Research article

Assessment of Biogas Production Potential from Commercial Pig Farms in Cambodia

LYHOUR HIN*
Biogas Technology and Information Center and Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia
Email: hlyhour@rua.edu.kh

BUNTHAN NGO
Royal University of Agriculture, Phnom Penh, Cambodia

LYTOUR LOR
Biogas Technology and Information Center and Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

SUYHEANG SORN
Biogas Technology and Information Center and Faculty of Animal Science, Royal University of Agriculture, Phnom Penh, Cambodia

DYNA THENG
Biogas Technology and Information Center and Faculty of Agricultural Engineering, Royal University of Agriculture, Phnom Penh, Cambodia

CHANPHAKDEY DOK
Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh, Cambodia

SOKHOM MECH
Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh, Cambodia

CHAN MAKARA MEAN
Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh, Cambodia

SOVANNDY YUT
Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh, Cambodia

MAKARA LAY
Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh, Cambodia; Laboratory of Organic Electronic, Department of Science and Technology, Linköping University, Norrköping, Sweden

BART FREDERIKS
Independent Bioenergy Consultant and Biogas Technology and Information Center, Royal University of Agriculture, Phnom Penh 12401, Cambodia

Received 28 December 2020 Accepted 30 June 2021 (*Corresponding Author)

Abstract Commercial pig farms in Cambodia are increasing, representing 30% of the overall pig production in 2018. To run the farms, huge quantity of water is used on daily basis, and its large proportion ends up being wastewater that can cause air and water pollution, fly-related illnesses, and methane emissions. In response, anaerobic digestion (AD) is applied to convert waste into energy. Covered lagoons are an anaerobic biodigester that has long been used for commercial biogas plants in Cambodia due to acceptable investment cost and favorable climatic conditions for biogas production. However, lack of local technical data and technical assessment is a barrier to wider implementation of biogas systems in the country. Therefore, the study was conducted to explore the characteristics of commercial pig farms and wastewater use; to analyze the quality of biogas compositions from different covered lagoons; and to estimate biogas production, electricity generation, and CO_2 reduction equivalent from the collected data. The study was started from January to October 2020, selecting 9 farms with evaporative cooling systems for in-depth interviews, along with direct observations, biogas analysis, and power analysis. The findings indicate that all the studied farms were fattening farms operated under purchase contract with private companies. Pig production varied from 2,800 to 7,200 head per cycle, with two cycles per year. Moreover, daily wastewater was 0.033 m^3 d^{-1} $head^{-1}$, with dry matter (DM) accounting for 0.9%. Annual biogas production and electricity generation were 32.7 m^3 y^{-1} $head^{-1}$ and 42.5 kWh y^{-1} $head^{-1}$, respectively. Biogas quality was 59.5% CH_4, 31.5% CO_2, 1.3% O_2, and 2,256 ppm H_2S. With biogas systems, individual farms could reduce CO_2 emission by 0.676 tCO_2eq y^{-1} $head^{-1}$, which is economically and environmentally beneficial. However, a business model should be taken into account for successful implementation.

Keywords CO_2 reduction, covered lagoon, methane emission, pig manure

INTRODUCTION

Pork is considered an important protein source for daily Cambodian diets. In this country, an average person eats 17.6 kg of meat per year, of which 9.29 kg is pork. Likewise, annual domestic demands for meat in 2018 was estimated at 285 thousand tons, and pork alone accounted for 52.8%. This high demand led to a 126% increase in local pig production between 2014 and 2017, from 2.44 million to approximately 3.18 million heads. A tendency toward large-scale production has emerged, as commercial pig farms rose by 30% in 2018 (MAFF, 2019). Commercial pig farms in Cambodia are farms with more than 100 fattening pigs, or more than 50 sows. There are around 500 farms in operation across 10 provinces, with 30-40% concentrated in Kampong Speu Province (NBP, 2019). Commercial pig farms in Cambodia are operated similarly with Thailand because they use evaporative cooling systems to maintain optimal temperatures inside the barns from 25 to 27 ^{0}C (Thanapongtharm, 2018). Such operation is vital for pig growth and disease prevention. For secure market and prices, farms turn to contract farming with private companies, such as C.P. Cambodia Co., Ltd., that provide both technical and financial support. Farm operation differs by pig type. In Cambodia, pig farms are classified into breeding farm and fattening farm. Among them, fattening farms are more popular. Fattening farms have three categories: small-sized (100 - 1,000 heads), medium-sized (1,001 - 5,000 heads), and large-sized (>5,000 heads) (MAFF, 2018).

