Life cycle assessment of alternative swine management practices

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ABSTRACT: Life cycle assessment of various alternative management strategies in the swine industry was performed to evaluate their impact on greenhouse gas (GHG) emissions, cumulative energy use, and cumulative water use. The management strategies included the use of immunocastration (IC), production without ractopamine (NoRAC), production without antimicrobials used for either growth promotion (NoAGP) or disease prevention (NoPREV), production of entire males (boars) (EM), and use of gestation pens (PENS). A common baseline scenario representing standard management practices in the swine industry was created against which all alternative management practices were compared pairwise. The study scope was from cradle-to-farm gate with a functional unit of 1 kg live weight at the farm gate. The baseline and each alternative management scenario was simulated in Pig Production Environmental Footprint Calculator (PPEC) model by varying key variables to populate life cycle inventory inputs for SimaPro V7.3 (Pre' Consultant, the Netherlands), a life cycle assessment modeling program. Increase in GHG emissions, energy use, and water use were observed for NoAGP (1.56, 1.75, and 1.03%, respectively), NoPREV (17.32, 18.40, and 15.58%, respectively),

and NoRAC (6.52, 4.87, and 7.52%, respectively) scenarios. For EM scenario, GHG emissions and energy use increased by 2.09 and 3.75%, respectively but water use decreased by 2.29%. Lower GHG emissions, energy use, and water use were observed for PENS (0.97, 1.50, and 0.97%, respectively) and IC (2.39, 2.57, and 2.96%, respectively) scenarios. These changes in the impact categories were statistically significant ($P < 0.05$) for all scenarios except for changes to GHG emissions for EM and changes to water consumption for PENS and NoAGP. However, the uncertainty analysis showed that the tails of distribution for baseline and alternative management scenario pair overlapped. The impact of management practices on sustainability metrics resulted from differences in pig performance parameters, manure production, feed consumption, etc. between various management practices and the baseline scenario. Due to uncertainties in input parameters, the results should be interpreted as general trends which specifically highlight trade-offs that may result from shifts in production practices. The study identified some of the hot spots in pig production and can be useful in determining best management practices to make swine production more environmentally sustainable.

Key words: life cycle assessment, management practices, sustainability, swine

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INTRODUCTION

There is an increasing awareness of the need to evaluate the sustainability of pork production

systems using a system-level analysis. Pork producers in the United States are facing unprecedented pressure from special interest groups, regulatory agencies, and supply chain customers to demonstrate improvements across sustainability metrics including animal welfare. There is a demand for changes to some of the management practices prevalent in the swine industry and the industry is responding to these pressures. In 2002, Florida banned the use of sow gestation crates through a voter referendum and a similar ban was imposed on the swine industry in Arizona in 2006 (Mench, 2008). In 2007, [Smithfield Foods Inc. \(2007\)](#) announced a phase out of gestation stalls on company-owned farms over the next 10 yr and replace them with group pens. The company reported in January 2018 that it has fulfilled this commitment and has recommended its contract sow growers in the United States to provide group housing to pregnant sows by the end of 2022 ([Smithfield Foods Inc., 2018](#)). However, it is important to understand that even small production changes might have large environmental impacts. If the changes to management practices are based on a single measurement criterion, it could result in undesirable outcomes across other metrics. Therefore, assessment of impact trade-offs associated with change to production practices is necessary to ensure continual progress towards more sustainable production. Life cycle assessment (LCA) has proven to be a powerful tool for this assessment.

LCA provides quantitative management models to evaluate production processes, analytical options for innovation, and improved understanding of complexity in agricultural systems. Life cycle assessment in the swine industry holds the promise of identifying inefficiencies in the system and changes to the sustainability metrics resulting from possible changes in management practices, which can be addressed to foster the long-term health of the industry.

The objective of this study was to quantify differences or establish the absence of differences in the global warming potential (GWP), cumulative energy demand, and cumulative water consumption between current practices and proposed alternatives in U.S. pork production. Alternative management practices included the use of: immunocastration replacing surgical castration, removal of ractopamine from diets, removal of antimicrobials as growth promoters, removal of antimicrobials to prevent emergence of herd infection in addition to removal as growth promoters, use of pen gestation, and split sex management of boars.

