Development of Life Cycle Inventory Data for U.S. Swine Production Scenarios

Dataset Documentation and User's Guide, Version 2

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1. INTRODUCTION

1.1. Project Background

The following document describes the development of life cycle inventory datasets for swine production practices in the United States for the USDA LCA Digital Commons. The swine production datasets are the product of ongoing work by the University of Arkansas Center for Agricultural and Rural Sustainability, the United States Department of Agriculture, and the National Pork Board. The following documentation describes the project background and nomenclature, in addition to a description of the dataset structure, individual unit processes, and production scenarios. Flow-level metadata descriptions for selected unit processes within the U.S. swine dataset can be found in the Appendix section.

1.2. Pork Production in the United States

The livestock sector competes for scarce resources, such as land, water, and energy, and has an impact on air, water and soil quality due to its emissions (de Vries and de Boer, 2010). The FAO reported that the animal agriculture sector accounts for 18% of global greenhouse gas emissions (Steinfeld et al., 2006). In the US, the EPA has estimated that the entire agricultural sector is responsible for approximately 5.8% of anthropogenic GHG emissions for the US (Pitesky et al., 2009). As a result, agricultural producers, including pork producers, and the general public are both aware of the importance of understanding the sustainability of the products they produce, purchase and consume.

On a global scale, pork accounts for approximately 40% of the world's meat production (FAO, 2011). Producing over 50 million metric tons (carcass weight equivalent) and over 50% of the world's pork production, China is by far the leading regional producer of pork by weight (USDA FAS, 2014). The European Union and United States come in second and third place with 20% and 10% of the world's pork production in 2014 (USDA FAS, 2014).

The number of pork producers has steadily decreased since the 1960s, while the total herd size has remained relatively constant, signifying a shift from small, frequently independent operations to larger, high throughput operations common in today's modern facilities (Stone et al. 2012). These larger, more concentrated operations have placed increased demands on local feedstuff production, water and energy resources, and manure handling processes. The meat production sector has been under increasing scrutiny and criticism from the consuming public due to perceived impacts of production on the environment. Partially in response to this public concern, there has been a movement within the US pork industry to quantify and continually reduce environmental impacts as part of sustainable agriculture efforts. One important aspect of this effort consists of reviewing the entire supply chain using life cycle assessment (LCA) modeling to quantify environmental impacts associated with the various stages of pork production. LCA modeling provides both industry and regulatory agencies a tool to identify and quantify 'hot spots' within the pork supply chain (Thoma et al., 2013a; 2011).

2. Methodology

2.1. Goal and Scope

The goal of this work was to provide pork producers and consumers with objective, science-based information on the environmental performance of various pork production practices in the United States. The scope of this work was a cradle-to-farm gate assessment with emphasis on the different management strategies used in the live swine housing and production phases.

2.2. Dataset Boundaries, Functional Unit, and Cutoff Criteria

The system boundaries encompassed the extraction of raw material and feed production through the live swine production facility processes to the farm gate (see Figure 1). The reference flow for the system is one market pig at the farm gate. The market weight of the pig is assumed to be 275 pounds. It should be noted that it is not appropriate for the user to assume different market weights when using this dataset.

2.3. Allocation Methods

Where co-products are produced, an allocation of burdens associated with the unit process is necessary. We evaluated allocation choices using the ISO hierarchy for allocation (ISO, 2014). The primary stage where allocation occurred was in byproducts generating in feed processing (e.g., distiller's grains and soy meal).

The ISO approach recommends system expansion as highest priority. For the allocation necessary in this project there exists a situation of joint production, where the relative quantities of, for example meal and oil, cannot be independently varied (beyond variation in the oil content of the seeds) which causes the allocation priority to be system expansion. In this analysis, system expansion would require identification of the economically marginal substitute products and ensure that quality LCI data exist. This was deemed out of the project scope, and we instead have adopted economic value allocation as the default (lowest of ISO hierarchy). However, because we have provided multi-output unit processes, the user can modify the allocation percentages.

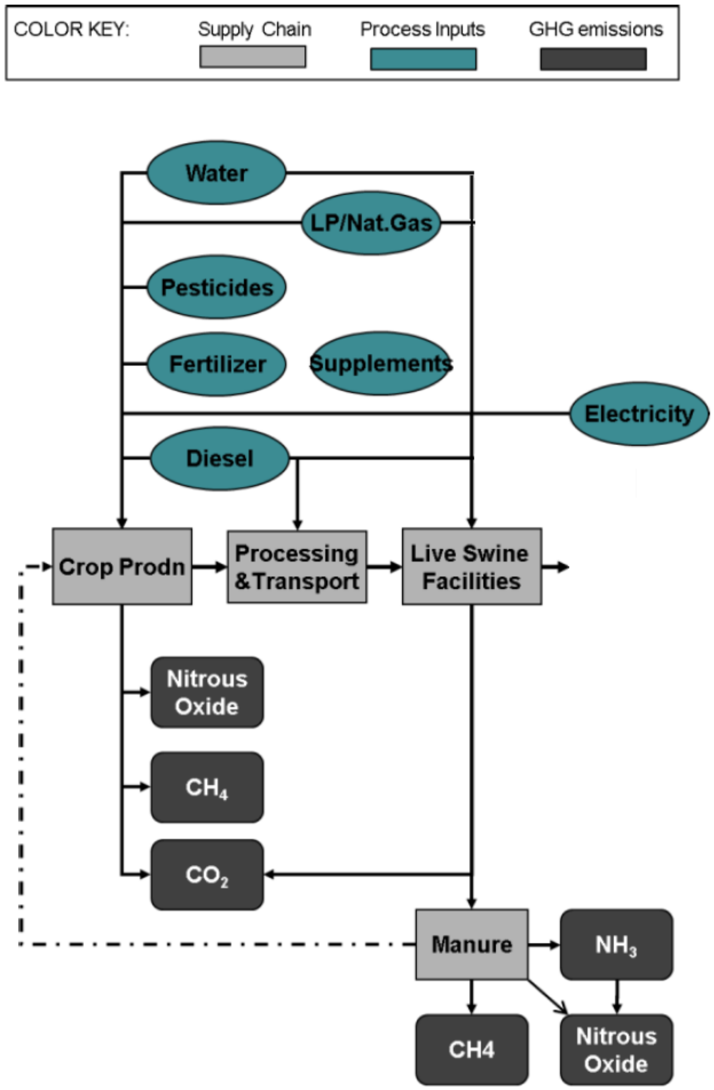

Figure 1. Schematic of pork production supply chain showing major inputs and outputs relating to CO_2 emissions. Adapted from Thoma et al. (2011).

2.4. Nomenclature and Naming Conventions

The U.S. swine life cycle inventory datasets were prepared following standard naming conventions for LCA data. Each reference flow within the dataset was designated with an International Standard Industrial Classification (ISIC) code (United Nations, 2014). Unit process titles were created following a standard naming convention that includes the product name, treatment, and, where appropriate, reference region.