Pig farms normally use large amounts of water for pig drinking, pig bathing, and barn cleaning. Daily water use rates vary by production type and pig weight. It is reported that average daily required water rates for breeding farms, fattening farming, and nursery farms are 92, 48, and 32 L d^{-1} $head^{-1}$, respectively. However, a large proportion (50-70%) ends up being wastewater (Nokyoo, 2016). Improper treatment of wastewater is associated with odor, flies, water pollution, and greenhouse gas emission. Some key elements used as pollutant indicators include chemical oxygen demand (COD), biological oxygen demand (BOD), total Kjedahl nitrogen (TKN), and total suspended solid (TSS). A study by Tokhun (2010) indicates that untreated wastewater from large-scale pig farms in Thailand contains 4,889 mg L^{-1} COD, 3,555 mg L^{-1} BOD, 481 mg L^{-1} TKN, and 2,317 mg L^{-1} TSS. These parameters are too high to be directly discharged into natural lakes. In the Cambodian wastewater standards for public water areas and sewers, COD, BOD, TSS, and nitrate (NO_3) must be no more than 100, 80, 80, and 20 mg L^{-1}, respectively (Council of Ministers, 1999). Thus, sound waste management is strongly required, as it is important for the sustainable operation of pig farms. One of the most effective wastewater treatment methods is the adoption of anaerobic digestion (AD). AD is known as a process under which organic matters, mainly in the form of fine particles, are fermented with the absence of air. The process consists of four stages: hydrolysis, acidogenesis, acetogenesis , and methanogenesis, with biogas produced as a final product and convertible into energy (Deublein and Steinhauser, 2011). Biogas is a gas mixture that contains 50-70% methane (CH_4), 30-40% carbon dioxide (CO_2), and other trace elements (EESI, 2017). CH_4 contained in biogas is the only source of energy such as heat and electricity. Nevertheless, it is harmful to the environment, if released into the atmosphere, because it is 28 times more powerful than CO_2 in terms of global temperature potential (GTP) for 100 years (IPCC, 2014). In contrast, converting biogas into electricity or upgrading it into bio-methane can reduce its harmfulness.

To promote manure management, the National Biodigester Program (NBP) was established in Cambodia in 2006 to turn cow manure into biogas for cooking and lighting. The program has built nearly 30 thousand biodigesters for smallholder farmers nationwide. In recent years, attention has been turned to large-scale biogas systems, which are covered lagoons. Covered lagoons are an AD technology, commonly used in commercial pig farms in Cambodia. It is reported that there are 44 covered lagoons in operation across the country (NBP, 2019). This number is still considered low in comparison to the potential pig farms and other biogas resources. This is due to lack of necessary documents and knowledge, or biogas skills. Therefore, in-depth studies on commercial pig farms are deemed vital for solving problems with wastewater and for economic profitability through energy generation.

OBJECTIVE

The objectives of this study were (1) to explore the characteristics of commercial pig farms and wastewater use; (2) to analyze the quality of biogas from covered lagoons; and (3) to estimate methane production, electricity production, and CO_2 reduction equivalent.

