Summary Report
Life Cycle Assessment for U.S. Pig Production

Production Years 2017-2019, 2022, and 2023

SES, Inc.

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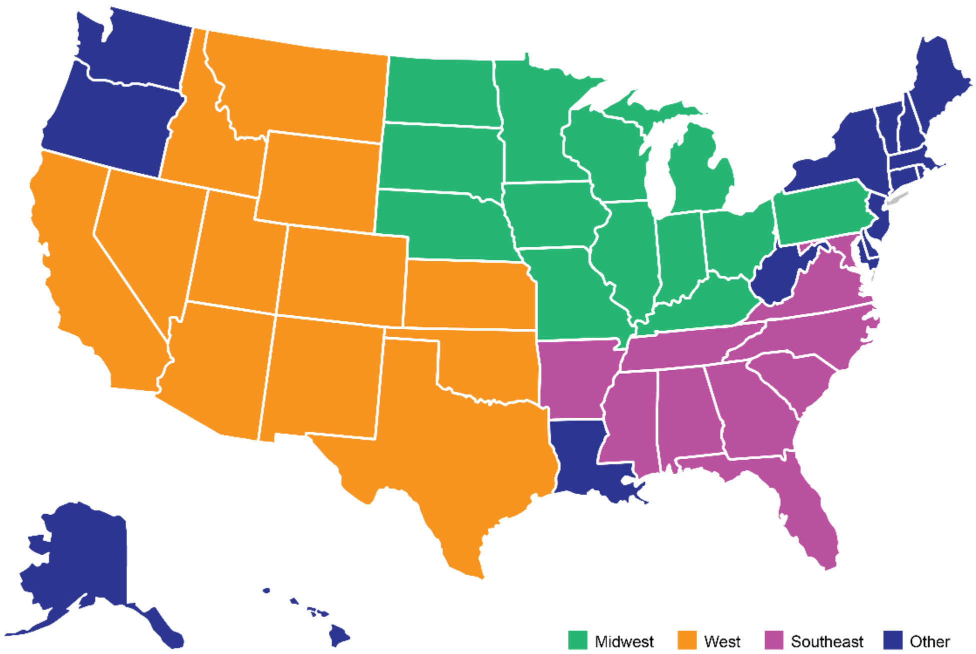
1.0 Project Overview

The objective of this LCA was to quantify environmental impacts of pork production across the U.S. The study focused on three primary regions for pork production: Midwest, Southeast, and West (Figure 1).

Figure 1. U.S. Pig Production Regions



1.1 Use of Primary Data

The data inventory for the study included primary production metrics from 10,560 operations in the Midwest and West, including diet composition, to establish a baseline for U.S. pig production (Attachment 1). The production data covered the years 2017-2019, 2022, and 2023. All data was anonymized and aggregated to protect producer privacy. Primary data was not available for the Southeast region due to the concentration of a limited set of producers and the need to protect proprietary industry data. Data from the years 2020 and 2021 was excluded due to anomalies from the Covid 19 pandemic.

The use of primary data improved the Midwest and West regional analyses (Attachments 2 and 3) in the following ways:

- Highest level of accuracy and reliability (certainty) for results.
- Reflected stages of actual U.S. production and accounted for benefits of production efficiencies and diet composition within each phase.

- Allowed region- and phase-specific accuracy for diet impacts, one of largest contributions to the environmental impacts of pig production.
- Enables future comparison of production efficiencies and diet composition to historical values when assessed at an annual basis, including insight on which production metrics contributed to the change.
- Provided an accurate benchmark for comparison to a specific operation or changes in production and diet composition.

1.2 Methodology

The data inventory and full methodology description is available in Attachment 1. The U.S. assessment was based on USDA National Agriculture Statistics Service (NASS) pig inventory data (USDA NASS, 2023) that covered 99.5% of the U.S. pig population and the regional analysis for the three primary pork production regions as defined in Figure 1 (Attachments 2-5).

Each regional analysis assessed:

- The impacts of 1 kilogram (kg) of live weight pork at farm gate
- Contributions to the total impact categories (GWP, eutrophication, land occupation, and water use) from each phase of production occurring in-region
- Crop production, availability of resources and system inputs (source of grain, fertilizer type, production metrics) based on region-specific data, where available
- Where required, such as for climate data, the studies used a representative state in region (Iowa, Oklahoma, and North Carolina)

The regional analysis identified production differences including adoption of sustainability practices. These regional scenarios were applied in the U.S. analysis.

Midwest:

- Deep pit manure management
- Integrated livestock and crop production
- Land-applied manure displaced 91% of the synthetic fertilizer use and provides the corn ingredient sourced for pig production
- Remaining feed sourcing is assumed to be conventional to address the gap between corn acreage that is manure fertilized, and the total acreage needed for feed use in Iowa.

The scenario was based on Iowa corn acreage required for pig feed (Iowa Pork Council, 2020; USDA NASS, 2023), and the percentage of Iowa corn acreage with swine manure fertilization (USDA ARMS, 2020; Andersen, 2013). Feed exported from the Midwest to other regions was assumed to be conventional.

Southeast:

- Lagoon system with land application
- 2.46% covered lagoon adoption for the Southeast (US EPA AgSTAR, 2024)
- 70% of feed imported from the Midwest, conventionally produced (NASS, 2023; Piggott, 2019).

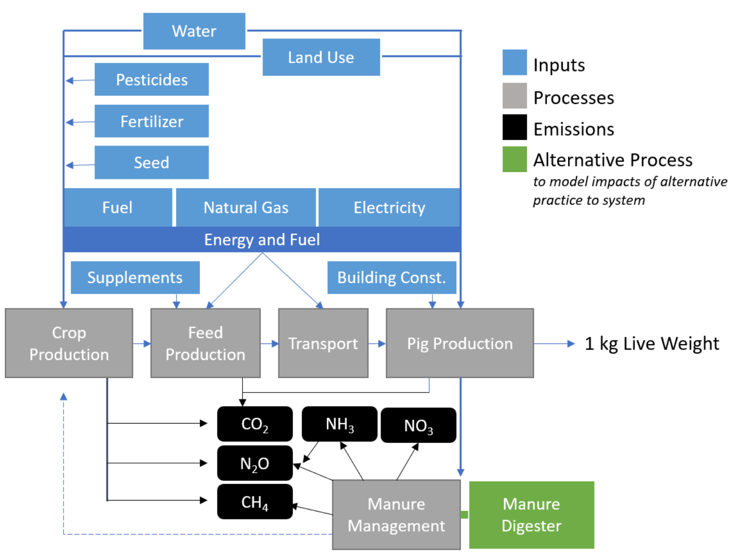
West:

- Lagoon system with land application
- 13.44% covered lagoon adoption for the West (US EPA AgSTAR, 2024)
- 80% of feed imported from the Midwest, conventionally produced (Shurson et al. 2022; USDA NASS)

1.2.1 Boundary and Scope

The LCA boundary was cradle-to-farm-gate. The following scenario, boundary, and scope were used for the LCA (Figure 2).

