Research article

Assessing the Efficiency of Different Biogas Generators in Energy Production and Greenhouse Gas Emissions for Commercial Pig Farms in Cambodia

MENGCHHAY KIM*
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia
Email: kmengchay@rua.edu.kh

LYHOUR HIN
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia

CHAN MAKARA MEAN
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia

NARETH NUT
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia

LYTOUR LOR
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia

GERALD HITZLER
Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Cambodia

Received 29 December 2023 Accepted 31 December 2024 (*Corresponding Author)

Abstract Covered lagoon digesters are commonly used by commercial pig farms in Cambodia to manage their wastewater and produce biogas for electricity generation. In these biogas systems, dual or modified pure biogas generators are utilized, but the efficiency of different generators in the context of Cambodia has yet not been rigorously evaluated. Therefore, the current study aimed to (1) determine biogas production and quality in two pig farms, (2) compare the working performance of a pure biogas generator and a dual generator, and (3) estimate CO_2 emission reduction in the two cases. The study was carried out between May 2022 and May 2023 on two large-scale pig farms that hosted fully operational biogas systems. The first farm operated an all-in-all-out system with 8,000 fattening pigs in Kampong Speu Province, while the second farm operated a full system with 5,000 fattening pigs and 600 sows. The portable biogas analyzer, electrical power logger, and a vortex flowmeter were used to measure biogas quality and record the power consumption and daily biogas production. The results show that the first farm produced 792 Nm^3/day, whereas the second farm produced 495 Nm^3/day of biogas daily. Additionally, the methane content in both cases was not significantly different (60% of CH_4). However, the dual generator can generate power up to 1,118 kWh/day, while the pure biogas generator can produce only 743 kWh/day. The first farm that used the dual generator could save up to 80% of total power consumption, whereas the second farm could save only 24% due to a larger demand for electricity. Thus, the first farm (3,408.2 t CO_2equ) could reduce greenhouse gas emissions more than the latter (697.8 t CO_2equ). The results of the study suggest that using biogas from wastewater treatment to produce electricity reduces both electricity costs and greenhouse gas emissions.

Keywords covered lagoon, pig farm, biogas, electricity, dual generator and greenhouse gas

INTRODUCTION

Pig production plays a major role in sustaining the Cambodian economy, producing meat, and providing jobs for millions of people. So far, there have been more than 8 million pigs raised nationwide, and about 21% of them are raised in commercial farms (NIS, 2021). Between 2017 and 2021, large-scale pig production increased more than two-fold, meaning that more wastewater is being generated. Without proper treatment, environmental catastrophes may occur. Those include potential pollution of surface and groundwater, disease spread by flies, bad odor, which leads to complaints from neighboring communities, and greenhouse gas emissions (ADB, 2022). In 2018, almost 50 commercial pig farms were using these systems in the form of simple covered lagoon digesters to treat and convert wastewater into energy for farm use (Hin et al., 2021).

Until now, there have been more than 500 officially recorded commercial pig farms across the country, while the unofficial number may be higher. So, there is a high potential for producing biogas from those farms, while eliminating issues related to wastewater, contributing to renewable energy production, and reducing greenhouse gas emissions (NBP, 2019). Year after year, the number of simply covered lagoon digesters is increasing without the latest data from the government, which means that wastewater treatment is not a concern anymore; then, a few local biogas suppliers have started to jump in, providing services such as covering lagoons to hold wastewater and to trap biogas and converting second-hand diesel generators into running on biogas. This is the main reason why the number of large-scale biodigesters keeps increasing. According to the studies conducted by Biogas Technology and Information Center (BTIC) between 2019 and 2023, 50-80% of pig farm electricity demand can be replaced by electricity produced from biogas. This is an enormous benefit because an average farm of 30,000 pigs can save 48000 USD per year. At the same time, the efficiency of dual generators in producing electricity from biogas and in reducing CO_2 emissions is poorly documented (BTIC, 2021).

OBJECTIVE

This research was to assess the efficiency of different biogas generators operated on pig farms. Thus, this research aimed to (1) determine biogas production and quality in two pig farms, (2) compare the working performance of a pure biogas generator and a dual generator, and (3) estimate CO_2 emission reduction in the two cases.

