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LIFE CYCLE ASSESSMENT OF BROILER PRODUCTION IN TUNNEL-VENTILATED AND CONVENTIONAL POULTRY HOUSES IN GENERAL AGUINALDO, CAVITE, PHILIPPINES

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ABSTRACT

The growing demand for chicken meat necessitates the expansion of the poultry industry. To address production challenges, technology is being increasingly adopted, especially to mitigate the effects of climate change. However, the industry's rapid growth raises concerns about its sustainability, with intensive poultry farming leaving a significant ecological footprint. Notably, research in the Philippines has not adequately addressed the environmental performance of broiler production. This study aims to bridge this gap by conducting a comparative environmental impact assessment of conventional and tunnel-ventilated poultry houses in General Aguinaldo, Cavite. Life cycle assessment was done to evaluate the environmental impact of both types of poultry houses. The system boundary of the study is the operation involving broilers from brooding to post-brooding. The environmental impacts include global warming potential (GWP), eutrophication potential (EP), and acidification potential (AP). Results of the study showed that tunnel ventilated system had higher GWP and EP while conventional production had higher AP per harvested live chicken. The use of renewable energy sources, proper orientation of poultry houses, rainwater harvesting, efficient water quality management, and adding adsorbents to reduce odor emitted by poultry manure were recommended to minimize environmental impacts.

Key words: life cycle assessment, system boundary, global warming potential, eutrophication potential, acidification potential

INTRODUCTION

Chicken consumption has witnessed a remarkable surge worldwide, becoming a staple in the diets of people from diverse cultures and regions. The growing global population, changing dietary preferences, affordability, and ease of production and distribution have all contributed to the increasing popularity of chicken meat. According to recent statistics, chicken is now the most consumed meat globally, surpassing beef and pork (FAO 2021). This shift in consumer behavior has significant implications for the poultry industry, global food systems, and sustainability considerations.

In the Philippines, the poultry industry ranked third as one of the most significant contributors to the country's agriculture. In 2021, the total chicken production was estimated at 1.74 million metric tons, liveweight. It shared 12.5 percent of the total agricultural output. The total chicken population in the country stood at 190.74 million heads for the last quarter of 2021. At current prices, the gross value of poultry production amounted to PhP 193.48 billion, or 7.7 percent higher than the earnings in 2020 (PSA 2021). Chicken meat is the second most popular meat in the Philippines, following pork. Broiler chicken, mainly for meat production, accounts for 34 percent of the total chicken inventory. This is 5.5 percent higher than the previous year (PSA 2021). At present, chicken broiler production has become one of the most progressive animal enterprises in the country. This is evident with backyard enterprises shifting to form large integrated contract farming operations. Most broiler entrepreneurs venture into contract growing, technically in collaboration with large private companies that provide them the chicks, feeds, technical services, and the market for the products.

In order to increase production efficiency, new technologies have been employed in the poultry industry. The livestock industry, through which it is included, is among the most technology-intensive in the agriculture sector. For the past years, there has been a wide application of technology in its operations spanning from farmhouses establishment, production operations, and even product packaging and tracking. In effect, technology enables farm operations to become more mechanized, resulting in the expected time and labor savings, reduced input costs, reduced production periods, and significant increase in productivity.

Climate change poses a significant challenge for the global animal industry, impacting the performance and well-being of animals, particularly chickens. Chickens are particularly vulnerable to heat stress, and their productivity is highly dependent on narrow temperature ranges. A study by Kang et al. (2020) examined the effects of rapid versus gradual temperature increases on laying hens and revealed that rapid temperature elevations had more severe consequences, particularly in terms of mortality rates. In a related study, Liang et al. (2020) conducted a review of sprinkler technology as a physical intervention to mitigate heat stress in broilers, highlighting its positive impact on cellular metabolism and its potential to counteract heat stress effects. Additionally, a study by Kim et al. (2020) investigated the influence of heat stress on laying hens exposed to varying temperature conditions. Hens subjected to high temperatures exhibited elevated rectal temperature, heart rate, and infrared surface temperature readings throughout the study, emphasizing the challenges chickens face when exposed to rapidly rising temperatures. These studies underscore the need to regulate temperature increases within poultry housing systems.

Due to the varying climatic conditions, technological advances related to environmental control to provide suited conditions necessary for a specific life stage of the livestock became of critical importance. In the poultry industry, mechanical ventilation systems have gained significant attention for years owing to the growing need to regulate the environmental parameters necessary for production. Ventilation in livestock shelters controls several environmental factors by diluting inside air with outside air (Holmes 1989). A proper ventilating system must perform three essential functions, namely: bring in fresh air into the building through planned openings; thoroughly mixes outside and inside air; pick up heat, moisture, and air contaminants; lower temperature, humidity, and contamination levels; and withdraw moist and contaminated air from the building.

There are various types of poultry house ventilations. In the Philippines, natural or conventional ventilation is widely used. Natural or conventional ventilation relies on opening the house to the right extent to allow outside breezes and inside convection currents to blow air into and through the house. This is often done by lowering or raising sidewall curtains, flaps, or doors. Natural ventilation is often referred to as “curtain ventilation”. This ventilation works well only when outside conditions are near desired in-house conditions.

