

**Food Product  
Environmental Footprint  
Literature Summary:**

# Pork



State of Oregon  
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A report by: Center for  
Sustainable Systems,  
University of Michigan

Martin Heller  
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## Executive Summary:

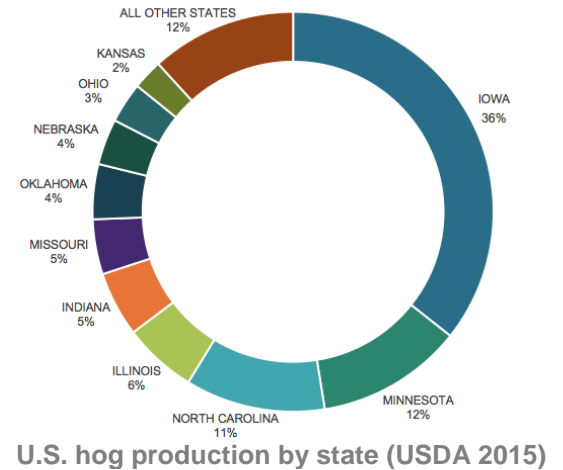
# Pork



Pork is the most popular meat consumed globally, representing 37% of total global meat production. The U.S. is second only to China in pork production, and is the largest global exporter, with 2.3 billion pounds of pork exported in 2013. In the U.S., pork is the third most popular meat, behind chicken and beef, with the average American consuming an estimated 29.2 pounds (boneless weight) in 2014. Oregon ranks 36th in hog production, with 3.6 million pounds produced in 2015.

The purpose of this summary is to highlight what is known about the environmental impacts of pork production, processing, distribution and consumption based on a review of publicly available life cycle assessment (LCA) studies. Such studies can identify those parts of the value chain with disproportionately high environmental burdens, allowing improvement efforts to focus where they are likely to have the most benefits.

Due to the diversity of pork production found in literature, we provide an “average” environmental impacts per kilogram boneless pork for the life cycle of pork production. The life cycle of pork production is depicted below. The GHGE of the pork life cycle are dominated largely due to feed production, and to a lesser extent, manure management. This conclusion—that production of feed is the largest contributor to environmental burdens in the pig supply chain—also holds true for water use and land use, and is consistent across all studies reviewed.

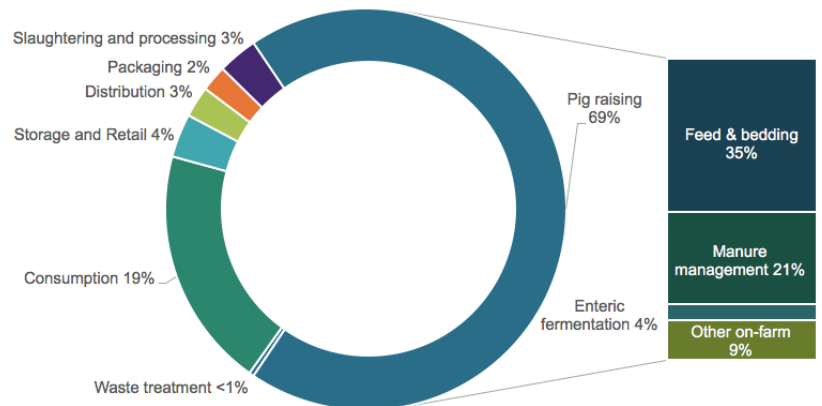


## Key Findings

The chart to right shows the breakdown of life cycle stages of pork production and the average GHGE for each activity found in LCA literature, including studies from both inside and outside the U.S.

For the U.S. pork industry in the U.S., feed production represents 27% of the full life cycle GHGE, 96% of land occupation, and up to 93% of the water use. Manure management contributed an additional 25% to GHGE. Packaging, distribution, and retail stages contribute minimally to the environmental impacts of the pork product chain. The consumer stage – refrigeration, cooking, and methane from food waste in landfill – accounted for 24% of the total.

