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# Global Warming Potential and Life Cycle Cost of Conventional and Potentially Low-Carbon Philippine Swine Production Systems


## ABSTRACT

*This study identified and evaluated conventional and low-carbon swine production systems through a review of literature and visits to commercial farrow-to-finish swine farms in the Philippines, aiming to recommend a swine production system that cost-effectively reduces GHG emissions. Parameters assessed were greenhouse gas (GHG) emission, carbon and payback period, and return on investment through conduct of life cycle assessment. The identified conventional technologies are open-sided housing system, slatted flooring, modified manual feeding system, nipple drinker, and scrapper and power sprayer as cleaning systems. The identified low carbon technologies are low protein swine feed formulation supplemented with amino acids and partial substitution of soybean meal with Protein-Enriched Copra Meal (PECM), open-sided housing with cemented flooring, manual feeding system, bite ball valve, scrapper combined with power sprayer as cleaning system, and biogas digester as manure management system. These entailed a GHG emission reduction potential of 31.93% in reference to the conventional system. The low carbon production system accounted for higher return on investment of 36.75% and shorter payback period at 2.72 years, compared to the conventional system that yielded 19.96% and 5.01 years, respectively. The identified low carbon swine farm production system can be a cost-effective alternative to the conventional production system.*


**Keywords**: *life cycle environmental impacts, swine farm technologies, low carbon, life cycle costing, carbon debt analysis*


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## INTRODUCTION

With the increasing food demand due to population growth, swine production industry in the Philippines is inevitably increasing in inventory through time. From 11.06 million heads in January 2001 (*Bureau of Agricultural Statistics 2002*), swine inventory in the country increased to 12.71 million heads in January 2019 (*Philippine Statistics Authority 2019*). Though beneficial in addressing hunger and food security, increase in swine inventory also translates in increase in waste generation causing water, soil and air pollution to intensify (*Singh and Rashid 2017*).

In a span of 50 years, the equivalent $CO_2$ emissions (or generally known as greenhouse gas (GHG) emissions), from the livestock sector have increased by 51% worldwide because of increased demand for livestock products (*Caro et al. 2014*). In the Philippines, out of the 152.34 million tons of total GHG emissions, almost 10% is contributed by the livestock sector (*UNFCCC 2015*).

The equivalent $CO_2$ emissions, when translated to climate change, has diverse effects to livestock production such as decreased feed supply, spread of animal diseases and parasites, and damage to water sources (*Galang 2017*).

Since GHG emission can be generally accounted during the production of material and energy inputs to the system, during farm operations, and during manure management handling (*Zhou et al. 2018*), GHG emission reduction in swine farms can be approached in two ways: utilizing raw materials and energy inputs that entail low carbon footprint, and employing environmentally sustainable technologies and practices that can minimize waste generation without sacrificing the efficiency of the farm operations. In the Philippine context, studies on low carbon swine farm practices and technologies are limited, and there is a low number of studies locally conducted that explored environmentally sustainable swine farm operations. This study evaluated different swine farm technologies and practices surveyed from literature and visited commercial swine farms based on their impacts to the environment in terms of global warming potential (GWP). The most common practices and technologies utilized among the visited commercial farrow-to-finish swine farms were classified under conventional production system, and a low carbon production system was designed based on the result of the GWP assessment. The conventional and potential low carbon swine production systems were also compared in terms of carbon payback period, financial payback period, and return on investment. The study aimed to recommend a swine production system that cost-effectively reduces GHG emissions within the farm.

## MATERIALS AND METHODS

This study conducted a life cycle assessment (LCA), involving goal and scope definition, inventory analysis, impact assessment and interpretation (*Pazmiño and Ramirez 2021*) to examine the technologies and practices used in selected commercial farrow-to-finish swine farms in the Philippines and those found in literatures.

### Goal and Scope Definition

Three modules were considered within the boundary of farrow-to-finish swine production system, namely feed production module, animal production module, and manure management system (MMS) module.

The functional unit used for the whole system was the amount of GHG emitted in terms of grams $CO_2$ equivalent per kilogram live weight, which is recommended by the Food and Agriculture Organization (FAO) for LCA studies with system boundaries up until farm gates (*FAO 2016*).

Table 1. Data requirements from key informant interviews with swine farm owners and operators.

| Herd Parameters |
|---|
| Period per Pig Class (in days)<br>Daily Feed Consumption (in kg feed day$^{-1}$)<br>Breeding, Pre-weaning, Post-weaning, Replacement, and Culling Rate<br>Parity before Culling<br>Culling Weight<br>Slaughtering Weight |
| Swine Farm Technologies |
| Manure Management System<br>Cleaning System<br>Feeding System<br>Drinking System<br>Housing Technology |

### Life Cycle Inventory

For the inventory analysis, key informant interviews (KII) with nine commercial swine farm owners and operators with farrow-to-finish operations across the country were conducted from May 2018 to June 2019 to gather data, such as herd parameters, material and energy inputs and outputs of the farms, and the technologies and practices implemented in the farms (**Table 1**).

To compare the different farm technologies in each farm operation (**Table 2**), farms were selected from the top swine producing provinces in the country with sow level varying from 31 to 7,500.

Common practices found in the visited commercial swine farms were identified as conventional technologies. Under the MMS, different biogas digesters surveyed from farms include High-density polyethylene (HDPE) covered anaerobic lagoon, Don Severino Agricultural College (DSAC) model biogas digester, fixed-dome biogas digester (**Table 3**).

Data on potential low carbon swine technologies were collected through KII with suppliers of alternative feed raw materials as well as desktop research of various literature exploring low carbon swine production systems (**Table 4**).

To come up with a recommended low carbon swine production system, different parameters were assessed within the three modules (**Table 5**).

