Comparative Life Cycle Assessment of Field-to-Fork Pork Supply Chains in the United States and the European Union

Final Report

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Acronyms and Abbreviations

ADG	Average Daily Gain (lb/day)
CH_4	Methane
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
FCR	Feed Conversion Ratio (lb feed/lb gain)
GHG	Greenhouse Gases
GWP	Global Warming Potential (CO_{2e})
IPCC	Intergovernmental Panel on Climate Change
LCI	Lifecycle Inventory
LCIA	Lifecycle Impact Assessment
LUC	Land Use Change
MCS	Monte Carlo Simulation
MMT	Million metric tons
N_2O	Nitrous Oxide
NASS	National Agricultural Statistical Service
PPEC	Pig Production Environmental Footprint Calculator.
USDA	United States Department of Agriculture

Executive Summary

The goal of this study was to compare impacts of pork production and consumption in the US and EU. The impacts were calculated using life cycle assessment (LCA) methodology. The LCA provides quantitative, confirmable, and manageable models to evaluate production processes, analysis options for innovations, and improve understanding of complexity in agricultural production systems. Therefore, LCA can be an effective tool to identify and quantify differences in two systems. The environmental impact categories used in this study were: global warming potential (GWP), agricultural land occupation, fossil fuel depletion, and water consumption.

A functional unit of 1 kg of pork consumed was selected for comparison. The system boundaries were defined as cradle-to-grave. The system included crop production, pig farming, transportation, slaughtering and processing of animals, packaging, retail storage, and preparation and consumption of pork. Burdens arising from all activities upstream of crop and pig production were also accounted in the study. Pig production was simulated for Iowa, North Carolina, and Minnesota in the US and for Germany, Denmark, Netherland, France, and Spain in the EU using Pig Production Environmental Footprint Calculator (PPEC). Outputs from PPEC were used as life cycle inventory (LCI) for pig production model developed in SimaPro. The SimaPro model incorporates the PPEC results to provide the necessary reference flows through the supply chain to produce the functional unit of 1 kg of pork. It accounts for distribution of products among domestic and export markets as well as by-products from processing and food waste. The focus of this work is only fresh lean meat for domestic retail and does not include an accounting of pork for export and food service markets. Data from DATASMART, EcoInvent, and Agri-Footprint databases were used for background processes. Data for pig performance parameters, manure management systems, pig inventory, and foreground data for post-farm gate processes were obtained from peer-reviewed publications, industry and government reports, and publicly available data repositories such as USDA-NASS and Eurostat.

Comparative analysis of US and EU pork supply chains showed mixed results (Table ES-1). The US pork supply chain performed better in agricultural land occupation and GWP. However, European pork supply chain had lower consumptive water use and fossil fuel depletion. The

Table ES-1: Impact assessment results for US and EU pork supply chains (cradle-to-grave) for 1 kg of pork consumed.

Impact category	**US**	**EU**
GWP, IPCC 100a, kg CO_2e	9.94	12.42
Agricultural land occupation, m^2a	9.02	10.11
Water consumption, m^3	0.515	0.254
Fossil fuel depletion, kg oil eq	2.33	1.53

larger water consumption for the US production systems is driven by the higher fraction of feed that is irrigated, primarily corn, which has continually increasing irrigated acreage.

Higher GWP for EU was attributed to land use changes associated with production, import, and use of soy feed from Latin America. It has been estimated that 90 percent of soybean meal in European pig feed was imported from Brazil and Argentina (Blonk Agri Footprint BV 2015a). To evaluate the importance of land use change in South America (deforestation for agriculture expansion), when burdens associated with land use change were excluded from the analysis, the GWP for US and EU were 9.92 and 8.71 kg CO_2e respectively for 1 kg of pork consumed. The US also declined slightly because some soy is imported from South America; however, the majority of soy used in EU is imported from Argentina and Brazil. The inclusion of land transformation in the evaluation of these systems is important from not only a climate change impact perspective, but also, although not quantified in this project, the adverse effects to biodiversity associated with the conversion of tropical forest to agricultural production. In Table ES-1, the lack of correlation of GWP with fossil energy consumption is solely due to the inclusion of land use change for the EU; when LUC is removed, the expected correlation, where both GWP and fossil energy consumption are lower for the EU is observed.

Water consumption for 1 kg of pork consumed for EU was 0.254 m^3, approximately 51 percent lower compared to the US (0.514 m^3). High water consumption in US was a result of larger blue water footprint of US crops, and larger fraction of irrigated crop use in the ration of US swine. Agricultural land occupation was lower for US (9.02 m^2a per kg pork consumed) compared to the EU (10.11 m^2a per kg pork consumed), which was attributed to higher yield observed for US crops compared to European or Latin American production. Higher fossil fuel depletion observed for the US (US- 2.33, EU-1.53 kg oil eq per kg pork consumed) was due to a larger fraction of fossil fuels used in electricity generation and transportation in the US. Somewhat surprisingly, the long distance ocean transport from South America to the EU contributes relatively little additional fossil energy use as ocean freight is the most energy efficient transportation option. The contribution of the trans-Atlantic transport of soy products is approximately 0.55 kg CO_{2e} / kg pork consumed for the EU (4.4%), and is therefore not a significant driver of difference in GWP between the US and EU. The difference in fossil consumption between the two regions is driven significantly by the US's heavier reliance on coal and other fossil fuels in the electricity grid and not as a result of specific practices in the swine industry itself.

The differences in means were confirmed by uncertainty results. At least 85 percent of Monte Carlo Simulations yielded similar results observed in comparative analysis for GWP including land use change, water consumption, agricultural land use, and fossil fuel depletion (Figure 1 and Figure 2). Therefore, while the absolute magnitude of the differences reported in the comparative analysis has some uncertainty, the directionality of the differences are robust, as the Monte Carlo Simulations account for propagation of input uncertainty to the output.

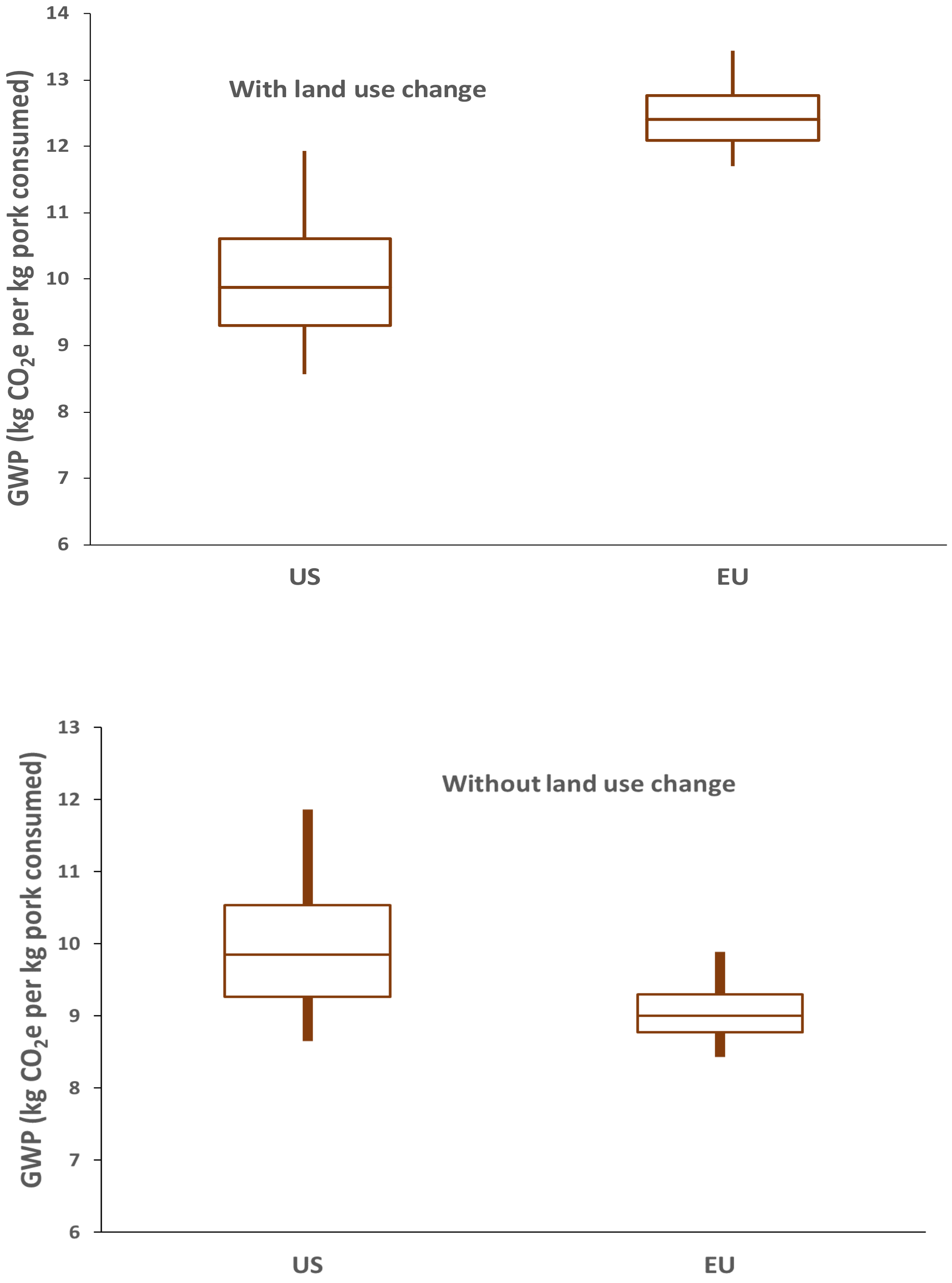


Figure 1: Results of comparative analysis of US and EU pork supply for GWP chains for 1 kg of pork consumed. The boxes in these plots represent 25th, 50th, and 75th percentiles of MCS results. The whiskers represent 5th and 95th percentiles.

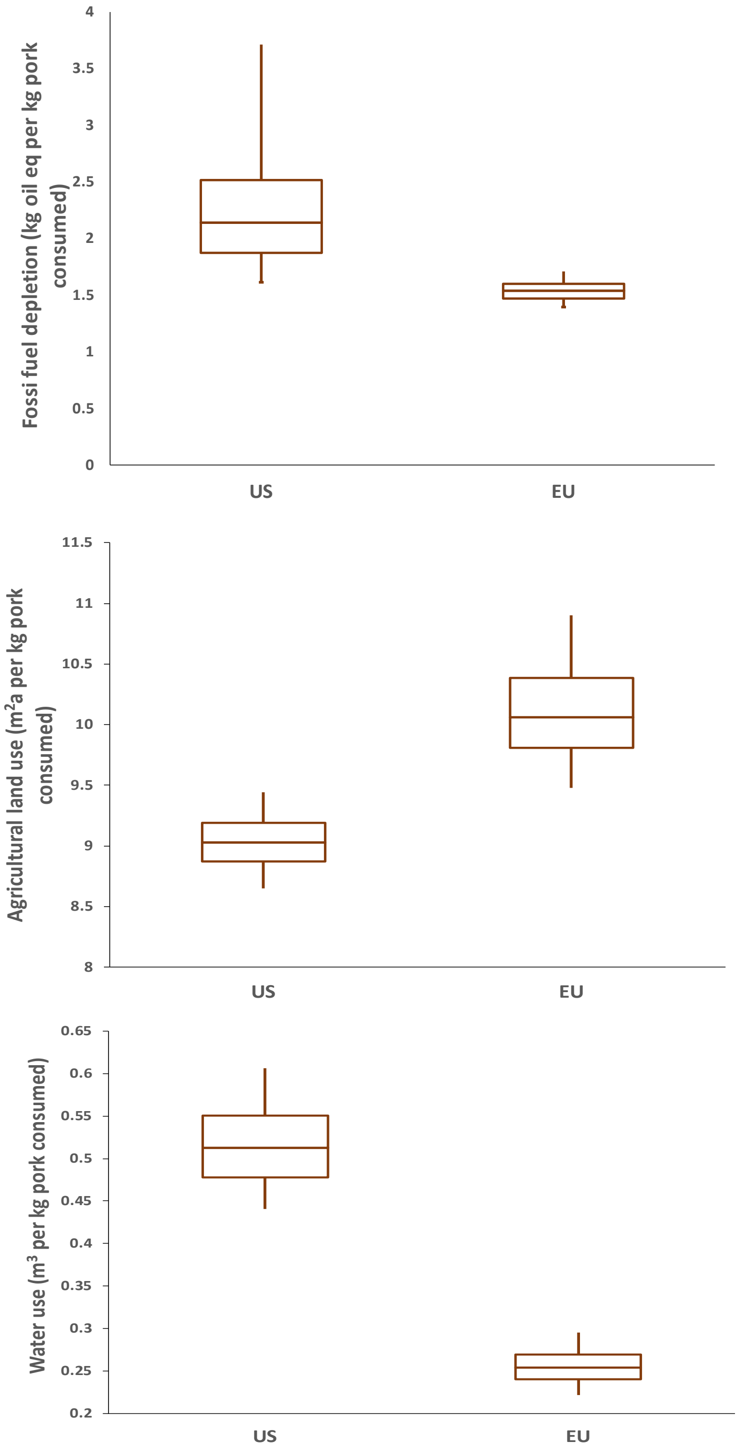


Figure 2: Results of comparative analysis of pork supply chains for EU and US, for fossil fuel depletion, agricultural land occupation, and water consumption for 1 kg pork consumed. The boxes in these plots represent 25th, 50th, and 75th percentiles of MCS results. The whiskers represent 5th and 95th percentiles.

Comparative Life Cycle Assessment of Field-to-Fork Pork Supply Chains in the United States and the European Union

Part 1: Introduction

Background

Meat production has been under increasing scrutiny due to perceived impacts of production practices on our natural resources and environmental quality. The livestock sector utilizes resources such as land, water, and energy to produce animal products, and has an impact on air, water, and soil quality (de Vries and de Boer, 2010). On a global scale, pork accounts for just over a third of the world's meat production. China is the largest producer of pork followed by the European Union, the United States, and Canada (Food and Agriculture Organization of the United Nations 2016). In 2015, pork production in the US accounted for approximately 10 percent of global pork production or 11.12 million metric tons of carcass weight equivalent (USDA, 2016a). Until 2014, the US was the largest exporter of pork, contributing approximately 32 to 33 percent of global trade of pork meat. In 2015, the EU surpassed the United States, becoming the largest exporter of pork in the world. The European Union is the second largest producer and consumer of pork in the world. According to (USDA, 2016a), in 2015, EU produced approximately 21 percent of global pork (23.29 million metric tons of carcass weight equivalent). Around 41 percent of pork in the EU is produced in two Member States, Germany and Spain (EUROSTAT, 2016). Other major producers of pork in the EU are Denmark, France, Italy, the Netherlands, and Poland. While overall annual meat consumption in the US is 115 kg per capita, higher than 81 kg per capita in the EU, more pork is consumed in the EU than in the US. (Food and Agriculture Organization of the United Nations, 2016). Annual per capita pork consumption in the US and EU are 28 and 39 kg respectively (Food and Agriculture Organization of the United Nations, 2016).

The pork production supply chain can be divided into following stages: crop and feed production and transportation, production of sows, piglets, and market pigs, transportation of live animals, slaughtering of animals and meat processing, meat packaging and transport to retail stores, storage and sale of meat at retail, and transportation, preparation, consumption, and disposal of pork at home. Each of these stages contributes to global warming potential (GWP), energy use, and water consumption at varying degrees.

The environmental impact at each stage of the supply chain depends on various factors such as management practices, diet composition of pigs, crop production practices, genetics of animals, manure management, post-farm gate activities, etc. Differences in these factors between the US and the EU could lead to differences in estimated environmental impact. Analyzing these impacts requires a life cycle approach that standardizes processes within and across supply chain sectors. The goal of this project was to identify and quantify the difference in potential environmental impact of pork production and consumption for supply chains in the EU and US. This was achieved using Life Cycle Assessment (LCA) to evaluate impacts associated with the production of a 1 kg serving of pork produced and consumed in the US and the EU, respectively.

Part 2: Literature Review

Review of pork LCA

Most of the published life cycle assessment studies of pork supply chains are for the European pork industry. While a majority of these studies focused on the cradle-to-farm gate supply chain, some included slaughterhouse processes (Table 2). A comprehensive review of pork LCA studies by de Vries and de Boer (2010) showed that GWP related to production of one kilogram of pork varied between 3.9 and 10 kg CO_2e in the EU. Fossil fuel use varied between 18 and 45 MJ and land use varied between 8.9 and 12.1 m^2 for one kg of pork produced. The authors also reported acidification potential for one kilogram of pork produced, which varied between 43 and 741 g SO_2 per year.

The GWP and water footprint of pork increases as system boundaries are expanded to include more downstream processes with production of spicy sausage showing highest GWP and water footprint (Table 1) (Lamnatou et al., 2016; Noya et al., 2016). The LCA studies identified cradle-to-farm gate activities such as crop production and manure management, as hotspots for various impact categories. According to de Vries and de Boer (2010), post-farm gate processes were responsible for 30-40 percent of total energy use and 20-25 percent of total GWP for pork production in European countries.

Table 1: Carbon and water footprints of different pork products at retail for pork supply chain in Catalonia, Spain, adapted from Noya et al., (2016)

Product	Functional Unit	GWP (kg CO_2 eq)	Water footprint (m^3)
Fodder	1 kg of fodder	2.01	1.74
Live pig at farm gate	1 kg of live-weight pork	6.70	5.70
Pork at slaughterhouse gate	1 kg carcass pork	8.70	8.10
Fresh/frozen cut pork	1 kg of cut pork	10.30	9.60
Ham (slicing and packaging)	1 kg of ham	10.70	9.10
Dry-cured ham (slicing and packaging)	1 kg of dry-cured ham	12.70	10.60
Spicy sausage (slicing and packaging)	1 kg spicy sausage	17.80	15.60
Fuet (slicing and packaging)	1 kg of fuet	11.30	10.30

Post-farm gate LCA

A detailed LCA for cradle to grave was prepared by Winkler et al. (2016). The functional unit used in the study was one-kilogram fresh Austrian pork (carcass weight). This functional unit was used to represent tare weight commonly used in the retail trade. The system boundaries included feed production, animal rearing, slaughter, retail, transportation, and consumption; because the FU is based on ‘retail tare weight, we do not believe that post packaging waste is accounted in the system. The authors report that one kg fresh carcass weight resulted in global warming potential of 4.75 kg CO_2e. The cradle-to-farm gate processes (feed production and animal rearing), were responsible for 92 percent of GWP. The contribution of slaughterhouses, consumption, and transportation was approximately 3, 1, and 3.5 percent, respectively. The study used transportation distances of 50 km between farm and slaughterhouse, 110 km between slaughterhouse and retail, and 11.55 km for consumer shopping. Data used for slaughtering, normalized for carcass weight, included water use of 2.56 liters, liquid and solid CO_2 use of 2.6 and 3.1 g respectively, electricity consumption of 0.14 kWh, and heat consumption of 0.17 kWh. Packaging material used at the plant included 4.2 g of Expanded Polystyrene (EPS), 3.6 g of High Density Polyethylene (HDPE), 4.7 g of Polypropylene (PP), 18 g of packaging paper, and 25 g of packaging cardboard per kg carcass weight processed. Processing 1 kg of carcass resulted in 0.8 kg of packaged meat, 0.2 kg of organic waste, and 2.56 liters of wastewater.

Weidema et al. (2008) reported GWP of 11.2 kg CO_2e per kilogram slaughtered weight (excluding edible offal) for European pork. The study included entire life cycle of meat and dairy products. The contribution of pork to overall GWP from dairy, beef, pork, and poultry sectors was 26 percent. Non-renewable energy and land occupation for one kilogram of slaughtered weight were 193 MJ and 12.2 m^2 arable land respectively. However, pork had the lowest impact per Euro consumption expenditure compared to other three products. The authors also identified options to reduce impacts associated with dairy and meat consumption. Some of these options included reducing household waste, reducing energy use at various stages in production, using more efficient equipment, reducing emissions from manure by lowering manure pH, and improving crop yields and growing practices. A novel option suggested by authors was meal planning and home delivery of groceries to reduce impacts associated with meat and dairy consumption. Meal planning and home delivery will primarily reduce impacts associated with transportation by the consumer and household food waste.

A cradle-to-grave LCA study of US pork production was performed by Thoma et al. (2011). The GWP for a four-ounce serving of pork was 1.13 kg CO_2e. Crop production, manure management, retail distribution, and consumption were identified as hotspots for GWP. The largest on-farm contributor to GWP was wean-to-finish farm (including crop production necessary for feed). Approximately, 6 percent reduction in overall GWP was observed when distiller’s grain use was avoided in the diet. The type of on-farm manure management system also had an impact on GWP, with anaerobic lagoon showing highest GWP and solid storage showing the lowest.