On the other hand, in recent years, tunnel ventilation has emerged in order to mitigate thermal stress. This system is defined by a linear arrangement of air inlets and outlets, with air inlets situated at one end and exhaust fans positioned at the opposite end (Sarentonglaga et al. 2019). Tunnel ventilation aims to keep animals comfortable in warm to hot weather by using the cooling effect of high-velocity airflow. The tunnel setup is suited to warmer areas. Tunnel systems are designed to handle the expected need for heat removal and provide a condition for air exchange and let out excess house heat in hot weather. The tunnel setup also provides wind-chill cooling, moving air as in a wind tunnel through the length of the house.

Based on the Bureau of Animal Industry (BAI), there were 36 poultry farms registered in 2010, which increased to more than seven times in 2016, for a total of 269 farms. However, only 33 and 244 farms were located based on BAI registration in 2010 and 2016, respectively. Of the 33 farms registered in 2010, 23 use natural or conventional ventilation. The majority of those registered in 2016, or 163 farms of the 244 farms, are still into natural or conventional ventilation. On the other hand, there is also a growing adoption of tunnel ventilation technology in the poultry industry. Based on the BAI registration, poultry farms using the technology increased from 8 farms in 2010 to 81 farms in 2016.

With the growing demand for chicken meat, it is evident that the poultry industry will continue to expand in the foreseeable future. This expansion will be accompanied by the ongoing adoption of technological solutions to address production challenges, particularly those arising from the effects of climate change. However, as poultry operations increase in size, concentration, and intensity, concerns about the industry's sustainability have become more pronounced. During the past years, the environmental impact of the poultry industry has received ever-growing attention. Intensive poultry farming leaves a substantial ecological footprint, posing significant risks to both the environment and human health, demanding effective management practices. The poultry industry and its by-products contribute to NH_3, N_2O, and CH_4 emissions, impacting global greenhouse gas levels and the well-being of both animals and humans. Poultry litter and manure may contain contaminants like pesticide residues, microorganisms, pathogens, pharmaceuticals (including antibiotics), hormones, metals, and imbalanced macronutrient ratios, resulting in air, soil, and water pollution and the development of drug-resistant pathogenic strains. The release of dust from intensive poultry operations, containing feather and skin fragments, fecal matter, feed particles, microorganisms, and other pollutants, adversely affects poultry health, as well as the health of farm workers and nearby communities. Persistent odors compound these concerns, negatively affecting worker health and community well-being (Gržinić et al. 2023). In light of these issues, the broiler industry faces the critical challenge of achieving a balance between meeting the growing population's demands for increased production and the imperative to minimize its environmental impact for long-term sustainability.

Recent research on broiler production in both tunnel-ventilated and conventional poultry facilities within the Philippines has predominantly addressed grower satisfaction (Franco 2021), enhancements to cooling systems (Ballaran and Victoria 2019), the quantitative evaluation of biosecurity practices in broiler farms (Tanquilut et al. 2020), and considerations of productivity and financial viability (Salas et al. 2016). However, there remains a notable gap in the literature, with no existing study evaluating the comprehensive environmental performance of broiler production. Consequently, this study aims to rectify this gap by conducting an environmental impact assessment of broiler production, driven by the increasing adoption of tunnel ventilation technology in the Philippines. In light of this trend, a comparative analysis between this emerging technology and conventional practices was conducted, given expectations that the reliance on tunnel ventilation will continue to grow as a significant adaptation measure to address climate variability and unpredictability arising from climate change.

To facilitate a better understanding of the environmental impacts of broiler production, life cycle assessment (LCA) was employed to determine the overall environmental performance of broiler production. General Aguinaldo, located in Cavite, was selected as the study area due to its status as one of the major broiler producers in the country. This region also exhibits a widespread adoption of tunnel ventilation technology and substantial number of poultry farms using conventional poultry housing. This will ensure the results of the analysis for the types of poultry houses to be readily comparable due to the consistent environmental conditions. Now, this study aimed to identify as well as quantify the various environmental impacts of the commercial broiler production using tunnel ventilated house and conventional house in General Aguinaldo, Cavite.

METHODOLOGY

This study used the LCA methodological framework established by ISO 14040. It involves four phases, namely, the definition of goal and scope, life cycle inventory, life cycle impact assessment, and interpretation of the results.

Goal and scope of the study. The goal of the study is to analyze the environmental performance of broiler production between conventional and tunnel-ventilated poultry houses. Specifically, the system boundary of the study is the operation involving broilers from brooding to post-brooding. Inventory analysis was conducted in the facility of purposively selected poultry farm co-operators in General Emilio Aguinaldo, Cavite. There were four conventional and five tunnel ventilated houses investigated for this study. There were two farms that had two conventional houses each while all of the tunnel ventilated houses are located in one farm. The functional unit used in the study was per harvested animal unit. The impact categories include global warming potential (GWP), atmospheric acidification potential (AP), and eutrophication potential (EP).

