Joel Tallaksen

West Central Research and Outreach Center

University of Minnesota

Version 1.1

Summary Activity 3 of LCCMR Project FY14 122E: Life Cycle Assessment of Swine Production

2013-2017

Table of Contents

Funding Acknowledgment

LCCMR-This project was supported by The Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative - Citizen Commission on Minnesota Resources (LCCMR) Project #: FY 2014 - 122E Michael Reese Project Manager.

The Trust Fund is a permanent fund constitutionally established by the citizens of Minnesota to assist in the protection, conservation, preservation, and enhancement of the state's air, water, land, fish, wildlife, and other natural resources. Currently 40% of net Minnesota State Lottery proceeds are dedicated to growing the Trust Fund and ensuring future benefits for Minnesota's environment and natural resources.

Disclaimer

All data, models, and predictions contained in this report are solely works of the authors. Neither the University of Minnesota nor the funding agency(ies) have reviewed these statements for accuracy or completeness. For comments or questions, please contact the author.

LCA Subsection Author:

Dr. Joel Tallaksen, Research Scientist, University of Minnesota

1 Introduction

Over the last decade, a prevailing trend in agriculture research and marketing is to examine the sustainability of agricultural products and the commodities used to make them. On the producer's part, these concerns are centered on avoiding the excess use of fossil energy and other costly resources. From the marketing standpoint, there is more demand from consumers and regulators for products that use less natural resources or have less impacts on the environment. This can be seen in press releases from companies such as McDonald's and Wal-Mart, which are adding environmental reporting requirements for their suppliers and for the products they purchase from those suppliers.

Although many companies have greatly improved the sustainability of their manufactured food products, they have done so mostly by making the changes that they can make at their manufacturing, packaging, and retail facilities. At their core, these products are agricultural products and are produced on farms across the country. Therefore, these companies need to drive changes in farming practices in order to continue to improve the sustainability of their products.

In terms of agricultural production, sustainability can have many different meanings. It can include factors such as animal welfare, environmental impacts, and social impacts. Many of the sustainability policies that companies are implementing are centered on environmental impacts of product production. Depending on the product and location, this can include issues like air, water, and soil pollution or other factors such as energy use or global warming potential. Probably the largest measure of sustainability in manufacturing is global warming potential. Global warming potential (GWP) is a measure of how much a product or process impacts global climate change and is usually expressed as the amount of carbon dioxide emitted by making a product. When a company states that their product is carbon neutral or has a low carbon footprint, it refers to a product that emits no or little carbon dioxide during its production, meaning it has zero or low GWP.

In a 2012 study by Thoma et al, swine production was found to have a GWP of 2.48 lbs of CO_2 equivalents per 4 ounce pork delivered to the consumer. Although a percentage of this was from energy used in meatpacking, packaging, and retail areas of the pork supply chain, the initial production of hogs on the farm was approximately 63% of the overall GWP. Thoma's study looked at swine production using a very high level national analysis of the swine supply chain. Unfortunately, this information is difficult to use for targeted improvements at the farm level. In addition, the study didn't report energy use for the swine system.

The work in this study was conducted to identify areas where farm operations could be changed to improve the downstream sustainability of the pork supply chain. In order to engage more pork producers at the farm level, a key focus was on areas where sustainability improvements would improve swine production economics. Therefore, much of the work looked at energy use in the swine production system. A typical Midwestern swine production system uses fossil-based electricity for ventilation and heating, natural gas for heating and hot water, and diesel fuel for tractor and vehicle use. Energy is a significant cost in swine production and has a notable impact on the global warming potential of swine farms. Additionally, indirect energy used to grow feed ingredients greatly increases the overall GWP of pork.

The study employed lifecycle assessment (LCA) methodology to track resource inputs and outputs of the system and to analyze the amount of fossil energy used by and carbon dioxide (GWP) emitted during the swine production cycle. The specific goal of the work was to develop a model for understanding how energy use and greenhouse gas emissions could be reduced using energy conservation techniques or the addition of renewable electricity. To get a broader sampling of data, energy use information from commercial operations was compiled and analyzed alongside energy consumption data from the University of Minnesota, West Central Research and Outreach Center (WCROC) swine research system. In addition to examining the amount of energy consumed in pork production systems, the analysis looked at energy use for production of swine feed ingredients.

Alternative scenarios were modeled to explore changes to both the University's research system and commercial operations to identify areas of high energy use and high impact that could be altered to reduce energy expenses and improve sustainability. Specifically, the model was also used to examine the impacts of solar PV electricity on both the commercial and University swine production systems.

2 Methods

The LCA methodology used in this study is essentially an organized method of tracking inputs and outputs of the swine production system and assigning impacts to them. In addition to energy data, cropping system data was used from the WCROC research farm. This model was designed as a 'Swine Stage Centric' model, where individual stages correspond to discrete parts of the animal production systems and which are linked to the specific inputs and outputs at each of the growth stages. This makes it easily to change the model based on different animal management assumptions, different inputs, or different scenarios being modeled. For example, the question could be asked, "what is the impact on global warming potential of a 5% reduction in protein content for grow-finish hogs if it adds 5 days to that stage of growth"? This results can easily be calculated by changing a few variables for the diet and number of days in the grow-finish stage.

Current commercial swine production practices have animal production spread among different farm types based on animal growth stage. Most hogs are born on one farm (farrowing), moved to a second farm to be raised to roughly 75 pounds (nursery), then moved to a final farm where they are raised to market weight at around 275 pounds (grow-finishing). Breeding stock may also be raised on a totally separate farms or be part of the farrowing operation.

2.1 Life Cycle Assessment

The LCA work done for this project was conducted using ISO 14000 standard methodology as a general guide. SimaPro (7.2) software was used for modeling swine systems and calculating result data. Background databases used in conjunction with the SimaPro work included Ecoinvent (2.0), US LCI, and Agri-footprint. For global warming calculations, GWP 100a (IPCC 2013) was used to calculate impacts. Fossil energy impacts were calculated using the CED 1.08 method with the addition of United States-based fossil energy sources.