Figure 2. In-scope Processes, Inputs, and Emissions



Inputs, processes, emissions, and alternative processes within the scope of producing 1 kg live weight at farm gate.

Processes within the system boundary included:

- Crop cultivation and feed sourcing and related inputs (excluding capital goods)
- Feed production (excluding labor and commuting)
- Transport of grain, feed, and animals

- Pig production, including
    - Emissions, water, energy, infrastructure, and land occupation along with manure management strategies were assessed for representative regional practices

The studies assessed the following impacts from pig production per 1 kg of live weight (LW) pig at farm gate:

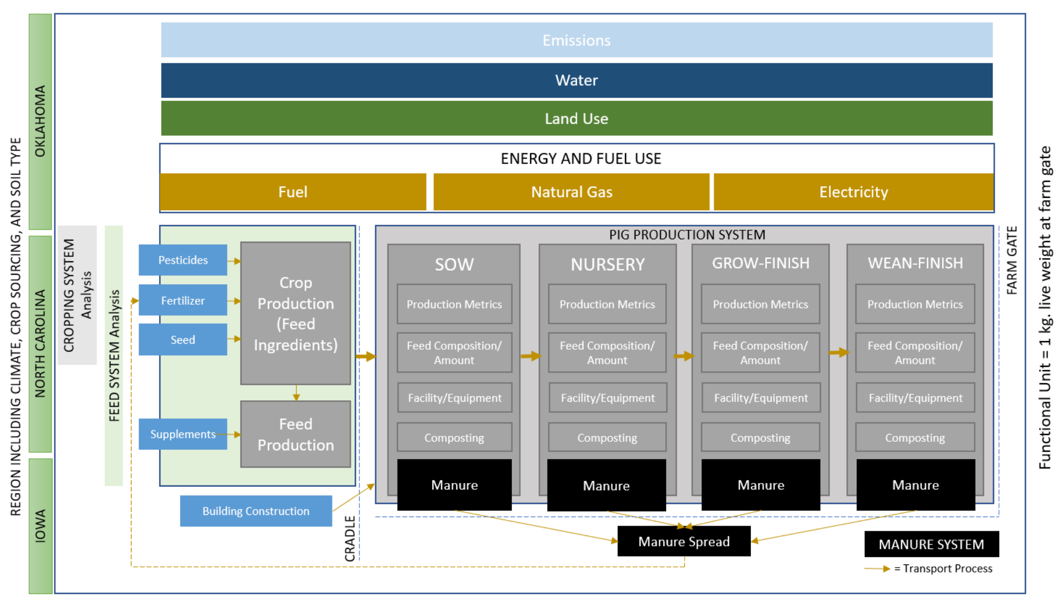
- Global warming potential (GWP) impact measured in kg carbon dioxide (CO_2) equivalent (kg CO_2e)
- Freshwater eutrophication in grams phosphorous equivalent (g P e)
- Marine eutrophication in grams nitrogen equivalent (g N e)
- Land use occupation in square meters per annum (m^2a)
- Water consumption in cubic meters (m^3)

Freshwater and marine eutrophication were assessed under baseline pig production of conventional feed production and no manure management system alternatives. This was necessary due to limitations in available data for alternative scenarios.

1.2.2 System Modeling

This LCA was structured to model U.S. pork production phases as the sub-systems, including the Sow, Nursery, Finisher, and Wean-to-Finish phases (Figure 3). The modeling allowed comparison of impact by production phase.

Figure 3. Sub-systems Within Boundary



Cradle-to-farm-gate framework within the scope of the LCA boundary including four production system phases with a functional unit of 1 kg live weight at farm gate.

2.0 Executive Summary

Table 1 provides results from this LCA the regional analyses with two comparative studies. The comparative LCA studies are from Putman et al. (2018), *A Retrospective Assessment of US Pork Production: 1960 to 2015*, and Blonk (2023), *Sustainability performance of pork production*.

Table 1. LCA Results for U.S. and Regional Pig Production (per kg live weight at farm gate)

U.S., Regional and Comparative LCA Studies					
Study	GWP (kg CO2e)	Freshwater Eutrophication (g P e)	Marine Eutrophication (g N e)	Land Use (m^2a)	Water Consumption (m^3)
U.S. LCA	2.939	1.009	2.072	2.661	0.139
Southeast LCA AD Adoption (2.46%)	5.174	0.808	2.266	3.011	0.141
West LCA AD Adoption (13.44%)	5.055	0.810	2.240	2.957	0.148
Midwest LCA 91% Feed Produced Manure Fertilization	2.539	1.060	2.026	2.578	0.138
Putman et al. (2018) *	3.04	N/A	N/A	3.03	0.125
Blonk (2023) *	2.786	1.54	2.38	3.310	0.130

**Putman et al. (2018) LCA results reference 2015 data. Putman et al. (2018) and Blonk (2023) were U.S. National results.*

Comparisons of LCA studies should be considered for approximate benchmarking only. Underlying data sources, literature, methodologies, scenarios, and inputs including diet composition varied significantly across LCA studies and affected the LCA results (Attachment 5).

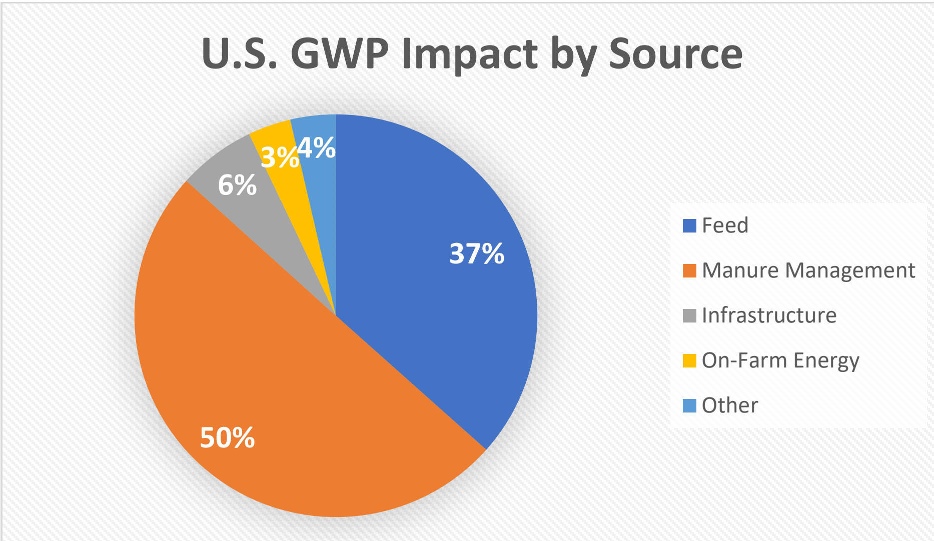
2.1 U.S. Production GWP Impacts

The U.S. LCA assessment was consistent with previous LCA findings, observing feed and manure management as the largest contributors to GWP impacts of pig production (Table 2 and Figure 4).

