# Life cycle analysis on energy generation via anaerobic digestion of chicken manure

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**Abstract.** Fossil fuels are the primary reservoir of Malaysia's energy supply hence, the government and major stakeholders are looking into renewable means for energy generation. Chicken manure on the other hand is an abundant biomass waste as chicken is the second most staple food item in the country after rice. Thus, green energy generation via anaerobic digestion of chicken manure is an option. The motivation behind this research is to dismiss claims that green energy generation is more detrimental to the environment compared to the conventional fossil fuel driven approach. A Life Cycle Analysis comprising of Life Cycle Inventory and Life Cycle Impact Assessment was conducted using Microsoft Excel to evaluate the environmental constraints of energy generation via anaerobic digestion specifically in the global warming, eutrophication, and acidification potential impact categories. The findings revealed that the global warming potential is up to 832248.183 kg $CO_2$ equivalents (eq), outweighing the concern of the other two impact categories. This is because carbon dioxide is the main greenhouse gas emitted during the process primarily due to poor management of chicken manure at the broiler house. Thus, recommendations were put forth in terms of introducing other practices parallel to anaerobic digestion such as composting and gasification which also yield value added products.

## Introduction

The steady growth in the nation's population has resulted in enhanced energy demand. The main challenge put forward by such circumstances is the high dependency on fossil fuels derived energy, up to 92.31 % in the year 2020 [1]. Accordingly, there is a relevant demand for more renewable energy reservoirs which prevents any rising issues associated to energy security. One approach to better invest in renewable energy reservoirs is by adopting circular economy practices instead of the linear economy norm [2]. This means that any form of waste or by-product from the process is recycled to some extend in consecutive cycles of the similar process or is incorporated elsewhere for other applications.

Chicken manure which is been produced in abundance as of lately due to the popularity of chicken meat as a source of protein [3], is oftentimes misused as organic fertilizer without any form of pre-treatment [4]. This normalized practice observes adverse effects to the environment particularly in the form of enhanced greenhouse gas (GHG) emissions which contradicts with the Sustainable Development Goals (SDG) established by the United Nations in 2015, especially SGD 13 which aspires to solve the issue of climate change. On the contrary, chicken manure exhibits potential as feedstock for multiple waste-to-wealth treatment methods such as composting, pyrolysis and gasification [5] however, anaerobic digestion (AD) specifically has been receiving substantial attention. This is because such efforts are in line with the 12th Malaysia plan which observes the nation making a progressive shift to be carbon-neutral by the year 2030. Consequently, renewable energy derived from solar, biomass and biogas specifically will be put at the forefront [6].

Life Cycle Assessment (LCA) is a holistic, standard means of evaluating the environmental burdens of new products or technology designs by distinguishing the energy, consumables and emissions released to the surrounding [7]. Additionally, LCA is also a method of assessing the GHG emissions of different technologies associated to the desired outcome hence, aiding the identification of environmentally preferred technologies [8]. This paper evaluates the environmental constraints for biogas generation via AD of chicken manure primarily on global warming potential (GWP).

## Methodology

The research is executed by firstly defining the goals and scope, followed by the Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and finally the results' interpretation as depicted in Figure 1.

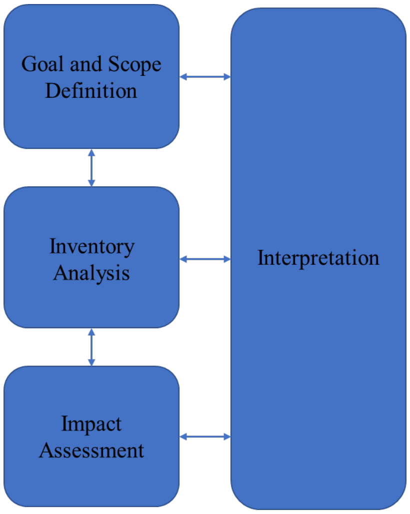

*Figure 1: Life Cycle Assessment (LCA) workflow [9].*

Define Goal and Scope. The items that need to be defined are the functional unit and the system boundary. The functional unit is defined as 30000 units of chickens in a broiler house with the duration of one cycle defined as 30 days. The system boundary is as shown in Figure 2.

