International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-7 Issue-4s2, December 2018

Multi-criteria Evaluation for Determination of Anaerobic Di-gester Location in Rural Area

Christia Meidiana, Istiq Dhany Nurfitriya, Kartika Eka Sari

Abstract: ***Multi-criteria analysis is used in this study to support the decision making of choosing the suitable location for anaerobic digester (AD). Land availability is the main factor in the area of study influencing the interest of farmers to utilize manure for biogas production indicated by low manure utilization rate which is only 22%. The rest is disposed of in ditches and streams threatening the environment. Analytical Hierarchy Process (AHP) comprising four criteria, land suitability, land availability, farmer's capability, and safety requirement are used to assess the most appropriate AD scale in the study area. The most suitable AD scale has the highest total value. Seven experts in rural biogas management are asked for their opinion about the most appropriate AD scale for processing the manure waste. The result of AHP shows that land availability is the main factor as it has the highest value (77.03%), while farmer's capability, land suita-bility and safety requirement has less value which is 0.1977, 0.0165 and 0.0155 respectively. Furthermore, household scale AD with ca-pacity from 4 m3 – 12 m3 is the most suitable AD scale for the location. However, not all capacities of AD can be necessarily constructed because of land availability factor. Overlay technique is used to identify the location and type of AD. Overlaid of three variables i.e. interest, land availability and cows ownership comes to the result that there are 155 out of 167 farmers interested in constructing AD. There are 75 farmers who meet the land availability criteria, while 80 farmers have no adequate land area for constructing the AD. However, only 64 individual ADs can be constructed when all variables (interest, land availability and cow ownership) are considered. Other farmers who have interest should be construct either the individual AD under the stall (67 farmers) or communal AD (24 farmers).***

Index Terms: ***Analytical Hierarchy Process, Spatial Cluster Analysis, Rural Area, Biogas,***

I. INTRODUCTION

Globally, the use of renewable energy is growing fast in the last decades in response to some occurrences such as increasing energy demand, climate change, and energy security [1]. Some regulations and support mechanisms are implementing to speed up the development of renewable energy sector, worldwide. Indonesia has been introducing some regulations and schemes for national renewable energy development since 2006 through the enactment of the Presidential Regulation no. 5/2006 on National Energy Policy. Targets were set up to address dependence on fossil fuel, share of final energy consumption and carbon emissions.

Biogas from biomass (manure waste) is one of the renewable energies promoted by the Government of In-donesia (GoI). Biogas from manure waste is potential to be developed in rural area for robustness, source availability, geographical settings, and direct economic effect [2, 3, 4, 5]. Nowadays, the trend of biogas utilization for household purposes (cooking, heating, cooling and lighting) is tremendously increasing in South-east Asia countries, including Indonesia. It is more or less is influenced by the promising advantages of biogas com-pared to other renewable energies. Easy storage, flexibility of production time, use of existing gas network for distribution and different kinds of end uses are some of advantages [6]. However, some challenges for biogas technology application in rural areas exist for technical limitations, unskilled human resources, and low affordability of individual farmer [7, 8, 9]. These shortcomings have hindered the rural biogas development worldwide. In Indonesia, some biogas development schemes are introduced to support rural families in constructing small-scale anaerobic digesters (ADs) to produce biogas, i.e. self-sufficient energy village (SSEV) and household biogas (BIRU). Using the schemes, the individual or grouped farmers can propose financial support for construction cost. However, another factor being a hindrance is land availability since AD construction requires a minimum area depending on the amount of feedstock. Dusun Cukal which is situated in dense populated area is facing this problem. MCA-GIS technique is used to analyses suitable location for AD location in the area of study, Dusun Cuka. Some previous studies using MCA-GIS technique in the context of renewable energy development were assessment of the viability of local renewable energy sources [10] and determination of criteria and weights assignment in sustainable bio-energy projects [11]. [12] proposed a MCA-GIS technique to determine location of biomass, while [13] used it for deciding the suitable location for biogas plants. However, all these studies focused on biogas/biomass management on large scale. None of them proposed a small scale bio-gas/biomass management. Therefore, the paper ad-dressed to determine suitable anaerobic digester in rural areas with some limitations for implementing large scale biogas/biomass management, such as inadequate land area, minimum livestock ownership, and farmer's affordability as well as other criteria that should be considered comprehensively. A decision support system is used enabling handling of rough information on the multiple criteria regarding not only technical, but also social and environmental.