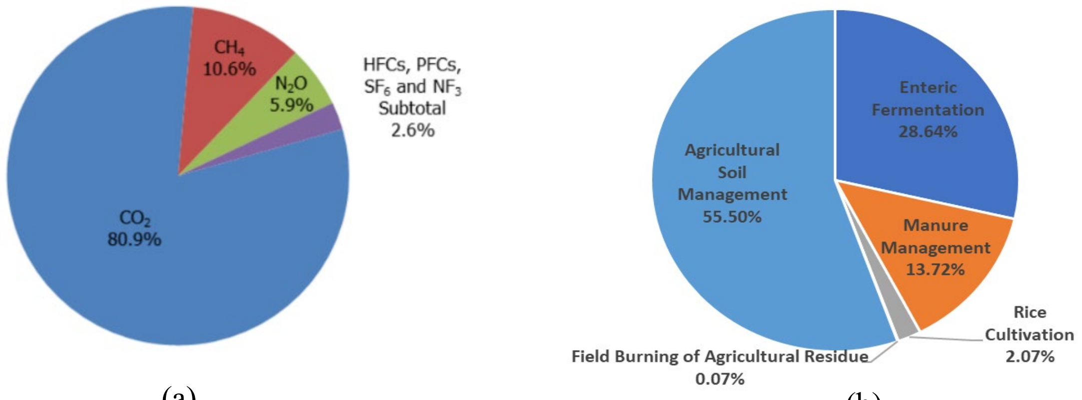
Most other studies which analyzed the post-farm gate supply chain included processes up to slaughterhouse gate only, with an exception of Macleod et al. (2013) who included retail distribution as well. Electricity and water use for a processing plant in Germany was reported to be 0.22 kWh and 0.003 m^3 per kg live weight, respectively (Reckmann et al., 2013a). The study included production of pigs, transportation to the processing plant, slaughtering, and processing of pork and resulted in 3.22 kg CO_2e per kg of pork. However, post-farm gate processes accounted for only 1-12 percent of overall emissions depending upon the impact category. Macleod et al., (2013) reported only 5.7 percent of total GHG emissions from post-farm gate activities, which included processing and transportation of products to retail.

These studies provide insight into the pork industry and provide critical data used in constructing our comparison. Data from these studies were used to fill data gaps in the present study. The US and European pork production systems differ in the genetics of pigs, animal feed, housing types, market weight, and manure management practices (Stone et al., 2010). Therefore, region-specific data were used to fill the data gaps.

Greenhouse gas emissions

Contribution of agriculture

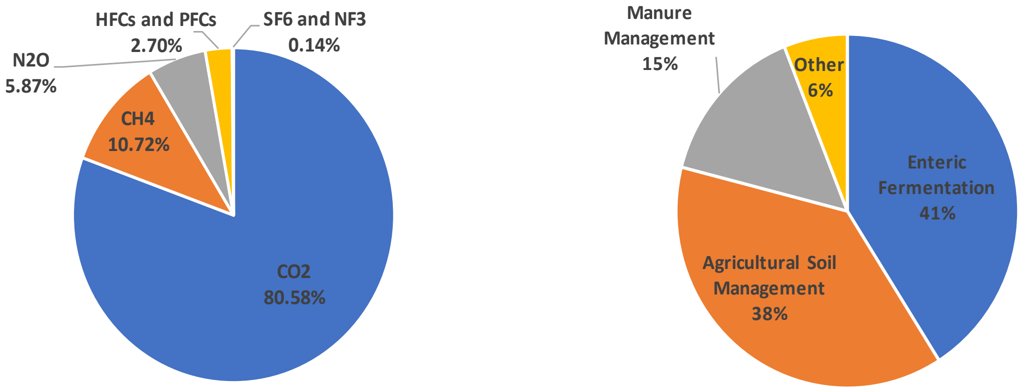
In the US, total anthropogenic GHG emissions were 6,870 million metric tons (MMT) CO_2e in 2014, 80.9 percent of which was CO_2 (USEPA, 2016). Methane (CH_4) and Nitrous Oxide (N_2O) contributed 10.6 and 5.9 percent while only 2.6 percent of greenhouse gases emissions were from hydrofluorocarbon (HFC), perflurocarbon (PEC), hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Fossil fuel combustion for electricity generation, transportation, industrial, commercial, and residential purposes released 5,208 MMT of CO_2 in the atmosphere (USEPA, 2016) which also



(a) (b)

Figure 3: GHG emissions in the US in 2014 (a) percentages of greenhouse gases to total anthropogenic GHG emissions, adapted from USEPA (2016) and (b) contribution of various agricultural activities to GHG emissions from agriculture. All percentages are based on MMT CO_2e

included fossil fuel combustion for agricultural purposes. Agriculture contributed 8.3 percent (573.6 MMT CO_2e) of total GHG emissions in the US. The largest contributor to GHG emissions from agriculture were agricultural soil management (56%), enteric fermentation (29%), and manure management (14%) (Figure 3a). The majority of GHG emissions from agricultural activities were in the form of CH_4 and N_2O. Enteric fermentation and manure management were responsible for 22.5 and 8.4 percent of CH_4 emissions from anthropogenic activities, respectively. In domestic animal farming sector, beef and dairy cattle were the largest emitters of CH_4. Fertilizer application and other cropping activities were responsible for 78.9 percent of N_2O emissions in the US (USEPA, 2016).



(a) (b)

Figure 4: 2014 GHG emissions in the EU-28 plus Iceland, Source EEA, 2016 (a) percentage of various greenhouse gases in total anthropogenic emissions; (b) contribution of various agricultural activities to GHG emissions from agriculture. All percentages are based on MMT CO_2e.

Greenhouse gas emissions in Europe were lower compared to the US but the proportion of CO_2, CH_4, and N_2O in total GHG emissions was similar. Greenhouse gas emissions in 2014 were 4,290 MMT CO_2e, which included emissions from 29 EU members and Iceland (EEA 2016). About 81 percent of these emissions were in the form of CO_2 emitted from fossil fuel combustion. Major contributors to CO_2 emissions were electricity and heat production (31%), road transportation (24%), manufacturing industry and construction (14%), and residential (11%) (EEA 2016). Methane and N_2O emissions were 11 and 6 percent of total GHG emissions in EU. Agriculture was responsible for 10.1 percent (436 MMT CO_2e) of total GHG emissions. Methane (54.5%) and N_2O (43.2%) dominated GHG emissions from agriculture sector. Major contributors to GHG emissions from agriculture were enteric fermentation, emissions from fertilizer and manure application from managed soils, and manure management (Figure 4).

Contribution of pork

Livestock is estimated to be responsible for 14.5 percent of global GHG emissions (Gerber et al., 2013). Emissions from agriculture and livestock production primarily include CO_2, CH_4, and N_2O.

According to 2006 estimates, the contribution of pork production to total CO_2, CH_4, and N_2O emissions from livestock production was 18, 9, and 12 percent respectively (Steinfeld et al., 2006). These emissions however, did not include emissions from processes upstream or downstream of a pig farm. Factors such as climatic conditions, housing floor type, manure management, and nutrition influence GHG emissions in pork production (Philippe and Nicks 2015). The supply chain GHG emissions for one kilogram of pork can vary between 3.9 and 10.0 kg CO_2e for cradle-to-farm gate (de Vries and de Boer 2010), and between 4.0 and 11.0 kg CO_2e for cradle-to-retail production (Nijdam et al., 2012) (Table 2). Variation in GWP can be attributed to variation in lifecycle inventory (LCI) used for the analysis. The GWP of pork production is known to be influenced by number of piglets born alive, the lean-meat content, feed conversion ratio, feed consumption, and manure emissions (Reckmann and Krieter 2015; Boles et al., 2015). Variations in these factors influence the results of LCA. Global warming potential for pork production from various studies reviewed for this research work are listed in Table 2.

Table 2: Summary of GWP of pork production from various sources reviewed in this study. The system boundary and functional units were defined in the studies.

Study	**System Boundary**	**Functional Unit**	**Region**	**GWP (kg CO2 e)**
Winkler et al. (2016)	Cradle-to-plate	1 kg carcass weight	Austria	4.75
Reckmann et al. (2013)	Cradle-to-slaughterhouse gate	1 kg slaughter weight	Germany	3.22
Noya et al. (2016)	Cradle-to-slaughterhouse gate	1 kg live weight	Spain	6.7
		1 kg carcass weight	Spain	8.7
		1 kg cut fresh pork	Spain	10.3
		1 kg ham	Spain	10.7
		1 kg dry-cured ham	Spain	12.7
		1 kg spicy sausage	Spain	17.8
		1 kg fuet	Spain	11.3
Stone et al. (2012)	Cradle-to-farm gate	118 kg	US	398
Lamnatou et al. (2016)	Cradle-to-farm gate	1 kg live weight	Spain	3.2
		1 kg carcass weight	Spain	5.5
Philippe and Nicks (2015)	Cradle-to-farm gate	1 kg carcass weight		4.87
Noya et al. (2017)	Cradle-to-farm gate	1 kg at farm gate	Spain	3.42
Pirlo et al. (2016)	Cradle-to-farm gate	1 kg live weight	Italy	3.3
Dourmad et al. (2014)	Cradle-to-farm gate	1 kg live weight	EU	2.3
Weidema et al. (2008)	Cradle-to-grave	1 kg slaughter weight	EU	11.2
Thoma et al. (2011)	Cradle-to-grave	1 kg serving of pork	US	9.95
Bava et al. (2017)	Cradle-to-farm gate	1 kg live weight	Italy	4.25
Jones and Cherruault (2011)	Cradle-to-slaughterhouse gate	1 kg pork leaving abattoir	UK	2.2
Pelletier et al. (2010)	Cradle-to-farm gate	1 kg live weight	US	2.76
Nguyen et al. (2011)	Cradle-to-slaughterhouse gate	1 kg carcass weight	Denmark	3.1

Water use

Agriculture and livestock production can have negative impacts on freshwater resources. In 2010, irrigation for agricultural production accounted for 135 billion gallons per day (511 million m^3/day), which was 38 percent of total freshwater withdrawals in the United States (Maupin et al., 2014). Estimated freshwater withdrawals for livestock production were 2 billion gallons per day in the same year. However, these estimates included on-farm water use only. From the perspective of life cycle assessment, on-farm water use, as well as water embedded in upstream products and processes, should be considered while estimating water footprint of the animal product. Annual freshwater abstraction in EU-28 was little over 117 billion gallons per day (162 million m^3 / day) in 2010 (EUROSTAT 2016). The contribution of agricultural sector to overall freshwater abstraction in EU was 19 percent (30,650 million m^3), while irrigation was responsible for 85 percent (26,140 million m^3) of total agricultural water use.

A life cycle assessment study conducted by (Boles, 2013) reported that production and consumption of 4oz boneless serving of pork requires 8.2 gal (0.031 m^3) of water in the US. It was estimated that US pork industry consumes 525 billion gallons (1.99 billion m^3) of water annually. Swine rations were responsible for 83 (commodity feed) to 93 (regional feed) percent of this water footprint while on-farm water use accounted for only 5 to 13 percent of the water footprint. The post-farm gate pork supply chain was responsible for only a small fraction of overall pork water footprint.

Mekonnen and Hoekstra (2012) estimated green, blue, and grey water footprint of 3404, 563 and 634 m^3/ton (899,000; 149,000; 167,500 gal/ton) of carcass weight respectively for pork production in the US. Green, blue, and grey water are defined as water received from precipitation, water sourced from surface and groundwater sources, and fresh water required to assimilate nutrients and pollutants to meet water quality standards, respectively (Hoekstra et al., 2011). Grey water is not used in LCA as it confounds water quantity and quality. Compared to the US, the Netherlands had slightly larger green water footprint (3,776 m^3/ton; 997,500 gal/ton) but lower blue (236 m^3/ton; 69,500 gal/ton) and grey (427 m^3/ton; 112,800 gal/ton) water footprints (Mekonnen and Hoekstra 2012). Among the various type of pork farming systems, grazing showed the largest water footprint in both the Netherlands and the US. Spain had an average overall water footprint of 3,765 m^3/ton of live weight with approximately 3,125 m^3/ton (825,500 gal/ton -80%), 264 m^3/ton (69,700 gal/ton - 7%), and 377 m^3/ton (99,600 gal/ton - 10%) coming from green, blue, and grey water (de Miguel et al., 2015). Water footprint of pork depends on product type and system boundaries as well. Noya et al. (2016) reported that water footprint of pork ranged between 1506 gal (5.7 m^3) per kilogram live weight to 4120 gal (15.6 m^3) per kg of spicy sausage at slaughterhouse gate. These studies implemented water footprint network method developed by Hoekstra et al. (2011), which includes direct and indirect green, blue, and grey water in total water footprint of a product. Noya et al. (2016) reported that green water dominated crop production, while blue water dominated animal husbandry and meat processing. In slaughterhouse and pork cutting stages nearly all water footprint resulted from grey water. The results reported here do not account for green or grey water, and therefore direct comparison with these reported literature values is not appropriate, we include them as part of a general review of the literature.

Energy use

Energy is used in pork production at various stages such as crop production, animal rearing, transportation, animal and meat processing, refrigeration etc. In 2001 total energy consumption by entire meat sector was 39, 35, 10, and 32 PJ in France, Germany, the Netherlands, and the United Kingdom, 40 to 60 percent of which was used by meat processing industries (Ramirez et al., 2006). According EUROSTAT, total number of live pigs produced in 2001 was 26 million, 15 million, 12 million, and 6 million head in Germany, France, Netherlands, and UK, respectively. For a typical swine facility in Iowa total non-renewable energy consumption was 744.6 MJ per pig in a farrow-to-finish barn (Lammers et al., 2012). The largest contributor to this energy use was crop production followed by facility operation and feed processing. The type of barn, efficiency of energy consuming equipment, feed efficiency of pigs, synthetic nitrogen use in crop production are some of the factors which influence energy use in cradle-to-farm gate pork production system.

Post-farm gate supply chain energy use consists of electricity use for refrigeration and for running large machinery, and natural gas, liquid petroleum gas, or fuel oil consumption in boilers for heating and steam generation. In a typical processing plant, approximately 80-85 percent of energy is produced on-site by burning coal, fuel oil, natural gas, or liquid petroleum gas and only 15-20 percent is provided by electricity (Hansen, P. Christiansen, K. Hummelmose, B. 2000). Between 45-90 percent of total electricity use at a processing plant is utilized for refrigeration (Ramirez et al., 2006).

Land Use

Approximately 38 percent of global land was used for agriculture-related activities in 2014 (World Bank, 2015). Land provides ecosystem services essential for agricultural production. Land use and land use change both contribute to global warming potential (IPCC). Carbon is released to the atmosphere from croplands during tilling activities and manure application. Clearing large forest areas for agricultural and other activities releases carbon to the atmosphere when biomass is burned or naturally decomposes. Therefore, greenhouse gas emissions associated with land use and land use change should be considered when studying agricultural systems.

Land use in pork production can be separated into on-farm and off-farm land use. On-farm land use consists of land required for animal housing, roads, feed storage, manure storage etc. while, off-farm land use comprises land required for crop production for animal feed, processing and packaging plants etc. Land occupation for conventional pig production, required to produce one kilogram live weight, was 4.22 m^2a in the United States (Thoma et al., 2015) and 4.13 m^2a in Europe (Dourmad et al., 2014) at the farm gate. This included both off-farm and on-farm land use up to the farm gate. A large proportion of land use is attributed to production of feed. Crop production for swine feed requires 11.7 m^2 of surface area per kilogram of edible pork (Lesschen et al., 2011), which is equivalent to 6.8 m^2 for one kilogram of live pig. However, land use for crop production will vary depending on feed conversion ratio (FCR) and crop yield. Increasing crop yields, decreasing FCR of animals, and reducing wastage can lower land use and GWP related to crop production (Lesschen et al., 2011; Ermgassen et al., 2016).

Opportunities to reduce impacts

Since crop production and manure were responsible for a large proportion of GWP in pork production, modifications to animal feed presents as an opportunity to reduce GWP. Reckmann et al. (2016) compared low environmental impact ingredients, legumes, and synthetic amino acids to supplant soy protein used in standard diets for their impact on GWP, land use, eutrophication potential, and acidification potential. The authors concluded that synthetic amino acids had lower impact compared to all three diets, primarily due to reduced crude protein which, lowered N and CH_4 excretion of pigs. The overall impact of pig production can vary depending upon manure management system used. Thoma et al. (2011) reported lowest GHG emissions from solid storage manure management systems. The highest GHG emissions were observed from anaerobic lagoons. Therefore, manure management system selection can lead to reductions in GHG emissions associated with pork production. Other opportunities to reduce GHG emission of pork production are reducing wastage at various stages in production and consumption, reducing energy use, using energy efficient equipment, and improving crop yields.

Allocation

Production and processing of pork results in creation of both byproducts and waste. Allocation of burden between pork meat, byproducts, and accounting for emissions associated with waste is therefore important. According to a United Nations report (Hansen et al., 2000), slaughtering and processing of a pig results in 64 percent boneless meat, 20 percent inedible material for rendering, 10 percent edible offal like liver, heart etc., 3 percent blood, and 3 percent miscellaneous material. These data can be utilized for mass allocation of burden between pork meat, byproducts, and waste.

Pig production characteristics in the US and EU.

The US and EU pork production systems differ in pig performance parameters, litter size and number of weaned piglets, manure management systems, dies, mortality, lean meat content, market weight, and housing type for gestating sows. Analysis of data obtained from the National Pork Board (NPB) and the Joint Research Commission (JRC) indicated higher average daily gain (ADG) and feed conversion ratio (FCR) for wean-to-feeder pigs in EU member states included in this study compared to the US (Figure 7). For the feeder-to-finish phase, the pigs in US showed better ADG compared to all EU members, except Denmark. The mortality for all EU member states was lower compared the US (Figure 6). Average lean meat percentage, expressed as lean meat weight as a percentage of live weight, was higher for Denmark and France compared to the

US. A larger number of piglets were weaned per sow in Europe compared to the US, and pigs marketed in the US were heavier compared to market pigs in the EU (Figure 5).

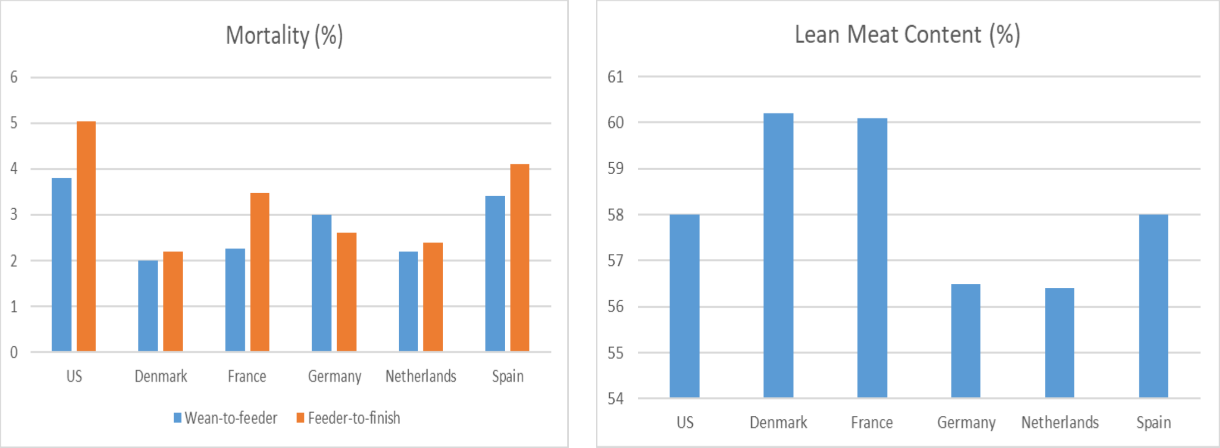


Figure 5: Mortality rate (%) and lean meat content (%) of pigs in US and EU member states

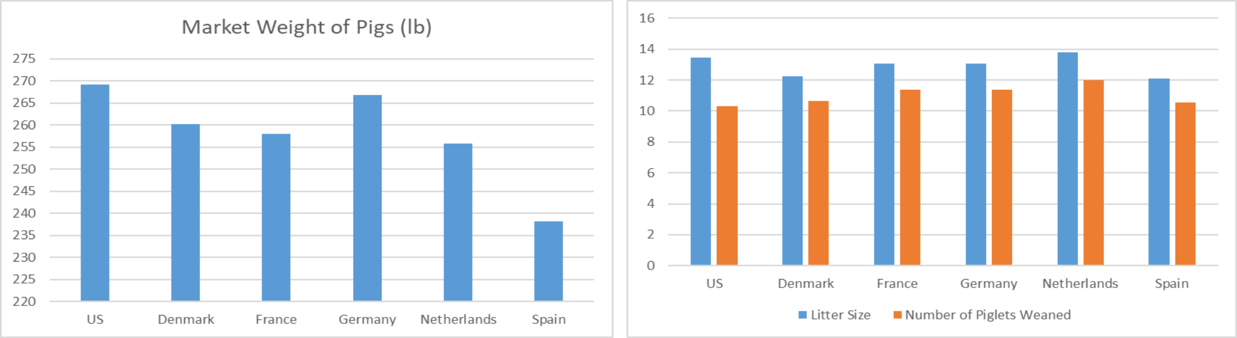


Figure 6: Market weight of pigs (lb.), litter size, and number of pig weaned per litter for US and EU member states

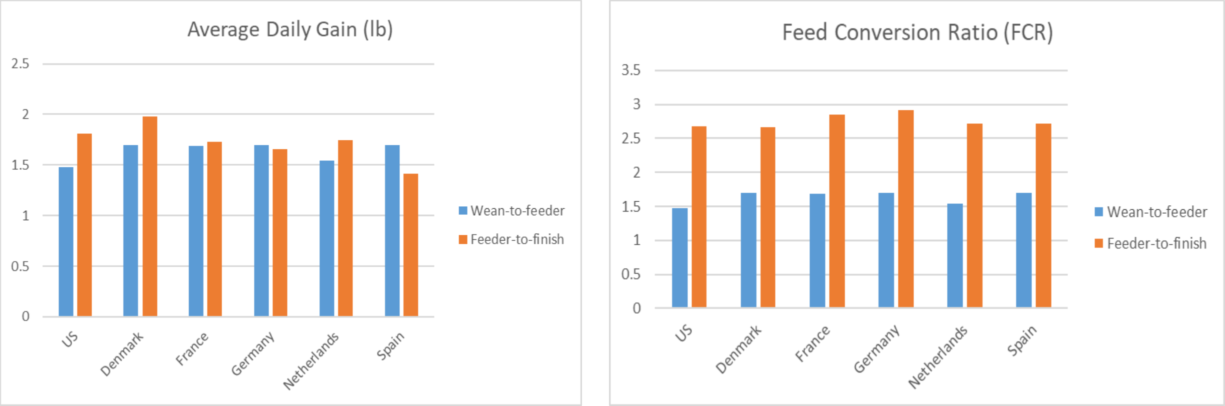


Figure 7: Average daily gain and feed conversion ratio of pigs in US and EU member states for the wean-to-feeder and feeder-to-finish stages.