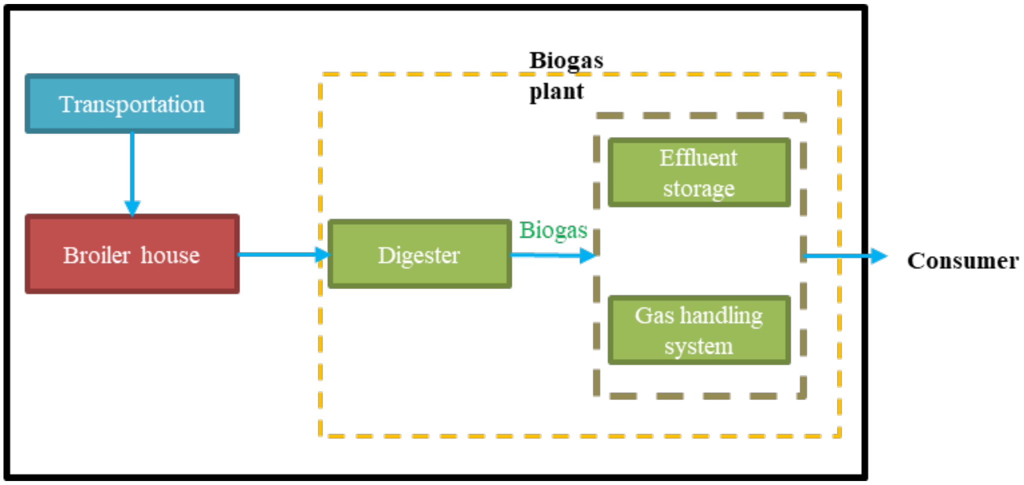

*Figure 2: System boundary outlined in black marker for the study.*

Life Cycle Inventory (LCI). Essentially, the LCI stage involves an inventory of input and output flows for a biogas production which revolves around data associated to the operations of the broiler house and biogas plant. Use of water, energy and raw materials are a few examples of the inputs whereas emission released to the air or leachates in the soil and water bodies are considered as outputs with respect to the system boundary [10]. The inventory data can be acquired from literature study primarily from journal articles. Additionally, statistical data associated to the operations of the poultry house and chicken production were obtained via personal contact from Dindings Poultry Processing Sdn. Bhd. (DPP). The data comprises of the total number of chickens, generation of chicken manure as well as energy consumption for heating and electricity supply. Journal articles on the other hand were used as reference to estimate the hazardous emissions within the system boundary [11].

Life Cycle Impact Assessment (LCIA). The consecutive step is to perform LCIA utilising the inventory database acquired in LCI with respect to the system boundary. First and foremost, the impact categories to be evaluated within the system boundary need to be defined. Impact categories aid in screening the different emissions to observe which exhibits the most prominent effect on the environment. Accordingly, the different emissions are integrated into one representative unit with respect to a characterization factor. For instance, in the GWP impact category, the different emissions are expressed as kg $CO_2$ equivalents (kg $CO_2$-eq). The kg $CO_2$-eq for different emissions were calculated using in Equation 1:

$$\mathrm{IC_i} = \sum\left(\mathrm{E_j}\right) \times \mathrm{CF_{ij}} \tag{1}$$

where $IC_i$ (impact category indicator) is the indicator value per functional unit for the impact category i, $E_j$ is the release of emission j or consumption of resource j per functional unit, $CF_{ij}$ is characterization factor for emission j or resource j contributing to impact category i [12].

Interpretation and LCA Tool. Life cycle interpretation is a systematic approach to identify, quantify and evaluate information and data from the LCI and LCIA stages with respect to the ISO 14040:2006 standards. These standards entail identifying apparent concerns and constraints based on the LCI and LCIA stages as well as drawing conclusions and providing recommendations [13]. The findings aid in the identification of key challenges with respect to the scope definition for the study. Microsoft Excel is the primary tool used in this research to tabulate the inventory data during the LCI phase and generate graphical data during the LCIA stage as executed in past research by Feiz, et al. [14].

## Results and Discussion

Data associated to the broiler house operations such as the daily feed intake and utility requirements are attained through personal contact from Dindings Poultry Processing Sdn Bhd., a primary chicken supplier in Malaysia, accounting to 10 % of the national chicken supply. Cumulatively, 3.5 kg of feed is required per chicken during each cycle. For chicken bedding, it is estimated 2.76 kg of bedding needed per chicken. Inventory data associated to the biogas plant is extracted from a study by Morero, et al. [15] which revolves around anaerobic digestion as well. The data from the LCI stage for broiler house and biogas plant operations are depicted in Table 1 and 2 respectively.