METHODS

This study compared global warming potential (GWP), cumulative energy use, and cumulative water use for 6 alternative management practices against a common baseline. A common baseline scenario was defined which represents current industry practice. Each scenario evaluated a single alternative management practice, in which 1 key element was different from the baseline scenario. The scope of the study was from cradle (crop, fertilizer, and fuel production) through farm gate with a functional unit of 1 kg live weight at the farm gate.

Description of Models

Assessment and comparison of alternative management practices involved a 2-step process. In the first step, nursery, grow-finish, and sow barns were simulated using the Pig Production Environmental Footprint Calculator (PPEC) model ([National Pork Board, 2011](#)). The PPEC model uses growth performance model developed by the National Research Council (NRC) to predict growth and feed consumption of pigs ([National Research Council, 2012](#)). The PPEC model simulates: pig growth, feed intake and water consumption, electricity, and natural gas use in each barn, manure handling, and greenhouse gas emissions over an annual cycle. Growth and feed conversion performance of pigs, resource consumption, and emissions to the environment were simulated using PPEC model. Outputs of these simulations were used as lifecycle inventory in the second step: LCA using SimaPro V7.3 (Pre' Consultant, The Netherlands).

The SimaPro software platform was used to compare each management scenario to the baseline and for uncertainty analysis. The EcoInvent database, corrected for U.S. electricity, was used for background processes ([EarthShift, 2011](#)).

Scenario Description

Production barns were simulated for Wright County, Iowa to provide a representative location for the Typical Meteorological Year (TMY). As mentioned, different production phases are stimulated independently and combined using SimaPro to provide a cradle-to-farm-gate impact. Life cycle inventory data required for the scenario simulations were obtained from peer-reviewed literature and from reports provided by a National Pork Board Task Force (Des Moines, Iowa, USA, personal communication). The National Pork Board Task Force provided expert opinion related to animal

performance for various scenarios simulated in this study. The NPB Task Force provided data on potential changes to pig performance parameters such as ADG, daily feed intake (DFI), pig mortality for removal of ractopamine, and removal of antimicrobial scenarios and litter size and preweaning mortality for use of pen gestation. These data were used in combination with data obtained from peer-reviewed literature. An underlying assumption for all scenarios is that the total sectorial output remained constant, that is these scenarios do not change overall demand. Therefore, changes leading to reduced (e.g., higher mortality rate) or increased production were scaled to provide the same total domestic supply of pork.

Baseline scenario. The baseline scenario included surgically castrated male pigs (barrows) and female pigs in equal numbers and included growth promoting antimicrobial (AGP) 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. According to National Pork Board

Task Force (2012, unpublished data), pigs spend approximately 42 d in wean-to-feeder barn and 114 d in feeder-to-finish barn. Therefore, the metabolizable energy requirement (MMER) of pigs, in both wean-to-feeder and feeder-to-finish phases, was adjusted, with barn temperature set to a constant 20 °C, to achieve the or recommended days in barn under ideal conditions. These adjustment factors were used throughout the study for all scenarios. For scenario simulation, hourly data from a Typical Meteorological Year (TMY) ([National Solar Radiation Database, 2005](#)) was used. The PPEC model controlled temperature inside the barn using simulated heating and/or cooling systems. A standard diet for all management scenarios was developed following recommendations from a swine nutrition specialist at the University of Arkansas ([Table 1](#)). Differences in diet requirements of pigs in various growth phases were captured by modeling wean-to-feeder pigs, feeder-to-finish pigs, gestating sows, and lactating sows as distinct systems. The standard diet for feeder-to-finish pigs included 0.05% Paylean-9 that provided 10 ppm ractopamine in the last 4 wk ([See et al., 2004](#); [Rikard-Bell et al., 2009](#)).

Table 1. Diet formulation (% of dry feed) used for life cycle assessment of alternative management practices in the United States for breeding and market pigs

[illegible]

Table 2. Baseline scenario for market pigs

	Units	Wean-to-feeder	Feeder-to-finish
Age when pigs enter the barn	Days	21	
Weight when pigs enter barn	Kg	5	23
Weight when pigs leave barn	Kg	23	125
No of pigs entering barn each cycle		500	500
Mortality rate		2.9%	3.9%
Floor space per pig	m ²	0.23	0.696
Heating and cooling system		Tunnel Ventilation	Tunnel Ventilation
Heating Fuel		Natural Gas	Natural Gas
Maximum total throughput of all fans	cfm	282000	282000
Manure system		Deep Pit	Deep Pit

It was assumed that pigs had ad libitum access to water. Pig mortality was set to 2.9 and 3.9% for wean-to-feeder and feeder-to-finish barns, respectively (Table 2). All pigs were marketed at 125 kg.