2.2 LCA Model Scope and Goals

This analysis is focused on two key areas of environmental impact, GWP and fossil energy resource depletion. The study used a 'cradle gate to gate' analysis of lifecycle impacts of the swine system, which includes all of the swine production system from the production of crops until the hogs are at market weight and ready to be loaded onto a truck at the farm gate. The main focus of the study was on activities occurring on the swine farm. Boundaries of the foreground system focus on the swine system activities related to (Figure 1).

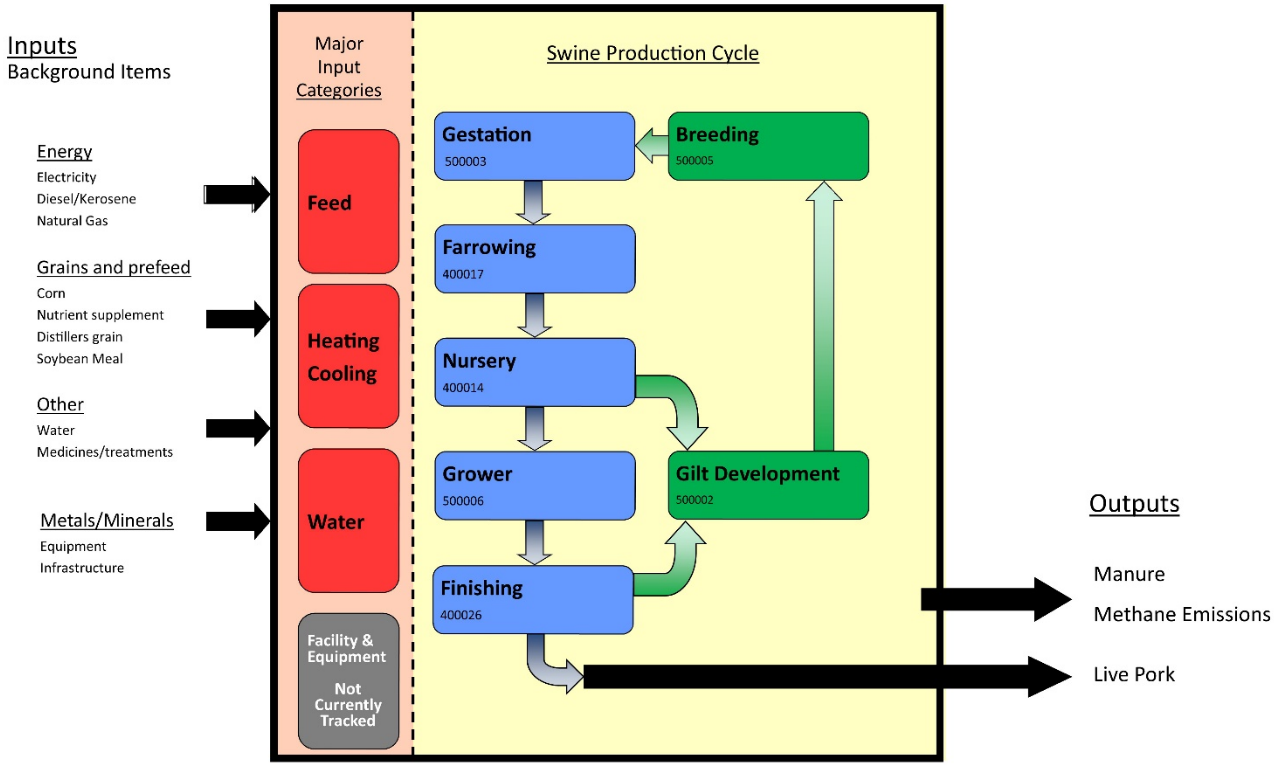


Figure 1 LCA Overview and Boundaries for the Swine Production System. The schematic shows the foreground and background components of the swine systems being analyzed. Items within the foreground system boundaries (peach and yellow areas) are considered the main focus of the study. Items in the background system (outside the black boundary lines) are items that are considered secondary and can't be varied as part of the main system.

2.2.1 Foreground System Items

Life cycle assessment is often divided into two areas of study, the foreground system and the background system. The foreground system is typically the area where the model focuses most of its effort and it is assumed that is the area where those using the LCA results are interested in making changes. In this LCA work, the foreground system includes the activities where swine production is directly occurring. As seen in the peach and yellow colored areas of Figure 1, this includes the different stages of swine production and the direct inputs needed for those areas. Mixed feed, heating, cooling, and ventilation are major inputs into the swine production stages. In addition, several other activities and energy resources are needed to operate the swine production system. These include things like lighting, office heating, worker showers, and laundry facilities.

At this time, infrastructure items, such as buildings, are not included in the LCA efforts for this project. The capacity has been added to models to allow for inclusion of infrastructure should accurate building data become available. Similarly, water and energy for water pumping are not fully implemented in the model.

2.2.2 Background System Items

The background system refers to items that are generally not in the control of those managing the main foreground system or within the scope of research of those analyzing the foreground system. On Figure 1, these are the items under the heading inputs on the left. For this study, this meant activities such as crop production, electricity generation/transmission, and natural gas extraction/delivery were in the background system.

2.3 Examining The Swine Production System

To evaluate a variety of swine systems, different sets of data were used to observe the specific systems used at WCROC and hypothetical systems designed based on data from commercial farms. It was intended that using the different data would allow researchers to assess high performing and lower performing systems from the sustainability standpoint. The data was used to examine both the impacts on individual growth stages and on the complete cradle to gate modeled swine production systems. The following systems were designed based on energy audits.

- WCROC Conventional System
  The conventional swine system used for research at WCROC includes a standard crated farrowing system, nursery building, a standard finishing barn, and hoop barn gestation pens. Due to the research nature of WCROC and the smaller scale of production, it is expected that the system would be less efficient than current large-scale industry facilities. Energy data needed to be scaled up to represent facilities running at near capacity, which is uncommon for research activities.

