Title: LCA of Alternate Swine Management Practices – **NPB #12-207**

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Industry Summary:

Life cycle analyses of eight pork production strategies for three environmental impact categories yielded a range of results, from a 17 percent increase in global warming potential (removing preventative antimicrobials) to approximately 3 percent reduction in energy use (immuno-castration). Based on the LCA results, the following pork production strategies increased environmental impact metrics across all three impact categories: Anesthesia, not using antimicrobials for growth promotion or disease prevention. Conversely, using immuno-castration, entire male production and pen gestation production strategies decreased global warming potential and energy use, and immuno-castration reduced water use. These results are the product of simulation of pork production strategies combined with unit process LCAs; these models are very sensitive to time in the barn at each growth stage, rates of conversion of feed to lean meat, and mortality rates. Model sensitivity and uncertainty are difficult to characterize due to the limited observational data for which the pork production models were calibrated, and the limited Life Cycle Inventory data for alternative production strategies.

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LCA of Alternate Swine Management Practices

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pork checkoff

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Executive Summary

Project Goal

Life Cycle Assessments (LCAs) are quantitative analyses of complex systems for evaluation of impacts and risks associated with management decisions. LCAs can be effective tools for determining comparative advantages of management strategies across specific impacts of concern. The University of Arkansas performed a series of LCAs on pork production management alternatives for the National Pork Board Environmental Committee (Table ES-1). These LCAs evaluated the impact of each management strategy on three environmental impact categories: greenhouse gas emissions (GHG), cumulative energy use, and cumulative water use (Table ES-2).

Table ES - 1: Alternate Pork production management strategies evaluated in the LCA

Management Strategy	Description
1. Anesthesia	Use of anesthesia or pain modifier medication when performing castration or tail docking
2. Immuno-Castration	Use of immune-castration methods/product(s)- Improvest®
3. No ractopamine	Removal of ractopamine (RAC) as a tool to improve growth and production
4. No GP Antimicrobials	Removal of antimicrobials as growth promoters (GP)
5. No Prev. Antimicrobials	Removal of antimicrobials to prevent (Prev) emergence of herd infection in addition to removal of GP antimicrobials
6. Pen Gestation	Use of pen gestation housing (2 scenarios[1,2])
7. Boars (entire males)	Split sex management without surgical- or immuno-castration
8. Euthanasia	Use of alternative methods of euthanasia

[1]Based on McGlone et al., 2004 data; [2] Based on Lammers et al., 2007 data

The goal of this project was to evaluate differences in impact category metrics of each of the pork production management strategies compared against a baseline or control production management strategy broadly representative of the current industry average management. The scope of the study was from cradle (crop

Table ES - 2: Environmental impact categories used to evaluate pork production management strategies

Environmental Impact Category	Unit	Description
Global Warming Potential (GWP)	kg CO_2e	Greenhouse gas emissions based on IPCC GWP 100a
Cumulative Energy Demand	MJ	Non-renewable fossil fuel consumed by process
Water Use	m^3	Total volume of water consumed by process

and fuel production) through the farm gate. The functional unit for the analysis was one kilogram of edible meat at the farm gate, defined as lean, bone-free edible portion.

Project Approach

The approach used for evaluating the impacts of pork management strategies was to simulate each practice using the National Pork Board Pig Farm Model to create lifecycle inventory inputs for unit processes for SimaPro V7.3 (Pre' Consultants, The Netherlands), an LCA modeling program. The Farm Model was adjusted to match key performance variables (Table ES-3) and each pork production management scenario was compared against the baseline scenario. For male pigs the base scenario included surgical castration and tail docking performed in the lactation barn, growth promoting (GP) antimicrobial use in the nursery, preventive antimicrobial use as required, and ractopamine use in grow-finish barn. Ractopamine was supplemented to the pigs through diet during the last 28 days in the grow-finish barn. The baseline scenario for gilts was the same as for males, except, of course, without castration in the lactation barn. The post-weaning growth performance, for all scenarios except for immune-castration and entire males, did not differentiate between gilts and barrows. The baseline pork production management practice against which all alternatives were compared was a representative scenario including gestation and lactation in a sow facility and three post-weaning growth stages: Wean-to-Feeder, Feeder-to-Finish, and Finish. The Wean-to-Feeder stage included all inputs for 42 days in the barn, Feeder-to-Finish included inputs for the next 86 days, divided into four feeding phases, and Finish phase for the final 28 days prior to harvest, for a total of 156 days, wean to market. Impacts across all categories were sensitive to the number of days in each growth stage.

Results and Discussion

Results of the LCA for the baseline and alternate pork production management strategies are presented in Table ES-3. Euthanasia techniques were, ultimately, not analyzed, as we could not identify differences expected to significantly impact environmental performance. All other pork production management strategies were analyzed based on changes in unit processes life cycle inventories (which affected animal performance and thus indirectly feed consumption or the time required to reach market weight). Analysis of the changes in environmental impact category metrics for each pork production management strategy for one kg edible pork (equivalent, based on expected carcass and edible portion yields during processing) at the farm gate showed that some strategies increased impacts, while others decreased impacts (Table ES-4). These analyses represent simulated estimates of impacts and should be interpreted as directional rather than absolute differences; significance between estimators is difficult to assess given the paucity of field data on the effects of these changes. More data of this type would decrease the error bars on all results.

Table ES - 3: Results of Environmental Impact Category Comparisons for Baseline and Six Pork Production Management Strategies, for one kg edible pork at the farm gate.

Management Strategy	Environmental Impact Category		
	Global Warming Potential (kg CO_2e)	Energy Use (MJ)	Water Use (m^3)
Baseline Strategy	6.85	50.82	0.91
1. Anesthesia	7.12	53.55	0.94
2. Immuno-Castration	6.64	48.76	0.88
3. No ractopamine	7.22	52.75	0.98
4. No GP Antibiotics	7.07	52.17	0.93
5. No Prev Antibiotics	8.03	59.75	1.03
6. Gestation Stalls[1]	6.76	49.96	0.91
7a. Gestation Pens[2]	6.76	50.00	0.91
7b. Gestation Pens[1]	6.74	49.69	0.90
8. Entire Males	6.83	52.00	0.87
9. Euthanasia	-	-	-

[1] Based on McGlone et al., 2004; [2] Based on Lammers et al., 2007

One caution in evaluation of reported numerical values is that for this work an incomplete allocation of farm burdens has been applied. Specifically, there is value associated with the non-edible portion of the animal which, based on the farm-gate system boundary and functional unit of edible portion, is NOT allocated to that material, but the full burden of production to the farm gate is assigned to the edible portion. This methodological issue results in an over estimate of the burdens compared to a full life cycle analysis (which would include allocation of some farm-gate impacts to the non-edible products from the processing stage).

Table ES - 4: Changes in Environmental Impact Category Metrics for each Pork Production Management Strategy, for one kg edible pork at the farm gate.

Management Strategy	Change in Environmental Impact Category*		
	Global Warming Potential (kg CO_2e)	Energy Use (MJ)	Water Use (m^3)
1. Anesthesia	-0.27	-2.7	-0.03
2. Immuno-Castration	0.21	2.1	0.03
3. No ractopamine	-0.37	-1.9	-0.07
4. No GP Antibiotics	-0.22	-1.4	-0.02
5. No Prev Antibiotics	-1.18	-8.9	-0.12
6. Gestation Stalls[1]	0.08	0.9	0.0
7a. GestationPens[2]	0.09	0.8	0.0
7b. Gestation Pens[1]	0.11	1.1	0.01
8. Entire Males	0.02	-1.18	0.04

*** Differences calculated as the Baseline minus the Alternate using un-rounded data, and therefore may be slightly different than the differences calculated directly from Table ES-3.**
[1] Based on McGlone et al., 2004; [2] Based on Lammers et al., 2007

Anesthesia use for tail docking and castration increased global warming potential of 3.9 percent, energy use by 5.4 percent, and water use of 3.3 percent. The use of anesthesia for surgical castration and/or tail docking procedures is reported to double pre-weaning mortality to 28%, compared to the baseline 14%. This is a significant loss of productivity and results in increased requirements for feed, barn infrastructure, as well as increased manure production on a per kilogram of lean meat basis.

Immuno-castration resulted in a 3.1 percent decrease in global warming potential, 4.1 percent decrease in energy use, and 3.3 percent decrease in water use. This alternative approach to controlling boar taint capitalizes on the improved feed efficiency and weight gain of boars compared to barrows and gilts. In our modeling, to reach an equivalent average market weight for barns with ½ the population modeled as immune-castrated barrows required approximately 2 days less than for the baseline scenario of surgically castrated barrows. This resulted in less overall feed consumption and manure production as well as a small reduction in the necessary barn infrastructure associated with the faster average turn-around for the barns. Another very important and sensitive parameter was the approximately 1% increase in lean yield for IC barrows.

Removal of ractopamine resulted in an increase in global warming potential of 5.4 percent, an increase in energy use of 3.8 percent, and a 7.7 percent increase in water use. The driving factor for the increase in GWP from removal of ractopamine as a growth promoting agent was lowered productivity during the last month of finishing. The model, based on the taskforce report, assumes 4 additional days would be needed to reach market weight if ractopamine is not used. This directly affects the quantity of feed consumed, manure produced, and requires a small increase in necessary barn infrastructure to support the same annual lean pork production (i.e., a decrease in the number of turns per barn per year).

Removal of antimicrobials as a growth promoting strategy resulted in a 3.2 percent increases in global warming potential, a 2.7 percent increase in energy use, and a 2.2 percent increase in water use. The increased GWP was driven by two factors: lowered daily gain and feed efficiency leading to increased feed consumption and time required to reach market weight, and thus additional manure production as well. If preventative use of antimicrobials is avoided, there will be additional mortality, as well as further decrease in daily gain and feed efficiency compounding the effect. Finally, additional barn infrastructure will be needed due to the lengthened time to reach market weight.

Coupling removal of antimicrobials for growth promotion with not using antimicrobials for disease prevention resulted in the largest changes in this assessment. This production strategy increased global warming potential by 17.2 percent, energy use by 17.6 percent and water use by 13.2 percent. The effects of not using antimicrobials for disease prevention were driven by the same process impacts as not using them for growth promotion, compounded by increased mortality across the entire herd. These impacts did not include the efficiency losses from voluntary culling of animals that did not achieve market weight in the prescribed time.

Using pen gestation structures rather than stall gestation structures resulted in a decrease in global warming potential of 1.3 percent, an energy reduction of 1.7 percent, and no change in water use. There is essentially no net difference in GWP from this management change. This is the result of competing effects. Based on the available literature, we expect that the productivity of the sow barn will increase (approximately 0.2 – 0.5 weaned piglets per litter) in pen housing systems. This results in a decrease in GWP for the system; however, the barn infrastructure requirements for pens are approximately 65% larger, based on our modeling of the space requirements for sows in stalls compared to pens; however, this change in infrastructure is not a significant factor in these differences. This increases the GWP, which is amortized over the expected life of the barn, and essentially offsets the benefit of increased productivity. The reduction in energy demand appears to be directly related to the small increase in the number of live weaned piglets which lowers the feed consumption of the sows on a per piglet basis, as the model does not account for differences in daily feed intake as a function of housing style. There is also a slightly lower temperature in the simulated larger barn necessary to hold the same number of sows in pens, which reduces cooling demand and also results in a slightly lower emission of methane from the subfloor.

Growing entire males to 200 lbs potentially decreased the global warming potential by 0.3 percent and water consumption by 4.4 percent, however, non-renewable fossil energy consumption increased by 2.3 percent. This counterintuitive result (decreased GHG emissions and increased fossil fuel consumption) appears to be associated with the relatively larger (i.e., per kg live weight) amount of energy needed for maintaining temperatures at a suitable level in the barn for smaller animals. Smaller animals do not generate as much body heat and will, in general, and have a larger surface area to weight ratio, thus requiring relatively more heating energy from external sources. The reduction in GHG emissions can be attributed to lower feed consumption and lower manure excretion.

Conclusions

Life cycle analyses of alternate pork production strategies for three environmental impact categories yielded a wide range of results, from an almost 18 percent increase in global warming potential (not using preventative antimicrobials) to more than 4 percent reduction in energy use (immuno-castration). Based on the LCA results, the following pork production strategies increased metrics across all three impact categories: Anesthesia, not using antimicrobials for growth promotion or disease prevention. Conversely, using immuno-castration and pen gestation production strategies decreased global warming potential and energy use, and immune-castration reduced water use. These results are the product of simulation of pork production strategies combined with unit process LCAs; these models are very sensitive to time in the barn at each growth stage, rates of conversion of feed to lean meat, and mortality rates. Model sensitivity and uncertainty are difficult to characterize due to the limited observational data for which the pork production models were calibrated, and the limited life cycle inventory data for alternative production strategies. A final note of caution regarding use of the footprint values reported here is that they were prepared as case studies specifically to enable comparison of management alternatives, and should not be interpreted as being representative of production at national scale, nor are they detailed representations of specific practices. These results do represent to the best capability of existing lifecycle inventory data, the direction and rough magnitude of the changes in environmental impact associated with changing to the alternative management practice.

Introduction

There is an increasing awareness of the need to evaluate the sustainability of pork production systems using a systems level analysis. Pork producers in the US are facing unprecedented pressures from special interest groups, regulatory agencies, and supply chain customers to demonstrate improvements across sustainability metrics. Frequently decisions in modern large-scale agriculture are made on the basis of single measurement criteria, resulting in undesirable outcomes across other metrics. These complex optimization challenges often result in a reluctance to engage in sustainability strategy implementation by agricultural producers.

Life Cycle Assessment (LCA) is an effective tool for performing these analyses. LCA has the potential to foster changes in agricultural practices that lead to environmental, social and economic improvements, the so-called triple bottom line. Life cycle assessment in the swine industry holds the promise of identifying inefficiencies in the system which can be addressed to foster the long-term health of the industry. This project supports the goal of the national pork board environment committee to: optimize management practices to enable producers to make informed management practice decisions to continually improve their farms; provide pork producers with the information and education they need to evaluate and implement appropriate management practices on their farms; and educate customers about the environmental and sustainability consequences of their purchase decisions.

Life cycle assessment

Life Cycle Assessments provide quantitative, confirmable, and manageable models to evaluate production processes, analyze options for innovation, and improve understanding of complexity in agricultural production systems. An LCA can identify areas where process changes, potentially enabled by new research and development, can significantly reduce the associated impacts. Broadly, LCA consist of four stages: 1) Define the goal and scope; 2) Conduct life cycle inventories (collection of data needed to perform the necessary calculations); 3) Perform impact assessment; 4) Analyze and interpret the results.

The structure of an LCA is determined by its purpose. The scope of LCAs can be as broad as "*all material and energy inputs and outputs of a process or product*" to "*water use in production of cotton fabric from raw cotton.*" The scale of the purpose defines the scale of the analysis. We report on a comparative LCA for pork management practices.