While the grow barn was an all-in all-out batch operation, the sow barn was simulated as a continuous operation, housing 1,500 animals at any time in individual gestation crates. Litter size for the baseline scenario was set to 10.5 piglets per year with 8.08 piglets surviving to weaning (Table 3). Based on the data reported by Bates et al. (2003), it was estimated that sows will be inseminated 16 d following piglet removal.

Ractopamine (NoRAC). Ractopamine is a dietary supplement, which improves ADG and feed efficiency (FE, ratio of average daily gain to daily feed intake) in finishing pigs (Dunshea et al., 1993; Armstrong et al., 2004; Hinson et al., 2011; Barbosa et al., 2012). Without RAC, reduced ADG and FE is observed, which results in a longer time to reach market weight and higher daily feed intake (Armstrong et al., 2004; Patience et al., 2009; Rikard-Bell et al., 2009; Hinson et al., 2011; Barbosa et al., 2012; Lanferdini et al., 2013). To simulate the effects of removal of RAC, Paylean-9 was replaced with an equivalent mass of corn in the last phase in grow-finish diet.

Antimicrobials. Antimicrobials are used in animal industry for disease prevention and animal health improvement (Ross et al., 2010), and as growth promoters (Kiarie et al., 2011). Two scenarios included in this study evaluated impacts associated with elimination of antimicrobial growth promoters (AGP) and elimination of both growth promoting and preventive antimicrobial use from productions.

Production without growth promoting antimicrobials (NoAGP). Studies reported lower ADG and lower FE when antimicrobial use was eliminated from the nursery phase (Dritz et al., 2002; Keegan et al., 2005; Hahn et al., 2006; Gottlob et al., 2007;

Table 3. Production parameters used for baseline scenario

Parameter	Units	Sow Barn
No. of piglets per litter surviving to weaning	Animals	8.08
No. of pigs dying per litter before weaning	Animals	2.42
Age at which piglets are removed from barn	Days	21
No. of days between piglet removal and insemination	Days	16
Piglet birth weight	Kg	1.5

Li et al., 2008; Shen et al., 2009; Choi et al., 2011; Kiarie et al., 2011; Wang et al., 2011; Lee et al., 2012; Yoon et al., 2013). Williams et al. (1997) estimated 12.7% increase in the maintenance metabolizable energy requirement (MMER) of low health status wean-to-feeder pigs compared with high health status pigs. To simulate elimination of AGP from the production in nursery phase, the MMER of wean-to-feeder pigs was increased by 12.7%. Pig performance parameters in grow-finish phase of the production were assumed to be unaffected by elimination of AGP. However, elimination of AGP was estimated to result in fewer pigs reaching expected market weight and therefore, the voluntary cull rate in nursery and grow-finish barns was increased to 0.25% for median health facilities (NPB Task force, 2012, unpublished data). Mortality rate for this scenario was increased by 0.2% in the nursery phase. No changes due to elimination of AGP were anticipated on other performance factors, such as diet formulation or average vet visits.

Production without growth promoting and preventing antimicrobials (NoPREV). Effects of production without use of either AGP or preventive antimicrobials on performance and sustainability metrics were studied in this scenario. When herd health starts trending downward, antimicrobials are commonly used prophylactically to reduce the chance of herd-wide infection. Whittemore et al. (2001) reported that chronic diseases in pigs increase the MMER by up to 30% above normal.

In the current scenario, it was assumed that elimination of preventive antimicrobials would only result in lower ADG and FE but would not necessarily result in herd-wide sickness. This reduced ADG and FE was simulated by increasing MMER of pigs by 12.7% (Williams et al., 1997) and 15% in wean-to-feeder and feeder-to-finish pigs, respectively. Without AGP and preventive antimicrobials, voluntary cull rate and mortality were each estimated to increase by 4% in the nursery barn. In grow-finish barns, without AGP or preventive antimicrobials, 5 and 5.5% increases were estimated in voluntary cull rate and mortality, respectively. The term mortality is used when animals die of natural causes. Voluntary cull rate on the other hand refers to sick animals that are euthanized if they do not respond to therapeutic antibiotic treatment.