- WCROC Alternative Systems
  The swine researchers at WCROC are continually testing alternative housing, climate, and behavioral systems. These alternative systems represent potential future swine management techniques to improve animal welfare, health, or economics in swine production systems. The current alternative systems included in this research were the Swedish style farrowing unit, the hoop barn grow-finish system, and the outdoor gilt development unit. As with the WCROC conventional system, alternative production systems at WCROC are small-scale and thus likely to be somewhat less efficient than is seen in the commercial operations.

- Commercial Farm Average
  For each growth stage, the commercial farm data for the two paired growth stage (i.e. nursery) farms was averaged to come up with a combined measure for data on energy use in commercial swine production. It should be noted that there were significant differences between many of the farms depending on the type of equipment and technologies employed by the commercial operators.

- Commercial Farm Best Energy Technology
  The total energy use was analyzed for each of the paired commercial farms, and the farm using the least energy on was analyzed for impacts at each stage and then used to create an ideal best technology full production system model.

- Renewable Electricity Scenarios
  All of the above systems were tested with solar energy replacing the grid energy being used at the farms. This was done at the system level looking at complete cradle to gate use of renewable electricity in each of the different systems.

2.4 Data Collection

A number of different sources of data are used in this study. Priority was given to data generated by WCROC staff from work done on the WCROC swine production research systems or collected at local commercial operations. However, some information was outside the ability or scope of staff to collect and, therefore, was found in databases or literature. This was primarily background data for items brought into the swine and the cropping system.

Data collection at WCROC included all stages of a standard swine production system; farrowing, nursery operations, grow-finish production, gilt development, and gestation. Also included in the WCROC information was data on feed use, the length and conditions of each growth stage, natural gas use, and continuously logged electricity data. Commercial system auditing analyzed electricity and natural gas/propane use. Each commercial system focused on a single stage of production. However, for commercial systems, farrowing, gestation, and replacement gilt development were considered a single operation (breed-to-wean).

2.5 Feed Systems

The feed mixes used for this LCA analysis of all production stages are based on feed guidelines from the US Center for Pork Excellence, as applied at WCROC. For very young animals (nursery stages 1 & 2), pre-made pellets were purchased that conformed to these guidelines. All older stages received feed mixes produced on-site that met these nutritional recommendations. The majority of each mix is corn, with a high percentage of ground corn grain (starch source) and some dry distiller's grain (protein and fat source). Alternatively, soybean meal is used as a protein source. There are a number of other nutrients and minerals required at low levels, these are mixed with corn and soybean meal to make a complete feed. Throughout the production process, a number of different feeds and feed ingredients are provided at different stages to promote swine growth and health as they progress to market weight.

2.6 Energy Sources

Swine production uses a number of different energy types; electricity, propane, and diesel fuel are the most common. However, natural gas and gasoline use is also common. For this study, the impacts of electricity were studied using a Minnesota grid electricity mix calculated using the 2011 Minnesota electricity production mix data collected by EIA (Energy Information Agency). The EIA based percentage of each type of electricity production (coal, nuclear, wind…) was used in conjunction with data on database literature on the production of each energy type. This Minnesota mix was used for all on farm and regional energy demands. Since most of the feed and other products used on the swine farm were produced regionally, the large majority of electricity used was the Minnesota mix. For renewable scenarios, infrastructure and background energy was not included in the LCA for solar PV system. Therefore, they were considered to be carbon neutral and fossil energy free sources of electricity.

Natural Gas data in this model were derived from the Ecoinvent database, which used NREL (National Renewable Energy Lab) data to assess the impacts of natural gas supplied to consumers across North America. Propane data were assessed using the US LCI database, which unfortunately was modeled at a US based refinery and not the consumer. Similarly, impacts of diesel energy on the farm were modeled at the point of production at the US refinery.

2.7 Manure Management System

Although not an important component of energy in these systems, manure management is an important part of the carbon emissions during pork production. After manure is excreted from livestock, microorganisms continue to break it down into methane and carbon dioxide. Since methane is a chemical with high global warming potential, examining the breakdown of the manure is important part of looking at global warming potential in livestock systems. Direct measurements of manure emissions are very difficult, expensive, and require fairly significant changes to livestock system. Therefore, manure emissions for this project are based on standardized calculations developed by ASABE. Using a number of previous studies on manure breakdown, they have modeled how much methane is released depending on what manure management system, diet, and temperatures are being used for a given livestock system.

3 Results & Discussion

3.1 Model Development

The initial LCA model developed as part of this project has been continually updated with new data on growth stages, inputs and outputs as the data has become available. The current model (Figure 5) includes data on all major inputs and outputs including; feed systems, building systems, and manure systems. By its nature, LCA models are designed to allow continual improvements and refinements. With the model that we have developed, we plan to examine individual heating, cooling, and ventilation system changes in newly funded grant projects. In addition, there are a number of improvements that we hope to make in the model as new data becomes available. Appendix A list some of the areas that we are working on to collect data for revisions. Therefore, this model will move continue to be used for swine production energy and GWP research into the future.

3.2 Model Output Energy vs. GWP

For this summary report, much of the output data presented explores the input energy component of swine production. The GWP results are expressed only for the final emissions impact data, but not individual growth stages of the system. This is not to imply that the GWP component of the study is less important. However, it is important to recognize that fossil input energy is much more easily changed by altering swine management practices. Global warming potentials includes many factors that are difficult for pork producers to change such as manure emissions or that occur in the background system that are not directly managed by pork producers.

