science, engineering and health studies

Research Article

Science, Engineering and Health Studies
https://li01.tci-thaijo.org/index.php/sehs
ISSN (Online): 2630-0087

Overview on the potential of renewable energy generation in poultry farms: A case study in the Manjung Region, Malaysia

M. Devendran Manogaran[1,2], *Rashid Shamsuddin*[3*], *Khai Zhi Yeow*[1], *Jun Wei Lim*[4,5], *Mohd Hakimi*[1], *and Ahmer Ali Siyal*[6]

[1] Chemical Engineering Department, Faculty of Engineering, Universiti Teknologi Petronas, Seri Iskandar, Perak 32610, Malaysia
[2] Centre of Carbon Capture, Utilisation and Storage (CCCUS), Institute of Sustainable Energy and Resources, Universiti Teknologi Petronas, Seri Iskandar, Perak 32610, Malaysia
[3] Department of Chemical Engineering, Faculty of Engineering, Islamic University of Madinah, Madinah 42311, Saudi Arabia
[4] HICoE-Centre for Biofuel and Biochemical Research (CBBR), Fundamental and Applied Sciences Department, Faculty of Science and Information Technology, Universiti Teknologi Petronas, Seri Iskandar, Perak 32610, Malaysia
[5] Department of Biotechnology, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai 602105, India
[6] Micropollutant Research Centre (MPRC), Institute for Integrated Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor 86400, Malaysia

***Corresponding author**:
Rashid Shamsuddin
r.shamsuddin@iu.edu.sa

***Received**: 27 September 2023*
***Revised**: 19 June 2024*
***Accepted**: 2 July 2024*
***Published**: 14 October 2025*

***Citation**:*
Manogaran, M. D., Shamsuddin, R., Yeow, K. Z., Lim, J. W., Hakimi, M., & Siyal, A. A. (2025). Overview on the potential of renewable energy generation in poultry farms: A case study in the Manjung Region, Malaysia. Science, Engineering and Health Studies, 19, 25040003.

ABSTRACT

Poultry farming in the Manjung region of Malaysia is constantly expanding to accommodate the country's increase in protein intake. Consequently, poultry farming is facing problems such as high usage of energy and carbon emissions from waste due to a lack of energy alternatives and poor waste management. The purpose of this study is to evaluate the economic feasibility of introducing biogas and solar energy as an alternative energy source in broiler houses. The effectiveness of green energy to sustain the daily operations in the poultry farm was evaluated by calculating and comparing the energy generation from the aforementioned sources, thus reducing dependence on the national power grid and having more affordable, sufficient and environmentally benign energy. For the biogas production, waste from the poultry farms was anaerobically digested to produce methane and carbon dioxide and later methane was used to produce energy through combustion. On the other hand, solar energy was trapped via the photovoltaic modules and converted into electricity which could be used for lighting and ventilation in the poultry farm. Each cycle of biogas production depicted the potential amount of electricity generation at 27,452.04 kWh, which had a surplus of 15,522.04 kWh per cycle. By installing a 100-kW solar system in 25% of the total roofing area of broiler houses in Manjung, with the capacity of producing 12,000 kWh per month when optimal angle of installation of solar panel is achieved, a 5% grid consumption reduction through photovoltaic would be obtainable. This approach has the potential to advance the circular economy within the poultry industry, while also promoting the adoption of carbon-neutral farming practices.

Keywords: chicken manure; biomass conversion; biogas; solar power; electricity generation

1. INTRODUCTION

The poultry industry is constantly growing in the Manjung region, Malaysia to fulfil the protein meat demand of Malaysians, which has increased by 53.83% over the last thirty years (Khairul Amri Kamarudin et al., 2018). As such, the Manjung poultry industry is accountable for 10% of the total national broiler production leading to chicken manure generation in abundance. Consequently, the fresh manure is sold as organic fertilizer for as low as RM 3 per 30 kg to the local farmers in the area (Singh et al., 2018). This norm results in a widespread flies' problem and potential pathogens' propagation concern in the region; both of which are identified as health hazards. Additionally, the raw manure's high nitrogen content makes it susceptible to runoff and groundwater leaching, adversely affecting marine ecosystems (Manogaran et al., 2022b). Overall, the conventional norm for disposal of chicken manure jeopardizes the quality of life in nearby residential areas.