Castration

Immunocastration (IC). Surgical castration of male pigs without anesthesia within first 1 to 2 wk of age is a standard industry practice (FAO, 1994; Thun et al., 2006). Castration removes boar taint, improves meat quality, and suppresses aggressive behavior in pigs (Dunshea et al., 2001; Thun et al., 2006; Morales et al., 2010). However, surgical castration is under scrutiny of animal welfare groups because the procedure inflicts pain and distress (Morales et al., 2010; Millet et al., 2011). An alternative to the surgical castration is immunocastration, in which male pigs are administered a dose of gonadotropin-releasing hormone (GnRH). The GnRH reduces skatole production in pigs, which is responsible for boar taint. Dunshea et al. (2001) reported that immunocastration reduces the size of testes in male pigs suppressing aggressive sexual behavior. Pfizer Pharmaceuticals Inc. recommends administering GnRH at about 9 wk of age and followed by a second dose at least 4 wk after the primary dose (Zoetis United States, 2016). Slaughter is scheduled between 3 and 10 wk following the second dose to avoid boar taint.

Until the second dose of GnRH compound, male pigs grow at a similar rate to boars, showing improved ADG and FE compared with surgically castrated pigs (barrows) (Batorek et al., 2012), after which, they show performance similar to barrows. Therefore, immunocastration (IC) scenario was created in PPEC model by simulating a split sex barn with equal number of boars and gilts. For boars, the NRC growth model as a lower metabolizable energy intake (MEI) requirement than that for barrows. It also simulates higher protein deposition rate in boars than barrows. Due to lower MEI and higher protein deposition, boars grow with better FE and

higher muscle mass compared to barrows. After the second GnRH dose, however, IC pigs show growth patterns similar to barrows. To capture this effect, PPEC model was configured to simulate a second dose of GnRH when pigs reached body weight of 88 kg (Fabrega et al., 2010) by increasing MEI by 21% and reducing MMER and protein deposition by 12 and 8%, respectively (National Research Council, 2012). At a body weight of 96 kg, IC pigs were supplemented with 10 mg RAC per kg of feed by adding 0.05% Paylean-9 in the diet. No changes to the diet were made for IC scenario.

Entire males (EM). For the uncastrated (entire) male (EM) scenario, inputs similar to the IC scenario were used with exceptions of administration of GnRH inhibitors and use of RAC in diet. Based on expert opinion (Bill Close, Closes Consultancy, UK, personal communication) EM pigs were marketed at 91 kg of body weight to avoid boar taint in the meat. Female pigs in the barn, however, were marketed at 125 kg.

Gestation pens (PENS). Use of gestation stalls for housing pregnant sows has been criticized by animal welfare groups because the stalls restrict the animals' movement (Lammers et al., 2007). Environmental impact trade-offs associated with using gestation pens in place of stalls are studied in this scenario. Use of pens was assumed for gestation period only. It was assumed that farrowing stalls were used for both group and individual stalls scenarios. The modeled performance differences between sows housed in gestation stalls and group pens were the number of live births, litter size, preweaning mortality, and piglet weight at birth. An analysis of data obtained from peer-reviewed articles (Schmidt et al., 1985; Bates et al., 2003; McGlone et al., 2004; Anil et al., 2005; Harris et al., 2006; Jansen et al., 2007; Lammers et al., 2007; Weng et al., 2009) was performed to prepare scenarios for group and gestation housing (Table 4). Preweaning mortality of 14 and 15% (Lammers et al., 2007) were used for stalls and group pens, respectively.

Table 4. Production parameters used for gestation pens scenario

Parameters	Units	Sow Barn, pens
No. of piglets per litter surviving to weaning	Animals	7.88
No. of pigs dying per litter before weaning	Animals	2.47
Age at which piglets are removed from barn	Days	21
No. of days between piglet removal and insemination	Days	14
Piglet birth weight	Kg	1.53

Bates et al. (2003) reported that 72% of sows housed in group returned to estrus within 7 d of weaning compared with 68% of sows in gestation stalls. In addition, 94% of group housed sows remained pregnant after initial service compared with 89.4% of sows in stalls. These differences were captured in PPEC model by adjusting the average number of days between piglet removal and insemination to 14 and 16 for group and stall housing, respectively.