Goal and Scope

The goal of this study is to quantify differences or establish the absence of differences in greenhouse gases (GHG), cumulative energy, and water consumption between current practices and proposed alternate management systems. Table 1 lists the alternate practices. The scope of the study is from cradle (crop and fuel production) through the farm gate. In 2011, commercial hog slaughter totaled 110.9 million head, 1 percent higher than 2010 with 99.2 percent of the hogs slaughtered under federal inspection. The average live weight was up 3 pounds from 2010 at 275 pounds. Barrows and gilts comprised 96.9 percent of the total federally inspected hog slaughter (NASS, 2012). The average carcass dressing yield was 0.749 based on NASS Quickstats information for average live weight and dressed weight in 2011. The Economic Research Service publishes a food availability database (ERS, 2012) in which they report a bone-free edible portion-to-carcass yield of 72.9%. Based on these statistics, we have chosen a functional unit of 7.55Mt (million metric tons) edible dressed equivalent at the farm gate to capture differences arising due to changes in the yields that result from alternate production practice. The 7.55 Mt is approximately the total edible mass of pork reported for the US by USDA. The national scale is adopted specifically to ensure that each scenario meet the total market demand.

Description of Models

In this section, we describe the parameters which define each of the scenarios identified in Table 1. There are several parameters which are common across all scenarios and some which are specific to particular scenarios.

Table 1: Proposed alternate management practices.

Management Strategy	Description
1. Anesthesia	Use of anesthesia or pain modifier medication when performing castration or tail docking
2. Immuno-Castration	Use of immune-castration methods/product(s)- Improvest®
3. No ractopamine	Removal of ractopamine (RAC) as a tool to improve growth and production
4. No GP Antimicrobials	Removal of antimicrobials as growth promoters (GP)
5. No Prev. Antimicrobials	Removal of antimicrobials to prevent (Prev) emergence of herd infection *in addition* to removal of GP antimicrobials
6. Pen Gestation	Use of pen gestation housing (2 scenarios[1,2])
7. Boars (entire males)	Split sex management without surgical- or immuno-castration
8. Euthanasia	Use of alternative methods of euthanasia

[1] Based on McGlone et al., 2004; [2] Based on Lammers et al., 2007

All scenarios include specified values for average daily gain (ADG) and either Feed Efficiency (FE; defined as Feed:Gain) or daily feed intake (DFI).

Pig Barn Models

The growth and feed conversion performance of pigs, resource consumption, and emissions to the environment were simulated using the Pig Barn Model developed at the University of Arkansas. The Pig Barn Model uses mathematical relationships to simulate pig growth, feed intake and water consumption, electricity and natural gas use, manure handling, and greenhouse gas emissions during each production cycle. Separate models have been created for sow barns and grow-finish barns. Depending on model input parameters, the grow barn model can simulate nursery, feeder-to-finish, or wean-to-finish barns. Growth, feed consumption, and water consumption relationships in the model were adjusted to create a base scenario and treatment scenario simulations to match ADG, DFI, feed efficiency, and water consumption data obtained from published literature or expert opinion from the NPB taskforce for individual scenarios.

Barn model "scaling"

The barn model uses a parametric relationship for animal growth and feed intake as a function of age. In the modeling, we included phased feeding to enable different daily gain rates; however, we kept an average feed efficiency based on the reported weight to feed consumption reported by KSU (KSU Starter Pigs Recommendations). For each scenario, the barn model parameters describing the growth curve were "scaled" to match the model's simulated performance to reported (i.e., target) values of swine performance for each scenario (Table 2). The internal model parameters were scaled by successive simulations to minimize the relative error (RE) between the simulated and target values for each of the scenarios:

$$RE(\%) = \left|\frac{O - P}{O}\right| * 100$$

where O is the target value for a performance variable and P is the simulated value obtained from the barn model. Combining the output variables of interest, an objective function (F) was defined for each scenario by

$$F(O,P) = \sum_{1}^{v} RE(O,P)$$

Where, v is the number of variables (3). Model calibration was performed independently for the baseline and alternate management scenarios. For each scenario, parameter scaling was performed for both nursery and grow-finish phases.

SimaPro LCA Model

The SimaPro software platform was used for comparing the mean values of each of the alternate

Table 2: Baseline scenario for assessing the environmental impacts of US swine management practices

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	127	175	215
Weight leaving (lb)	50	85	127	175	215	275
Days in barn[1]	42	22	22	22	20	28
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain (lb/day)	0.93[2]	1.60[2]	1.92[2]	2.15[2]	2.02[2]	2.14[3]
Daily feed intake (lb/day)	1.44[4]	4.48[4]	5.38[4]	6.02[4]	5.66[4]	6.09[3]
Feed efficiency	1.54[5]	2.78[5]	2.78[5]	2.78[5]	2.78[5]	2.86[7]
Water consumption per animal (gal/day)	0.7[3]	1.5[3]	1.5[3]	1.5[3]	1.5[3]	1.75[3]
Area per animal (sq ft)	2.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]
Mortality (%)	2.9[8]	3.9[3]	3.9[3]	3.9[3]	3.9[3]	3.9[3]
Manure excretion wet basis (lb/day)	2.3[8,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	8.47[9,11]
Carcass yield (%)	NA	NA	NA	NA	NA	75.83[3]
Edible portion (%)	NA	NA	NA	NA	NA	72.08[3]

[1] Calculated from entering and leaving weights and ADG, [2] From regression model estimating ADG as a function of age of pigs, [3] Hostetler et al. (pers. comm., October 2012), [4] ADG/FE, [5] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [6] Kansas State University Growing-Finishing Pigs Recommendations – average value for the full period rather than specific to the ration phase, [7] DFI:ADG, [8] Lammers et al. (2012), [9] Sutton et al. (2004), [10] Not including aisles and ancillary rooms, [11] Data not used for this analysis but retained for process documentation.

management scenarios to the baseline or average production impacts and for analysis of the degree of confidence in the reported differences. The barn model simulation output was used as input life cycle inventory and was imported to a life cycle analysis model developed in SimaPro V7.3 (Pre' Consultants, The Netherlands).. Life cycle assessment has inherent uncertainties. Normally Monte Carlo simulation is used to quantify the confidence band on the mean value. If two systems are compared with separate estimates of the uncertainty, real differences between the systems can be masked as a result of "noise" in the shared background processes (e.g., electricity production). To compensate for this, Monte Carlo simulations are performed on the difference between two systems so that artificial differences from background processes are eliminated by choosing the same random variate for each one. Thus, comparisons to the base scenario were made by using paired Monte Carlo simulations with 80% confidence intervals. This paired process for comparison of impacts from life cycle inventories which have common background systems ensures that differences between the systems being compared are not introduced as artifacts arising from independent choice of Monte Carlo simulation variables.

Baseline Scenario

A single baseline scenario chosen to represent common management practice in the US was defined for the study. Scenarios without use of ractopamine (RAC), antimicrobials, gestation stalls, use of anesthesia during castration and tail docking, and inclusion of immuno-castration were compared pairwise with this baseline scenario. The data for baseline scenario were collected from published studies and from the task force reports prepared by committees convened by National Pork Board. For male pigs, baseline scenario included surgical castration and tail docking performed in the lactation barn, growth promoting (GP) antimicrobial use in the nursery, preventive antimicrobial use as required, and ractopamine use in grow-finish barn. Ractopamine is supplemented to the pigs through diet during last few weeks in the grow-finish barn. Hostetler et al., (pers. comm. 2012), upon reviewing the studies, suggested using RAC during last 28 days before slaughter. Pig performance with RAC improves during last 28 days. Moreover, diet requirements and performance of pigs vary during their growth period in nursery and grow-finish barn. To capture these differences in diet and pig performance, we modeled the nursery (wean to feeder) and grow-finish (feeder to market) individually. The grow-finish barn was divided in five phases as per the recommendations in a scan level feed summary datasheet provided by swine nutrition specialist at the University of Arkansas. Each phase represented typical diet composition and weight gain in common management practice in the US (it should be noted that not all parameters were known for each phase – e.g., water consumption – and in this case we assigned the whole barn estimate to each phase). The last phase in the grow-finish barn was adjusted to include 28 days on ractopamine (Table 2). The average market weight of 275 lb (2012 NPB Strategic Plan Service, National Pork Board, 2012; Pork Production Phases, U.S.E.P.A, 2012; Animal Products/Hogs-pork, USDA, 2012) was chosen for this study.

Average daily gain for each phase was determined using predictive regression model that explained ADG as a function of age of pigs. This model was developed by using data provided in the scan level summary datasheet prepared by a swine nutritionist at the University of Arkansas. For last 28 days in the baseline scenario, which includes RAC use in the production, ADG of 2.13 lb day^{-1} suggested by Hostetler et al., (pers. comm. 2012) was adjusted to 2.14 lb day^{-1} to achieve the market weight of 275 lb. For feeder and grower pigs, feed efficiencies of 1.55 (KSU Starter Pigs Recommendations) and 2.80 (KSU Growing and Finishing Pigs Recommendations) respectively were used. For last 28 days in the grow-finish barn, a feed efficiency of 2.85 was used (Hostetler et al., pers. comm., October, 2012). A corresponding DFI for each phase was calculated from the ADG and FE values.

The barn model was calibrated using the procedure mentioned above. While simulating grow-finish barn, scaling factors for individual phases were combined in to one phase and number of days in the barn were matched to the baseline scenario (Table 2). Figure 1and Figure 2 present the growth curves of the pigs for each phase obtained using scaled factors. For all the scenarios weights of pigs entering and leaving each phase were fixed to the baseline scenario and number of days spent in each phase were adjusted based on the ADG for that phase.

Removal of Ractopamine

Ractopamine hydrochloride (RAC) is a dietary supplement, which improves ADG, FE, and lean meat yield in finishing pigs (Armstrong et al., 2004; Barbosa et al., 2012; Dunshea et al., 1993; Hinson et al., 2011). With improved FE and ADG in pigs, finishing floors can be turned about 1 week sooner with ractopamine supplementation supplemented to pigs (Patience et al., 2009). The task force convened by the National Pork Board suggests using RAC for last 28 days in a pig production finishing cycle at the weight basis concentration of 6.75 g/T of feed. Without RAC, total annual pork production may decrease as the result of decreased ADG and feed efficiency in pigs (Hostetler et al., pers. comm., 2012). A comparative LCA of current practice to a scenario with removal of RAC supplementation was performed. Data from Hostetler et al., (pers. comm., 2012) and from other peer-reviewed research articles were used to create scenarios with and without RAC.

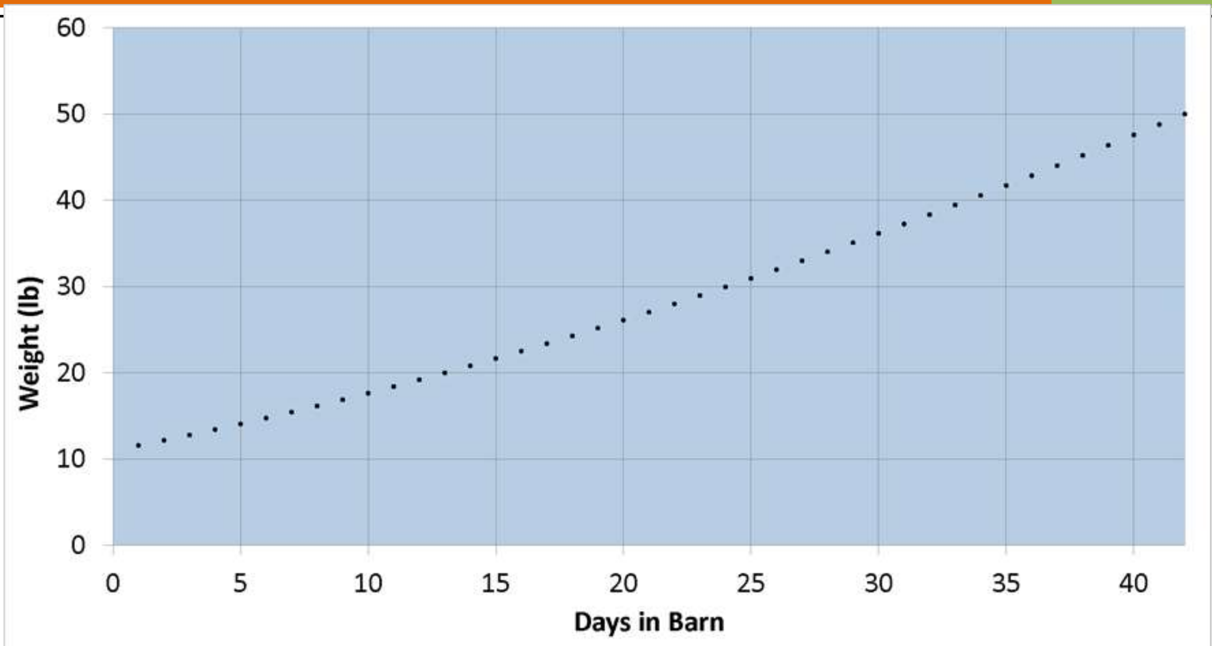

Figure 1: Scaled growth curve for baseline nursery.

Hostetler et al., (pers. comm, October 2012) estimate that without RAC, ADG in adult pigs would decrease by 12.5% and average DFI would increase by about 1.7%. Increased DFI and reduced ADG would decrease feed efficiency by 13.5%, compared to RAC supplementation and the pigs might take 4 additional days to reach the market weight. Scenarios in this study assumed 4 additional days are required to reach market weight rather than 7 as reported by Patience et al., (2009). Not using RAC would reduce the lean tissue growth and impact carcass yield and edible portion. For the purposes of this report the carcass yield refers to the ratio of the dressed carcass (removal of entrails, hooves, and head) to the animal live weight. Lean, edible portion refers to the ratio of bone- and fat-free lean meat weight as a fraction of the dressed carcass weight. Ractopamine repartitions absorbed nutrients and enhances lean tissue growth in pigs (Smith et al., 1995). Hostetler et al., (pers. comm., October 2012) estimated that without RAC carcass yield and edible portion would decrease by 0.59 and 1.5% respectively.