### Average pork life cycle greenhouse gas emissions from all literature reviewed



## Feed

As previously indicated, feed production is known to be the largest contributor to environmental impacts in the pork supply chain. Feed rations for conventional growing-finishing pigs commonly include cereals (corn, wheat, barley) to fulfill the energy requirements of the animals and soybean meal to fulfill protein needs. Options for reducing environmental impacts could include shifting from soybean meal to lower impact feed such as peas and rapeseed meal, in combination with

synthetic amino acids. Another option is the practice of using food waste as feed for pigs. Food waste has historically been recycled as livestock feed, particularly for pigs, and it is thought that food waste in early human settlements attracted wild pigs, leading to their domestication. Cooked food waste fed to pigs is colloquially known as swill; sufficiently heating the food waste sterilizes it and prevents the spread of disease. Swill was a prevalent pig feed in the early 20th century, but fell out of popularity as abundant, cheap grains became available. One LCA study comparing food waste disposal methods, including conversion into dry and wet pig feed, anaerobic digestion, and composting found that recycling of food waste as wet pig feed had the best score for 13 of the 14 environmental and human health impacts considered. In Oregon, food served to people cannot be used as swill, but bakery by-products and select other manufacturing discards can be fed to hogs.

## Pig Production Strategies

The bulk of U.S. pork production occurs in conventional, intensive systems, but alternatives do exist offering choices to the consumer. Comparisons of the conventional intensive commodity production with low-density techniques using alternative manure management (deep-bedded systems using straw, corn stalks, sawdust, etc. as an alternative manure management strategy to slatted floor pens in which manure falls through and is collected in pits) found small differences in GHGE. However, the differences in eutrophication potential (the result of excessive nutrient loading from manure) were substantial with conventional production performing better per kilogram live weight pork, suggesting that manure management is an important driver of GHGE.

## Organic Production Practices

The literature suggests that organic pork production systems consistently have higher carbon footprints than conventional. While organically produced feeds have lower carbon footprints than conventional feeds, organic pork production requires higher quantities of feed per kilogram of pork produced. The study also found that GHGE associated with manure management of pigs raised outdoors on pasture can be greater than for pigs raised indoors because of the nitrous oxide emissions associated with manure excretions on pasture.

## Manure Management

Much of the GHGE associated with manure management in pork production stems from the fact that the most common manure management system is storage of manure slurry in open tanks, which can result in large emissions of methane, a potent greenhouse gas. Alternatives include using enclosed anaerobic digestion systems and either flaring (burning) the captured methane, or using the methane to generate heat or electricity. Another alternative often used in deep-bedded production methods is to handle solid manure by composting.

## Conclusions

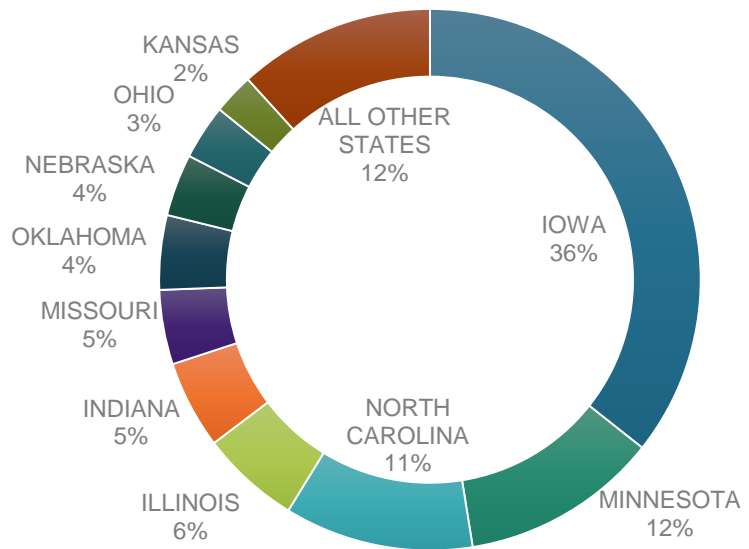
The LCA literature on pork production and consumption offers the following conclusions:

- Environmental impact of the pork product chain is dominated by emissions occurring on or before the farm.
- The production of feed is the largest contributor to environmental impacts, including greenhouse gas emissions, energy use, water use, and land occupation. Lower-carbon feeds offer the potential to reduce carbon footprint, although they must be considered very cautiously as they may require more land.
- Manure management can also be an important source of impacts. Anaerobic digestion of manures presents an opportunity to improve environmental performance across multiple impact categories. Open, anaerobic manure lagoons without methane recovery likely represent the worst manure management option from a GHGE standpoint.
- Multiple studies indicate that when comparing environmental impact per kilogram of pork produced in conventional, commodity production systems versus alternatives such as deep-bedded, organic, or pasture-based, the conventional systems, which have benefitted from a long history of efficiency improvements, are generally favorable. However, similar efficiency improvements for alternative production systems could serve to lower their environmental impacts as well.
- Recycling food waste as pig feed shows promising environmental benefits, although may currently be restricted by policy and perception.
- Refrigeration and home cooking appear to be significant contributors to the overall carbon footprint of pork.
- Packaging, distribution and retail stages contribute minimally to the environmental impacts of the pork chain.