Uncertainty Analysis

One of the sources of uncertainty in this analysis was from the data used to parameterize the model and analyze the system. A few parameters in PPEC model were changed, especially for use of gestation pens and production without antimicrobials, using the data obtained from various sources. Feed consumption, manure production, number of days to market weight, etc. predicted by model are influenced by growth rate, feed conversion ratio, and mortality rate. Any uncertainty in data used to alter the model parameters would affect the results of PPEC model. For this study, it was assumed that pigs were kept in medium health facility. Hygienic conditions maintained in barns can improve or degrade pig performance and pig mortality, especially for production without antimicrobials. This uncertainty in data was addressed in the study by performing uncertainty analysis using Monte Carlo simulations. The uncertainty analysis provided a confidence interval around the means for each of the management practices.

An uncertainty analysis for baseline and each of the alternative scenarios in the comparative study was performed using Monte Carlo simulation to assess robustness of the results. Beginning from the average values of ADG, daily feed intake (DFI), FE,

water consumption, and mortality rates used in the comparative study, 2 additional parameter sets for each scenario and the baseline were prepared. The model parameters were adjusted, within their respective ranges, to obtain extremes in the environmental footprint for each scenario. For example, one of the parameters affecting pig growth is MMER. For a given body weight, MMER can vary between $191 \times \text{BW}^{0.6}$ kcal to $215 \times \text{BW}^{0.6}$ kcal, with average of $197 \times \text{BW}^{0.6}$ (National Research Council, 2012). This gives a range of MMER values, which could be 3% lower or 9.65% higher compared with the mean value of $191 \times \text{BW}^{0.6}$ kcal used for the comparative analysis. This range was used to define a lognormal distribution about the mean value for the Monte Carlo simulations (MCS). Pigs simulated with lower MMER grew faster and lower GWP was observed per kilogram live weight. Increasing MMER on the other hand increases the energy requirement for body maintenance and leads to slower growing pigs which in turn increases GWP. Therefore, MMER in NRC growth model was lowered by 3% and increased by 9.65% to provide distribution of life cycle inventory (LCI) about the mean value for MCS. Changes to mortality rate and voluntary cull rate were also made following the recommendations of the National Pork Board (Table 5). For sow barns, scenarios yielding maximum and minimum GWP were prepared using maximum and minimum numbers for preweaning mortality, pigs born alive, and litter birth weight (Table 6).

A pair-wise bootstrap hypothesis testing was used to evaluate statistical differences between baseline and alternative management scenarios (Neave and Granger, 1968). The bootstrap method involved randomly selecting, with replacement, 300 of 1,000 MCSs for each impact category of a baseline and alternative management scenario pair and performing a paired two-tailed t-test on this sample. This procedure was

Table 5. Changes made to mortality rate and voluntary cull rate for uncertainty analysis of antimicrobial use scenarios

Parameter	Units	Minimum impact	Maximum impact
No growth promoting antimicrobials			
Change to mortality rate (nursery)	%	0	2
Change to mortality rate (grow-finish)	%	0	1
Change to voluntary cull rate (nursery)	%	0	2
Change to voluntary cull rate (grow-finish)	%	0	1
No preventative antimicrobials			
Change to mortality rate (nursery)	%	2	15
Change to mortality rate (grow-finish)	%	0	10
Change to voluntary cull rate (nursery)	%	2	6
Change to voluntary cull rate (grow-finish)	%	0	10

Mortality rate for uncertainty analysis was sum of respective mortality rates used for comparative analyses (2.9% for nursery; 3.9% for grow-finish) and changes to the mortality and voluntary cull rate

Table 6. Sow barn parameters used for uncertainty analysis for gestation stalls and group housing

Parameter	Units	Minimum impact	Maximum impact
Gestation stalls			
No. of piglets per litter surviving to weaning	Animals	9.09	7.31
No. of pigs dying per litter before weaning	Animals	1.91	3.59
Age at which piglets are removed from barn	Days	21	21
No. of days between piglet removal and insemination	Days	16	16
Piglet birth weight	kg	1.53	1.31
Gestation pens (group housing)			
No. of piglets per litter surviving to weaning	Animals	9.03	6.33
No. of pigs dying per litter before weaning	Animals	1.77	3.18
Age at which piglets are removed from barn	Days	21	21
No. of days between piglet removal and insemination	Days	14	14
Piglet birth weight	kg	1.64	1.48

Table 7. Environmental impact estimates for baseline and alternative US swine management practices, reported per kg live weight at the farm gate

	IPCC GWP 100 ^a (kg CO ₂ e)	Nonrenewable, fossil (MJ)	Water (m ³)
Baseline	3.37	21.99	0.18
Entire Males	3.44 ^c	22.81 ^b	0.17 ^b
Gestation Pens	3.34 ^b	21.66 ^b	0.18 ^c
Immunocastration	3.29 ^b	21.43 ^b	0.17 ^b
No Growth Promoting	3.43 ^b	22.37 ^b	0.18 ^c
No Preventive	3.96 ^b	26.04 ^b	0.21 ^b
No Ractopamine	3.59 ^b	23.06 ^b	0.19 ^b

^aGWP calculated for 100-year horizon.