Along with growth performance, RAC also affects water consumption. Pigs supplemented with 10 mg g^{-1} RAC consumed one liter less water per day compared to the control group (Ross et al., 2011). However, the

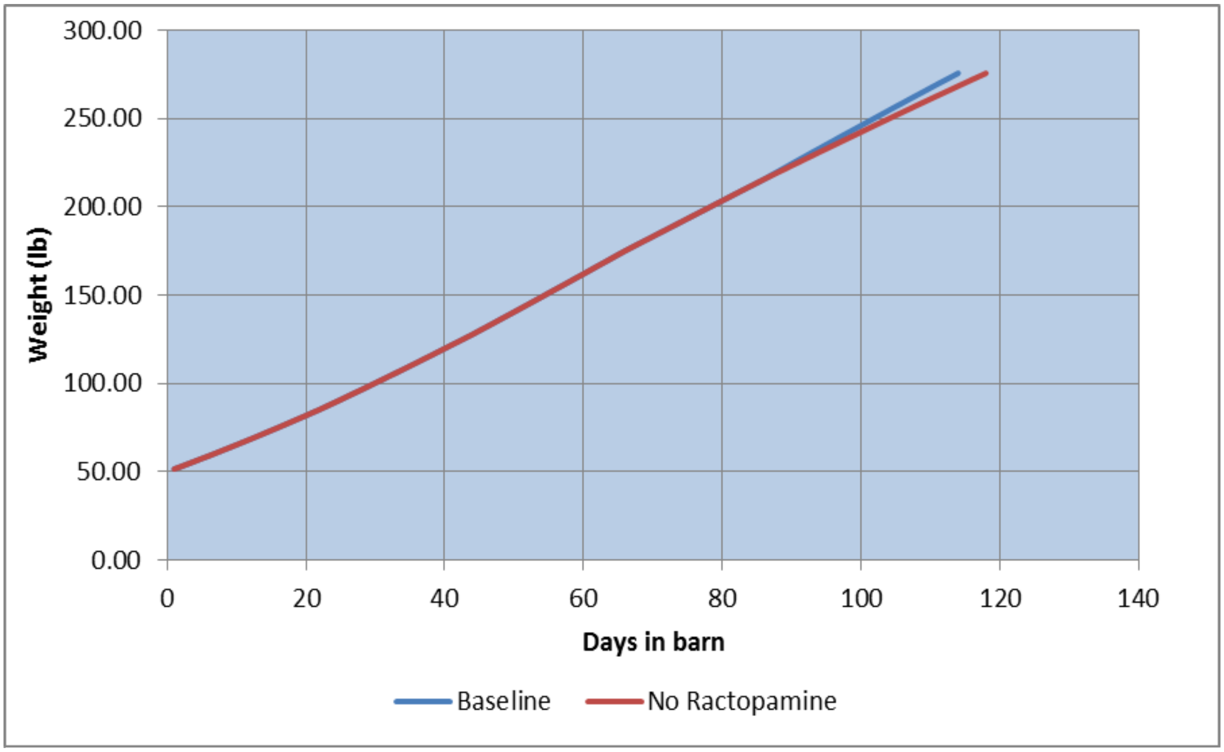

Figure 2: Scaled growth curves for grow-finish baseline scenario and the scenario without Ractopamine use, which requires additional 4 days to reach the same market weight.

authors found these results inconsistent with the theory that lipid content and water in the swine tissue are inversely related and therefore with increased lean tissue in pigs fed RAC, water consumption was expected to increase. Due to the conflicting information available, no change was assumed in the water consumption with removal of RAC.

Lower carcass and lean, edible yield percentages require raising more animals to meet the annual pork consumption demand, which places additional pressure on resources. To evaluate environmental impacts of these hypothesized changes in swine production, results of model simulations with changes in the growth performance of pigs were compared with the baseline scenario. For these simulations, nursery and grow-finish barns were simulated individually. Considering that growth performance of pigs without RAC would change only in the last phase in grow-finish barn, we considered the simulation of the production system beginning with the nursery up to last 32 days in grow-finish were identical to the corresponding baseline phases (Table 3). The last phase in grow-finish barn was simulated for 32 days with ADG and feed efficiency values suggested by (Hostetler et al., pers. comm., 2012).

Surgical versus Immuno-Castration and Entire Males (Boars)

Castration of male pigs is performed to avoid boar taint in the meat, improve the meat quality and also reduce aggressive behavior in swine. Boar taint is a result of skatole levels higher than 0.2 μg g^{-1} of fat in pork (Dunshea et al., 2001; Morales et al., 2010; Thun et al., 2006). Surgical castration (SC) of male pigs is usually performed without anesthesia within first 1 to 2 weeks of life (FAO 1994; Thun et al., 2006). While this technique efficiently eliminates boar taint in the meat, its practice raises concern for animal welfare as the procedures cause

Table 3: Performance data for swine production without use of ractopamine

Parameter	Wean to Feeder	Feeder to Finish (up to last 32 days)				Finish (last 32 days)
Weight entering (lb)	11	50	85	127.5	175	215
Weight leaving (lb)	50	85	127.5	175	215	275
Days in barn[1]	42	22	22	22	20	32
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain (lb/day)	0.93[2]	1.601[2]	1.92[2]	2.15[2]	2.02[2]	1.87[3]
Daily feed intake (lb/day)	1.44[4]	4.48[4]	5.38[4]	6.02[4]	5.66[4]	6.21[3]
Feed efficiency	1.54[5]	2.78[6]	2.78[6]	2.78[6]	2.78[6]	3.33[7]
Water consumption per animal (gal/ day)	0.7[3]	1.5[3]	1.5[3]	1.5[3]	1.5[3]	1.75[3]
Area per animal (sq ft)	2.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]	7.5[3,10]
Mortality (%)	2.9[8]	3.9[3]	3.9[3]	3.9[3]	3.9[3]	3.9[3]
Manure excretion wet basis (lb/day)	2.3[8,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	8.47[9,11]
Carcass yield (%)	NA	NA	NA	NA	NA	75.24[3]
Edible portion (%)	NA	NA	NA	NA	NA	70.58[3]

[1] Calculated from entering and leaving weights and ADG, [2] From regression model estimating ADG as a function of age of pigs, [3] Hostetler et al. (pers. comm. October 2012), [4] ADG/FE, [5] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [6] Kansas State University Growing-Finishing Pigs Recommendations – average value for the full period rather than specific to the ration phase, [7] DFI:ADG, [8] Lammers et al. (2012), [9] Sutton et al. (2004), [10] Not including aisles and ancillary rooms, [11] Data not used for this analysis but retained for process documentation.

pain and distress in pigs (Morales et al., 2010).

An alternative technique developed to avoid boar taint in the pigs without surgical castration is immuno-castration (IC). In this procedure pigs are administered two injections of an analog of gonadotropin-releasing hormone (GnRH) that causes the animal's immune system to create antibodies against GnRH and down regulate the skatole production pathway. This compound reduces the size of testes and suppresses testicular activities (Dunshea et al., 2001). One of the GnRH analogs compounds is marketed as Improvac® (also called Improvest®) developed by Pfizer Pharmaceuticals Inc., which is administered at about 9 weeks of age and then again at least 4 weeks after the primary dose (Pfizer Animal Health). Pfizer recommends slaughtering the pigs between third and tenth week following the second dose to avoid boar taint.

Batorek et al., (2012) conducted a statistical analysis of data collected from 41 papers which revealed that IC effectively reduced reproductive activities and concentration of substances causing boar taint. The IC showed a statistically significant positive effect on the performance of the pigs (improved ADG and feed efficiency). Until the second injection the male pigs performed similar to boars (that is, improved gain and FE compared to SC barrows). After second vaccination however, their performance was more like barrows. The daily feed intake of the pigs increased after second vaccination and feed efficiency declined. The ADG for IC was slightly higher than observed for boars.

Similar changes in the performance of IC pigs have been reported by other researchers. In most of the studies, weights and feed intake of the pigs were monitored for the period between the first vaccination and slaughter and ADG and DFI were reported for times between the first and second vaccinations and between the second vaccination and slaughter or also between the first vaccination and slaughter. For period between first vaccination and slaughter, Morales et al., (2010) reported higher ADG for IC pigs (1.86 lb d^{-1}) over the study duration compared to both surgically castrated pigs (SC, 1.82 lb d^{-1}) and entire males (EM, 1.81 lb d^{-1}). IC pigs showed higher feed conversion efficiency, compared to SC pigs. After the second injection, IC pigs consumed more feed (6.47 lb d^{-1}) compared to boars (5.59 lb d^{-1}) and surgically castrated pigs (6.44 lb d^{-1}). During the same sub-period, while there was no significant difference in ADGs for IC, SC, and EM pigs, feed efficiency was highest for EM (0.41), intermediate for IC (0.39) and lowest for SC (0.36). Backfat thickness was intermediate for IC, higher for SC and lowest for EM. The average carcass yield was 75.98, 76.05, and 74.26% for SC, EM, and IC respectively. These numbers were in accordance with numbers reported by (Andersson et al., 2012; Cronin et al., 2003; Dunshea et al., 2001; Fabrega et al., 2010; Font-i-Furnols et al., 2012; Morales et al., 2010; Pauly et al., 2009; Skrlep et al., 2012; Zamaratskaia et al., 2008).

For evaluation of environmental impacts of these changes in performance of IC pigs, time weighted averages of data reported by (Fabrega et al., 2010) and (Morales et al., 2010) were used for preparing the scenario. These researchers reported data for three sub-periods: first to second vaccination, second vaccination to slaughter, and first vaccination to slaughter (i.e., the combination of the first two periods). In our simulations, to maintain same number of days between vaccinations and slaughter, the age of pigs at vaccinations was calculated with the target number of days in barn set to 153 at market weight. It was assumed that for both boars and IC barrows, their performance in the nursery would remain unchanged. Growth performance parameters for boars suggested by Pauly et al., (2008) were used for the period until the first vaccination in the grow barn. The average age of pigs at the first and second vaccinations and at slaughter was 76, 146, and 176 days respectively (Fabrega et al., 2010; Morales et al., 2010). We assumed that the IC barrows perform like boars until the first vaccination and used the same performance parameters from weaning to the first vaccination (first 13 days in grow barn).

Fabrega et al., (2010) and Morales et al., (2010) compared performance of IC pigs to SC. However, the reported performance parameters for SC (which should be the same as barrows in the baseline) were different than the baseline parameters adopted for this study (Table 2). To maintain consistency with the baseline scenario, percentage changes in growth performance from the SC study were determined and this percentage change was applied to our baseline parameters to define IC performance. It was assumed that after the second injection the pigs are supplemented with RAC and therefore, percentage change in performance parameters for the period between the second injection and slaughter were applied to the parameters for the last 28 days in the baseline scenario. Calculated percentage changes for period between first and second injections were applied for the period up to last 28 days in the grow-barn; except for first 13 days in the barn, when IC pigs perform like boars. The growth curves in the Pig Barn Model were tuned to match these performance parameters (Table 4).

The use of GnRH inhibitors requires well trained teams to inject the animals behind the ear. Pfizer Animal Health guidelines also require records to be collected and maintained and also include quality assurance visits to the farms. This results in a minimum of three trips to the farm for each barn cycle (2 injections and a QA visit). We have included a sensitivity analysis of the effect of the distance these teams may be required to travel – for example in North Dakota, the round trip could be as far as 200 miles.

Based on expert opinion (Bill Close, pers. comm.), market weight of entire males was set to 200 lb. It was assumed that the performance of boars does not change from the baseline in the wean-to-feeder phase. Weight gains in each phase were matched to the baseline scenario to maintain the consistency. For the first phase in the grow barn, performance parameters reported by Pauly et al., (2008) were used for the feeder pigs (Table C-

Table 4: Performance parameters for immuno-castrated swine production scenario.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	72	114	161	207
Weight leaving (lb)	50	72	114	161	207	281
Days in barn[1]	42	13	23	23	24	28
Market weight (lb)	NA	NA	NA	NA	NA	281
Average daily gain (lb/day)	0.93[2]	1.69[3]	1.82[4]	2.04[4]	1.92[4]	2.64[4]
Daily feed intake[5] (lb/day)	1.44	3.68	4.73	5.30	4.98	6.71
Feed efficiency	0.65[6]	0.46[3]	0.39[4]	0.39[4]	0.39[4]	0.39[4]
Water consumption per animal (gal)	0.7[7]	1.5[7]	1.5[7]	1.5[7]	1.5[7]	1.75[7]
Area per animal (sq ft)	2.5[7,10]	7.5[7,10]	7.5[7,10]	7.5[7,10]	7.5[7,10]	7.5[7,10]
Mortality (%)	2.9[8]	3.9[7]	3.9[7]	3.9[7]	3.9[7]	3.9[7]
Manure excretion wet basis (lb/day)	2.3[8,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	9.46[9,11]	8.47[9,11]
Carcass yield (%)	NA	NA	NA	NA	NA	74.26[12]
Edible portion (%)	NA	NA	NA	NA	NA	73.50[13]

[1] Calculated from entering and leaving weights and ADG, [2] From regression model estimating ADG as a function of age of pigs, [3] Pauly et al. (2008), [4] Applied percentage delta calculated for IC barrows compared to surgically castrated pigs to baseline, data for IC and surgically castrated pigs was obtained from Fabrega et al. (2010), Morales et al. (2010), [5] ADG/FE. [6] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [7] Hostetler et al. (pers. comm, October, 2012), [8] Lammers et al. (2012), [9] Sutton et al.(2004), [10] Not including aisles and ancillary rooms, [11] Data not used for this analysis but retained for process documentation, [12] average of data from Andersson et al. (2012), Font-i-Furnols et al. (2012), Morales et al. (2010), Pauly et al. (2009), Skrlep et al. (2012), Zamaratskaia et al. (2008)), [13] Zamaratskaia et al. (2008).

1). Percentage changes in ADG and DFI of boars compared to the SC was computed from data obtained from Fabrega et al., (2010) and Morales et al., (2010), which was then applied to the rest of the grow-finish phases in the baseline scenario to determine performance parameters for corresponding phases for boars. Dunshea (2010) reviewed the impacts of physical and immune-castration on swine growth performance. However, the data presented was not in a consistent format to be easily integrated into our dataset. Nonetheless, it was reported that the results observed were consistent with that reported in the literature (Dunshea et al., 2001). Average of carcass yields reported by Morales et al., (2010), Pauly et al., (2009), Skrlep et al., (2012), Andersson et al., (2012) and Zamaratskaia et al., (2008) and percentage edible portion reported by Zamaratskaia et al., (2008) were used for carcass yield and edible portion in EM scenario respectively. For Daily water consumption per animal and mortality rates, the same values as were adopted from the baseline scenario.

Anesthesia for Castration and Tail Docking

Tail docking reduces biting and helps avoid infliction of pen-mate infected injuries in pigs and resulting abscesses (FAO 1994; Sutherland et al., 2011). The prevalent practice in the swine industry is surgical castration and tail docking the pigs without any anesthetics (Morales et al., 2010). The current practice in swine industry does not include anesthetics or analgesics during castration of male pigs and tail docking. There have been concerns over this practice from the perspective of animal welfare. While anesthetics and analgesics were proved to change pain related response in terms of hormone levels and behavioral patterns in the pigs (Hansson et al., 2011; Kluivers-Poodt et al., 2012; McGlone and Hellman, 1988; Reiner et al., 2012; Sutherland et al., 2010; Sutherland et al., 2012), there is no evidence to suggest that using anesthetics or analgesics impacts growth performance of the pigs in any way; however, some methods do result in increased mortality (Kluivers-Poodt et al., 2012; McGlone and Hellman 1988; Reiner et al., 2012; Sutherland et al., 2010; Sutherland et al., 2011). The National Pork Board Animal Welfare Task Force Report suggested that under some conditions with some anesthetics used for castration or tail docking increases in pre-weaning mortality in the sow barn can reach 28% (Table 5). To capture this difference pre-weaning mortality in the sow-baseline scenario was set to 28%. The performance of pigs was assumed to not change in the nursery or grow finish barns.