Table 2. GWP Impacts of U.S. Pig Production

Category	**kg CO_2e per kg LW**
Feed	1.076
Manure Management	1.472
Infrastructure	0.183
On-Farm Energy	0.101
Other	0.107
Grand Total	**2.939**

Figure 4. Relative GWP Impact for U.S. Pig Production



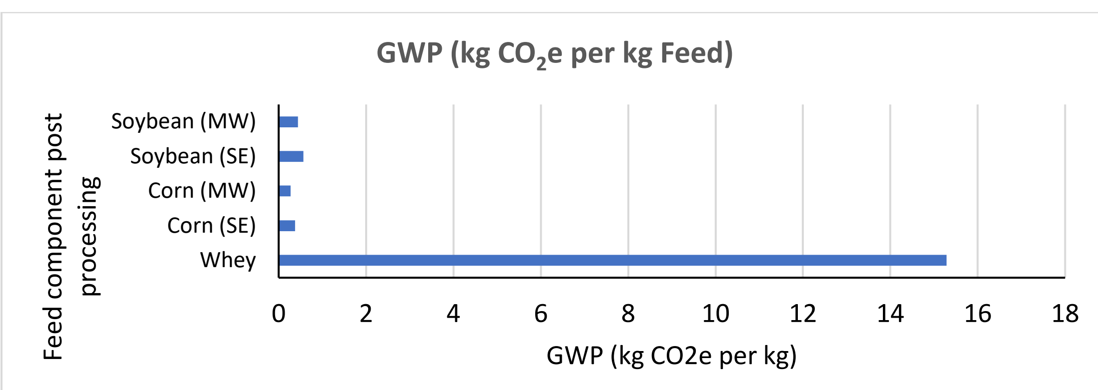
Relative GWP impacts of pig production by source or process in pig production.

Manure management contributed 50% of the GWP impact of pig production in the U.S., based on the allocation of different manure management systems in the regions. Section 2.1.2 provides further information on GWP impacts and manure management.

Feed had 37% of the relative GWP impact to produce 1 kg live weight pig at farm gate, in the conventional feed scenario. Feed impacts are further described in Section 2.1.3. The largest contributors to GWP impacts from diet ingredients included:

- Corn, soybean meal, Distillers Dried Grains with Solubles (DDGS), and whey use in Nursery diet (Figure 5)
- Diet composition and feed production practices, which varied across regions

Figure 5. Comparison of GWP Impacts for Feed Ingredients



Comparison of GWP per kg of feed ingredients including corn from Midwest (MW) and Southeast (SE), soy from MW and SE, and whey.

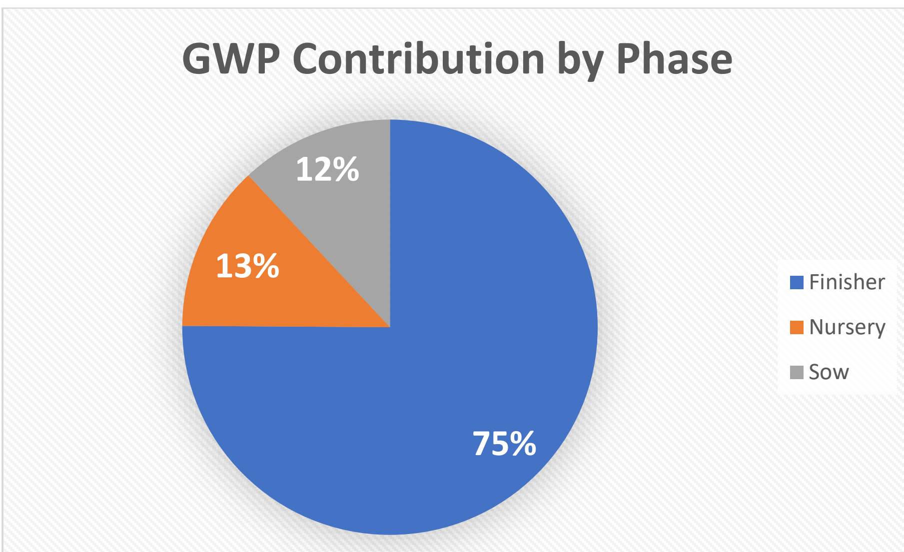
On-Farm Energy Use GWP impact comprised 3% of the GWP impact, and 6% was attributed to infrastructure. Infrastructure included building materials and construction, amortized over a 50-year time horizon.

2.1.1 GWP Impacts by Production Phase

The overall GWP impact of 1 kg of live weight pig at farm gate is a cumulative total from the pig's life cycle, with different contributions from each life cycle phase, Sow, Nursery, and Finisher.

Figure 6 provides the relative GWP impact by phase. The length of the pig's life cycle in phase, amount of feed use, and manure management impacts contributed to differences in GWP impact by production phase. Regional analyses of the GWP impact of production phases identified factors that contribute to these differences, which are summarized here, and can be further reviewed in the regional LCAs (Attachments 2-4).

Figure 6. GWP Impact Contribution by Production Phase



GWP impact by production phase for Finisher, Nursery, and Sow

Based on the U.S. and regional analysis, phases of production had the following differences that explain their relative contribution to GWP impact.

Finisher phase:

- The largest GWP impact by phase of a market pig's lifecycle.
- Longest phase in comparison to sow and nursery, with more feed inputs and manure outputs.
- Greatest GWP impact of all phases across the U.S. and regional analyses.

Sow Phase:

- Included gilts, dry sows, lactating sows, and the breeding, gestation, and farrowing activities to produce piglets.
- Higher relative GWP impact for energy use due to increased heating required to maintain temperatures for the piglets and for sow cooling.
- Higher GWP impact per day in phase than other phases, but shortest period of the pig life cycle.
- Greater in-region relative impact for the West and Southeast regions than the Midwest.

Nursery Phase:

- The Midwest imports piglets from the West and Southeast, which was accounted for in the inventory data for the U.S. study.
- Included the pig's life cycle from piglet weaning to placement in the Finisher phase.
- The Nursery phase had the highest relative GWP impact from feed compared to other phases at 42% for the Southeast, 66% for Midwest, and 40% for the West (Attachments 2-4).
- GWP impact primarily due to the whey diet ingredient fed during piglet weight gain post-weaning (Figure 5).
- The phase required increased energy use for heating but had lower impact from manure management than other phases.

Wean-to-Finish Phase:

According to the primary data averaged from the West and Midwest regions, 74.5% of pig production consisted of the phases Sow → Nursery → Finisher. The other 25.5% of production included two phases, Sow → Wean-to-Finish. Based on the regional analyses, the Wean-to-Finish phase:

- Lower relative manure management impacts (mix of smaller and larger animals) than the Finisher phase
- Greater feed impacts (nursery and finisher diet mix) due to whey ingredient in nursery diet.

2.1.2 Manure Management

Manure emissions are influenced by factors including the nitrogen content of feed rations, type of manure management system, and climatic conditions such as temperature (Putman et al., 2018). Southeast and West pig production primarily use uncovered lagoon manure storage with field application. This manure management system has greater GHG emissions than the deep pit systems that characterize the Midwest pork production region (Gavrilova et al., 2019).

Table 3 provides a regional comparison of the kg of methane (CH_4) and nitrous oxide (N_2O) and associated GWP for manure emissions per pig by phase. The GWP totals in kg CO_2e were calculated with both ReCiPe 2016 and IPCC AR6 values for methane, for comparison.