As per the directive of Council of European Union, gestation stalls in Europe have been replaced with group pens (The Council of the European Union 2008). The difference in sow housing is reflected in area allowed per animal. Due to the housing requirement, at least 24 ft^2 (2.23 m^2) floor space per sow is needed compared to 14 ft^2 (1.3 m^2) commonly used in the US (Safranski, 2007; Schenck et al., 2010). Group housing reduces the stocking density and therefore, requires additional housing to maintain animal production. Minimum floor space for wean-to-finish pigs differed between two regions as well. The EU requires at least 10 ft^2 (0.93 m^2) for pigs heavier than 110 kg compared to 8 ft^2 (0.74 m^2) commonly used in the US. Table 3 shows minimum pig space required in the EU.

Table 3: Recommended pig space for market pigs in Europe. (The Council of the European Union, 2008)

Live weight of pig (kg)	**Recommended pig space (ft^2)**	**Recommended pig space (m^2)**
Not more than 10	1.61	0.15
More than 10 but not more than 20	2.15	0.20
More than 20 but not more than 30	3.23	0.30
More than 30 but not more than 50	4.30	0.40
More than 50 but not more than 85	5.92	0.55
More than 85 but not more than 110	7.00	0.65
More than 110	10.76	1.00

Part 3: Comparative LCA Methodology

Goal and Scope of study

The primary goal of this study was to compare impacts associated with production and consumption of pork in the US and EU. The impacts will be compared for GWP, energy use, water use, and land occupation. These impact categories are chosen as a representative of sustainability indicators for pork industry. Greenhouse gas emissions from both supply chains were evaluated with and without considering land use change (LUC).

Functional unit

The functional unit of 4-ounce serving of fresh pork prepared and consumed at home was selected for this study. Individual cuts of meat were not differentiated. Processes associated with meat curing were out of scope for this study.

System boundary

This life cycle assessment was a cradle (production of the ration and live swine) to grave (consumption at the consumer's home) analysis of pork produced in the US and the EU. The system boundaries encompassed fertilizer and crop production and transport, live animal production and ended with purchase, transport, and consumption of fresh pork by the consumer. Food service consumption was not included in the analysis except for allocation at the processing stage. A cutoff criterion of 1 percent was established for mass flows and/or environmental impact for any category of interest. However, where data were readily available, they were included regardless of the cutoff criterion.

Allocation methodology

For processes with multiple outputs, and allocation of burdens is required for an attributional study such as this one. For unit processes where allocation of inputs and emissions was required, we followed ISO 14044 allocation hierarchy. For allocation of processing, a revenue-based approach was adopted. An allocation based on shelf space occupied was used for retail and in-home burdens with a mass-based allocation as an alternative approach.

LCA Methodology

Life cycle assessment (LCA) provides quantitative, confirmable, and manageable models to evaluate production processes, analyze options for innovation, and improve understanding of complexity in agricultural production systems. A LCA can identify areas where process changes, potentially enabled by new research and development, can significantly reduce the associated impacts. Broadly, LCA consists of four stages (Figure 8)

1. Define the goal and scope
2. Conduct life cycle inventories (collection of data needed to perform the necessary calculations)
3. Perform impact assessment
4. Analyze and interpret the results

Life cycle assessment has the potential to foster changes in agricultural practices that lead to environmental, social, and economic improvements, the so-called triple bottom line.

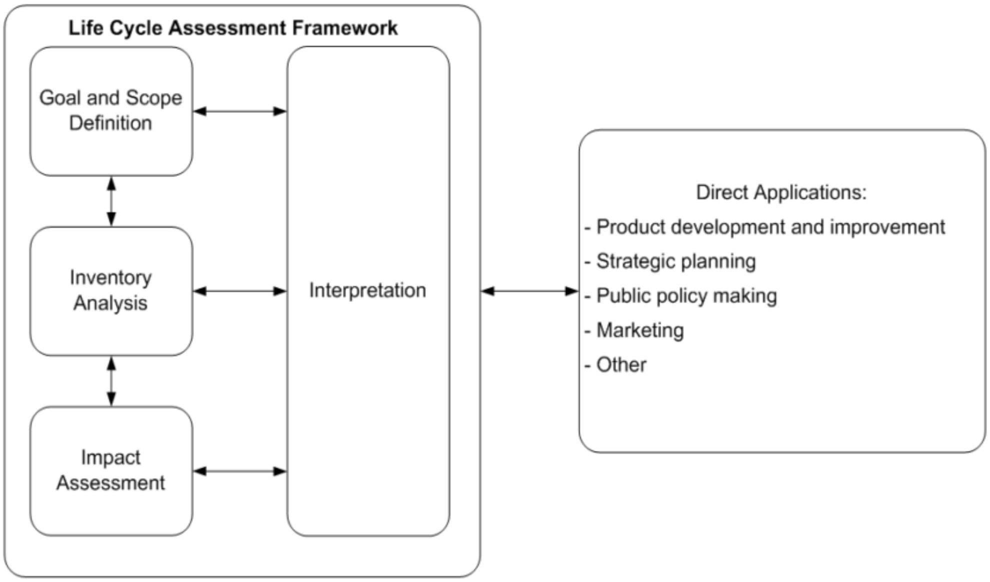


Figure 8: Stages of a life cycle assessment. (International Orgainzation for Standardization 2006)

Model description

Pig Production Environmental Footprint Calculator (PPEC)

The Pig Production Environmental Footprint Calculator (PPEC), developed by the University of Arkansas, is a mathematical model that simulates pig growth and estimates feed and water intake, energy use, manure production, and methane and nitrous oxide emissions from manure management systems during each production cycle. The PPEC implements growth and performance models published by the National Research Council (NRC) (National Research Council 2012), which simulate growth, feed consumption, and manure excretion of wean-to-finish pigs, and gestating and lactating sows. The PPEC supports hoop, tunnel, and drop curtain barns with deep pit, dry bedding, storage tanks, lagoons, and digesters for manure management. Process flow diagrams for each barn model are shown in Figure 9 and Figure 10. The PPEC was used to simulate archetypal farms in the US and EU. The simulation results of PPEC were used as life cycle inventory (LCI) for the farming stage of pork production. Swine farms were simulated for three locations in the US and five locations in EU. Counties and Eurostat regions producing largest number of pigs were selected for analysis.

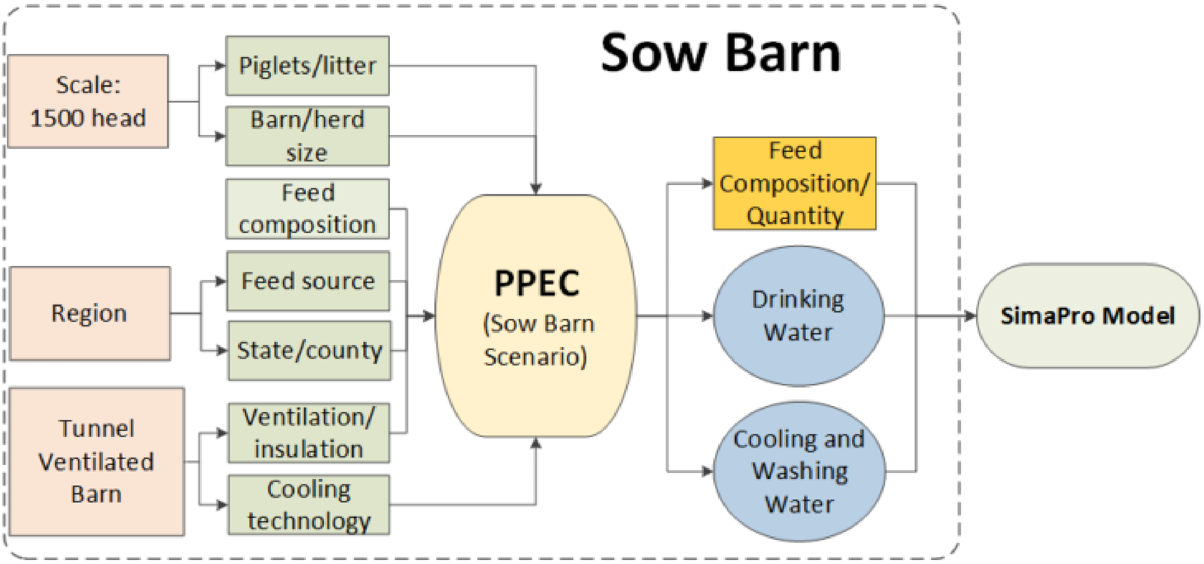


Figure 9: Process flow diagram for the PPEC grow barn model. Adopted from (Matlock et al. 2014).

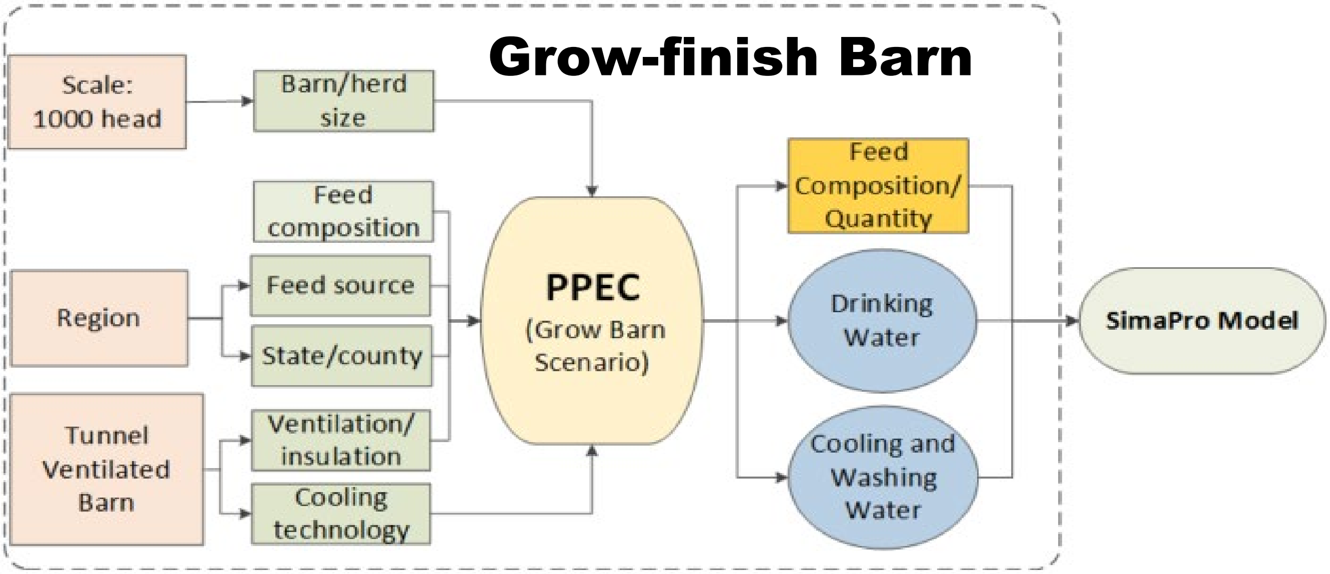


Figure 10: Process flow diagram for the PPEC grow-finish barn model. Adopted from (Matlock et al. 2014).

SimaPro model

SimaPro® software was used to conduct LCA of pork production systems. The simulation results from PPEC were used as LCI to a model developed in SimaPro V8.3 (Pre' Consultant, The Netherlands). Since, PPEC does not balance the flow of pigs from one barn to the other, this step was performed in the SimaPro model. Cradle-to-farm gate processes were modeled as separate systems for each of the different locations used. Post-farm gate processes for the US supply chain were modeled as a single process flow representing national average, from farm gate-to-grave. Five post-farm gate process flows, representing each country used in the EU region, were modeled in SimaPro. These flows, for EU, were later combined to represent a regional average.

Scenario Selection

Scenarios used for this study are listed in Table 4. Scenarios were created to represent typical swine farms in the US and EU. According to the 2012 USDA census data, Iowa, North Carolina, and Minnesota were the three largest producers of pigs in the United States. These three states represented more than 64 percent of national inventory (USDA, 2016b). Three pork production regions (Iowa- Region 7, North Carolina- Region 4, Minnesota- Region 5) to which these states belong, contributed to 86 percent of the US pig production (Boles et al., 2015). Archetypical farms were simulated at Sioux County, Iowa, Sampson County, North Carolina, and Martin County Minnesota. These three counties were the largest pig producing counties in each state. The five European countries selected for this study were Germany, Denmark, Spain, France, and Netherlands. These countries together represented more than 62 percent of pork production in the EU (EUROSTAT, 2012). Farms representative of typical production practices in these five European countries were simulated at Niedersachsen, Germany, Cataluna, Spain, Limburg,

Table 4: Description of scenario used for this study. The archetypal farms were simulated at county/EUROSTAT regions producing largest number of pigs.

Production region	Eurostat Region/US County	Life stages	Impact categories
US	Sioux County, IA	Wean-to-finish	GHG emissions
US	Martin County, MN	Sow	Fossil fuel demand
US	Sampson County, NC		Water consumption
EU	Niedersachsen, Germany		Agricultural land use
EU	Cataluna, Spain		
EU	Limburg, Netherlands		
EU	Bretagne, France		
EU	Midtjyllad, Denmark		

Netherlands, Bretagne, France, and Midtjyllad, Denmark. The PPEC uses 10-year weather parameters such as temperature, precipitation, solar insolation, humidity, and wind speed at a one-hour temporal resolution to simulate barn temperature, estimate emissions from manure management systems, and estimate growth of pigs. Simulating typical farms at multiple locations provided an opportunity to capture impacts associated with temperature differences. The US and EU pig production differed in weather, manure management, feed, pig performance parameters such as ADG and FCR, and weaning and market weight. The farms were simulated to capture these differences in pig production.

Inputs to PPEC model

Demographic information

County and region-specific swine inventory data for 2012 for the US and EU were obtained from USDA-NASS and Eurostat databases respectively. The inventory data consisted of breeding and market pig inventory, which was used to create sow and wean-to-finish barns respectively (Table 5). It was assumed that the inventory characterized number of animals of each type present in a county at any time. A facility created in PPEC can accommodate up to 10 barns with up to 5000 sows or 9999 wean-to-finish pigs in each barn. Due to these limitations, only 0.8 percent of breeding and market inventory was used to create farms. Animals were distributed on various manure management systems to match state-level distribution for the US and country-level distribution for the EU (elaborated later in this chapter).

Table 5: Census data for year 2012 for the US and EU. The breeding and market inventory represent sows and wean-to-finish pigs in each county or region respectively.

Production Region	Eurostat Region/US County	Total Inventory	Breeding Inventory	Market Inventory
US	Sioux County, IA	1,176,751	24,866	1,151,885
US	Martin County, MN	812,229	42,917	769,312
US	Sampson County, NC	1,858,801	164,869	1,693,932
EU	Niedersachsen, Germany	9,013,400	541,950	8,471,450
EU	Cataluña, Spain	6,840,970	519,140	6,318,540
EU	Bretagne, France	7,724,000	574,000	7,142,000
EU	Limburg, Netherlands	1,809,000	176,000	1,633,000
EU	Midtjylland, Denmark	4,210,000	430,000	3,776,000

Animal housing

A tunnel ventilated barn equipped with sprinklers for grow barns and cooling cells for sow barns were used for farms in the US. We could not find any evidence suggesting the European farms used different systems for large pig farms. Therefore, the same types of barn were used for

European farms as well. The main difference between barns in US and EU exists for pig space requirements and housing type for sows. The European farms are required to use group housing for gestating sows (The Council of the European Union, 2008) while, most of the farms in US still use individual stalls. The EU farms are also required to provide more pig space in wean-to-finish barns compared to the farms in the US. Therefore, larger area per wean-to-finish pig was used for European farms (Table 6).

Table 6: Pig space, illuminance and photoperiod used for US and EU barns.

	Pig Space Used (ft^2) [m^2]		**Illuminance (lux)**	**Photoperiod (hour)**
Barn Type	**US**	**EU**		
Sow barn	14 [1.3]	24 [2.23]	100	15
Wean-to-finish barn	8 [0.74]	10 [0.93]	50	6.5

Lighting is estimated to contribute 17 percent of electricity consumption in swine operation (Alberta Government, 2013). The luminous flux and photoperiod recommended by The American Society of Agricultural and Biological Engineering (ASABE) Standard ASAE EP344 were used inside the barn for both US and EU farms (Table 6). It was assumed that the barns used incandescent bulbs. The incandescent bulbs have lower luminous efficacy (7-20 lumens/W) compared to compact fluorescents (62-100 lumens/W) or LED (4.5-150 lumens/W) bulbs (Alberta Government, 2013). Which means, CFL or LED bulbs would consume less energy compared to the incandescent bulbs. However, we could not find any information suggesting CFL or LED bulbs are ubiquitous on swine farms.

Ventilation fans are critical, especially in tunnel ventilated houses. Fans assist in maintaining barn temperature within a desirable range for the comfort of animals. Higher temperatures have been documented to adversely impact pig growth, especially in heavier pigs (Quiniou et al., 2000). Therefore, more than the required number of fans were provided in each barn. However, the PPEC uses only the required number of fans based on difference in temperature inside and outside the barn. This eliminates the possibility of overestimating electricity consumption associated operation of fans, while ensuring enough ventilation.

Swine diets

Diets are responsible for a large proportion of GWP on swine farms. They are also critical for maintaining health and guaranteeing growth of pigs. To estimate growth of pigs and feed consumption, a multi-phase diet was defined for each barn type. Multi-phase diets use several ingredients at varying proportions included at several stages in the production to meet the nutrient requirements of pigs. A multi-phase diet comprised of (1) one phase for wean-to-feeder pigs; (2) five phases for feeder-to-finish pigs; (3) one phase for gestating sows; and (4) one phase for lactating sows.

A standard diet provided by an animal nutritionist at the University of Arkansas was used for Minnesota (Appendix 1). A propriety mix of feed ingredients was provided by an animal feed manufacturing company. This information was used in Windows User-Friendly Feed Formulation (WUFFDA) model to formulate multi-phase diets Iowa and North Carolina (Appendix 1). The last phase of diets for wean-to-feeder pigs in the US included 0.03 percent Paylean 9 (Rikard-Bell et al., 2009; See et al., 2004) as a ractopamine supplement. Diets developed by Boles, et al (2015) were used for EU member states included in this study (Appendix 1). Feed ingredients used in these diets were similar to swine feed recommended by (Tybirk 2016) for Danish farms. The primary ingredients in these diets were wheat, barley, corn, and soybean meal.