## Overview

Pork is the most popular meat consumed globally, representing 37% of total global meat production. Global demand for pork was forecasted to grow by 32% between 2005 and 2030 (Macleod et al., 2013). The U.S. is second only to China in pork production, and it is the largest global exporter, with 2.3 billion pounds of pork exported in 2013<sup>1</sup>. In the U.S., pork is the third most popular meat, behind chicken and beef, with the average American consuming an estimated 29.2 pounds (boneless weight) in 2014<sup>2</sup>.

U.S. pork production is concentrated in a handful of states, with the top 10 states representing 88% of 2015 hog production. Oregon ranks 36<sup>th</sup> in hog production, with 3.6 million pounds produced in 2015<sup>3</sup>. The majority of contemporary pork production in the U.S. comes from large, high-volume “commodity” farms operating climate-controlled, slatted floor barns and producing over 50,000 pigs annually. A much smaller share of production nationwide – but much of the pork production in Oregon – comes from niche producers using alternative rearing systems.



**FIGURE 1. U.S. hog production by state (USDA 2015).**

The purpose of this summary is to highlight what is known about the environmental impacts of pork production, processing, distribution and consumption based on a review of publically available life cycle assessment (LCA) studies. Such studies can identify those parts of the value chain with disproportionately high environmental burdens, allowing improvement efforts to focus where they are likely to have the most benefits. These LCA studies can also point to potential trade-offs between environmental indicators or abatement strategies.

*This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the [Food Product Environmental Footprint Foreword](#).*

<sup>1</sup> Food and Agriculture Organization of the United Nations: [faostat.fao.org](http://faostat.fao.org)

<sup>2</sup> USDA Loss Adjusted Food Availability: <http://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/food-availability-per-capita-data-system/#Loss-Adjusted-Food-Availability>

<sup>3</sup> <https://quickstats.nass.usda.gov>

## Available Research

LCA is a useful tool for measuring the potential environmental performance of pig production and has been implemented extensively to date. In addition to two review articles focused on LCA of pig/pork production, we identified six studies that consider the pork product chain through consumption, an additional 10 studies that consider some aspect (such as slaughter or processing) beyond the farm gate, and 11 studies that look only at pig production up to the farm gate (see Figure 2). Given the importance of feed production in the pork product chain, an additional six studies focus only on feed choices, and two studies look only at pig slurry manure management using LCA. Of the 35 studies reviewed, eight were based in the U.S. or Canada. Most studies look at global warming potential (greenhouse gas emissions), but the additional environmental impacts of water and land use, energy use, eutrophication potential and acidification potential are also well represented in LCAs of pork.