*Table 1: Inventory data for a broiler house.*

| Type of Input | Measurement/Type | Type of Output | Measurement |
|---|---|---|---|
| Feed intake | | Solid waste | |
| Pre starter | 325.00 g | Municipal solid waste | 3.30 kg |
| Starter | 807.00 g | | |
| Grower | 2.40 kg | Air emission | |
| Average | 3.50 kg/chicken | $NH_3$ | 11.40 kg |
| Transportation related | | $SO_2$ | 0.38 g |
| Distance | 213.20 km | CO | 4.89 kg |
| Diesel | 81.02 litre | $NO_x$ | 47.10 kg |
| Type of transport | Lorry | $CO_2$ | 336234.81 kg |
| Physical parameters | | $N_2O$ | 3677.08 g |
| Start weight | 100 g | $CH_4$ | 27724.93 g |
| Finish weight | 2.50-3.00 kg | Water emission | |
| Mortality rate | 3.60 % | $PO_4^{-3}$ | 3.60 kg |
| Bedding | 2.76 kg/chicken | $NO_3^-$ | 159.30 kg |
| Utilities | | | |
| Amount of water for drinking | 0.10 $m^3$/chicken | | |
| Electricity | 15580.00 W | | |

*Table 2: Inventory data for biogas plant.*

| Parameter | unit | Value |
|---|---|---|
| Feedstock (poultry litter) | kg/year | 680400.00 |
| Digester capacity | $m^3$ | 500.00 |
| Hydraulic retention time (HRT) | days | 34.00 |
| Working temperature | °C | 37.00 |
| Biogas production | $m^3$/year | 107231.04 |
| $CH_4$ content of biogas | % | 56.00 |
| $CH_4$ leakage | % | 2.40 |
| Installed electrical power | MW | 1.50 |
| Electrical efficiency of biogas conversion | % | 30.00 |
| Electricity generated | kWh/year | 214462.08 |
| Electricity used | kWh/year | 1404000.00 |
| Heat production | kWth/year | 268077.60 |

| | | |
|---|---|---|
| Digestate production | kg/year | 595350.00 |
| Water | $m^3$ | 15.00 |
| Output in terms of emissions (30 days) | | |
| $CO_2$ | kg | 355140.00 |
| $CH_4$ | g | 19305.90 |
| $N_2O$ | g | 3352.50 |
| $O_2$ | kg | 2976.75 |
| $N_2$ | kg | 58968.00 |

In terms of transportation consideration for the broiler house operations, the distance defined is that between the broiler house and feed mill with 13 trips assumed to be taken in the period of one cycle. As there are large amounts of broiler feed to be transported, it is assumed that the mode of transportation is a lorry, hence, is estimated that 38 L of diesel is consumed per 100 km.

The data gathered is accordingly used in the manual calculations which employ the gas emission factors as provided by the guidelines in the Environmental Protection Agency guideline. The results for the calculations are depicted in Table 3.

*Table 3: Total of GHG emission for the whole system boundary.*

| **Type of material/activity** | **Value** | **Carbon dioxide emission (kg $CO_2$ eq)** | **Methane emission (g $CH_4$ eq)** | **Nitrous oxide emission (g $N_2O$ eq)** |
|---|---|---|---|---|
| Transportation: Diesel | 81.02 liter | 214.70 | 4.41 | 1.78 |
| Distance | 213.20 km | | | |
| Feed material | 105000.00 kg | 336000.00 | 27720.00 | 3675.00 |
| Electricity | 117015.60 kW | 117015.60 | 1275.47 | 971.23 |
| Manure | 56700.00 kg | 238140.00 | 18030.60 | 2381.40 |
| Bedding | 82800.00 kg | 135792.00 | 10432.80 | 5216.40 |
| Total | | 827162.30 | 57463.28 | 12245.80 |