Pig performance parameters

Pig performance parameters affect the environmental impact of pork production (Reckmann and Krieter, 2015). Performance parameters such as ADG and FCR determine feed consumption and growth of a wean-to-finish pig. These parameters are a function of the genetics and health of pigs. Genetics and health of animals are not directly modeled into PPEC model. However, the PPEC can adjust the growth curves to achieve desired (or reported) ADG and FCR values. Data from the National Pork Board and the Joint Research Center were used to define ADG and FCR values for the US and EU farms respectively (Table 7). While country-specific ADG and FCR data were available for European member states, data for the US were available at a national level only.

Table 7: Grow-finish barn performance parameters for US and EU member states used in this study.

Parameter	**US**	**Denmark**	**Germany**	**Spain**	**France**	**Netherlands**
Transfer weight to wean-to-finish barn (lb.)	11	17.1	17.0	13.9	16.8	15.1
Market weight (lb.)	275	260.1	266.8	238.1	257.9	255.7
ADG, wean-to-finish (lb.)	1.53	1.54	1.49	1.29	1.51	1.46
FCR, wean-to-finish	2.52	2.41	2.62	2.50	2.56	2.42
Mortality, wean-to-finish	4.4	2.10	2.80	3.75	2.87	2.30
Lean meat content (%)	58	60.2	56.5	58.0	60.1	56.4

Litter size, number of piglets weaned, and age of piglets at weaning differed for EU and US. More piglets were weaned per sow on European farms compared to their US counterparts (Table 8). Data from NPB and JRC were used to incorporate these differences in sow barn performance parameters. Compared to the EU farms, piglets were weaned at a younger age in the US. Age at weaning was 21.5 days for the US while it ranged between 23 and 31 days in EU member states.

Bates et al. (2003) reported that 72 percent of sows housed in group returned to estrus within seven days compared to 68.4 percent of sows housed in gestation stalls. In addition, 94.3 percent of group housed sows remained pregnant after initial service compared to 89.4 percent of sows in stalls.

Table 8: Sow barn performance parameters for US and EU member states.

Parameter	**US**	**Germany**	**Spain**	**France**	**Denmark**	**Netherlands**
Age when piglets are removed	21	27	23	25	31	25
Piglets weaned per litter	10.3	11.4	10.5	11.4	10.6	12.0
Pre-weaning mortality (%)	15.5	12.9	12.9	12.9	12.9	12.9
Sow cull rate %	46	43	53	45	54	51

These differences were captured in the PPEC by adjusting number of days between weaning and insemination to 16 and 14 days for the US and EU respectively (Bandekar 2015).

Mortality

Loss of animals in wean-to-finish or sow barns results in wastage of resources and reduced productivity. Therefore, accurate estimation of mortality is important. The mortality rate in sow barn is the difference between number of gilts added to the barn and number of sows marketed and is necessary to maintain a stable population of sows in the barn. The mortality rate for wean-to-finish pigs for the US was taken as the average of available data for wean-to-feeder and feeder-to-finish barns obtained from NPB. The gilt replacement rate (percentage of house population replaced) and sow cull rate (percentage of house population marketed) for the US were obtained from (Safranski, 2007; Schenck et al., 2010). Data for these parameters for EU were obtained from JRC.

Manure management systems

The type of manure management system and animal nutrition influence greenhouse gas emissions from manure (Philippe and Nicks 2015; Thoma et al., 2011; Clark et al., 2005; Amon et al., 2007; Kaparaju and Rintala, 2011). Dry bedding (solid storage), outside storage (liquid/slurry), anaerobic lagoons, digesters, and deep pits are commonly used manure management systems in pig production. The distribution of animals on each management system was estimated for the US using state-level data for percentage manure distribution among manure management systems by operation published by Environmental Protection Agency (EPA) (USEPA 2014) and 2012 swine inventory (USDA 2016b).

United Nations Framework Convention on Climate Change (UNFCCC) collects data for national greenhouse gas emissions inventory for each member state (UNFCCC, 2016). These inventory data also include pig population, annual nitrogen excretion rate per pig, and nitrogen excretion per manure management system. These parameters for 2012 were used to calculate distribution of animals among manure management systems for EU member states. Table 9 shows distribution of animals on manure management systems for US and EU farms.

Table 9: Distribution of animals among manure management systems for US and EU farms

Region/County	Solid Storage	Liquid Slurry	Anaerobic Lagoon	Deep Pit	Digester
Iowa	0.01	0.20	57.70	42.08	0.00
Minnesota	0.02	0.35	26.77	72.85	0.00
North Carolina	0.01	0.02	65.06	34.91	0.00
Germany	6.09	80.67	0.00	1.23	12.01
Spain	13.70	0.00	8.70	75.60	0.00
France	7.10	92.18	0.00	0.00	0.00
Denmark	0.23	91.99	0.00	2.12	5.56
Netherlands	0.81	99.19	0.00	0.00	0.00

Weather data

Ten-year weather data for locations simulated in this study were downloaded from NASA's Modern-Era Retrospective Analysis for Research and Application (MERRA) repository (Rienecker et al., 2011). The weather data included temperature, humidity, precipitation, solar insolation, and wind speed at an hourly temporal resolution. Weather data spanned ten years to include 2012, which was used as a reference point for inventory data for this study.

Post-farm gate data

Post-farm gate supply chain includes various activities in following stages, including transportation: Slaughterhouse; Packaging; Retail; Purchase and consumption.

Data for these post-farm gate processes were obtained from peer-reviewed publications, publicly available data repositories, and other published reports. Where data were missing, data provided by ten slaughterhouses in the US and aggregated to protect sensitive information were used (Thoma et al., 2011). These data were normalized for a kilogram of lean meat and were extrapolated for current production. This information was provided in 2007 and therefore, was used only to fill data gaps.

Production data for total carcass weight were obtained from USDA-NASS and Eurostat. To maintain consistency, 2012 production data were used for post-farm gate supply chain as well. Total carcass weight produced in the US was 8.19 billion kg (USDA-NASS). Pork production combined for five EU member states used in this study was 13.82 billion kg carcass weight equivalent - weight of skeletal muscles and bone after other parts (feed, head, tail, hide, and internal organs) are removed (Eurostat). Lean meat production was calculated using lean content of pig for US and five EU member states.

Slaughterhouse

Transportation to slaughterhouses

Live animals are transported from farm to slaughterhouses in trucks. The transport distance depends on location of farms and abattoirs. (Schwartzkopf-Genswein et al., 2012) reported that

51.8 percent of pigs were transported less than 161 km, 32.6 percent were transported between 162 and 322 km, and 15.6 percent of market pigs were transported more than 323 km in the US. Since about 84 percent of pigs were transported less than 322 km in the US this distance was used in the model for transportation of live pigs to slaughterhouse. In Germany, it was considered that live pigs were transported 350 km to slaughterhouse (Reckmann et al., 2013b). Transportation distance of 80 km was used for Denmark (Nguyen et al., 2011). Country-specific data on transportation of live animals was not available for France, Spain, and Netherlands. A Corporate Social Responsibility (CSR) report published by Vion Food Group in 2016 reported less than 200 km transportation distance for more than 93 percent of pigs slaughtered between 2014 and 2016 (Vion Food Group, 2016). Therefore, 200 km was used for transportation of live animals for France, Spain, and Netherlands. A unit process in SimaPro, 'Transport, lorry >16t, fleet average' was used as transportation input.

Energy use

Electricity, natural gas, liquid petroleum gas (LPG), heavy and light fuel oils are used in slaughterhouses as the primary sources of energy. Electricity consumption data for US slaughterhouses were obtained from 2012 Annual Survey of Manufacturers (ASM) (U.S. Census Bureau, 2012). The dataset provides quantity of electricity consumed by the meat sector, excluding poultry, at animal slaughtering, meat processing from carcass, and rendering stages. The sum of electricity consumption for these individual stages was considered to represent the entire meat processing stage. The estimated contribution of pork to the value retail sales of red meat was 42 percent (Appendix 2). Economic allocation of 42 percent was used to allocate electricity consumption to pork processing (Table 10) from the total meat processing sector.

The Manufacturing Energy Consumption Survey was used to determine fuel consumption data for natural gas, heavy fuel oil, and light fuel oil. This energy use information was aggregated for the meat and poultry sectors. The contribution of red meat to total meat and poultry retail sales value was estimated to be 77 percent, which was used first to allocate energy use to red meat sector. This was subsequently allocated to pork using the 42 percent economic allocation factor (Table 10).

Table 10: Energy consumption allocated to pork for the US. The economic allocation was used to allocate energy use to pork.

Energy type	Amount
Electricity (kWh)	4,899,509,935
Natural gas (cu.ft.)	39,507,913,883
Heavy fuel oil (MJ)	2,396,946,442
Light fuel oil (MJ)	2,255,618,614

Most animal slaughtering and processing plants also have associated rendering facilities. The Annual Survey of Manufacturers reports data for value of total shipments and receipts for meat processed from carcass and rendering of by-products. Although, the ASM data includes meats other than pork, due to absence of other data, these values were used for economic allocation. The ratio of rendering of by-products to meat processed from carcass assigns 89 percent of GHG burden to meat processing and 11 percent to rendering of by-products.

In 2012, 28 percent of pork was exported to other countries, which included various cuts of pork (USMEF, 2016). Therefore, 28 percent of total lean meat produced in the US was modeled as export. According to USDA-ERS estimates 22.2 percent of total pork was consumed away from home in the US, while 77.8 percent was consumed at home (Davis and Lin 2005). The term 'away-from-home' is used to describe pork consumed at places such as restaurants, school cafeterias, community feeding programs, or child/adult care centers. Therefore, 77.8 percent of pork in domestic sector was considered for household consumption and 22.2 percent was considered for purchase and consumption at domestic food services.

Country-specific energy use data for electricity, natural gas, fuel oils, and liquid petroleum gas was obtained from Eurostat database. These data, however, were aggregated for the food and tobacco sector. The share of pork in the overall turnover of food and tobacco sector, estimated using production mass of lean meat and average price of lean meat for 2012, was 32 percent for Denmark, 14 percent for Germany, 18 percent for Spain, 6 percent for France, and 13 percent for the Netherlands. These values were used for economic allocation of energy consumption to pork (Table 12).

Table 11: Energy consumption allocated to pork slaughtering and processing sector in EU using economic allocation

Energy type	**Denmark**	**Germany**	**Spain**	**France**	**Netherlands**
Natural gas (TJ)	6898.9	3118.1	1150.1	1088.7	1346.2
Electricity (GWh)	752.9	2555.1	1744.9	1209.6	818.9
Fuel oil, (TOE[1])	5.1	8.35	8.84	4.05	0.27
LPG (1000 tons)	0.38	0.23	0.66	0.88	0.03

[1] TOE (ton of oil) = 41.9 GJ

The Eurostat also provides production and export quantities for EU members by type of meat product. Meat types and cuts included fresh or chilled carcasses, ham shoulders, fat-free lean meat, lard and other pig fat rendered, guts, bladder and stomach of animals, and other parts unfit for human consumption (Appendix 2). These data were used to estimate proportions of lean meat for domestic markets, exports, and rendering of by-products. Overall, 18 percent of lean meat content sold in domestic market was attributed to domestic food service sector (Weidema et al., 2008). The percentage of overall impact assigned to household consumption, export, domestic food sector, and rendering of by-products in EU member states is listed in Table 11.

Packaging Material

Meats in the US are packed on polystyrene plate with absorbent pad and wrapped with plastic film (Thoma et al., 2011). The amount of packing material reported by Thoma et al. (2011) and Winkler

Table 12: Percentage of overall impact allocated to meat flows at slaughterhouse using economic allocation

Meat Flows	**US**	**Denmark**	**Germany**	**Spain**	**France**	**Netherlands**
Domestic Retail	50	6.14	48.14	46.22	50.62	25.29
Export	25	71.49	32.70	31.19	20.15	55.09
Domestic Food Service	13.4	1.35	9.99	10.15	11.11	5.55
Rendering	10.6	21.02	9.17	12.44	18.12	14.07

et al. (2016) were used for the US and EU respectively. The packaging material included Expanded Polystyrene (EPS), High Density Polyethylene (HDPE), Polypropylene (PP), and absorbent material for packing individual meat cuts. The packaging material was disposed in a landfill.

Retail

Packaged meats are transported to retail stores in refrigerated trucks for sale. The transportation distance can vary depending upon locations of packaging facility and retail stores, and the retail transportation and supply chain logistics. A transportation distance of 1800 km and 110 km, in a 20-ton truck equipped with refrigeration unit, were simulated for the United States and five EU member states respectively (Weber and Matthews, 2008; Winkler et al., 2016). Transportation required for exports to other countries was out of scope for this study.

Environmental impact at retail stores is a result of refrigeration electricity use, refrigerant leaks, electricity use for retail store overhead (heating/cooling/lighting, etc), and natural gas consumption for space heating. Space allocation of burdens to pork sold at retail stores, estimated by (Thoma et al., 2011), was used for the United States. For European supermarkets, electricity and natural gas consumption suggested by the (Technical Secretariat for the Red Meat Pilot, 2015) was used. A loss rate of 4.3 percent was used at both EU and US supermarkets (Venkat, 2011).

Pork purchased by consumers carries the burden of refrigeration electricity and emissions associated with refrigerant leaks. Refrigerant replacement data used by Thoma et al. (2011) was used for both EU and US retail stages. However, Thoma et al. (2011) assumed use R22 and R404A in refrigerators. Refrigerant R-404A contains R-134A in combination with other chemicals. Refrigerant R-134A is banned in Europe therefore, HFC-152a was used in European retail stage (Calm 2008).

Consumer

Transportation, refrigeration, electricity and natural gas consumption for cooking, cleaning utensils, and transportation for shopping contribute to environmental impacts at the consumer stage. About 11 percent of total household energy use in the US and about 28 percent in the EU is attributed to refrigeration (De Almeida et al., 2011); USEIA, 2016). Household energy use for refrigeration was calculated using these fractions (Table 13). Same allocation fraction used for the retail sector (1.3%) was used to allocate burden of refrigeration electricity consumption to pork.

Table 13: Refrigeration electricity consumption for households in US and EU

Country	Household Refrigeration Electricity (kWh)
US	1258
Denmark	1201
Germany	979
Spain	1162
France	1603
Netherlands	880

According to USGS estimates, dishwashers use 6-16 gallons (22.7 -60.5 liters) of water each cycle (USGS 2016). An average 41.6 liters of water was assumed for dishwashers. According to European Environmental Agency, 32.23 gallons (122 liters) of water was used by an individual in the EU in 2008 (EUROSTAT, 2013). Average household size for each EU member states was used to estimate total household water consumption. Six percent of this daily water consumption was attributed to dishwashing (Schleich and Hillenbrand 2007). An allocation fraction of 4.4 percent was used to allocate water use to pork (Thoma et al., 2011). Transportation distance of 0.4 km per kg of pork purchased was used (Winkler et al., 2016).

Energy required for preparation of pork depends on the cooking method. Electricity and natural gas used for cooking was adopted from Thoma et al. (2011) for the US. For Europe, it was assumed that 25 percent of consumers cooked on electricity and 75 percent cooked on natural gas stove (Technical Secretariat for the Red Meat Pilot, 2015). Electricity consumption of 0.137 kWh and natural gas consumption of 2.03 MJ was used for preparation of 1 kg of pork (Technical Secretariat for the Red Meat Pilot, 2015). In addition to this, 4.21 g of sunflower oil was considered for pan frying and roasting for both EU and US consumer stages (Technical Secretariat for the Red Meat Pilot, 2015).

Total household consumption of pork was estimated using per capita consumption of pork and average household size (Table 14). Loss of pork at consumer for EU member states was estimated using share of pork in per capita food consumption and per capita waste generated by consumer at

Table 14: Per capita pork consumption, household size, and percentage wastage in US and EU

Country	Per capita consumption (kg)	Household Size	Per capita wastage (%)
US	21	3	10
Denmark	81	2	17
Germany	54	2	26
Spain	37	2.5	2
France	34	2.3	10
Netherlands	41	2.2	17

home. These data were obtained from Eurostat data repository. For US 10 percent waste of pork by consumer was assumed (Thoma et al., 2011).

Life Cycle Impact Assessment Method (LCIA)

After the SimaPro model was populated with LCI for cradle-to-grave processes, the ReCiPe LCIA methodology (heuristic, using world normalization) (ReCiPe, 2013) was used for impact assessment. The ReCiPe method includes 18 midpoint categories out of which, GWP, agricultural land occupation, and fossil energy depletion was used in this study. Water use was reported in this study as an inventory of water transferred from one watershed to the other. This included blue and grey water only. The green water use was not included in this study. Ecoinvent and Agri-footprint databases for European supply chain and DATASMART database for the US supply chain were used for background processes (Wernet et al., 2016; Blonk Agri Footprint BV 2015b; Blonk Agri Footprint BV 2015a; LTS 2016).

Uncertainty analysis was performed using one thousand Monte Carlo simulations (MCS) to address uncertainties in the model input parameters. Probability distributions available in background databases were used without modifications. We used normal distributions to estimate uncertainty of inputs obtained from PPEC to SimaPro model, as well as post-farm gate inputs used for foreground processes. The PPEC model is a daily time-step model. These daily data generated for each barn were used to calculate standard deviation for output variables. Daily standard deviation was converted to yearly standard deviation to serve as input to SimaPro. Standard deviation for post-farm gate processes was calculated using data published by commercial slaughterhouses and meat processing plants. In absence of published data, the standard deviation was calculated assuming a 5 percent coefficient of variation around the mean values.

Part 4: Results and discussion

Comparison of US and EU impacts

Environmental impact categories used in this study were global warming potential (GWP), agricultural land occupation, water depletion, and fossil fuel depletion. The results of impact assessment for EU and US average pork consumption for a 4-oz serving are shown in Table 15. The GWP for US and EU were 1.13 and 1.41 kg CO2e per year, respectively.

On a per kilogram basis, the GWP was 9.94 and 12.42 kg CO_2e per year for the US and EU supply chains respectively (Table 16). This GWP also included GHG emissions associated with the land use change. Compared to the US, European pork supply chain showed higher GWP (24.98%), higher agricultural land occupation (12.15%), lower water depletion (50.56%), and lower fossil depletion (34.36%) (Figure 11). The water depletion calculations in the ReCiPe Midpoint method also include water consumption for hydroelectric power plants. However, since water consumption is intended to be an inventory of water transferred from one watershed to another because of pork production and processing, water consumption for hydroelectric generation was excluded from the analysis. These results align with our previous work involving comparison of EU and US cradle-to-farm gate processes (Boles et al, 2015).

Table 15: Impact assessment results for US and EU pork supply chains (cradle-to-grave) for 4-oz serving of pork prepared and consumed

Impact category	**US**	**EU**
GWP, IPCC 100a, kg CO_2e	1.13	1.41
Agricultural land occupation, m^2a	1.02	1.15
Water consumption, m^3	0.06	0.03
Fossil fuel depletion, kg oil eq	0.27	0.17

Table 16: Impact assessment results for US and EU pork supply chains (cradle-to-grave) for 1 kg of pork consumed.

Impact category	**US**	**EU**
GWP, IPCC 100a, kg CO_2e	9.94	12.42
Agricultural land occupation, m^2a	9.02	10.11
Water consumption, m^3	0.515	0.254
Fossil fuel depletion, kg oil eq	2.33	1.53

Global warming potential of pork production was also analyzed without greenhouse gas emissions associated with land use change. Greenhouse gas emissions associated with LUC had a substantial impact on GWP of pork supply chains. When land use changes were excluded, EU pork supply chain had lower GWP compared to the US scenario (Figure 12), which is consistent with the lower fossil fuel consumption. The GWP for EU was 8.71 kg CO_2e without land use change. This was a reduction of 30 percent from 12.42 kg CO_2e observed previously. The GWP for US supply chain reduced only by 0.2 percent (9.92 kg CO_2e) when LUC is excluded. These changes to GWP were a result of impacts associated with deforestation in Latin America for soybean farming, which were included in Agri-Footprint database. The difference in magnitude of impact the land use change had on EU and US results from amount of soybean from Latin America used in pig rations. About 90 percent of soybean meal was imported from Latin America was used in swine feeds in EU (Blonk Agri Footprint BV, 2015a). For the US, only 4 percent of soybean meal was considered to be imported from Latin America. Impacts associated with land use change were also the reason for higher GWP reported above for the EU.