Table 5: Effect of anesthesia use during castration.

	Sow barn
Litter size[1]	11.3
No. born alive[1]	9.3
No. stillborn[1]	2.0
Pre-weaning mortality[2]	28%

[1] Lammers et al., (2007); [2] National Pork Board Animal Welfare Task Force Report citing McGlone & Hellman (1988).

Antimicrobial Use

Antimicrobial use in animal production has shown many positive effects on animal health. Antimicrobial use in animal production has become a societal issue because of concerns about development of antibiotic resistant bacteria strains that could affect human health. Antimicrobials are most commonly used in swine production for growth promotion in the nursery phase and for prevention of epidemics and endemics in grow-finish barns as well as, for treating sick pigs. We constructed scenarios to evaluate the impacts associated with reduced use of antimicrobials in pig production (Table 6 and Table 7)

The NPB task force provided two scenarios to evaluate potential effects of reducing or eliminating antimicrobials on productivity of pig growth. The first scenario describes effects data for impact of eliminating on growth promoting (GP) antimicrobials use, while the second scenario describes effects on production from eliminating both growth promoting and preventive antimicrobials. The estimated effects of reducing or eliminating of GP and preventive antimicrobial use for high, median, and low health facilities were provided. It was estimated that about 70% of the pigs reared in US are in median health status facilities, while remaining 10% and 20% of the pigs are in low and high health system facilities respectively. Considering these estimates LCA analysis was carried out for median health status facilities only.

For median health facilities, not using GP antimicrobials is expected to reduce ADG by 5% in nursery and 3% in grow-finish barns. Feed efficiency was expected to be affected as well and was estimated to decrease by 3.5 and 2% in nursery and grow-finish barns respectively. Production without GP antimicrobial use leads to changes in ADG and FE, which will impact the DFI of the pigs as well.

Table 6: Performance parameters for pigs without growth promoting use of antimicrobials in the nursery barn.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	128	176	217
Weight leaving (lb)	50	85	128	176	217	275
Days in barn[1]	44	23	23	23	21	28
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain[2] (lb/day)	0.88	1.553	1.86	2.09	1.96	2.08
Daily feed intake[3] (lb/day)	1.42	4.44	5.32	5.96	5.60	6.03
Feed efficiency[2]	1.61	2.86	2.86	2.86	2.86	2.94
Water consumption per animal (gal)	0.7[4]	1.5[4]	1.5[4]	1.5[4]	1.5[4]	1.75[4]
Area per animal (sq ft)	2.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]
Mortality (%)[2,5]	3.3	4.1	4.1	4.1	4.1	4.1
Manure excretion wet basis (lb/day)	2.3[6,8]	9.46[6,8]	9.46[6,8]	9.46[6,8]	9.46[6,8]	8.47[6,8]
Carcass yield (%)	NA	NA	NA	NA	NA	75.83[4]
Edible portion (%)	NA	NA	NA	NA	NA	72.08[4]

[1] Calculated from entering and leaving weights and ADG, [2] Applied percentage delta suggested by National Pork Board task force to the baseline scenario, [3] ADG/FE, [4] Hostetler et al.pers. comm., October 2012), [5] Mortality also includes increased voluntary cull rate suggested by National Pork Board task force report, [6] Lammers et al. (2012), [7] Not including aisles and ancillary rooms, [8] Data not used for this analysis but retained for process documentation.

Not using of GP could mean fewer pigs would reach the expected weight and size requirements in the production facility, which was estimated to increase voluntary cull rate in nursery and grow-finish barn to 0.25% for median health facilities. Without GP, the mortality rate was expected to increase by 0.2% in the nursery phase. Because GP is used mostly in nursery phase, production without use of AGP was expected to have no impact on mortality rates in grow-finish barn. No change due to loss of GP was anticipated on other performance factors such as diet formulation, water consumption or, and average vet visits.

Table 7: Performance parameters for pigs without growth promoting (nursery) or preventive (grow-finish) use of antimicrobials.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	128	176	217
Weight leaving (lb)	50	85	128	176	217	275
Days in barn[1]	45	24	24	24	22	30
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain[2] (lb/day)	0.87	1.49	1.79	2.00	1.88	1.99
Daily feed intake[3] (lb/day)	1.43	4.32	5.18	5.80	5.45	5.87
Feed efficiency[2]	1.64	2.94	2.94	2.94	2.94	2.94
Water consumption per animal (gal)	0.7[4]	1.5[4]	1.5[4]	1.5[4]	1.5[4]	1.75[4]
Area per animal (sq ft)	2.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]	7.5[4,7]
Mortality (%)[2,5]	10.9	14.4	14.4	14.4	14.4	14.4
Manure excretion wet basis (lb/day)	2.3[6,8]	9.46[6,8]	9.46[6,8]	9.46[6,8]	9.46[6,8]	8.47[6,8]
Carcass yield (%)	NA	NA	NA	NA	NA	75.83[4]
Edible portion (%)	NA	NA	NA	NA	NA	72.08[4]

[1] Calculated from entering and leaving weights and ADG, [2] Applied percentage delta suggested by National Pork Board task force to the baseline scenario, [3] ADG/FE, [4] Hostetler et al. (pers. comm., October 2012), [5] Mortality also includes increased voluntary cull rate suggested by National Pork Board task force report, [6] Lammers et al. (2012), [7] Not including aisles and ancillary rooms, [8] Data not used for this analysis but retained for process documentation.

In the second scenario, the effects of production without use of either GP or preventive antimicrobial use on performance parameters were estimated. When herd health is trending downward antimicrobials are used prophylactically to reduce the chance of herd -wide infection. Animals which become sick are treated therapeutically and will recover or die. Without preventative use, more animals are likely to need therapeutic doses. It was estimated that removal of both GP and preventive antimicrobials would decrease ADG by 7% in both nursery and grow-finish barns for a median health animal facility. Low health status of animals in this case, would result in estimated reduction in FE by 6 and 5% for nursery and grow-finish barns respectively. Voluntary cull rates and mortality is expected to increase by 4% in nursery and by 5 and 5.5% respectively in grow-finish barn.

Gestation Stalls

Gestation stalls used for sows provides maximum barn space utilization density and allows individual monitoring and controlled feeding (Lammers et al., 2007). However, this method is under scrutiny because gestation stalls do not allow sows free movement (Lammers et al., 2007). At the same time sows housed in group pens are prone to injuries due to aggression resulting in stress and injury; however, we found no quantitative data to enable inclusion of these effects in the modeled animal productivity. There is a trade-off between protecting animals from injuries and providing freedom of movement. Also, group housing reduces the stocking density and thus requires additional housing to maintain animal production. Due to the difference in barn infrastructure necessary for the alternate management using gestation pens, the LCA scenarios have included the effect of changes in the infrastructure. We have assumed a 50 year life for the barn facility, including the stalls and pens. We created estimates for the bill of materials for construction of sow, nursery and grow-finish barns from plans published by the Iowa State University Midwest Plan Service (MWPS, 2012); the material quantities assumed for each barn type are presented in Appendix B.

This scenario was designed to evaluate environmental impact of production management using gestations pens. Data for comparison between gestation stalls and group pen housing were obtained from published articles. We only evaluated the option of using gestation stalls for the entire gestation period; we assumed that farrowing stalls were used for both group pen and individual stall scenarios. The differences between sows housed in gestation stalls and in group pens were observed in number of live births, litter size, pre-weaning mortality, and piglet weights at birth. Lammers et al., (2007) observed statistically significant difference in number of piglets born alive and number of stillborn piglets between sows housed in stalls and group hoop barns. The number of piglets born alive was 10 and 9.3 for group and individual stalls respectively. While the litter size did not change much (11.3 for stalls and 11.7 for group), higher number of stillborn piglets were observed for stalls compared (2.0) to groups (1.7). Pre-weaning mortality however, was higher for group housing (15%) compared to gestation stalls (14%). Slightly different results were reported by McGlone et al., (2004) in their meta-analysis of gestation housing. The authors reported no significant difference between use of stall or pens for gestation housing in terms of litter characteristics. As a result, we compared data from a recent study by Lammers et al., (2007) to that of McGlone et al., (2004) (Table 8). Pre-weaning mortality data were not available in McGlone et al., (2004) we therefore adapted 14% for both the gestation stalls and group housing.

Although body weights and backfat thickness of sows at different times into the pregnancy were higher for group housing (Munsterhjelm et al., 2008; Salak-Johnson et al., 2007), the current Pig Barn Model does not capture and simulate these differences. Therefore, these parameters were excluded from current study.

Bates et al., (2003) reported that 72% of sows housed in group returned to estrus within 7 days compared to 68.4% of sows in gestation stalls. In addition 94.3% of group housed sows remained pregnant after initial service compared to 89.4% of sows in stalls. These differences were captured in the Pig Barn Model by adjusting the number of average number of days between piglet removal and insemination. An example calculation to estimate the herd average time between weaning and successful insemination is presented in Table 8. For life cycle analysis and comparison of gestation stalls and group housing, litter size, number of piglets born alive, and number of stillbirths and pre-weaning mortality were used (Table 8).

Table 8: Production parameters for gestation stalls and group housing for assessing environmental impacts of alternate management practices.

	Gestation Stalls		Group Housing	
	Lammers et al, 2007	McGlone et al, 2004	Lammers et al., 2007	McGlone et al, 2005
Litter size	11.3	10.5	11.7	10.8
No. born alive	9.3	9.9	10.0	10.1
No. stillborn	2.00	0.58	1.70	0.73
Pre-weaning mortality	14%	14%[1]	15%	14%[1]
Weaned piglets/litter	8.0	8.53	8.5	8.66

[1] Pre-weaning mortality data were not available in McGlone's paper; we used a 14% in both stalls and group housing.

Table 9: Example calculation for comparison of gestation stalls and group housing: post-weaning time to be successful insemination1.

Estrus/ Insemination Group Pens				
Number of Animals	Days after weaning	Fraction coming to estrus	Fraction remaining pregnant	Number pregnant of original 1000
1000	7	0.72	0.934	672
328	28	1	0.934	306
22	49	1	0.934	20
Weighted Average:	14.3			
Estrus/ Insemination Stalls				
Number of Animals	Days after weaning	Fraction coming to estrus	Fraction remaining pregnant	Number pregnant of original 1000
1000	7	0.684	0.894	611
389	28	1	0.894	347
42	49	1	0.894	37
5	70	1	0.894	4
Weighted Average:	16.1			

[1] Data for calculations were obtained from Bates et al., (2003)

Uncertainty Analysis

An uncertainty analysis for baseline and each of the treatments in the comparative study was performed to gain a confidence in the results obtained in the study. Assuming that ADG, DFI, FE, water consumption, and mortality values in the comparative study represent the mid values, two more scenarios for each treatment including the baseline were prepared. The parameter values for these scenarios were set to obtain minimum and maximum carbon footprint for baseline and corresponding treatment scenarios. The growth curves in the Pig Barn Model were tuned to match the new performance parameters for uncertainty scenarios. To avoid noise introduced by the differences in the population of pigs exiting the barn, the number of pigs leaving sow and grow barn each year in the uncertainty scenarios were matched to the mid values for the corresponding treatment scenario. After simulating pig growth in the barn model, truncated triangular distribution was fitted using the results of treatment and uncertainty scenarios to each output parameter of barn model that was used by the SimaPro model for life cycle assessment. 1000 Monte-Carlo simulations were performed on the differences between two systems by comparing each alternate treatment scenario individually with the baseline scenario with truncated triangular distributions for the parameters of interest; background processes, from the ecoinvent database, were adopted with their pre-defined uncertainty distributions. This paired process for comparison of impacts from life cycle inventories ensures that differences between the systems being compared are not introduced as artifacts arising from independent choice of Monte-Carlo simulation variables. The appendix contains tables of the growth and barn simulation parameters of the scenarios chosen to represent the extreme parameter values of each scenario which give rise to an expected minimum or maximum change in system environmental performance.

Results

Results of the LCA for the baseline and seven pork production management strategies are presented in Table 10. Euthanasia techniques were not analyzed, as we could not identify significant differences across unit processes for which data were available. All other pork production management strategies were analyzed based on changes in unit processes life cycle inventories or days in the barn. Analysis of the changes in environmental impact category metrics for each pork production management strategy for one kilogram lean pork (equivalent, based on expected carcass and lean yields during processing) at the farm gate showed that some strategies increased impacts, while others decreased impacts (Table 11). These analyses represent simulated estimates of impacts and should be interpreted as potential trends rather than absolute estimators.

Anesthesia

Anesthesia use for tail docking and castration increased global warming potential 3.9 percent, energy use 5.4 percent, and water use 3.3 percent. The use of anesthesia for surgical castration and/or tail docking procedures is reported to double pre-weaning mortality to 28%, compared to the baseline 14%. This is a significant loss of productivity and results in increased requirements for feed, barn infrastructure, as well as increased manure production on a per kilogram of lean meat basis.

Table 10: Environmental impact estimates for baseline and alternative US swine management practices. Reported per kg edible portion at the farm gate.

Management Strategy	Environmental Impact Category		
	Global Warming Potential (kg CO_2e)	Energy Use (MJ)	Water Use (m^3)
Baseline Strategy	6.85	50.82	0.91
1. Anesthesia	7.12	53.55	0.94
2. Immuno-Castration	6.64	48.76	0.88
3. No ractopamine	7.22	52.75	0.98
4. No GP Antibiotics	7.07	52.17	0.93
5. No Prev Antibiotics	8.03	59.75	1.03
6. Gestation Stalls[1]	6.76	49.96	0.91
7a. Gestation Pens[2]	6.76	50.00	0.91
7b. Gestation Pens[1]	6.74	49.69	0.90
8. Entire Males	6.83	52.00	0.87
9. Euthanasia	-	-	-

[1] Based on McGlone et al., 2004 data; [2] Based on Lammers et al., 2007 data

Immuno-Castration / Entire Males (Boars)

This management alternative resulted in a 3.1 percent decrease in global warming potential, 4.1 percent decrease in energy use, and 3.3 percent decrease in water use. This alternative approach to controlling boar taint capitalizes on the improved feed efficiency and weight gain of boars compared to barrows and gilts. In our modeling, to reach an equivalent average market weight for barns with ½ the population modeled as immune-castrated barrows required approximately 2 days less than for the baseline scenario of surgically castrated barrows. This resulted in less overall feed consumption and manure production as well as a small reduction in the necessary barn infrastructure associated with the faster average turn-around for the barns. Another very important and sensitive parameter was the approximately 1% increase in lean yield for IC barrows.