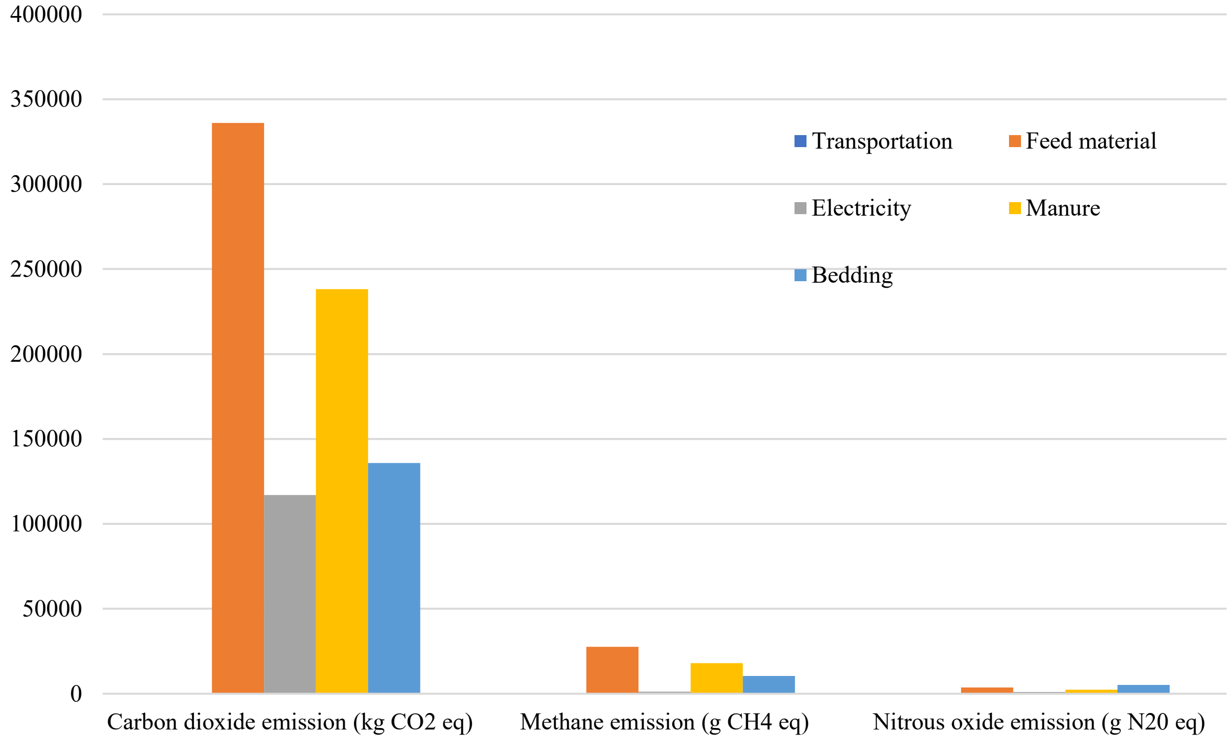

*Figure 3: Total GHG emission by material/activity.*

From Figure 1, it is apparent that the $CO_2$ emission is significantly higher in comparison to $CH_4$ and $N_2O$ emissions. Additionally, it can be observed that the feed for the chickens which is primarily from agricultural biomass waste and the chicken manure which acts as the feedstock for the biogas plant contribute significantly to GHG emissions in comparison to the other factors. In terms of $N_2O$ emission, the attribute that contributed dominantly is the use of bedding materials as it constitutes of nitrogenous rich elements such as wood and tree barks.

The impact category observed is the Global Warming Potential (GWP). The different emissions are standardized to a single attribute which in the case of GWP is kg $CO_2$-eq using the characterization factor, otherwise known as the equivalent factor as reported by Fallahpour, et al. [16]. GWP is arguably one of more significant impact categories to be taken into consideration especially when it revolves around discussions on sustainable energy generation. As $CO_2$ is the standard for GWP, it can be described as the heat absorbed by any GHG in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of $CO_2$. Each GHG species significantly contributes to GWP as they persist for different durations in the atmosphere. Accordingly, other constituents that contribute to GWP are converted to kg $CO_2$-eq as well. In the case of $CH_4$ and $N_2O$ emissions, it is identified as equivalent to 25-year and 298-year kg $CO_2$-eq per kg GHG respectively. The GWP calculation is as summarized in Table 4.

*Table 4: GWP calculation*

| **Emission** | **Values (in kg)** | **$CO_2$ equivalent factor** | **GWP (kg $CO_2$-eq)** |
|---|---|---|---|
| $CO_2$ | 827162.30 | 1.00 | 827162.30 |
| $CH_4$ | 57.46 | 25.00 | 1436.58 |
| $N_2O$ | 12.25 | 298.00 | 3649.31 |
| Total | | | 832248.18 |

Based on the results depicted in Table 4, it can be observed that $CO_2$ is the primary contributor to GWP in comparison to $CH_4$ and $N_2O$. As such, variables significantly contributing to $CO_2$ emission is identified such that practical steps are taken to control $CO_2$ emission. In a study by Montemayor, et al. [17], extremely low GWP values were observed in the case of digested manure slurry application, to which the GHG offset due to bioenergy generation from digested manure slurry production was the primary contribution. Krexner, et al. [18] on the other hand deduced that biogas generation attributing to manure management only contributed to 10.07 % of GWP with respect to the cradle-to-gate system boundary of his study inclusive of manure acquisition up to synthesis of product. Nonetheless, chicken manure can also be treated through other waste-to-wealth approaches such as composting, pyrolysis, and gasification [19].