The nutrient-rich chicken manure, however, presents an excellent opportunity for circular economy application and value creation through anaerobic digestion (AD) (Siyal et al., 2023). In fact, AD has become a much talked-about strategy for organic waste treatment due to its significant potential for biogas energy generation (Farobie et al., 2023). Additionally, it is imperative to note that AD caters well to the high moisture content of poultry manure as compared to other circular economy-based treatment methods like pyrolysis and gasification (Manogaran et al., 2022a). It is also vital to note that in the case of AD of chicken manure, the mesophilic temperature conditions have been identified as optimal based on a study by Manogaran et al. (2023). Such circumstances indicate that the process does not require additional heating or cooling attributed to its geographical advantage. Furthermore, Malaysia's year-round sunshine offers a viable renewable energy alternative in the form of solar power. In fact, solar energy plays a pivotal role in Malaysia's Energy Transition Plan 2021–2040 which aims to increase the installed renewable energy capacity target to 40% by 2035 as stated by Tee et al. (2024).

The Manjung poultry industry is well-equipped to support these efforts considering its 14 million steady-state chicken population producing 1,400 tonnes of manure daily (Hakimi et al., 2021a). This translates to large amounts of land dedicated to broiler farms to house these chickens. The three primary environmental associated concerns for broiler farm operations are energy use, hazardous gaseous emissions, and manure management. Energy use is a large fraction of the cost due to the feeding, ventilating, lighting, and heating operations (Costantino et al., 2018), resulting in higher operational costs. Consequently, the increasing reliance on fossil fuel driven energy and concerns on energy security urge a paradigmatic shift to renewable energy options. Thus, with respect to the resources' availability and the geographical edge of the Manjung region in Malaysia, biomass harnessing and solar energy are missed opportunities that need to be further explored. In fact, capitalizing on biomass energy from AD of chicken manure essentially aids in addressing the issue associated with improper chicken manure disposal.

The framework of this study entails the potential of energy generation from AD of broiler manure and the sun via the design of a broiler house with solar panels installed on the rooftop. To the best of the authors' knowledge, a comprehensive case study evaluating the potential of energy generation from organic waste produced in poultry farms, alongside solar energy to meet the energy demands of the broiler farms has not been explored. Accordingly, the significance of this work lies in its real-life applications whereby stakeholders from poultry industries can adopt the design of the smart broiler house with solar panels, thereby reducing reliance energy from the national power grid.

2. MATERIALS AND METHODS

2.1 Data collection

The data necessary for modelling was acquired from resources such as news articles, journals, and theses. Data collection involves parameters required for computation of energy acquisition through both forms of renewables. In terms of biogas production, the independent variables needed were the amount of manure produced in the broiler houses, time, and energy generation from biogas production. The independent variables needed for solar energy were time, intensity of solar radiation and generation of energy.

The data for the number of chickens, area of broiler house and amount of electricity used in the year 2021 were obtained from Dindings Poultry Development Centre Sdn Bhd, which is the leading industry in Malaysian poultry operations (Dindings Tyson, 2021). To have a better overview of the geographical distribution of the broiler, a population map of the broiler houses in the Manjung region was obtained from the Veterinar Service Department, Ipoh (Hakimi et al., 2021b). In terms of solar energy, specifications on the solar panels such as the average area, power and energy generation were collected from established solar panel providers such as Solar Choice, SEDA. Furthermore, the dimensions of a typical broiler house were sketched to have a more accurate calculation and prediction for the number of solar panels that could be installed. As the number of solar panels increases, the amount of electricity that can be generated through solar power increases as well, thus providing a way to estimate the amount of electricity generated for the broiler house. Figure 1 shows a sketch of how the solar panels would be installed to a broiler house.

Based on a study report done by Bryne et al. (2005) on the electricity requirement for poultry farms in Delaware, an average broiler house is equipped with electrical appliances that require up to 15.5 kW. Ventilation accounts for 82% of the electricity consumption, lighting accounts for 13%, and feed lines account for 5%. The data for average usage of electricity and appliances used in a broiler house is as shown in Table 1. The broiler house employs a scheme that ranges from full 24 hours of lighting daily for the first five days while the final week of the cycle calls for 14 h of lighting daily when the birds are in their first week of age.