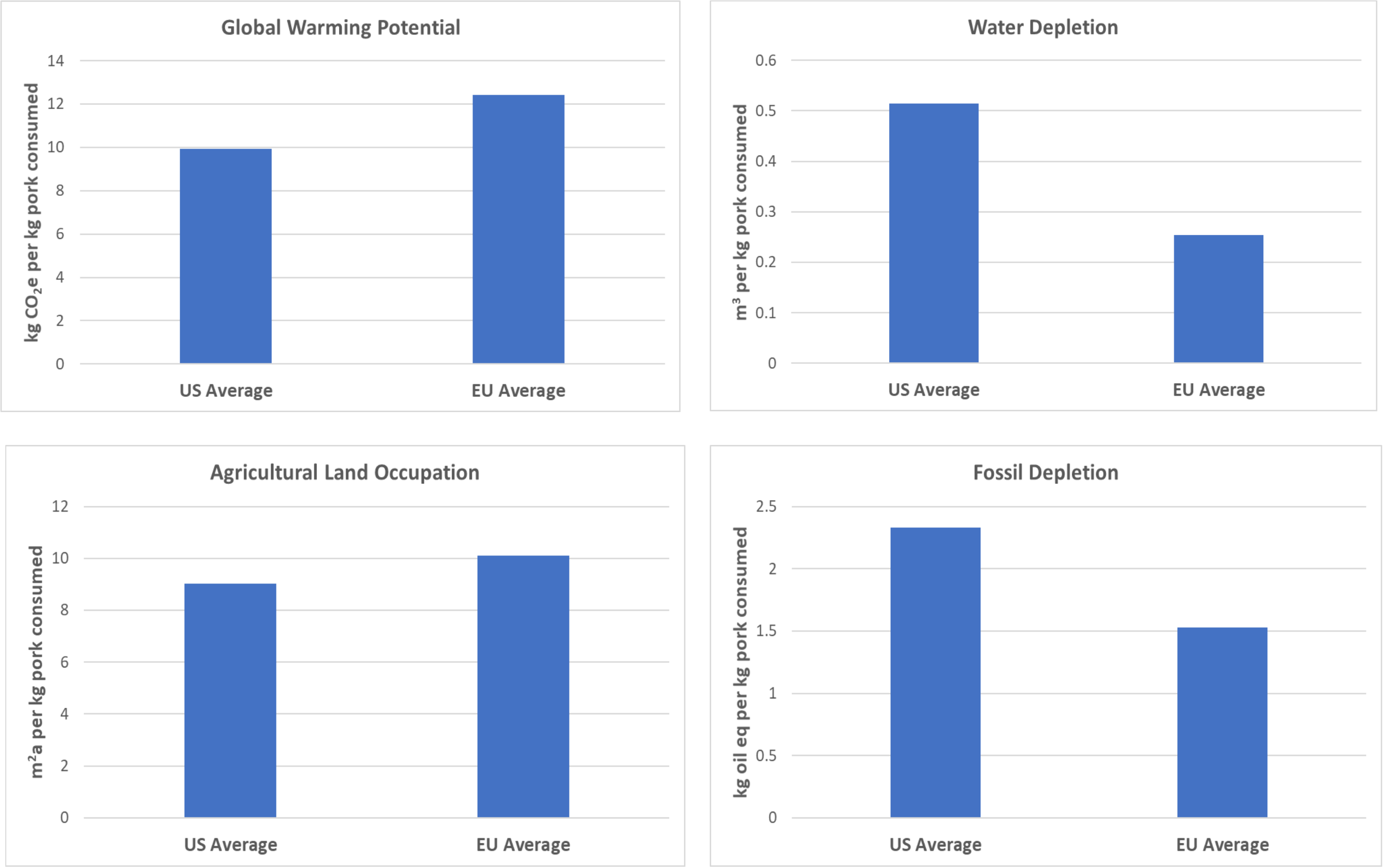


Figure 11: Life cycle assessment results US and EU pork supply chain (cradle-to-grave) for 1 kg pork consumed

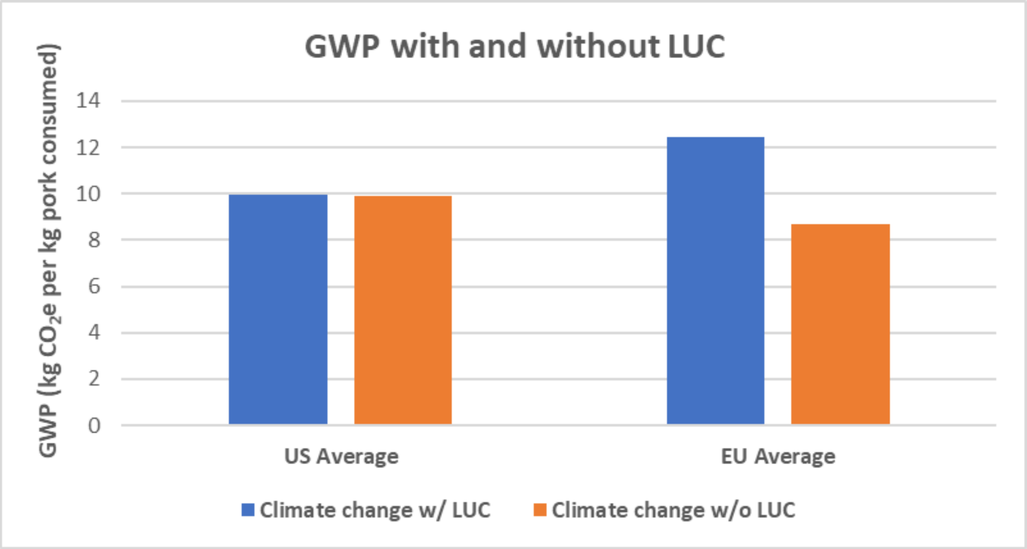


Figure 12- Global warming potential for 1 kg pork consumed for EU and US with and without land use change

The contribution of cradle-to-farm gate and post-farm gate processes to each impact category are shown in Figure 13. Cradle-to-farm gate processes were responsible for majority of impact on agricultural land occupation and water depletion. For GWP and fossil fuel depletion, post-farm gate processes for US and cradle-to-farm gate processes for EU were responsible for large proportion of the impact.

The cradle-to-farm gate supply chain for US was responsible for only 43 percent of total GWP. This is in contrast to Thoma et al. (2011) who reported that cradle-to-farm gate processes contributed to about 63 percent of total GWP. The lower relative contribution of cradle-to-farm gate processes was the result of increased contribution of processing and retail stages and slight reduction in the live animal contribution. The contribution of the consumer stage remained approximately the same. The difference in results between two studies resulted from differences in LCI. The current study used PPEC model to create LCI for pig farming stage and publicly available data to create LCI for post-farm gate stages. Thoma et al. (2011) used ADG and FCR of pigs to estimate feed consumption at pig farming stages while, LCI for post-farm gate stages was created using proprietary data obtained from meat processors in the US. In this work, publicly available data for post-farm gate processes were used for both US and EU to maintain consistency in our approach. The change in LCI resulted in lower GWP for cradle-to-farm gate supply chain in current study. Electricity, natural gas, and heavy fuel oil use at processing stage was three times higher per kilogram lean meat processed in the current study compared to Thoma et al. (2011). These differences were responsible for the difference in results between these studies. The lower contribution of post-farm gate processes to overall GWP for EU production was attributed to lower natural gas and fuel oil use compared to the US at processing stage. The processing stage in EU relied more on electricity than natural gas and fuel oil compared to the US (Table 17).

Table 17: Energy use from various sources at processing stage of US and EU. All values are per ton of lean meat.

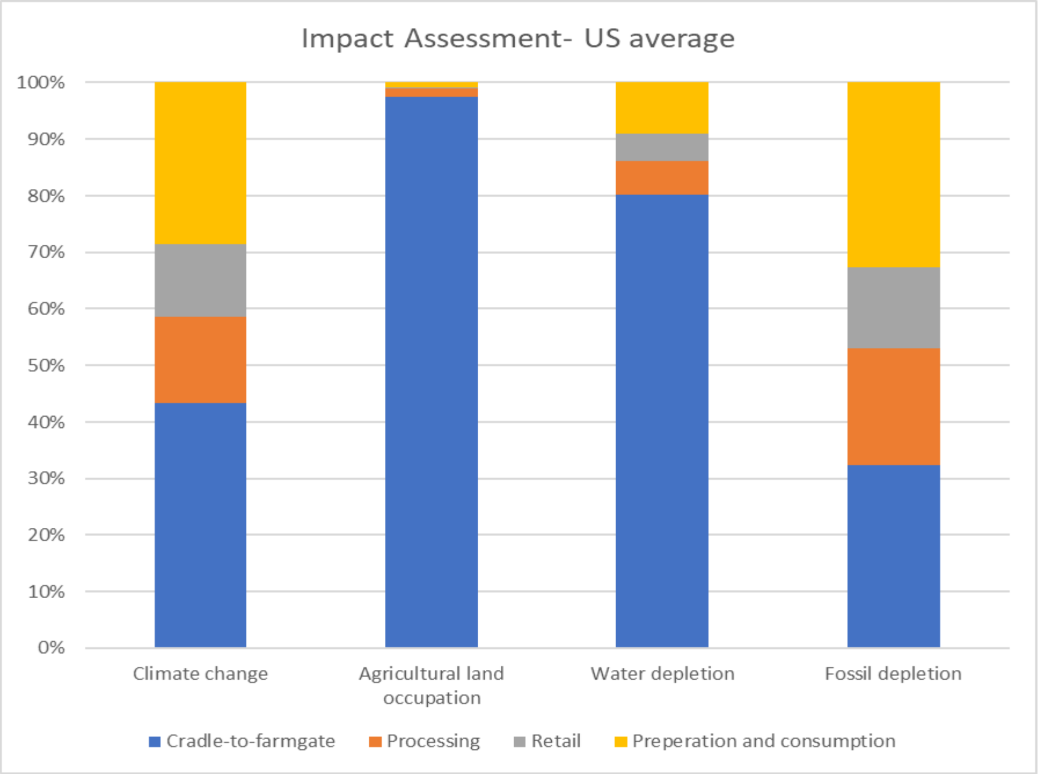
	US	**Germany**	**Denmark**	**France**	**Netherlands**	**Spain**
Natural gas, cu. ft.	4823	751	541	680	1329	415
Electricity, MWh	0.6	632.6	606.5	777.5	831.2	647.0
LPG, lb.	0.354	-	-	-	-	-
Propane, lb.	-	0.026	0.141	0.255	0.012	0.112
Heavy fuel oil, MJ	292.63	0.08	0.15	0.1	0.01	0.12
Light fuel oil, MJ	275.37	0.01	0.02	0.013	0.001	0.016

In addition, an added explanation for higher fossil fuel use observed for the US supply chain is attributed to background processes used for transportation and electricity production (Boles et al, 2015). Transportation in the US is assumed primarily by road, while use of water and rail transportation was also used for Europe. Rail and water transportation are generally more efficient compared to road transportation which, could lead to differences in fossil fuel use. Another factor driving fossil fuel use is electricity generation. Average electricity generation in the US relies more heavily on fossil fuels, which increases fossil energy depletion. These differences were also observed in the contribution analysis. For EU scenarios, diesel use for transportation dominated (14%) overall fossil fuel use. This explains higher contribution of cradle-to-farm gate processes to overall fossil fuel use for EU. For US scenarios on the other hand, natural gas, electricity, and coal contributed more than 66 percent of total fossil fuel use. These energy sources were used more in post-farm gate supply chain leading to higher contribution of post-farm gate processes to fossil fuel use.

Contribution of post-farm gate supply chain to total GWP for the US and EU was substantially higher compared to Winkler et al. (2016), who reported contribution of only 8 percent of total GWP from post-farm gate supply chain. However, electricity use at processing plant in current study was three orders of magnitude higher for EU and approximately six times higher for US, compared to Winkler et al. (2016). The natural gas use at processing stage was approximately ten times higher for US but similar for EU in current study compared to Winkler et al. (2016). These differences in electricity and natural gas use at processing stage between two studies, and apparently excluding food loss from the assessment, were responsible for differences in contribution of post-farm gate supply chain to total GWP.

Water consumption for EU was lower compared to the US. The higher contribution of cradle-to-farm gate water use observed for the US was primarily because of corn production in the US, which contributed to more than 44 percent of total water use. The ration was responsible for approximately 60 percent of water consumption in the US. This was attributed to higher water consumption for corn considered in US and larger proportion of corn in swine diets in US. Corn production unit processes in SimaPro require 61.7 and 49.2 liters of water per kg of corn for US (DATASMART) and EU (Agri-Footprint Economic Allocation), respectively. The proportion of corn in swine diets in US ranged between 33 and 80 percent of dry feed, compared to 2 to 31 percent in EU (Appendix 1). The large amount of corn in swine diets and higher water use per kilogram of corn resulted in higher cradle-to-farm gate water use for US swine production. Municipal water use was responsible for 26 percent of total water use for EU scenario. However, about 93 percent of this water use was by cradle-to-farm gate processes. Feed was responsible for about 23 percent of overall water use for EU scenarios.

Agricultural land occupation (Figure 13) was primarily attributed to crop production for both EU and US scenarios. More than 92 percent of land use in US and 82 percent of land use in EU was attributed to crop production. Corn and soybean were responsible for a large proportion of this land use in US and EU respectively. Agricultural land use for post-farm gate supply chain resulted from softwood and hardwood used for building construction.



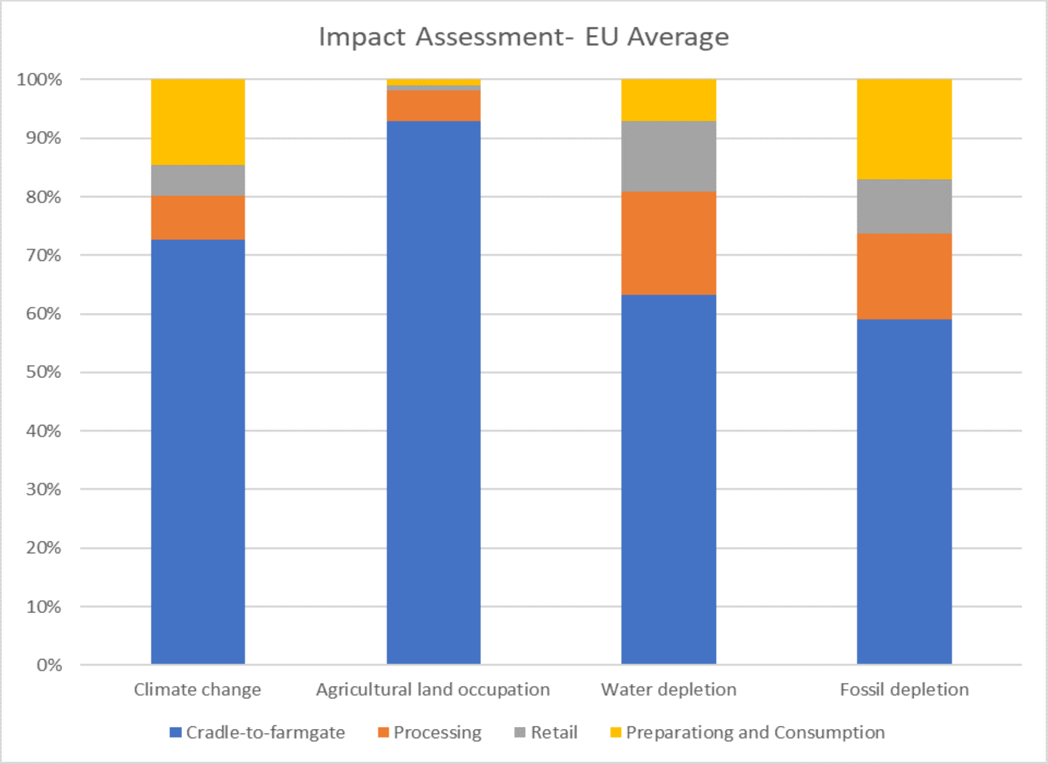


Figure 13- Contribution of various pork production stages to overall GWP for US and EU

Uncertainty Analysis

Uncertainty in the results was assessed using Monte Carlo Simulations. Uncertainty estimates assigned to background processes in Ecoinvent, Agri-footprint, and DATASMART databases were adopted without modification. For pig production and post-farm gate LCI, standard deviation of data was used as an estimate of uncertainty. Where standard deviation could not be calculated due to absence of enough sample data, standard deviation was estimated by applying 5 percent coefficient of variation around the mean.

Uncertainty analysis results are shown in Figure 14 as a percentage of one thousand MCS runs resulting in one production system performing better or worse than the other and in Figure 15 and Figure 16 using box and whisker plots. The box and whisker plots represent difference in median values for US and EU scenarios. The boxes in these plots represent 25th, 50th, and 75th percentiles of 1000 Monte Carlo runs. The 5th and 95th percentiles are shown with vertical lines. The graphs

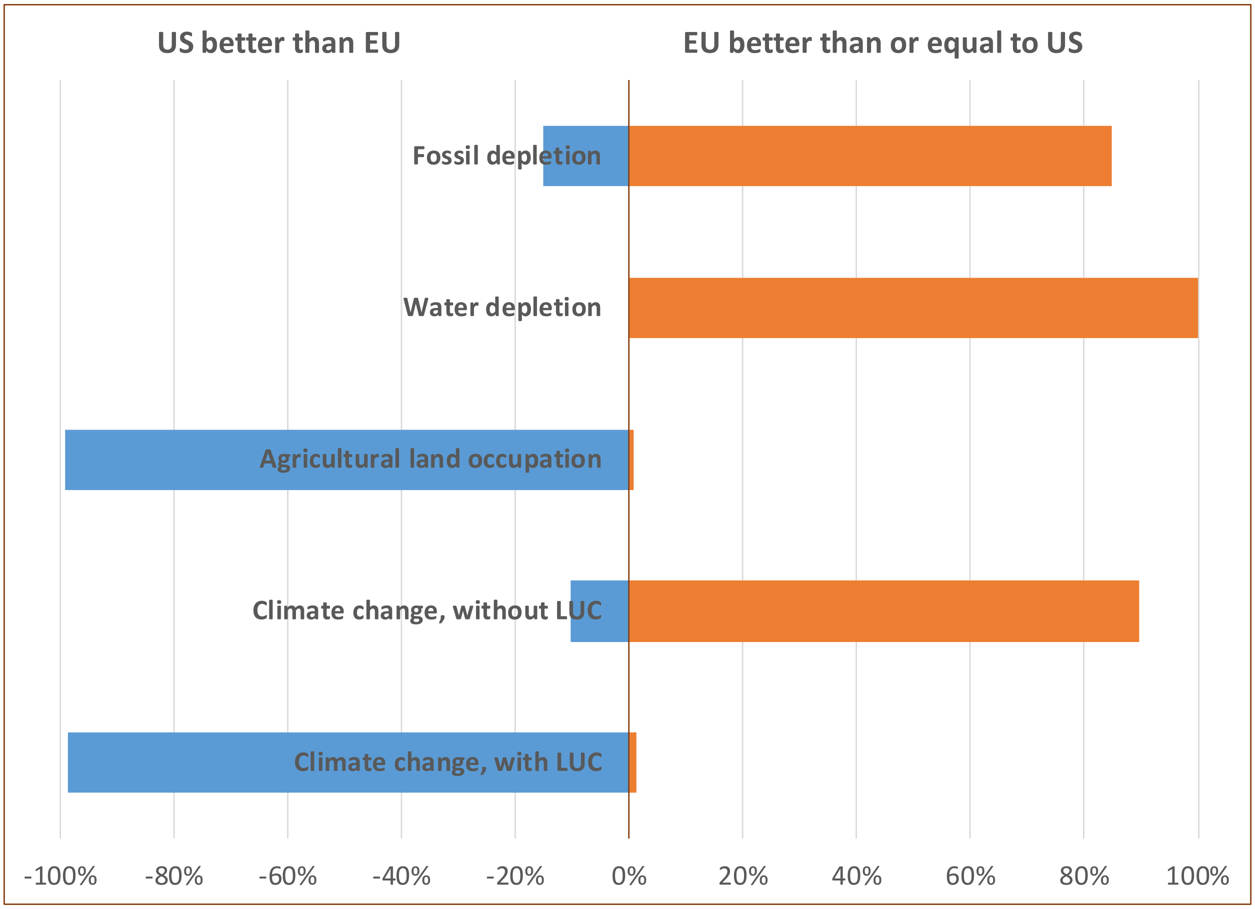


Figure 14- Uncertainty analysis results for US and EU pork supply chains including GWP with and without LUC. The figure shows percentage of 1000 MCS which resulted in one scenario performing better or worse than the other.

show distribution of results for each impact category. There was less uncertainty in data for European pork supply chain for all impact categories, except land use. This was because of Agri-footprint database which was used for background processes for crop production for EU pig production. The Agri-footprint database has limited uncertainty information for background processes (Boles et al, 2015). Difference in means between two supply chains for an impact category can be concluded with certainty when the box and whisker plots do not overlap.