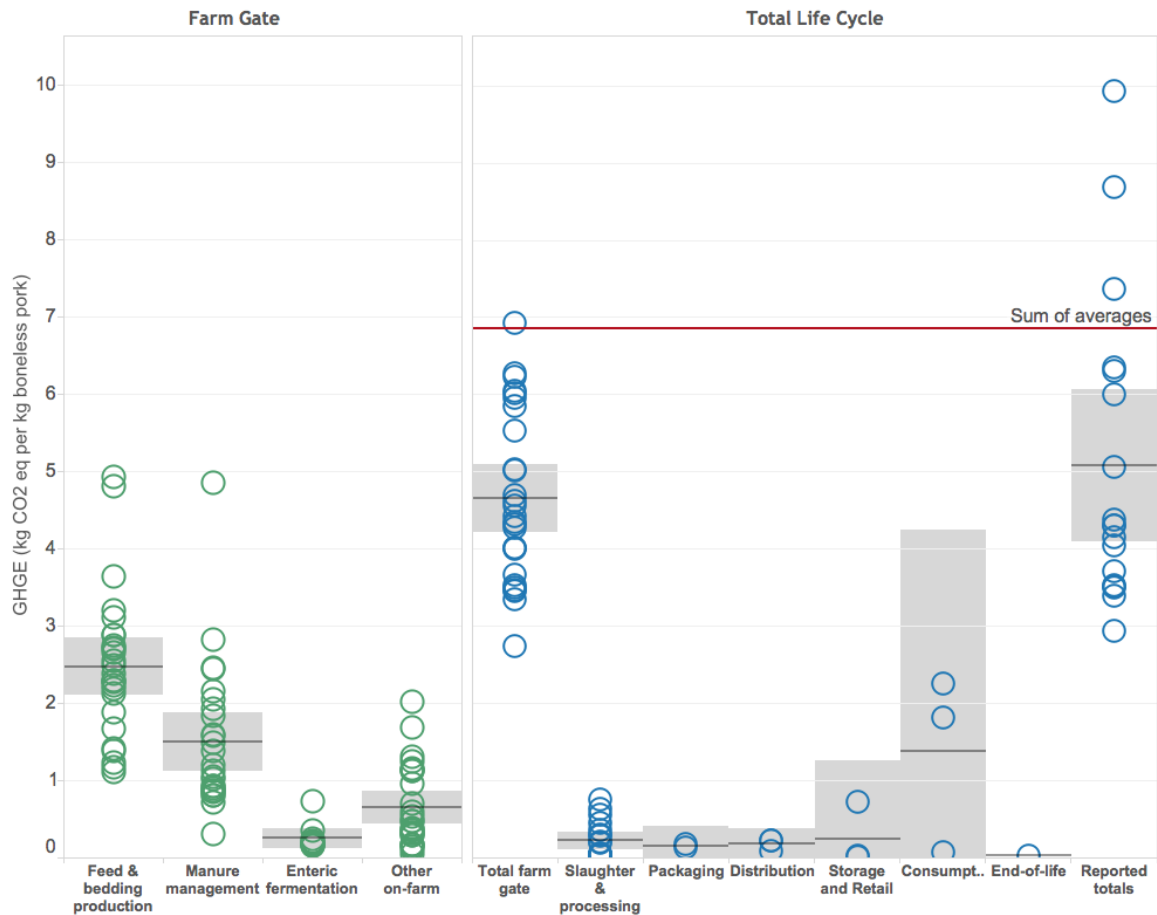
**FIGURE 2. Generic life cycle of pork production.**

## Key Findings

The diversity of LCA studies of pig and pork production has resulted in differences in functional unit bases – the relative basis that environmental results are presented against – e.g., environmental impacts per kilogram live weight, per kilogram carcass weight or per kilogram boneless pork. It also has resulted in studies covering varying boundary conditions – cradle to farm gate, cradle to slaughterhouse gate, or cradle to grave – and various representations of intermediate stages (see Figure 2). These differences make it difficult to draw accurate comparisons between case studies. To overcome these limitations and provide an “average” look at the overall life cycle of pork production, we converted all functional units to environmental impacts per kilogram boneless pork<sup>4</sup>. Figure 3 offers an aggregate look at the greenhouse gas emissions (GHGE) associated with the pork product chain. While Figure 3 shows large variability in each stage as might be expected from an analysis that combines numerous production methods, locations, and modeling assumptions, it is clear that GHGE from the pork life cycle are dominated by up-to-farm-gate emissions. In turn, those on-farm impacts are largely due to feed production, and to a lesser extent, manure management. This conclusion – that production of feed is the largest contributor to environmental burdens in the pig supply chain – also holds true for water use and land use, and is consistent across all studies reviewed. On-farm eutrophication and acidification impacts are also greatest, although sometimes manure management is greater than feed production, depending on the type of manure management system. While monogastric animals such as pigs do not produce as much

<sup>4</sup> This conversion uses a yield factor of 75% in converting both from live weight to carcass weight and carcass weight to boneless retail meat, as suggested in Nijdam, D., T. Rood and H. Westhoek. 2012. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy* 37(6): 760-770.

methane through enteric fermentation as do ruminants like cows, they do generate some. The consumption stage – comprised of home storage and cooking – demonstrates large variability across the three studies that considered it, as might be expected from a stage that is highly dependent on consumer behavior, and thus modeling assumptions. Two studies corroborate that packaging, distribution, and retail stages contribute minimally to the environmental impacts of the pork product chain.



**FIGURE 3. Life cycle greenhouse gas emission results from eleven reviewed studies, displayed across life cycle stages.**

*Circles represent individual scenario results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The “Total” column shows totals for a given scenario, although it is important to recognize that not all studies include the full life cycle stages represented here. The red bar indicates the sum of the averages from each life cycle stage.*



## U.S. Pork Industry

A series of reports by researchers at University of Arkansas look at the cradle-to-grave environmental impact of the U.S. pork product chain (Burek et al., 2014; Matlock et al., 2015; Thoma et al., 2011; Thoma et al., 2013). This research resulted in a carbon footprint calculator tool, available from the National Pork Board, which can help U.S. pork producers identify areas for potential improved efficiency<sup>5</sup>. “The calculator links environmental and economic performance and lets producers evaluate potential management changes in a simulated environment, which is a much lower risk than full-scale testing in their facilities,” said Greg Thoma, one of the University of Arkansas researchers.