METHODOLOGY

The research was conducted from July 2022 and May 2023 on two large-scale pig farms that operated a full biogas system in the form of a covered lagoon digester. The first farm operated an all-in-all-out pig-raising system in Kampong Speu Province, raising 8,000 fattening pigs per cycle and two cycles per year (Table 1), while the second farm operated a full pig-raising system in Kampong Thom Province, raising 5,000 fattening pigs and 600 sows (Table 2). The biogas system run by the first farm consists of a 4,725 m^3 covered lagoon for accepting wastewater, a desulfurizing system for cleaning biogas, a flow meter for recording biogas consumption, and a second-hand dual 200 kW generator for producing electricity from biogas. The second farm had a biogas system that included a 2,560 m^3 covered lagoon, a desulfurizing system, a flow meter, and a second-hand 296 kW diesel generator modified to run on pure biogas. Because the second farm used only wastewater from fattening pig barns to produce biogas and then electricity, the study focused on all estimations based on the fattening pigs.

Biogas quality was measured by using a 5000-biogas analyzer, biogas flow rate by recording biogas flow rates on a biogas meter, and electricity generation by a HIOKI power logger (Hin et al., 2021; Mean et al., 2023). Throughout the study, the inspection was made 5 times with an interval of 1-2 months, depending on the permission from the farms and when biogas is fully used.

Biogas quality was measured before and after desulfurization, and the collected parameters include methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S). Each measurement was made three times to detect variations, and before every next measurement, the biogas analyzer was flushed out first to avoid the effects of previous samples. Biogas flow rates were also recorded when the generators were in full operation (Tippayawong et al., 2007). The measurement was done three times with an interval of 15 min to detect changes in consumption.

Output power produced by the generators were also recorded at any time that the biogas flow rates were recorded. In doing so, the total amount of time estimated to run generators based on the daily biogas production can be calculated using Eq. 1.

$$TW = WS + MP + UP \tag{1}$$

TW (m^3/day) accounts for the total wastewater generated in each farm daily. WS (m^3/day) represents the total daily water supplies for pigs on each farm, and it was calculated by multiplying the number of pigs by the average amount of water used per head, which is 30 L/head/day. MP (ton/day) represents the daily manure produced by a pig, being 1.5 kg/head/head (Mek et al., 2018). UP (m^3/day) accounts for daily urine excreted by a pig, estimated to be 2.5 L/head/day, while EV (m^3/day) represents daily evaporation from pig barns, which is 0.5 m^3 per barn (Hin et al., 2021).

Table 1 Information of the first farm

Farm	Type/Quantity	Description
Pig farm in Kampong Speu Province		Called the first farm
GPS location		11°16'55.8"N 104°36'51.4"E
Raising type	All-in-all-out	Piglets are supplied by a contracting company whenever new cycles come.
Fattening pig (head)	8,000	
Digester type	Simple covered lagoon	
Digester size (m^3)	4,725 m^3	
Generator type	Second-hand, dual-engine	30:70 (diesel:biogas)
Generator power (kW)	2 x 200	Two sets each with 200 kW
Desulfurizing system origin	V.W. gas	A local supplier
Desulfurizing system specifications	2 tanks and one cyclone without a blower	
Testing period	Oct 2021 – Jul 2022	

Table 2 Information of the second farm

Farm	Type/Quantity	Description
Pig farm in Kampong Thom		Called the second farm
GPS location		12°43'48.5"N 105°08'41.4"E
Raising type	Full production	Piglets are produced for own farm raising
Fattening pig (head)	5,000	
Sow (head)	600	
Digester type	Simple covered lagoon	
Digester size (m^3)	2,560	This pond accepts wastewater from fattening pig barns only
Generator type	Second-hand, modified from diesel to biogas	
Generator power (kW)	296	Two sets, 360 kW and 290 kW
Desulfurizing system origin	BTIC prototype	Called BTIC desulfurizing system in this study
Desulfurizing system specifications	2 tanks and one cyclone without a blower	
Testing period	May 2022 – May 2023	

In this study, the first farm had 10 barns, and the second farm had 8 barns. Likewise, the total quantity of biogas produced daily on the farms were calculated as Eq. 2 below.

$$Q_{biogas} = N \times MP \times DM \times BY \tag{2}$$

Q_{biogas} (kWh/day) represents the total quantity of biogas produced daily on each pig farm. N is the number of pigs, while MP is the daily manure. DM represents the content of dry matter present in the manure, and, in this study, DM is 20% (Department for Environment Food and Rural Affairs, 2021). BY stands for biogas yield, which is approximately 0.33 Nm^3/kg DM (Hin et al., 2021).