Eutrophication Potential (EP) on the other hand entails the impact on environments caused by over-fertilisation or excess supply of nutrients. The surplus of nutrients leads to enhanced growth of plants, especially plankton algae. In the ecosystem of a water body, excessive development of microorganisms deters the supply of oxygen and sunlight, adversely effecting the plants. The characteristics of the water body is also bound to change. For example, a formerly clean lake with drinking water quality can evolve into water with an anoxic (free of oxygen) depth layer [20]. Similar to GWP, the different constituents are expressed in a single attribute which is kg $NO_3$-eq. The EP calculation is as depicted in Table 5.

*Table 5: EP calculation*

| Emission | Values (in kg) | $NO_3^-$ equivalent factor | EP (kg $NO_3^-$-eq) |
|---|---|---|---|
| $NO_3$ | 159.30 | 1.00 | 159.30 |
| $NH_3$ | 11.40 | 3.64 | 41.50 |
| $PO_4^3$ | 3.60 | 10.45 | 37.62 |
| Total | | | 238.42 |

Based on Table 5, the EP is largely contributed by nitrate, $NO_3$ emission from the broiler house stage. This is because chicken manure is rich in nitrogen hence the practice of soil conditioning without any form of pre-treatment is not a sustainable management approach as major accumulation of $NO_3$ in the soil profile increases the $NO_3$ concentration in groundwater, contributing to EP [21]. This correlation has also been observed in a study conducted by Huang, et al. [22] which observed rise in EP when nitrogen rich fertilizers are used to enhance crop yield. The phosphate, $PO_4^3$ and ammonia, $NH_3$ emissions are relatively low compared to the $NO_3$ emission. However, in comparison to GWP, EP is still manageable.

Acidification Potential (AP) is associated to acid deposition of acidifying contaminants on soil, groundwater, surface waters, biological organisms, ecosystems, and substances [23]. There are a few inventory items relevant to the AP including sulphur dioxide, $SO_2$ which is the standard equivalent for AP. The AP calculation is as depicted in Table 6.

*Table 6: AP calculation*

| Emission | Values (in kg) | $SO_2$ equivalent factor | AP (kg $SO_2$-eq) |
|---|---|---|---|
| $SO_2$ | 0.00038 | 1.00 | 0.00038 |
| $NH_3$ | 11.40 | 1.88 | 21.43 |
| $NO_x$ | 47.10 | 0.28 | 13.19 |
| Total | | | 34.61 |

With respect to Table 6, it can be deduced that $NH_3$ is the main contributor for emissions followed by nitrogen oxides, $NO_x$ resulting in acidification despite $SO_2$ being the standard in this impact category. The broiler house exhibits notable $NH_3$ emission due to poor manure management. This is coherent with a study by Kacprzak, et al. [24] which observed that $NH_3$ emission from poultry manure is higher in comparison to cattle and cow manure. The emission of $NO_x$ is justified in a similar manner due to the volatilization of nitrogenous content in the manure [25]. Additionally, the nature of $NH_3$ which evolves to $NO_x$ in the atmosphere is also used to infer this observation [26]. Hence, apart from considering circular economy-based treatment approaches for the management of chicken manure, reinforcing legislations entailing proper livestock manure management practices as executed in China is a pragmatic measure to alleviate adverse effects to the environment [27].

## Conclusion

In a LCA framework, GWP, EP and AP are oftentimes regarded as the more prominent impact categories that need to be evaluated as it is directly correlates to GHG emissions which is rising concern. The findings revealed that EP and AP are not much of a concern however control measures need to be put in place to reduce the impact of GWP with respect to GHG emissions. Of the few GHG emissions, $CO_2$ seems to be the most apparent primarily due to broiler house activities associated to feedstock acquisition for the chickens and manure management. Consequently, more sustainable practices should be introduced to further reduce the GWP.

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