Entire Males

Growing entire males to 200 lbs potentially decreased the global warming potential by 0.3 percent and water consumption by 4.4 percent, however, non-renewable fossil energy consumption increased by 2.3 percent. This counterintuitive result (decreased GHG emissions and increased fossil fuel consumption) appears to be associated with the relatively larger (i.e., per kg live weight) amount of energy needed for maintaining temperatures at a suitable level in the barn for smaller animals. Smaller animals do not generate as much body heat and will, in general, and have a larger surface area to weight ratio, thus requiring relatively more heating

Table 11: Changes in impact category metrics for each alternative US pork production management practice. Reported per kg edible portion at the farm gate.

Management Strategy	Change from Baseline Environmental Impact		
	Global Warming Potential (kg CO_2e)	Energy Use (MJ)	Water Use (m^3)
1. Anesthesia	0.27	2.73	0.03
2. Immuno-Castration	-0.21	-2.06	-0.03
3. No ractopamine	0.37	1.93	0.07
4. No GP Antibiotics	0.22	1.35	0.02
5. No Prev Antibiotics	1.18	8.93	0.12
6. Gestation Stalls[1]	-0.08	-0.86	0.0
7a. Gestation Pens[2]	-0.09	-0.82	0.0
7b. Gestation Pens[1]	-0.11	-1.13	-0.01
8. Entire Males	-0.02	1.18	-0.04
9. Euthanasia	-	-	-

[1] Based on McGlone et al., 2004 data; [2] Based on Lammers et al., 2007 data

energy from external sources. This is supported through additional simulations in which the market weight of the boars was varied from 175 to 275 lbs. We observed steady decreases in environmental impact as the market weight increased which suggests that taking boars to the maximum weight prior to the onset of boar taint will provide the greatest achievable reductions. The reduction in GHG emissions can be attributed to lower feed consumption and lower manure excretion.

One limitation of the approach taken in this modeling work is that an average feed efficiency has been used for the feeder-to-finish barn (for reasons explained previously) which will, particularly for this scenario, bias the result because smaller animals are known to have somewhat higher feed to gain efficiency. Thus the decrease in feed and manure predicted for boars is, at least slightly, underestimated. This limitation in interpretation is not important for other scenarios as the final weights are held to a more nearly constant value.

Ractopamine

Not using ractopamine resulted in an increase in global warming potential of 5.4 percent, an increase in energy use of 3.8 percent, and 7.7 percent increase in water use. The driving factor for the increase in GWP from removal of ractopamine as a growth promoting agent was lowered productivity during the last month of finishing. The model, based on the taskforce report, assumes 4 additional days would be needed to reach market weight if ractopamine is not used. This directly affects the quantity of feed consumed, manure produced, and requires a small increase in necessary barn infrastructure to support the same annual lean pork production (i.e., a decrease in the number of turns per barn per year).

Antimicrobials

Not using antimicrobials as a growth promoting strategy resulted in a 3.2 percent increases in global warming potential, a 2.7 percent increase in energy use, and a 2.2 percent increase in water use. The increased GWP was driven by two factors: lowered daily gain and feed efficiency leading to increased feed consumption and time required to reach market weight, and thus additional manure production as well. If preventative use of antimicrobials is avoided, there will be additional mortality, as well as further decrease in daily gain and feed efficiency compounding the effect. Finally, additional barn infrastructure will be needed due to lengthened time to reach market weight.

Coupling removal of antimicrobials for growth promotion with not using antimicrobials for disease prevention resulted in the largest changes in this assessment. This production strategy increased global warming potential by 17.2 percent, energy use by 17.6 percent and water use by 13.2 percent. The effects of not using antimicrobials for disease prevention were driven by the same process impacts as not using them for growth promotion, compounded by increased mortality across the entire herd. These impacts did not include the efficiency losses from voluntary culling of animals that did not achieve market weight in the prescribed time.

Pen Housing

Using pen gestation structures rather than stall gestation structures resulted in a decrease in global warming potential of 1.3 percent, an energy reduction of 1.6 percent, and no change in water use. There is essentially no net difference in GWP from this management change. This is the result of competing effects. Based on the available literature, we expect that the productivity of the sow barn will increase (approximately 0.2 – 0.5 weaned piglets per litter) in pen housing systems. This results in a decrease in GWP for the system; however, the barn infrastructure requirements for pens are approximately 65% larger, based on our modeling of the space requirements for sows in stalls compared to pens. This increases the GWP, which is amortized over the expected life of the barn, and essentially offsets the benefit of increased productivity. The reduction in energy demand appears to be directly related to the small increase in the number of live weaned piglets which lowers the feed consumption of the sows on a per piglet basis, as the model does not account for differences in daily feed intake as a function of housing style. There is also a slightly lower temperature in the simulated larger barn necessary to hold the same number of sows in pens, which reduces cooling demand and also results in a slightly lower emission of methane from the subfloor. These results are essentially identical using the data from Lammers (2007) or McGlone (2004). In the case of the pen vs. stall comparison using McGlone's data, we show in a later section, the comparison of both pen and stall to the baseline scenario. This was done because the stall system from McGlone was slightly different than our baseline system. We have separately made a direct comparison of the pens and stalls using only McGlone's data and obtain a virtually identical result to that from Lammer's data – the pen system very slightly outperforms the stall system; however, these differences are not statistically significant in either case.

The potential total annual environmental impacts for each management strategy were evaluated across impact categories for US total annual pork production of 7.55 Mt lean-dressed equivalent (USDA estimated production for 2011) at the farm gate (Table 12). These analyses provide an estimate of the cumulative environmental impact for each pork production strategy, if adopted by all US pork producers. Immuno-castration strategies could reduce global warming potential by more than 2 million metric tons (Mt) per year while not using antibiotics for disease prevention could increase carbon emissions by more than 9 Mt per year (Figure 3). Immuno-castration reductions in global warming potential could be equivalent to saving more than 237 million gallons of gasoline per year.

The potential increase in energy consumption without using antimicrobials to prevent disease was estimated to be almost 70 PJ (10^{14} J) per year (Figure 4). Using immuno-castration could reduce energy use by 20 PJ per year. Water use was increased by more than 226 million m^3 per year by not using antimicrobials for disease prevention or growth promotion (Figure 5). The greatest predicted decrease in water use across strategies was when immune-castration was used, saving more than 75 million m^3 water per year.

Table 12: Potential total annual impact from pork production management strategies for producing 7.55 Mt lean pork at the farm gate.

Management Strategy	Environmental Impact Category		
	GWP (Mt CO_2e)	Energy Use (PJ)	Water Use (million m3)
1. Anesthesia	2.0	20.6	226
2. Immuno-Castration	-1.6	-15.5	-226
3. No ractopamine	2.8	14.6	528
4. No growth promoting Antimicrobials	1.7	10.2	151
5. No preventative Antimicrobials	8.9	67.4	906
6. Pen Gestation	-0.68	-6.2	0
7. Entire males	-0.23	9.6	-302

Uncertainty Analysis

As described in the methods section, we conducted an analysis of uncertainty to support the robustness of the conclusions. The detailed results of the analysis are shown in Table D - 6. This table shows the output from 1000 Monte Carlo runs in which the background processes were held invariant for the comparison. Environmental impact categories for each of the management strategies were compared to the baseline and confidence intervals created. For example, when using anesthesia for castration or tail docking, the results show that the use of anesthesia leads to an increase in GHG emissions for 85% of the simulations and that the mean difference in GHG emissions, for all 1000 simulations, was an increase 0.213 kg CO_2e from increased mortality in the farrowing barn.

Overall, the IC uncertainty analysis indicated lower footprint for over 70% of the time across all three impact categories. On the other hand, the removal or GP and preventive antimicrobials resulted in a higher carbon footprint for all 1000 simulations (100%) compared to the baseline with a mean difference of 1.55 kg CO_2e increased emissions.

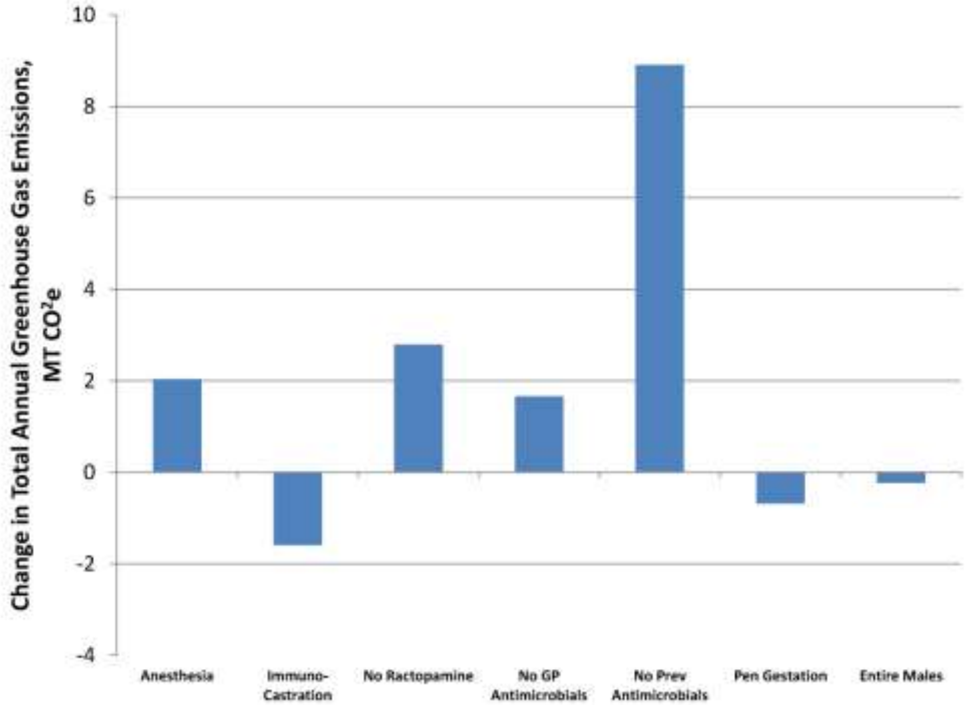

Figure 3: Estimated Potential Change in Total Annual Global Warming Potential (MT CO_2e) Resulting from US Pork Production Strategies.

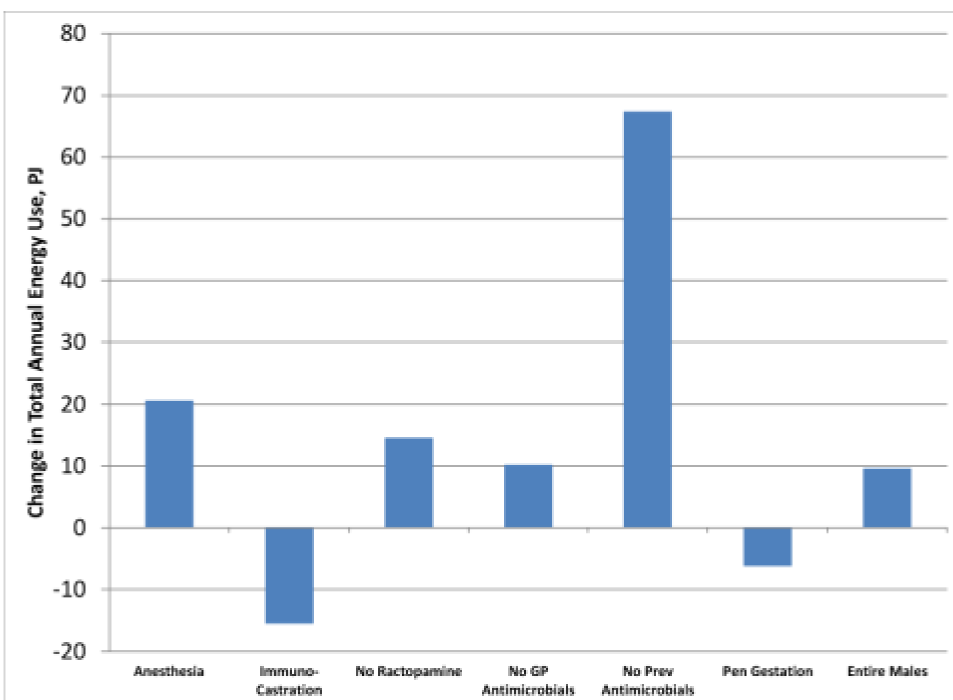

Figure 4: Estimated Potential Change in Total Energy Use (PJ) Resulting from US Pork Production Strategies.

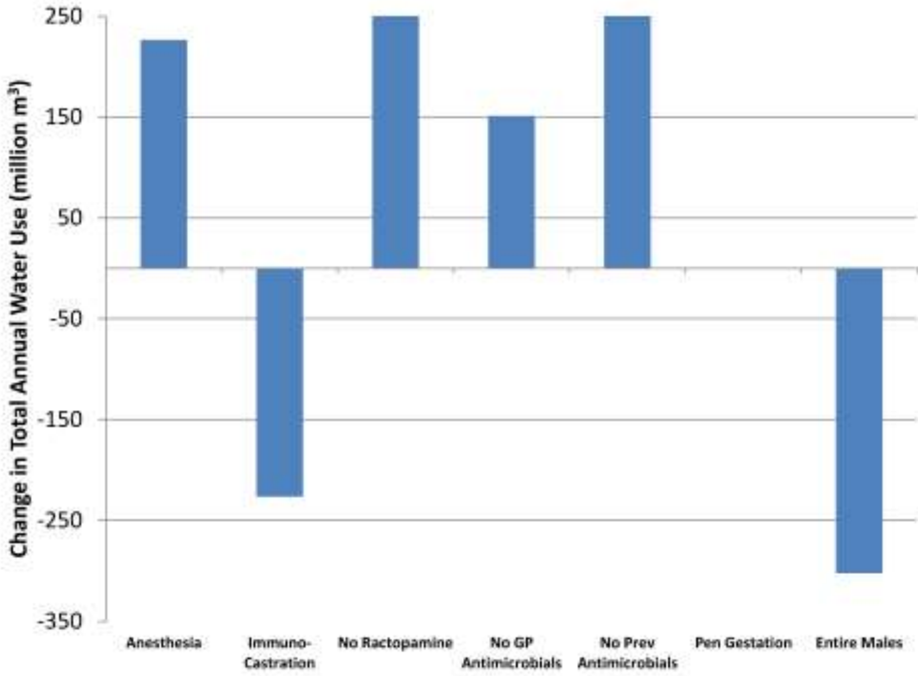

Figure 5: Estimated Potential Change in Total Water Use (million m³) Resulting from US Pork Production Strategies

Figure 6: presents the results of comparative LCA in the form of a histogram of the difference of paired simulations. The mean value for the difference is 0.335 kg CO_2e; the arrow shows the point in the distribution where the uncertainty in the input parameters leads to a few simulations where the absence of AGP results in a lower footprint than the baseline (0.2% of the time, equivalent to the area beneath the curve to the left of zero and as reported in Table D - 6). The distributions used for each of the input parameters are described in Appendix D.