Inventory analysis, This phase involves identifying and quantifying the inputs and outputs of the production process as covered in the system boundary. At this stage, the following were quantified: the number of poultry animals, feeds, volume of water required for each of the life cycle stages, volume of diesel used for transportation, electricity consumption, amount of liquified petroleum gas (LPG) used for warming the air inside the poultry houses, amount of solid wastes, excess nitrogen (N) and phosphorus (P), methane (CH_4), carbon dioxide (CO_2) and sulfur dioxide (SO_2) emissions.

The quantity of animals, amount of feeds, water, diesel and LPG were derived from farm records and interviews with the farm managers and operators. The electricity consumption was measured in kilowatt-hour (kWh) which will be obtained by determining the power (in Watts) of the light bulbs, fans, feed motor, and water pump and other electrical equipment used during the production and the time this equipment are used. The product of the power and the time used provides the electrical energy required for each of the equipment. In conventional houses, the estimate of water usage per house was calculated by determining the number of waterers used and frequency of refilling them. The data on water consumption in tunnel ventilated buildings, on the other hand, were collected from the LCD screen of the monitor of the automatic control system verified thru water meter readings. Daily electric power consumption in conventional and tunnel ventilated house was derived from the readings on designed microcontroller-based power consumption logger and kilowatt-hour meters, respectively.

The estimation of amount of the manure was based from results from the study of American Society of Agricultural and Biosystems Engineers (ASABE) (2010) wherein it was stated that on the average, 0.23 lb of manure is excreted by one broiler per day (Ni and Heber 2013). The volume of wastewater was approximated by applying the values recommended by Economopoulos (1996) which 37.5 m3 of wastewater per 1000 birds in poultry processing. Since such numbers were derived from the whole life cycle of poultry production starting from its initial stage until meat processing, it is important to note that integrating these to this study provides an overestimate of the amount of wastewater that might have been discharged in the actual production since the boundary was set only to brooding to post-brooding in broiler production.

The Total N and total P of water were analyzed before and after the operation. Water samples was submitted to an analytical laboratory for the total N and total P analyses. Composite sampling was employed, i.e., water samples were collected from outlets of the farmhouses before the analysis. The total N and P was analyzed in three replicates. Excess N and P was calculated using Equation 1:

$$\text{Excess N and P} = O_{NP} - I_{NP}$$ Equation 1

Where:

I_{NP} is the N and P content of the water before the operation, and O_{NP} is the N and P content of the water after harvesting.

Impact assessment. The impact categories that were applied are global warming potential (GWP), atmospheric acidification potential (AP), and eutrophication potential (EP). These were derived using the results of the inventory analysis. The GWP of a substance is the ratio between the contribution to the heat radiation absorption resulting from the instantaneous release of 1 kg of greenhouse gas and an equal emission of CO_2 integrated over time (Heijungs 1992). The GWP of CO_2 and CH_4 expressed as equivalent over a 100-year life span. The GWP characterization factor of CO_2 is 1.00 (Houghton et al. 1994), while CH_4 is 28.00 (IPCC 2014).

$$\begin{aligned}\mathrm{CO_2\ emission, kg} = {} & \left[(\text{Electricity consumption, kWh})\left(\frac{0.53606\ \mathrm{kg\ CO_2}}{\mathrm{kWh}}\right)\right] \\ & + \left[(\text{Volume of diesel, L})\left(\frac{2.778\ \mathrm{kg\ C}}{3.74\ \mathrm{L\ diesel\ fuel}}\right)(0.99)\left(\frac{44}{12}\right)\right] \\ & + \left[(\text{Weight of LPG, kg})\left(\frac{3.03\ \mathrm{kg\ CO_2}}{\mathrm{kg\ LPG\ fuel}}\right)\right] \\ & + \frac{\left[\begin{array}{c}(\text{Average daily gain (g)})(\text{ Total population})\left(\frac{0.002946\ \mathrm{g}}{\mathrm{hour}}\ \mathrm{CO_2}\right) \\ x\ (\text{Total Hours of Broiler Production})\end{array}\right]}{\frac{1000\ g}{1\ kg}}\end{aligned}$$ Equation 2

$$CH_4\ of\ Manure_{\mathrm{a}} = (Pop_{\mathrm{a}})(EFmanure_{\mathrm{a}})$$ Equation 3

Where:
$\mathrm{CH_4}$ of $\mathrm{Manure_a}$= methane emission from manure management (Gg/year)
$\mathrm{Pop_a}$= population (in 1000 heads)
$\mathrm{EFmanure_a}$= emission factor (kg CH_4 /head/year)

$$\begin{aligned}\mathrm{GWP} = {} & (\mathrm{CO_2\ emission})(\text{GWP characterization factor}) \\ & + (\mathrm{CH_4\ emission})(\text{GWP characterization factor})\end{aligned}$$ Equation 4