METHODOLOGY

The selection criteria for pig farms were farms that had thousands of pigs, used evaporative cooling systems, and were interested in setting up biogas systems. However, the scope of this research was based on a one-year study period only, from January to October 2020. To represent diverse pig farm characteristics, 9 commercial farms were selected from 6 different provinces: 5 from Kampong Speu and 1 each from Kampong Chhnang, Kampong Cham, Kampong Thom, Siem Reap, and Kratie. More farms were selected from Kampong Speu, as this province had the greatest farm number in the country. The study procedure was arranged by face-to-face interviews with farm owners on the site, direct observation, biogas analysis, and power analysis.

Materials

Biogas quality is an important indicator to determine generator efficiency. A 5000 gas analyser, supplied by Geotech, UK, was used to analyze biogas quality based on the percentage of CH_4, CO_2, O_2, and H_2S in ppm with the maximum of 5,000 ppm.

Peak load is considered a vital indicator to determine the generator size for the farm. A Hioki

PW3365-20-01/5000 power logger was used to measure daily peak loads. It is capable of measuring three-phase voltage with high electrical current of up to 5,000 A.

Sampling Methods and Data Analysis

In the study, a set of questionnaire was used to collect information on pig type, business type, pig number, barn number, cycle number, and duration within a cycle, as well as plans to increase farm size within the next few years. Moreover, information on sources of farm power supplies, existing biogas systems, biogas system type, generator type, and operation was also gathered. Annual electricity demand was estimated based on collection of electricity bills from the farms. All the information was verified by direct observation.

In the sampling process, biogas was directly measured before and after desulfurization—a process for removing hydrogen sulfide from the biogas systems. As desulfurizing systems did not function, biogas quality was only measured in the outlet pipe from covered lagoons. The measurement lasted 2 min, and average values were plotted from at least 3 different measurements. Before measuring new samples, the biogas analyzer was flushed. In the sampling process, peak loads were measured by attaching the power logger to the electricity panels of the farms for 1 hour. Night load was not recorded due to low electricity demand. Nevertheless, peak load recording was possible for a few farms only due to blackouts.

Total daily wastewater production from pig farms was estimated by combining daily water use for individual pigs, daily manure, and urine rate. In Thailand, daily wastewater left from cleaning, bathing, and drinking is estimated at 24 L d^{-1} $head^{-1}$ for fattening farms (Kulpredarat, 2016). Because Thai pig farms share similarity with Cambodia, wastewater rate used in this study was assumed to be 30 L d^{-} $head^{-1}$, about 20% more for conservative estimation. In this study, manure production used for individual pigs was 1.5 kg d^{-1} $head^{-1}$ (Mek et al., 2018), and urine rate was assumed to be 2.5 L d^{-1} $head^{-1}$. These estimated values were roughly similar to the data in Thailand, where daily manure and urine production for typical fattening farms are 1.2-1.4 kg d^{-1} $head^{-1}$ and 3.0-3.2 L d^{-1} $head^{-1}$, respectively (Nokyoo, 2016). Besides that, the evaporation rate was also included and assumed to be 0.5 m^3 d^{-1} $barn^{-1}$.

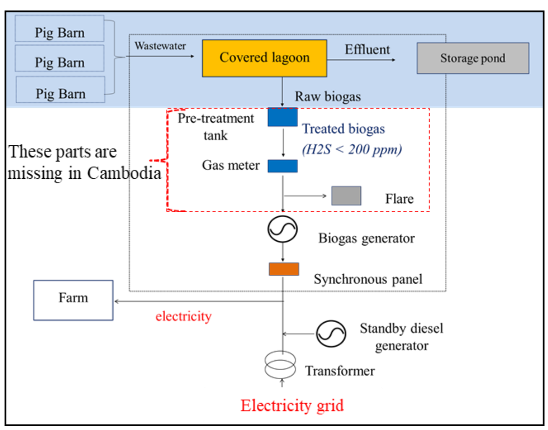

Fig. 1 Diagram of full biogas systems in a typical pig farm, but in Cambodia, desulfurizing systems, gas meter, and flare are missing

Daily biogas production was estimated by multiplying manure dry matter (DM) with biogas yield. It is reported that average pig manure contains 20% DM (DEFRA, 2011), and that biogas yield is 0.33 Nm^3 kg^{-1} DM based on the experimental result by the Biogas Technology and Information Center (BTIC). Electricity production potential was calculated by multiplying biogas production with the conversion factor that varies from 1 to 1.7 depending on scale and average loading rate of the generator.