$$PE = CF \times Q_{biogas} \quad (3)$$

PE (kWh/day) represents daily amounts of potential electricity produced by the generators in each farm, and CF accounts for a conversion factor from biogas to electricity, which ranges from 1 to 1.7 kWh/Nm^3 biogas for second-hand generators, depending on the quality and age of the generator. In this study, CF of 1.5 kWh/Nm^3 biogas was used because the generators were large. Q_{biogas} (Nm^3/day) represents the total quantity of biogas produced daily from each pig farm.

$$LR = P_{output}/GP \quad (4)$$

LR (%) represents the loading rate of each generator when they were operated to produce electricity. P_{output} (kW) is the output power produced by individual generators, while GP is the generator power (kW).

$$CO_2 \text{ by avoidance of } CH_4 \text{ emission} = Q_{CH4} \text{ x } D_{CH4} \text{ x } CH_4\text{-to-}CO_2 \text{ equivalent} \quad (5)$$

$$CO_2 \text{ by avoidance of grid electricity use} = EM \text{ x electricity-to-}CO_2 \text{ equivalent} \quad (6)$$

Q_{CH4} (Nm^3/year) represents the amounts of CH_4 produced annually by the biogas systems on each farm, while D_{CH4} is the density of CH_4, which is 0.717 kg/m^3. The CH_4 - to - CO_2 an equivalent is 30 times more potential to cause global warming. EM (kW) represents the amount of electricity produced by biogas generators on an annual basis, and the electricity - to - CO_2 equivalent is 0.657 kg CO_2/kWh electricity. Total CO_2 emission reduction is calculated based on the addition of both CO_2 emission reductions in both of the above-mentioned cases.

Data analysis was made by using MS Excel to perform descriptive statistics. Meanwhile, graphs were created by using R Program and RStudio, which are free online software programs.

RESULTS AND DISCUSSION

Wastewater characteristics were studied and compared between the two farms (Table 3). It can be seen that all the studied parameters are 1.6 times higher in the first farm than in the second farm. This is because the first farm had more fattening pigs than the second farm did. On average, 12 tons of manure were produced by the first farm, while the second farm produced only 7.5 tons of manure per day. Urine production was 20 m^3/day on the first farm and 12.5 m^3/day on the second farm. Total dry matter for the first and second farms was 2.4 tons/day and 1.5 tons/day, respectively. With that, the total quantity of wastewater was 269 m^3/day and 171 m^3/day, respectively.

Table 3 Comparison of manure production, dry matter, and total wastewater in the two farms

Source	Unit	First farm*	Second farm*	Ratio
Fattening pigs	Head/cycle	8,000	5,000	1.6
Manure	ton/day	12	7.5	1.6
DM content	%	0.9	0.9	1.0
Total water use	m^3/day	240	150	1.6
Urine	m^3/day	20	12.5	1.6
Total DM	ton/day	12	7.5	1.6
Evaporation	m^3/day	5	4	1.3
Total wastewater	m^3/day	267	166	1.6

Biogas quality was inspected and compared before and after biogas was desulfurized in both farms (Table 4). The results show that there was no difference in CH_4, CO_2, and O_2, regardless of applied desulfurization and farms. On average, biogas had 62.8% CH_4, 32.0% CO_2, and 0.6% O_2. In contrast, H_2S decreased after desulfurization in both farms. Untreated biogas had a much higher H_2S concentration in the first farm than in the second farm. After treatment, H_2S was lower than 200 ppm, which is good enough for smooth generator operation.

Table 4 Comparison of biogas quality before and after desulfurization in both farms

Biogas quality	First farm		Second farm		Average
	Before	After	Before	After	
CH_4 (%)	63.0	62.5	63.0	62.7	62.8
CO_2 (%)	32.0	31.4	32.4	32.0	32.0
O_2 (%)	0.5	0.5	0.5	0.7	0.55
H_2S (ppm)	3,470	10	2,500	87	

Table 5 compares generator size, potential biogas production per day and pig head, biogas flow rate consumed by the generators, estimated generator-running time based on the estimated biogas production, estimated electricity production, output power produced by the generators, and their loading rate between the two farms. It is observed that the first farm (200 kW) had a smaller generator size than the second farm (296 kW) but produced more daily biogas. This is because the first farm had more pigs, thus having greater amounts of manure necessary to generate biogas. In our case, the size of generators suitable for daily biogas production was estimated to be 792 Nm^3/day for the first farm and 495 Nm^3/day for the second farm. Nevertheless, daily biogas production per head was the same, being 0.01 Nm^3/head/day. Because the first farm used a smaller generator, while producing more biogas, the estimated time that it could run the generator was more than a surplus. Meanwhile, the generator operated by the second farm might use up the daily produced biogas in 4.3 hours. After that, it depends solely on grid electricity. The reason why the first farm used much less biogas is because it operated a dual generator that ran on both biogas and diesel. In this regard, 90 L of diesel was consumed daily. The output power was 93 kW and 125.5 kW for the first and second farms, respectively. It can be noted that the total number of pigs raised in the second farm was much less than that of the first farm even with sows included, but more electrical power was required. This is because sow raising requires a considerable amount of energy, 3 times higher than the electricity needed for one fattening pig (39 kWh/year).