Manuscript published on 30 December 2018.
*****Correspondence Author(s)
Christia Meidiana, Faculty of1 Engineering, Brawijaya University, Malang, 65147, Indonesia,
Istiq Dhany Nurfitriya, Faculty of1 Engineering, Brawijaya University, Malang, 65147, Indonesia, (co-first author).
Kartika Eka Sari, Faculty of1 Engineering, Brawijaya University, Malang, 65147, Indonesia (co-first author).

II. MATERIALS AND METHODS

Planning of renewable energy including biogas re-quires multiple aspects to be considered. It involves multiple quantitative and qualitative attributes which has to be analysed not in only one single-phase evaluation. Therefore, the study consist of two phases i.e., decision making of biogas management scale and decision making of AD location based on scale which each involves some indicators. Enabling the evaluation of these multiple indicators, multiple criteria decision aid method is used for choosing the location of biogas plants according to a given set of criteria. The multi-criteria analysis (MCA) allows decision makers to make knowledgeable decisions and attain optimal outputs. Data collected for MCA was gained from primary surveys via questionnaires followed by interviews with non-biogas farmers, while the geographical information is gathered using the ArcGIS 10.1 software [14]. GIS approach is used for spatial cluster analysis. Secondary data were collected from different rural authorities and from key persons who actively promote the biogas management in the study area. All is supplemented with scientific research papers. The location of the research is in the smaller unit of Bendosari Village, called Dusun Cukal. There are 214 farmers raising 581 cows. Currently, 47 farmers are using biogas from manure waste for cooking, while 167 farmers either use the manure waste for fertilizer or throw away to ditches or streams. Fixed dome is the common type of AD used in the area with the variety of capacity ranging between 4 m3 and 12 m3.

2.1 Determination of Relevant Criteria

MCA comprises 3 components i.e. goal, criteria and alternatives. MCA includes defining the problem, setting goals for solving the problem, selecting the appropriate method, generating alternatives, establishing criteria, assigning criteria weights, construction of an evaluation matrix, and ranking of the alternatives [15]). The choice of the decision criteria for MCA is based on some local standards and regulations, and alternative are proposed referring to similar previous studies which is possible to be implemented. There are some methods in MCA which is one of them is Analytical Hierarchy Process (AHP). Analytical Hierarchy Process (AHP) developed by [16] is used to rank alternatives from best to worst. It accommodates the ranking of alternatives and enabling the assessment process in which the experts are requested to assess each level parameter in a pairwise comparison with respect to their parent node. This comparison determines the relative importance of a criterion over the others based on the scale (Table 1). A matrix for pairwise comparison is constructed to determine the priority weight. According to the references and local conditions, there are four general criteria for AHP; (i) Land Suitability, (ii) Land Availability, (ii) Safety Requirement, (iv) Farmer's Characteristic.

In this study, 7 experts are involved to determine the most appropriate AD scale in Dusun Cukal. The scores of each criterion, sub criterion and each alternative are calculated using this matrix. The matrix is normalized by dividing all values in each rows with sum of values of each column resulting value called normalized relative weight which indicates the rank of criteria. The higher the value, the more important the criteria. Since pairwise comparison could be subjective, inconsistency must be checked by using equation of consistency ratio (CR) given by CI/RI. RI is the random consistency index varying according to the number of elements in a comparison (n). CI is the consistency index, which equals to (λmax – n)/(n – 1). Here, λmax are the maximum eigenvalues of the comparison matrix. The value of CR must be at least 0.1 indicating that AHP result is valid for decision making, otherwise the process must be repeated until the CR value meets the criteria.

Distance to Anaerobic Digester

Distance is calculated based on average nearest neighbor value using cluster spatial analysis. Cluster spatial analysis will first identify whether some objects are clustered or dispersed. These objects are considered as a cluster if the results meet the critical values.