^bDifference in means of a sustainability metric between a scenario and the baseline is statistically significant ($P < 0.05$).

^cDifference in means of a sustainability metric between a scenario and the baseline is statistically nonsignificant ($P > 0.05$).

repeated 300 times and 95% confidence interval was built around the P -values. The differences in means were statistically significant if the P -values were smaller than the 95% confidence interval.

RESULTS AND DISCUSSION

Comparative LCA

Results of comparative LCA for GWP (kg CO₂e), nonrenewable energy use (MJ), and cumulative water use (m³) are represented in Table 7. For the baseline scenario, 1 kg of live pork at the farm gate resulted in global warming potential of 3.37 kg CO₂e. The major contributors to GWP were feed production and emissions from manure storage. Cumulative energy- and water use for the baseline were 21.99 MJ and 0.179 m³, respectively. Average daily gain and DFI were 0.29 and 0.44 kg d⁻¹ for the wean-to-feeder phase and 0.78 and 1.74 kg d⁻¹ for a feeder-to-finish phases, respectively.

Each management strategy was evaluated based on the changes in the associated environmental impacts resulting from changes in unit processes. Analysis of changes in environmental impact

category metrics showed that some strategies increased impacts, while others decreased impacts (Fig. 1 through 3). These analyses are simulated estimates of impacts, based on literature and expert opinion regarding operating performance associated with each management practice, and should be interpreted as trends rather than absolute estimates.

Removal of ractopamine. This change in management resulted in increases for GWP, cumulative energy use, and cumulative water use of 6.52, 4.87, and 7.52%, respectively. The driving factor for increased impact across all sustainability metrics was reduced animal performance. The model simulations showed that without added ractopamine, ADG was reduced by 5% (0.78 kg d⁻¹ for baseline; 0.72 kg d⁻¹ for NoRAC), and DFI increased by 3.5% (1.8 kg d⁻¹ for baseline; 1.74 kg d⁻¹ NoRAC). Due to reduced ADG, pigs raised without ractopamine required 11 additional days in the grow-finish barn to reach 125 kg. The reduced DFI and extra time required in barn resulted in increased feed consumption, increased manure production, and fewer production cycles per year. To support the same annual production, a small increase in necessary barn infrastructure was also required.

Figure 1. Estimated potential change in greenhouse gas emissions for alternative management practices. The horizontal line represents the project baseline production scenario.

Figure 2. Estimated potential change in cumulative nonrenewable energy use for alternative management practices. The horizontal line represents the project baseline production scenario.

Removal of antimicrobials. When growth promoting antimicrobials were removed from production, GWP increased to 3.43 kg CO₂e, cumulative energy use increased to 22.37 MJ, and cumulative water use increased to 0.18 m³. This was 1.56% increase in GWP, 1.75% increase in energy use, and 1.04% increase in water use. When preventive use of antimicrobials, in addition to AGP, was eliminated GWP, cumulative energy use, and cumulative water increased use by 17.32, 18.40, and 15.58%, respectively. The “no preventative use” scenario yielded GWP of 3.96 kg CO₂e, energy use of 26.04 MJ, and water use of 0.21 m³.

Changes in sustainability metrics for both scenarios were a result of reduced AGP and increased daily feed intake (DFI) in pigs. Removing AGP decreased ADG by 8% and increased DFI by 0.52% in wean-to-feeder pigs. This effect was further increased with the additional elimination of preventative antimicrobials which decreased ADG by 10% in wean-to-feeder pigs and by 5.1% in feeder-to-finish pigs compared to the baseline. These changes in ADG and DFI increased total feed used in wean-to-feeder phase by 1.4%. For this scenario, higher voluntary cull rate and mortality rate were used in both wean-to-feeder and feeder-to-finish phases.

Figure 3. Estimated potential change in cumulative water use for alternative management practices. The horizontal line represents the project baseline production scenario.