2.5. Dataset Parameterization and Completeness

In its current form, the life cycle inventory dataset for U.S. swine production contains static flow values for each exchange, and is not parameterized. The core unit processes modeled for U.S. swine production are included in each dataset (see Section 3.2); however, upstream unit processes from external databases are used throughout the dataset. The third party datasets used in the life cycle inventory are described in more detail in Section 3.2.

2.6. Data Quality

Where available, recent data (less than 5-7 years old) was used in the model. Geographic relevance was emphasized during data collection, and a hierarchy of data acceptance criteria was imposed. This hierarchy consisted of—in order of importance—primary data available from pork producers and ongoing academic research and experimentation; peer-reviewed data published in scientific journals; internet sources; and data from industrial reports.

All data were checked for validity and consistency in unit conversions, and were checked in order to ensure that material flows balanced within the model. Where possible, background data were taken from the US-EI 2.2 and US LCI databases (EarthShift, 2014; NREL, 2015).

2.7. Scenario Selection

The production of swine in the US is distributed across several regions. In order to provide data for a range of production conditions, three individual datasets were prepared based on the regional scenario information shown in Table 1. Iowa and North Carolina were selected for inclusion due to the fact that they had the largest pig populations in the US. The state with the third highest production was Minnesota, but most of this production occurs in the southern half of the state in close proximity to Iowa. Illinois was selected as the third scenario in order to provide more regional variation. The three production regions considered (Regions 4, 5, and 7) represent 86% of production in the US (see Figure 2; USDA NASS, 2012).

Table 1. Regional scenarios for the U.S. swine production datasets. Life cycle inventory datasets were generated for each of the three locations representing the three principal swine production regions (see Figure 2).

State	County	Swine Production Region
Iowa	Hardin	Region 7
North Carolina	Duplin	Region 4
Illinois	Jasper	Region 5

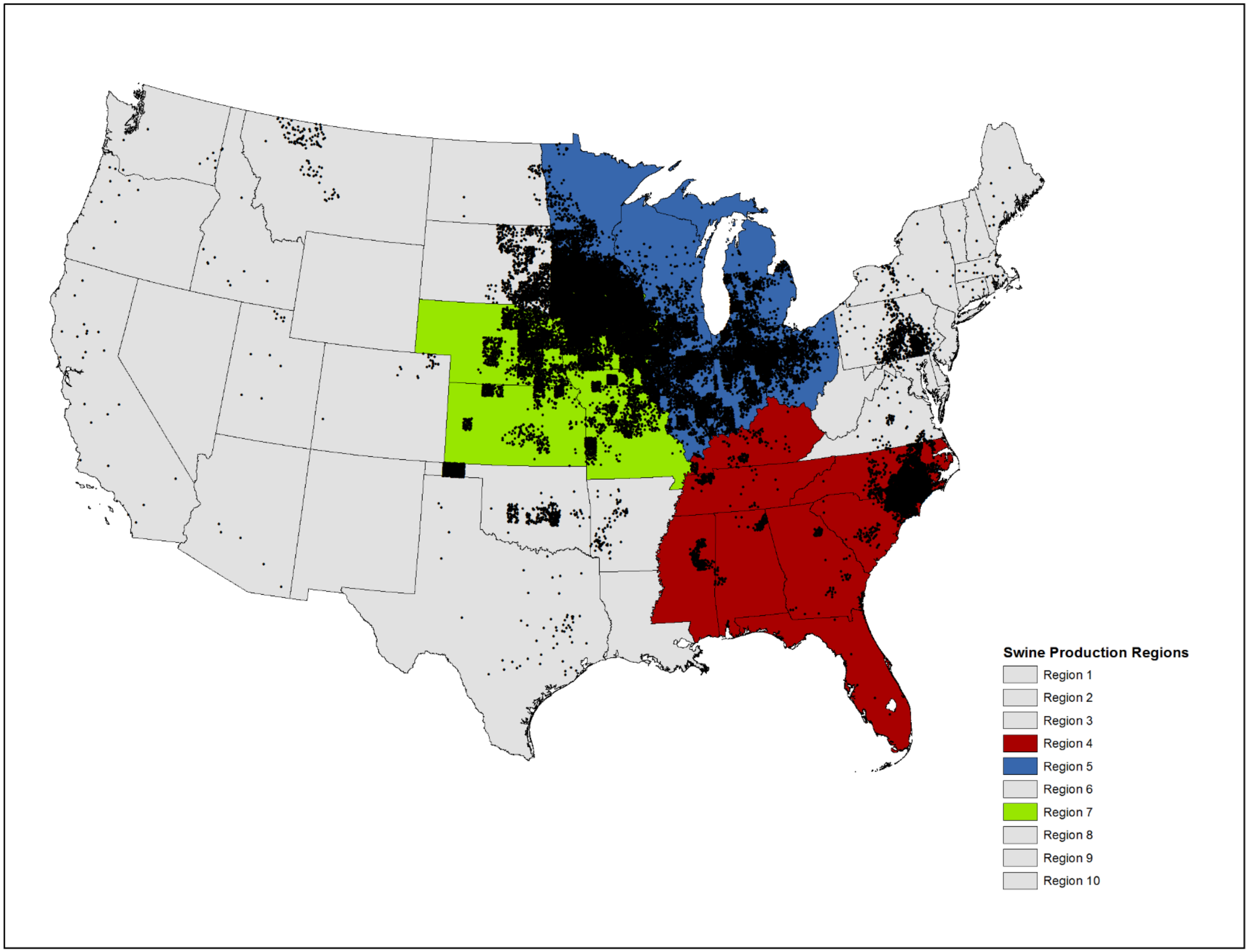

Figure 2. US production regions considered in this analysis. The black dots represent the density and distribution of pig production in each region (USDA NASS, 2012).

3. Life Cycle Inventory

3.1. Pig Production Environmental Calculator (PPEC)

The on-farm live swine production system that was modeled in this dataset consisted of three phases: the sow barn, nursery barn, and the grow/finish barn. In order to estimate the feed composition and consumption, water consumption, electricity and natural gas use, and manure handling associated with each barn, the Pig Production Environmental Calculator (PPEC) was used to simulate the production of pigs within each facility. The PPEC is a process model for swine production systems developed by the University of Arkansas Center for Agricultural and Rural Sustainability for the National Pork Board. Animal growth and performance, as a function of its ration and environmental parameters are simulated within the model using the recent NRC equations (National Research Council, 2012). The results of the PPEC simulations served as the basis for the life cycle inventory for each production scenario contained within this dataset.

3.1.a. Overview of the PPEC Process Model

The Pig Production Environmental Calculator (PPEC) uses mathematical relationships to simulate swine growth, feed intake and water consumption, electricity and natural gas use, manure handling, and greenhouse gas emissions during each production cycle. Within the calculator there are individual models that simulate the operation of sow, nursery and grow-finish barns. Process flow diagrams for each barn model are shown in Figures 3 through 5. In order to determine the inputs and emissions associated with the production of a market pig at the farm gate for each production scenario, the PPEC was used to simulate each barn as a separate and independent stage. The production parameters derived from the simulations were used as inputs to the lifecycle inventory model constructed using the SimaPro software program.