3.3 Production System Inputs

In terms of total energy, one of the largest requirements for energy in the entire system is the production of animal feed ingredients. Figure 2 shows the relative amount of energy needed to produce the ingredients for feeding one market ready hog. Production of corn is the single most energy intense ingredient needed for feed, requiring almost 50% of the total energy needed for producing swine feed. An examination of the inputs into corn production show that nitrogen fertilization and grain drying are the two most significant energy uses in production of corn. Needing neither nitrogen fertilizer nor drying, soy products are the second most energy intense input into swine feed. Most of this energy is for tillage, harvest, and transportation. The last inputs listed are amino acids produced artificially. Production of these amino acids is complex and requires a significant amount of energy. Even though they are added to feed mixes at very low levels, they significantly increase the energy embodied in the final feed product. Several other ingredients are used in feed production. However, they were not significant in the overall amount of energy being used in swine production.

In terms of fossil energy sources used for entire swine production system (base on WCROC data), natural gas and crude oil and lignite coal were the most used primary energy sources (Figure 3). In addition to being used in the grain production system (for grain drying), natural gas was used for electricity generation, building heat, and hot water. Much of the crude oil was used for vehicles and tractors for growing and transporting feed. Lignite coal was used in production of electricity, with the Minnesota based grid using more than 50% coal-based electricity. Commercial swine operations were slightly different in terms of natural gas use as rural farms are often not connected to a natural gas utility. These farms typically use propane as a heating source and for grain drying.

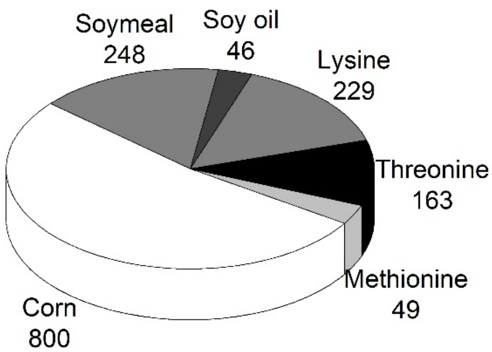


Figure 2. Fossil Energy for Major Feed Ingredients. Each of the feed ingredients is listed with the amount of fossil energy (in MJ) required to produce of the ingredients required to grow a single 120 kg market weight hog.

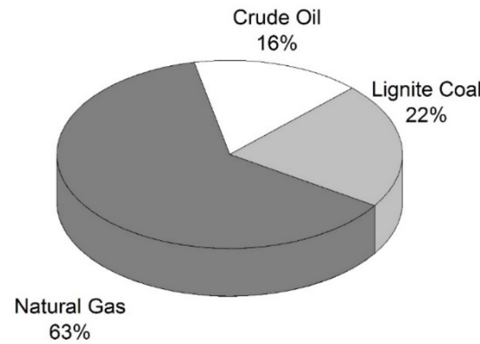


Figure 3. Key Sources of Fossil Energy for The Swine Production System. The primary energy sources for the production of pork and the relative percentage of each used.

3.4 Growth Stage & Building Systems Fossil Energy Results

The initial analysis of the swine production system looked at individual growth stages and the fossil energy needed for each of the different stages (Figure 6). Each stage was examined in terms of one unit of output as indicated panels in the figure, in most cases one animal. Comparisons were made between the WCROC swine production system and commercial systems. If an alternative system was being used at WCROC, it was included as well. To more closely look at areas where swine producers may have more ability to reduce fossil energy use, a second analysis was done looking more specifically at the building systems (Figure 7).

For comparing the different swine systems, (commercial vs. WCROC), it is important to understand that the feed and animal management are modeled after WCROC operations. Only building energy use from commercial and alternative production systems is changed. For example, in all systems the length of time a piglet is assumed to stay with a sow before weaning is 28 days. Current commercial practices are often 21 day, which improves turnaround time for facilities and cycles sows through faster. Specific animal husbandry data for commercial operations is not available, but will be added in the future.

3.4.1 Gestation

The gestation stage for swine is just short of 4 months. During this time the sows are fed a balanced diet to promote healthy litters of piglets. The WCROC system is a bit different in that gestation is done in an unheated hoop barn. Thus, the only energy used is to heat waterers in winter. Looking at Figure 6A, one can see that total fossil energy in the WCROC gestation system is slightly lower in commercials systems. When comparing only the building system energy (Figure 7A), one can see a significant fossil energy consumption for the unheated WCROC gestation hoops.

3.4.2 Farrowing

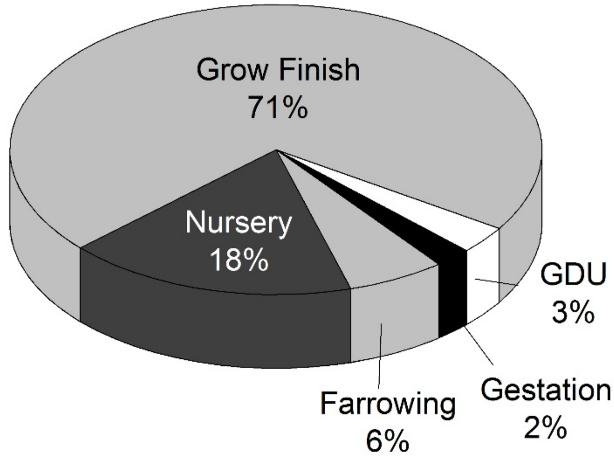


Figure 4. Relative Fossil Energy Contribution of Each Growth Stage. The relative contribution of the building system energy is shown for each stage is shown for the WCROC swine production system.

The farrowing stage is a fairly short stage of between 21 to 30 days where animals are confined in a heated space to give birth and raise the young until they can eat solid food. Fossil energy for the farrowing was difficult to calculate for WCROC because the research farm only farrows when hogs are needed for research. That limited data set was extrapolated to estimate the amount of energy needed to fully utilize the farrowing facilities on a continuous basis. It is highly doubtful that WCROC's system is as efficient as indicated in Figure 6B and Figure 7B. The WCROC alternative system data is more likely to have yielded realistic data, as it showed the expected increase in fossil energy use due to a higher demand per animal for space, heating, and straw. The commercial barn data in Figure 6B is probably much more representative of real-world farrowing system energy use. Upcoming rotations of large groups of sows through the farrowing system at WCROC will provide a better set of baseline data for analysis.