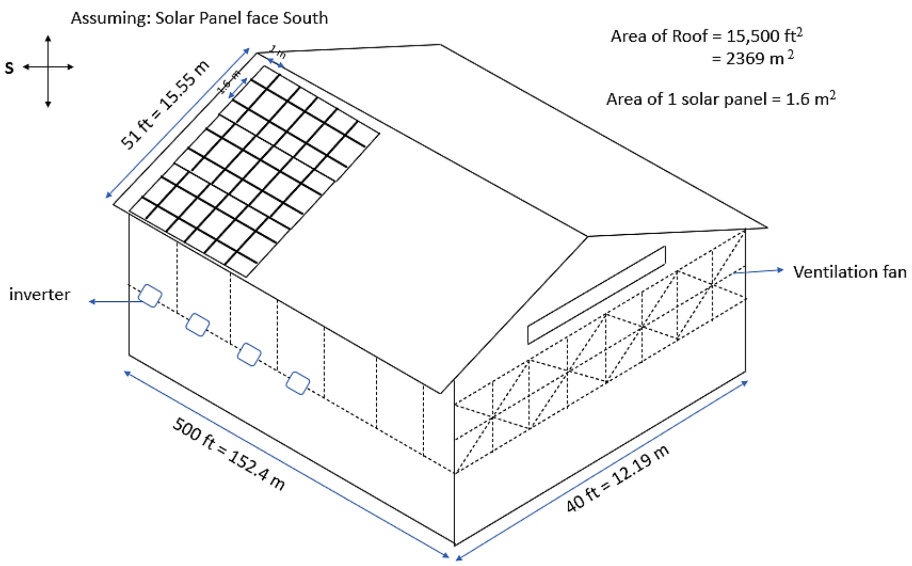

Figure 1. Sketch of broiler house with solar panel installed south oriented

Table 1. Electrical usage for a single broiler house

Device	Number	Voltage	Power (watts)	Total watts
Sidewall fans	5	240	580	2,900
Tunnel fans	8	240	1,235	9,880
Lighting	64	120	25	1,600
Feed line motors	2	240	600	1,200
Total				15,580

2.2 Data analysis

Data collected were analyzed by determining the effect of the manipulated parameters, namely energy requirement of the broiler house, time, waste production by the broiler house for biogas generation and intensity of solar radiation. Data on the amount of biogas produced, amount of chicken, amount of chicken manure and time were further studied to understand their relationship for the biogas energy generation. Constant variables which may affect the calculations such as the calorific value of biogas were studied as well.

In terms of solar energy, data such as the sizing of the broiler house, area of roof, area of solar panel, amount of solar radiation and solar panel power were studied before proceeding to the next step which was the energy generation analysis.

The potential quantity of energy that can be generated by AD was estimated using Equations 1–4. According to Catarino et al. (2009), the biogas capacity for poultry litter is 0.1576 m^3/kg, with a calorific value of 6.21 kWh/m^3 and a biogas to power/electricity conversion efficiency of 25%, resulting in a calorific value of 1.55 kWh/m^3. The bedding substance used for manure gathering (rice husk or sawdust) was also considered. Carbon additives are beneficial to the AD system because they enhance biogas generation (Hakimi et al., 2021a). Using this data, Equations 1–4 were used to calculate the predicted energy generation potential of chicken manure feedstock (including bedding material) for one cycle of poultry farming.

$$B = m * P_b \tag{1}$$

where:
B = biogas total (m^3)
P_b = potential of biogas (m^3/kg) = 0.1576 m^3/kg
m = total mass of chicken manure (kg)

Equation 2 was used for the estimation of the electricity generated over the span of 60 days by multiplying the total amount of biogas produced with the energy potential of 1.55 kWh/m^3 (Catarino et al., 2009).

$$E = B * P_{cr} \tag{2}$$

where:
E = electric energy (kWh)
B = biogas total (m^3)
P_{cr} = energy potential value of biogas (kWh/m^3) = 1.55 kWh/m^3

With this average calorific value of 11.25 MJ/kg, the Manjung region's gross energy potential was estimated via Equation 3. The technical energy potential of poultry litter was calculated through Equation 4 with the assumption of 60% of average efficiency (Oliveira et al., 2012).

