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Geographical Information System Based Planning and Economic Assessment of Centralized and Decentralized Biogas Plants for Electricity Generation

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Biogas plant could sustainably solve the waste issues in the high-intensity area of small-scale swine farms. Additionally, it can provide additional revenues by selling electricity and fertilizer. Accordingly, this work was to find the optimal business models of centralization and decentralization biogas plants by considering the suitable biogas plant location and transportation in Ratchaburi province, Thailand. Geographical Information System (GIS) and economic assessment of two operation models were considered. The central feature function with simple additive weight was used to analyse the suitable biogas plant location while the suitable transportation route for collecting feedstock was analysed by the function of network analysis. The analytical results showed that the optimal location of the 0.1 MW biogas power plant was located at Mueang Ratchaburi district where the highway was connected with the location of the power plant making convenient for transportation. The shortest travel distance in one trip per day from selected small-scale swine farms was 96 km. In addition, the economic assessment of operational models between centralization and decentralization was compared by considering financial indicators including net present value (NPV), internal rate of return (IRR), benefit-cost ratio (B/C), and payback period (PB). The costs of biogas plants comprising transportation cost of feedstock, investment, operating and maintenance costs, and benefits of biogas plants were considered. The results of the economic feasibility analysis of the different operational models revealed that centralization was optimal, feasible, and profitable. The NPV, IRR, B/C, and PB were 664,430 USD, 28 %, 3.38, and 4.02 years, respectively.

1. Introduction

Nowadays, the world energy consumption has been increasing every year according to the continuous growth of the world population. This results in the increase in electricity demands and services for its development (Pinas et al., 2019). For this reason, a share of fossil fuel use increases, leading to the rising of climate change and environmental impacts. Therefore, many countries bring the use concept of sustainable energy to consideration, mitigating the energy and environmental issues as well as meeting the social and environmental needs, and future economic development (Mainali and Silveira, 2015).

Biogas is a biomass-derived fuel which becomes one of the most promising choices and a very attractive renewable energy source (Khan et al., 2015). The process of biogas production provides a cheap solution and solves the problem of waste management. Biogas is produced by anaerobic digestion using organic material feedstocks such as animal manure, agriculture residues, household wastes, and wastewater, etc. As part of

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by-products of biogas production, fertilizer enables the recycling of nutrients (Wiwatwongwana et al., 2019). Biogas mainly contains methane (CH_4) which can be used as fuel for electricity generation (Chuichulcherm et al., 2017). Moreover, biogas utilization is considered a solution for balancing between business management and environmental management for converting waste to energy (Saikaew et al., 2010). Thai government recognizes the benefit of biogas. For this reason, the policy of the Alternative Energy Development Plan (AEDP) has the target to increase a share of electricity generation to 30 % of the total energy consumption in the year 2036 to generate 1,280 MW from biogas (Achawangkul, 2017).
The Department of Livestock Development of Thailand has reported that animal husbandry, especially swine, has a great number of around 95 % for domestic consumption and swine farming is distributed all over the country. The waste management of swine farms like wastewater and manure is one of the most important and that is much of a concern because the waste of swine husbandry is highly dirty and causes environmental pollution. To reduce problems of waste management and pollution, the transformation from waste to energy using the biogas production method is the best solution as well as the increase in the proportion of renewable energy in the total energy generated in Thailand (Achawangkul, 2017). However, the comparison between the amount of biogas production and the potential of production and utilization of renewable energy can be indicated by the capable loss of about 61 Mm^3/year biogas production. This loss is mostly in small-scale swine farms where biogas could have been produced but lack of the appropriate method in building biogas production system for increasing the potential and effective in biogas utilization (DEDE, 2014).
The waste management of swine farms via biogas production needs to identify the suitable biogas plant location, and the shortest and feasible transportation networks in collecting feedstock for reducing the total costs of electricity generation and energy consumption. GIS is a versatile software tool to produce geographical information for management and analysis of spatially varying parameters. It has been used for assessment of biomass-availability, identification of the optimal plant location, and selection of the suitable road transport network (Brahma et al., 2016).
The economic feasibility of biogas production is highly related to various parameters such as investment, operating and maintenance cost and product prices. However, the costs for biomass and the revenue from the energy produced are the major factors influencing profitability (Sabki et al., 2018). The objective of this work is to find the optimal operational model of biogas plant by considering the suitable biogas plant location and the shortest and feasible transportation networks in Ratchaburi province, Thailand using GIS and comparing the economic assessment of operational models between centralization and decentralization.