The AP is based on the emissions of SO_2, an acidifying substance to the air. SO_2 emission was computed using Equation 5. The electricity consumption was converted to an equivalent volume of diesel in liters using the conversion factors 3.6 megajoule (MJ) which is the available for every kilowatt-hour of electricity, and 36 MJ which is the heating value of one liter of diesel fuel (Korres 2013). The resulting value was added to the actual volume of diesel used for transportation. The total volume of diesel was multiplied by 0.850 kg/L, which is the density of diesel fuel based on the Philippine standards, 0.05%, which is the estimated sulfur content in diesel (Philippine Clean Air Act of 1999), and 64/32, which is the ratio of molecular weights of sulfur dioxide and sulfur, respectively (Abasolo and Zamora 2016). The weight of LPG was multiplied by 0.014%, which is the estimated sulfur content in LPG (PNS/DOE QS 005:2016), and by the same molecular weight ratio as before. AP was calculated using Equation 6. The AP factor of SO_2 is 1.00 (Heijungs 1992).

$$\begin{aligned} &\mathrm{SO_2\ emission,\ kg} \\ &= \left[(\text{Electricity consumption, kWh})\left(\frac{3.6\text{x}10^6\ \text{J}}{\text{kWh}}\right)\left(\frac{1\ \text{L diesel fuel}}{36\text{x}10^6\ \text{J}}\right)\right. \\ &\left.+\ (\text{Actual volume of diesel used, L})\right]\left[\left(\frac{0.850\text{kg}}{1\ \text{L diesel fuel}}\right)(0.05\%)\left(\frac{64}{32}\right)\right] \\ &+\left[(\text{Weight of LPG, kg})(0.014\%)\left(\frac{64}{32}\right)\right] \end{aligned} \qquad \text{Equation 5}$$

$$\text{AP of SO}_2 = (\text{SO}_2\ \text{emission})(\text{AP factor}) \qquad \text{Equation 6}$$

The EP converts the inventory data to phosphate equivalents. This is calculated based on the excess N and P using Equation 7 where m_i is the amount of N and P released to soil and water. The EP factors of N and P are 0.42 and 3.06, respectively (Heijungs 1992).

$$\text{EP} = \sum_i (\text{EP factor}_i)(\text{m}_i) \qquad \text{Equation 7}$$

Interpretation. In this final phase of LCA, the most significant environmental impact category and the life cycle stage were identified based on inventory analysis and impact assessment results. Conclusions and recommendations were also formulated based on the same results.

RESULTS AND DISCUSSION

Broiler production. Broiler production is divided into two stages: brooding and post-brooding. The animals stay in the broiler house for more than 30 days, from brooding to post-brooding, until they are ready for harvesting. Brooding is the mechanism of providing young chickens with heat after hatching up or when they are a day old until their natural heat-regulating system becomes fully developed, usually when they are 14 days old. During the brooding stage, for this study, one conventional farm used an infrared heater suspended about 80 cm from bird height to warm the in-house air or the surrounding of the broiler chicken, while the other conventional farm provided heat to the chickens by burning charcoals inside a metal container hanged approximately 60 cm above bird level. Both conventional farms used coffee pulp as floor litter to aid in the brooding process. Meanwhile, the tunnel-ventilated house uses a direct-fired gas heater to heat the air and old newspapers as floor cover during brooding. Infrared and direct-fired gas heaters use liquefied petroleum gas (LPG) tanks for combustion.

To ensure that the chickens are comfortable not only during brooding but also throughout the remaining production period, one factor that is maintained is proper ventilation. Conventional broiler house employs natural ventilation wherein air exchange happens as a result of temperature and pressure differences inside and outside the house. During the whole course of broiler production, the conventional broiler house is in natural ventilation mode. Flock man manually adjusts sidewall curtains to take advantage of natural ventilation depending on the ambient air condition, which is mainly influenced by temperature. However, the flock man does not have any measuring device to determine the temperature and humidity levels inside the house, and the adjustment of the curtain depends solely on the flock man's observation of the chickens' behavior or response to the thermal condition of the surrounding air. For instance, if the flock man feels that the air is too cold for the chickens, he will roll up or fully close the curtains, and if it is too hot, the curtains will be rolled down or fully open. Nevertheless, in general, curtains are fully closed during the brooding stage and are gradually rolled down starting from post-brooding at the age of 15 days until they are fully open at the last week of production.

Aside from the manual adjustment of curtains in a conventional house, a large part of the labor handled by the flock man is the manual refilling of feeders and waterers. Trough and round feeders and galloners are used when the birds are still small, and when they grow older and are bigger in size, trough feeders are pulled out while round feeders are retained, and all of the galloners are replaced with round pan waterers. Meanwhile, since in-line feeders and nipple drinkers are fully automatic, the only labor needed in the feeding and watering system of the tunnel-ventilated house is the manual refilling of feed hoppers and preparation of antibiotics, vitamins, or other medicine to be mixed with water to be supplied to the birds.