$$PB = \frac{m * P_c}{k} \tag{3}$$

where:
PB = gross energy potential (MW)
m = biomass amount in one year
P_c = average calorific value of poultry litter (MJ/kg) = 11.25 MJ/kg
K = seconds in one year = 31,536,000 s

$$PT = PB * n \tag{4}$$

where:
PT = technical energy potential (MW)
PB = gross energy potential (MW) = 44.5 MW
N = efficiency of conversion system = 30%

On the other hand, the output and dimensions of an average solar system along with the available area for solar system instalment was taken into consideration for the calculation of solar energy generation.

3. RESULTS AND DISCUSSION

3.1 Electricity and energy potential generation from biogas

For each 60-day cycle, the chicken manure production in the Manjung region is about 112,379.4 kg, with potential biogas generation of up to 17,710.99 m^3, based on Equation 1 (Oliveira et al., 2012). With the biogas yield of 17,710.99 m^3, it is possible to generate up to 27,452.04 kWh based on the energy potential of biogas (1.55 kWh/m^3).

Generally, the electricity consumption per cycle is approximately 11,930 kWh. This means that the energy demand by the broiler house can be satisfied each cycle with a surplus of 15,522.04 kWh. On a yearly basis, the Manjung poultry industry produces approximately 124,740,000 kg of poultry litter which can be translated to a gross energy potential of 44.5 MJ/s, or 44.5 MW based on the calorific value of poultry litter.

Poultry litter exhibits significant potential to be utilized as an energy source in turbine-powered steam engines. In previous research, the technical energy capacity of poultry litter was estimated to be around 13.35 MW, assuming 30% average efficiency. Table 2 summarizes the technical energy potential of the Manjung area.

Table 2. Technical energy potential in Manjung area

Element	Unit	Value
Number of broiler houses	Number	185
Number of chickens	Number	5.5 million
Amount of chicken litter in one year	kg	124,740,000
Average calorific value	MJ/kg	11.25
Gross energy potential	MJ/year	1,403,325,000
	MW	44.5
Efficiency of conversion system	%	30
Technical energy potential	MW	13.35

A similar study done was conducted by Oliveira et al. (2012) in Brazil based on the poultry industry in the city of Treviso, Southern Santa Catarina, Brazil which houses an average of 22,000 chickens per batch. Table 3 summarizes the technical energy potential derived from chicken litter in the Santa Catarina state.

Table 3. Technical energy potential to Southern Santa Catarina state

Element	Unit	Value
Number of aviaries	Number	1,035
Number of chickens	Number	24,056,866
Amount of chicken litter in one year	kg	316,107,219.24
Average calorific value	MJ/kg	11,25
Gross energy potential	MJ/year	3,556,206,216
	MW	112,8
Efficiency of conversion system	%	30
Technical energy potential	MW	34

Using the case study as a reference for calculation, and considering the substantial quantity of chicken litter produced in the Manjung region, it is evident that the potential energy generation through biogas production is significantly higher. This suggests that the biogas energy could sustain the daily operation of the poultry farms across the entire region.

3.2 Solar energy generation

Several commercial PV makers are working on PV systems for the poultry farming industry. These systems include PV panels, a charge controller, an inverter to change DC power to AC current, and a battery system. PV panels could be readily attached to poultry shed roofs. Those facing south will receive the most solar insolation; the optimal angle of the panel changes based on latitude and whether winter or summer optimization is desired.

A standard modern broiler house is 500 ft long and 66 ft broad. These larger structures require more energy, especially for heating, cooling, and ventilation. Typically, energy efficiency is not taken into consideration during planning and construction of these structures. Implementing energy efficient and conservation steps helps to decrease energy consumption. Conservation and efficiency are expected to save up to 20% of the energy used in poultry production (Bryne et al., 2005).

