



Greenhouse Gas Inventory in Commercial Swine Farms in the Philippines Using Life Cycle Assessment



ABSTRACT

A continuous growth in commercial swine farm stock becomes alarming due to its environmental consequences. To evaluate the environmental impacts of commercial swine production in the Philippines, the commercial swine production system in the country was assessed using Life Cycle Assessment (LCA) with the goal of calculating the greenhouse gas (GHG) emission of the entire production system from cradle-to-farmgate. The carbon footprint of representative commercial swine farms was 2,001.63 g CO₂ e kg per liveweight for farrow-to-finish enterprise, 3,142.72 g CO₂ e kg per liveweight for farrow-to-feeder enterprise, and 2,062.86 g CO₂ e kg per liveweight for farrow-to-breeder enterprise. Feed production module proved to have the greatest contribution in the entire commercial swine production system in which its emission ranged from 73.51% to 75.06% of the total GHG emission from cradle-to-farmgate system boundary. Therefore, innovative strategies to reduce GHG emissions in commercial swine production should focus on this critical segment.

Keywords: *life cycle assessment, commercial swine production, greenhouse gas emissions*

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INTRODUCTION

Commercial swine farms are those with more than 20 heads of adult animals (PSA 2016). The Philippines has small and large commercial farms with different sow levels, some reaching more than a thousand of sow levels. Commercial swine production in the country has a highly complex manufacturing system and well-structured distribution and marketing inputs (Espino *et al.* 2022).

A continuous growth in commercial swine farm to backyard swine farm ratio can be observed in the annual swine situation reports presented by the Philippine Statistics Authority from 2017 to the first quarter of 2019. Total stocks in swine commercial farms have increased by 4.73% and 0.66% by end of the year 2017 and 2018, respectively, while by the end of the first quarter of 2019, commercial swine farm stocks have increased by 1.2% compared to their respective previous years (PSA 2017, PSA 2018, PSA 2019).

The steady increase in livestock on commercial swine farms is becoming a growing concern because of its environmental impact. Problems such as the increasing emission of greenhouse gases become inevitable. These gases, when released to the environment, are contributors to climate change which inflicts negative effects to

humanity. Problems in food security may arise as livestock production is affected by climate change. In addition, climate change can alter the nutritional content of livestock products (Hoque *et al.* 2022).

The livestock sector, where swine production falls under, is a significant climate change contributor, emitting 14.5% of global GHG emissions (Rojas-Downing *et al.* 2017). As the global population is increasing, this sector is continuously accelerating leading to a significant impact to climate change brought about by direct emissions of methane and nitrous oxide released in these production systems (Caro 2018). In piggeries, GHG emissions originate from two sources, from animals and from manure. Carbon dioxide is emitted through exhalation and CH₄ is released due to enteric fermentation. Carbon dioxide, CH₄, and N₂O are released in varying manure management systems (Philippe and Nicks 2015).

In a study by Wang *et al.* (2017), the GHG emission impact in terms of CO₂ equivalent from pig production sectors in China from 1960 to 2010 was 17% from methane emission from enteric fermentation, 62% from methane production from manure management and 21% from nitrous oxide production from manure management.

In the Philippines, the agriculture sector contributed about 27% out of the 204 MT CO₂ emission in 2020 (*Philippine Climate Change Commission 2024*). Swine meat is considered one of the major livestock products of the country thus, it is one of the main contributors of GHG in the agriculture sector under the livestock category.

Assessing the environmental impacts associated with commercial swine production by quantifying GHG emissions along the swine production chain is crucial for the formulation of recommendations and response strategies to mitigate climate change. One way to evaluate the environmental impacts is through life cycle assessment. *Reckman et al. (2013)*, for instance, reported that the global warming potential of pork production in Germany was 3.22 kg CO₂ eq per kg pork while *Cherubi et al. (2015)* calculated the environmental profile of swine production in Brazil to be at 3503.29 kg CO₂ eq per 1000 kg swine carcass.

Studies found that concentrate feed production and on-farm emissions were the major contributors of GHG in pig production (*Noya et al. 2017*). Feed chain which includes crop production at farm and purchased feed is considered to be the most significant contributor (*Bava et al. 2017*).

In the Philippines, no environmental profile of commercial swine production has been established. With this, life cycle assessment was used to determine the GHG emissions and to identify environmental hotspots of the current commercial swine production system in the country.