On the other hand, there are three stages of ventilation modes applied in tunnel-ventilated broiler houses: minimum, transitional, and tunnel ventilation (Aviagen 2019). These ventilation modes are set and controlled using automatic control systems. Minimum ventilation is set from the first day of growing until the last part of the brooding stage, wherein direct-fired gas heaters, sidewall inlets, and exhaust fans intermittently operate based on the set threshold temperature and humidity values. After which, transitional ventilation, as the term implies, is the ventilation setting amid the transition period from brooding to post-brooding production. This setting is performed to prepare the homeothermic capacity of chicks to adapt to the shift from a warm to a cool in-house environment. In transitional ventilation, alongside the sidewall exhaust fans, one to two tunnel exhaust fans are also running to withdraw the mixture of stale air and air coming from the sidewall and tunnel inlets. There will come a time when one or two tunnel exhaust fans will not be sufficient to withdraw the heat or cool the inside of the poultry house because the amount of heat in the building will increase since the chickens are also emitting more body heat due to gain in mass as the production progresses. During such times or hot weather, the broiler house is set to tunnel ventilation mode. In the tunnel ventilation setting, the tunnel exhaust fans withdraw the stale air, and fresh air enters the tunnel inlets located at the opposite end of the tunnel fans. All sidewall inlets are closed when the house operates in tunnel ventilation mode. Evaporative cooling pads are also switched on with the tunnel inlets and fans if the exhaust fans are insufficient to bring the in-house air to the desired cool temperature.

The conventional house had no sidewalls, rather the house was only covered by polyester plastic curtains during brooding and cold periods. In contrast, the side wall of tunnel-ventilated houses is either made up of concrete or sandwich panel polyurethane, depending on the owner's preference. The conventional house, which is elevated has cylindrical concrete columns and bamboo posts to support the structure of the house. It means that chicken manure and other animal excretions passing through the spaces between bamboo slats are accumulated on the soil surface under the conventional house. In contrast, the concrete floor of tunnel-ventilated houses is not elevated or is directly connected to the ground resulting to all excreted elements being amassed in the concrete basement below the plastic slats flooring.

There were four conventional and five tunnel-ventilated houses investigated for this study. Two farms had two conventional houses each while all tunnel-ventilated houses were located in one farm. The capacities of the conventional house were 2,450, 4,000, 5,000, and 6,600 birds. Only one tunnel-ventilated house had a 32,000 bird capacity, while each remaining house had 25,000 birds. It can be noticed that tunnel-ventilated houses can accommodate five to seven more birds per square meter than a conventional one. For the conventional type, 18,009 day-old chicks were distributed to four houses, while 135,072 day-old chicks were placed accordingly in five houses for the tunnel-ventilated facilities. After the brooding stage, 17,196 chickens remained in the conventional facilities, while there were 133,890 chickens in the tunnel ventilated confinement. The final population for the two types of houses come harvest time was 16,890 and 128,567 live chickens, respectively. Table 1 compares the characteristics of the two types of broiler houses.

Table 1. Broiler house design, structure, and management practices

Item	Conventional	Tunnel Ventilated
House floor dimensions width x length (m), capacity per storey, stocking density (birds/m2), number of storeys	11 x 60, 6600, 10, 1 11 x 35, 4000, 10, 1 10 x 48, 5000, 10, 1 10 x 24, 2450, 10, 1	12 x 122, 25000, 17, 1 12 x 122, 25000, 17, 1 12 x 122, 25000, 17, 1 12 x 122, 25000, 17, 1 15 x 137, 32000, 15, 1
Housing type	Elevated, open sided with lumber on concrete columns	Non-elevated, closed housing
Roof type	Corrugated GI sheets without insulation, monitor type with wood trusses	Corrugated GI sheets with insulation, gable/double span type with steel trusses
Floor type	Bamboo slats	Plastic slats mounted on concrete
Sidewalls	None	Concrete or sandwich panel polyurethane
Brooding set-up	Infrared heater or charcoal; coffee hull mounted on double-layer net overlaid on bamboo slats	Direct-fired gas heater; old newspaper overlaid on plastic slats
Ventilation system	Natural ventilation; manual adjustment of tarpaulin curtains	Combination of minimum, transitional, and tunnel ventilation; evaporative cooling pads; exhaust fans; automatic controls
Feeding system	Ad libitum feeding using trough and round feeders	Ad libitum feeding using automatic in-line feeders
Watering system	Ad libitum drinking using galloners and round pan with grills	Ad libitum drinking using automatic in-line nipple drinkers

Inventory analysis. In order to make values comparable, data were normalized per 10,000 birds. The inventory revealed that about 10,553 kg of feeds and 6,343 liters of water were consumed while using 203 kWh of electrical energy were used in conventional production. On the other hand, 8,614 kg of feeds, 18,406 liters water, and 1,127 kWh electrical energy were expended to come up to a same harvest population in the tunnel-ventilated houses. It can be seen in Table 2 that values increased significantly in post-brooding periods as broiler chickens need more feeds and water as they grow.

Electricity consumption did not differ much in conventional poultry houses during the brooding and post-brooding stages. This is because they only rely on natural ventilation to regulate the temperature inside the poultry house. Meanwhile, electricity consumption in tunnel-ventilated poultry houses increased more than double in the post-brooding stage. During this stage, broiler chickens need proper ventilation to lower temperature because their feathers inhibit heat loss. Tunnel-ventilated poultry houses consume higher electrical energy because of the tunnel and sidewall fans, the pump for the evaporative cooling system, the water pump for the drinking line, and another pump for the feeder line, in contrast to the conventional setting where the light bulbs and fluorescent lamps are only the electrical fixtures used during the production since the water and feeds are manually provided to the animals through human labor.