From biogas systems, CO_2 emission can be reduced in two ways: reduction by not emitting CH_4 directly into the atmosphere and reduction by using it to run biogas generators instead of grid electricity. In this regard, CO_2 reduction by avoidance of CH_4 release is equal to CH_4-to-CO_2 equivalent x CH_4 density x Annual CH_4 production. Meanwhile, CO_2 reduction by avoidance of grid electricity is equal to electricity-to-CO_2 equivalent x annual electricity demand met by methane production.

Descriptive statistics and frequency distribution were applied to analyze the data using MS Excel. To determine relations between CH_4 and O_2, or CH_4 and H_2S, a simple linear regression was used at $\alpha = 0.05$ probability level using R program 4.0.4, available for free online.

RESULTS AND DISCUSSION

Table 1 Characteristics of commercial pig farms in the studied areas (N = 9)

Variable description	Frequency (N = 9)	Percentage (%)	Mean ± SE	Min	Max
Fattening farm					
Yes	9	100%			
No	0	-			
Contract farming					
Yes	9	100%			
No	0	-			
Production cycle (cycle/year)			2		
Barn Number			5.6 ± 0.6	4	9
< 5	3	33%			
≥ 5	6	67%			
Production size (head/cycle)			4,194 ± 470.4	2,800	7,200
< 1000	0	-			
1000 – 3000	2	22%			
3001 – 4999	5	56%			
≥ 5000	2	22%			
Plan to increase production					
Yes	4	44%			
No	5	56%			
Sources of Energy supply					
Electricity grid	5	56%			
Other Energy sources	4	44%			
Existing covered lagoons (m^3)			4,085 ± 564	2,965	4,761
Yes	4	44%			
No	5	56%			
Biogas systems in operation					
Yes	3	33%			
No	6	67%			
Generator range (kVA)			186 ± 49.1	100	375
< 100	0	-			
100 – 200	2	67%			
> 200	1	33%			
Generator type					
New	0	-			
Modified	3	100%			
Pig number per barn (head/barn)			749 ± 11.8	740	800
working days (d/y)			330		
Daytime peak load (kW)			59.8 ± 9.4	32	97
Max peak load (kW/barn)			9.1 ± 0.4	7.8	10

Pig Farm Characteristics and Wastewater Use

The studied farms were all fattening farms operated under official contract with private companies (Table 1). The farms had two cycles per year, 5.5 months each. In early production, the farms were given piglets and had to sell back pigs to the contracting companies at the end of the cycle, also known as all-in/all-out batch operations. The number of barns varied from 4 to 9, with an average of 5.6 barns per farm. Average production size was 4,194 heads per cycle, but varied from 2,800 to 7,200 heads per cycle. No farms had pigs less than 1,000 heads per cycle. Of all the farms, 7 were medium-sized farms (1,000 to 5,000 heads); 2 were large-sized farms (>5,000 heads).

In Table 1, when asked about plans to increase production within the next few years, about 44% of the farm owners said yes. The main electricity supplies came from the local electricity grid. Of all the interviewees, 5 depended solely on EDC, while 4 also used biogas as an alternative. The biogas systems in the farms were simple covered lagoons that had different sizes, but the average value was 4,085 m^3. Only 3 farms had the systems in operation, while another one just stopped due to problems with the biogas generator. In addition, the farms that had biogas systems preferred to second-hand, modified diesel generators for economic reasons.