Results of uncertainty analysis shows distribution that is skewed toward one scenario. Global warming potential was lower for US pork supply chain for 98.7 percent of the simulations than EU when GHG emissions associated with land use change were considered. Therefore, it can be concluded that pork supply chain in the US has lower GWP than EU when LUC is included in the analysis. On the other hand, EU pork supply chain performed better 89.7 percent of the simulations, when GHG emissions associated with LUC were exclude. However, there is a general consensus that LUC is important to include in the analysis (this is not indirect LUC, but direct LUC associated with soybean supply to the EU supply chain). The pork supply chain in the US had lower agricultural land occupation while, EU supply chain consumed less water for more than 99 percent of the times. The EU supply chain also had lower fossil fuel consumption compared to the US.

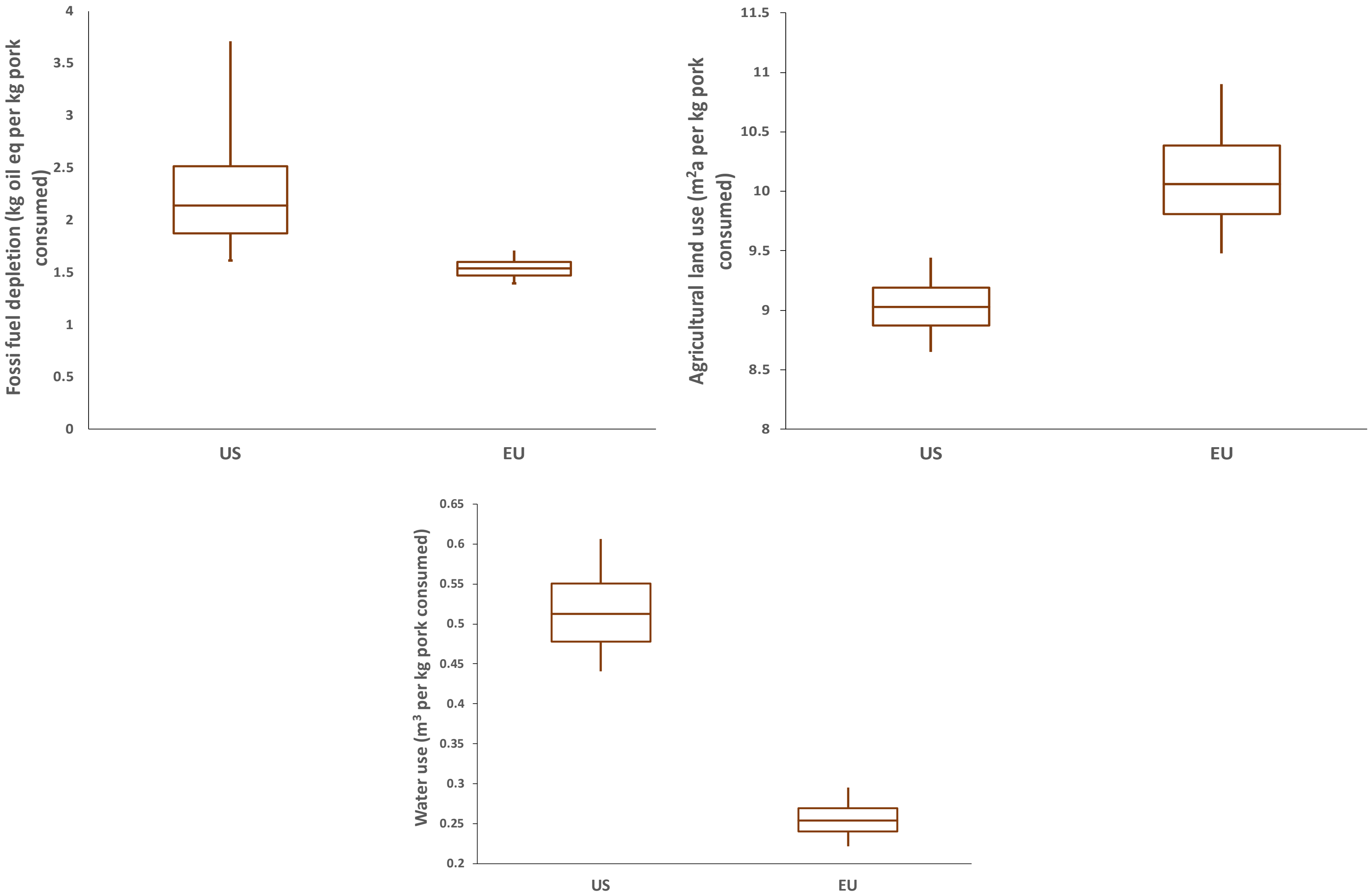


Figure 15- Comparative analysis of US and EU pork supply chains. The box represents 25th and 75th percentile of 1000 MCS and the whiskers represent 5th and 95th percentile

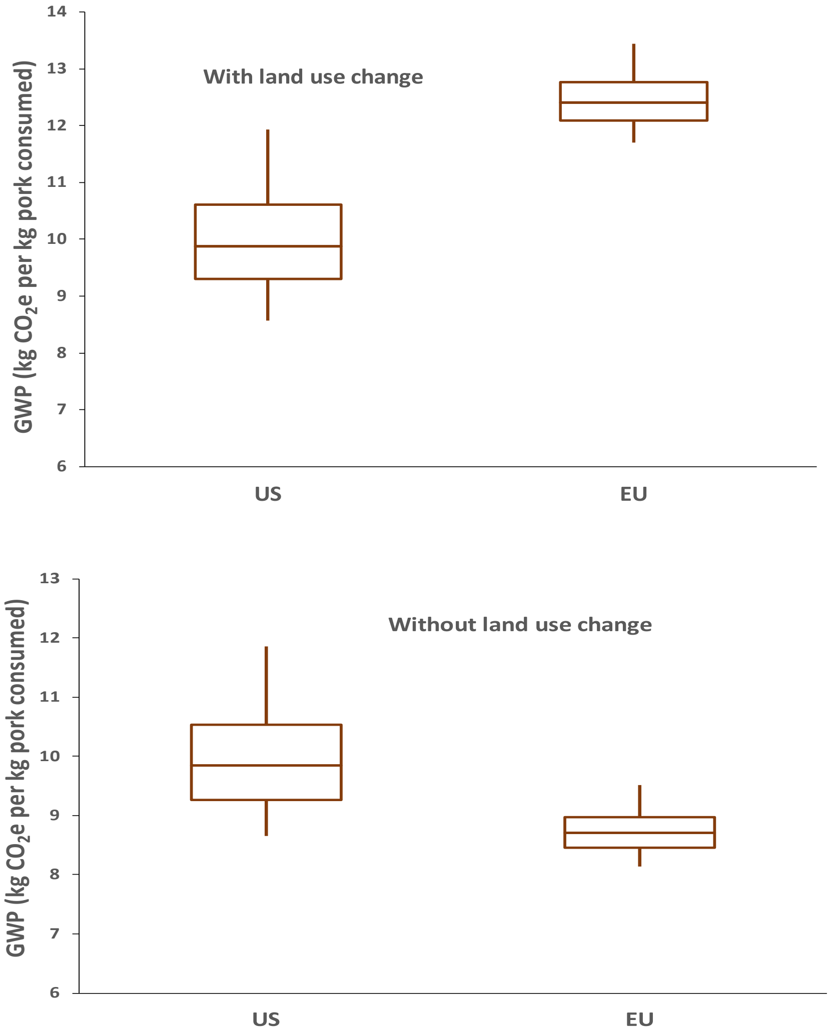


Figure 16- Comparative analysis of US and EU pork supply chains. The box represents 25th and 75th percentile of 1000 MCS and the whiskers represent 5th and 95th percentile

Sensitivity analysis

A sensitivity analysis of post-farm gate supply chain was performed to identify processes which required high quality and accurate data. Each input in post-farm gate supply chain was changed by ±10 percent in SimaPro model while holding all other inputs constant. Impact of these changes was measured on GWP and energy use. The results of sensitivity analysis showed that high quality data are required mainly for natural gas and electricity consumption. The model was comparatively less sensitive to carbon dioxide, diesel, and heavy fuel oil consumption. Even for the more sensitive parameters, a 10% error in the input value leads to less than 1% change in the final result, suggesting that the conclusions of the study are reasonably robust to small errors in input data for the post-farm supply chain.

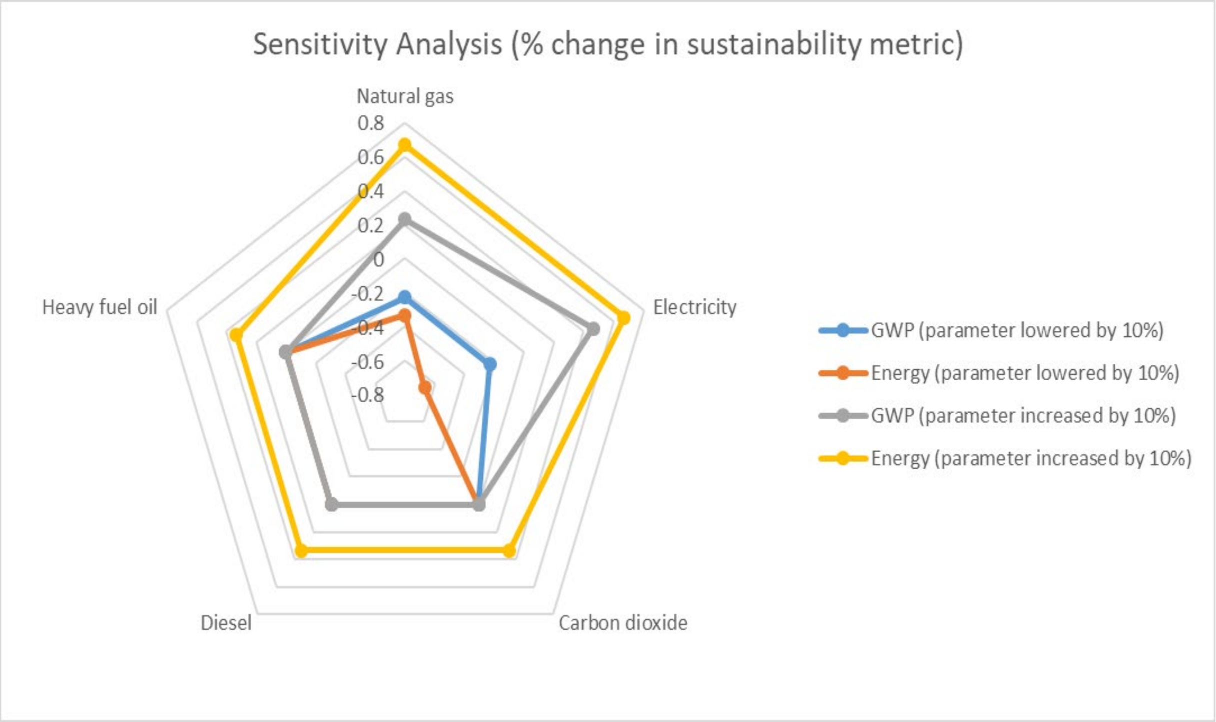


Figure 17- Percentage change in GWP and energy consumption of pork-farm gate pork supply chain with changes in input parameters

Part 5: Conclusion

Life cycle assessment of EU and US supply chains resulted in differences in environmental impacts which varied across impact assessment categories. The US pork supply chain showed lower GWP when LUC was included in the analysis. This difference in the direction of change for GWP was a result of GHG emissions associated with about 90 percent of soy feed that was sourced from Brazil and Argentina for European pig production. Lower agricultural land use for US was attributed to higher crop yields, especially for corn, in the US compared to EU or Latin America. Higher water consumption for US resulted from higher water consumption for crop production in the US and the use of more irrigated feeds in the ration compared to the typical EU ration. Electricity and transportation in the US, which relied more on fossil fuels, lead to higher fossil fuel consumption for US pork supply chain. The uncertainty analysis confirmed the differences in means observed in the comparative analysis. It was therefore concluded that pork supply chain in the US performed better in terms of GWP with land use change and agricultural land occupation. However, the EU supply chain showed better performance for fossil fuel and water consumption.

Cradle-to-farm gate processes, which involved activities associated with swine and crop production, contributed to about 72 and 43 percent of overall GWP for EU and US, respectively. Meat processing and household preparation and consumption of pork were largely responsible for post-farm gate impacts in pork supply chain. Activities associated with retail showed the least contribution to environmental impacts.

Sensitivity and uncertainty analysis of post-farm gate scenario indicated that model results were most sensitive to electricity and natural gas use, but that conclusions of the study are robust to small uncertainties in the data.

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Appendix 1- Feed formulated for pig production in US and EU

Table 18: Diet formulation (% of dry feed) used for Iowa swine farm

	Wean-to-feeder	Feeder-to-finish					Gestation	Lactation
		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5		
Blood Plasma	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium Phosphate (Dicalcium)	0.86	1.00	0.98	0.81	0.64	0.52	1.70	1.70
Choline Chloride 60%	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper Chloride, Tribasic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn DDG	9.24	14.20	4.97	6.24	6.40	7.27	0.00	0.00
Corn, No. 2	59.42	62.43	80.00	80.00	79.99	80.00	51.77	51.77
DL-Methionine	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.00
Fat, Choice White Grease	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limestone, Ground	0.00	0.97	0.90	0.91	0.91	0.88	0.83	0.83
L-Isoleucine	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.00
L-Lysine-HCl	0.34	0.10	0.10	0.10	0.00	0.00	0.00	0.00
L-Threonine	0.02	0.10	0.10	0.10	0.00	0.00	0.00	0.00
L-Tryptophan	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.00
L-Valine	0.00	0.10	0.10	0.10	0.00	0.00	0.00	0.00
Meat and Bone Meal	5.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk Lactose	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses, Sugarcane	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oat Grain	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paylean- 9	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Poultry Meal, Rendered	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salt	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sow Add Pack (NB-6442)	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Soybean Hulls	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00
Soybean Meal, 48% High Protein	8.28	20.28	12.08	11.00	11.62	10.88	34.89	34.89
Trace Mineral Premix (NB-8534)	0.15	0.13	0.13	0.10	0.10	0.08	0.15	0.15
Vitamin Premix (NB-6508)	0.15	0.15	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin E (20,000 units)	0.20	0.03	0.03	0.03	0.03	0.03	0.10	0.10
Wheat Middlings	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00
Zinc Oxide, 72% Zn	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 19- Diet formulation (% of dry feed) used for swine farm Minnesota

	Wean-to-feeder	Feeder-to-finish					Gestation	Lactation
		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5		
Blood Plasma	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium Phosphate (Monocalcium)	0.73	0.65	0.60	0.51	0.50	0.85	0.00	0.00
Copper Sulfate	0.07	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Corn DDG HP	13.16	20.00	20.00	20.00	20.00	0.00	40.00	20.00
Corn, No. 2	46.55	56.41	61.92	66.22	68.77	76.76	53.13	61.02
DL-Methionine	0.10	0.00	0.00	0.00	0.00	0.04	0.00	0.00
Fat, Poultry	2.50	0.00	0.00	0.00	0.00	0.00	0.00	1.78
Fish Meal, Combined	1.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limestone, Ground	0.84	0.97	0.98	0.95	0.90	0.63	1.45	1.45
L-Lysine-HCl	0.35	0.35	0.31	0.28	0.26	0.28	0.20	0.25
L-Threonine	0.06	0.02	0.00	0.00	0.00	0.12	0.00	0.00
Milk Lactose	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk Whey Powder	4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paylean 9	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Phyzyme 1200	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Ronozyme CT (10000)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Salt	0.45	0.60	0.49	0.49	0.49	0.49	0.45	0.50
Sow Add Pack (NB-6442)	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Soybean Meal, 48% High Protein	27.22	20.60	15.30	11.25	8.85	20.50	3.94	14.30
Trace Mineral Premix (NB-8534)	0.15	0.15	0.15	0.15	0.13	0.15	0.15	0.15
Vitamin E (20,000 units)	1.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00
Vitamin Premix (NB-6508)	0.25	0.15	0.15	0.15	0.10	0.15	0.25	0.25
Zinc Oxide, 72% Zn	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 20: Diet formulation (% of dry matter) used for swine farm in North Carolina

	Wean-to-feeder	**Feeder-to-finish**					**Gestation**	**Lactation**
		Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**		
Calcium Carbonate	0.11	0.74	0.77	0.81	0.84	0.83	0.77	0.77
Calcium Phosphate (Dicalcium)	0.35	1.00	0.71	0.50	0.29	0.14	0.64	0.64
Calcium Phosphate (Monocalcium)	0.80	1.00	1.00	1.00	1.00	1.00	2.00	2.00
Corn DDG	15.00	30.00	30.00	30.00	28.30	20.00	31.00	20.00
Corn Germ Meal	3.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Gluten Feed	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	33.47	45.62	50.22	54.14	59.08	66.38	33.37	34.68
DL-Methionine	0.27	0.17	0.14	0.13	0.11	0.14	0.00	0.00
Fat, Beef Tallow	5.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L-Lysine-HCl	0.35	0.35	0.35	0.35	0.35	0.28	0.00	0.00
L-Threonine	0.08	0.10	0.10	0.10	0.08	0.08	0.00	0.00
L-Tryptophan	0.01	0.10	0.10	0.10	0.06	0.02	0.00	0.00
Meat and Bone Meal	7.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molasses, Sugarcane	2.47	0.00	0.00	0.00	0.00	0.00	5.00	5.00
Salt	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Soybean Hulls	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00
Soybean Meal, 48% High Protein	25.00	17.45	13.45	10.12	7.35	9.00	11.00	21.00
Soybean Oil	0.05	2.86	2.59	2.32	2.10	1.69	5.41	5.10
Wheat Middlings	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vitamin Premix (NB-6508)	0.15	0.15	0.10	0.10	0.10	0.10	0.10	0.10
Sow Add Pack (NB-6442)	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Trace Mineral Premix (NB-8534)	0.15	0.13	0.13	0.10	0.10	0.08	0.15	0.15
Copper Sulfate	0.02	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Zinc Oxide, 72% Zn	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamine E (20,000 units)	0.06	0.03	0.03	0.03	0.03	0.03	0.10	0.10
Choline Chloride 60%	0.02	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Paylean 9	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 21: Diet formulation (% of dry matter) used for swine farm in Germany

	Wean-to-feeder	**Feeder-to-finish**					**Gestation**	**Lactation**
		Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**		
Barley	16.11	19.12	19.12	19.12	19.12	19.12	39.30	41.12
Beet Pulp	0.00	2.59	2.59	2.59	2.59	2.59	0.00	0.00
Calcium Phosphate (Monocalcium)	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.50
Canola Meal, Solvent Extracted	8.41	5.41	5.41	5.41	1.66	1.65	0.00	0.00
Citrus Pulp	5.00	2.00	2.00	2.00	2.00	2.00	8.59	12.23
Copper Sulfate	0.07	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	4.15	7.15	7.15	10.81	11.15	11.15	0.00	5.53
DL-Methionine	0.33	0.19	0.18	0.18	0.10	0.10	0.00	0.00
Limestone, Ground	0.00	0.18	0.17	0.22	0.26	0.26	0.00	0.00
Liquid Potato Feed	0.00	0.00	0.00	0.00	1.60	1.40	0.00	0.00
L-Lysine-HCl	2.91	0.35	0.31	0.28	0.26	0.28	0.00	0.00
L-Threonine	0.06	0.02	0.00	0.00	0.00	0.12	0.00	0.00
Molasses, Sugarcane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grow-Fin Vitamin Premix	0.00	0.15	0.15	0.15	0.10	0.15	0.00	0.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trace Mineral Premix	0.15	0.15	0.15	0.15	0.13	0.15	0.00	0.00
Oat Grain	0.00	0.67	0.67	0.67	0.67	0.67	0.00	0.00
Other Grains	2.03	5.86	5.53	9.03	9.03	9.03	0.00	0.00
Palm Kernel Oil	2.75	2.37	2.37	2.37	2.37	2.37	4.32	4.66
Peas, Field Peas	5.93	2.93	2.93	0.00	0.00	0.00	0.00	0.00
Protein Fodder	11.78	9.04	9.06	7.53	9.04	9.04	11.61	0.00
Rye Grain	0.00	1.86	1.86	5.86	5.86	5.86	0.00	0.00
Soybean Meal, Dehulled, Solvent Extracted	12.50	9.50	9.50	5.50	5.50	5.50	27.50	27.50
Sunflower Meal, 42%, Dehulled, Solvent Extracted	3.11	2.03	2.33	0.00	0.00	0.00	0.00	0.00
Vegetable Oil	0.00	1.87	1.96	1.67	2.10	2.10	0.00	0.00
Vitamin E (20,000 units)	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat, Hard Red	23.46	26.46	26.46	26.46	26.46	26.46	8.46	8.46
Zinc Oxide, 72% Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 22: Diet formulation (% of dry matter) used for swine farm in Spain