Each scenario was evaluated to determine parameter values, within a reasonable range, that would maximize or minimize the impact associated with the parameter. Thus, for example, the combination of low ADG and high mortality represent a worst case possibility within the range of uncertainty for those parameters. The worst and best case parameter values defined the end points of a truncated triangular distribution which was used to select the random variate for the specific Monte Carlo simulation run.

Figure 7 through Figure 9summarize the results of the Monte Carlo simulations for each alternative management scenario for the three impact categories. These figures each show the baseline result as a horizontal gray line and the range of the paired Monte Carlo simulations as a box and whisker plot. The interpretation of these graphs is important because this analysis is an indication of the robustness of the conclusions that can be made from the study (this is distinct from any discussion which may result in modification to the parameters used to generate the results). Specifically, the horizontal lines of each box represent the 25th, 50th, and 75th percentiles of the 1000 MCS runs. The lower and upper colored extensions denote the 10th and 90th percentiles, respectively.

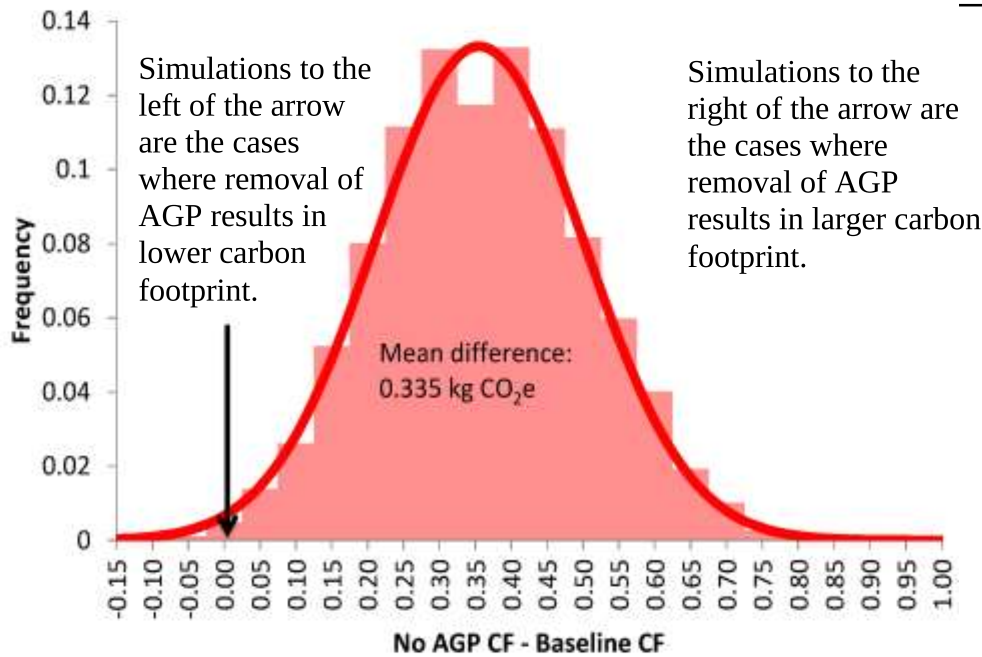

Figure 6: Example of Monte Carlo comparative simulations for assessing the environmental impacts of US swine management practices.

Clearly where the simulations represented by the box or whisker lie above the horizontal line, the alternate practice resulted in an increase in environmental impact. As an example, consider the immuno-castration scenario for GHG emissions (Figure 7). In this scenario, the 75th percentile is approximately equal to the baseline. The interpretation of this result is that we can state with 75% confidence that immuno-castration will result in a decrease in GHG emissions. Further, as the 50th percentile is approximately 0.1 kg CO_2e lower than the baseline, we can state that we have 50% confidence that at least 0.1 kg CO_2e reduction will be achieved on average.

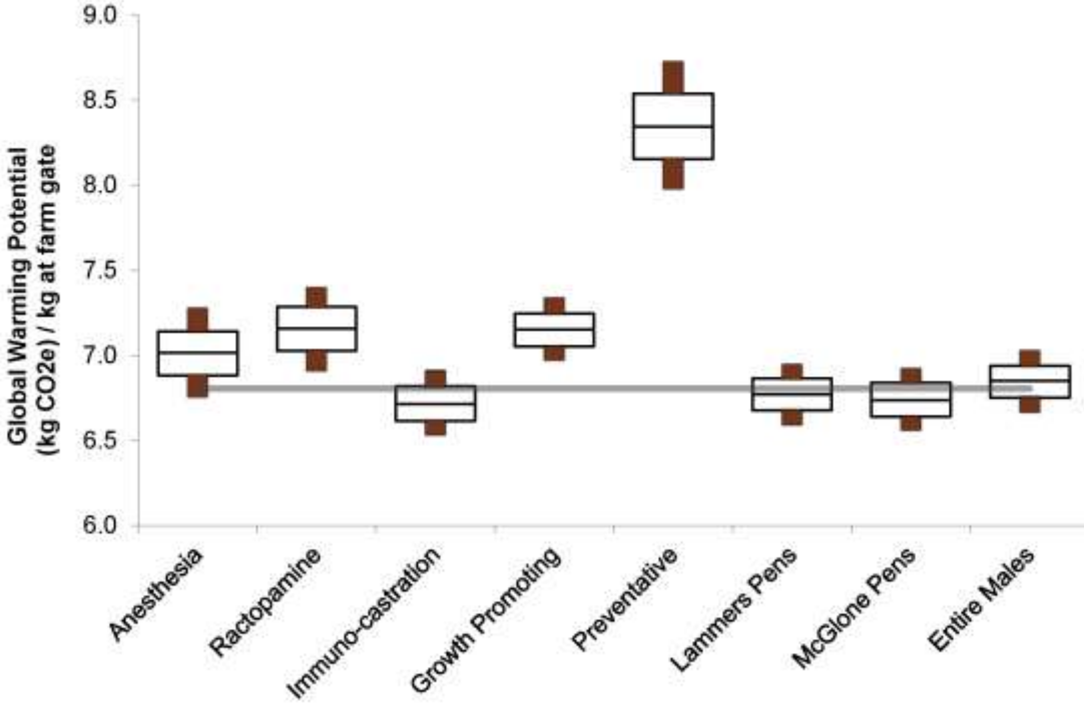

Figure 7: Estimated potential change in GHG emissions for alternate management practices. The horizontal line represents the project baseline production scenario.

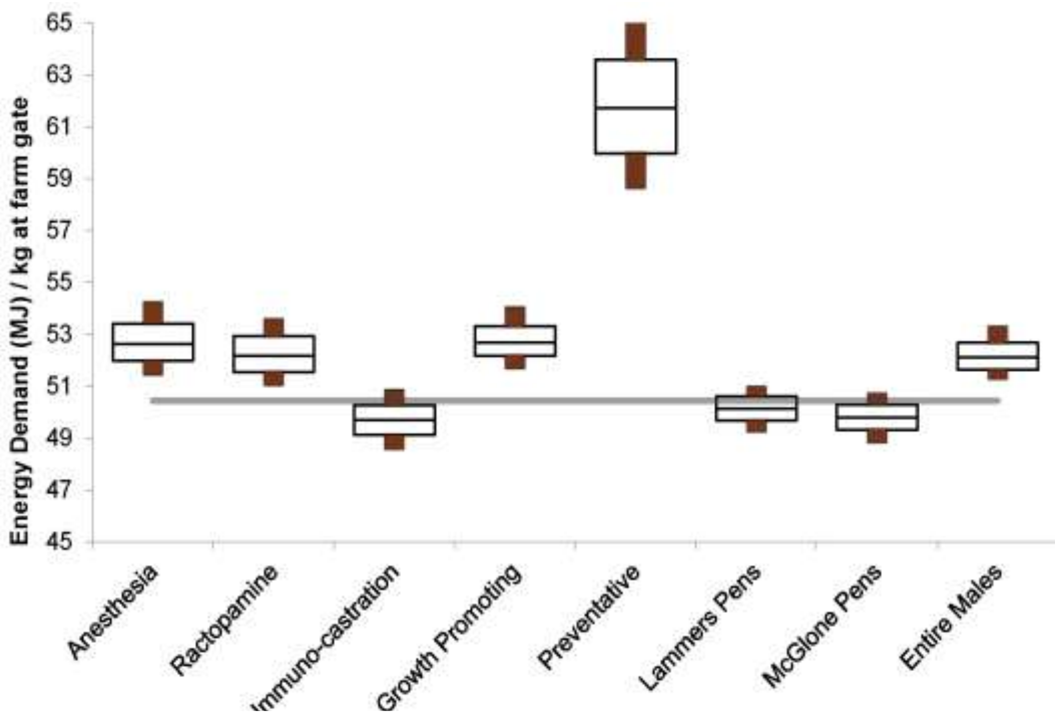

Figure 8: Estimated potential change in energy demand for alternate management practices. The horizontal line represents the project baseline production scenario.

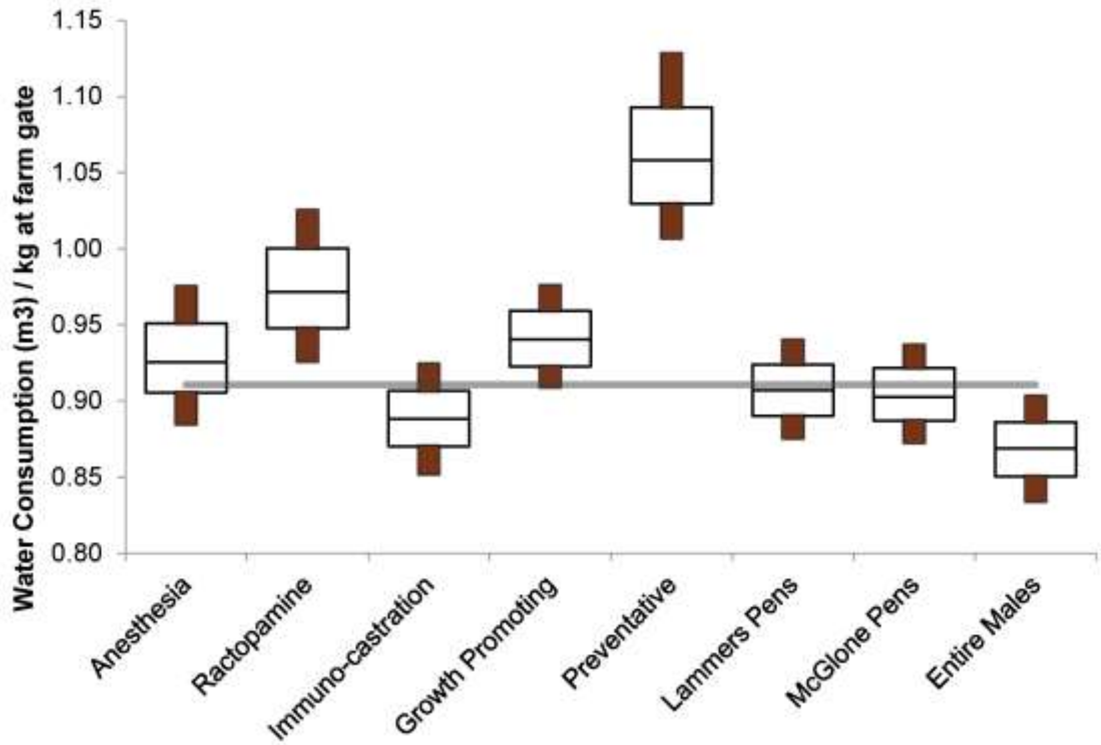

Figure 9: Estimated potential change in energy demand for alternate management practices. The horizontal line represents the project baseline production scenario.

Considering the Pen and Entire Male scenarios, in which the 50th percentile is approximately equal to the baseline, it is not possible to conclude that the alternate management scenario is different from the baseline. The differences presented in these figures may differ from the tabular presentation due to the MCS process, which is stochastic and thus will not exactly reproduce the mean or average values. The differences indicate the strength of our conclusions regarding the direction, and to a slightly lesser extent, the magnitude, of the expected change.

Conclusions

Life cycle analyses of eight pork production strategies for three environmental impact categories yielded a range of results, from a 17 percent increase in global warming potential (removing preventative antimicrobials) to approximately 3 percent reduction in energy use (immuno-castration). Based on the LCA results, the following pork production strategies increased environmental impact metrics across all three impact categories: Anesthesia, not using antimicrobials for growth promotion or disease prevention. Conversely, using immuno-castration, entire male production and pen gestation production strategies decreased global warming potential and energy use, and immuno-castration reduced water use. These results are the product of simulation of pork production strategies combined with unit process LCAs; these models are very sensitive to time in the barn at each growth stage, rates of conversion of feed to lean meat, and mortality rates. Model sensitivity and uncertainty are difficult to characterize due to the limited observational data for which the pork production models were calibrated, and the limited Life Cycle Inventory data for alternative production strategies.

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Appendix A: Feed rations assumed for simulations

Table A - 1: Dietary Rations Assumed for Nursery Simulation.

Ingredients	lbs	%
Corn 2012 NRC	931	46.6
SBM 48% 2012 NRC	544	27.2
DDGS 2012 NRC	263	13.2
Poultry Fat, 2012 NRC	50	2.5
Mono calcium P, 2012 NRC	14.7	0.73
Limestone, 2012 NRC	16.7	0.84
Salt, 2012 NRC	9	0.45
L-Lysine	7	0.35
DL-Methionine	2.1	0.10
L-Threonine	1.1	0.06
Milk, Whey powder 2012 NRC	89.7	4.5
Lactose 2012 NRC	5.1	0.26
Plasma 2012 NRC	11.8	0.59
Fish Meal, combined 2012 NRC	22.8	1.14
ZnO 2012 NRC	1.8	0.09
Copper Sulfate 2012 NRC	1.4	0.07
Vitamin Premix (NB-6508)	5	0.25
Trace Mineral Premix (NB-8534)	3	0.15
Neo-Terramycin 10/10	20	1.00
Total	2000	100.00

This ration was assumed for the time required for animals to reach 50 lbs, which varied depending on ADG for each scenario.

Table A - 2: Dietary Rations Assumed for Grow Simulation.