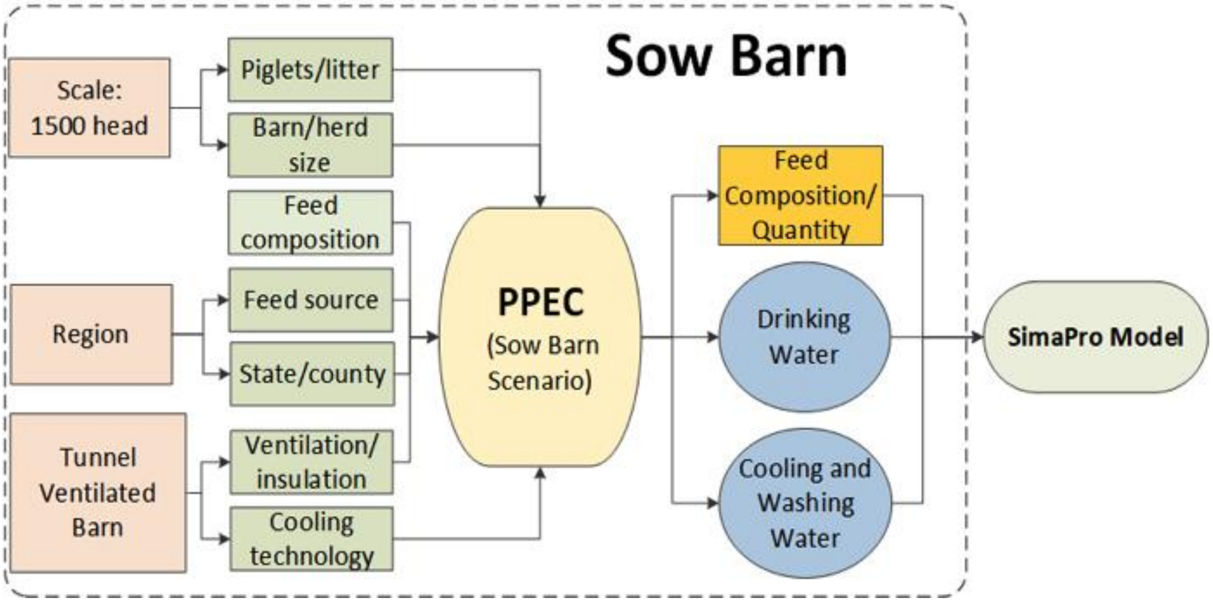

Figure 3. Process flow diagram for the PPEC sow barn model. Adapted from Matlock et al. (2014).

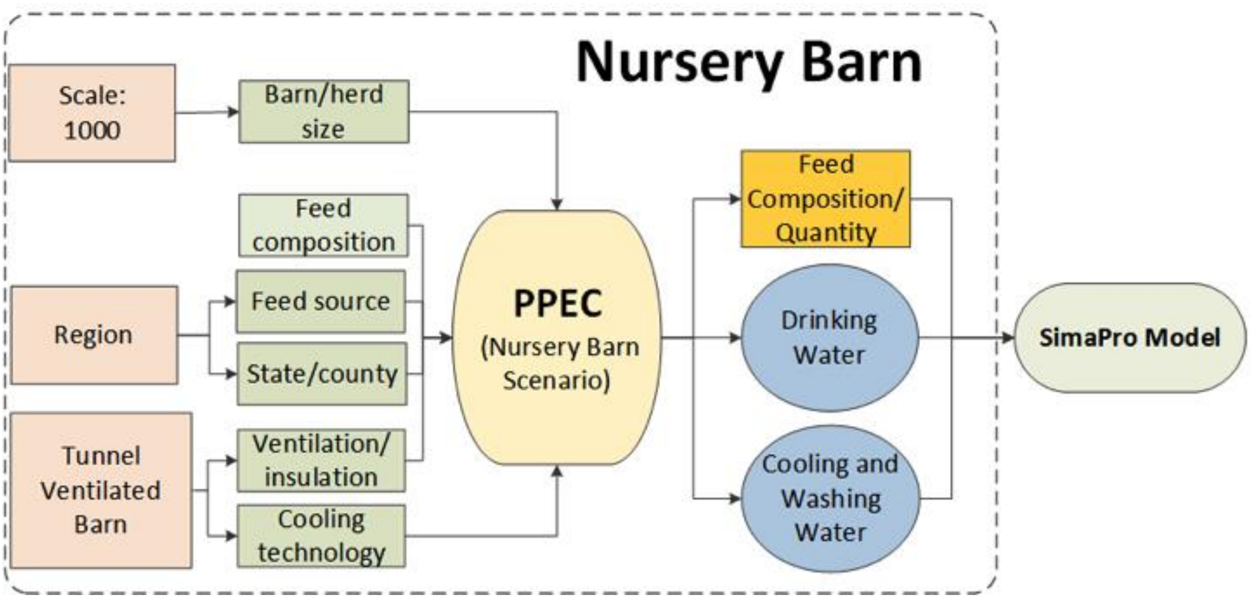

Figure 4. Process flow diagram for the PPEC nursery barn model. Adapted from Matlock et al. (2014).

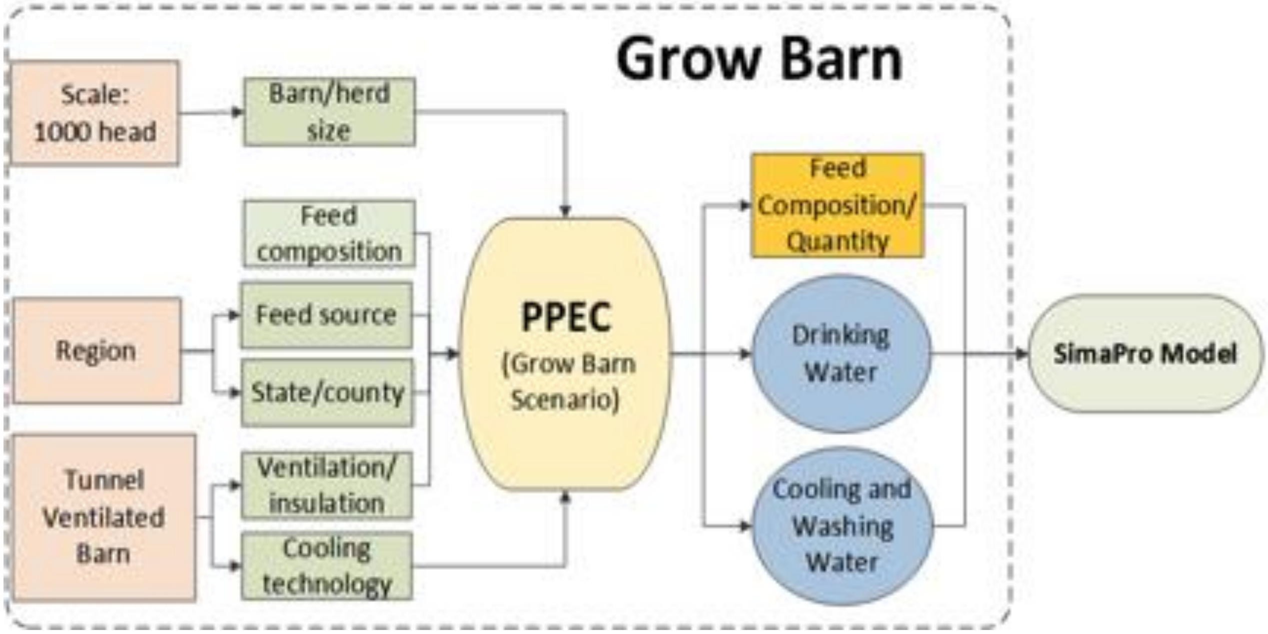

Figure 5. Process flow diagram for the PPEC grow barn model. Adapted from Matlock et al. (2014).