Farm electricity was mainly consumed by evaporative cooling systems and to some extent by pumping and lighting (Table 1). Average maximum daytime peak load the farms was 59.8 kW, but varied from 32 to 97 kW according to the production size. Maximum peak load per barn was also measured with full operation of evaporative cooling systems. It was 9.1 kW and varied from 7.8 to 10 kW. However, peak loads were low at night, in cold seasons, and in early production.

Table 2 Estimated total wastewater production in the fattening farms (N = 9)

Source	Unit	Average ± SE
Water	m^3 d^{-1}	125.8 ± 14.1
Dung (fresh)	t d^{-1}	6.3 ± 0.7
Urine	m^3 d^{-1}	10.5 ± 1.2
Evaporation	m^3 d^{-1}	2.8 ± 0.3
Total waste water	m^3 d^{-1}	139.8 ± 15.7
	m^3 d^{-1} $head^{-1}$	0.033 ± 0.004
DM content	%	0.9%
Total DM	t d^{-1}	1.3
Biogas	Nm^3 d^{-1}	415
	Nm^3 y^{-1}	137,033
	Nm^3 y^{-1} $head^{-1}$	32.7

Wastewater rate produced from pig bathing and barn cleaning was 125.8 m^3 day^{-1} in each farm (Table 2). Fresh manure and urine production was 6.3 t d^{-1} and 10.5 m^3 d^{-1}, respectively. Evaporation rate was estimated at 2.8 m^3 d^{-1}, so total wastewater produced by individual farms was 139.8 m^3 d^{-1}, or 0.033 m^3 d^{-1} $head^{-1}$. DM accounted for 0.9%, so average daily biogas production in each farm was estimated to be 415 Nm^3 d^{-1}, or equivalent to 137,033 Nm^3 y^{-1}. Thus, biogas production rate per pig was 32.7 m^3 y^{-1} $head^{-1}$. However, this calculated value was just an average because swine growth stage affects biogas production yield (Amara et al., 2015).

Biogas Quality

In Table 3, CH_4, CO_2, O_2, and H_2S were 59.5%, 31.5%, 1.3%, and 2256 ppm, respectively. O_2 measured in this study might come from air that had entered the biogas system. Its presence suggests that there is also N_2 in the biogas, in a ratio of approximately 4:1. So 1.3% O_2 will mean 5.2% N_2, possibly more. Biogas also contains water vapor, which may then lower CH_4 content. So, less air needs to be mixed for the generator. High H_2S content may reduce the generator lifespan through corrosion. Thus, desulfurizing systems are needed to lower its content before running any biogas generator. Nevertheless, the measured biogas quality was similar to a study by Sweeten, Fulhage, and Humenik (1981), who reported 50-60% methane, 40-50% CO_2, and H_2S <10,000 ppm. Dumont (2015) reported higher methane content (60-70%), lower CO_2 content (30-40%), and H_2S (10-20,000 ppm) for biogas produced from organic waste.

Table 3 Biogas quality measured on the pig farms that had biogas systems (N = 9)

Biogas quality	Unit	Mean ± SE	Min	Max
CH_4	%	59.5 ± 3.0	52.0	64.5
CO_2	%	31.5 ± 2.8	26.9	40.0
O_2	%	1.3 ± 0.7	0.1	3.0
H_2S	ppm	2,256 ± 504	818	3,295