### Life Cycle Impact Assessment

The environmental impacts of local swine production were assessed through the Global Warming Potential (GWP) or GHG emitted. The overall GWP of swine production was derived from the inventory of energy and material inputs and outputs of the entire system.

### Greenhouse Gas Emission Accounting

The greenhouse gas (GHG) emission of the farrow-to-finish swine production system was accounted per module. Emissions due to the feed production module were accounted from the cultivation, production, and transportation of crops as raw materials. The total GHG emission from raw materials was calculated as the summation of individual emission of each raw material shown in Equation 1. The GHG emission due to the transportation of raw materials was calculated as shown in Equation 2.

Table 2. Profile and technologies implemented in farrow-to-finish commercial farms visited in the top swine-producing provinces in the Philippines in 2018 - 2019.

| Farm | Sow Level | Feeds | Feeding System | Cleaning System | Waste Management System | Type of Housing |
|---|---|---|---|---|---|---|
| 1 | 31 | association | conventional feeders; nipple drinkers | scraping; power sprayer | liquid slurry without crust | open type |
| 2 | 36 | commercial | conventional feeders; nipple drinkers | scraping; power sprayer | septic tank | open type |
| 3 | 54 | association | modified conventional feeders; nipple drinkers | scraping; power sprayer | anaerobic digester | open type |
| 4 | 59 | commercial | conventional feeders; nipple drinkers | scraping; hosing | septic tank | open type |
| 5 | 60 | commercial | conventional feeders; nipple drinkers | scraping; power sprayer | open lagoon | open type |
| 6 | 300 | commercial | | scraping; power sprayer | anaerobic digester | |
| 7 | 900 | self-mixed | conventional and automatic feeders; nipple drinkers | scraping; power sprayer | anaerobic digester | tunnel ventilation system |
| 8 | 1600 | self-mixed | automatic feeding system; nipple drinkers | scraping; power sprayer | anaerobic digester | tunnel ventilation system |
| 9 | 7500 | self-mixed | automatic feeding system; nipple drinkers | scraping; power sprayer | anaerobic digester | open type |

Table 3. Identified conventional swine production technologies in visited commercial farms in the Philippines in 2018 - 2019.

| Swine Production System | Conventional Swine Production Technologies |
|---|---|
| Feed Formulation | Standard Feed Formulation |
| Housing System | Open-sided Housing |
| Flooring System | Slatted Flooring |
| Feeding System | Manual Feeding |
| Drinking System | Nipple Drinker |
| Cleaning System | Scrapper and Power Sprayer |
| Manure Management System | Anaerobic Biogas Digester |

$$GHG\ Emission_{raw\ material} = \sum (Amount\ of\ Raw\ Material \times Emission\ Factor_{raw\ material}) \quad (1)$$

$$GHG\ Emission_{transportation} = \frac{Amount\ of\ Raw\ Material}{Truck\ Capacity} \times Fuel\ Economy \times Diesel\ Density \times Transportation\ Distance \times Emission\ Factor_{fuel} \quad (2)$$

Table 4. Information on other potential low carbon swine technologies gathered through KII and desktop research.

| Module | Technology | Source |
|---|---|---|
| Feed Production Module | Protein Enriched Copra Meal Soya Substitute<br>Low Protein Diet Supplemented with Amino Acid | Key Informant Interview with UPLB BIOTECH |
| | Farm Performance Comparison Between Open | Online Journal (*Ogino et al. 2013*) |
| Animal Production Module | Sided Housing and Tunnel Ventilated Housing | Online Journal (*Lally and Edwards 2000*) |

Table 5. Parameters considered in developing a low carbon swine production system.

| Module | Parameters Considered |
|---|---|
| Feed Production Module | Feed Formulation<br>Feed Wastage<br>Land Transportation Distance |
| Animal Production Module | Housing System<br>Flooring System<br>Feeding System<br>Drinking System<br>Cleaning System |
| Manure Management System Module | Manure Management Systems |

For the estimation of GHG emission due to animal production module, the electricity consumption of the farm and the enteric fermentation of the swine population in the farm were considered. The emission factors used to calculate for the emission from electricity consumption were derived from the 2015-2017 National Grid Emission Factor (NGEF) provided by the *Department of Energy* (*2017*). Based on the NGEF, the simple operating margin (OM) emission factor for Luzon-Visayas grid is 0.7122 $tonCO_2\ MW\ h^{-1}$. For Mindanao grid, the OM emission factor is 0.7797 $tonCO_2\ MW\ h^{-1}$. The GHG emission due to energy consumption was calculated as shown in Equation 3.

$$GHG\ Emission_{energy\ consumption} = Total\ Daily\ Herd\ Inventory \quad (3)$$

The GHG emission based on the type of MMS employed in the swine farms was estimated using the method prescribed by *IPCC* (*2006*), which focused on two GHGs, namely methane ($CH_4$) and nitrous oxide ($N_2O$). The total $N_2O$ emission was accounted from the direct and indirect $N_2O$ emission based on the type of MMS utilized in the farm, and the indirect $N_2O$ emission due to leaching. Estimation of GHG emission based on MMS involved several steps, such as classification of the type of MMS, determination of volatile solids, and determination of daily amount of nitrogen excreted. For MMS that employed anaerobic biogas digestion, the $CO_2$ resulting from the combustion of biogas from the digester was not considered as an anthropogenic emission based on international accounting guidance, therefore, it was not included as part of the total GHG emission due to MMS *(Pulles et al. 2022*).