3.1.b. Inputs for the PPEC Process Model

The input values used for the sow, nursery, and grow barn simulations in each scenario are presented in Tables 2 and 3. The baseline input productivity parameters (e.g., live piglets per litter and mortality) for the US were the same across all of the production scenarios, and were derived from the Thoma et al. (2013) LCA on US pork production and from Hayes (2014). Heating and cooling was simulated based on barn location, which was assumed to be in the counties listed in Table 2. Climate data for these locations were used by the models to estimate barn heating and cooling loads.

Off-farm manure management was assumed for each scenario. This system involves the use of a deep pit for on-farm storage. This method of manure management utilizes subfloor pits to collect and store manure until removal for land application and does not require additional water. Deep pits are estimated to be most common method and account for over 40% of manure management systems (NASS Census, 2007; EPA, 2011).

In order to simulate the feed consumption for each barn in the process model, a multi-phase diet was defined for each production scenario. The multi-phase diet is a term used to describe the use of several diets in pig production in order to closely meet the pig nutrient requirements as their nutritional requirements change as they gain weight. The proposed feeding phases within the pig production stages for the US are: nursery (1 phase), grow (5 phases), and sow (2 phases). The multi-phase diet used in US pig production was provided by the nutritionist from the Department of Animal Science at the University of Arkansas, and can be found in Table 4 (Thoma et al., 2012; Thoma et al., 2013a).

Table 2. Sow barn input parameters for the Pig Production Environmental Calculator. These values were used in the PPEC for each of the three manure management scenarios used in this study. Data was obtained from Reckman et al. (2013) and Matlock et al. (2014).

Parameter	Sow Barn Input
Barn infrastructure	Tunnel Ventilated
Adult sows (# pigs)	1500
Gilts (gilts/year)	725
Avg. age gilt (days)	180
Culled sows (sows/year)	593
Sow deaths (pigs/year)	132
Mortality (%)	8.8%
Piglets per liter after weaning	10.48
Age piglets removed (days)	21
Barn area (ft^2/sow)	22
Heat source	Natural Gas
Outside temp to activate cooling cells (°F)	82
Outside temp to activate drip cooling (°F)	87
Drip cooling water (gal/sow space/hr)	0.77
Drinking water (gal/sow space/day)	6.4
Washing water (gal/pigspace/wash)	31.6

Table 3. Nursery and grow/finish barn input parameters for the Pig Production Environmental Calculator. Data were obtained from Reckman et al. (2013) and Matlock et al. (2014).

Parameter	Nursery Barn Inputs	Grow Barn Inputs
Barn infrastructure	Tunnel Ventilated	Tunnel Ventilated
Pigs in per cycle (# pigs)	1000	1000
Weight entering (lb)	13	40
Weight leaving (lb)	40	274
Pig death per cycle (# pigs/cycle)	39	50
Mortality (%)	3.9%	5%
Time to clean between cycles (days)	5	7
Barn area (ft^2/pig)	3	9.7
Heat source	Natural Gas	Natural Gas
Outside temp to activate cool cells (°F)	85	80
Outside temp to activate sprinkler (°F)	90	85
Sprinkler cooling water (gal/pigspace/hr)	0.1	0.1
Drinking water (gal/pig/day)	0.9	1.87
Washing water (gal/pigspace/wash)	3.17	7.41
Feed conversion ratio	1.53	2.76
Average daily gain (lb/day)	0.83	1.75
Lean Meat (%)	-	56.0

Table 4. Formulated multi-phase pig production diets for the United States (Thoma et al., 2012; Thoma et al., 2013a). These values were used in the Pig Production Environmental Calculator to estimate the mass of feed requirements in each swine production stage.

	Nursery Phase 1	Grow Phase 1	Grow Phase 2	Grow Phase 3	Grow Phase 4	Grow Phase 5	Sow Gestation	Sow Lactation
Feed Ingredient	United States							
Blood Plasma	2.0%	-	-	-	-	-	-	-
Calcium Phosphate (Dicalcium)	0.8%	1.2%	0.9%	0.6%	0.5%	1.0%	1.0%	1.8%
Copper Sulfate	0.1%	0.1%	0.1%	-	-	-	-	-
Corn DDG	7.9%	15.0%	15.0%	15.0%	15.0%	-	30.0%	10.0%
Corn, No. 2	39.6%	50.7%	56.3%	62.1%	68.6%	75.1%	56.0%	58.0%
DL-Methionine	0.2%	-	-	-	-	0.0%	-	-
Ethoxiquin (Quinguard)	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-	-
Fat (Darling, Yellow Grease)	-	2.3%	2.3%	2.4%	1.4%	2.0%	-	2.4%
Fat, Poultry	3.8%	-	-	-	-	-	-	-
Fish Meal, Combined	3.4%	-	-	-	-	-	-	-
Limestone, Ground	0.7%	0.9%	0.8%	0.7%	0.8%	0.7%	1.5%	1.1%
L-Lysine-HCl	0.3%	0.2%	0.2%	0.2%	0.2%	0.3%	-	0.1%
L-Threonine	0.1%	-	-	-	-	0.1%	-	-
Milk Whey Powder	16.1%	-	-	-	-	-	-	-
Paylean 9	-	-	-	-	-	0.0%	-	-
Salt	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Soybean Meal, 48%	23.3%	28.7%	23.6%	18.3%	12.9%	20.0%	10.4%	25.6%
Trace Mineral Premix (NB-8534)	0.2%	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.2%
Vitamin E (20,000 units)	0.4%	0.1%	0.1%	0.1%	0.0%	0.0%	-	-
Vitamin Premix (NB-6508)	0.3%	0.2%	0.2%	0.2%	0.1%	0.2%	0.3%	0.3%
Zinc Oxide, 72% Zn	0.4%	-	-	-	-	-	0.3%	0.3%

3.2. Life Cycle Inventory Datasets

After the PPEC was used to simulate production under each scenario, the estimated values for feed composition and intake, water consumption, electricity and natural gas use, manure handling, and greenhouse gas emissions were used to populate an LCI dataset for each scenario. The LCI model was constructed using the developer version of SimaPro software package (Pre, 2014), and the integration process is shown in Figure 6.