This series of studies characterizing the U.S. pork industry found that feed production represented 27% of the full cradle-to-grave GHGE, 96% of land occupation, and 83-93% of the water use. Manure management contributed an additional 25% to GHGE, and the consumer stage – refrigeration, cooking, and methane from food waste in landfill – was 24% of the total. The GHGE assessment assumed a 10% consumer-level spoilage and plate loss and cooking with a gas oven. If cooking at home were instead done using an electric oven, the *total* pork life cycle GHGE would increase 2.4%, although this will be dependent on the electricity grid mix.

Because feed production represents a large portion of the environmental footprint of pork, the researchers considered alternative feed rations that met nutrient requirements but also minimized different environmental impacts – carbon footprint, water use, and land occupation – or cost. Table 1 shows how these rations, optimized for one parameter, perform relative to a baseline feed ration for all four parameters. Table 1 clearly demonstrates the challenges and tradeoffs faced when formulating feed rations.

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<sup>5</sup> <http://www.pork.org/production-topics/environmental-sustainability-efforts-pork-production/carbon-footprint-pork-production-calculator/>



**TABLE 1. Percent change in feed impacts from the baseline feed ration (representing a typical feed ration used by U.S. pork producers) for four optimized scenarios.**

Negative values (green boxes) represent a decrease in impact from the baseline. Values in boxes along the diagonal represent the impact category for which the scenario ration was optimized. Values along a given row show the tradeoffs encountered; for example, a feed ration that minimizes water use shows a 73% decrease in water use from the baseline and a 7% decrease in carbon footprint, but a 92% increase in feed cost and a 130% increase in land occupation. It is important to note that the percent changes are for feed impacts only. Since feed represents 27% of the baseline full life cycle GHGE, the “least carbon footprint” feed scenario would reduce full life cycle GHGE by about 8% (=30% of 27%). Table adapted from Thoma et al. (2013).

Percent change in FEED ONLY from baseline				
Scenario	Carbon footprint	Water use	Feed cost	Land occupation
Least carbon footprint	-30%	-42%	21%	43%
Least water use	-7%	-73%	92%	130%
Least cost	1%	2%	-2%	86%
Least land occupation	-11%	-56%	56%	-65%

## Feed

As previously indicated, feed production is known to be the largest contributor to environmental impacts in the pork supply chain. Feed rations for conventional growing-finishing pigs commonly include cereals (corn, wheat, barley) to fulfill the energy requirements of the animals and soybean meal to fulfill protein needs. A number of European LCA studies point to reducing soybean meal in the feed ration, and replacing it with feeds such as peas and rapeseed meal, in combination with synthetic amino acids, as a way of reducing environmental impacts. These results must be interpreted in context, however, since most of Europe’s soybeans are imported (typically from South America) and carries additional transport burdens, as well as significant GHGE associated with land use change in some LCAs. The U.S., on the other hand, produces large quantities of soybean, and soybean meal is prevalent.

Two recent studies look at the environmental implications of using food waste as feed for pigs. Food waste has historically been recycled as livestock feed, particularly for pigs, and it is thought that food waste in early human settlements attracted wild pigs, leading to their domestication. Cooked food waste fed to pigs is colloquially known as swill; sufficiently heating the food waste sterilizes it and prevents the spread of disease. Swill was a prevalent pig feed in the early 20<sup>th</sup> century, but fell out of popularity as abundant, cheap grains became available. The 2001 foot-and-mouth disease outbreak in the UK led to the ban of swill feeding in the UK and later the EU. In the U.S., swill feeding is banned in more than 18 states; in Oregon, food served to people cannot be used as swill, but bakery by-products and select other

manufacturing discards can be fed to hogs. In Japan, South Korea and Taiwan, on the other hand, recent policies have been introduced that promote the inclusion of food waste in animal feed via a tightly regulated industry. In 2006-2007, Japan and South Korea recycled 36% and 43% of food waste as animal feed, respectively. Zu Ermgassen et al. (2016) estimate that if swill feeding were legalized in the EU and reached similar recycling levels, the land requirement of EU pork production could be reduced by 1.8 million hectares, a 22% reduction. Salemdeeb et al. (2016) conducted an LCA study comparing food waste disposal methods, including conversion into dry and wet pig feed, anaerobic digestion, and composting. They found that recycling of food waste as wet pig feed had the best score for 13 of the 14 environmental and human health impacts considered. It is important to note that this study credits the recycling of food waste with the avoided emissions of displaced pig feed including soybean meal, and in the European context, the impacts of soybean meal included emissions due to land use change.