	Grower 1		Grower 2		Finisher 1	
	50-95#		95-140#		140-185#	
Ingredients	lbs	%	lbs	%	lbs	%
Corn 2012 NRC	1128	56.4	1238	61.9	1324	66.2
SBM 48% 2012 NRC	412	20.6	306	15.3	225	11.2
DDGS 2012 NRC	400	20.0	400	20	400	20
Monocalcium P, 2012 NRC	12.90	0.65	12.0	0.6	10.2	0.5
Limestone, 2012 NRC	19.50	0.98	19.50	0.98	19.0	0.95
Salt, 2012 NRC	12.0	0.60	10.0	0.50	10.0	0.50
L-Lysine	7.0	0.35	6.15	0.31	5.5	0.28
DL-Methionine	0.0	0.0	0.0	0.0	0.0	0.0
L-Threonine	0.46	0.02	0.05	0.0	0.0	0.0
Copper Sulfate 2012 NRC	2.0	0.10	2.0	0.10	0.0	0.0
Vitamin Premix (NB-6508)	3.0	0.15	3.0	0.15	3.0	0.15
Trace Mineral Premix (NB-8534)	3.0	0.15	3.0	0.15	3.0	0.15
Paylean-9	0.0	0.0	0.0	0.0	0.0	0.0
Total	2000	100	2000	100	2000	100

Table A - 3: Dietary Rations Assumed for Grow Simulation

	Finisher 2		Finisher 3		Finisher 3 (Paylean)	
	185-215#		215-275#		215 - 275#	
Ingredients	lbs	%	lbs	%	lbs	%
Corn 2012 NRC	1375	68.8	1722	86.1	1535	76.8
SBM 48% 2012 NRC	177	8.9	228	11.4	410	20.5
DDGS 2012 NRC	400	20.	0.0	0.0	0.0	0.0
Monocalcium P, 2012 NRC	10.0	0.5	18	0.9	17	0.9
Limestone, 2012 NRC	18.0	0.9	13	0.7	12.5	0.6
Salt, 2012 NRC	10.0	0.5	10.	0.5	10.	0.5
L-Lysine	5.2	0.3	4.1	0.2	5.6	0.3
DL-Methionine	0.0	0.0	0.0	0.0	0.8	0.0
L-Threonine	0.0	0.0	0.8	0.0	2.5	0.1
Copper Sulfate 2012 NRC	0.0	0.0	0.0	0.0	0.0	0.0
Vitamin Premix (NB-6508)	2.0	0.1	2.0	0.1	3.0	0.2
Trace Mineral Premix (NB-8534)	2.5	0.1	2.5	0.1	3.0	0.2
Paylean-9	0.0	0.0	0.0	0.0	0.5	0.0
Total	2000	100	2000	100	2000	100

Table A - 4: Dietary Rations Assumed for Sow Barn Simulation

	Gestation		Lactation	
Ingredient	lbs	%	lbs	%
Corn 2012 NRC	1063	53	1220	61
SBM 48% 2012 NRC	78.8	3.9	286	14
DDGS 2012 NRC	800	40	400	20
Fat (Darling, Yellow Grease)	0	0	35.5	1.8
Monocalcium P, 2012 NRC	0	0	0	0
Limestone, 2012 NRC	29	1.5	29	1.5
Salt, 2012 NRC	9	0.45	10	0.5
L-Lysine	4	0.2	5	0.25
L-Tryptophan	0	0	0.07	0.0035
Vitamin Premix (NB-6508)	5	0.25	5	0.25
Trace Mineral Premix (NB-8534)	3	0.15	3	0.15
Sow Add Pack (NB-6442)	5	0.25	5	0.25
Rozozyme(10000)	0.37	0.019	0.37	0.019
Ethoxiquin (Quinguard)	0.6	0.03	0.6	0.03
Tylan-40	2.5	0.125	0	0
Total	2000	100	2000	100

Appendix B: Gestation Barn Infrastructure

The barn infrastructure requirements for changing from individual stalls to group housing/pens is the result of an increase in the area per animal from approximately 22 square feet to 35 square feet. This results in additional barns to be constructed, and there can be significant environmental impacts associated with production and installation of the barn material. In this analysis, we used the following estimates for bills of material for each barn type (Table B - 1). This is not an exhaustive accounting of all the material and the unit process modeled does not account for disposal of construction waste, nor for potential sediment runoff or other possible direct impacts associated with barn construction. The following figures provide a comparison of the impact profile

Table B - 1: Bill of materials (major components) for barns used in simulations.

		Grow Barn (slatted floor)	Nursery Barn (mesh floor)	Gestation (pens, slatted floor)	Gestation (stalls, slatted floor)
		240 head	160 head	120 head	120 head
Aluminum roofing/siding	kg	754	382	1410	892
Concrete	m^3	64.6	16.3	130	80.2
Concrete block	kg	998	0	2990	1800
Copper (Wiring)	kg	3.1	3.1	3.1	3.1
Excavation	m^3	211	65.2	471	287
Foam Insulation	kg	899	522	1810	1150
Framing lumber	kg	2970	2060	3370	3060
Gestation Pen	p	#N/A	#N/A	12	#N/A
Gestation Stall	p	#N/A	#N/A	#N/A	120
Grow Barn Pen	p	12	#N/A	#N/A	#N/A
Nails	kg	40.6	25.3	58	44.4
Plastic sheeting	sq.ft	3970	2300	8000	5070
Plywood	kg	832	554	1450	978
Reinforcing steel	kg	760	366	1430	900
Sand	kg	16900	8700	37700	23000
Sanitary ceramics	kg	120	120	120	120
Transport (all materials)	tkm	46500	46500	93700	58100
Land	m^2	208	107	464	282

associated with Gestation pen housing and Gestation stall housing. The more densely populated barns with individual stalls have lower impact for global warming and water consumption; however, as discussed in the main report, there is a slight improvement in piglet productivity which offsets this reduction in efficiency; this analysis does not assess the economic implications of this change in management.

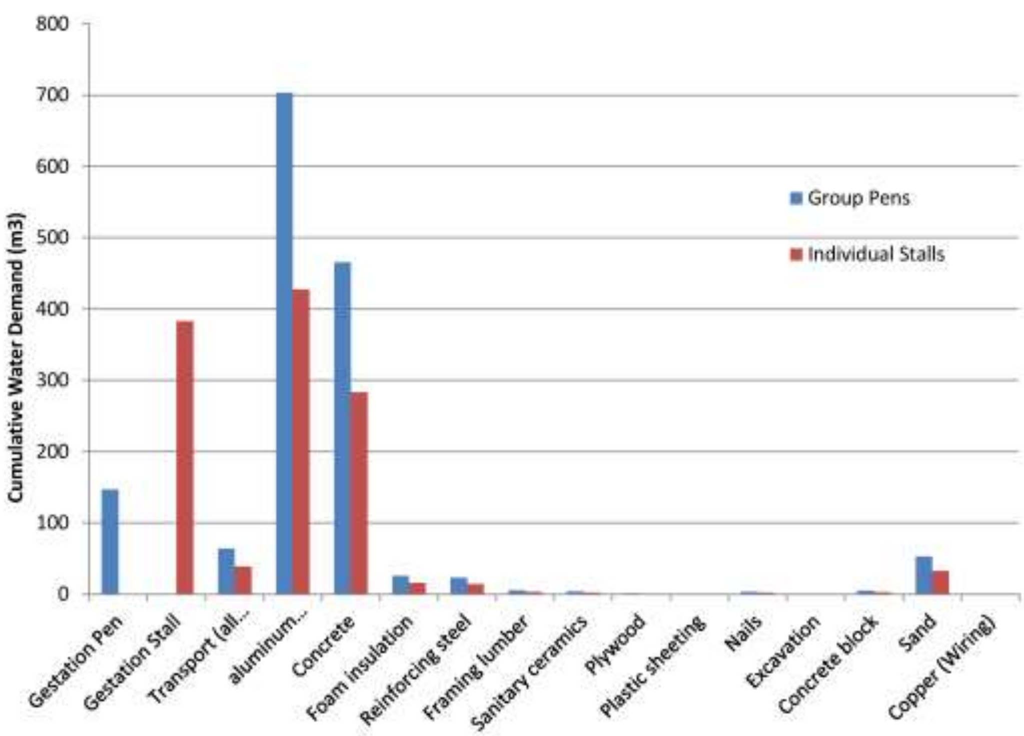

Figure B - 1: Relative contribution to water demand for sow barns (design based on 120 animals to be housed)

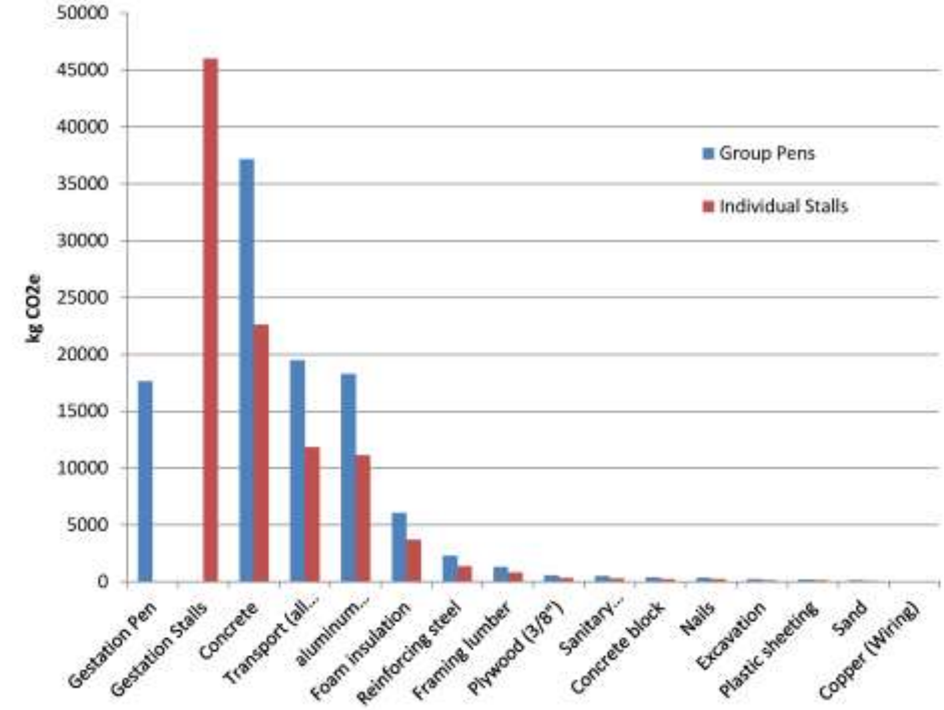

Figure B - 2: Relative contribution to global warming potential for sow barns (design based on 120 animals to be housed).

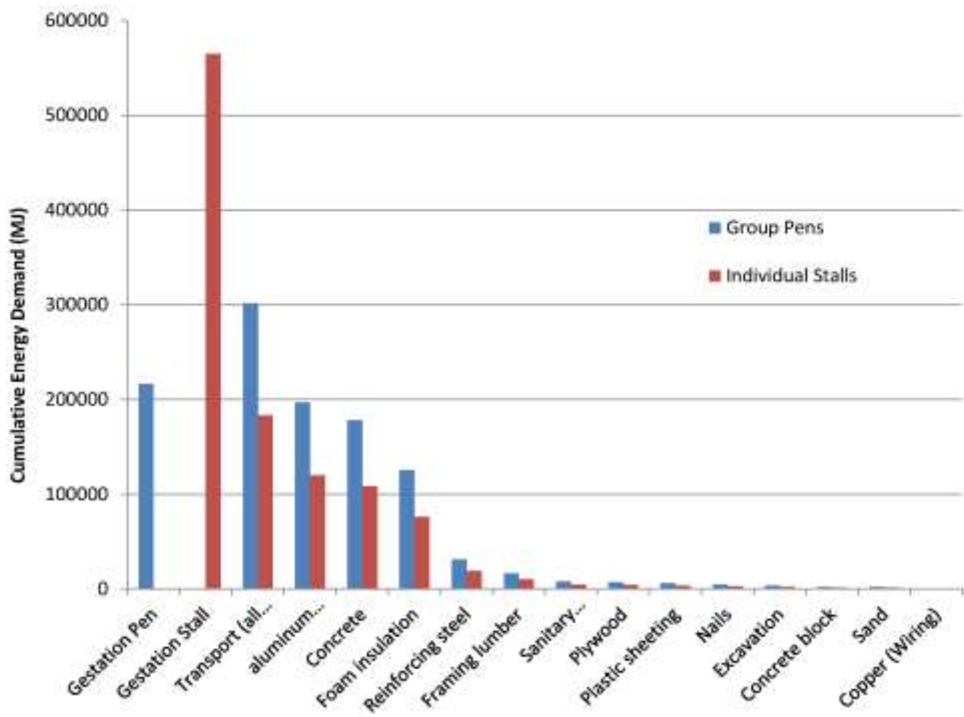

Figure B - 3: Relative contribution to cumulative energy demand for sow barns (design based on 120 animals to be housed).

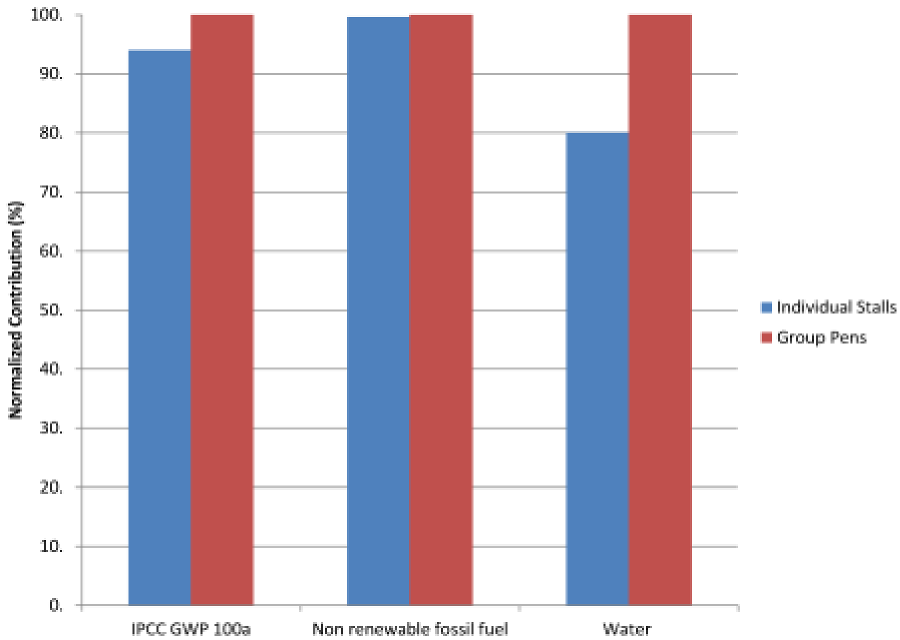

Figure B - 4: Normalized impact contribution for sow barns (design based on 120 animals to be housed)

Appendix C: Boar production

Although not included in the original scope of work for this project, a question arose regarding the possibility of avoiding castration completely and marketing boars. In order for this management option to produce meat without boar taint, it is necessary to take the animals to slaughter at a younger age before the offensive

Table C - 1: Performance parameters for entire males.