3.2.a. Swine Production Unit Processes

The primary swine production unit processes resulting in the production of a market pig, at farm are shown in Figure 7. Flow-level metadata documentation for select unit processes can be found in the Appendix. Upstream unit process data for the pork production dataset were obtained from the US-EI, US LCI, and Agri-footprint databases (EarthShift, 2014; NREL, 2015; Agri-footprint, 2014). The structure of the swine LCI dataset was largely adopted from our past swine LCAs, and is documented in Thoma et al. (2011), Thoma et al. (2013a), and Matlock et al. (2014). The US-EI database is based on the eco-invent database (ecoinvent, 2014), but has been adapted for the US energy system. The majority of upstream unit processes used in this model that are not included in the swine dataset were obtained from US-EI 2.2. Exceptions include unit processes for transportation, electricity, and natural gas (obtained from US LCI) and processes for the production of soy from Brazil (obtained from Agri-footprint) (NREL, 2015; Agri-footprint, 2014).

For upstream unit processes, evaporative losses from cooling water use were considered to be negligible. Pork produced from sow culling was estimated to decrease overall impacts by approximately 3% and would approximately affect all of the analyzed regions equally. In this model, sow meat was not included in order to focus results on the higher-value finish market animals.

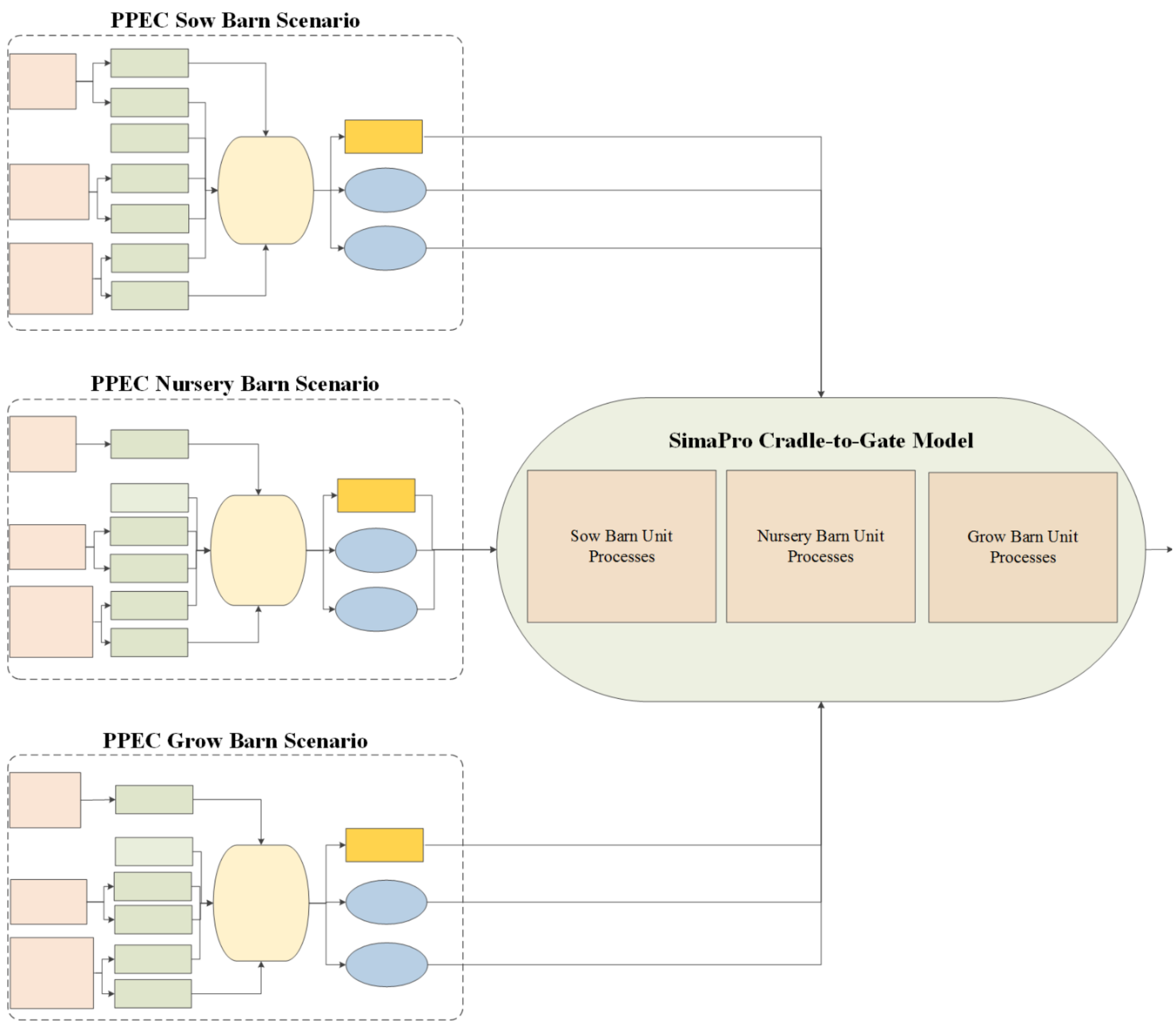

Figure 6. Process flow diagram showing linkages between the Pig Production Environmental Calculator (PPEC) outputs and the swine life cycle inventory dataset in SimaPro. Adapted from Matlock et al. (2014).