## Comparison of Conventional and Low Carbon Swine Farm Production System

The global warming potential (GWP) or GHG emission of each farm was calculated and the average GWP of conventional technologies was compared with the GWP of the identified low carbon technologies. The GHG reduction potential of the established low carbon swine production system was also calculated relative to the average GWP of the conventional swine production system. Carbon debt analysis and life cycle costing analysis were also conducted for both conventional and low carbon swine farm technologies to further verify the environmental sustainability and cost-effectiveness of the identified low carbon technologies. The flowchart shows the process of comparison between conventional and low carbon swine production system (**Figure 1**).

## Carbon Debt Analysis

Carbon debt analysis involved calculation of the carbon footprint due to the establishment of the swine farm, and the annual carbon savings of the system, if there are any. The two parameters were used to calculate the carbon payback period, defined as the duration wherein the carbon savings would offset the carbon footprint accounted from the construction of the farms (*Vergé et al. 2012*). The carbon footprint accounted from the construction of swine farms was limited on the estimated construction materials used for the pig housing and MMS facility, and was calculated by multiplying the embodied carbon of the materials by the amount of materials used as shown in Equation 4. The embodied carbon of a material is the GHG emitted during the production of the material

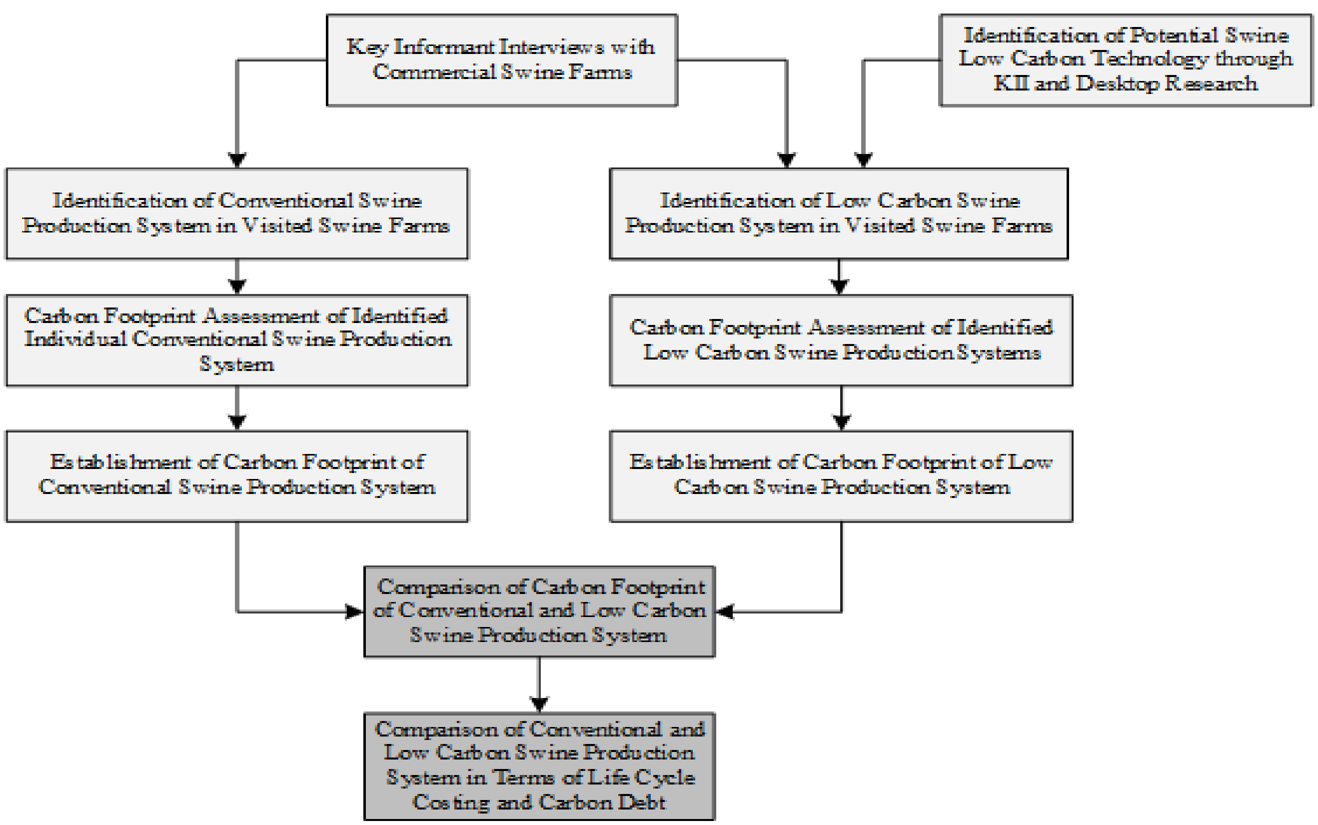


Figure 1. Flowchart for conducting the comparison be conventional and low carbon swine production system.

(*Iddon and Firth 2013*), which is generally expressed as grams carbon dioxide equivalent per kilogram material produced.

$$Carbon\ Footprint = Embodied\ Carbon \times Amount\ of\ Material \quad (4)$$

Carbon payback period was calculated as shown in Equation 5. Annual carbon savings is the difference between the GHG avoided by the system and the GHG emitted by the system.

$$Carbon\ Payback\ Period = \frac{Carbon\ Footprint\ due\ to\ Construction}{Annual\ Carbon\ Savings} \quad (5)$$

**Life Cycle Costing Analysis**

Return on investment (ROI) and payback period were used as financial indicators to assess the cost-effectiveness of reducing the GHG emission of swine production in the country. This is calculated using the Equations 6 and 7, respectively.

$$\%ROI = \frac{Gross\ Profit}{Cost\ of\ Investment} \times 100 \quad (6)$$

$$Payback\ Period = \frac{Initial\ Investment}{Yearly\ Cash\ Flow} \quad (7)$$

The total cost of the construction estimates of pig housing and MMS facility were considered as the initial investment cost, while annual feeds and electricity consumption were considered as the annual operating cost. Gross profit was calculated as the difference between the annual revenue and operating cost.

