Economics of Rural Domestic Biogas Development: Applying Spatial Analysis to Evaluate Profitability

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Abstract. The aim of this paper is to calculate the profitability of communal anaerobic digester (AD) development in rural area. For that purpose, spatial cluster analysis is used to determine the cluster size and location for low affordability of non-biogas farmers to construct individual anaerobic digester. Cluster size is characterized by the number of households and the spatial proximity among the cluster member, while cluster location is determined by the land suitability. The potential energy production for each cluster is calculated afterwards as it may be distributed to non-farmer households. Meanwhile, the economics of communal (AD) is estimated using the Net Present Value, the Internal Return Rate, the Payback, and the Profitability as Return/Investment Ratio. As a result of the study, we have attained energy values ranging between 193,026.6 (MJ/yr) and 649,510.2 (MJ/yr). The BCR varies for both communal and individual AD which is 1.57 – 1.61 and 1.28 – 1.46, respectively. Furthermore, the calculation shows that Net Present Value, Internal Return Ratio, Payback, and profitability is US$ 12,112, 18%, 4.3 years and 110% respectively.

1. Introduction

These The Government of Indonesia (GoI) has set out the National Energy Policy targeting increase of share of renewable energy (RE) in final energy consumption which was below 4% in 2011 to 23% by 2025 [[1]. It includes also increase of share of biomass, including waste, in RE final energy consumption which was 0.5% in 2014 to 2.4% by 2025 [2]. The use of biomass for energy production is promising in Indonesia, since the source are abundant, i.e. crop residue waste, domestic waste and manure waste but the utilization is relative low. According to [2], total biomass potential for electricity is 32,654 MW, while the installed capacity is only 1,626 MW (5%).

Biological treatment of biomass, such as anaerobic digestion can produce biogas as energy sources [3]. Biogas is a mixture gas primarily composed of methane and carbon dioxide. Biogas utilization offers some advantages appropriate for many different application areas. It is flexible in production and consumption since it can be produced when it is required, applied for the medium level of technology and economic aspect and easily to be stored [4,5]. Therefore, biogas can be consumed for cooking to substitute conventional domestic energy source i.e. liquid petroleum gas (LPG), charcoal and firewood and for transportation [6].

Livestock manure is a potential source for biogas production, especially in rural areas with geographical setting hindering access to on-grid network since it can be processed even by using smallest AD capacity of 4 m³ [7]. However, biogas development in rural areas is relatively deliberate, especially in developing countries. The main disadvantage of AD is the return on investment caused mainly by the high initial cost mostly spent on construction and the relatively low degradability rate of
waste, especially manures [8,9]. The construction cost can be reduced by grouping the non-biogas farmers into clusters because it is shared among the farmers [7]. Planning rural biogas development considers some spatially related requirements due to geographical dependence. In most cases, location of biomass supply and biogas demand is scattered. Therefore, geographical data consisting of land suitability, land availability and distance between AD and household (HH) is necessary. The use of geographical information system (GIS) approach can fulfil this demand. Previous studies have used GIS to find the appropriate sites for biogas plant [10,11]. Using GIS, [12] evaluated the potential of biogas production from livestock waste as well as from forage crops.

Referring the above review, this study attempts to identify the potential rural biogas energy from livestock manure and to develop a spatial plan allocating the appropriate location for AD based on the GIS. The profitability of AD construction is evaluated afterwards.

2. Method

2.1. Data collection
The research is conducted in Galengdowo Village. There are 152 farmers raising 641 cows. Currently, only 14.09% of total cows has been utilize for biogas production. The rest either being used for fertilizer or being thrown away to the ditch or river. Fixed dome is the common type of AD used in the area with the variety of capacity ranging between 4 m³ and 12 m³ for individual or communal AD. A cross-sectional survey was conducted by collecting primary and secondary data through surveys carried out between March and May 2017. Primary data were collected through questionnaires, interview and observation. The questionnaires were developed and evaluated beforehand for unambiguity and refinery. Some previous studies and office reports related to the topic were used as secondary data sources to compose rationales of the study, to cross-validate statistical results, as well as to support arguments. More detailed information is attained from respondents using a standard open-ended interview.

2.2. Spatial Cluster Analysis
Spatial cluster analysis (SCA) is usually used to analyze the pattern of distribution of objects’ data considering their proximity describing the similarity of the objects. The proximity and cluster boundary are calculated using K-Nearest Neighbor Method in which the value indicates mean of distance of the objects. In this study, lots are the objects and their location are identified as either clustered, random, or dispersed. SCA also calculates the average distance among the objects used as the average maximum radius to form a group of objects. There are two indicators i.e. critical value and significance level should be within the limit to identify that the distribution pattern of the objects as showed in Figure 1. Distribution pattern is clustered if the value is not more than 1, -2.58 and 0.01 for nearest neighbor ratio, z-score, and p-value, respectively. Geographical data for SCA are number of lots and area of the village, which are 1462 and 968,990 m², respectively.