A 100-kW system appears to be optimal for the typical broiler house's electricity needs. A 100-kW solar system has 400 PV panels of 250 W (Tan & Chow, 2016). Each panel is approximately 1.6 m x 1 m in size, thus at least 656 m^2 of roof space is required. A PV array with this capacity is approximately 7,061.13 ft^2 in size. Poultry farms typically have more than 25,500 ft^2 of rooftop space (Bryne et al., 2005). The estimated PV system installation cost varies depending on the manufacturer and type of PV system. This 100-kW microinverter requires roof space whereby the solar panels take up approximately 7,061.13 ft^2. Fortunately, with microinverters, modules can be placed anywhere and do not need to be grouped together. A 100-kW solar kit produces 100-kW of direct current power which can generate an estimated 12,000 kWh of AC power per month, assuming at least 5 h of sunlight per day and the solar array facing south. For maximum solar power output, an unobstructed south-facing view of the sun is required (Rhodes et al., 2014). Assuming the maximum roof space of the broiler house can accommodate 4 pieces of 100-kW solar system, the solar system can potentially produce 48,000 kWh per month, which is more than the average electricity usage of a typical broiler house.

Manjung has approximately 185 broiler houses spread across the region. Assuming that one-quarter of these houses have a roof facing south, approximately 47 houses can receive the maximum solar energy. The Manjung poultry growers would have a total peak generating capacity of 4,700 kW of PV if each of these 47 houses installed a 100-kW PV array (i.e., 47x 100-kW) and 18,800 kW if maximum roof capacity was used.

The average broiler house uses about 71,580 kWh of electricity per year. As a result, Manjung's 185 broiler houses consume approximately 13.24 GWh. If 4,700 kW of PVs were installed in the poultry farm sector (47 houses x 100-kW), this would provide 6,768 MWh of renewable energy per year, reducing grid electricity reliance by up to 5%. Each of the 185 broiler homes has a peak demand of 15.6 kW, for a total peak demand of 2.886 MW. Under the aforementioned conditions, the installed PV would have a peak value of 4,381 kW and could decrease peak grid energy use in the sector by up to 0.16%. It is also worth noting that the highest demand for broiler houses is 38.5 MW, which is considerably higher than the average load of 8.2 MW (i.e., 71,580 kWh per year divided by 8,760 h per year). PV systems have the potential to cut average load needs by 38%. Table 4 summarizes the effects of PV installation on grid consumption and demand in the poultry sector.

3.3 Feed in tarif (FiT) for biogas and solar PV

According to the data collected from the management of the broiler house, it can be said that generally, the electricity demand per cycle is approximately 11,930 kWh, which is equivalent to RM 5,365 per cycle. In terms of the potential electricity generation from biogas in one cycle, assuming that an average broiler house holds 29,730 chickens, the potential amount of electricity that can be generated via the production of biogas using chicken manure as the feedstock is around 27,452.04 kWh per cycle. If this were to be multiplied with the number of cycles in a year (6 cycles), the potential electricity generation via biogas production is equivalent to 164,712.24 kWh per year. This shows that there is a surplus of 93,132.24 kWh per year. Other than consuming the electricity being produced for personal usage, the owner of the broiler house has the option of selling the electricity generated to certain organizations such as Sustainable Energy Development Authority (SEDA) Malaysia as FiT. FiT is a program that allows stakeholders to generate their own electricity and sell it to the national power grid. Table 5 indicates the FiT rate for the category of biogas in agriculture waste for non-individual projects less than 500 kW. According to the rates given by SEDA (2019), based on the highest rate for each kWh generated including bonus FiT rate, RM 0.41 could be generated for each kWh sold. Assuming all the surplus electricity generated is sold, a broiler house has the potential to gain a total of RM 38,184.22 every year, and this could act as a passive income for the farmers.

Table 4. The effects of PV on poultry industry grid consumption and demand

Annual electricity consumption (MWh)	**13,242.3**
Annual PV systems production (MWh)	6,768
Grid consumption reduction through PV use (%)	5
Peak demand (MW)	**2.886**
Peak generation of PV system (kW)	4700
Peak demand reduction through PV use (%)	0.16

Table 5. FiT rate for biogas (landfill/agricultural waste) (SEDA, 2019)

Biogas (landfill/agricultural waste)	**FiT rate (RM/kWh)**
Basic FiT rates having installed capacity of:	
Up to and including 5MW	0.2210–0.2814
Bonus FiT rates having the following criteria (one or more)	
Use of locally manufactured or assembled gas engine technology	+0.0500
Use of landfill, sewage gas or agricultural waste including animal waste as fuel source	+0.0786