The inventory also shows that about 1,391.02 kg CO_2, 0.1526 kg SO_2, and 0.0096 kg CH_4 were emitted in conventional ventilation settings. On the other hand, 1,488.57 kg CO_2, .1502 kg SO_2, and 0.0088 kg CH_4 were the emissions calculated for the tunnel-ventilated setting. Higher emissions were obtained in the tunnel-ventilated facilities due to more intensified production and electrical equipment use. In conventional poultry houses, the brooding stage has higher CO_2 emissions because of LPG fuel consumption to heat the facility's air. LPG is not used during the post-brooding stage because the animals by that time require cooler temperature as they age. On the other hand, the post-brooding stage in tunnel-ventilated poultry houses still had higher CO_2 emissions despite the non-use of LPG. Higher emission in the said stage is due to the respiration of broiler chickens. Furthermore, it was found that conventional production released 7,916 kg of manure and176,896 liters of wastewater which is lower when compared to tunnel-ventilated production, which released 7,979 kg of manure and 179,254 liters of wastewater.

Results from the laboratory analyses detected that the total N and P in conventional had smaller concentrations, 94.9 mg/L, and 65.3 mg/L, compared with the values in the tunnel ventilated production, which are 368.65 mg/L and 101.72 mg/L, respectively. This may be because lesser manure flows out of the conventional poultry house system than the tunnel-ventilated poultry house. Moreover, this could be attributed to the presence of wastewater in conventional systems, including the water utilized for cleaning bamboo slats or floors, and minimal solid waste because a large part of the bulk volume of the manure passes through the space between the slatted floors and are accumulated on the soil beneath the elevated flooring of the house. In contrast, the wastewater in the tunnel-ventilated system is more concentrated with solid waste as all of the accumulated manure is not released out of the effluent pipe until the last day of harvest.

Table 2 summarizes all the inputs and outputs for broiler production in conventional and tunnel-ventilated poultry houses per 10,000 birds.

Table 2. Inventory of input and output values for broiler production per 10,000 birds.

Input	Conventional	Tunnel Ventilated	Output	Conventional	Tunnel Ventilated
Brooding (Day 1-14)					
Feeds (kg)	2,166	1,892	CO_2 (kg)	862.05	716.85
Water (L)	1,328	5,677	SO_2 (kg)	0.0932	0.0656
Electricity (kWh)	94	311			
Diesel for transportation (L)	99.95	31.09			
LPG (kg)	305.40	185.09			

Input	Conventional	Tunnel Ventilated	Output	Conventional	Tunnel Ventilated
Post-brooding (Day 15-30)					
Feeds (kg)	8,387	6,722	CO_2 (kg)	528.97	771.72
Water (L)	5,015	12,729	SO_2 (kg)	0.0594	0.0846
Electricity (kWh)	109	816	CH_4 (kg)	0.0096	0.0088
Diesel for transportation (L)	118	35.85	Manure (kg)	7,916	7,979
			Wastewater (L)	176,896	179,254
			Total N (mg/L)	94.9	368.65
			Total P (mg/L)	65.3	101.72

Impact analysis. The potential environmental impacts of broiler production for both conventional and tunnel-ventilated poultry houses are presented in Table 3. The results showed that broiler production in the tunnel-ventilated house has higher global warming potential with 40,036.67 kg CO_2 equivalent and acidification potential value of 4.03744 SO_2 kg equivalent because of its higher electricity consumption. Tunnel-ventilated broiler houses consume higher electrical energy because of tunnel and sidewall fans, a pump for the evaporative cooling system, a water pump for the drinking line, and another pump for the feeder line. Meanwhile, in the conventional setting, light bulbs and fluorescent lamps are the only electrical fixtures used during production since water and feeds are manually provided to the animals through human labor.

Higher eutrophication potential in the tunnel-ventilated house is also reported with 2,247.18 kg PO_4^{3-} equivalent, wherein higher concentrations of total N and total P values were present in the wastewater from the tunnel-ventilated house. This implies that broiler production in tunnel-ventilated poultry houses generates higher amount of nutrients that could lead to excessive plant growth and oxygen depletion in the receiving water bodies. In the rapid health impact assessment of a proposed poultry processing plant conducted by Baskin-Graves at al. in 2019, the growth of toxic microorganisms such as *Pfiesteria piscicida* was impelled by eutrophication associated with chicken manure. This microorganism has been found to cause temporary memory loss, immunosuppression, decreased cognitive function in exposed populations, respiratory problems and eye irritation, gastroenteritis, headaches, and fatigue. Excess and N and P can also seep into groundwater during water runoffs and can be highly toxic to fish and humans when dissolved in water due to its high ammonia level (Keena and Meehan 2022). Aside from the eutrophication potential caused by the higher concentration of N and P, it was found in the study of Nowak et al. in 2016 that long-term exposure and inhalation of odorous compounds from wastewater and chicken manure demonstrated marked cytotoxic effects and acute cell damage to people.