2. Materials and methods

2.1 Study area

The small-scale swine farms in Ratchaburi province were considered in this study because this province has the highest amount of fattening swine of Thailand (ICT, 2014). The amount of swine in small-scale farms is defined 50-500 fattening swine. The number of small-scale swine farms in each district of Ratchaburi province was found by investigating through field survey to find the high-intensity area of small-scale swine farms in Ratchaburi province. The amount of manure of swine from each small-scale farm was collected for estimating a daily basis as obtainable biomass feedstocks. The values of specific swine manure yield are taken from literature as manure of fattening swine averaged 3.8 kg/day (Kiratikarnkul, 2010). The locations of small-scale swine farms were identified by the global positioning system (GPS).

2.2 Potential of biogas production, methane yield, and electricity generation

The potential of biogas production is calculated as presented in Eq(1), which can be produced through digestion per unit of mass of swine manure under mesophilic conditions. In this study, swine manure is considered as a potential feedstock and covered lagoon is used as the digestion system. The value of total solids (TS) in fresh swine dung is 8 % while the value of volatile solid (VS) in total solid is 80 %. The value of the biogas produced per kilogram of the volatile solid is 0.5 m^3 (Pipatmanomai et al., 2009). The methane yield is calculated using the 68 % methane fraction of biogas (Chuichulcherm et al., 2017). Moreover, the operation of the power plant is considered 24 hours. The calorific value of methane is 35.78 MJ/m^3 while the efficiency of the overall conversion is considered as 33 % of electricity generation (Brahma et al., 2016).

$$\text{Biogas yield } (\text{m}^3/\text{kg of waste}) = \text{Biogas yield} \left(\frac{\text{m}^3}{\text{kg of VS}}\right) \times \text{TS } (\%) \times \text{VS } (\%) \quad (1)$$

2.3 Biogas plant location and transportation networks

The suitable biogas plant location was identified by using GIS programing. The favorable biogas plant location was at site with high raw material availability supply and easy transport of the raw material to the production site. The maps of small-scale swine farm locations, road network, land use, and the watershed of the study area were used by converting to digital format using ArcGIS software and integrating using the overlay technique. Then, the central feature function with the simple additive weight of ArcGIS software was used to analyse the suitable biogas plant location. The suitable transport network was found by considering the shortest and cost-effective transportation network in transport swine manure or biogas using network analysis of ArcGIS software in planning and road classification including highway, main road, and rural road.

2.4 Operational models of biogas plants between centralization and decentralization

The operational model of biogas plant can be divided into two main systems including centralization and decentralization. These systems were considered for increasing the potential of biogas utilization from small-scale swine farms to biogas plant for electricity generation. Centralization is characterized as a large biogas plant. The waste materials are collected from many places of waste source to keep in one place, where normally biogas plant, and the biogas produced can be treated to upgrade the quality of biogas at the same place of biogas plant for utilization as needed. The centralization consists of four components which are feedstock collection, biogas production on the biogas plant, biogas treatment, and biogas utilization. Decentralization is characterized as individual on-site systems where waste source is located near the biodigester. The produced biogas has to be transported to the biogas plant for purification and upgrading in utilization as needed. The decentralization consists of four components which are biogas production on farms, biogas collection, biogas treatment, and biogas utilization.

2.5 Economic analysis

The economic assessment is calculated to investigate the feasibilities of operational models from small-scale swine farms to biogas plant. In this study, the discount rate of 5 % and 20 years of project lifespan were considered. The system of electricity generation was assumed to operate at 80 % of time per year. The 90 % of total generated electricity was sold to the national grid while 10 % of total generated electricity was used in the system. The price of electricity from Feed-in Tariff (FIT) is considered as 0.12 USD/kWh for 20 years (IEA, 2015). The amount of fertilizer production was about 70 % of total amount of collected swine manure. The price of fertilizer is considered as 46.88 USD/t (Nanagarden, 2019). The debt to equity ratio of projects for centralization and decentralization were considered 60:40. Moreover, the depreciation of project was taken in flat rate basis considering project life to be 20 years. The economic parameters used for the analysis were the net present value (NPV), internal rate of return (IRR), benefit-cost ratio (B/C), and payback period (PB) (He et al., 2013).

3. Results and Discussions

3.1 Suitable biogas plant location and transportation network

The study area is the high-intensity area of small-scale swine farms in Ratchaburi province, Thailand. There are 3 districts including Photharam, Pak Tho, and Mueang Ratchaburi having 12, 11, and 11 farms, respectively. The amount of swine manure and the potential of biogas production and electricity generation in the study area are shown in Table 1. The total amount of swine manure in the entire study area is about 2.85 t/day, and this is a dry matter. The potential of biogas production and CH_4 yield that can be produced according to the total amount of collecting swine manure is 1,140.57 m^3/day and 775.58 m^3/day, respectively. The CH_4 yield of biogas will be used to produce electricity. The potential of CH_4 yield is sufficient to generate approximately 0.1061 MW of electricity. Therefore, the size or capacity of the biogas power plant suitable in this study area is 0.1 MW.