	Wean-to-feeder	**Feeder-to-finish**					**Gestation**	**Lactation**
		Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**		
Barley	23.37	24.46	24.46	25.10	25.10	25.10	33.76	34.46
Beet Pulp	0.922	1.93	1.93	1.98	1.98	1.98	0.00	0.00
Calcium Phosphate (Monocalcium)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canola Meal, Solvent Extracted	3.29	0.47	0.62	0.18	0.18	0.18	0.00	0.00
Citrus Pulp	3.52	0.87	0.87	0.89	0.89	0.89	4.03	4.13
Copper Sulfate	0.08	0.11	0.11	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	17.45	22.50	22.50	23.09	23.09	23.09	30.62	30.52
DL-Methionine	0.11	0.04	0.04	0.05	0.05	0.05	0.00	0.00
Limestone, Ground	0.00	0.18	0.18	0.19	0.19	0.19	0.00	0.00
Liquid Potato Feed	0.00	0.00	0.00	0.65	0.65	0.65	0.00	0.00
L-Lysine-HCl	0.39	0.39	0.35	0.32	0.30	0.32	0.00	0.00
L-Threonine	0.07	0.02	0.00	0.00	0.00	0.14	0.00	0.00
Molasses, Sugarcane	0.00	1.00	1.00	1.02	1.02	1.02	0.00	0.00
Grow-Fin Vitamin Premix	0.00	0.17	0.17	0.17	0.11	0.17	0.00	0.00
Nursery Vitamin Premix	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trace Mineral Premix	0.17	0.17	0.17	0.17	0.15	0.17	0.00	0.00
Oat Grain	0.00	2.71	2.61	0.63	0.63	0.63	0.00	0.00
Other Grains	0.00	3.49	3.49	3.58	3.58	3.58	0.00	0.00
Palm Kernel Oil	0.68	1.77	1.76	2.29	2.24	2.27	0.00	0.00
Peas, Field Peas	5.84	0.93	0.93	0.95	0.95	0.95	0.00	0.00
Protein Fodder	7.49	7.52	7.52	7.72	7.72	7.72	1.64	0.00
Rye Grain	1.03	2.99	2.99	3.07	3.07	3.07	0.46	1.32
Soybean Meal, Dehulled, Solvent Extracted	18.78	16.26	16.28	14.25	14.26	14.25	25.84	25.84
Sunflower Meal, 42%, Dehulled, Solvent Extracted	3.51	0.20	0.20	0.20	0.20	0.20	0.00	0.00
Vegetable Oil	3.34	2.24	2.24	2.30	2.30	2.30	2.08	2.05
Vitamin E (20,000 units)	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat, Hard Red	8.58	9.61	9.61	11.20	11.34	11.09	1.67	1.67
Zinc Oxide, 72% Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 23: Diet formulation (% of dry matter) used for swine farm in France

	Wean-to-feeder	Feeder-to-finish					Gestation	Lactation
		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5		
Barley	9.86	9.86	9.86	9.86	9.86	9.86	26.86	26.86
Beet Pulp	1.67	1.67	1.67	1.67	1.67	1.67	0.00	0.00
Calcium Phosphate (Monocalcium)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canola Meal, Solvent Extracted	5.20	5.20	5.20	1.20	1.20	1.20	0.00	0.00
Citrus Pulp	0.00	2.00	2.00	2.00	2.00	2.00	0.11	0.22
Copper Sulfate	0.07	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	14.06	14.06	14.06	18.06	18.06	18.06	31.06	31.06
DL-Methionine	0.32	0.20	0.20	0.11	0.03	0.04	0.00	0.00
Limestone, Ground	0.25	0.21	0.21	0.24	0.24	0.26	0.14	0.14
Liquid Potato Feed	0.00	0.00	0.00	2.11	2.11	2.11	0.00	0.00
L-Lysine-HCl	3.00	0.35	0.31	0.28	0.26	0.28	0.00	0.00
L-Threonine	1.04	0.02	0.00	0.00	0.00	0.12	0.00	0.00
Molasses, Sugarcane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grow-Fin Vitamin Premix	0.00	0.15	0.15	0.15	0.10	0.15	0.00	0.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trace Mineral Premix	0.15	0.15	0.15	0.15	0.13	0.15	0.00	0.00
Oat Grain	0.44	0.44	0.44	0.44	0.44	0.44	0.00	0.00
Other Grains	4.06	8.06	8.06	8.06	8.06	8.06	0.00	0.00
Palm Kernel Oil	0.00	2.14	2.14	2.14	2.14	2.14	1.57	1.47
Peas, Field Peas	4.58	0.58	0.58	0.58	0.58	0.58	0.00	0.00
Protein Fodder	4.33	8.34	8.33	8.14	8.32	4.32	11.66	11.65
Rye Grain	0.36	2.36	2.36	2.36	2.36	2.36	0.36	0.36
Soybean Meal, Dehulled, Solvent Extracted	13.47	9.98	10.10	9.47	9.47	9.47	26.47	26.47
Sunflower Meal, 42%, Dehulled, Solvent Extracted	3.47	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Vegetable Oil	2.04	0.39	0.39	0.83	0.80	0.79	0.00	0.00
Vitamin E (20,000 units)	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat, Hard Red	30.38	31.97	31.92	30.38	30.40	34.17	0.00	0.00
Zinc Oxide, 72% Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 24: Diet formulation (% of dry matter) used for swine farm in Denmark

	Wean-to-feeder	Feeder-to-finish					Gestation	Lactation
		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5		
Barley	24.80	24.80	24.80	24.80	24.80	24.80	33.44	30.17
Beet Pulp	1.20	1.20	1.20	1.20	1.20	1.20	0.00	0.00
Calcium Phosphate (Monocalcium)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canola Meal, Solvent Extracted	4.70	4.54	4.70	0.00	0.00	0.00	0.00	0.00
Citrus Pulp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper Sulfate	0.07	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	0.00	2.70	2.70	2.70	2.70	2.70	0.00	15.70
DL-Methionine	0.30	0.19	0.19	0.10	0.02	0.04	0.00	0.00
Limestone, Ground	0.32	0.36	0.36	0.42	0.42	0.42	0.32	0.22
Liquid Potato Feed	0.00	2.60	2.53	2.60	2.60	2.60	0.00	7.14
L-Lysine-HCl	3.00	0.35	0.31	0.28	0.26	0.28	0.00	0.00
L-Threonine	0.22	0.02	0.00	0.00	0.00	0.12	0.00	0.00
Molasses, Sugarcane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grow-Fin Vitamin Premix	0.00	0.15	0.15	0.15	0.10	0.15	0.00	0.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trace Mineral Premix	0.15	0.15	0.15	0.15	0.13	0.15	0.00	0.00
Oat Grain	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00
Other Grains	0.00	3.10	3.10	3.10	3.10	3.10	0.00	0.00
Palm Kernel Oil	1.68	2.70	2.70	2.70	2.70	2.70	2.82	2.57
Peas, Field Peas	2.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Protein Fodder	5.50	6.41	6.39	9.50	9.50	9.50	13.31	0.00
Rye Grain	0.00	2.70	2.70	2.70	2.70	2.70	0.00	15.70
Soybean Meal, Dehulled, Solvent Extracted	15.50	11.50	11.50	11.50	11.50	11.50	28.50	28.50
Sunflower Meal, 42%, Dehulled, Solvent Extracted	1.81	0.00	0.00	0.00	0.00	0.00	0.51	0.00
Vegetable Oil	2.00	1.33	1.32	1.65	1.62	1.64	0.00	0.00
Vitamin E (20,000 units)	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat, Hard Red	34.10	34.10	34.10	35.45	35.65	35.40	21.10	0.00
Zinc Oxide, 72% Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 25: Diet formulation (% of dry matter) used for swine farm in Netherlands

	Wean-to-feeder	**Feeder-to-finish**					**Gestation**	**Lactation**
		Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**		
Barley	5.38	5.38	5.38	5.38	5.38	5.38	19.79	22.38
Beet Pulp	7.00	7.00	7.00	7.00	7.00	7.00	0.00	0.00
Calcium Phosphate (Monocalcium)	0.17	0.11	0.11	0.07	0.07	0.07	0.00	0.00
Canola Meal, Solvent Extracted	5.13	5.13	5.13	1.54	1.13	1.13	0.00	0.00
Citrus Pulp	2.07	2.07	2.07	2.07	2.07	2.07	0.00	0.00
Copper Sulfate	0.07	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Corn, No. 2	9.54	9.54	9.54	13.54	13.54	13.54	26.54	26.54
DL-Methionine	1.09	0.16	0.16	0.10	0.02	0.04	0.00	0.00
Limestone, Ground	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.23
Liquid Potato Feed	9.69	9.69	9.69	12.49	13.69	13.69	0.00	0.00
L-Lysine-HCl	3.00	0.35	0.31	0.28	0.26	0.28	0.00	0.00
L-Threonine	3.00	0.02	0.00	0.00	0.00	0.12	0.00	0.00
Molasses, Sugarcane	1.25	1.25	1.25	1.25	1.25	1.25	0.00	0.00
Grow-Fin Vitamin Premix	0.00	0.15	0.15	0.15	0.10	0.15	0.00	0.00
Nursery Vitamin Premix	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trace Mineral Premix	0.15	0.15	0.15	0.15	0.13	0.15	0.00	0.00
Oat Grain	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Other Grains	0.68	2.68	2.68	2.68	2.68	2.68	0.68	0.68
Palm Kernel Oil	3.54	6.35	6.35	7.08	7.08	7.08	0.15	0.30
Peas, Field Peas	2.47	1.65	1.65	1.65	1.65	1.65	0.00	0.00
Protein Fodder	7.46	11.47	11.47	11.47	10.71	10.46	11.97	5.93
Rye Grain	1.24	3.24	3.24	3.24	3.24	3.24	11.88	15.16
Soybean Meal, Dehulled, Solvent Extracted	15.28	14.02	14.14	11.28	11.28	11.28	28.28	28.28
Sunflower Meal, 42%, Dehulled, Solvent Extracted	2.24	2.24	2.24	2.24	2.24	2.24	0.00	0.00
Vegetable Oil	2.09	0.09	0.09	0.13	0.27	0.29	0.09	0.09
Vitamin E (20,000 units)	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat, Hard Red	15.80	16.75	16.69	15.80	15.80	15.80	0.00	0.00
Zinc Oxide, 72% Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Appendix 2- Raw data used in this study

Table 28: Calculations for economic allocation of energy to pork in the US

	Beef	Pork	Poultry
Production[1], lb. (carcass weight equivalent)	25,912,600,000	23,268,000,000	43,644,998,000
Retail price of meat[2], $/lb.	4.99	3.47	1.89
Retail equivalent value[3], $	85,269,634,241	62,595,475,325	45,429,024,165[4]
Share in total meat turnover (red meat and poultry), %	44.11	32.38	23.50
Share in total red meat turnover, %	57.67	42.33	-

[1] Source- USDA-NASS 2012 data

[2] Source- USDA-ERS 2012 data

[3] Calculated using lean meat volume and retail volume. Lean to hot carcass fraction used, Beef- 66%, Pork- 77.6%

[4] Retail equivalent value data for 2010, source- USDA-ERS

Table 27: Pork exports from China, EU, and US; 1000 metric tons (carcass weight equivalent). Source- FAO

Country	2012	2013	2014	2015	2016
China	235	244	276	231	180
EU	2165	2227	2164	2389	3300
US	2440	2262	2309	2272	2356
Total (incl. other countries)	7263	7008	6962	7224	8538

Table 26: Pork production data, 1000 metric tons (carcass weight equivalent). Source- FAO

Country	2012	2013	2014	2015	2016
China	55427	54930	56710	54870	51850
EU	22526	22359	22540	23290	23350
US	10554	10525	10368	11121	11307
Total (incl. other countries	106873	108828	110566	110376	107201

Table 29: Calculations for economic allocation of energy to pork in the EU

	Denmark	Germany	Spain	France	Netherlands
Total turnover, food and tobacco sector (million €)	23,149	184,487	87,496	153,064	62,745
Pork production, kg (carcass weight equivalent)	1,603,700,000	5,459,000,000	3,466,320,000	1,957,360,000	1,331,730,000
Price of pork loin, €/kg	6.0	6.49	6	6	8.27
Turnover, fresh pork at retail (million €)	7,415	26,216	16,118	9,298	8,148
Share of pork in food and tobacco turnover	32.03	14.21	18.42	6.07	12.99

Data source- 2012 EUROSTAT data

Table 30: Raw data used to estimate mass of various meat flows at meat processing plants in France. Source- 2012 EUROSTAT data

	Production, kg	Import, kg	Export, kg
Fresh or chilled carcasses and half-carcasses of pig meat (including fresh meat packed with salt as a temporary preservative)	336,461,303	4,707,400	86,263,400
Fresh or chilled hams; shoulders and cuts thereof with bone in; of pig meat (including fresh meat packed with salt as a temporary preservative)	589,754,760	67,054,000	102,254,200
Fresh or chilled pig meat (including fresh meat packed with salt as a temporary preservative; excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	737,213,033	200,561,500	125,177,000
Frozen carcasses and half-carcasses of pig meat	4,882,917	291,300	734,700
Frozen hams; shoulders and cuts with bone in of pig-meat	66,656,384	6,729,500	10,062,200
Frozen pig meat (excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	208,920,402	79,164,500	156,858,600
Pig fat free of lean meat; fresh; chilled; frozen; salted; in brine or smoked (excluding rendered)	112,767,417	22,861,200	38,469,800
Lard and other pig fat; rendered	51,395,614	7,416,200	56,487,400
Guts; bladders and stomachs of animals; whole or in pieces (excluding fish)	76,786,402	48,271,000	20,291,700
Animal disposal; unfit for human consumption (excluding fish, guts; bladders and stomachs)	905,186,007	256,417,600	76,696,500
Guts; bladders and stomachs of animals; whole or in pieces (pigs only)	23,719,877.50	14,911,262.63	6,268,253.57
Animal disposal; unfit for human consumption (pigs only, guts; bladders and stomachs)	279,618,534.60	79,209,259.76	23,692,106.12

Meat flows included: lean meat for domestic retail, lean meat for domestic food service, lean meat exported, and by-product rendering. A 18% share of domestic food services to pork consumption was assumed (Weidema et al. 2008)

Table 31: Raw data used to estimate mass of various meat flows at meat processing plants in Denmark. Source- 2012 EUROSTAT data

	Production, kg	**Import, kg**	**Export, kg**
Fresh or chilled carcasses and half-carcasses of pig meat (including fresh meat packed with salt as a temporary preservative)	68,461,488	32,600	72,804,700
Fresh or chilled hams; shoulders and cuts thereof with bone in; of pig meat (including fresh meat packed with salt as a temporary preservative)	295,176,039	1,479,700	343,949,600
Fresh or chilled pig meat (including fresh meat packed with salt as a temporary preservative; excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	491,084,384	40,562,600	350,148,300
Frozen carcasses and half-carcasses of pig meat	58,743	14,200	60,600
Frozen hams; shoulders and cuts with bone in of pig-meat	11,047,098	266,900	11,206,700
Frozen pig meat (excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	339,638,279	9,390,800	323,788,500
Pig fat free of lean meat; fresh; chilled; frozen; salted; in brine or smoked (excluding rendered)	61,277,713	14,854,300	38,957,300
Lard and other pig fat; rendered	99,019,714	11,842,200	22,443,400
Guts; bladders and stomachs of animals; whole or in pieces (excluding fish)	35,059,851	22,262,200	24,088,900
Animal disposal; unfit for human consumption (excluding fish, guts; bladders and stomachs)	214,187,942	181,421,100	71,458,000
Guts; bladders and stomachs of animals; whole or in pieces (pigs only)	28,638,253.48	18,184,633.09	19,676,752.88
Animal disposal; unfit for human consumption (pigs only, guts; bladders and stomachs)	174,957,063.41	148,191,829.10	58,369,680.95

Meat flows included: lean meat for domestic retail, lean meat for domestic food service, lean meat exported, and by-product rendering. A 18% share of domestic food services to pork consumption was assumed (Weidema et al. 2008)

Table 32: Raw data used to estimate mass of various meat flows at meat processing plants in Netherlands. Source- 2012 EUROSTAT data

	Production, kg	**Import, kg**	**Export, kg**
Fresh or chilled carcasses and half-carcasses of pig meat (including fresh meat packed with salt as a temporary preservative)	336,834,000	12,395,800	119,027,800
Fresh or chilled hams; shoulders and cuts thereof with bone in; of pig meat (including fresh meat packed with salt as a temporary preservative)	201,472,000	15,352,100	262,507,400
Fresh or chilled pig meat (including fresh meat packed with salt as a temporary preservative; excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	282,944,000	165,389,700	192,129,700
Frozen carcasses and half-carcasses of pig meat	0	196,900	398,200
Frozen hams; shoulders and cuts with bone in of pig-meat	315,629,581.27	10,916,500	13,154,700
Frozen pig meat (excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	185,165,000	32,402,200	163,861,000
Pig fat free of lean meat; fresh; chilled; frozen; salted; in brine or smoked (excluding rendered)		73,918,800	54,190,600
Lard and other pig fat; rendered	125,382,000	83,101,200	72,974,500
Guts; bladders and stomachs of animals; whole or in pieces (excluding fish)	74,508,000	65,228,100	71,922,300
Animal disposal; unfit for human consumption (excluding fish, guts; bladders and stomachs)		230,707,300	301,564,300
Guts; bladders and stomachs of animals; whole or in pieces (pigs only)	35,894,866.65	31,424,195.41	34,649,183.55
Animal disposal; unfit for human consumption (pigs only, guts; bladders and stomachs)	-	111,145,216.21	145,281,182.37

Meat flows included: lean meat for domestic retail, lean meat for domestic food service, lean meat exported, and by-product rendering. A 18% share of domestic food services to pork consumption was assumed (Weidema et al. 2008)

Table 33: Raw data used to estimate mass of various meat flows at meat processing plants in Germany. Source- 2012 EUROSTAT data

	Production, kg	**Import, kg**	**Export, kg**
Fresh or chilled carcasses and half-carcasses of pig meat (including fresh meat packed with salt as a temporary preservative)	3,354,931,330	424,753,100	201,134,500
Fresh or chilled hams; shoulders and cuts thereof with bone in; of pig meat (including fresh meat packed with salt as a temporary preservative)	760,432,278	192,255,900	237,204,400
Fresh or chilled pig meat (including fresh meat packed with salt as a temporary preservative; excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	2,007,021,411	313,685,000	703,170,300
Frozen carcasses and half-carcasses of pig meat		1,359,500	29,532,300
Frozen hams; shoulders and cuts with bone in of pig-meat	1,043,333,804.16	6,734,300	59,918,500
Frozen pig meat (excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	228,582,067	43,551,500	462,700,800
Pig fat free of lean meat; fresh; chilled; frozen; salted; in brine or smoked (excluding rendered)	61,011,043	33,069,300	213,617,500
Lard and other pig fat; rendered	179,647,216	15,915,200	57,689,700
Guts; bladders and stomachs of animals; whole or in pieces (excluding fish)	156,039,430	66,614,800	115,677,700
Animal disposal; unfit for human consumption (excluding fish, guts; bladders and stomachs)	219,356,045	393,431,800	597,179,700
Guts; bladders and stomachs of animals; whole or in pieces (pigs only)	94,751,863.00	40,450,522.05	70,242,999.37
Animal disposal; unfit for human consumption (pigs only, guts; bladders and stomachs)	133,199,627.33	238,903,692.57	362,625,582.01

Meat flows included: lean meat for domestic retail, lean meat for domestic food service, lean meat exported, and by-product rendering. A 18% share of domestic food services to pork consumption was assumed (Weidema et al. 2008)

Table 35: Raw data used to estimate mass of various meat flows at meat processing plants in Spain. Source- 2012 EUROSTAT data

	Production, kg	**Import, kg**	**Export, kg**
Fresh or chilled carcasses and half-carcasses of pig meat (including fresh meat packed with salt as a temporary preservative)	1,258,721,000	10,977,300	29,501,100
Fresh or chilled hams; shoulders and cuts thereof with bone in; of pig meat (including fresh meat packed with salt as a temporary preservative)	719,336,000	16,305,000	209,891,800
Fresh or chilled pig meat (including fresh meat packed with salt as a temporary preservative; excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	1,450,732,000	18,776,700	348,118,700
Frozen carcasses and half-carcasses of pig meat	5,342,000	353,200	3,655,600
Frozen hams; shoulders and cuts with bone in of pig-meat	88,107,000	6,224,500	65,655,700
Frozen pig meat (excluding carcasses and half-carcasses, hams; shoulders and cuts thereof with bone in)	541,547,000	29,412,400	373,677,800
Pig fat free of lean meat; fresh; chilled; frozen; salted; in brine or smoked (excluding rendered)	215,629,741	3,017,900	72,642,800
Lard and other pig fat; rendered	239,950,922	36,396,800	16,342,800
Guts; bladders and stomachs of animals; whole or in pieces (excluding fish)	128,052,263	20,995,000	71,494,700
Animal disposal; unfit for human consumption (excluding fish, guts; bladders and stomachs)	137,861,624	43,725,200	121,338,900
Guts; bladders and stomachs of animals; whole or in pieces (pigs only)	76,064,029.06	12,471,191.47	42,468,401.66
Animal disposal; unfit for human consumption (pigs only, guts; bladders and stomachs)	81,890,864.93	25,973,105.09	72,076,239.80