Table 3. Regional Comparison of Manure Emissions by Phase per Piglet/Pig

Phase	**CH_4 (kg)** *Methane*	**N_2O (kg)** *Nitrous oxide*	**GWP ReCiPe (kg CO_2e)** *(Methane = 34 GWP)*	**GWP IPCC AR6 (kg CO_2e)** *(Methane = 27 GWP)*
SOUTHEAST				
Sow (per piglet)	1.35	0.005	47.30	37.82
Nursery	1.04	0.004	36.26	29.00
Finisher	10.89	0.038	380.52	304.30
WEST				
Sow (per piglet)	1.43	0.005	49.00	39.81
Nursery	1.10	0.004	37.80	30.81
Finisher	11.49	0.038	393.00	320.62
MIDWEST				
Sow (per piglet)	0.385	0.005	14.10	11.81
Nursery	0.292	0.004	10.80	8.96
Finisher	3.09	0.042	115.00	94.87

The ReCiPe 2016 methodology was applied in this LCA analysis. The difference in the GWP for methane between IPCC AR6 and ReCiPe 2016 would result in an 20.59% less GWP impact for manure management if the study used IPCC AR6. A discussion of LCA methodologies is provided in Attachments 2-5.

2.1.2.1 Alternative System: Manure Management

The type of manure management system (MMS) used in pig production had a significant impact on the contribution to GWP. This LCA accounted for the current adoption of covered lagoon MMS in the Southeast and West regions, 2.46% and 13.44%, respectively. Reductions in GWP impact from anaerobic digester (AD) MMS systems were modeled in the regional analysis for the Southeast and West regions. (Attachments 3 and 4). Changing the MMS from an uncovered lagoon system to a low-leakage AD system would decrease the overall GWP impact of regional production as follows (Table 4):

Table 4. Reduction in GWP with Alternate MMS (per 1 kg LW at farm gate)

Region	Reduction in GWP Impact (kg CO_2e per 1 kg LW farm gate)		
	Total GWP Low leakage compared to baseline	MMS only, high leakage	MMS only, low leakage
Southeast	-62%	-66%	-91%
West	-63%	-84%	-91%

Table 5 provides the MMS GWP totals in kg CO_2e calculated with both the ReCiPe 2016 and IPCC AR6 values for methane, for comparison.

Table 5. GWP of MMS (per 1 kg LW at farm gate)

Region	Methane GWP Value	Uncovered Lagoon	High Leakage	Low Leakage
Southeast	ReCiPe 2016 (CO_2e)	3.577	0.595	0.328
	IPCC AR6 (CO_2e)	2.930	0.487	0.269
West	ReCiPe 2016 (CO_2e)	3.790	0.606	0.334
	IPCC AR6 (CO_2e)	3.107	0.497	0.274

While the current adoption of covered lagoons for these regions is limited, MMS alternatives to uncovered lagoons presented the largest potential improvement for GWP impact for these two regions.

2.1.3 Feed Production

Production practices used for crop production can have a significant impact on the contribution to GWP from feed ingredients. The Midwest was the primary source of grain for U.S. pig diets. The Midwest LCA compared the GWP impact of different feed production scenarios for soybean meal and corn ingredients, and for the corn used to produce the DDGS (Attachment 2).

The scenarios included:

- Conventional production with full tillage and synthetic nitrogen fertilizer (conventional)
- Iowa production with pig manure displacing synthetic fertilizer for 91% of the acreage producing corn for pig feed (integrated)
- Regenerative crop scenario with no-till, manure fertilization, and a cover crop (regenerative)

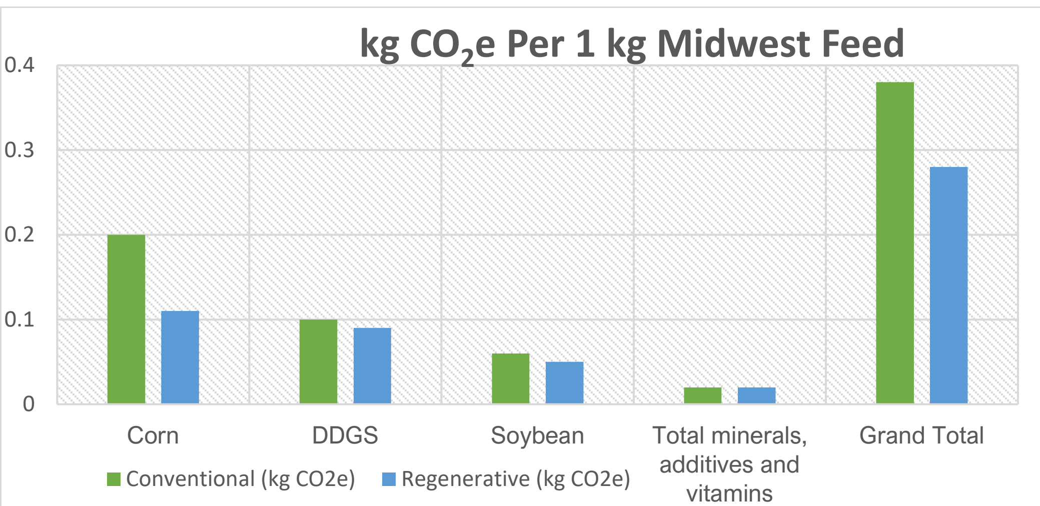
Table 6 provides the scenario comparison for the total GWP impact for pig production in the Midwest region, based on feed sourcing.

Table 6. Total Midwest GWP Impact by Feed Sourcing

Feed Production	Conventional	Manure/Iowa Model	Regenerative
Total Midwest GWP Impact per 1 kg LW at farm gate (kg CO_2e)	2.758	2.539	2.472

Crop production practices represents the primary pathway for reducing GWP impacts for the Midwest region, and potentially other regions as feed produced with regenerative practices becomes more widely available. Figure 7 shows a comparison of feed ingredients produced in the Midwest with either conventional or regenerative practices.

Figure 7. Feed Scenario Comparison



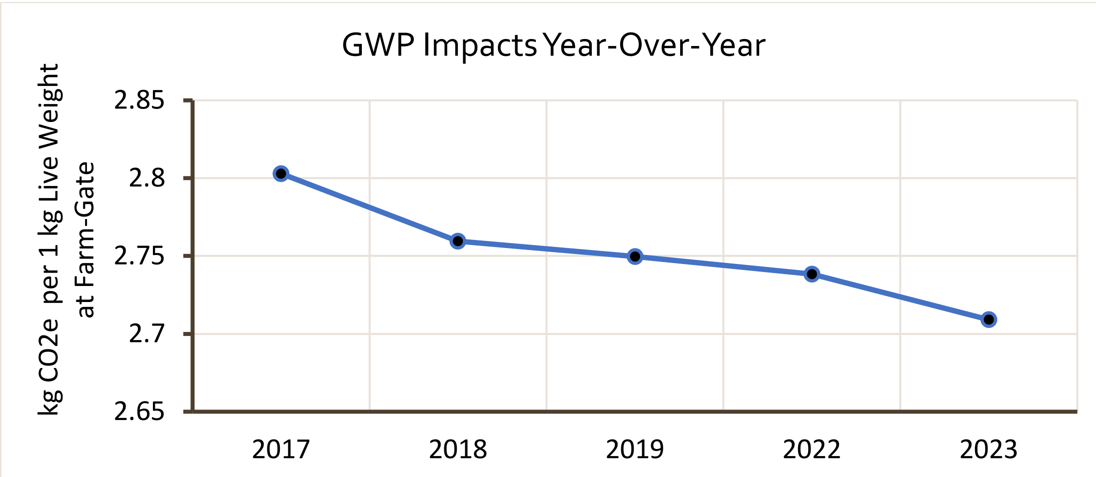
GWP impact per 1 kg of feed ingredients, Midwest production, compared by production scenario.