Table 5 Comparison of electricity production, generator efficiency, and loading rate by the two desulfurizing systems

Item	First farm	Second farm	Ratio
Generator size (kW)	200	296	0.7
Estimated daily biogas production (Nm^3/day)	792	495	1.6
Daily biogas production per head (Nm^3/head/day)	0.01	0.01	1.0
Biogas flow rate (Nm^3/h)	32	114.5	0.3
Estimated time for running generators by using biogas (h/day)	24.8	4.3	5.8
Potential Electricity production (kWh/day)	1,188	743	1.6
Diesel consumption (L/day)	90	0	
Output power (kW)	93	125	0.7
Loading rate (%)	47	41	1.1

Energy saving based on the utilization of biogas systems was calculated based on two different scenarios: when the farms did not use biogas and when they used biogas (Table 5). It was found that the first farm consumed 90 L of diesel on daily biogas when its generator was operated with a biogas mixture. However, diesel consumption rose to 450 L/day, when its generator was fully operated by using diesel. Thus, with the use of biogas, 80% of diesel consumption was reduced, which represents energy savings. These results are in line with a study by Leykun and Mekonen (2022) and Tippayawong et al. (2007) which suggested that using biogas with dual generator can reduce diesel up to 80%. Likewise, when biogas was used, the second farm reduced dependency on grid electricity from 2,784 to 2,256 kWh/year, a reduction of 24%. This result clearly indicated that using biogas can reduce electricity consumption that normally stems from the use of fossil fuel.

Table 6 Comparison of diesel consumption on the first farm and grid electricity consumption on the second farm when biogas is either used or not used

Description	First farm	Second farm
Diesel consumption mixed with biogas (L/day)	90	0
Diesel consumption without using biogas (L/day)	450	0
Grid electricity consumption mixed with biogas	0	2,256
Grid electricity without using biogas	0	2,748
Energy saving (%)	80	24

CO_2 reduction and CO_2 emission were compared on both farms when they use biogas in combination with diesel or grid electricity (Fig. 4). The results show that the first farm could reduce much more CO_2 emission (2,483 tCO_2equ) when biogas used, when compared with the second farm (1,552 tCO_2equ), which is equivalent to a 1.6-to-1 ratio. At the same time, the farms also used other sources of energy to meet the electricity demands. The first farm used diesel, while the second farm used grid electricity. As a result, they emitted 79.6 and 1,482 tCO_2equ, respectively. Despite that, they still had reduced carbon emissions, at 2,403 tCO_2equ for the first farm and 70 tCO_2equ for the second. It can be concluded that by using biogas to generate electricity, the farms can both save electricity costs and contribute toward CO_2 emission reduction, supporting the transition to a green economy.

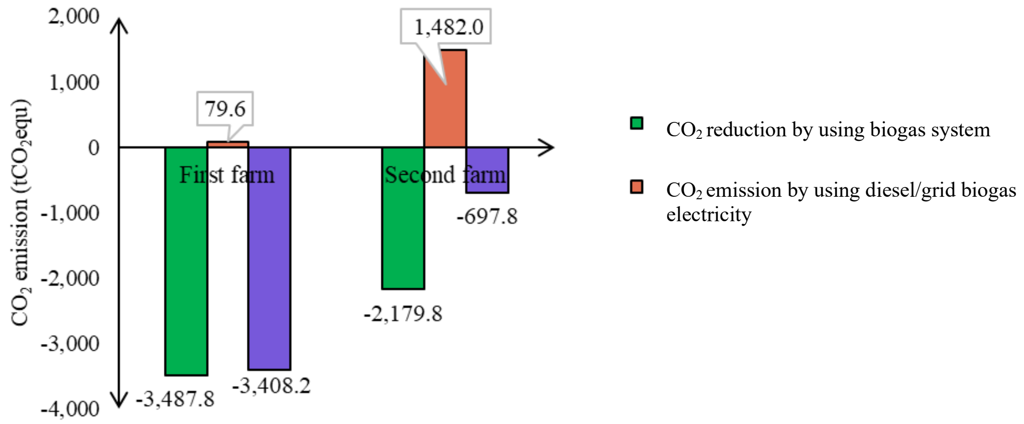

Fig. 1 Comparison of CO_2 reduction due to the use of biogas and CO_2 emissions due to the use of diesel and grid electricity in both farms