3.4.3 Nursery

Piglets brought into the nursery system usually spend a short time (45 days) in the climate controlled facility as then transition to a higher starch based diet, gain strength, and increase their disease resistance. The WCROC nursery is fairly typical of modern swine systems, although the number animals produced in the facility is lower than could be produced under commercial production. Both in terms of total fossil energy (Figure 6C) and building system energy (Figure 7C), all three systems were comparable.

3.4.4 Grow finish

During the grow-finish stage, hogs increase in size from roughly 27 kg to 120 kg, with feed available at all times. This stage lasts roughly 90 days and is typically in a heated/ventilated facility. In addition to a conventional facility, WCROC uses an alternative system where animals are housed in a sheltered hoop barn. The hoop barn is unheated and uses electricity only for heating waterers in cold weather. Because of the length of this stage and amount of feed consumed, it is a fairly fossil energy intense stage of the production system (Figure 6D). However, relatively little building system energy is used when the number of days spent in the stage is considered. (Figure 7D). In the case of the WCROC conventional system, the building system fossil energy use is significantly higher. One of the likely reasons for this is the small scale of production at WCROC. The overhead energy demand for operating small barns makes them much more energy intense per head raised. On the other hand, the outdoor alternative system at WCROC used almost no building system energy.

3.4.5 Gilt Development

Replacement sows are produced in the gilt development units of swine production systems. In most modern farms, breeding stock is separated from the market animals early in production and raised somewhat differently to promote animals that can more successfully produce piglets. For this study, animals were put into the gilt development unit after the nursery stage. They are fed diets similar to the grow finish stage animals. However, the diet is modified to reduce growth of fat as the animals approach market weight and continue to grow to breeding weight. For this model, gilts spent an extra 30 days in the development unit (total of 120 day) above what grow-finish hogs spend in that stage. WCROC has a standard gilt development unit (GDU) in a heated and ventilated building, but also has a temperate seasonal GDU that is unheated. Typical commercial barns will have heated indoor slatted floor GDU's. The energy use of WCROC's conventional GDU system was similar to the commercial systems (Figure 6E), with a significant amount of the fossil energy being used for feed. In terms of building system energy (Figure 7E), the WCROC conventional GDU was similar to the commercial systems. However, the WCROC outdoor GDU used almost no building systems energy.

3.5 Total System Impacts

So far, this analysis has focused mostly on the individuals production stages and how fossil energy intense they are. However, it is important to look at the overall performance of the system as well. By combining the different stages at WCROC and the average and best systems at commercial operations, a better understanding of how differences in the stages impact the system as a whole.

3.5.1 Energy

The total fossil energy for the modeled production systems is shown in Figure 8A, which is expressed in terms of the energy used for producing one market hog when combining these systems. The large impact that feed production has on the overall system is visible in the systems shown. A more detailed assessment of energy needed specifically for housing or building systems (Figure 8B) shows that there are differences in the amount of fossil energy needed between the different production systems. This figure also shows how the use of renewable electricity can decrease the amount of fossil energy needed. Depending how much fossil based electricity was used in the swine production building system, solar PV electricity reduced the fossil energy demand by between 42% (alternative) and 68% (commercial best).

3.5.2 Global Warming Potential

The analysis showed a similar situation in management of swine GWP as with swine fossil energy use, very little of the GWP emissions are able to be directly controlled by swine producers. The major areas of GWP impacts are feed production and manure management (Figure 9A). Though there are some methods of reducing manure emissions with feed additives, these are not economically feasible and are not all that effective. As with fossil energy, carbon emissions in feed production are also difficult for farmers to influence. This leaves the building system part of swine production as the major area for pork producers to manage for GWP reduction, which accounts for only about 10% of the total GWP impacts. However, our work with renewable energy does show that greenhouse gases can be significantly reduced in the building systems area (Figure 9B).

3.6 Implications

The findings of this work indicate that there are some areas that could be more heavily targeted by producers wishing to reduce their environmental impacts. Activities of the on-farm hog operations are within their control and can be impacted by farm manager decisions. Unfortunately, because grain and feed ingredient production is such a large part of the impacts, it is difficult for swine producers to directly reduce the majority system sustainability impacts.

To continue reducing the environmental impacts monitored (fossil energy and GWP), a combination of conservation and other renewable technologies will be needed. On the conservation side, changing buildings, heating and cooling, ventilation, and lighting can all lower fossil electricity use. One solution that would both decrease fossil energy use and lower the GWP from manure emissions is the use of an anaerobic digester. Anaerobic digestion systems capture methane and use it to make electricity or heat, which are both needed at different points in swine production systems. In some areas of the U.S., anaerobic digestion could also be a source of additional revenue.

3.7 Future Work and Areas For Refining LCA

The swine life cycle model was designed as a tool to investigate a wide variety of issues related to the sustainability of pork production. It is able to be customized and expanded to meet many needs for swine sustainability research and is an important asset for Minnesota researchers. It was anticipated that the model would be used for new research efforts, and new funding has been secured to examine other swine production issues. As with all LCA models, the data collected on swine production is the key to making an accurate model. Going forward, WCROC will continue to collect new data, both on the farm and off, to improve model results. Appendix A lists some of the changes that will be made, but is only a small part of the continual improvements and additions the model is expected to have in the future.

4 Conclusions

- A model was developed that can track energy use and greenhouse gas emissions (GWP) though the swine production system at a moderate resolution, with the ability to be refined as more data becomes available. This model is designed and already committed for further research that examines questions regarding swine life cycle energy and carbon footprints with potential new technologies and organic production.
- Energy use and GWP emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.
- The fossil energy portion of the production system that can be directly controlled by the hog growers is roughly 25% of the energy of producing pork. Renewable energy replacements for fossil based electricity, such as solar PV, can significantly lower fossil energy use for swine production. However, replacements for natural gas/propane, diesel, and gasoline will be needed to further reduce fossil energy use.
- The fossil energy and GWP impacts for feed crop production and feed ingredients are an important area that must be addressed to continue reductions in environmental impacts of swine production systems.