In terms of solar energy generation, the broiler house must install a 100-kW solar power system, which potentially generates a total of 12,000 kWh per month while satisfying the criteria of having at least 5 h of sunlight per day and the solar array facing south for maximum generation. This leads to a total of 144,000 kWh per year generated via the solar PV system. With the help of the solar system, a broiler house can potentially have a surplus of 72,420 kWh energy per year. Table 6 indicates the FiT rate for the category of solar PV for non-individual projects less than 500 kW, which started from the 1st January 2020. With the amount of surplus electricity generated, according to the rates given by SEDA (2019), a broiler house has the potential of gaining a total of RM 0.57 per kWh sold, assuming that all the surplus electricity is being sold with the highest rate for each kWh generated, thereby fulfilling all the criteria above including the bonus FiT rate. Consequently, a total of RM 40,953.51 could be generated with the surplus electricity generated through the solar power system.

Table 6. FiT rate for solar PV (non-individual less than 500 kW) (SEDA, 2019)

Solar PV (non-individual less than 500 kW)	**FiT rate (RM/kWh)**
Basic FiT rates having installed capacity of:	
Above 72 kW and up to including 1 MW	0.3096
Bonus FiT rates having the following criteria (one or more)	
Use as installation in building or building structures	+0.1017
Use as building materials	+0.0542
Use of locally manufactured or assembled solar PV modules	+0.0500
Use of locally manufactured or assembled solar inverters	+0.0500

As such, the intent of this study is to highlight the potential of harnessing biogas and solar energy to supplement the electricity requirement of a broiler house such that the reliance on fossil fuel driven energy is alleviated. To fulfil this purpose, a holistic, conceptual framework was applied governed by a series of relevant calculations with sound assumptions. The findings from this study are especially crucial to draw the attention of primary stakeholders, essentially poultry farmers, to invest in renewable alternatives which significantly reduce their operation costs. Additionally, the framework of this study does not call for a centralized collection point for the chicken manure which means that there are no additional costs required for transportation and wages. This is also beneficial for the environment as this measure further reduces the carbon footprint inflicted by poultry farms. Instead, the proposed solution recirculates the chicken manure to anaerobic digesters built-in the broiler houses for biogas energy generation. Meanwhile, the copious rooftop space of the broiler houses is purposefully aligned with PV modules, contributing to solar energy harness which further reduces dependence on the external energy supply. Surplus energy can also be sold to the national power grid, generating side revenue for the poultry farms.

This study also shows that by introducing green energy through biogas and solar energy, it could help overcome the issue of grid dependant energy in the poultry industry. Through biogas and solar energy, a surplus of electricity can be generated throughout the poultry farms which could help sustain the energy consumption daily and make a profit for the farmers through the FiT programme. On the other hand, the crisis of waste management in poultry farms can be dealt with through biogas production using the waste as energy resources.

4. CONCLUSION

By introducing green energy through biogas production and solar energy to the poultry industry in the Manjung region, the crisis of energy shortage for operations in broiler houses such as lighting, ventilation and heating can be overcome. Through biogas production, 27,452.04 kWh of electricity could be produced, which is more than the electricity consumed in a broiler house during each cycle. Furthermore, through solar energy generation by installation of a 100-kW solar energy system in a quarter of the broiler houses in Manjung, a 5% grid consumption reduction could be achieved. Furthermore, assuming all criteria were achieved, the surplus of the electricity being produced in a broiler house could be sold through the FiT program, which could generate a total profit of RM 38,184.22 and RM 40,953.51 from biogas production and solar energy respectively. Future work should consider incorporating other forms of green energy alternatives, such as wind energy, to sustain the daily operations in poultry farms. Furthermore, different data of poultry farms could be obtained and undergo analysis to provide a more thorough understanding on the potential of renewable energy usage in poultry farms in Manjung. Economically, details such as capital expenditure and operating expenditure for the operations could be considered in future work to have a better view on the limitations and potential of implementing biogas and solar energy in poultry farms. Experiments could be done to have a better understanding of the characteristics of the chicken manure such as the effect of the carbon–nitrogen ratio on methane production.

ACKNOWLEDGMENT

The authors acknowledge Dindings Poultry, Manjung for providing industrial data on broiler operations.

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