![Figure 1. Indicators used in Spatial Cluster Analysis](image-url)
2.3. Energy Calculation
In this study, the theoretical biogas potential is specified as the possible amount of biogas generation from manure waste. According to [13] biogas potential can be calculated using some parameters i.e. livestock weight, typical biogas production per kg manure, typical methane content and the ratio of the annual manure generation to livestock weight. Since cows is the only livestock in the village, the parameters refer to cow as shown in Table 1. With this purpose, information about the number of cows and cow weight was surveyed. The average weight of cow was estimated according to samples which typically ranges between 350 and 500 kg. There is no direct measurement for the total biogas generation. Therefore, methane potential was calculated using Eq. (1).

\[
TBP = cp \ast awm \ast 0.033 \ast 0.65
\]  

where \( TBP \) stands for the theoretical biogas potential (m\(^3\)/year), \( cp \) is the cow population, \( awm \) denotes for average weight of cow manure and 0.033 is the biogas production rate[14] and 0.65 is the methane content in biogas [15]. Calculation of energy generated from methane (MJ/year) was conducted afterwards using Eq. (2) according to [13].

\[
E_{\text{methane}} = TBP \ast ECM
\]

where \( TBP \) (m\(^3\)/year) and ECM (36 MJ/m\(^3\)) denotes for the theoretical biogas production and the coefficient of methane energy content respectively referring to Table 1.

| Cow weight | Volume of produced biogas m\(^3\)/kg* | Methane content % | Methane energy content MJ/m\(^3\) |
|------------|-------------------------------|------------------|-------------------------------|
| 350 - 500  | 0.033 – 0.04                   | 55 – 65          | 36                            |

*according to [14]

2.4. Cash flow analysis
The initial investment of AD construction consisting of material, labor and fuel is estimated firstly. Benefits from the domestic biogas model are estimated from the savings made by biogas replacing the use of firewood and liquid petroleum gas (LPG). Cost and benefits of biogas system are used to calculate the following indicators of profitability with a life span period of 5 years referring to the local condition, i.e.:  
1. Net present value (NPV) at a marginal discount rate of 5.25%. Inflation rate and depreciation are not considered.
2. Simple Payback period (PBP) calculated based on the annual discounted cash flow.
3. Project internal rate of return (IRR) was calculated.

The NPV converts expected future cash flows of a project into their present values [16] Therefore, NPV is the total present values of a project's cash flows. If it is more than zero, the project is profitable during the period and vice versa [17]. The higher the NPV of a proposed project, the higher the profitability [18]. Furthermore, PBP was also calculated to express the actual economics of a facility according to [19] and [20]. PBP is the time when the NPV reaches zero [21,22]. The internal rate of return (IRR) was also calculated as the inverse of the pay-back [23]. Eq. (3) – (5) were used to estimate the NPV, PBP and IRR, as proposed by [24]. Meanwhile, Profitability (PROF) in percentage was calculated using Eq. (6). It is a ratio between NVP and initial investment for the AD as proposed by [25].

\[
NPV_t = -C_o + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_t}{(1+r)^t}
\]  

\[
0 = \sum_{t=1}^{N} NPV_t - \frac{C_t}{(1+r)^t} - C_o
\]
\[ IRR = \frac{1}{PBP} \quad (5) \]
\[ PROF = \frac{NPV_n}{C_0} \quad (6) \]

3. Result and discussion

Two-month survey is conducted to collect the data of socio-economic and demographic household (HH) in the area of study (Galengdowo Village), including the geographical setting to conduct SCA. The result of SCA showed that all values meet the criteria for clustering, which is 0.88, - 8.54766, and 0.00 for nearest neighbor ratio, z-score, and p-value respectively. The observed and expected mean distance is 11.3681 meter and 12.8723 meter, respectively. Cluster is formed with maximum radius of 12 meter instead of 13 meter considering that shorter distance includes fewer houses to be one cluster enabling easier biogas management due to technical requirements.

AD with the capacity of 6 m³, 8 m³, 10 m³, 12 m³ is a common type in this village to process the manure waste. The AD price is proportional to the capacity ranging between Rp. 4.500.000. – Rp.12.000.000. The exchange rate used in the study was: 1 US$ = Rp. 13,350. Using Eq. (1) – (2), the energy production from biogas was calculated and the results are presented in Table 2. Meanwhile, the components for profitability calculation of biogas development is presented in Table 3.

| Table 2. Energy potential in 2 community units in Galengdowo Village |
|---------------------------------|-------|-----------------|-----------------|
| Unit   | Energy potential (MJ/yr) | Potential of energy demand (MJ/yr) | Potential of unused energy (MJ/yr) |
|--------|--------------------------|-----------------------------------|-----------------------------------|
| 1      | 2,664,792                | 649,510.2                         | 2,015,150                         |
| 2      | 1,450,656                | 193,026.6                         | 1,257,629                         |

| Table 3. Calculations of the main parameters necessary to estimate profitability |
|---------------------------------|-------|-----------------|-----------------|----------------|----------------|
| Year    | Total investment (US$) | Potential of energy distribution (MJ/yr) | Potential annual income from sale of biogas (US$) | Operating costs or maintenance costs (US$) | Finance costs (US$) | Cash flow (US$) |
|---------|------------------------|------------------------------------------|-------------------------------------------------|---------------------------------|--------------------|-----------------|
| 1       | 295.02                 | 2,664,792                               | 154.98                                          | 29.52                           | 12.75              | -182,310         |
| 2       | 1,450,656              | 154.98                                  | 29.52                                          | 12.75                           | 112,710            |
| 3       | 1,009,152              | 154.98                                  | 29.52                                          | 12.75                           | 112,710            |
| 4       | 1,624,104              | 154.98                                  | 29.52                                          | 12.75                           | 112,710            |

4. Conclusion

Please the investment under study is sufficiently profitable in terms of NPV, profitability ratio of return on investment and Payback. The result can be concluded as follows:

1. Based on BCR calculation, the average BCR for all ADs is 1.57 – 1.61 for communal AD and 1.28 – 1.46 for individual AD.
2. The average PBP is 4.3 years where 12% Farmers (109) has PBP less than 4 years and 88% farmers (15) has PBP more than 4 years as the typical lifetime of the AD.
3. IRR is 18% which is above the interest rates of the market (9%).
4. Profitability is 110 % indicating cash inflow is higher than cash outflow.

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