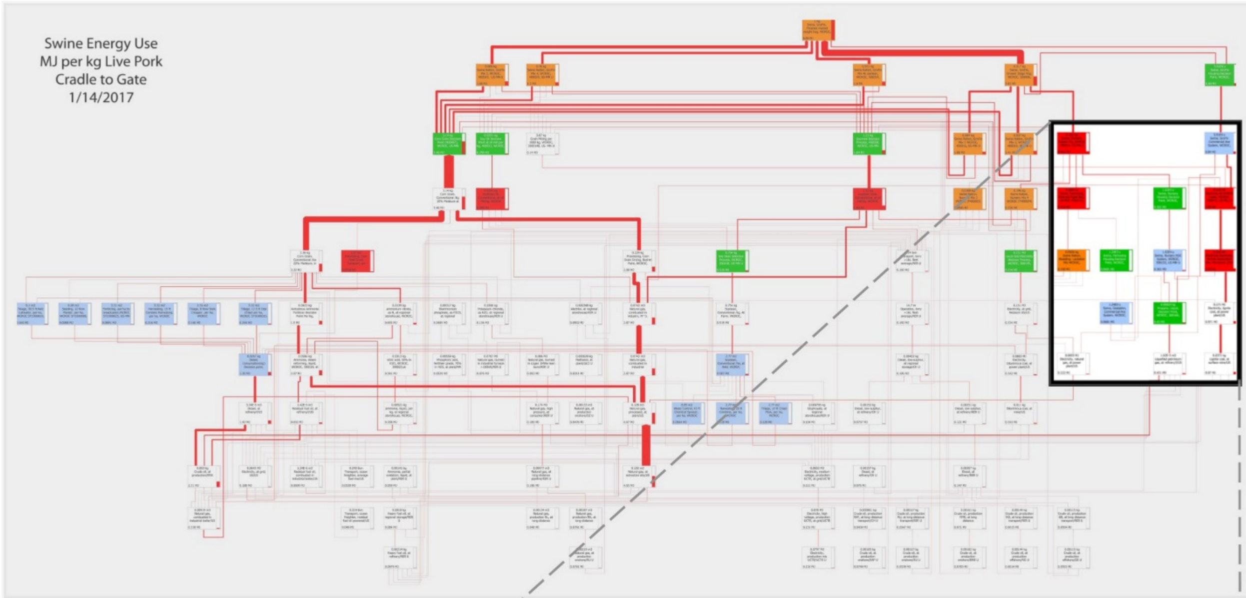
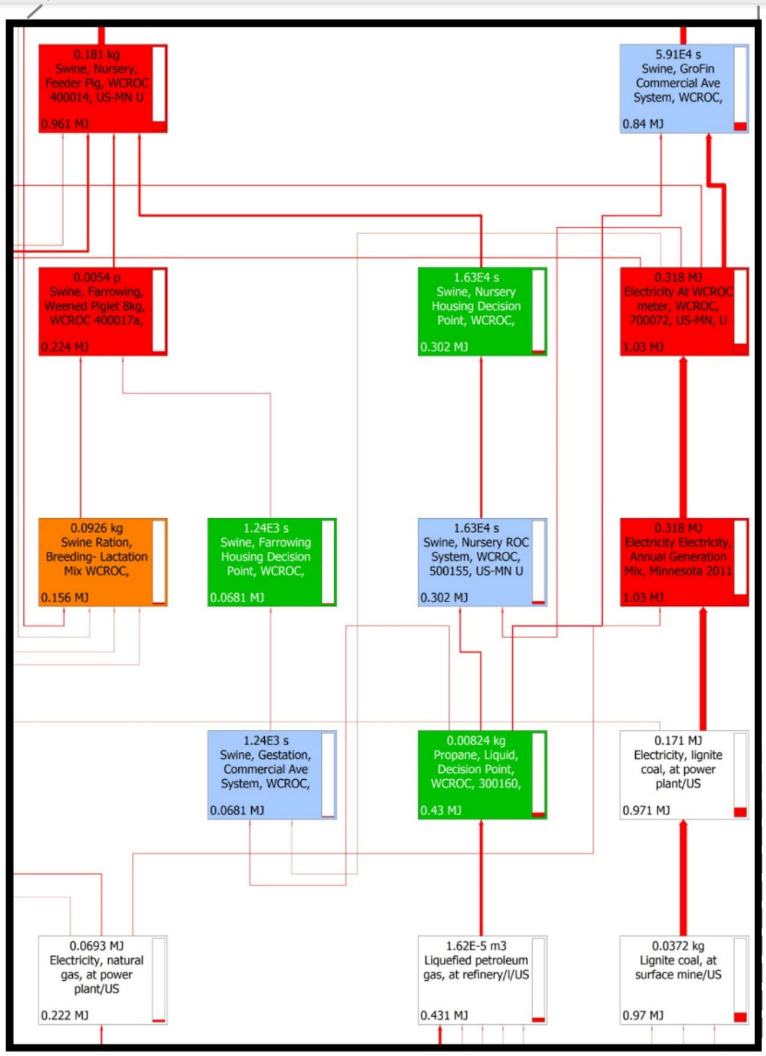
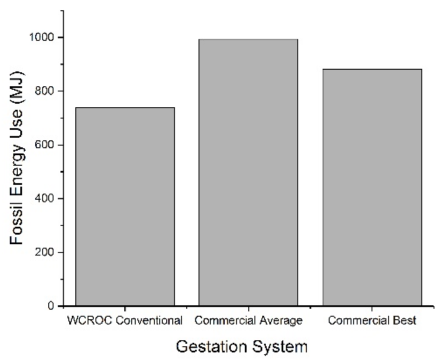