Higher mortality in pigs combined with decreased performance resulted in fewer production cycles per barn each year compared with baseline and thus fewer pigs reaching market weight per facility. While 1,300 pigs were marketed per year for the baseline scenario, only 1,297 and 1,105 pigs reached market weight for NoAGP and NoPrev scenarios, respectively. Decreased animal production per barn results in a requirement for additional infrastructure to meet annual demands, which incurs added emissions and environmental impact.

Immunocastration. Use of immunocastration as a replacement of surgical castration reduced GWP to 3.29 kg CO₂e, energy use to 21.43 MJ, and water use to 0.174 m³. This is 2.39, 2.57, and 2.96% reduction in GWP, energy use, and water use, respectively. Better sustainability metrics observed for this scenario were attributed to increased ADG and FE. In the wean-to-feeder phase, ADG in pigs improved by 5.61%. This improved ADG was a result of benefits of better FE observed in uncastrated pigs. While ADG did not change much in the feeder-to-finish phase, the DFI decreased by 3.1% which led to an overall decrease of 1.81% in total feed used for the wean-to-feeder operation. Immunocastration of pigs also reduced electricity and natural gas use by 1 and 5.98%, respectively. Improved pig performance resulted in less overall feed consumption and manure production as well as a small reduction in necessary barn infrastructure associated with the faster average turn-around for the barns.

Gestation pens. Using group gestation pens rather than individual stalls resulted in a decrease in GWP, energy use, and water use compared with the baseline. Global warming potential, energy use, and water use decreased by 0.97, 1.5, and 0.97% when pen gestation was used. The NRC growth equations for gestating sows include a smaller impact of temperature on MMER for group housed sows, which reduces maintenance energy requirements, leaving more energy available for fetus development and weight gain. Therefore, better sustainability metrics observed in this scenario were the result of better performance of sows, lower feed consumption and lower manure emissions. Use of gestation pens reduced overall feed consumption for 500 sows by 1.92%, or 37,758 kg of feed per year. It also reduced CH₄ emissions by 2.9% and N₂O emissions by 2.1%; however, based on our modeling of the space requirements for sow in stalls compared to pens, the barn infrastructure requirements for pens are 65% larger. This additional infrastructure requirement increases the GWP, which, amortized over an expected 10-yr life of the barn, partially offsets the lower operational GWP observed for this scenario.

Production of boars. This scenario was evaluated by stimulating the growth of boars (uncastrated males) to 91 kg and gilts to 125 kg and resulted in 2.09% increase in GWP, 3.75% increase in energy use, and 2.25% decrease in water use. While entire males have an advantage of leaner body composition, this was not captured in the scenario because a functional unit of 1 kg live weight at the farm

gate was used. Production of entire males offered slightly better ADG and FE compared with the baseline. Average feed efficiency for the combined her of entire male and gilts improved over the baseline by 3.14 and 1.47% for wean-to-feeder and feeder-to-finish scenarios, respectively. Overall, annual feed consumption was 7.65% lower compared with the baseline. Since feed is a major contributor to greenhouse gas emissions, reduced annual feed consumption is expected to reduce GWP. Therefore, higher GWP observed in this scenario appears to be associated with a larger number of pigs required to reach annual live weight production demand. The animal number-weighted average market weight of pigs for this scenario was 108 kg compared with 125 kg for the baseline scenario. For smaller animals, higher fossil fuel consumption appears to be associated with a 5% increase in annual natural gas use observed for the feeder-to-finish phase needed to maintain barn temperatures at suitable levels. Smaller animals do not generate as much body heat and will, in general, have a larger surface area to weight ratio, requiring somewhat more heating energy from external sources.

Uncertainty Analysis

An uncertainty analysis was performed using 1,000 pairwise Monte Carlo simulations for which the background processes were held invariant for the comparison. Environmental impact categories for each of the management strategies were compared with the baseline and confidence intervals were created. Figures 1 through 3 summarize the Monte Carlo simulations for each alternative management scenario. These figures show baseline results as horizontal blue lines and the range of the paired Monte Carlo simulations, as differences from the baseline, are shown as box and whisker plots. Interpretation of these graphs is important because this analysis is an indication of the robustness of conclusions that can be made from the study. The horizontal lines of each box represent the 25th, 50th, and 75th percentiles of 1,000 Monte Carlo simulations and lower and upper extensions represent 10th and 90th percentiles, respectively. Where the simulations represented by box and whisker lie above the horizontal line, the alternative management practice resulted in an increase in environmental impact. On the other hand, where simulations lie below the horizontal line, the alternative management practice resulted in a decrease in environmental impact.