MATERIALS AND METHODS

Life cycle assessment (LCA) was used to analyze commercial swine farms in the Philippines. Three

different GHGs were evaluated, with CO₂, CH₄, and N₂O having 100-year horizon global warming potentials of 1, 28, and 265, respectively (*IPCC 2013*). Swine production facility's farm performance, animal inventory, feeding plan, waste management, farm management technologies, and waste utilization technologies were considered while calculating GHG emissions.

System Boundary

This study accounted for the carbon footprint from the cradle to the farm gate of 10 commercial swine farms (**Figure 1**). The study was divided into three modules: feed production, animal production, and manure management system.

The manufacture of the raw materials and the energy required to compound the feeds comprised the feed production module. The energy use in the swine farm and emissions from enteric fermentation made up the animal production module. The emissions resulting from the manure management system encompassed direct and indirect N₂O emissions, indirect N₂O emissions due to leaching, and CH₄ emissions resulting from the manure management system.

Functional Unit

If the system boundary is limited to the farm gate only, then the appropriate functional unit, as per FAO criteria, is in live-weight. As a result, the study's functional unit of measurement was 1 kg of live pig weight.

Feed Production

Two carbon footprint tools, Feedprint and CCalc2, were used to estimate GHG emissions for the production

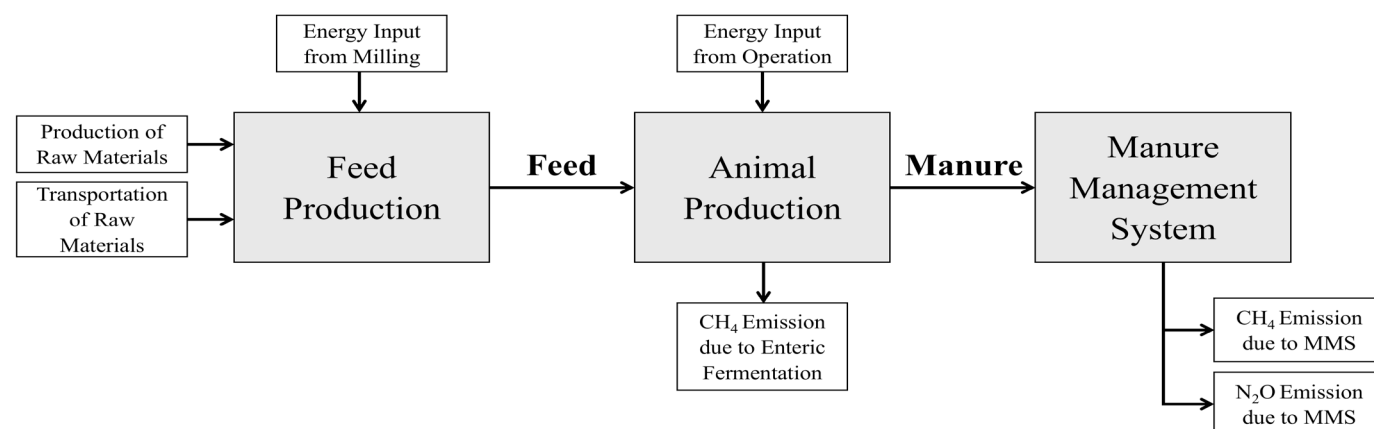


Figure 1. System boundary of the life cycle assessment of commercial farms in the Philippines.

of raw materials used in feeds. Wageningen UR Livestock Research created Feedprint to quantify greenhouse gas emissions from the processing of the raw materials used in animal feeds. The Sustainable Industrial System group at the University of Manchester created CCalc2, which allows for simple and fast estimations of the life cycle greenhouse gas emissions in the production of a certain product such as corn and soya used as feed raw materials. For feed processing energy, total energy use was estimated to be 160.9 MJ per 1,000 kg feeds produced (*Gilbert 2009*).

Animal Production

Animal production parameters required for calculating the carbon footprint of swine production were collected during farm visits to 10 swine farms in the Philippines (**Table 1**). The farms had an average daily herd inventory of 12 pigs per breeding sow, with an average total pig meat production of 2,317 kg per sow-yr. During farm interviews, the period (days) for each pig class and its average daily consumption were also obtained. Based on these data, an annual average feed consumption per breeding sow of about 7,783 kg was calculated. Furthermore, the mortality rate in each pig class was determined and was factored into the pig's daily herd inventory calculation.