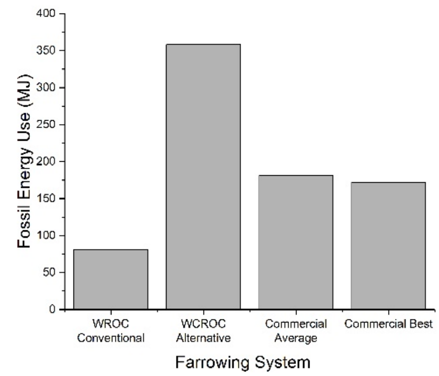
Figure 5. Schematic of the LCA Model as displayed by SimaPro. The image at the top is a Sankey diagram of the key processes using fossil energy in the swine production model. Drawn by the SimaPro LCA software, all the activities in the system are linked by lines indicating energy flow. The highlighted section on the top drawing is expanded in the image on the right to show a more detail look at some of the activities in the production model. Each process (box) in the expanded view has a process name, the amount of material- time- or energy moving on to the next stage and the cumulative amount of energy used at that process. The size of the lines linking the processes represent the relative amount of energy being used. These drawings are used to help visualize the large tables of data the software produces. The same method is used to diagram GWP models.



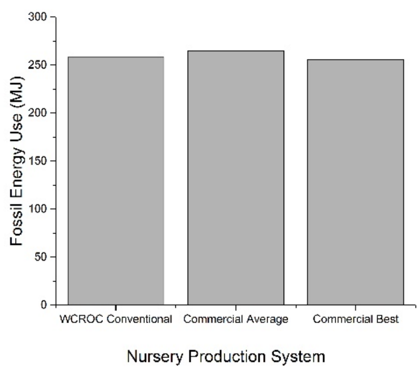
A). Gestation (Per Bred Sow)



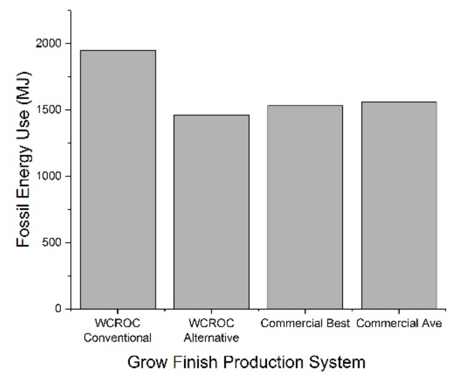
B.) Farrowing (Per Liter)



B.) Nursery (Per Pig)



C.) Grow Finish (Per Pig)



D.) Gilt Development (Per Pig)

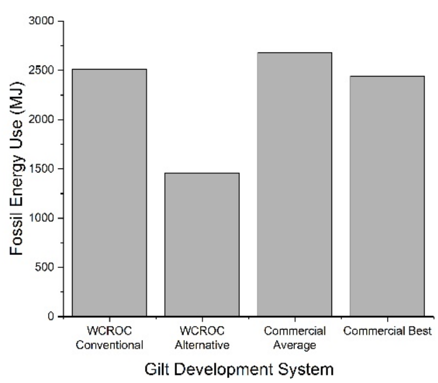
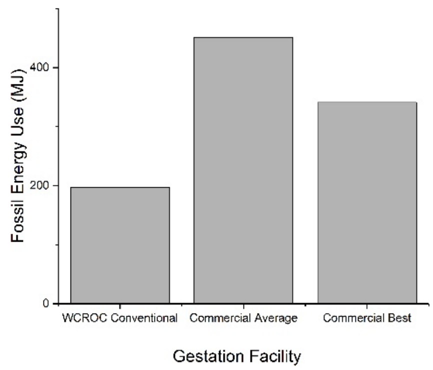
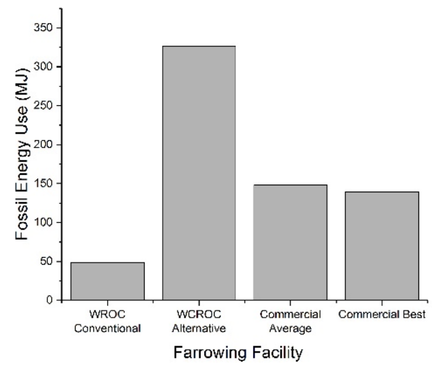


Figure 6. Total Fossil Energy Required for Individual Growth Stages. For each stage, the fossil energy needed for the commercial average and best systems were compared with the WCROC research farm conventional system and alternative system if one existed for the stage. Results are the total fossil energy used in producing one unit of output (output unit for each stage is shown in parenthesis). These graphs include all fossil energy for feed and other inputs needed for the given stage.

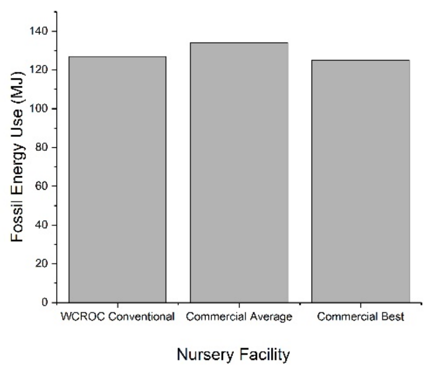
A.) Gestation (Per Bred Sow)



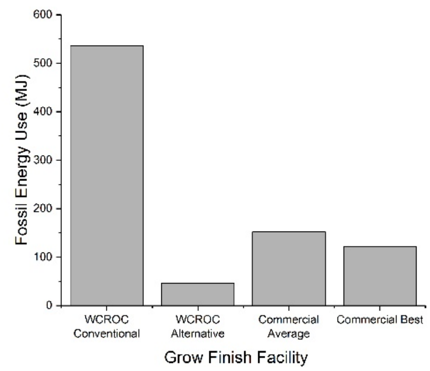
B.) Farrowing (Per Liter)



C.) Nursery (Per Pig)



D.) Grow Finish (Per Pig)