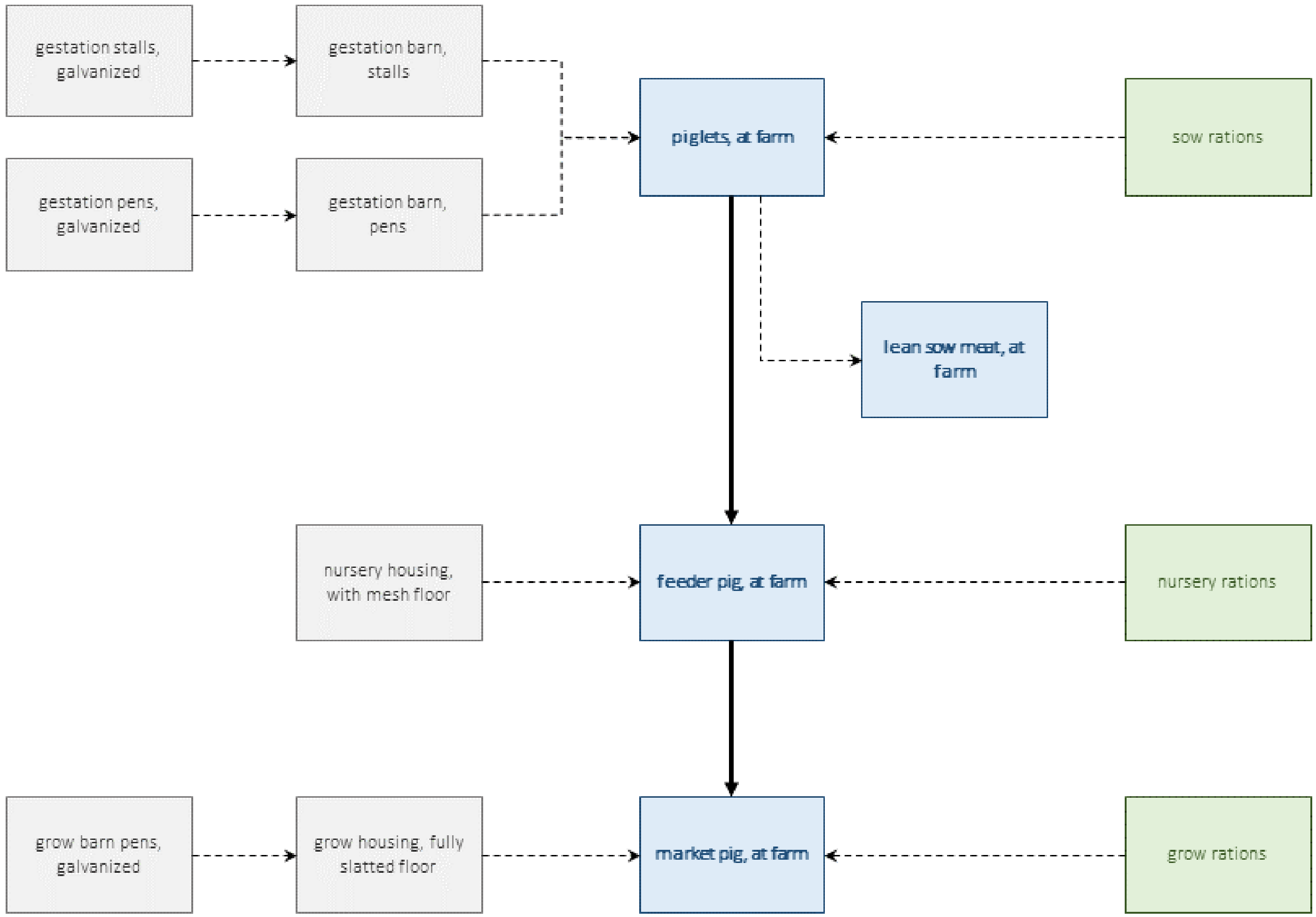

Figure 7. Flow diagram of the primary unit processes in the U.S. swine production datasets. This unit process structure is largely the same for each production scenario. Actual unit process names within the datasets vary by scenario. Additional infrastructure processes for the production of nails, aluminum siding, and plastic sheeting are included in the dataset but are not shown here.

3.2.b. Upstream Unit Processes for Rations Ingredients

Upstream unit processes for the production of swine ration ingredients were developed by the University of Arkansas and are included in this dataset. The amounts of each ration ingredient required for each swine production phase were simulated by the PPEC (see Section 3.1). The primary feed ingredients used in the unit processes for feed rations were corn and soybean meal. The production of corn and soy in the United States was modeled using a five region approach developed by the University of Arkansas for an LCA of US dairy production (Thoma et al., 2013b). The five regions used to model corn and soy production are shown in Figure 8. These regions are aggregated within the dataset to model corn and soybean meal production within the 10 region framework used for the production of US swine (see Figure 2). The dependencies and linkages for the ration unit processes for corn, soy, and other feed additives are shown in greater detail in Figure 9.

Based on import/export data, it was assumed that 20% of the soy used in US swine rations was sourced from Brazilian producers. This was the average percentage of soybean imports from Brazil, as a fraction of the annual soybean production, to the Wilmington North Carolina port from 2011 through 2014 (see Table 5).

Table 5. Brazilian soybean imports for the state of North Carolina for the years 2011 through 2014 (US Census Bureau, 2014).

Year	Brazilian Soybeans (% of annual production)
2014	16%
2013	22%
2012	17%
2011	26%

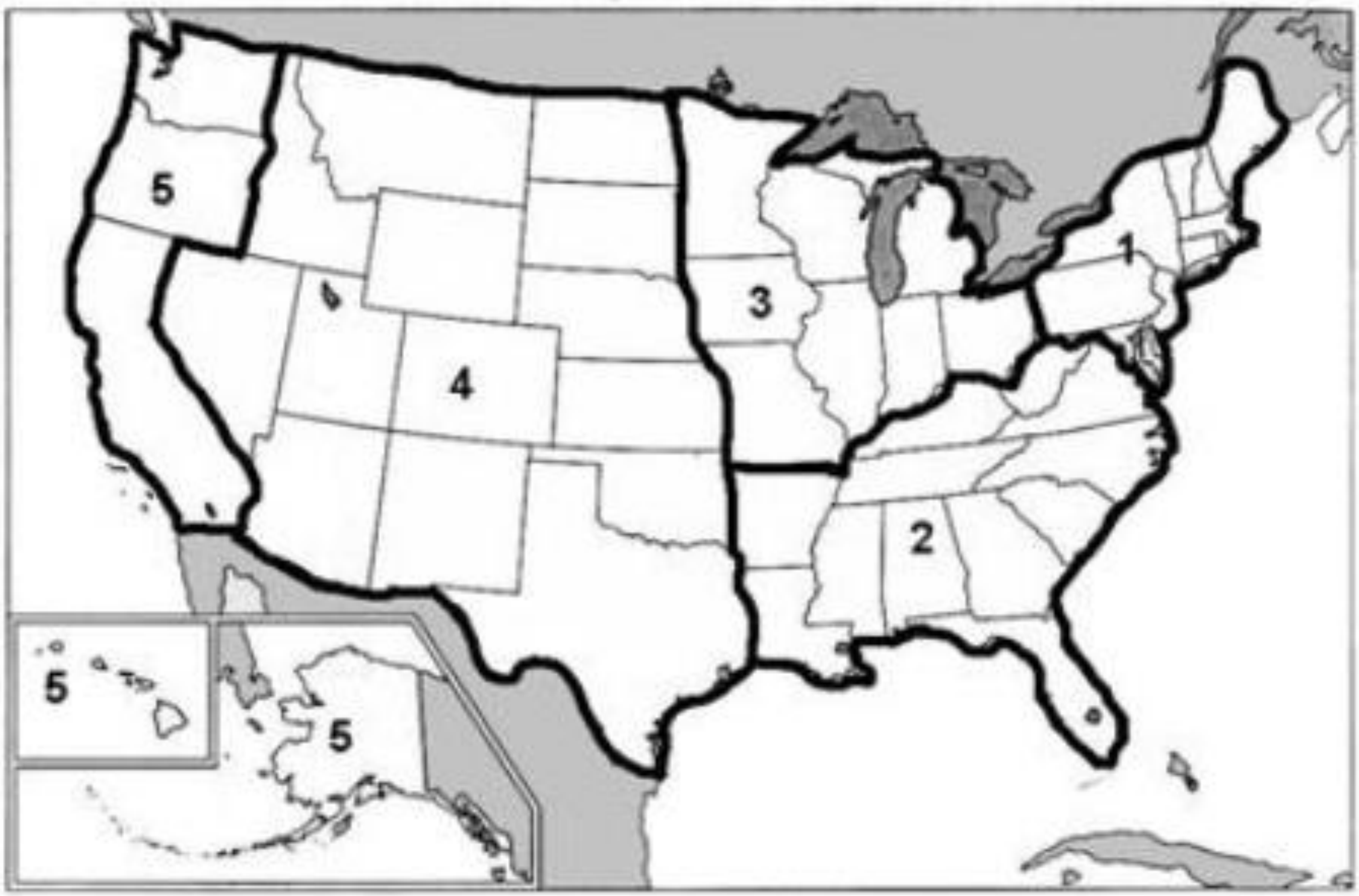

Figure 8. Feed production regions used to model the production of corn and soy for use in swine feed.