Enteric Fermentation

The daily herd inventory of each farm was used to estimate the emission caused by enteric fermentation. Once the daily head count was determined, the GHG emission from enteric fermentation for non-ruminants was calculated using a Tier 1 methodology from IPCC (*Dong et al. 2006*). Regardless of the pig's physiological stage, the study adopted a value of 1.0 kg CH₄ yr⁻¹ per head.

Manure Management

The kind of manure management was identified. The Intergovernmental Panel on Climate Change's approach was used to assess the GHG emissions caused by manure management. Two greenhouse gas emissions as a result of manure management, specifically CH₄ and N₂O, were calculated. Manure management systems also release CO₂, but because they are not regarded as anthropogenic emissions, they were not included in the total amount of GHG accounted for. Also, according to international accounting standards, CO₂ produced by the combustion of digester CH₄ is not classified as an anthropogenic emission.

The GHG emissions for the manure management come

Table 1. Main herd parameters of pig farms.

Type of Operation	Unit
Period per Pig Class	
Gestation Period	d
Lactation Period	d
Dry Period	d
Booster Period	d
Prestarter Period	d
Starter Period	d
Grower Period	d
Finishing Period	d
Type of Breeding System	
Boar-to-Sow Ratio	
Litters/ Sow	
Daily Feed Consumption	
Lactating Sow	kg d ⁻¹
Dry Sow	kg d ⁻¹
Gestating Sow	kg d ⁻¹
Boar	kg d ⁻¹
Gilt	kg d ⁻¹
Booster	kg d ⁻¹
Pre-starter	kg d ⁻¹
Starter	kg d ⁻¹
Grower	kg d ⁻¹
Finisher	kg d ⁻¹
Rate	
Breeding Mortality	%
Pre-weaning Mortality	%
Post-weaning Mortality	%
Replacement Rate	%
Culling Rate	%
Market	
Parity before Culling	
Market Weight	kg

from different sources (**Figure 2**). Manure management system is responsible for both direct and indirect N₂O emissions, as well as indirect N₂O emissions caused by leaching in the system. Also, emissions of CH₄ are brought on by manure management practices. The IPCC method was used to calculate emissions for CH₄ and N₂O produced in swine facilities' manure management system.

Transportation

Using a truck with a capacity of 25 tons and a baseline fuel usage of 42 L per 100 km of travel, GHG emissions from land transportation were calculated (*Delgado et al. 2016*). A 50-km distance between the feed mill and the farm was assumed for farms that obtain their feeds from industrial feed mills. Emissions from maritime transportation were calculated on the assumption that the ship capacity of 8000 TEU for foreign-imported raw materials like soybean and micro ingredients was used.

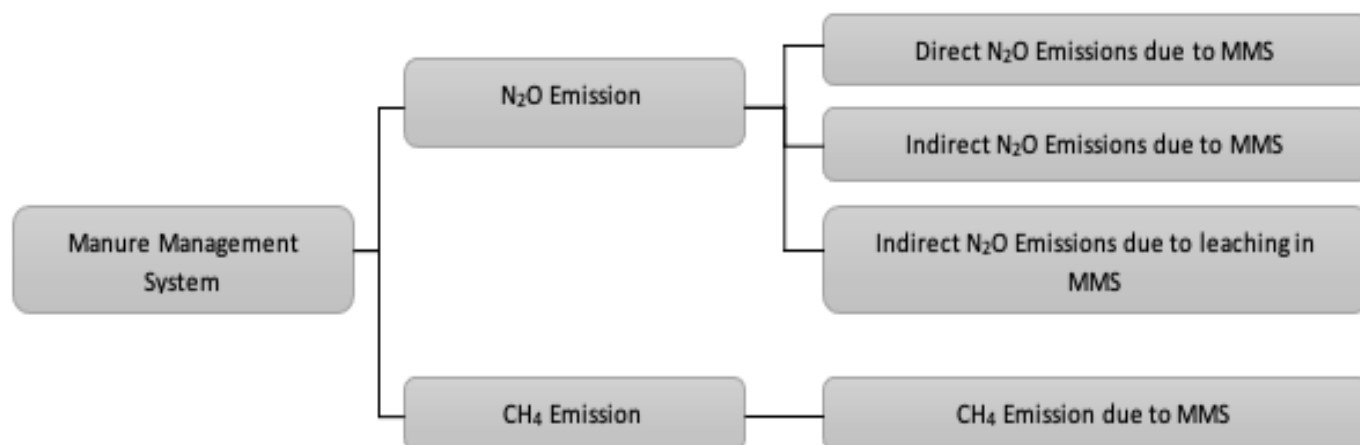


Figure 1. Emissions arising from the manure management system module.