With inclusion of DDGS and soybean meal, an economic allocation factor of 0.167 and 0.496, respectively, were applied, meaning that only 16.7% of the total burdens of DDGS were assigned to feed ingredient use due to the higher economic value of ethanol, also produced within the process (Haque et. al., 2022). Similarly, only 49.6% of the total burdens of soybean meal were assigned due to the economic value of the products of crude soy oil and soy hulls and the shared production processes.

2.1.4 Production Efficiencies

In the Midwest and West LCA studies, data to assess the impacts for feed, manure management, the cropping system, and energy use were constant in the analysis. As a result, the primary data in the regions enabled analysis of the effects of diet composition and production efficiencies on GWP impact (Figures 8 and 9). A reduction in GWP year-to-year scores occurred for varied reasons in these two regions.

Figure 8. Year-over-year GWP Impact, Midwest Baseline Scenario



Year-over-year GWP impact changes from feed composition differences and production efficiencies.

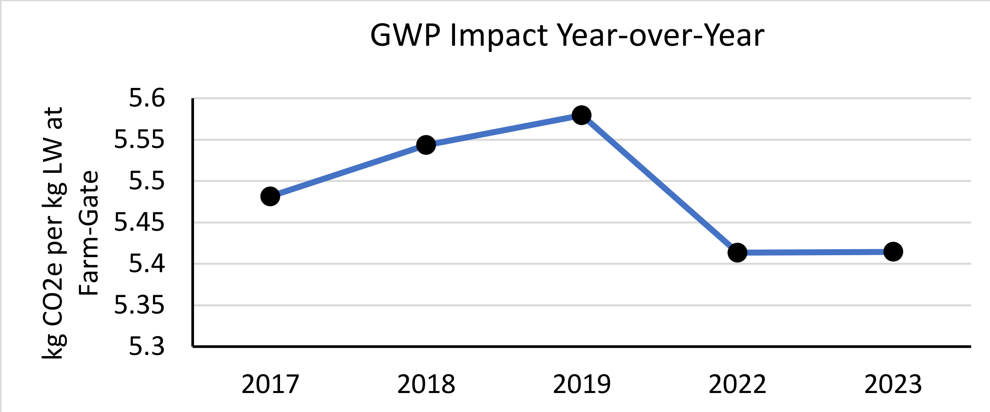
For the Midwest region, the study identified a 3.35% reduction in GWP, -0.09 kg CO_2e (Figure 8). The improvement was attributed to:

- A 34.38% reduction in the amount of DDGS in 2023 as compared to 2017, for the Finisher diet
- A 4.7% improvement in average daily gain and 3.5% fewer days on feed for the Finisher phase
- A 5.8% increase in piglets per litter for the Sow phase (Attachment 2)

The West region analysis showed a 2.97% reduction in GWP (Figure 9). The -0.166 kg CO_2e reduction was attributed to differences in key production metrics between 2017 and 2023, including:

- Average daily gain increased by 4.55% for the Finisher phase
- The Wean-to-Finish phase had a decrease of 11.5 average days on feed, a 6.8% improvement, between 2019 and 2022 (Attachment 3)

Figure 9. Year-over-year GWP Impact, West Baseline Scenario



Year-over-year GWP impacts during the years of primary data sourced in this LCA.

2.2 Other Impacts

The LCA analysis also included freshwater and marine eutrophication, water use, and land occupation.

2.2.1 Eutrophication

Feed production was the primary source of eutrophication, both freshwater and marine, in this analysis. This category includes impacts from crop production, feed processing, energy use within these processes, and sourcing of diet ingredients such as whey, minerals, and amino acids. Table 7 shows the total contribution to freshwater and marine eutrophication for U.S. pig production.

Table 7. Freshwater and Marine Eutrophication Impacts

Category	**Impact**
Freshwater Eutrophication	1.009 g P e per 1 kg live weight
Marine Eutrophication	2.072 g N e per 1 kg live weight

Key findings for eutrophication:

- Feed production contributed 76% of freshwater eutrophication impacts for the Midwest and 97% of the impact for the Southeast and West regions.
- The ReCiPe 2016 model does not include marine eutrophication impacts from the manure management system (Morelli et al., 2018).
- Feed production contributed about 99% of the marine eutrophication impact in the analysis for the U.S. and all regions.

2.2.2 Land Occupation

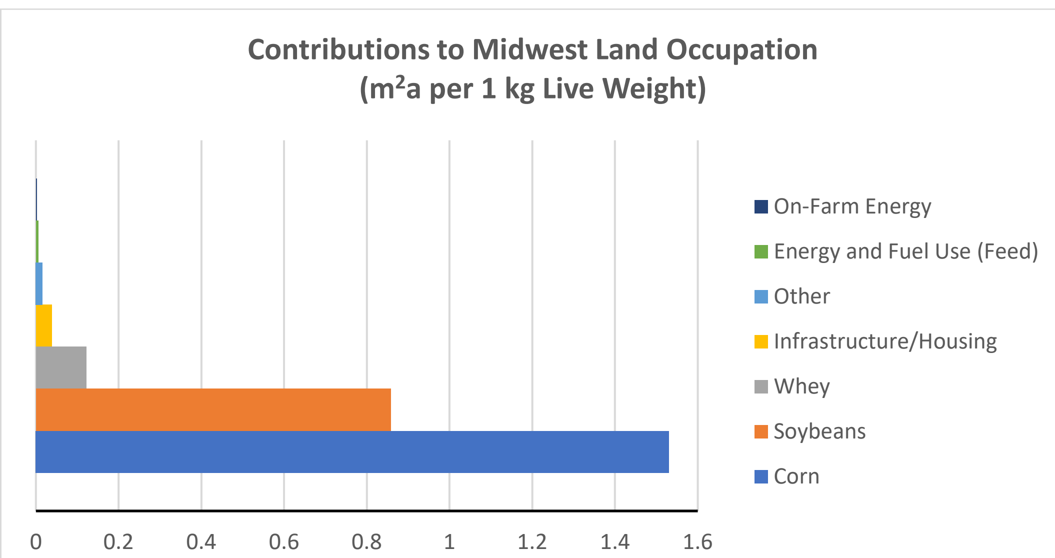
Land occupation included the land required for feed production (crop production and other feed ingredients), and infrastructure such as housing. Land use change, the historical conversion of land to agricultural production, was accounted for in the GWP impacts, Section 5.1.