Table 3. Environmental impact potentials of broiler production between conventional and tunnel ventilated poultry house.

STAGE	GWP kg CO_2 equiv		EP kg PO_4^{3-} equiv		AP SO_2 kg equiv	
	Conventional	Tunnel Ventilated	Conventional	Tunnel Ventilated	Conventional	Tunnel Ventilated
Brooding	3,104.95	19,365.33	151.81	2,247.18	0.335815	1.77185
Post-Brooding	1,883.61	20,671.33			0.21148	2.26559
Total	4,988.56	40,036.67	151.81	2,247.18	0.547295	4.03744
Equivalent per harvested live chicken	0.30	0.31	0.01	0.02	3.240e-05	3.140e-05

Note: GWP (global warming potential); EP (eutrophication potential); AP (acidification potential)

In order to make the values comparable, the equivalents per harvested live chicken were computed. The tunnel-ventilated system was also higher in terms of the equivalent GWP and EP per harvested live chicken with 0.31 kg CO_2 equivalent and 0.02 kg PO_4^{3-} equivalent, respectively. Interestingly, it can be noticed that conventional production had higher AP per harvested live chicken with 3.240e-05 SO_2 kg equivalent because of the higher amount of LPG fuel consumed per bird during the brooding period using such type of ventilation. Higher acidification potential leads to acidic deposition, which acidifies the soil, surface waters, and groundwaters and affects nutrient cycling. The sulfur accumulation in the soil can reduce plants' potential uptake of nutrients and water. High acidity can also reduce the diversity and abundance of aquatic species in nearby waters. Aside from the discharge of very acidic groundwater, it can also cause water pipes corrosion, leading to leakage and high heavy metal content in drinking water. Nevertheless, there is very little difference between the equivalent GWP, EP, and AP per harvested live chicken between the two types of poultry houses. It must be noted that these values can only be applied to the specific design of poultry houses and management practices mentioned in Table 1 with consideration to the climatic condition of the Philippines.

The percent contribution to the environmental impact potentials is shown in Table 4. In conventional poultry houses, the brooding stage has a higher GWP (62.24%) because of the consumption of LPG fuel to heat up the air inside the facility. LPG is not used during the post-brooding stage because the animals by this time require cooler temperatures as they age. On the other hand, the post-brooding stage in tunnel-ventilated poultry houses still had higher GWP (51.63%) despite the non-use of LPG during the brooding stage. Higher GWP in the said stage is due to high electricity consumption.

Moreover, methane emission from manure management was only accounted for in the post-brooding stage. The volume of manure generated by broiler chickens in tunnel-ventilated poultry houses was very high compared to its counterpart. This also adds up to higher GWP in the post-brooding stage of broiler production in tunnel-ventilated houses. Regarding the acidification potential (AP), the brooding stage in the conventional poultry house also had a higher value (61.36%). Again, this is due to the consumption of LPG during the said stage. On the other hand, higher AP (56.11%) in the post-brooding stage in the tunnel-ventilated system is due to its high electricity consumption. The percent contribution per stage of the eutrophication potential was not computed since laboratory analyses of water samples were done only on the last day of harvest.

Table 4. Percent contribution to the environmental impact potentials

Stage	**GWP kg CO_2 equiv**		**AP SO_2 kg equiv**	
	Conventional	**Tunnel Ventilated**	**Conventional**	**Tunnel Ventilated**
	Percent			
Brooding	62.24	48.37	61.36	43.89
Post-Brooding	37.76	51.63	38.64	56.11

Interpretation. The environmental characterization of broiler production in conventional and tunnel-ventilated poultry houses identified the stage with the highest contributions to the selected impact categories. For the conventional poultry house, the brooding stage has the highest global warming potential and acidification potential due to the consumption of LPG. On the other hand, broiler chickens production in tunnel-ventilated poultry houses showed the highest global warming potential and acidification potential during the post-brooding stage due to its high electricity consumption. The highest eutrophication potential was seen in broiler production in tunnel-ventilated poultry houses due to the release of higher volumes of wastewater with more concentrated solid waste.

Given these findings, improvements should be made to minimize the use of electricity and LPG. Renewable energy sources like solar energy, one with the highest potential among the renewable sources, can be considered to reduce emissions. Solar energy can be used to convert solar radiation into electricity using photovoltaic (PV) technology. This can be done by mounting solar panels on the roof of poultry houses. This technology can be a supplemental source of electricity for lighting and ventilation system. In the study conducted by Cui et al. in 2020, it was said that PV technology could provide 70 percent electricity savings and a reduction of CO_2 emissions of 6.23 tons annually. In 2017, a local poultry farm raising 36,000 heads of chicken per production cycle in Pangasinan was given financial assistance of P2 million by the Department of Science and Technology (DOST) to buy and install 50 solar panels that would generate power for the poultry farm. These solar panels could sustain the power needs of up to 50,000 heads of chicken per production cycle.