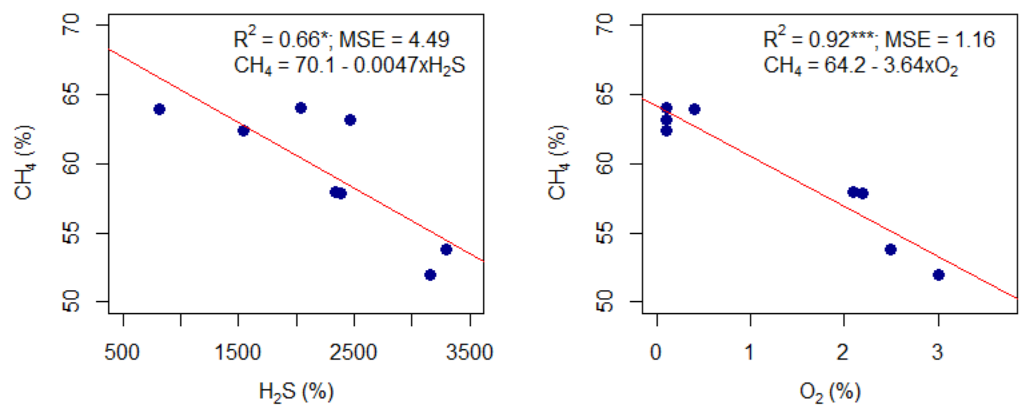

Fig. 2 Relationships between CH_4 and H_2S (left); CH_4 and O_2 (right); sample size (N = 9)

In Fig. 2, CH_4 had a negative relationship with both H_2S and O_2, meaning that increased concentrations of H_2S or O_2 may lower CH_4 content. H_2S reduction is made possible by desulfurization through the use of desulfurizing systems, and O_2 reduction by preventing air from entering the system through proper sealing. However, Siripat (2019) and Deublein and Steinhauser (2011) reported that increased H_2S content reduces biogas quantity, not CH_4 directly.

Methane Production, Electricity Generation and CO_2 Reduction

In table 4, annual electricity production in each farm was estimated to be 178,142 kWh y^{-1}, but varied by farm size. Pig weight varies by month, or by age, so does daily manure production. Daily biogas production also varies accordingly, but tends to increase constantly from early production to the end of the cycle. At the same time, electricity demands at the farms also showed variations, as the need for barn cooling varied with pig age and daily outside temperature. Thus, not all biogas could be used to produce electricity. In the study, the estimated average annual electricity demand for each farm was 166,667 kWh y^{-1}, and electricity produced from biogas could meet only an average of 75%, or 127,700 kWh y^{-1}. This estimation may vary according to farm production size.

Biogas systems also contribute to reduction in greenhouse gas emissions. In this study, the annual CO_2 reduction equivalent was estimated to be 2,832 $tCO_2eq\ y^{-1}$ in each farm. This amount was huge, and further reduction could be achieved when more and more farms turn to using biogas systems. In short, about 0.676 $tCO_2eq\ y^{-1}$ $head^{-1}$ could be reduced per pig. This CO_2 reduction equivalent was higher, when compared to Peerapong and Limmeechokchai (2017), whose estimatin was 0.469 tCO_2eq

y^{-1} $head^{-1}$ for a typical pig farm in Thailand. Thus, a business model should be considered for wider adoption of biogas systems for farm benefits and for the environment.

Table 4 Estimation of electricity demand potential and CO_2 reduction (N = 9)

Description	Unit	Value
Potential electricity production	kWh y^{-1}	178,142
Estimated electricity for farm coverage	kWh y^{-1}	124,700
Estimated farm demand	kWh y^{-1}	166,667
Percentage of farm coverage from biogas	%	75
CO_2 reduction	Unit	
From CH_4 reduction equivalent	tCO_2eq y^{-1}	2,751
From grid electricity equivalent	tCO_2eq y^{-1}	82
Total		2,832
CO_2 reduction per head/year	tCO_2eq y^{-1} $head^{-1}$	0.676

CONCLUSION

Commercial pig farms in Cambodia were studied in terms of pig production, wastewater use for biogas systems, electricity demands and contribution to CO_2 reduction. It can be seen that these farms are typical, and some already used covered lagoons to produce biogas. The farm size is huge, and there is a high potential for further development of biogas systems that may benefits socially, economically, and environmentally. However, further studies shall be made on profitability of actual biogas investment as a model for farm investment and policy making.