Key findings for land occupation:

- The total land occupation required per 1 kg live weight pig at farm gate is 2.661 m^2a.
- Regionally, 98-99% percent of the land occupation required for pig production was associated with production and processing of feed.
- Grain from the Midwest was the primary diet ingredient for pig diets in all regions.
- Crop production for the corn and soybean ingredients in feed account for 93% of the land occupation for the Midwest region.
- The whey ingredient, although it comprises less than 5% of the Nursery diet, requires 0.122 m^2a per 1 kg live weight pig at farm gate, or 4.7% of the total land occupation.

Figure 10 provides values for land use per 1 kg of feed ingredients for the diets in the Midwest region compared to other sources of land occupation.

Figure 10. Land Use in m^2a per 1 kg Live Weight at Farm Gate, Midwest Region



Midwest region, comparison of diet ingredient land occupation values to other sources

2.2.3 Water Use

Water use inputs for the dataset were composed of drinking water on farm, cooling system use when the temperature was above 85°F, wash water for sanitation, and water used in crop production. The methodology and data inventory provide sources and data used to assess water use (Attachment 1).

Climatic conditions and production practices drive slight differences in water use by region. Table 8 provides the U.S. value and comparative values from the regional analysis.

Table 8. Water Use per 1 kg live weight at farm gate, U.S. and Regional

U.S. or Region	U.S. Overall	Southeast	West	Midwest
Water Consumption (m^3)	0.139	0.141	0.148	0.138

Based on the regional analysis, feed production was the primary source of water use, followed by on-farm use. This trend was consistent across all three regions.

3.0 Regional Differences

The overall GWP impact for 1 kg live weight at the farm gate was 2.939 kg CO_2e, based on the regional analysis and sustainability measures adopted in each region. Table 9 highlights key differences from the regional analyses.

Table 9. Key Differences by Region

Criteria	**Midwest**	**West**	**Southeast**
GWP (kg CO_2e per 1 kg lw)	2.539	5.055	5.174
Primary GWP Impact	Feed	Manure	Manure
Biggest Improvement Lever	Circular/Regen Feed Sourcing	MMS Type	MMS Type
Production Efficiency Improvement (year-over-year)	3.35%	2.97%	N/A
GWP Rank (Least to Highest)	1	2	3
Standard MMS	Deep pit	Uncovered Lagoon	Uncovered Lagoon

The biggest difference in impacts across the regions was GWP, where the Midwest region had approximately half the GWP impact as the West and Southeast. The following sections cover key results from the regional analysis that help explain the GWP differences.

3.1 Midwest Region

The following summarizes the Midwest LCA analysis, focusing on contributors to GWP.

3.1.1 Feed Production in the Midwest

Based on the Midwest analysis, feed production is the primary contributor to GWP impact in the region (Figure 11). The Midwest regional analysis examined three scenarios for feed production:

- Conventional (baseline),
- Integrated crop and livestock production with manure displacing 91% of synthetic N fertilizer (integrated)
- Regenerative crop production for feed including use of cover crops, no-till, and 100% displacement of synthetic N fertilizer with manure use (regenerative).

The results of the analysis highlight the most significant lever for reducing GWP impact in the region (Table 10).

Figure 11. Sources of Relative GWP Impact, Midwest Baseline Scenario

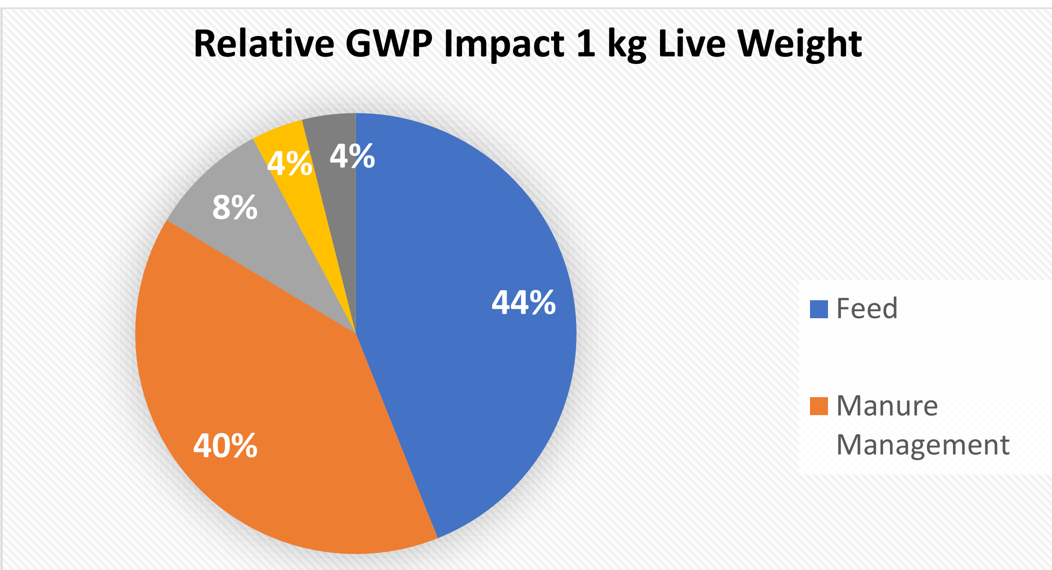


Table 10. GWP Impact of Feed Production Scenarios, Midwest

GWP in CO_2e per 1 kg live weight at Farm Gate		
Baseline	Integrated	Regenerative
2.758	2.539	2.472

Key findings on feed production:

- Regenerative production has the greatest GWP impact reduction for production of corn, at 45% (Figure 7, in Section 2.1.3).
- The GWP reduction is primarily due to displacement of synthetic N fertilizer with manure use, including emissions from fertilizer manufacturing.
- Tillage changes and the use of a cover crop reduced greenhouse gas (GHG) emissions were secondary in reducing GWP impact (Attachment 2).
- Overall, changing the production methods to regenerative for the corn and soy feed ingredients was associated with a 0.28 kg CO_2e reduction in the total GWP impact of pig production, or 11% for production of 1 kg live weight at farm gate.

3.1.2 Manure Management in the Midwest

Midwest pig production primarily uses deep pit manure storage with field application. The method retains the nitrogen content of manure available for crop fertilization. This manure management method has lower GHG emissions than the uncovered lagoon systems that characterize other pork production regions (Gavrilova et al., 2019). Table 11 shows the methane and nitrous oxide (N_2O) emissions from manure management by phase of production.