On the other hand, solar energy can be converted into thermal energy using solar collector technology to reduce the use of LPG during the brooding stage. The solar collector absorbs direct solar radiation, which is then converted into thermal energy. Thermal energy is stored in sensible heat, latent heat, or a combination of sensible and latent heat. The solar air heater system uses stored energy to pre-heat ventilation air to warm poultry houses (Zhang and Zhu 2022).

High electricity consumption can also be minimized by considering custom-designed poultry houses in terms of their orientation to the sun and the use of buffers like shade trees, shrubs, and ground cover plants. This can somehow control physical factors like temperature, humidity, solar radiation, and air movement, which can minimize the use of electrical fixtures to control indoor conditions. This can also contribute to the alleviation of heat stress which affects the mortality of broiler chickens.

Since poultry houses generate a high volume of manure, it can also be considered a secondary renewable energy source. Bird's manure can be converted into biomass energy by obtaining methane using an anaerobic digester. Using anaerobic digestion technology to produce methane from manure waste can also reduce total N and P from wastewater discharges, minimizing its eutrophication potential. Composting can also be done to minimize eutrophication potential. Composted manure releases nutrients slowly which causes less N and P to enter surface water and groundwater. Composting also eliminates pathogens that can harm broiler chickens' health. Higher mortality rates caused by these pathogens can lead to economic losses. Another method that can prevent animal waste from coming into contact with runoff and water sources is the creation of clean water diversion. This can be done by establishing rain gutters and downspouts, earthen ridges or diversion terraces, and the installation of a catch basin. These can keep precipitation runoff clean by directing precipitation away from the manure.

High water consumption was also observed in broiler production for both types of houses. In order to reduce its dependence on municipal water systems, which will also minimize its water bills, rainwater harvesting can also be considered. Another measure to improve the environmental performance of broiler production should deal with more efficient water quality management, such as wastewater treatment. It was observed that wastewater from the poultry farm was not treated before disposal. On the other hand, adding adsorbents like activated carbon, silica gel, and zeolite to the bedding materials can also reduce the odor emitted by poultry manure.

These technologies can be considered to minimize the environmental impact of broiler production. Since there are only slight differences in the values of the environmental impact potentials, these recommendations can be made to equalize the impacts of both poultry houses further. However, a further study on its cost-effectiveness and efficiency may need to be conducted to know its sustainability.

SUMMARY AND CONCLUSION

A comparative analysis of broiler production between conventional and tunnel-ventilated poultry houses was conducted in General Aguinaldo, Cavite. Life cycle assessment was done to evaluate the environmental performance of both types of poultry houses. The system boundary of the study is the operation involving broilers from brooding to post-brooding. Inventory of the material and energy input and output was conducted through direct measurements, interviews of key informants, and secondary data. The impact analysis was done using the results of the inventory. The environmental impacts include global warming potential, eutrophication potential, and acidification potential. The impact potentials were analyzed based on the functional unit per harvested animal.

The inventory analysis revealed that producing 10,000 broiler chickens in the conventional poultry house required 10,553 kg of feeds, 305.40 kg of LPG, 217.95 liters of diesel, 6,343 liters of water, and 203 kWh of electrical energy. It generated 1,391.02 kg CO_2, 0.1526 kg SO_2, and 0.0096 kg CH_4, 7,916 kg manure, and 176,896 liters of wastewater containing 94.9 mg/L of nitrogen, and 65.3 mg/L of phosphate. On the other hand, the production in the tunnel-ventilated poultry house required 8,614 kg of feeds, 185.09 kg of LPG, 66.94 liters of diesel, 18,406 liters of water, and 1,127 kWh of electrical energy. The process 1,488.57 kg CO_2, .1502 kg SO_2, and 0.0088 kg CH_4, 7,979 kg of manure, and 179,254 liters of wastewater containing 368.65 mg/L of nitrogen and 101.72 mg/L of phosphate.

The inventory analysis showed that broiler production with the tunnel-ventilated house had higher GWP and AP values because of its higher electricity consumption. Higher eutrophication potential in the tunnel-ventilated house is also reported because its wastewater is more concentrated with solid waste, as all of the accumulated manure is not released out of the effluent pipe until the last day of harvest.

In conventional poultry houses, the brooding stage has higher GWP (62.24%) and AP (61.36%) because of the consumption of LPG fuel to heat the air inside the facility. On the other hand, the post-brooding stage in tunnel-ventilated poultry houses still had higher GWP (51.63%) despite the use of LPG during the brooding stage. Higher GWP in the said stage is due high electricity consumption. Similarly, higher AP (56.11%) in the post-brooding stage in the tunnel-ventilated system is also due to its high electricity consumption.

The tunnel-ventilated system was also higher in terms of the equivalent GWP and EP per harvested live chicken. Interestingly, it can be noticed that conventional production had higher AP per harvested live chicken because of the higher amount of LPG fuel consumed per bird during the brooding period using such type of ventilation. However, there is very little difference between the equivalent GWP, EP, and AP per harvested live chicken between the two types of poultry houses. It must be noted that these values can only be applied to the specific design of poultry houses and management practices mentioned in the study with consideration of the climatic condition of the Philippines.

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