The various types of maps including locations of small-scale swine farms, road network, land use, and watershed of the study area were used to combine and consider for analysing the suitable location of the power plant. The GIS result of suitable location analysis of 0.1 MW biogas power plant is illustrated in Figure 1. Moreover, small-scale swine farms which supply manure and/or biogas to the power plant for generating 0.1 MW of electricity were also considered and selected to minimize the transportation cost. The number of selected small-scale swine farms is 31 farms which are shown in the green colour of the map (Figure 1). The 0.1 MW power plant is located at Mueang Ratchaburi district of Ratchaburi province, Thailand which is the centre part of the selected small-scale swine farms. In addition, it can be seen that the highway is connected with the location of the power plant making convenient for transportation. The values of latitude and longitude of the power plant location are 13.496646 and 99.830187, respectively. The map of the shortest travel route from the biogas power plant to selected small-scale swine farms for 0.1 MW size is presented in Figure 2. The shortest travel distance for collecting swine manure and/or biogas in one trip per day from 31 of selected small-scale swine farms was 96 km. The CH_4 yield requirement of 736 m^3/day for 0.1 MW electricity generation could be fulfilled from gathering the amount of swine manure and/or biogas yield which was 2,707 kg/day and 1,083 m^3/day, respectively

Table 1: Potential of biogas production and electricity generation in the study area

District	Number of small swine farms	Amount of swine manure (kg/day)	Biogas production (m^3/day)	Potential CH_4 yield (m^3/day)	Power potential (MW)
Pak Tho	11	1,203.26	481.31	327.29	0.0447
Photharam	12	841.36	336.54	228.85	0.0314
Mueang Ratchaburi	11	806.79	322.72	219.45	0.0300
Total	34	2,851.42	1,140.57	775.58	0.1061

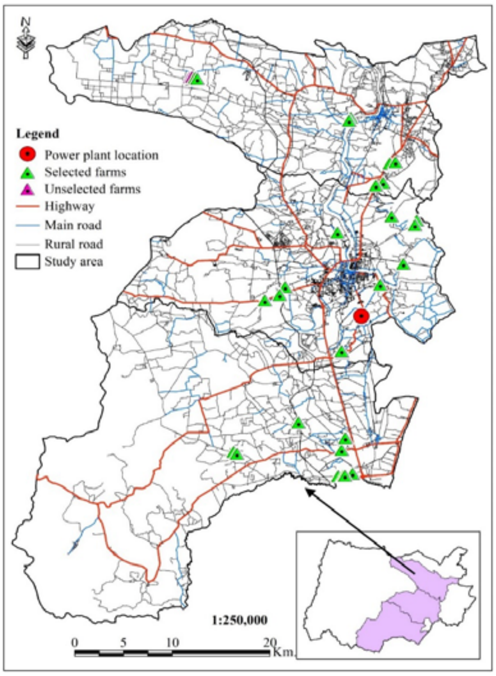

Figure 1: The suitable location of the 0.1 MW biogas power plant

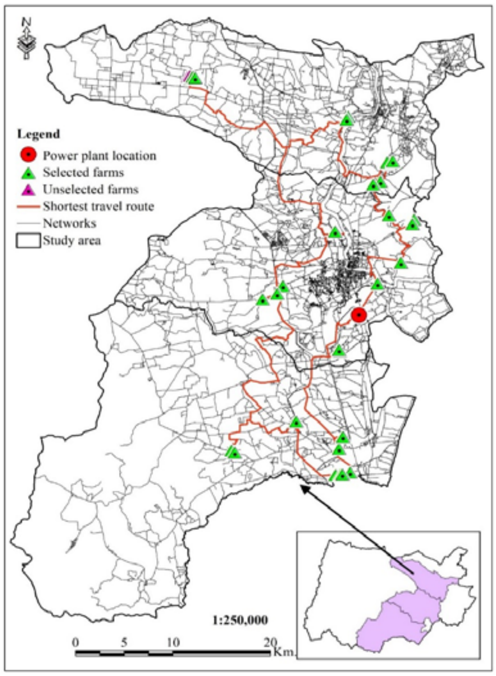

Figure 2: The shortest travel route from the biogas power plant to selected small-scale swine farms