Table 11. Midwest Manure Emissions by Phase per Pig

Phase	**CH_4 (kg)** *Methane*	**N_2O (kg)** *Nitrous oxide*	**GWP ReCiPe (kg CO_2e)** *(Methane = 34 GWP)*	**GWP IPCC AR6 (kg CO_2e)** *(Methane = 27 GWP)*
Sow	0.385	0.005	14.100	11.808
Nursery	0.292	0.004	10.800	8.962
Finisher	3.090	0.042	115.000	94.867
MMS emissions (Market pig)			139.900	115.637
Emissions per 1 kg live weight (MMS only)			1.094	0.906
Equivalent in emissions of cars on road for 1500-head operation annually*			118 cars	97 cars

**Based on annual production and primary data of 2.6 turns and 127.6 kg weight out. Manure system emissions only.*

The ReCiPe 2016 methodology was applied in this LCA analysis. The difference in the GWP for methane between ReCiPe 2016 and IPCC AR6 resulted in a 20.98% increase in the GWP impact for manure management per market pig over the IPCC AR6 result (Table 11).

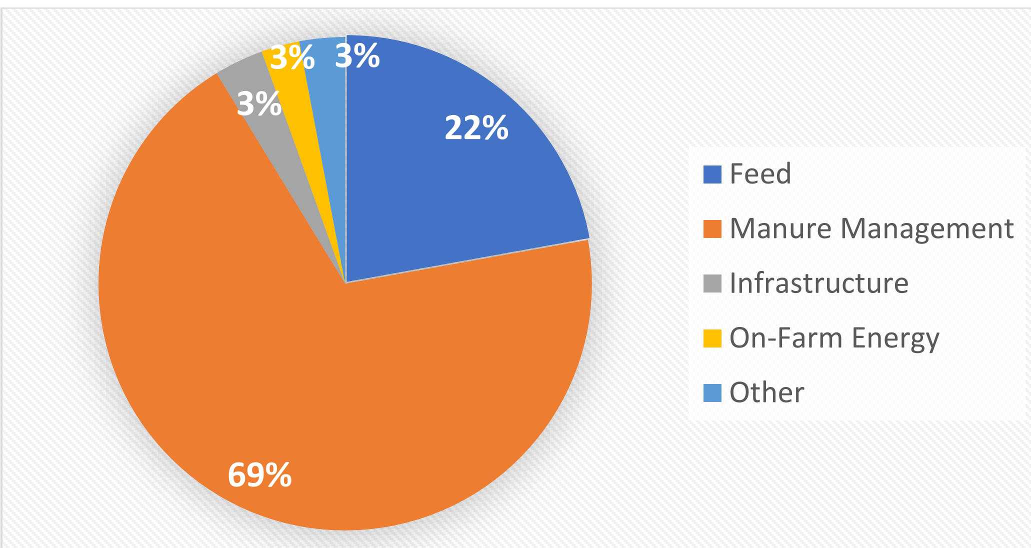
3.2 West Region

The following summarizes the West LCA analysis, focusing on contributors to GWP.

3.2.1 Manure Management in the West Region

Manure management was the primary contributor to GWP impact for the West region. Under the baseline scenario of uncovered lagoon use, manure management contributed 69% of the GWP impact of West pig production (Figure 12). Uncovered lagoons are the primary manure management system in the West region and have higher methane emissions than the deep pit systems more common in the Midwest region (Attachments 2 and 3). Due to the high relative contribution of manure management to the GWP impact in the region, this aspect of production represented the most significant lever to improve sustainability.

Figure 12. Sources of Relative GWP Impact, West

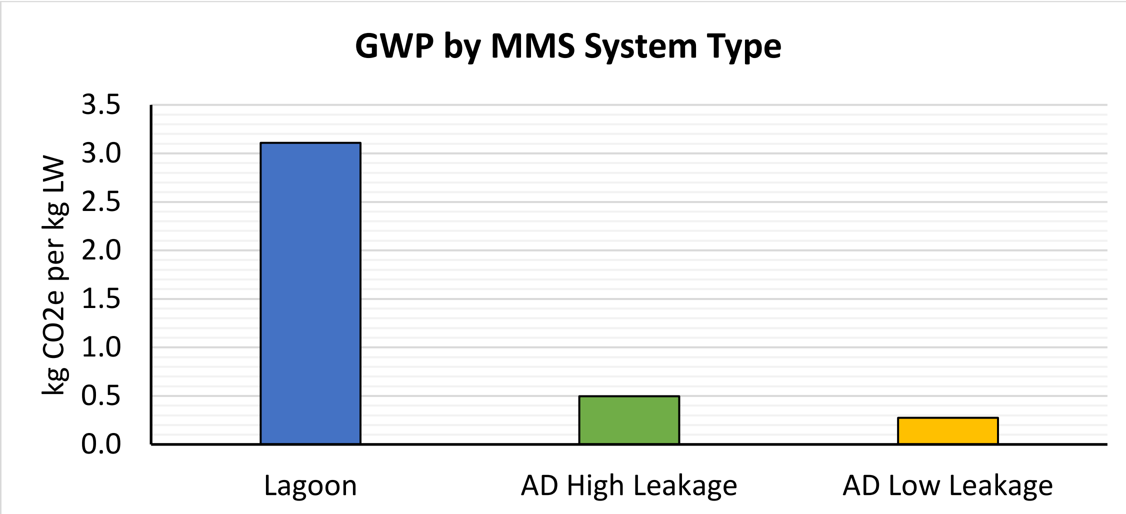


The West region analysis compared manure management scenarios of an uncovered lagoon (baseline), a high-leakage anaerobic digester (AD) or covered lagoon, current adoption of covered lagoons in region, and a low-leakage AD (Table 12 and Figure 13).

Table 12. West Pig Production LCA Results (per 1kg live weight at farm gate)

GWP Scenarios	Baseline (uncovered)	Regional AD Adoption (13.66%)	100% High Leakage AD	100% Low Leakage AD
	5.486	5.055	2.306	2.044

Figure 13. MMS GWP Impact by Type, West



Changing the manure management system from an uncovered lagoon system to a low-leakage AD system would decrease the overall GWP impact of West pig production by 62.7%. Within the manure management process alone, the reduction in GWP was 84% for a high-leakage AD and 91% for a low-leakage AD.

Table 13 provides the impact of different MMS on GWP for the equivalent of a market pig and the annual production for a 1500-head operation, based 2.5 turns per year. The values are also provided as an equivalent in the average emissions of 4.6 metric tons (MT) of CO_2e per passenger vehicle (4,600 kg CO_2e), per year on the road (EPA, 2024).

Table 13. MMS and Annual GWP Impact

Unit	Uncovered Lagoon	AD High Leakage	AD Low Leakage	50/50 AD High Leakage/Lagoon	50/50 AD Low Leakage/Lagoon
MMS GWP per Market Weight Pig (kg CO_2e)	484	77	43	280	263
Equivalent GWP in Cars on Road/year to Market Weight Pig	0.105	0.017	0.010	0.061	0.057
MMS GWP 1500 head/year operation (MT CO_2e)	1,879	300	171	1,090	1,025
Equivalent GWP in Cars on Road/year to 1500 head operation/year*	409	65	37	237	223

**Based on annual production and primary data of 2.5 turns and 125.9 kg weight out. Manure system emissions only.*

3.2.2 Feed Sourcing for the West Region

The West region LCA analysis identified the following regarding GWP impact and feed:

- Eighty percent of feed for the West region was transported from the Midwest (Attachment 3).
- In 2017, the Midwest and West Finisher diets were 0.423 and 0.456 kg CO_2e per kg feed, respectively.
- Feed produced in the West region required energy use for irrigation pumping.
- The West region had lower yields compared to the Midwest.
- While secondary to manure management interventions, sourcing of feed produced with regenerative practices including manure fertilization, planting cover crops, and no-till, could contribute to a lower GWP impact for the West region.