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) that not only provided funding, but also continuously assisted in strengthening the research team. Many thanks may also go to the farm owners that allowed for the interviews and site visits and to local authorities that helped facilitate the connections among us.

REFERENCES

Agriculture and Horticulture Development Board. 2019. How much water do your pigs need? AHDB Quarter report.

Amaral, A.C., Kunz, A., Steinmetz, R.L.R., Scussiato, L.A. and Tapparo, D. 2015. Anaerobic digestion of swine manure: Stratified production units and its biogas potential. IV Symposium on Agricultural and Agroindustrial Waste Management.

Council of Ministers. 1999. Sub-degree on water pollution control. Phnom Penh, Cambodia, Retrieved from http://www.cambodiainvestment.gov.kh/wp-content/uploads/2011/09/Sub-Degree-27-on-Water-Pollution-Control_990406.pdf

Department for Environment Food and Rural Affairs. 2011. Fertilizer manual. Agricultural Document Library, University of Hertfordshire, Hertfordshire, UK, Retrieved from http://adlib.everysite.co.uk/adlib/defra/content.aspx?id=2RRVTHNXTS.88UF9X3S7QMDH:

Deublein, D. and Steinhauser, A. 2011. Biogas from waste and renewable resources (2nd ed.). Weinheim, WILEY_VCH Verlag GmbH & Co. KGaA.

Dumont, A. 2015. H_2S removal from biogas using bioreactors: A review. International Journal of Energy and Environnement, International Energy & Environment Fondation, 6 (5), 479-498. hal-01945143, Retrieved from https://hal.archives-ouvertes.fr/hal-01945143/document

EESI. 2017. Fact sheet - biogas: Converting waste into energy. Environmental and Energy Study Instute, Washington DC.

IPCC. 2014. Anthropogenic and natural radiative forcing. Intergovernmental Panel on Climate Change, Retrieved from https://www.ipcc.ch/site/assets/uploads /2018/02/WG1AR5_ Chapter08_FINAL.pdf

Kulpredarat, N. 2016. The impact of pig wastewater to water environment in Thailand. Department of Livestock Development, Bankork, Thailand.

MAFF. 2018. Prakas 549. Ministry of Agriculture, Foresty, Fisheries, Phnom Penh.

MAFF. 2019. MAFF Annual report 2018-2019. Ministry of Agriculture, Forestry, and Fisheries, Phnom Penh.

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 from the Royal University of Agriculture, Phnom Penh, Cambodia.

NBP. 2019. Market study on medium-scale and large-scale biodigesters. National Biodiester Programme, General Department of Animal Production and Health.

Nokyoo, C. 2016. Swine waste management in Thailand. The 11th Annual Meeting of Water Environment Partnership in Asia (WEPA), Workshop and Field Visit in Vientiane, Lao P.D.R.

Peerapong, P. and Limmeechokchai, B. 2017. Biogas-based electricity generation in swine farm in Thailand: Economic and CO_2 reduction aspects. Energy Procedia. Elsavier, 657-661.

Siripat. 2019. Fundamental of biogas. Energy Research and Development Institute, Chiang Mai, Thailand.

Sweeten, J.M., Fulhage, C. and Humenik, F.J. 1981. Methane gas from swine manure. Michigan State University, Retrieved from https://archive.lib.msu.edu/DMC/Ag.%20Ext.%202007-Chelsie/PDF/e1532-1981.pdf

Thanapongtharm, W., Linard, C., Chinson, P., Kasemsuwan, S., Visser, M., Gaughan, A.E., Epprech, M., Robinson, T.P. and Gilbert, M. 2018. Spatial analysis and characteristics of pig farming in Thailand. BMC Veterinary Research, 12, 218.

Tokhun, N. 2010. Piggery farm wastewater: Alternative solution for agriculture and soil fertility. International Journal of Environmental and Rural Development, 1 (2), 55-61.