**RESULTS AND DISCUSSIONS**

**Greenhouse Gas Emission Contributors of Conventional Swine Farm Technologies**

The values considered in the analysis were the average greenhouse gas (GHG) emissions derived from local commercial farrow-to-finish swine farms visited.

**Feed Production Module**

Among the three modules, the GHG emission from feed production module entailed the highest, which amounted to an average of 1,624.18 $gCO_2e\ kgLW^{-1}$ and contributed by the production of raw materials at 88.53%, transportation of raw materials to the feed mill at 3.74%, feed processing (mixing and milling) at 7.49%, and transportation of feeds to farm at 0.24% (**Figure 2**).

Similar results were reported by *McAuliffe et al.* (*2016*) and *Zira et al.* (*2021*), wherein feed production was found to contribute the highest emission. Moreover, in the study of *Villavicencio-Gutiérrez et al.* (*2022*), production of feed materials was accounted for the highest GHG emission at more than 90% contribution to feed production module.

Further analyzing the activities under the production of raw materials for feeds, majority of it is the cultivation of crops and production of feed materials. Corn and soybean meal, typically imported from other countries such as US and Argentina, are the major raw materials used in standard swine feed formulation. According to the database of *Feedprint* (*2012*), the cultivation and production of these raw materials emit significant amount of GHG amounting to 456.00 $gCO_{2e}\ kg^{-1}$ soybean meal and 290.00 $gCO_{2e}\ kg^{-1}$ yellow corn. The emission factors were derived from the country-specific data of the major crop producers for soybean and corn. In the case of soybean, its from US, Brazil, and Argentina. In the case of corn, the emission factor was derived from countries such as France, Hungary, Germany, Brazil, US, etc. The said values justified the production of raw materials as the highest contributor under the feed production module. In the study of *Cherubini et al.* (*2015*), replacing soybean, the most common protein source in feed materials, with a low carbon alternative was recommended due to the intensity of GHG emitted during the cultivation of soybean.

**Animal Production Module**

The average GHG emission from the animal production module amounted to 230.17 $gCO_2e\ kgLW^{-1}$

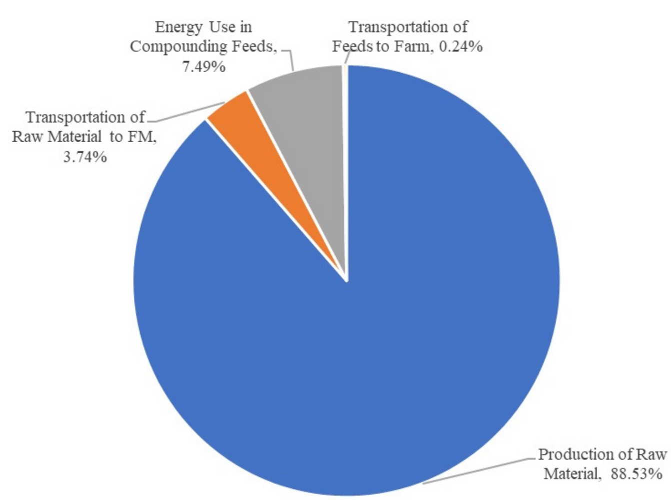


Figure 2. Greenhouse gas (GHG) emission contributors within the feed production module of commercial farrow-to-finish swine farm operations.

contributed by 57.88% enteric fermentation and 42.32% energy use in farm. The energy consumption in swine farms were correlated to the type of technology present in the farm. Equipment or facilities considered to contribute to the electricity consumption of the visited farms include the housing system, feeding system, and cleaning system employed in the farm. The more electrically-operated equipment used in the farm, the higher electricity consumed, thus greater GHG emission was accounted for energy use in swine farms. Emissions from enteric fermentation on the other hand were directly proportional to the number of heads in the farm. The higher the sow level and overall animal inventory of the swine farm, the higher the GHG emitted due to enteric fermentation.

**Manure Management Systems**

The manure management system (MMS) module entailed the second highest contributor of GHG emission consisting of methane ($CH_4$) emission, direct nitrous oxide ($N_2O$) emission, indirect $N_2O$ emission due to volatilization, and indirect $N_2O$ emission due to leaching, which were all dependent on the type of MMS employed in the farm. The result of the study is in parallel with the study done by *Cherubini et al.* (*2015*), wherein among four swine production systems, MMS module consistently accounted for the second highest GHG emission.

Based on the data gathered, the MMS used in the commercial farms visited included liquid slurry without crust, open lagoon (uncovered anaerobic lagoon), anaerobic digester, and septic tank. Liquid slurry without crust entailed the highest global warming potential (GWP) amounting to 464.70 $gCO_{2e}$ $kgLW^{-1}$, while the average emission from different types of anaerobic digester had the lowest GWP of 118.74 $gCO_{2e}$ $kgLW^{-1}$ (**Table 6**).

In the study of *Cherubini et al.* (*2015*), four different MMS, namely open slurry tanks without a natural crust cover, biogas digestor with flare, biogas digestor for energy purposes and composting, were compared in terms of environmental impacts. Similar to the present study, the biogas digestor used for energy purposes was deemed to have the lowest global warming potential due to the recovery of heat and energy in the system.

Manure management systems that tend to develop anaerobic conditions through time encourage the formation of $CH_4$ which will eventually be emitted to the atmosphere. Such MMS include liquid slurry without crust, open lagoon (uncovered anaerobic lagoon), and septic tank wherein the $CH_4$ emission were relatively high compared to other MMS (*IPCC 2006*). Open storages such as liquid slurry without crust and open lagoon stabilize waste, but entail disadvantages such as bad odor, risk of overflowing during heavy rainfall, and volatilization of GHG. On the other hand, closed storage such as septic tank minimizes odor, and volatilization of GHG depending on the ventilation and depth of tank, but sewage back up can occur due to clogging problems (*IPCC 2006*).