In order to estimate the amount of bunker fuel utilized during the transportation of raw materials, a value of 8.79 kg km⁻¹ was used.

Energy Consumption

The farm's monthly electricity bill was used to estimate GHG emissions related to energy use in the farm. Emission factors for Luzon-Visayas Grid of 0.7122t-CO₂ MWh⁻¹ and 0.7797 t-CO₂ MWh⁻¹ for Mindanao Grid were obtained from the emission factor developed by the Department of Energy [DOE] (2017).

RESULTS AND DISCUSSION

Farm characteristics of 10 commercial swine farms visited in the country were summarized (Table 2). Included in the assessment was identifying the type of feeds used and feeding system implemented, the type of cleaning system, type of housing, and waste management system used in the farms. This served as a guide in calculating greenhouse gas emissions and in identifying hotspots in the production of pig in the different commercial swine farms in the country.

Table 2. Swine farm characteristics of visited commercial farms in the Philippines.

Farm Code	Sow Level	Enterprise	Feeds	Feeding System	Cleaning System	Waste Management System	Type of Housing
02C	579	Farrow-to-Feeder	self-mixed feeds	modified conventional feeders; nipple drinkers	scraping; power sprayer	anaerobic digester	shed-type
03C	622	Farrow-to-Feeder	self-mixed feeds	conventional feeders; nipple drinkers	scraping; power sprayer	anaerobic digester	open-type; industrial fan
04C	31	Farrow-to-Finish	association feeds	conventional feeders; nipple drinkers	scraping; power sprayer	liquid slurry without crust	open-type
05C	36	Farrow-to-Finish	commercial feeds	conventional feeders; nipple drinkers	scraping; power sprayer	septic tank	open-type
06C	54	Farrow-to-Finish	association feeds	modified conventional feeders; nipple drinkers	scraping; power sprayer	anaerobic digester	open-type
07C	59	Farrow-to-Finish	commercial feeds	conventional feeders; nipple drinkers	scraping; hosing	septic tank	open-type
08C	60	Farrow-to-Finish	commercial feeds	conventional feeders; nipple drinkers	scraping; power sprayer	open lagoon	open-type
10C	900	Farrow-to-Finish	self-mixed feeds	conventional and automatic feeders; nipple drinkers	scraping; power sprayer	anaerobic digester	tunnel ventilation system
11C	1600	Farrow-to-Breeder	self-mixed feeds	automatic feeding system; nipple drinkers	scraping; power sprayer	anaerobic digester	tunnel ventilation system
12C	7500	Farrow-to-Breeder	self-mixed feeds	automatic feeding system; nipple drinkers	scraping; power sprayer	anaerobic digester	open-type

The study obtained the average GHG emission (**Table 3**) and module shares (**Figure 3**) per kg live weight of pig, of visited commercial farms with farrow-feeder, farrow-finish, and farrow-to-breeder enterprise per module, respectively (**Table 3**).

The average GHG emission from commercial farms with nine farrow-to-finish, a farrow-to-feeder, and two farrow-to-breeder operations were 2,001.63, 3,142.72, and 2,062.86 g CO₂ eq per kilogram of liveweight, respectively. Commercial farms operating as farrow-to-feeder enterprises generally have higher GHG emission compared to commercial farms operating as farrow-to-finish and farrow-to-breeder enterprises. Low liveweight in farrow-to-feeder enterprises did not compensate for the high GHG emission accounted for feeds. The trend generally led to higher GHG emission per kg live weight of the farrow-to-feeder enterprises.

Feed Production Module

For all the three enterprises, the highest GHG emission was contributed by the feed production module with average values ranging from 1,471.32 to 2,314.95 gCO₂e kg LW⁻¹. The percentage of feed production

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module in the overall GHG emission ranged from 73.51% to 75.06%. The feed production module was the greatest contributor to the overall GHG of swine production which can be due to the wide scope of the module. The module included feed crop production, feed crop processing, energy use in compounding the feeds, and transportation of feed raw materials and feeds to farms.

Greenhouse Gas emissions from feed production were from feed crop planting and feed processing. This means that emissions during the production of raw materials and energy used in compounding the feeds were accounted for. The major portion of the emissions came from the production of raw materials. Corn and soybean meals are the most common feed ingredients in the country. Large-scale commercial farms with a sow level greater than 500 have their own nutritionist who formulates feed ingredients for each pig class. The feed formulation for the farms could vary depending on the volatility of raw material prices and their availability in the market.