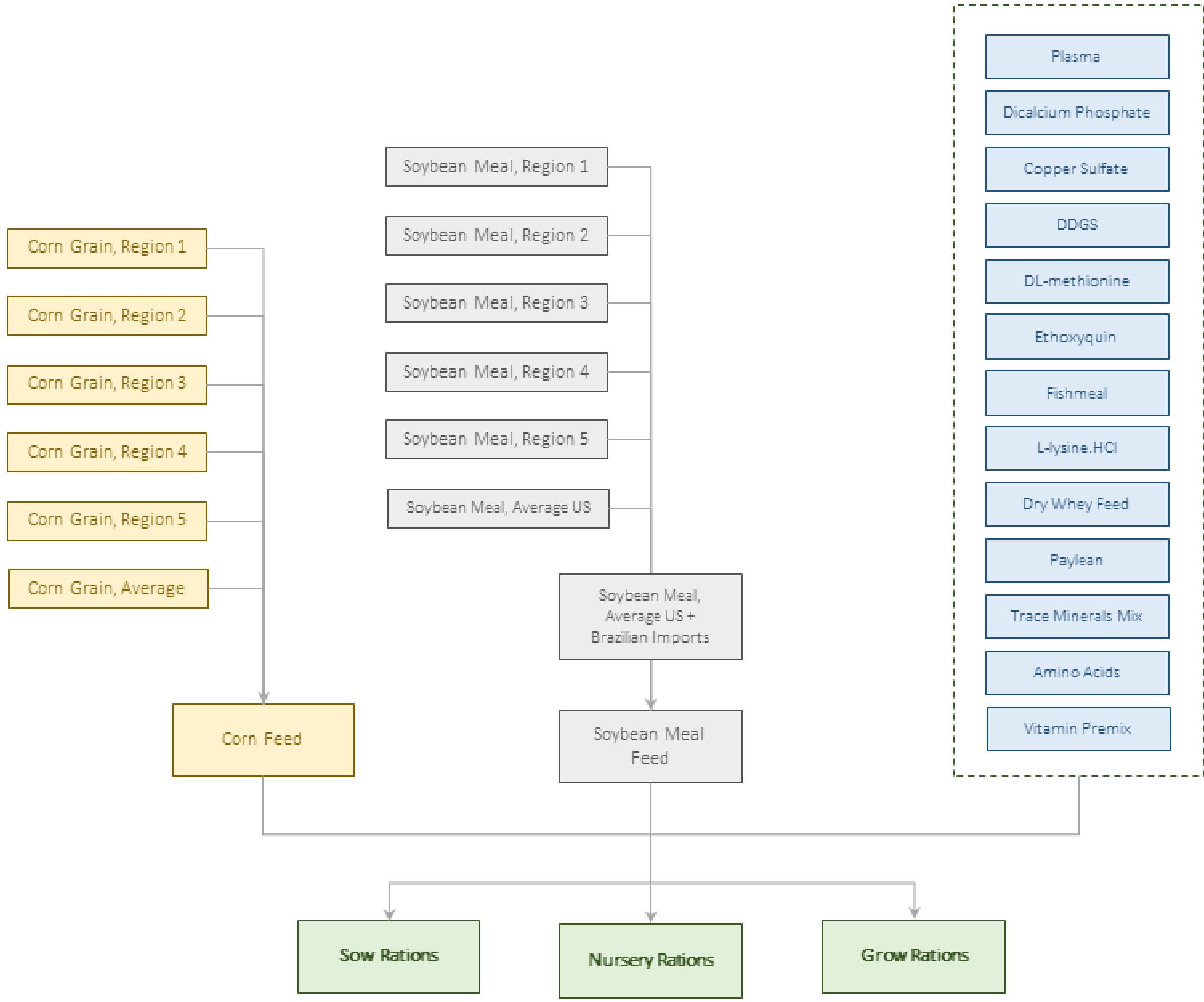

Figure 9. Flow diagram of the primary unit processes in the U.S. swine production datasets. This unit process structure is largely the same for each production scenario database submitted to the Digital Commons. Actual unit process names within the datasets.

4. Submission Preparation in OpenLCA

While the original swine production life cycle inventory datasets were assembled in SimaPro, they were exported to OpenLCA for documentation and submission to the LCA Digital Commons. In the OpenLCA platform, metadata was added to each unit process in each scenario. The metadata schema used in this dataset, which is common to the LCA Digital Commons, is shown in Table 6. After the dataset documentation was completed, the unit processes in each scenario were exported in the ILCD file format (ILCD, 2014) for submission and review by the LCA Digital Commons.

5. Next Steps

In subsequent submissions to the LCA Digital Commons, the University of Arkansas project team plans to expand the integration of the process model-based Pig Production Environmental Calculator with existing LCA platforms in order to give the user the ability to modify individual production parameters. While the current datasets represent a range of production practices and feed sources, increased parameterization will give the practitioner more freedom to create user-defined production scenarios.

In addition, the project team plans to migrate the upstream unit processes for feed production to the field crop production dataset now available for download on the Digital Commons website.

6. Acknowledgements

The authors would like to acknowledge the support of Alan Stokes and the National Pork Board by providing funding, guidance, and review of the University of Arkansas' ongoing swine research.

Table 6. Example metadata schema for U.S. pork production life cycle inventory datasets. This schema is based on the OpenLCA metadata fields, and is used by the LCA Digital Commons (USDA NAL, 2014).

Metadata Field	Example Description
General Information	
Name	market pig; at farm; deep pit; US-IA
Description	This unit process represents the production of one market pig in the specified state. This process includes flows for the material inputs and environmental emissions associated with swine production, at farm. The applicable classification is ISIC 0145.
Time	
Start Date	2014
End Date	2014
Comment	-
Geography	
Location	US-IA
Geography Comment	
Technology	
Description	This unit process dataset represents the production of one market pig in a grow/finish barn using a deep pit to off-farm manure management system, and feed sourced from within the production region specified.
Administrative Information	
Intended application	This dataset is intended for use in any life cycle assessment of a relevant material or service.
Data set owner	
Data generator	University of Arkansas Center for Agricultural and Rural Sustainability
Data documentor	Heather Sandefur
Publication	Development of Life Cycle Inventory Data for U.S. Agriculture at Multiple Scales: Documentation for LCI Dataset on U.S. Swine Production
Access and use restrictions	None
Project	Data were prepared by the University of Arkansas Center for Agricultural and Rural Sustainability for the United States Department of Agriculture National Agriculture Library. This project was supported in part by the National Pork Board.
Version	2
Creation Date	10/26/2014
Last Change	12/5/2014
Modeling and validation	
Process type	Unit Process
LCI method	Life cycle inventory was originally assembled using the SimaPro software platform and was modified for submission using the OpenLCA platform.
Modeling constants	

Data completeness	Includes upstream US-EI 2.2 and USLCI unit processes for the production of electricity, natural gas, and transport, in addition to upstream processes from within this dataset. Unit processes for pig cooling water, drinking water, and wash water are not included, and are designated as 'CUTOFF'.
Data selection	This is a cradle-to-gate process for the production of market pigs.
Data treatment	The market weight of the pig is assumed to be 275 pounds. It should be noted that it is not appropriate for the user to assume different market weights when using this dataset. The LCI data for the production of a market pig in a grow/finish barn were obtained from the University of Arkansas Pig Production Environmental Calculator (PPEC). The PPEC uses mathematical relationships to simulate swine growth, feed intake and water consumption, electricity and natural gas use, manure handling, and greenhouse gas emissions during each production cycle, which includes sow, nursery, and grow barns.
Data source information	
Sampling Procedure	Flow values used in this project dataset were obtained from a variety of sources, including the 2007 NASS Census of Agriculture and process model simulations of the pig production process (see supporting documentation).
Data collection period	Data for this project was collected from 2007 to 2014. Unit process data were compiled in 2014.