Table 6. Global warming potential of different types of manure management systems present in visited commercial swine farms in the Philippines from 2018 - 2019.

| Manure Management System | Global Warming Potential $gCO_2e$ $kgLW^{-1}$ |
|---|---|
| Liquid Slurry without Crust | 464.70 |
| Anaerobic Digester | 118.74 |
| Septic Tank | 399.76 |
| Open Lagoon | 364.87 |

In the case of anaerobic digester, accumulated $CH_4$ together with $CO_2$ and traces of gaseous compounds are collected as biogas and utilized as fuel. It is one of the advanced technologies in MMS wherein manure undergoes anaerobic digestion to favor the formation of $CH_4$ and recover it as biogas to generate fuel or power. According to *Poeschl et al.* (*2010*) as cited by *Esteves et al.* (*2019*), biogas consists of 50-75% $CH_4$, 25-45% $CO_2$, 2-7% moisture, and traces of other gases such us nitrogen, hydrogen, and hydrogen sulfide. Some farms with biogas digesters utilize gas scrubbers to remove the hydrogen sulfide content because this compound can cause corrosion to metal parts, and health risks to humans and pigs depending on the concentration. One disadvantage of anaerobic digester is the requirement for high technical skill for construction and maintenance (*Dilidili et al. 2011*) (**Table 7**).

**Assessment of Low Carbon Swine Farm Technologies**

**Feed Production Module**. Given that soybean meal and corn were the major contributors of GHG emission in the production of swine feeds, using alternative raw materials with lower GHG emission can reduce the overall GHG emission contributed by the feed production module. Reducing the amount of US soybean meal in standard feed formulation and substituting it with other raw materials that can provide the protein requirement of swine feeds can reduce the GHG emission due to the cultivation and production of soybean meal. The *UPLB BIOTECH* (*2020*) has a study regarding the partial replacement of US soybean meal with protein-enriched copra meal (PECM) in swine feed meals. Full replacement

Table 7. Advantage and disadvantages of manure management systems found in local farms.

| Manure Management System | Advantages | Disadvantages |
|---|---|---|
| Liquid Slurry without Crust (open) | • Low Maintenance (2-3 year cleaning frequency) | • Risk of overflowing during heavy rainfall<br>• Volatilization of GHG may occur<br>• Odor |
| Liquid Slurry with Crust (Septic Tank) | • Low Maintenance (2-3 year cleaning frequency)<br>• Minimizes odor | • Sewage back up due to clogging problems<br>• Extra cost for storage and transfer<br>• Volatilization depends on ventilation and depth of tank and length of storage |
| Uncovered Anaerobic Lagoon | • Waste stabilization and storage<br>• Water from lagoon may be recycled as flush water | • Leaching through lagoon bottom, discharge into water surface<br>• Odor<br>• High ammonia, and some methane and nitrous oxide emissions may occur |
| Anaerobic Digester/ Biogas Digester | • Minimizes odor<br>• Biogas product can serve as fuel source or power source | • Requires high technical skill for construction and maintenance<br>• High capital cost depending on type |

with PECM is not possible due to the limitations of the raw material in terms of digestibility. Another way of reducing the amount of US soybean meal in swine feeds is the utilization of low protein diet supplemented with amino acid based from the study of *Ogino et al.* (*2013*). Incorporating the partial replacement of PECM to the low protein diet supplemented with amino acid resulted the highest reduction of GHG emission by 18.88% in comparison with the standard feed formulation (**Table 8**).

Aside from opting for alternative raw materials for feed production, other factors that affect the GHG emission from feed production were the feed conversion ratio, feed wastage, and the distance between the source of feeds to the swine farm. Feed conversion ratio is the ratio of kilogram feed offered per kilogram liveweight gained. The GHG emission is directly proportional to the feed conversion ratio. The lower the amount of feed offered, the lower the GHG emission for the feed production module. Feed wastage is also directly proportional to the GHG emission for the feed production module. The percent feed wastage in pigs ranges from 5-20% (*James 2018*). The average feed wastage in the visited swine farms is 12.69% (**Table 9**). Some factors that cause feed wastage are the manner of how the pig eats, manner of refilling the feeding through, and feed contamination.

For land transportation, it is not recommended that the source of raw materials is farther away from the swine farm and feed mill since the farther the distance, the higher GHG is emitted due to the fuel consumed for transporting the raw materials. Raw materials sourced out within the 50-km radius from the farm was accounted for 110.25 $gCO_2e\ kg^{-1}$ feed, while for 250-km radius was 551.25 $gCO_2e\ kg^{-1}$ feed.

**Animal Production Module**. The type of housing generally determines the ventilation condition inside the animal confinement. Based from the consolidated data from visited farms, the most common housing system of small-scale commercial farms is the open-sided housing which utilizes natural ventilation and employs no energy use for fans. Modifications in the open-sided housing can be done by installing fans along the housing which control the airflow inside the animal confinement and not just rely on natural convection. Large scale commercial farms with greater than 900 sow employ tunnel-ventilated housing system which aim to control not just the airflow, but also the temperature inside the animal confinement.