CONCLUSION

The study compared biogas production, biogas quality, energy production, and CO_2 emission reduction in two large-scale pig farms that used a pure biogas generator and a dual generator. Wastewater characteristics were also studied and compared. The findings show that the farm that has a larger number of pigs will produce more wastewater and manure on a daily or yearly basis, thus generating more biogas when biogas systems are operated. Despite that, electricity demand on the farms depends significantly on the purpose of electricity use. The first farm had more fattening pigs but used less electricity than the second farm that included 600 sows. This is due to the large quantity of electricity required to fulfil the electricity demand for raising sows. With the use of farm-generated biogas, diesel or grid electricity consumption is greatly reduced, which translates to energy and cost savings. Additionally, using biogas can lead to reduced carbon emissions, although farms still depend on fossil fuel. This can in turn serve as an important contribution toward the green energy transition in the livestock sector. Nevertheless, future studies are needed to conduct a comprehensive cost-benefit analysis when the whole cost of a biogas system is included; it is expected such studies can reveal the full range of benefits provided by a biogas system.

ACKNOWLEDGEMENTS

The study was made possible thanks to the project "Reduction of Greenhouse Gas Emission through Promotion of Commercial Biogas Plant in Cambodia" implemented by United Nations Industrial Development Organization (UNIDO), which not only provided funding, but also continuously assisted in strengthening the BTIC research team. Many thanks may go not only to the farm owners that allowed for a long-term experiment, but also to students who helped collect data.

REFERENCES

Asian Development Bank (ADB). 2022. Cambodia, Greater Mekong Subregion cross-border livestock health and value chains improvement project. Detailed Livestock Subsector Assessment, Asian Development Bank, Retrieved from URL https://www.adb.org/sites/default/files/linked-documents/53240-003-ld-04.pdf

Biogas Technology and Information Center (BTIC). 2021. Biogas potential for Cambodia's pig farming industry. Biogas Technology and Information Center, Phnom Penh, Cambodia.

Hin, L., Ngo, B., Lor, L., Sorn, S., Theng, D., Dok, C., Mech, S., Mean, C.M., Yut, S., Lay, M. and Frederiks, B. 2021. Assessment of biogas production potential from commercial pig farms in Cambodia. International Journal of Environmental and Rural Development, 12 (1), 172-180, Retrieved from DOI https://doi.org/10.32115/ijerd.12.1_172

Leykun, M.G. and Mekonen, M.W. 2022. Investigation of the performance and emission characteristics of diesel engine fueled with biogas-diesel dual fuel. Fuels, 3 (1), 15-30, Retrieved from DOI https://doi.org/10.3390/fuels3010002

Mean, C.M., Hin, L., Ro, S., Nut, N., Sok, N., Lor, L. and Fredreriks, B., 2023. Conditions of bio-slurry application in crop production in Kampong Cham Province, Cambodia. International Journal of Environmental and Rural Development, 14 (1), 45-51, Retrieved from URL https://iserd.net/ijerd141/14-1-7.pdf

Mek, S., Vong, P., Khoem, N. and Mech, S. 2018. Assessment the potential of pig manure in electricity generation for pig commercial farms in Kean Svay District, Kandal Province and Oddong District, Kompong Speu Province. Bachelor's Thesis, Royal University of Agriculture, Phnom Penh, Cambodia.

National Biodigester Program (NBP). 2019. Market study on medium-scale and large-scale biodigesters in Cambodia. National Biodigester Program, General Directorate of Animal Health and Production (GDAHP), Phnom Penh, Cambodia.

National Institute of Statistics (NIS). 2021. Raising of livestock and poultry. Cambodia Agricultural Survey 2021, 3, National Institute of Statistics, Ministry of Planning, Phnom Penh, Cambodia, Retrieved from URL https://www.nis.gov.kh/nis/CAS23/CAS%202021%20-%20Report%203%20-%20Raising%20of%20Livestock%20and%20Poultry%20-%20ENG.pdf

Tippayawong, N., Promwungkwa, A. and Rerkkriangkrai, P. 2007. Long-term operation of a small biogas/diesel dual-fuel engine for on-farm electricity generation. Biosystems Engineering, 98 (1), 26-32, Retrieved from DOI https://doi.org/10.1016/j.biosystemseng.2007.06.013