Large-scale commercial farms mostly had their own feed mill. This is one way to minimize production costs, for they do not rely on commercial feed mills for feed

Table 3. Average GHG emission of visited ten commercial farms in the Philippines, 2019.

Module	Enterprise		
	Farrow - Finish g CO ₂ e kg per liveweight	Farrow - Feeder g CO ₂ e kg per liveweight	Farrow - Breeder g CO ₂ e kg per liveweight
Feed Production	1471.32	2314.95	1548.35
Animal Production	284.93	643.71	388.90
Manure Management	245.39	184.06	125.60
Total	2001.63	3142.72	2062.86

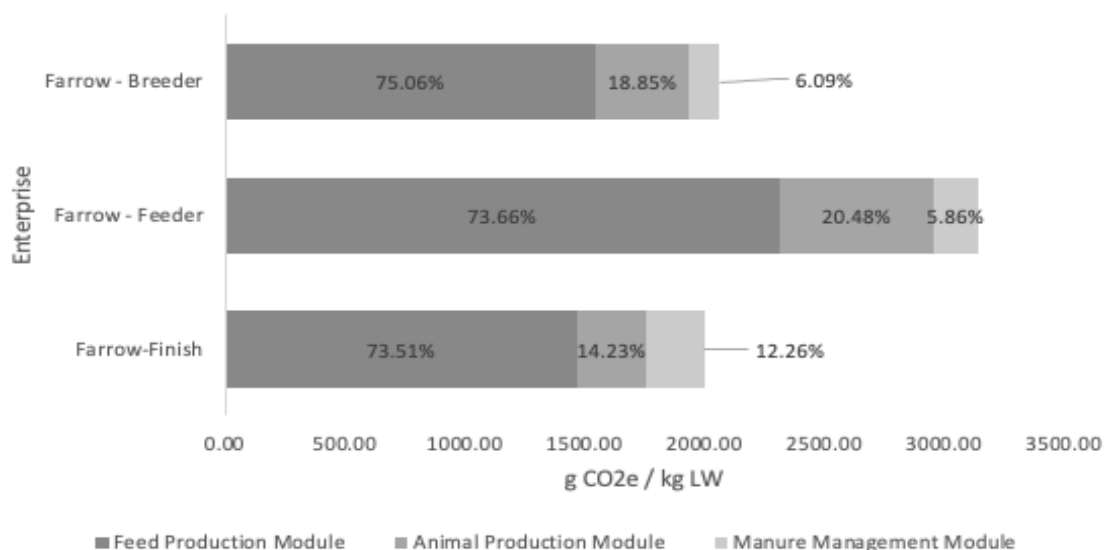


Figure 3. Comparison between the GHG emission of farrow-breeder, farrow-feeder, and farrow-finish commercial swine farm.

sources. On the other hand, small-scale commercial farms mostly relied on commercial feed mills for their source of feeds. Based on the survey, changing the brand of feeds may affect the pig's performance. Small-scale farmers selected the brand of feeds that has a better effect on the pig's growth and performance. More so, the majority of the farms preferred artificial insemination as breeding system. This could cut production costs and reduce GHG emission since feed consumption was reduced due to a lesser boar-to-sow ratio.

Transporting the raw materials for swine feeds (**Table 4**) to the feed mill would entail additional GHG emission due to consumption of fuel such as diesel and bunker oil.

For commercial farms that had their own feed mill, transportation emission from feed mill to farm was negligible. The feed mill and the farm were located near each other and would require less fuel consumption brought about by transporting the feeds to the farm.

Animal Production Module

The animal production module was the second highest GHG contributor which accounted for average values ranging from 284.93 to 643.71 gCO₂e kg⁻¹ liveweight. This module had a contribution ranging from 14.23% to 20.48% to the overall greenhouse gas emission. Emission due to energy use and enteric fermentation were the factors that contributed to the GHG in this module. Large commercial farms were more energy intensive compared to small scale commercial farms due to the technologies utilized within the farm. Such technologies included tunnel ventilation and industrial fans, which contributed additional emission due to energy use. On the other hand, enteric fermentation was dependent on the pig population in the farm.

Energy Use in Farm. Large commercial farms use a lot of energy for their production. Those farms with greater than 900 sow level employed tunnel ventilation system

for their operation to control the temperature in the farm all year round. Surveyed small commercial farms used open-type housing without ventilation. FC2020, a farrow-to-feeder farm, used an open-type housing and installed industrial fans inside the farm to keep the farm cool even during summer.