Table 8. Greenhouse gas (GHG) emission and the corresponding percent GHG reduction of different grower feed formulations with respect to the standard formulation.

| Formulation | **GHG Emission** $gCO_{2e}\ kg^{-1}$ feed | GHG Reduction |
|---|---|---|
| Standard Grower Feed Formulation | 339.78 | - |
| PECM as Partial Soya Replacement | 290.11 | 14.62% |
| Low Protein Feed Formulation Supplemented with Amino Acid | 320.83 | 5.58% |
| Low Protein Feed Formulation Supplemented with Amino Acid incorporated with PECM as Partial Soya Replacement | 275.65 | 18.88% |

Table 9. Percentage of feed wastage and corresponding greenhouse gas (GHG) emission.

| Feed Wastage | GHG Emission $gCO_{2e}$ $kg^{-1}$ feed | GHG Increase |
|---|---|---|
| 0% | 339.78 | - |
| 5% | 357.67 | 5.26% |
| 12.69% | 389.17 | 14.53% |

This usually utilizes a control system that automatically stops the ventilation when the temperature inside the animal confinement reaches 21°C.

In the study of *Lally and Edwards* (*2000*), open-sided housing was compared to tunnel-ventilated housing in terms of farm performance. The daily feed consumption, total gained weight, and feed conversion of swine in tunnel-ventilated housing were higher than that of the open-sided housing, wherein the statistical difference was significant. The mentioned parameters were directly proportional to the live weight of finishing pigs. While the cull rate was statistically inconclusive and the death loss rate was not significantly different, the value under tunnel-ventilated housing was still higher than that of the open-sided housing. The effect of tunnel-ventilated housing in farm performance was generally superior than open-sided housing (**Table 10**).

In terms of GHG emission, additional emission due to electricity consumption of the equipment were accounted for open-sided housing with fans, and tunnel-ventilated housing. Assuming the same herd inventory, the total electricity consumption of fans installed in an open-sided housing per breeding sow is 372.84 kWh, which can be translated to a GHG emission of 169.19 $gCO_2e$ $kgLW^{-1}$. For tunnel-ventilated housing, the total electricity consumption per breeding sow is 567.38 kWh, which can be translated to a GHG emission of 256.65 $gCO_2e$ $kgLW^{-1}$.

Despite enhancement of farm performance in tunnel-ventilated housing which can cause higher live weight of finishing pigs, and qualitative advantages of the tunnel -ventilated housing such as improved hygiene, control of flies and odor, open-sided housing still entailed lower GHG emission than tunnel-ventilated housing (**Table 13**).

Most commercial farms employ both manual and modified manual feeding system. Large scale commercial farms with sow level of at least 900 employ automatic feeding system.

In manual feeding systems, feeding throughs are manually refilled by laborers. On the other hand, modified manual feeding systems work based on displacement principle. The system is generally applicable for swine that are subjected to *ad libitum* feeding program, which are mostly growers and finishers. Manual and modified manual feeding systems does not involve electrically-operated equipment which therefore do not contribute to the total GHG emission accounted for animal production module. However, both systems are more prone to contamination and spoilage since excess feeds are exposed to moisture from the atmosphere which can encourage the growth of molds and bacteria. Automatic feeding system on the other hand includes a feed delivery system handling the feeds in an enclosed container which entails additional electricity consumption and eventually contributes to the overall GHG emission in the animal production module.

In terms of cleaning system, all commercial farms visited use scraper to remove dry manure, and power sprayer to clean the animal's housing and remove residual manure. Manual cleaning systems that use dipper do not have to account for additional cost from fuel or electricity consumption, but it is possible that more water is consumed if the method of washing will not be aided with manual removal of remaining manure. On the other hand, using power sprayer can remove remaining manure by the high pressure of water, thereforecleaning can be more efficient and less time-consuming. As a disadvantage, additional electricity or fuel consumption must be accounted for the pump, and therefore contributes to the overall GHG emission in the animal production module. Another disadvantage is that high pressure of water from power sprayers can cause serious injuries and damages if not carefully handled.

Table 10. Comparison on the effect of open-sided and tunnel -ventilated housing on the performance of pigs.

| Parameters | Open-Sided | Tunnel-Ventilated | Statistical Conclusion |
|---|---|---|---|
| Daily Feed Consumption, kg $day^{-1}$* | 1.95 | 2.00 | Significant |
| Total Gained Weight, kg* | 89.72 | 93.53 | Significant |
| Feed Conversion, kg gain kg $feed^{-1}$* | 0.34 | 0.36 | Significant |
| Cull Rate, % | 4.90 | 3.22 | Statistically Inconclusive |
| Death Loss Rate, % | 3.56 | 3.25 | Not Significant |

Source: *Lally and Edwards* (*2000*)
*Unit of measure was originally expressed in English units.

Table 11. Advantages and disadvantages of different swine housing systems.

| Housing System | Applicability | Advantages | Disadvantages |
|---|---|---|---|
| Open-sided | Backyard and Commercial Farm | • Less GHG emission due to the absence of fans<br>• Minimal capital cost and no additional electricity cost | Uncontrolled air flow |
| Open-sided with Fans | | • Sustained airspeed<br>• Less expensive than tunnel ventilated housing | Additional capital cost and electricity cost |
| Tunnel Ventilated | Commercial Farm | • Sustained airspeed and temperature<br>• May enhance farm performance | Higher capital cost and electricity cost |

For commercial farms with less than 100 sows, emission due to energy use had a GHG contribution of 25.65% of the total GHG emission in the animal production module. This was mainly due to the small commercial farms use operations that are less energy intensive such as manual feeding system, and open-type housing. Large commercial farms with greater than 100 sows had energy use GHG contribution of 55.39% to the emissions in the animal production module (**Figure 3**). Large commercial farms employed tunnel-ventilation system and power sprayer to improve farm productivity but the mentioned technologies entailed additional GHG emission and operating cost due to energy use.