3.2 Economic assessment of operational models

Various costs and revenue associated with operational models are listed as shown in Table 2. The operational models including centralization and decentralization were considered. The initial investment of centralization consists of four components which are feedstock collection, biogas production on the biogas plant, biogas treatment, and biogas utilization. The feedstock collection involved the cost of a fecal suction truck which can carry 3 t/trip of swine manure. The biogas production on the biogas plant involved the cost of covered lagoon digester which can produce about 1,083 m^3/day of biogas. The biogas treatment involved the cost of modified water absorption for eliminating some impurities before injecting into the generator. The biogas utilization involved the cost of electricity generation. Therefore, the total initial investment for the operational model of centralization was 279,319.25 USD. The initial investment of decentralization is similar to centralization but there are two different components, which is biogas production on farms and biogas collection. The biogas production on farms involved the cost of cover material to cover their lagoon for producing biogas. The biogas collection involved the cost of a gas truck which can accommodate 1,099 m^3 of biogas. Therefore, the total initial investment for operational model of decentralization was 422,035.63 USD. Another component of cost is the operating and maintenance costs of the project, which was kept at 10 % of the initial investment. The operating and maintenance costs included the cost of water, fuel, labor, equipment replacement, scheduled maintenance, insurance of project, etc. It can be seen that the cost of the project for decentralization is higher than the centralization. The revenue generated by the project for centralization and decentralization was considered according to the products generated by the biogas plant, which is in the benefit part. It can be seen that the revenue for centralization are obtained from sale of organic fertilizer and sale of electricity while the revenue for decentralization are obtained from sale of electricity only.

Table 2: Costs and revenue of the operational models of biogas plant

Items	Operational models	
	Centralization	Decentralization
1. Initial investment (USD)		
(a) Feedstock collection		
- Fecal suction truck	32,460.00	-
(b1) Biogas production on the biogas plant		
- Covered lagoon	19,687.50	-
(b2) Biogas production on farms		
- Cover material	-	116,250.00
(c) Biogas collection		
- Gas truck	-	78,613.88
(d) Biogas treatment		
- Modified water absorption	186,399.00	186,399.00
(e) Biogas utilization		
-Electricity generation	40,772.75	40,772.75
Total initial investment	**279,319.25**	**422,035.63**
2. Operating and maintenance cost (USD/year)		
(a) Labour cost	14,321.44	14,321.44
(b) Fuel cost	6,122.00	6,122.00
(c) Operating and maintenance cost	7,488.50	21,760.13
Total operating and maintenance cost	**27,931.94**	**42,203.57**
3. Benefit (USD/year)		
(a) Electricity	74,109.60	74,109.60
(b) Fertilizer	32,216.95	-
Total Benefit	**106,326.55**	**74,109.60**

The analysis of economic feasibility was aimed to make a decision to find the optimal operational model for use with small-scale swine farms. The considered financial indicators included net present value (NPV), internal rate of return (IRR), benefit-cost ratio (B/C), and payback period (PB). The results of the economic feasibility analysis on the different operational models of biogas plant are shown in Table 3. Based on the assumptions, the investment in the projects from centralization was feasible according to the positive NPV and IRR which is higher than the discount rate while decentralization was not feasible according to the negative NPV and IRR which is lower than the discount rate. Moreover, the B/C ratio value for the centralization was larger than one but the decentralization was lower than one. This confirmed that the project of centralization was profitable while the project of decentralization was not profitable. However, the centralization offers better financial benefits as shown in Table 3. In addition, the PB of centralization was shorter period than that of decentralization. This means that the project for centralization offered a shorter investment time.

Table 3: Results of the economic feasibility analysis

Economic indicators	Centralization	Decentralization
Net Present Value (NPV)	664,430 USD	- 23,253.21 USD
Internal Rate of Return (IRR)	28 %	4 %
Benefit-Cost ratio (B/C)	3.38	0.94
Payback period (PB)	4.02 years	22.20 years

4. Conclusions

Finding the optimal operational biogas plant model, a suitable location in Ratchaburi province with the shortest transportation networks was investigated by GIS. The results showed that there are three high-intensity areas of small-scale swine farms in Ratchaburi province including Photharam, Pak Tho, and Mueang Ratchaburi. Among these three areas, the most suitable 0.1 MW power plant is located at Mueang Ratchaburi where the travel route from the biogas power plant to the selected small-scale swine farms is shortest (96 km). The economic assessment of operational models found that the centralization was more profitable than the decentralization model with the NPV, IRR, B/C, and PB of 664,430 USD, 28 %, 3.38, and 4.02 years, respectively.

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