Uncertainty analysis shows that the predicted changes to GWP and cumulative water use can be concluded with 75% confidence for: IC, NoPrev, and production without ractopamine scenarios. The predicted changes to GWP cannot be considered robust for the production of entire males, production without growth promoting antimicrobials, and gestation pen scenarios-specifically, the significant overlap of the range of outcomes for the alternative scenarios with the baseline suggests only directionality, but not statistical significance. This indicates a strong sensitivity to specific implementation practices for each scenario. The predicted changes to cumulative nonrenewable energy use can be concluded with 75% confidence only for NoAGP, NoPrev, and NoRAC scenarios.

A statistical analysis indicated that differences in means of sustainability indices between baseline and alternative management scenarios were statistically significant ($P < 0.05$) for all scenario pairs, except for GWP for EM and water consumption for PENS and NoAGP (Table 7). However, it is important to understand that while the means were statistically significant, the tails of distribution of baseline and alternative management scenario pairs overlapped for EM, PENS, IC, NoAGP, and NoRAC scenarios as shown in uncertainty analysis.

Changes in sustainability metrics observed in this study resulted from changes to parameters such as manure production, total number of pigs marketed annually, growth parameters such as ADG and DFI, nonrenewable energy use, and water use induced by alternative management practices used. There were improvements across sustainability metrics when surgical castration was replaced with immunocastration and when gestation pens were used instead of stalls. However, GWP, energy use, and water use increased when antimicrobials and ractopamine were removed. This strongly suggests that if swine management practices are changed based on only one measurement criterion, it could bring undesirable outcomes across other metrics. Concerns about food safety, human health, and animal welfare are valid, but it is also important to understand relationships and trade-offs or synergy between addressing those concerns and maintaining or improving environmental impacts. This understanding enables informed decisions about changes in management.

Limitations

We recommend caution while interpreting the results of this study due to model uncertainties.

One of the sources of uncertainty in this analysis was the production model used for simulation of swine production facility. The PPEC model uses growth and nutrient requirement models developed by NRC, which are mechanistic models but also contain empirical elements (National Research Council, 2012). The empirical elements in the model do not account for influence of genetic differences or genealogical advances in various breeds of pigs in terms of parameters such as growth rate, feed conversion, lean content, immunity, etc. The NRC model can be adjusted to account for the influence of animal activity or genetic differences. However, quantification of these differences on animal growth and adjustment to the NRC model was out of scope for this study. These genetic differences in breed can influence sustainability metrics. For example, slower growth, increased mortality, and voluntary cull rate were assumed without antimicrobials use. However, pigs with better immunity or genetically lower susceptibility to certain diseases could overcome these problems. Therefore, to compensate for these differences, the same model was used to simulate all management practices, including the baseline. This ensured that model bias was not introduced into the comparison.

These results are the product of simulation of pork production strategies combined with unit process LCAs. These models are very sensitive to time in barn at each growth phase, rates of conversion of feed to body weight, and mortality rates. Model uncertainty is difficult to characterize due to lack of access to the observational data for which the pork production models were calibrated and the limited LCI data for alternative production strategies. It is therefore important to interpret these results as trends rather than absolute differences reported.

CONCLUSION

Life cycle assessment of 6 pork production strategies for 3 environmental impact categories yielded a range of results from a 17% increase in global warming potential for removal of AGP and preventive antimicrobials to a 2.5% reduction in energy use for immunocastration. Based on comparative and uncertainty LCA results, production without growth promoting and preventive antimicrobials and production without ractopamine increased GWP and cumulative water use. Cumulative nonrenewable energy use increased for production without growth promoting antimicrobials, production without growth promoting and preventive antimicrobials, and production without ractopamine.

There are increasing pressures on swine producers to modify their production practices based on public perception. Sustainability is inherently a multidimensional and complex concept that is difficult to fully quantify. Furthermore, there will frequently be trade-offs among the dimensions of sustainability because of changes in production practices. The study indicates that small changes made to production practices in the swine industry can affect sustainability metrics. Therefore, it is important to understand the effects of changes to management practices on overall sustainability, with a full and transparent accounting of potential trade-offs, decisions to change management practices are implemented.

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