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APPENDIX: FLOW-LEVEL METADATA COMMENTS FOR SELECT UNIT PROCESSES

Table 7. Flow-level comments for example piglet unit process (piglets; at farm; lagoon; region 2).

Flow Names	Units	Comment
Products		
piglets; at farm; lagoon; region 1	p	-
lean sow meat; at farm; lagoon; region 1	kg	-
Materials/fuels		
replacement gilt (pigs); at farm	p	Number of gilts delivered per year
sow rations; mix with additives; region 1	p	-
CUTOFF sow cooling water	kg	Water used in cooling cells, kg/yr
CUTOFF sow cooling water	kg	Water used in drip or sprinkle cooling, kg/yr
CUTOFF sow drinking water	kg	Water consumed by pigs, kg/yr
CUTOFF sow wash water	kg	Wash water, kg/yr
Transport, lorry >28t, fleet average/CH WITH US ELECTRICITY U	tkm	Feed delivery, tkm
Electricity, at grid, Texas US NREL /US	kWh	Electricity to lights, kWhr/yr
Transport, single unit truck, diesel powered NREL /US	tkm	Gilt delivery, tkm
Electricity, at grid, US NREL /US	kWh	Electricity to fans, kWhr/yr
Electricity, at grid, US NREL /US	kWh	Electricity to piglets heaters, kWhr/yr
Slurry spreading, by vacuum tanker/CH WITH US ELECTRICITY U	m3	Total volume of manure to be land applied, cu.m/yr
Natural gas, combusted in industrial equipment NREL /RNA	m3	Natural gas for heaters, cu.m/yr
gestation barn (pigs); tunnel ventilated; stalls with fully-slatted floors	p	10 year assumed life; barn holds 120 animals as designed per cycle
gestation barn (pigs); tunnel ventilated; pens with fully-slatted floors	p	-
dead animal management (pigs); average mix; disposal at farm	kg	-
Emissions to air		
Methane (low population)	kg	CH4 emissions from barn manure system and outside manure system, kg/yr
Nitrous oxide (low population)	kg	N2O emissions per year from barn manure system and output manure system, kg/yr

Table 8. Flow-level comments for example feeder pig unit process (feeder pig; at farm; lagoon storage; region 1).

Flow Names	Units	Comment
Products		
feeder pig; at farm; lagoon storage; region 1	p	-
Materials/fuels		
piglets; at farm; lagoon; region 1	p	Number of pig entering per year
nursery rations; mix with additives; region 1	p	-
CUTOFF nursery cooling water	kg	Water used in cooling cells, kg/yr
CUTOFF nursery cooling water	kg	Water used in drip or sprinkle cooling, kg/yr
CUTOFF nursery drinking water	kg	Water consumed by pigs, kg/yr
CUTOFF nursery wash water	kg	Wash water, kg/yr
Electricity, at grid, US NREL /US	kWh	Electricity to fans, kWhr/yr
Electricity, at grid, US NREL /US	kWh	Electricity to lights, kWhr/yr
Natural gas, combusted in industrial equipment NREL /RNA	m3	Natural gas for heaters, cu.m/yr
Slurry spreading, by vacuum tanker/CH WITH US ELECTRICITY U	m3	Total volume of manure to be land applied, cu.m/yr
Transport, lorry >28t, fleet average/CH WITH US ELECTRICITY U	tkm	Diesel for feed delivery, kg/yr
nursery barn (pigs); tunnel ventilated; mesh floor	p	-
dead animal management (pigs); average mix; disposal at farm	kg	Total weight of dead animals, kg/yr
Emissions to air		
Methane (low population)	kg	CH4 emissions from barn manure system and outside manure system, kg/yr
Nitrous oxide (low population)	kg	N2O emissions from barn manure system and outside manure system, kg/yr

Table 9. Flow-level comments for example market pig unit process (market pig; at farm; lagoon; region 1).

Flow Names	Units	Comment
Products		
market pig; at farm; lagoon; region 1	p	-
Materials/fuels		
feeder pig; at farm; lagoon storage; region 1	p	Number of pigs entering per year
grow rations; mix with additives; region 1	p	-
CUTOFF grow cooling water	kg	Water used in cooling cells, kg/yr
CUTOFF grow cooling water	kg	Water used in drip or sprinkle cooling, kg/yr
CUTOFF grow drinking water	kg	Water consumed by pigs, kg/yr
CUTOFF grow wash water	kg	Wash water, kg/yr
Electricity, at grid, US NREL /US	kWh	Electricity to fans, kWhr/yr
Electricity, at grid, US NREL /US	kWh	Electricity to lights, kWhr/yr
Natural gas, combusted in industrial equipment NREL /RNA	m3	Natural gas for heaters, cu.m/yr
Slurry spreading, by vacuum tanker/CH WITH US ELECTRICITY U	m3	Total volume of manure to be land applied, cu.m/yr
Transport, lorry >28t, fleet average/CH WITH US ELECTRICITY U	tkm	Diesel used for feed delivery, kg/yr
grow barn (pigs); tunnel ventilated; fully slatted floor	p	assuming 50 year life of barn
dead animal management (pigs); average mix; disposal at farm	kg	Total weight of dead animals, kg/yr
Emissions to air		
Methane (low population)	kg	CH4 emissions from barn manure system and outside manure system, kg/yr
Nitrous oxide (low population)	kg	N2O emissions from barn manure system and outside manure system, kg/yr

Table 10. Flow-level comments for dead animal management unit process (dead animal management (pigs); average mix; disposal at farm).

Flow Names	Units	Comment
Products		
dead animal management (pigs); average mix; disposal at farm	kg	-
Materials/fuels		
Quicklime, milled, packed, at plant/CH WITH US ELECTRICITY U	kg	For burial, carcass
Diesel, burned in chopper/RER WITH US ELECTRICITY U	MJ	For composting, carcass
Heavy fuel oil, burned in refinery furnace/kg/CH WITH US ELECTRICITY U	kg	For incineration, carcass
Industrial residual wood chopping, stationary electric chopper, at plant/RER WITH US ELECTRICITY U	ton	For rendering, carcass
Steam, for chemical processes, at plant/RER WITH US ELECTRICITY U	ton	For rendering, carcass
Electricity, medium voltage, at grid/US WITH US ELECTRICITY U	kWh	For rendering, carcass
Emissions to air		
Dinitrogen monoxide (low population)	ton	For composting, carcass