E) Gilt Development Unit (Per Pig)

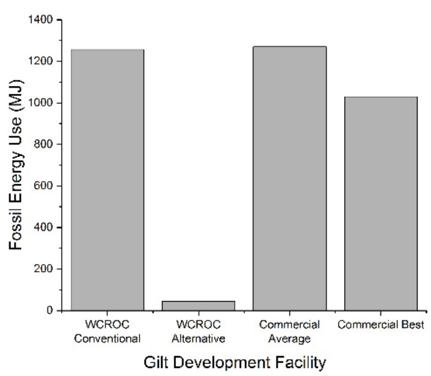
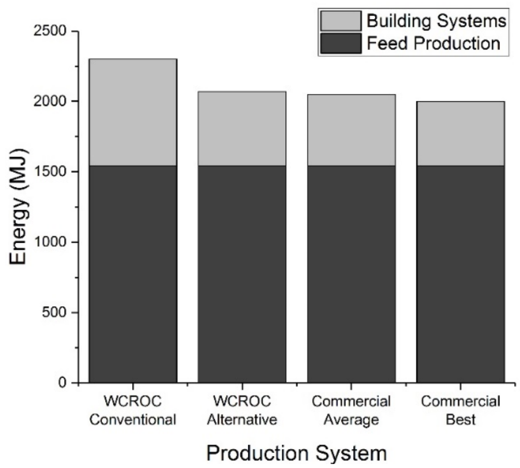


Figure 7. Building System Fossil Energy for Individual Growth Stages. For each stage, the fossil energy needed for the building system for commercial average and best systems were compared with the WCROC research farm conventional system and alternative system if one existed for the stage. Results are the total fossil energy used in producing one unit of output (output unit for each stage is shown in parenthesis). The graphs only include energy for heating, cooling, ventilation and other fossil energy use in the building system.

A) Total Swine System Fossil Energy



B) Building Energy With Renewable Production

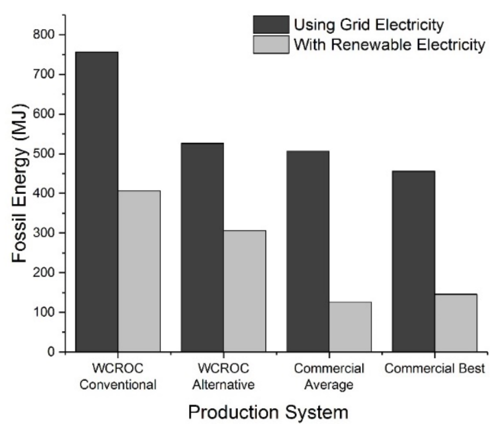
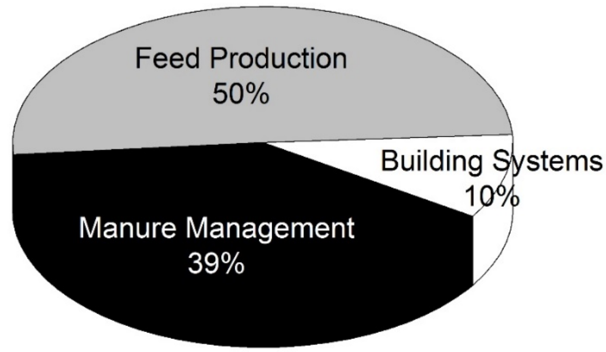


Figure 8. Fossil Energy For Swine Production Systems These figures show the fossil energy needed for A) the entire swine production system and B) building system. Data is based on the energy needed for one market weight hog (120kg)

A) GWP Emissions from Swine System Components



B) GWP Emissions With Renewable Energy

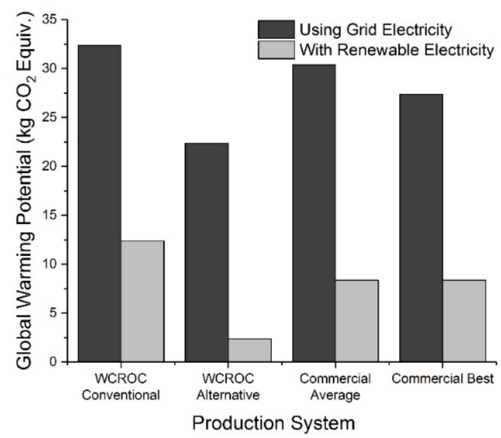


Figure 9. Global Warming Potential for the Swine Production System. The Global Warming Potential (kg of CO_2 Equivalents) for the system is shown A) as a comparison of the major GWP emitters and B) by the potential reduction using renewable energy.

Appendix A Future Model Revisions

Issue	Impact	Information Needed/Solutions
WCROC Farrowing Energy Accuracy	This has a significant impact on the energy used for WCROC farrowing in the model. However, it is likely of only a minor impact to the system as a whole.	More information is needed about the energy use when farrowing barns are full. The estimates used in the model were based on only a few periods where data was not precise. There was likely error in extrapolating to full barns.
On farm vehicle use	It is not likely to be a large impact at a typical farm. However, WCROC has a large number of vehicles in use on our research farm.	Need to develop better WCROC vehicle data, which factors out vehicle use for research or other animal systems. Or, data could be collected at outside commercial operations.
Water energy and inputs	Inconsistent use of water data in the current model may have some impact on the final results. However, is not likely to be a major factor in the system.	It is difficult to get accurate water data at WCROC due to a lack of water meters for individual buildings and little information on total water being pumped.
Updated Minnesota Grid Energy Data	Grid power is used as the regional electricity source. This is likely to impact the system as coal based electricity is used less than in the past. Wind and natural gas are a much higher percentage.	Data from IEA for energy mix and databases for power plant impacts can be used in revisions.
Specific Data Needed for stage length and feed use at commercial farms	Commercial farms may be more efficient than indicated by the findings of this report. The level of change is hard to gauge.	Commercial farms would have to be willing to provide more data, depending on the farm this may be easy or difficult to get