Parameter	Wean to feeder	Feeder to market			
Wight entering (lb)	11	50	85	127	174
Weight leaving (lb)	50	85	127	174	200
Days in barn	42	21	23	23	13
Market weight (lb)	NA	NA	NA	NA	200
Average daily gain (lb/day)	0.93[2]	1.69[2]	1.80[3]	2.02[3]	1.9[3]
Daily feed intake (lb/day)	1.44	3.68	4.64[3]	5.20[3]	4.89[3]
Feed efficiency[4]	1.54[6]	2.17[6]	2.56[6]	2.56[6]	2.56[6]
Water consumption per animal (gal)	0.7[7]	1.5[7]	1.5[7]	1.5[7]	1.15[7]
Area per animal (sq ft)	2.5[7,10]	7.5[7,10]	7.5[7,10]	7.5[7,10]	7.5[7,10]
Mortality (%)	2.9[8]	3.9[8]	3.9[8]	3.9[8]	3.9[8]
Manure excretion wet basis (lb/day)	2.3[8,11]				9.46[9]
Carcass yield (%)	NA	NA	NA	NA	75.05
Dressing yield (%)	NA	NA	NA	NA	73.70

[1] Kansas State Swine Nutrition Guide, [2] Pauly et al. (2008), [3] Time weighted average of data from Fabrega et al. (2010) and Morales et al. (2010), [4]DFI: ADG, [5] Whitney et al., [6] Ross et al. (2011), [7] Lammers et al. (2012), [8]Hostetler et al. (pers. comm, October, 2012), [9]Sutton et al., [10]average of data from Andersson et al. (2012), Font-i-Furnols et al. (2012), Morales et al. (2010), Pauly et al. (2009), Skrlep et al. (2012), and Zamaratskaia et al. (2008)), [11]Zamaratskaia et al. (2008)

compounds are produced by the gonads. The scenario presented in Table C - 1 was the basis for evaluation of the sales of lighter weight boars.

Appendix D: Uncertainty scenarios

Average daily gain and feed efficiency

High and low values of ADG and FE of pigs for the last phase in the grow-finish barn, when the pigs are supplemented with RAC, were obtained from Smith et al., (2005), Armstrong et al., (2004), Rickard-Bell et al., (2009), Patience et al., (2009), Hinson et al., (2011), and Barbosa et al., (2012). These values were used to define the last phase in the uncertainty scenarios for the baseline. Maximum and minimum values for ADG and FE for the control group (no RAC) in these studies were selected for last 32 days in the grow-finish barn for uncertainty scenarios of no ractopamine treatment. The percentage difference between the mid values for last 32 days in the no ractopamine treatment and the maximum and minimum values for control group obtained from the literature was calculated for both ADG and FE. This percentage difference was incorporated in first four phases in grow-finish barn for both baseline and no ractopamine treatment scenarios to define uncertainty scenarios (Table D - 1 through Table D - 6). Data from Kansas State University Starter Pig Recommendations was used to define uncertainty scenarios for wean to feeder phase in the barn. Daily feed intake for each phase was determined by taking the ratio of ADG and FE.

Water consumption

A range of water consumption for each pig was defined using data obtained from National Pork Board Swine Care Handbook (2003) (Table D - 1). This same range was used for defining water consumption for uncertainty scenarios for both baseline and no ractopamine. The water consumption reported in Table D - 1 is larger than used in the scenarios as the scenarios were constructed on the basis of information received from the taskforce groups. These data were used to define the minimum and maximum scenarios for the uncertainty analysis. Specifically, given the range reported for each animal class, we applied the same relative range of consumption to our scenarios, taken from the last column of Table D - 1.

Table D - 1: Water consumption per pig and percentage change.

Class of pig	Water consumption per pig (gal/day)	Average (gal/day)	Percentage change
Nursery (up to 60 lbs)	0.7-1	0.85	± 17.64
Grower (60-100 lbs)	2-3	2.5	± 20
Finisher	3-5	4	± 25

Mortality

National Pork Board Antibiotic Resistance Taskforce Report provided percentage change in ADG, FE, and mortality if antimicrobials were not used in the swine production. The task force expects only 50% of the reported impact on performance parameters, if Carbadox are still used in the production. For the baseline and no ractopamine, use of Carbadox was assumed in the production and change in the mortality was assumed to be 25% of the reported change without GP antimicrobial use in median health production.

Carcass yield and edible portion

The United States Department of Agriculture (USDA) livestock slaughter data for 2010 was used to obtain carcass yield for national production. The maximum and minimum values for carcass yield were selected and percentage change compared to the average value was determined. Uncertainty scenarios were defined by applying this delta to carcass yield and edible portion values in baseline and no ractopamine.

Overall statistics

The interpretation of the information in Table D - 6 requires the following explanation. Each row represents the statistical analysis of 1000 Monte Carlo simulations. The results are presented with the following characteristics: fraction of the MCS simulations for which the alternate practice impact exceeded the baseline impact; the mean and median value of the difference for the 1000 runs; the standard deviation and coefficient of variation for the distribution of differences; the 10^{th} and 90^{th} confidence interval limits.

Table D - 2: Baseline uncertainty scenario for maximum carbon footprint.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11.0	50	85	127.5	175	215
Weight leaving (lb)	50	85	127.5	175	215	275
Days in barn[1]	46	24	24	24	22	35
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain (lb/day)	0.85[2]	1.46[4]	1.75[4]	1.95[4]	1.84[4]	1.73[4]
Daily feed intake[3] (lb/day)	1.42	4.38	5.26	5.88	5.53	5.56
Feed efficiency	1.69[2]	3.03[4]	3.03[4]	3.03[4]	3.03[4]	3.23[4]
Water consumption per animal[5] (gal/day)	0.82	1.8	1.8	1.8	1.8	2.19
Area per animal[6] (sq ft)	2.5	7.5	7.5	7.5	7.5	7.5
Mortality[7] (%)	2.95	3.95	3.95	3.95	3.95	3.95
Manure excretion wet basis[8] (lb/day)	2.3	9.46	9.46	9.46	9.46	8.47
Carcass yield[9] (%)	NA	NA	NA	NA	NA	73.24
Edible portion[9] (%)	NA	NA	NA	NA	NA	69.62

[1] Calculated from weight gain and ADG, [2] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [3] ADG/FE, [4] Obtained by applying percentage delta calculated from Smith et al., (2005), Amstrong et al., (2004), Rickard-Bell et al., (2009), Patience et al., (2009), Hinson et al, (2011), and Barbosa et al., (2012) and mid values, [5] Obtained by applying delta from Table D-1, [6] Not including aisles and ancillary rooms, [7] Obtained by applying ±25% of change in mortality reported for production without GP antimicrobial use by NPB taskforce for median health production, [8] Data not used for this analysis but retained for process documentation [9] Obtained by applying percentage delta obtained from USDA Livestock Slaughter 2011 Summary

Table D - 3: Baseline uncertainty scenario for minimum carbon footprint.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	127.5	175	215
Weight leaving (lb)	50	85	127.5	175	215	275
Days in barn[1]	38	16	16	16	14	21
Market weight (lb)	NA	NA	NA	NA	NA	275
Average daily gain (lb/day)	1.03[2]	2.21[4]	2.65[4]	2.97[4]	2.79[4]	2.89[4]
Daily feed intake[3] (lb/day)	1.50	5.46	6.54	7.33	6.88	7.22
Feed efficiency	1.47[2]	2.5[4]	2.5[4]	2.5[4]	2.5[4]	2.5[4]
Water consumption per animal[5] (gal/day)	0.58	1.2	1.2	1.2	1.2	1.3
Area per animal[6] (sq ft)	2.5	7.5	7.5	7.5	7.5	7.5
Mortality[7] (%)	2.85	3.85	3.85	3.85	3.85	3.85
Manure excretion wet basis[8] (lb/day)	2.3	9.46	9.46	9.46	9.46	8.47
Carcass yield[9] (%)	NA	NA	NA	NA	NA	76.98
Edible portion[9] (%)	NA	NA	NA	NA	NA	73.18

[1] Calculated from weight gain and ADG, [2] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [3] ADG/FE, [4] Obtained by applying percentage delta calculated from Smith et al., (2005), Armstrong et al., (2004), Rickard-Bell et al., (2009), Patience et al., (2009), Hinson et al, (2011), and Barbosa et al., (2012) and mid values, [5] Obtained by applying delta from Table D-1, [6] Not including aisles and ancillary rooms, [7] Obtained by applying ±25% of change in mortality reported for production without GP antimicrobial use by NPB taskforce for median health production, [8] Data not used for this analysis but retained for process documentation [9] Obtained by applying percentage delta obtained from USDA Livestock Slaughter 2011 Summary

Table D - 4: No ractopamine uncertainty scenario for maximum carbon footprint.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	127.5	175	215
Weight leaving (lb)	50	85	127.5	175	215	275
Days in barn[1]	46	24	24	24	22	35
Market weight (lb)	NA	NA				275
Average daily gain (lb/day)	0.85[2]	1.45[4]	1.75[4]	1.95[4]	1.84[4]	1.70[4]
Daily feed intake[3] (lb/day)	1.42	4.48	4.38	5.26	5.88	6.07
Feed efficiency	1.69[2]	3.03[4]	3.03[4]	3.03[4]	3.03[4]	3.57[4]
Water consumption per animal[5] (gal/day)	0.82	1.8	1.8	1.8	1.8	2.19
Area per animal[6] (sq ft)	2.5	7.5	7.5	7.5	7.5	7.5
Mortality[7] (%)	2.95	3.95	3.95	3.95	3.95	3.95
Manure excretion wet basis[8] (lb/day)	NA	NA	NA	NA	NA	NA
Carcass yield[9] (%)	NA	NA	NA	NA	NA	72.68
Edible portion[9] (%)	NA	NA	NA	NA	NA	68.17

[1] Calculated from weight gain and ADG, [2] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [3] ADG/FE, [4] Obtained by applying percentage delta calculated from Smith et al., (2005), Armstrong et al.,(2005), Armstrong et al., (2004), Rickard-Bell et al., (2009), Patience et al., (2009), Hinson et al, (2011), and Barbosa et al., (2012) and mid values, [5] Obtained by applying delta from Table D-1, [6] Not including aisles and ancillary rooms, [7] Obtained by applying ±25% of change in mortality reported for production without GP antimicrobial use by NPB taskforce for median health production, [8] Data not used for this analysis but retained for process documentation [9] Obtained by applying percentage delta obtained from USDA Livestock Slaughter 2011 Summary

Table D - 5: No ractopamine uncertainty scenario for minimum carbon footprint.

Parameter	Wean to Feeder	Feeder to Finish (up to last 28 days)				Finish (last 28 days)
Weight entering (lb)	11	50	85	127.5	175	215
Weight leaving (lb)	50	85	127.5	175	215	275
Days in barn[1]	38	16	16	16	15	23
Market weight (lb)	NA	NA				275.
Average daily gain (lb/day)	1.03[2]	2.21[4]	2.65[4]	2.97[4]	2.79[4]	2.58[4]
Daily feed intake[3] (lb/day)	1.50	5.45	6.54	7.33	6.88	7.56
Feed efficiency	1.47[2]	2.5[4]	2.5[4]	2.5[4]	2.5[4]	2.94[4]
Water consumption per animal[5] (gal/day)	0.58	1.2	1.2	1.2	1.2	1.31
Area per animal[6] (sq ft)	NA	NA	NA	NA	NA	NA
Mortality[7] (%)	2.85	3.85	3.85	3.85	3.85	3.85
Manure excretion wet basis[8] (lb/day)	NA	NA	NA	NA	NA	NA
Carcass yield[9] (%)	NA	NA	NA	NA	NA	76.98
Edible portion[9] (%)	NA	NA	NA	NA	NA	73.18

[1] Calculated from weight gain and ADG, [2] Kansas State University Starter Pigs Recommendations – average value for the full period rather than specific to the ration phase, [3] ADG/FE, [4] Obtained by applying percentage delta calculated from Smith et al., (2004), Rickard-Bell et al., (2009), Patience et al., (2009), Hinson et al, (2011), and Barbosa et al., (2012) and mid values, [5] Obtained by applying delta from Table D-1, [6] Not including aisles and ancillary rooms, [7] Obtained by applying ±25% of change in mortality reported for production without GP antimicrobial use by NPB taskforce for median health production, [8] Data not used for this analysis but retained for process documentation [9] Obtained by applying percentage delta obtained from USDA Livestock Slaughter 2011 Summary

Table D - 6: Uncertainty analysis results for alternate management practices, with an 80% confidence interval (80% of the simulations fall between 10% and 90%).

Alternative Management Strategy	Impact category	Alternative Exceeds Baseline	Mean Exceedance	SD	COV	10%	90%
Anesthesia	IPCC GWP 100a	85%	0.21	-0.2	93%	-0.047	0.47
	Non-renewable, fossil	99%	2.3	-1.16	50%	1.01	3.8
	Water	67%	0.018	-0.04	200%	-0.026	0.07
Immuno-Castration	IPCC GWP 100a	27%	-0.09	-0.15	-170%	-0.27	0.1
	Non-renewable, fossil	19%	-0.75	-0.9	-120%	-1.9	0.39
	Water	20%	-0.02	-0.03	-128%	-0.06	0.014
No Ractopamine	IPCC GWP 100a	98%	0.31	-0.18	53%	0.11	0.6
	Non-renewable, fossil	97%	1.95	-1.15	59%	0.6	3.28
	Water	96%	0.064	-0.04	63%	0.014	0.12
No GP Antibiotics	IPCC GWP 100a	100%	0.35	-0.14	40%	0.17	0.54
	Non-renewable, fossil	100%	2.5	-1	40%	1.4	3.7
	Water	91%	0.033	-0.027	83%	0.0007	0.069
No GP No Prev. Antibiotics	IPCC GWP 100a	100%	1.6	-0.29	18%	1.9	1.92
	Non-renewable, fossil	100%	11.7	-3.4	29%	8.2	15.5
	Water	100%	0.15	-0.048	32%	0.097	0.22
Gestation Stalls[1]	IPCC GWP 100a	38%	-0.041	-0.14	-330%	-0.22	0.14
	Non-renewable, fossil	30%	-0.4	-0.73	-180%	-1.3	0.5
	Water	42%	-0.0047	-0.025	-580%	-0.036	0.028
Gestation Pens[2]	IPCC GWP 100a	56%	0.033	-0.2	610%	-0.23	0.3
	Non-renewable, fossil	67%	0.56	-1.2	220%	-0.89	2
	Water	51%	0.002	-0.032	1790%	-0.04	0.048
Gestation Pens[1]	IPCC GWP 100a	34%	-0.064	-0.14	-213%	-0.24	0.18
	Non-renewable, fossil	18%	-0.64	-0.75	-117%	-1.6	0.28
	Water	39%	-0.0065	-0.025	-390%	-0.038	0.026
Entire Males	IPCC GWP 100a	94%	0.25	-0.17	66%	0.04	0.48
	Non-renewable, fossil	100%	3.5	-1.27	37%	2.1	5
	Water	35%	-0.0093	-0.029	-305%	-0.045	0.027