of uncertainty, however, is rather high for impact of soy as compared to that of other crops. GHG emissions from soy production in South America manly depend on emissions from land-use change and vary greatly, depending on where the soy is planted. In an LCA study on soy-bean production in Brazil and Argentina, Castanheira and Freire (2013) showed that the GHG emission per kg of product varied between 0.3 kg - 17.8 kg CO_2-eq (including emissions from cultivation, land-use change and transport).

Careful and continuous evaluations using LCA or a similar method, on the level of individual countries, are necessary to monitor the progress of the release of undesired substances. Some mitigation may be technically feasible (e.g., air pollutants as in Bittman et al. 2014), which then could result in a direct positive response in the LCA, while in other cases (predominantly greenhouse gas related emissions), structural changes leading to a production shift may be more appropriate.

In order to verify the results determined and the robustness of the results, we compared the findings obtained with those published in other available studies, where the conditions and studied issues mirrored those in Austria. The following table shows the results of the chosen studies, their respective geographical coverage, and the references. Only a few studies were available beyond the stage of the farming process.

Table 9: Results for the functional unit, 1 kg pork (live and carcass weight) - geographical coverage and references

LCA	Results: Conventional farming	Results: Organic farming	Geographic coverage	Reference
g CO_2eq				
Agriculture	4,109	4,965	Germany	Woitowitz (2007)
	1,870		Germany	Koerber et al (2007)
	3,070	2,070	Germany	Hirschfeld et al. (2008)
	2,790	1,700		
	3,610	4,880	Germany	Kool et al. (2009)
	4,950	3,480	Austria	Kral (2011)
	2,882		Denmark	Nguyen et al. (2011)
	4,383		Austria	This study
Slaughterhouse	148	148	Germany	Woitowitz (2007)
	30	30	Germany	Kool et al. (2009)
	25	23	Austria	Kral (2011)
	179		Denmark	Nguyen et al. (2011)
	142		Austria	This study
Trade	18	18	Germany	Woitowitz (2007)
	8		Austria	This study
Consumption	50		Austria	This study
Transport	80	80	Germany	Woitowitz (2007)
	80	170	Germany	Kool et al. (2009)
	61	67	Austria	Kral (2011)
	151		Denmark	Nguyen et al. (2011)
	168		Austria	This study
g SO_2eq				
Agriculture	56.15		Denmark	Nguyen et al. (2011)
	60.48		Austria	This study
Slaughterhouse	0.17		Denmark	Nguyen et al. (2011)
	0.61		Austria	This study
Transport	0.97		Denmark	Nguyen et al. (2011)
	0.28		Austria	This study
g NO_3eq				
Agriculture	241.08		Denmark	Nguyen et al. (2011)
	336,82		Austria	This study
Slaughterhouse	1.46		Denmark	Nguyen et al. (2011)
	16.96		Austria	This study
Transport	1.46		Denmark	Nguyen et al. (2011)
	0.50		Austria	This study

In general, the conclusions drawn for Austria in this study may widely reflect a situation that has also been observed in other countries. Deviations are observed, but can be assigned to the varying settings of the goals and different system boundaries. Basically, the agricultural stage generated the highest emissions (92-99% of GHG emissions) in all analysed studies, which conforms to the calculated results. In particular, the outcomes of

Woitowitz (2007), Hirschfeld et al. (2008), Kool et al. (2009), Kral (2011) and Nguyen et al. (2011) generally supported the results obtained here. A good agreement for acidification and overall eutrophication was found that is in line with the results of different studies from other European countries. Daalgaard et al. (2007) provided an additional overview of LCA studies on pork in several European countries (Denmark, Sweden, France, Great Britain). However, the range of results indicated a high level of variability among environmental impacts of pork production. GWPs in this overview varied from 2.6 - 5.6 kg CO_2-eq, APs ranged from 37 - 290 g SO_2-eq and EPs were assessed between 170 and 760 g NO_3-eq per functional unit. The difference between the EP in slaughtering and transport observed in this study and that published by Nguyen et al. (2011) may be due to the different assumptions for waste water usage in the slaughterhouse and the absence of shipping in feed transport.

When we compare the results of this study with those from other LCAs (Table 9 and Daalgaard et al 2007, Leip et al. 2010), we see that the environmental impact of pork production in Austria is rather average to high. This is mainly the results of the high emission factors associated with agricultural products (Nemecek et al. 2005), which are estimated to be much higher than in other LCA studies. However, we argue that this high estimation makes sense for Austria's pork production due to its geographical characteristics, the different approach taken during manure application and different dietary assumptions.

7 Conclusions

This investigation of the environmental impacts of pork production allowed us to identify the major contributing factors and single out the stages of the production process that had only a minor impact. With 1 kg fresh Austrian pork (carcass weight) as the functional unit and the system boundary defined at the level of the consumer, the highest impacts are clearly caused by agricultural activities, specifically the feed production. With reference to eutrophication, the slaughtering stage is also important.

Similar impacts have been observed in comparable studies for greenhouse gas emissions, acidification and eutrophication. These observations support the general conclusion that aspects of consumption, transport and food preparation play only minor roles in the overall environmental impact of pork.

Clearly, any mitigation measures need to focus on animal feed production and total production numbers. It is not possible to single out just one contributor. Feed rations, however, may provide an alternative to explore in order to reduce the environmental impact. Eutrophication and acidification may potentially be reduced by ammonia abatement (see Bittman et al., 2014 for the respective options). In the long term, a change in diets is probably the only way to reduce emissions from pork and meat production in general. Raising awareness on this fact can lead to a substantial reduction in GWP, AP and EP. Such behavioural changes have been previously discussed and advocated in the scientific literature (e.g., Stehfest et al., 2009).

The situation in Austria differs with respect to those seen in the major pork-producing countries in Europe, especially those situated along the Atlantic coast. Austrian pigs are raised on a diet of about 90% domestically produced feed (AGT 2009), while many European countries rely on soy meal imports, often from South America, and the environmental footprints include the respective environmental impacts in the source regions. As compared results described in other European studies, Austrian pork production shows a tendency toward higher environmental impact due to the high emission factors of the agricultural crops. Further studies will be needed to ascertain whether this observed difference exceeds variability observed in data.

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Highlights

First comprehensive LCA of Austrian fresh pork

LCA incl. consumer phase, usually neglected by national LCAs of food products

Importance of nitrogen abatement for different impact categories

Detailed comparison of similar LCAs of pork

ACCEPTED MANUSCRIPT