Meat flows included: lean meat for domestic retail, lean meat for domestic food service, lean meat exported, and by-product rendering. A 18% share of domestic food services to pork consumption was assumed (Weidema et al. 2008)

Table 34: Volume of various meat flows estimated using raw data in Table 30 through Table 35

	France	**Denmark**	**Netherlands**	**Germany**	**Spain**
Edible lean meat production, kg	1,602,544,579	1,136,945,800	985,210,581	4,039,369,560	2,799,722,000
Edible lean meat export, kg	394,352,000	1,029,093,100	631,652,800	1,462,994,000	997,344,000
Edible lean meat production (excluding export), kg	1,208,192,579	107,852,700	353,557,781	2,576,375,560	1,802,378,000
Edible meat, Domestic food service[1]	217,474,664	19,413,486	63,640,401	463,747,601	324,428,040
Edible meat, Domestic Retail, kg	990,717,915	88,439,214	289,917,381	2,112,627,959	1,477,949,960
Rendering, kg	354,734,026.11	302,615,030.88	161,276,866.65	407,598,706.33	397,905,815.99

[1] Share of domestic food service- 18% of domestic lean meat volume. Source- (Weidema et al. 2008)

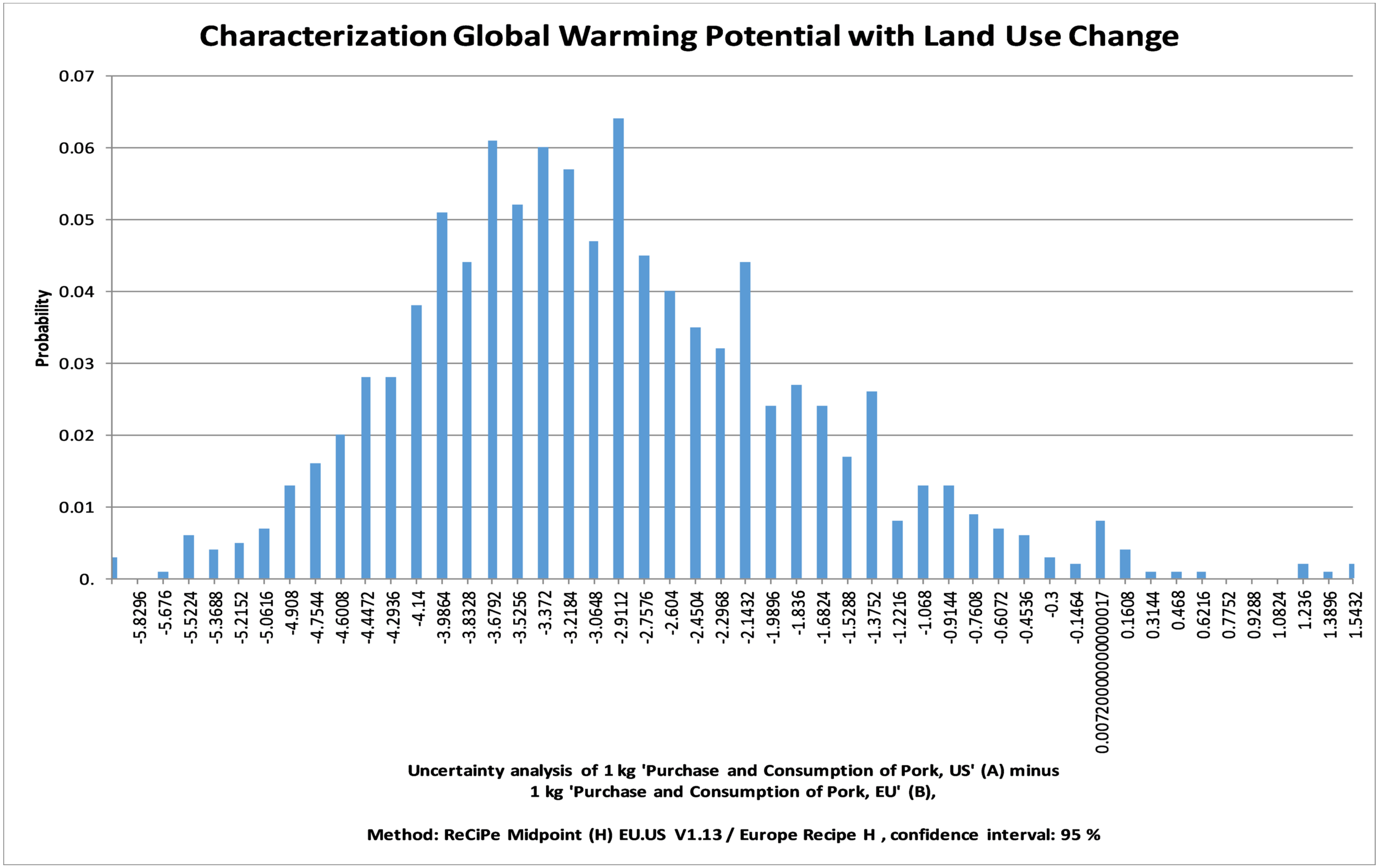

Figure 18: Probability distribution function for GWP with land use change from uncertainty analysis results

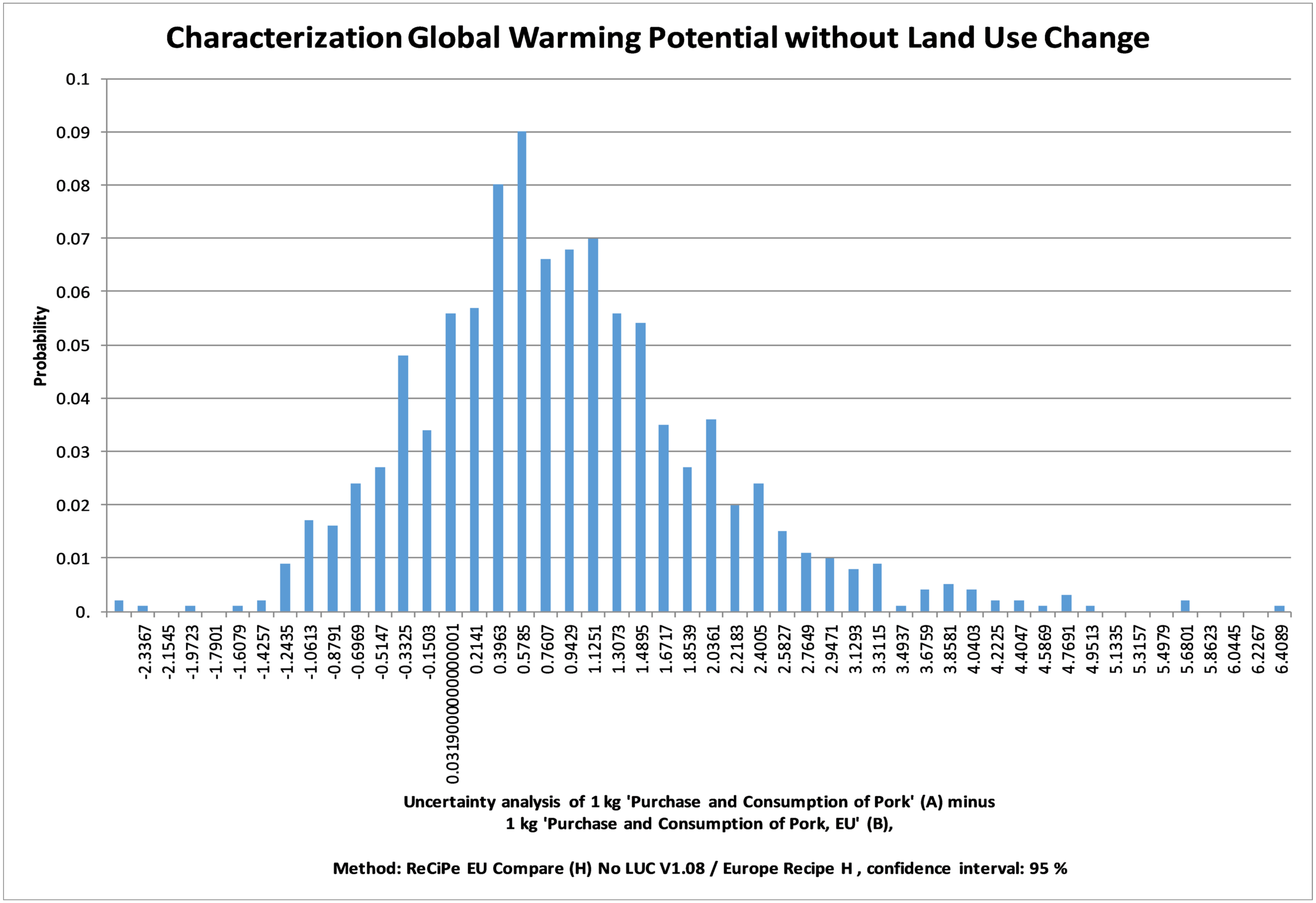

Figure 19: Probability distribution function for GWP without land use change from uncertainty analysis results

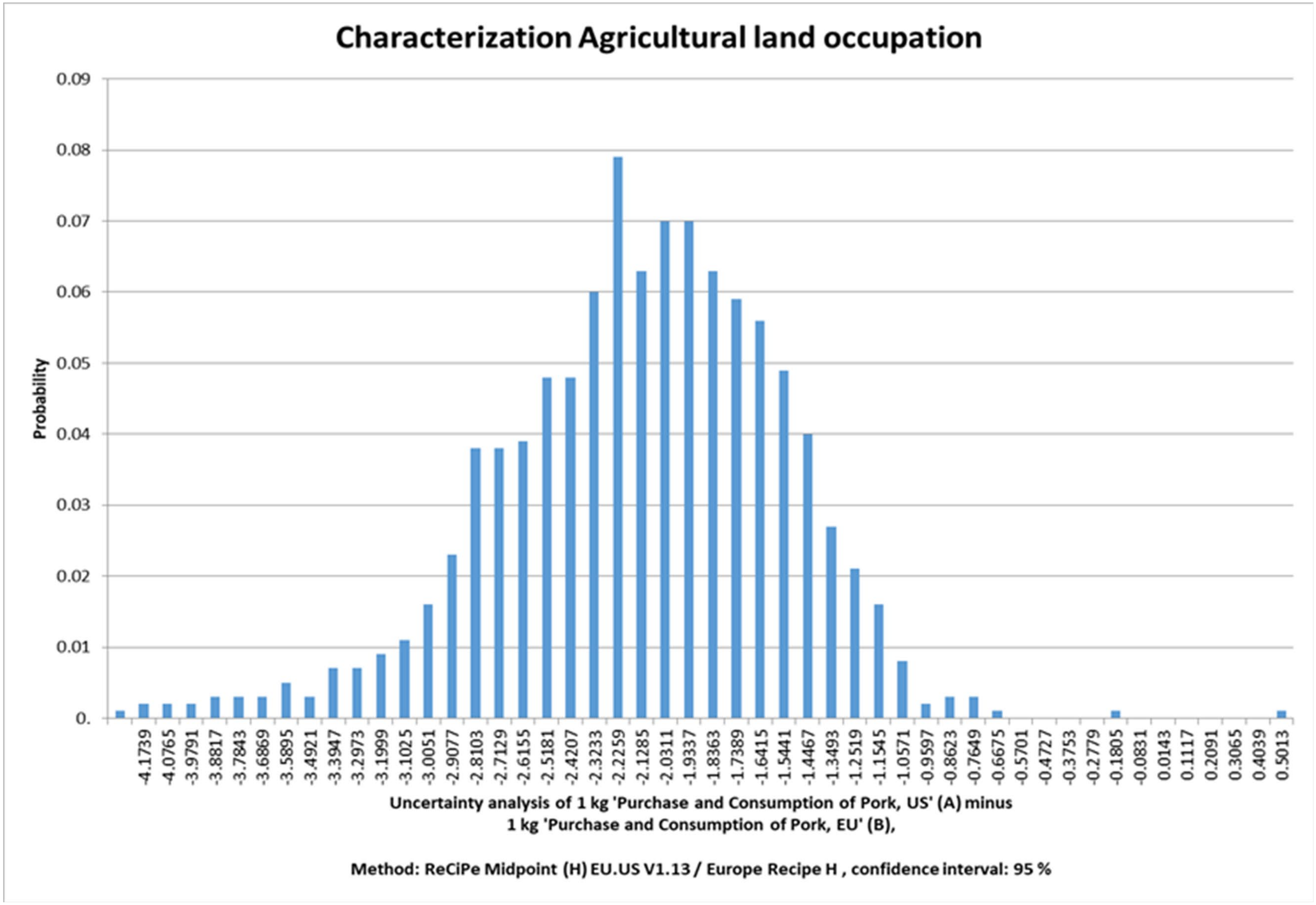

Figure 20: Probability distribution function for agricultural land occupation from uncertainty analysis results

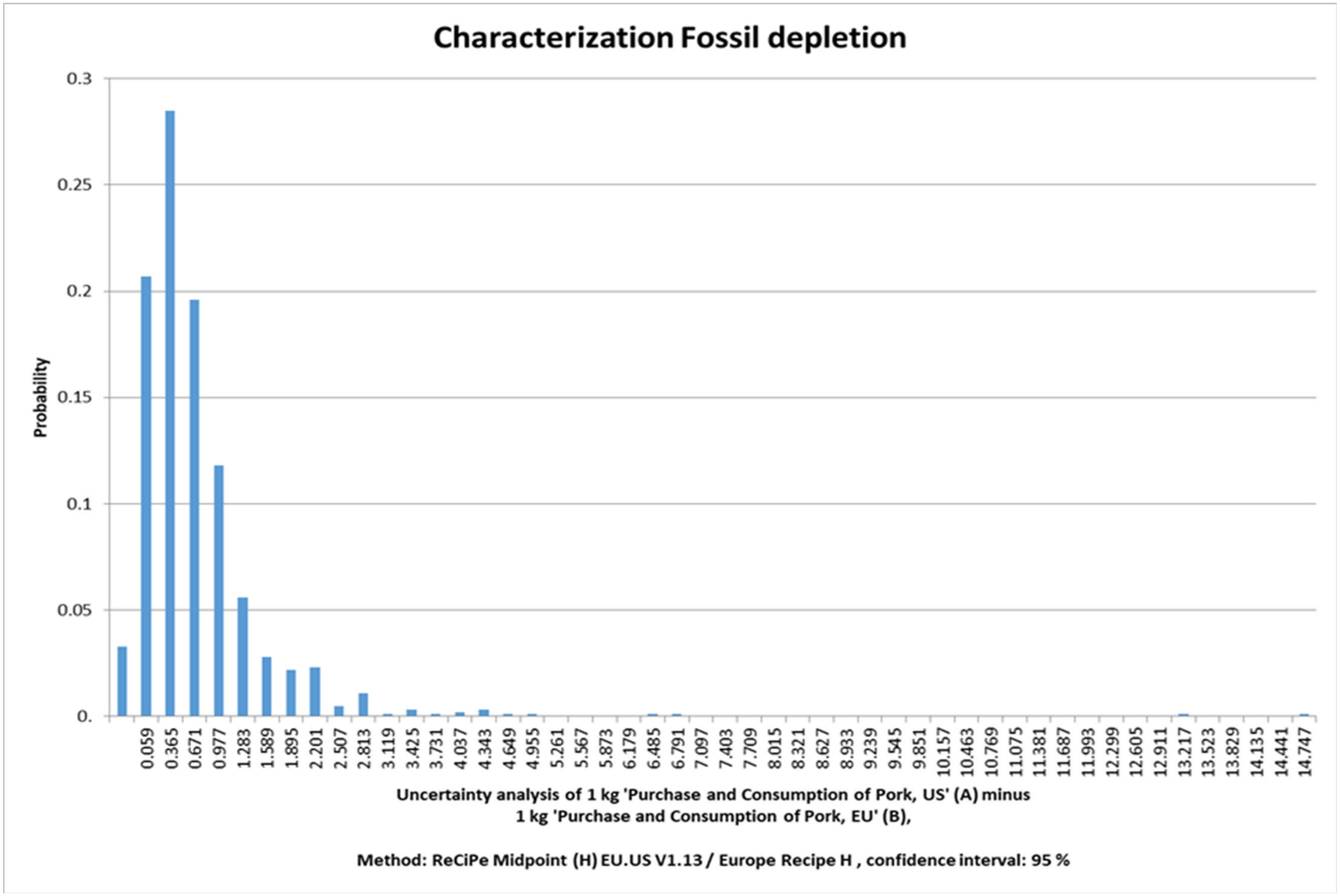

Figure 21: Probability distribution function for fossil fuel depletion from uncertainty analysis results

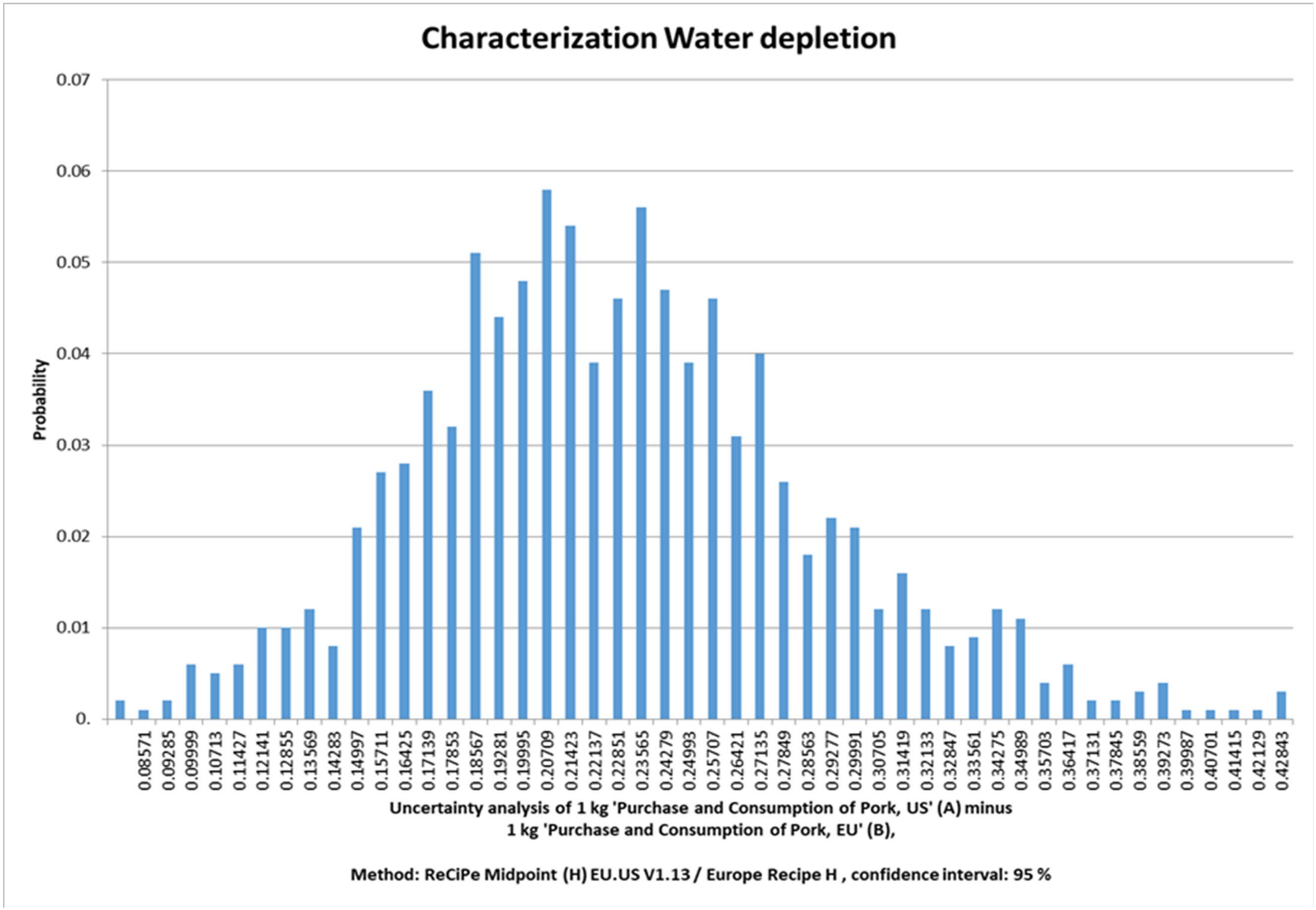

Figure 22: Probability distribution function for water consumption from uncertainty analysis results