## Pig Production Strategies

While the bulk of U.S. pork production occurs in conventional, intensive systems, alternatives do exist, offering choices to the consumer. How do these alternatives perform environmentally? Pelletier et al. (2010) compared conventional, intensive commodity production with low-density, deep-bedded<sup>6</sup> niche production systems in the Upper Midwestern U.S. They found that the differences in GHGE between the two production systems were small and likely due to analytical uncertainties, whereas differences in eutrophication potential were substantial (conventional performed better per kilogram live weight pork) and clearly linked to characteristic manure management strategies. While the commodity system's reliance on pit storage of liquid manure is disadvantageous with respect to GHGE, it does offer advantages over outdoor windrowed storage of solid manure, the assumed management for deep-bedded systems, when it comes to nutrient losses that lead to eutrophication impacts. Other identified important drivers of environmental efficiency (resource or emission intensity per unit of production) were feed efficiency (amount of feed per kilogram weight gain) and sow productivity, both of which were significantly higher in the commodity system. The authors note, however, that the commodity systems operate at levels of efficiency that are in part attributable to historical subsidies in the form of extensive research and education which have served to optimize commodity pork production, and the deep-bedded niche systems are a relatively recent alternative that has not been similarly optimized.

The University of Arkansas research team modeled the environmental outcomes of a number of common – and controversial – swine management practices in the U.S. (Bandeekar *et al.*, 2014). They considered production without ractopamine, a dietary supplement which improves the rate of weight gain and improves feed efficiency, but is banned in 160 countries including all of the European Union, Russia, and China; production without growth promoting antimicrobials (antibiotics), a practice that has come under increased scrutiny because of concerns about the

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<sup>6</sup> “deep bedded” pig production systems utilize bedding materials such as straw, corn stalks, sawdust, etc. as an alternative manure management strategy to slatted floor pens in which manure falls through and is collected. In addition to absorbing manures, deep bedding offers pigs an outlet for their natural rooting instincts, which in turn promotes composting of the bedding/manure mix.

development of antimicrobial resistance; production without growth promoting *and* preventive (prophylactic) use of antimicrobials, the latter used when herd health is in decline to reduce the chance of herd-wide infections; production with immunocastration, a hormone treatment alternative to surgical castration in male pigs; and production using group pens rather than gestation stalls or crates, the latter banned in a number of states. Ractopamine and antibiotics in feeds are uncommon in Oregon, where most producers are selling into niche markets requiring that pork be additive and antibiotic free. Results from the simulations are summarized in Table 2. The authors warn that the simulations are very sensitive to a number of production parameters with high variability, and the results should be interpreted cautiously.

**TABLE 2. Percent change in environmental impacts resulting from changes in specific swine management practices. Orange boxes indicate an increase in environmental impact from the baseline, green boxes show a decrease. Adapted from Bandekar et al. (2014).**

Percent change from baseline*			
Management strategy	Greenhouse gas emissions	Fossil fuel use	Water use
No ractopamine	6.5%	4.6%	5.6%
No growth promoting antimicrobials	1.6%	1.8%	3%
No preventive antimicrobial use	17.4%	18.6%	18.9%
Use of immunocastration	-2.3%	-2.5%	-1.9%
Use of gestation pens	-1%	-1.5%	-0.3%

\*Baseline scenario assumed gestation stalls rather than group pens, growth promoting antimicrobial use in the nursery, preventive antimicrobial use as required, ractopamine use in grow-finish barn, with tail docking and surgical castration of male pigs performed in the lactation barn. Impacts are assessed per kg live weight at the farm gate.