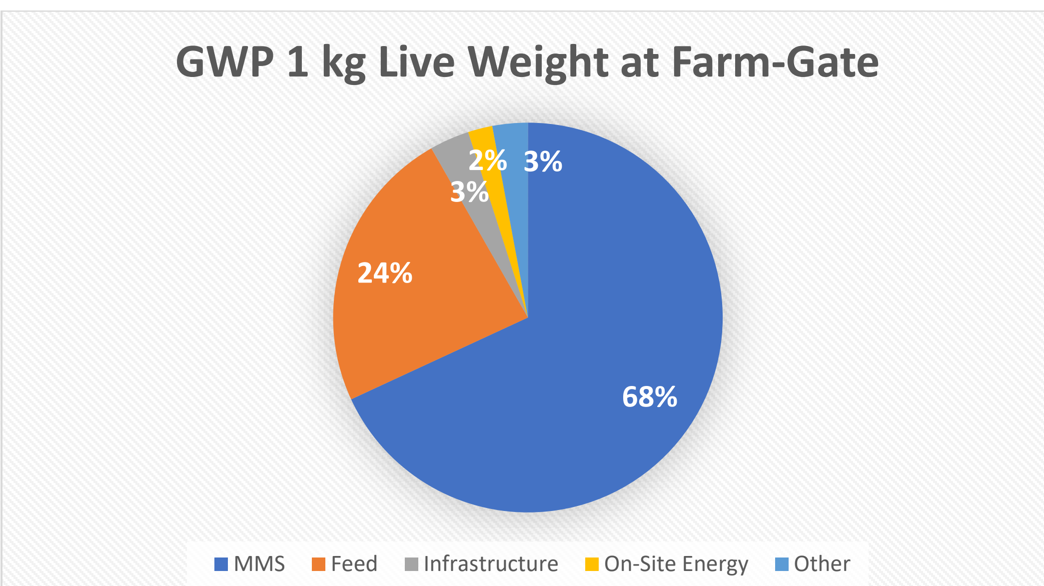
3.3 Southeast Region

The following summarizes the Southeast LCA analysis, focusing on contributors to GWP.

3.2.1 Manure Management in the Southeast Region

Manure management was the primary contributor to GWP impact for the Southeast region. Under the baseline scenario of uncovered lagoon use, manure management contributed 68% of the GWP impact of Southeast pig production (Figure 14). Due to the high relative contribution of manure management to the GWP impact in the region, this aspect of production represented the most significant GWP improvement.

Figure 14. Sources of Relative GWP Impact, Southeast

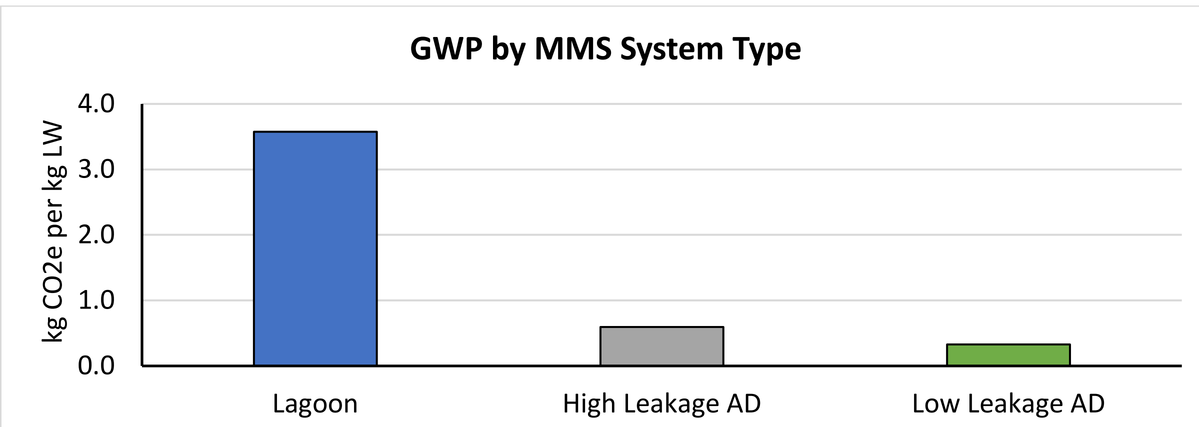


The Southeast region analysis compared manure management scenarios of an uncovered lagoon (baseline), a high-leakage anaerobic digester (AD) or covered lagoon, the current adoption of covered lagoons in region, and a low-leakage AD (Table 14 and Figure 15).

Table 14. Southeast Pig Production LCA Results (per 1kg live weight at farm gate)

Total GWP Scenarios	Baseline (uncovered lagoon)	Regional AD Adoption (2.46%)	100% High Leakage AD	100% Low Leakage AD
	5.247	5.174	2.306	2.002

Figure 15. MMS GWP Impact by Type, Southeast



The impact of different MMS on the total GWP (including feed and other inputs) was more evident when analyzed by the equivalent of a market pig and the annual production for a 1500-head operation (Table 15). The table also provides an equivalent in the average emissions of 4.6 metric tons (MT) of CO_2e per passenger vehicle (4,600 kg CO_2e), per year on the road (EPA, 2024).

Table 15. Annual GWP Impact by MMS Type, Southeast

Unit	**Uncovered Lagoon**	**AD High Leakage**	**AD Low Leakage**	**50/50 AD High Leakage/Lagoon**	**50/50 AD Low Leakage/Lagoon**
MMS GWP per Market Weight Pig (kg CO_2e)	464	74	39.6	269	252
Equivalent GWP in Cars on Road/year to Market Weight Pig	0.101	0.016	0.009	0.059	0.055
MMS GWP 1500 head/year operation (MT CO_2e)	1,802	289	154	1,046	978
Equivalent GWP in Cars on Road/year to 1500 head operation/year	392	63	33	227	213

**Based on annual production and primary data of 2.56 turns and 126.68 kg weight out. Manure management emissions only.*

3.3.2 Feed Sourcing for the Southeast Region

Seventy percent of feed for the Southeast region was transported from the Midwest (Attachment 4). While secondary to manure management interventions, sourcing of feed produced with regenerative practices including manure fertilization, planting cover crops, and no-till, could contribute to a lower GWP impact for the Southeast region.

4.0 Discussion and Limitations

This LCA used primary production data from the West and Midwest regions. While use of primary U.S. data was more relevant than national-level data or modeling, primary data was not available for the following:

- Southeast diet composition and production data
- Infrastructure
- Water use
- Energy use
- AD adoption and MMS by region
- Feed sourcing and crop production practices

Future studies could address the gaps in primary data to improve the relevance and accuracy of the LCA results. The data inventory and methodology for the reports are provided in Attachment 1. The full LCA analyses for each region and the U.S. overall are provided in Attachments 2-5.

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