## Manure Management System Module

Anaerobic biogas digester was accounted with the lowest GHG emission among the different types of MMS. Types of biogas digester depend on the material of construction and the design of the digester itself and the gas holder. The different the types of biogas digester that were found in local commercial swine farms visited include High-Density Polyethylene (HDPE) Covered Lagoon, Don Severino Agricultural College (DSAC) Model Biogas Digester, and Fixed-dome Biogas Digester (**Table 12**).

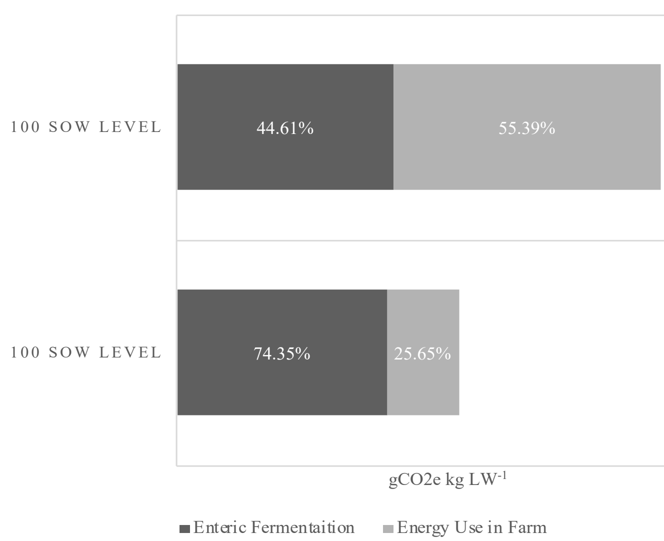


Figure 3. Greenhouse gas (GHG) contribution of animal production module.

The GHG reduction potential was based from the amount of fossil fuel, specifically liquified petroleum gas (LPG), replaced from the biogas yield of respective digester. The higher the yield of biogas from the system, the higher the LPG that can be replaced, therefore, the higher the potential of the system to reduce the GHG emission from using LPG.

Among the different types of anaerobic biogas digesters from the visited farms, DSAC model biogas digester had the highest reduction potential (**Table 13**).

## Assessment of Other Local Swine Farm Technologies

The swine farm technologies assessed in the study which do not directly affect the GHG emission of swine farms include flooring system and drinking system. Advantages and disadvantages were considered in assessing the said swine farm technologies.

## Flooring System

Flooring systems vary from cemented, to part-slatted, and completely slatted flooring. Flooring systems in commercial farms vary depending on pig stages. Slatted and part-slatted floorings are usually seen in lactating and nursery pens because slatted flooring minimizes the direct contact of piglets to manure. Piglets are more susceptible to diseases from manure, therefore slatted flooring is best employed. Moreover, the manure easily passes through the slats of the flooring, therefore waste collection is more convenient.

Table 12. Greenhouse gas (GHG) reduction potential of different types of anaerobic biogas digesters.

| Manure Management System | Global Warming Potential $gCO_{2e}$ $kgLW^{-1}$ |
|---|---|
| HDPE Covered Anaerobic Lagoon | 644.20 |
| DSAC Model Biogas Digester | 1,431.56 |
| Fixed-Dome Biogas Digester | 393.68 |

Table 13. Advantage and disadvantages of different types of anaerobic biogas digesters.

| Types of Anaerobic Biogas Digester | Advantages | Disadvantages |
|---|---|---|
| HDPE Covered Lagoon | • Applicable to commercial farms only<br>• Generally used in power generation<br>• Low cost<br>• Simple operation and maintenance<br>• Storage for deferred irrigation<br>• Increased fertilizer value (~35% more ammonia in effluent)<br>• Reduction of odor from effluent irrigation (by as much as 70%)<br>• Easily adaptable to hydraulic flushing<br>• High biogas production in warm climates | • Long retention time<br>• High dilution factor<br>• Poor mixing<br>• Poor energy yield<br>• Solids settling reduces useable volume<br>• Limited to warmer weather or warm climates<br>• Not suitable for use in areas with a high groundwater table |
| DSAC Model Biogas Digester; and Fixed-Dome Biogas Digester | • Applicable to backyard and commercial farms<br>• Durable<br>• Simple to operate<br>• Flexibility of design<br>• Self stirring<br>• Can generate biogas from 35-60% of the digester volume<br>• Underground construction saves space<br>• Can be constructed above/under ground<br>• Long lifespan if properly constructed<br>• Low maintenance | • Potential problems with the gas-tightness of the brickwork<br>• Difficult to repair leakage<br>• Requires high technical skill for gas tight construction |

Cemented flooring entails less capital cost and is more durable than slatted and part-slatted flooring. Slatted flooring requires elevation from the ground floor, therefore the construction involves additional cost for the materials used for elevation. The durability of slatted flooring depends on the material which can be cast iron or plastic. Cast iron is mostly applicable for sows, growers, and finishers to support the weight of the swine. On the other hand, plastic slatted floors are applicable for piglets (**Figure 4**).

## Drinking System

Drinking systems include manual refilling in drinking bowl or trough, and nipple drinker or bite ball valve. Like in manual feeding systems, the use of troughs and drinking bowls are more prone to contamination, as well as spillage. Moreover, stagnant water can attract rodents and insects. On the other hand, nipple drinkers reduce water spillage, and prevent contamination since water flows through a piping system. One modification of nipple drinker is the bite ball valve which is anatomically designed for swine wherein water starts to flow only when the valve is already inside the swine's mouth. This design entails water usage reduction by 15% compared to standard nipple drinker (*Rath 2000*).

## Global Warming Potential of Low Carbon Swine Farm Production System

Utilization of low protein diet supplemented with amino acids, and partial substitution of soybean meal with PECM entailed the highest GHG emission reduction of the feed production module. The shortest distance for the transportation of feed raw materials also contributed the least GHG emission in the feed production module.