A study looking at the carbon footprint of conventional and organic pork production in the Netherlands, England, Germany and Denmark found that the organic production systems consistently had higher carbon footprints (Kool et al., 2009). While organically produced feeds have lower carbon footprints than conventional feeds (90-99% certainty in this study), organic pork production required higher quantities of feed per kilogram of pork produced. The study also found that GHGE associated with manure management of pigs raised outdoors on pasture can be greater than for pigs raised indoors because of the nitrous oxide emissions associated with manure excretions on pasture. This result, however, is highly dependent on the amount of methane emitted from stored manure for the indoor pigs, and in a worse case methane emission scenario for stored manure, the result would be opposite. The two most obvious carbon footprint reduction options identified by the study were anaerobic digestion of manure to generate electricity (a potential 13% reduction in GHGE) and improving the feed conversion rate (lowering the amount of feed needed per kilogram of pig weight gain).

Additional LCA studies of pig production across the EU (Dourmad et al., 2014), in Denmark (Halberg et al., 2010), and in France (Basset-Mens and Van der Werf, 2005) show similar trends in comparing conventional, indoor production with alternatives. Organic, traditional, or other quality differentiated practices where animals are raised outdoors or in deep-bedded buildings at low animal density result in greater environmental impacts *per kilogram of pork produced* across a number of indicators. These authors also demonstrate however, that these less intensive production methods perform consistently better per hectare of land used for all environmental indicators considered.

## Manure Management

Much of the GHGE associated with manure management in pork production stems from the fact that the most common manure management system is storage of manure slurry in open tanks, which can result in large methane emissions, a potent greenhouse gas. Alternatives include using enclosed anaerobic digestion systems and either flaring the captured methane (i.e., converting it to CO<sub>2</sub> and reducing its global warming potential) or using the methane to generate heat or electricity. Another alternative often used in deep-bedded production methods is to handle solid manure by composting. A study considering swine production in Brazil compared these manure management options and found that anaerobic digestion with energy generation performs better for GHGE, freshwater eutrophication, cumulative energy demand, terrestrial ecotoxicity and biodiversity damage potential, and natural land transformation, even when accounting for uncertainties, than the base case of open tank slurry (Cherubini et al., 2015). On the other hand, composting performs worse than the open tank slurry for freshwater eutrophication, cumulative energy demand, terrestrial ecotoxicity, biodiversity damage potential, and natural land transformation. Differences are small in this study, however; anaerobic digestion with energy generation reduces the cradle-to-processor gate GHGE by 11% relative to open tank slurry, whereas composting increases GHGE 1.4 percent.

The University of Arkansas study also compared the impacts of manure management choices (Thoma et al., 2011). They found that managing manure in an anaerobic lagoon had the highest cradle-to-farm gate impacts at 3.8 kilograms CO<sub>2</sub> equivalents per kilogram live weight pig. According to this study, other manure management systems lead to a cradle-to-farm gate carbon footprints lower than anaerobic lagoon: liquid slurry management (storage in a tank or earthen pond) is 34% lower, both deep pit storage (manure storage in a pit under slotted floors) and on-pasture manure management result in carbon footprints 41% lower, and solid storage of manure/bedding is 53% lower.

## Research Gaps and Methodological Challenges

Environmental impacts of the pork product chain have been well researched with LCA. Strong U.S. case studies exist, and the best opportunities for reducing pork's environmental footprint are well documented. While consumers may desire to know about differences between retail cuts (ham vs. bacon, for example), this amounts to little more than an allocation problem, and is likely not very useful. Since it is well demonstrated that the impacts of raising pigs dominate the pork life cycle, "whole hog" or "snout to tail" efforts to value and utilize as much of the pig as



possible will result in the lowest impacts per individual cut. It is true that specific pork products will carry additional processing and packaging impacts, but existing evidence suggests that only in extreme cases will these stages compete with the dominance of on-farm production.

A number of perennial methodological challenges that arise in applying LCA to food and agriculture are particularly relevant to the pork product chain. The first is allocation. A number of agricultural production and processing systems generate multiple co-products: soybean processing yields soy oil and soybean meal; wheat milling produces flour and a number of milling by-products; hog processing results in pork meat but also hides, blood and bone meal, etc. Since the processes leading to these co-products cannot be separated, the environmental impacts associated with them must somehow be allocated between the co-products. Thus, different answers can result if co-products are allocated on the basis of mass, economic value, or energy content. The international standards for LCA offer guidance as to how this allocation should occur, but it remains a methodological choice and can complicate comparisons between studies.