An automatic feeding system was employed in the surveyed large-scale commercial farms. This cuts labor costs but using this system consumes electricity that eventually adds up to the GHG emission in the animal production module. Small commercial farms still used manual feeding systems that required no energy usage. All of the commercial farms surveyed used nipple drinkers for their water-feeding system. In terms of cleaning system, the majority of the surveyed commercial farms used scraping to collect manure accompanied by a power sprayer to clean the animal's housing. Power spraying systems are an effective way is an effective way to remove pig's manure in swine housings that are difficult to collect through scraping. This consumed electricity and added up to the GHG emission in the animal production module.

Manure Management Module

The lowest GHG emission was accounted for from the manure management system module with average values ranging from 125.60 to 245.39 gCO₂e kg⁻¹ liveweight. The contribution of the manure management module to the overall GHG emission ranged from 5.86 to 12.26%. This was dependent on the type of manure management system in the farm.

Most of the commercial farms in the country employed anaerobic digester as a manure management system (**Figure 4**). The biogas produced in this system was recovered and used as fuel for cooking and for co-generation to produce electricity which powered the farm's facility. There were many types of biodigester employed in the farm. Some of which were fixed dome-type, balloon-type, fixed-cone continuously fed, and HDPE biogas system.

Farm 04C used liquid slurry without crust for its manure management system. The waste generated in the farm's facility proceeded to a lagoon which was exposed to the open air. During the rainy season, the lagoon occasionally overflows and in summer time, the lagoon emits foul odor in facilities and nearby houses. Farm 08C employed an open-lagoon where all the manure and wash-water generated in the farm were ultimately discharged. Farm 05C and Farm 07C use septic tanks as their manure

Table 4. Common sources of raw materials used in swine feeds.

Raw Material	Source
Yellow Corn	Isabela, Nueva Ecija, and Bukidnon in the Philippines; Thailand
Soybean Meal	Argentina, United States
Copra Cake	Quezon, Philippines
Coco Oil	Camarines Sur, Philippines
Molasses	Negros Occidental and Camarines Sur, Philippines
Rice Bran	Nueva Ecija, Philippines

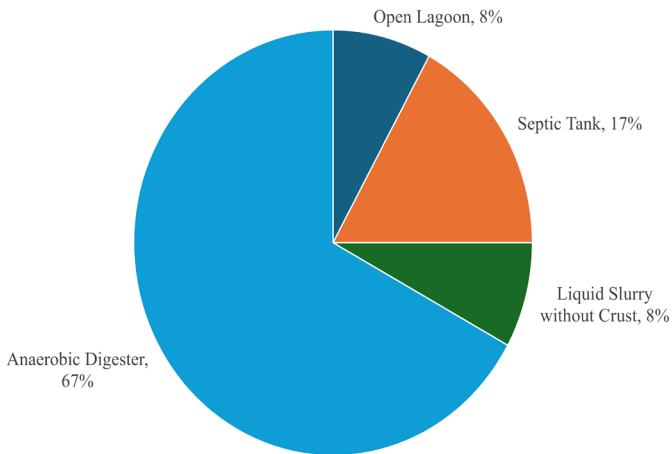


Figure 4. Manure management system employed in commercial farms in the Philippines.

management system where the manure is anaerobically digested, however, the gas produced was not utilized and just leaked. One farm its septic tank was planning to convert to an anaerobic digester and utilize the gas generated in the system.

CONCLUSIONS AND RECOMMENDATIONS

The greenhouse gas emissions of commercial swine production in the Philippines were accounted for and assessed using Life Cycle Assessment (LCA). Environmental hotspots were identified in the entire production system.

The carbon footprint of surveyed commercial swine farms was 2,001.63 gCO₂e kg⁻¹ liveweight for farrow-to-finish enterprise, 3,142.72 gCO₂e kg⁻¹ liveweight for farrow-to-feeder enterprise and 2,062.86 gCO₂e kg⁻¹ liveweight for farrow-to-breeder enterprise. From the three enterprises, the highest GHG emission was contributed by the feed production module which ranged from 73.51% to 75.06% of the total GHG emission from cradle-to-farmgate system boundary.

It is highly recommended to replicate this study to further prove the effectiveness of LCA as a tool for determining the environmental impacts of swine production in the country. Replication of this study may also provide guidelines for more swine production cases. These differences in cases are due to the differences in type of swine operations, to which each farm employs different operations and management practices.

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