Based from GHG emission due to electricity consumption of the housing, and feeding technology, the identified low carbon system are open-sided housing and manual feeding systems. Considering the advantages and disadvantages of different flooring systems, cemented flooring entailed less capital cost is more durable, while for drinking systems, bite ball valve entailed lesser water wastage. For cleaning systems, scrapper combined with the utilization of power sprayer were

Figure 4. Slatted flooring system in a lactating swine pen.

deemed to be efficient and entailed minimal water usage.

Among the types of MMS, anaerobic biogas digester was superior in terms of GHG emission reduction, and production of high-value products, energy in particular. Among the types of anaerobic biogas digesters surveyed from the visited farms, the DSAC Model Biogas Digester was deemed to be the best technology in terms of energy production, displacement of fossil fuel consumption, and payback period.

The GWP of low carbon swine farm production system was calculated for a farrow-to-finish commercial farm. Parameters used to calculate for the herd inventory and live weight such as mortality rate, farrowing index, and market weight were derived from the average values of swine farms visited (**Table 14**).

In comparison with the conventional swine production system with GWP of 2,264.13 $gCO_2e$ $kgLW^{-1}$, the low carbon production system entailed an overall GHG reduction of 31.93%.

**Carbon Debt Analysis and Life Cycle Costing**

For the carbon debt analysis of the swine farm production system, GHG emission due to the construction of swine housing and MMS were considered. The carbon payback period and carbon savings were analyzed within the boundary of the MMS module.

Conventional commercial swine farm production system had GHG emission due to construction of 2,534.37 $gCO_2e$ $kgLW^{-1}$. The GHG emission due to construction of low carbon production system was generally higher than conventional system with value 2,863.53 $gCO_2e$ $kgLW^{-1}$. Slightly higher value of low carbon swine production system was due to greater amount of materials for the construction of the DSAC Model Biogas Digester. Anaerobic digesters require more materials than septic tanks with the same volume capacity to ensure gas tightness and parts for the recovery of biogas.

Conducting the carbon debt analysis within the boundary of the MMS module, the GHG emission due to construction of the conventional MMS (non-anaerobic digester) is 1,420.20 $gCO_2e$ $kgLW^{-1}$. On the other hand, the low carbon MMS (DSAC model biogas digester) yielded the GHG emission due to construction of 1,749.36 $gCO_2e$ $kgLW^{-1}$. Accounting for the GHG reduction potential of the low carbon MMS from the GHG emission avoided from replacing fossil fuel with biogas recovered from the anaerobic biogas digester, the net annual carbon savings is 1,315.12 $gCO_2e$ $kgLW^{-1}$. The carbon payback period of the low carbon MMS is 1.33 years. The results implied that in approximately two years' time, the carbon emitted from the construction of the low carbon MMS will be paid back by the avoided GHG emission of the system. Since the conventional MMS had no GHG reduction potential, the carbon emitted due to construction will remain as carbon debt.

In terms of financial perspective, the return of investment and payback period were computed to assess the life cycle cost of the conventional and low carbon production system. Low carbon swine production system had generally higher return on investment (ROI) at 36.75% than conventional production system at 19.96%. Payback period was shorter for low carbon production system at 2.72 years than the conventional production system with at 5.01 years. Higher ROI and shorter payback period of the low carbon system were due to the additional

Table 14. Greenhouse gas (GHG) emission of low carbon swine farm production system.

| Farm Technologies | Low Carbon Swine Production System | GHG Emission $gCO_{2e}$ $kgLW^{-1}$ |
|---|---|---|
| Feed Formulation | Low Protein Feed Formulation Supplemented with Amino Acid incorporated with PECM as Partial Soya Replacement | 1,194.54 |
| Feed Wastage | 5% | |
| Land Transportation Distance | 50-km Radius | |
| Animal Production Module | | 230.17 |
| Housing System | Open-sided Housing | |
| Flooring System | Cemented Flooring | |
| Feeding System | Manual Feeding | |
| Drinking System | Bite Ball Valve Nipple Drinker | |
| Cleaning System | Scrapper and Power Sprayer | |
| Manure Management System Module | | 116.44 |
| Manure Management System | | |
| Total GHG Emission | DSAC Model Biogas Digester | 1,541.15 |

revenue from the biogas collected from the anaerobic biogas digester given that the biogas will be sold as alternative to liquified petroleum gas (LPG). The results implied that swine farm production system that employed low carbon technologies were also cost effective.

## CONCLUSIONS AND RECOMMENDATIONS

Utilizing the life cycle assessment (LCA) in selected commercial farrow-to-finish swine farms in the Philippines resulted to identifying the low carbon cost-effective commercial swine farm production system in the country, which included low protein swine feed formulation supplemented with amino acids and partial substitution of soy bean meal with PECM, open-sided housing with cemented flooring, manual feeding system, bite ball valve as drinking system, scrapper combined with power sprayer as cleaning system, and biogas digester as manure management system (MMS).

The low carbon swine farm production system entailed 31.93 % greenhouse gas (GHG) emission reduction as compared to the conventional swine farm production system. Moreover, the low carbon swine farm production system had generally higher return on investment and shorter payback period, which implied that the identified low carbon swine farm production system was a cost-effective alternative to the conventional production system.

Since identification of potential low carbon swine farm technologies is the first step in promoting a low carbon swine industry, it is recommended to conduct a validation study through actual measurements of GHG emissions of the potential low carbon technologies. It is also recommended to explore other advanced or present-day technologies and practices, such as new feed formulations, alternative protein sources and high technology manure management systems.

Furthermore, an acceptability study of the swine industry stakeholders on the proposed low carbon production system should be conducted to assess its viability in the local swine industry.

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