Another methodological choice is that of the functional unit – the relative basis for communicating results from the LCA. This is commonly on a product basis, for example per kilogram of live weight pig or per kilogram of boneless pork. But depending on the questions being asked and the perceived “function” of the system, it may be reasonable to consider impacts on a land area basis: per hectare of farmland. As is demonstrated in comparing pig production methods, the choice of functional unit can affect the comparative outcome. Typically we look to LCA to help us understand the environmental efficiency of providing a given product: which stage in the product’s life cycle generates the largest impact? Or which of comparative production strategies is least impactful? But it may also be desirable, in situations where land is not a limiting factor, to determine the relative impact per unit of land. This perspective assumes that impacts spread over a larger area are more easily assimilated by the environment and cause less disruption.

An additional methodological choice is the perspective used in the LCA. Most LCAs are what is called “attributorial”; they address the direct environmental impact of a product in a status-quo situation, resulting from the use of resources and emissions of pollutants directly related to the production of, say, one kilogram of pork. The goal here is to characterize the environmental impacts of a system at a given moment in time. A different perspective, “consequential LCA”, seeks to evaluate the direct *and* indirect environmental consequences of a change in the system, such as a change in farm inputs or a change in the use of farm outputs. Only those processes, both within and outside of the system, that respond to the change are included in the LCA. Here, the goal is to evaluate what happens when we change the system. For example, a

consequential LCA of replacing soybean meal with rapeseed meal in pig feed rations should consider the impact of a change in demand of the feed ingredients. Rapeseed meal is a co-product from the production of rapeseed oil; using it in pig feed results in a reduction of the original applications of rapeseed meal, perhaps use in dairy cow diets. Rapeseed meal in dairy cow diets would then need to be replaced with the marginal product, such as soybean meal. Increasing soybean meal production also results in increased production of soy oil, which is assumed to replace the marginal oil, palm oil, and so on. This procedure obviously requires insight into complex and dynamic market forces, and can therefore be quite difficult.

Attributional and consequential LCAs often point to similar results, but in special cases, they can tell very different stories – both of them “right”, but coming from different perspectives and answering different questions. To demonstrate this, a comparison was made of an attributional and consequential LCA of replacing soybean meal with rapeseed meal in pig diets (van Zanten et al., 2016). From the attributional perspective, replacing soybean meal with rapeseed meal had very small effects on GHGE and energy use, but decreased the required land use per kilogram of pig weight gain by 14%. From the consequential perspective, the replacement led to a 15% increase in GHGE, 12% increase in energy use, and a 10% increase in land use. In other words, according to this study, the indirect environmental consequences of using rapeseed meal were higher than the reduction in impacts due to decreasing soybean meal. These different perspectives serve different purposes: attributional LCA of feeds is useful to farmers and animal nutritionists interested in getting insight into the environmental impact of their feeds. Most of the studies referenced in this summary, including the University of Arkansas feed studies, are attributional. From a broader policy or industry perspective aimed at a mitigation strategy, however, consequential LCA may be preferred, but this must be balanced with the inherent uncertainty of complex market forces on which consequential LCA is dependent.

## Conclusions

Review of the life cycle assessment literature on pork production reveals the following conclusions:

- Environmental impact of the pork product chain is dominated by emissions occurring on or before the farm.
- In most cases, the production of feed is the largest contributor to environmental impacts, including greenhouse gas emissions, energy use, water use, and land occupation. Lower-carbon feeds offer the potential to reduce carbon footprint, although they must be considered very cautiously as there may be higher land use and the potential for consequential impacts.
- Manure management can also be an important contributor. Anaerobic digestion of manures presents an opportunity to improve environmental performance across multiple impact categories. Open, anaerobic manure lagoons *without* methane recovery likely represent the worst manure management option from a GHGE standpoint.
- Multiple studies indicate that when comparing environmental impact per kilogram of pork produced in conventional, commodity production systems versus alternatives such as deep-bedded, organic, or pasture-based, differences are either small or favor the intensive commodity production system. Some studies also demonstrate greater variability between

farms in the alternative production systems (compared to conventional), suggesting that efficiency improvements may be possible.

- Opportunities to reduce environmental impacts through optimizing feed rations likely involves trade-offs between impact categories, and also appears to be context dependent.
- Recycling food waste as pig feed shows promising environmental benefits, although may currently be restricted by policy and perception.
- Packaging, distribution and retail stages contribute minimally to the environmental impacts of the pork chain.
- Refrigeration and home cooking appear to be significant contributors to the overall carbon footprint of pork. Consumers can reduce the impacts of pork by minimizing waste through buying habits (purchasing only what can be consumed or freezing), cooking habits (preparing only what can be consumed) and eating habits (minimizing plate scraps and eating leftovers). Energy efficient home appliances can also reduce impacts at the household level.

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