Table 1. Value interpretation in AHP

Intensity of Importance (value of A – B)	Definition
1	Objectives A and B are of equal importance
3	Objective A is slightly more important than B
5	Objective A is moderately more important than B
7	Objective A is strongly more important than B
9	Objective A is extremely more important than B
2, 4, 6, 8	Intermediate values to compromise between judgment values

The input for the analysis are the land area of the vil-lage and the settlement generating some values referring to certain default value to identify whether the settlement in the village is clustered or dispersed. The value resulted from the analysis should be less than 1, less than 2.58 and less than 0.01 for nearest neighbor ratio, z-score, and p-value respectively for clustered pattern as showed in Figure 1. Clustered pattern enable grouping the non-biogas farmers. The mean distance is calculated after-wards comprising observed mean distance and expected mean distance. The decision of applied value (observed or expected mean dis-tance) is arbitrary based on certain considerations to create the cluster of farmers for communal AD according to [7].

The number of the members within the cluster is de-termined by the maximum land availability for certain AD capacity. The AD capacity defines the number of cows whose manure will utilized for AD feedstock. The share of livestock is decided by the members depending on the abil-ity to contribute to construction cost. The cost is propor-tional to the number of cows.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

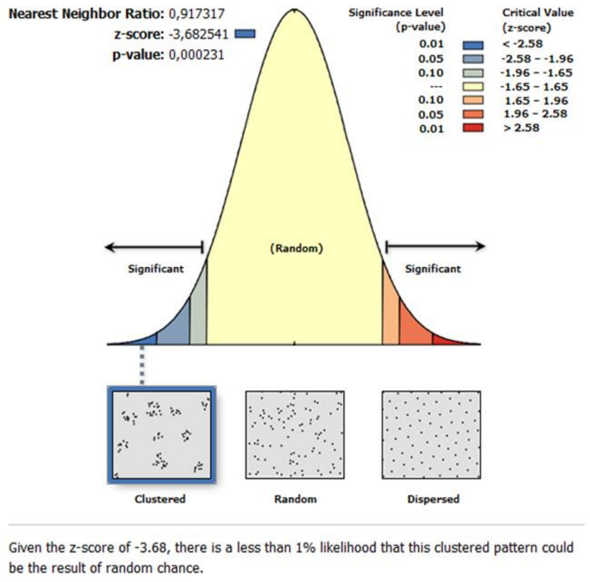

Figure 1. Average Neasrest Neighbor Summary from Spa-tial Cluster Analysis

III. RESULTS AND DISCUSSION

Data of socio-economic and demographic of house-holds (HHs) in Dusun Cukal were collected through the primary and secondary survey for about three months. Generally, there are three different scale for AD, i.e. small medium, and large with capacity between 4 – 50 m3 and the price is proportional to the capacity (Table 2).

Most farmers can not afford the individual AD. Therefore, referring to [7], clustering may increase the affordability since the cost will be shared among the cluster members.

In this study, the total number of cows provided by each group depend on the AD capacity defined by land availability. The larger the capacity, the more biogas will be generated but higher cost must be burdened by the group. Totally, there are 167 non-biogas-farmer in Dusun Cukal where 155 of them are interested in constructing the AD, while 12 farmers are not interested. Reasons for this are:

1. complicated maintenance (7 respondents)

2. getting acquainted with conventional fuel (firewood and gas). The non-biogas farmers who do not have interest in constructing the AD is excluded from the analysis for avoiding the bias result of clustering.

The result of weighing the criteria from each expert in MCA is presented in Table 3. The value of priority vector is used to calculate the value of CI and RI which is 0.369 and 0.9 respectively. Calculating CI/RI comes to CR value of 0.4104 which is less than 0.1 indicating that AHP result is valid and can be used for decision making. Table 4 shows that land availability has the highest value of priority vec-tor followed by farmer's characteristic, land suitability, and safety requirement with priority vector value of 0.1977, 0.0165, and 0.0155 respectively. The value indicates that land availability is the most important criteria. The same procedure is conducted for weighing the sub and the result is presented in Table 5. The result shows that minimum land area is the most important factor within the land availability criteria, while maximum distance from AD to kitchen is the least importance within safety requirement criteria. The values meet the result from the previous calcu-lation of criteria weight.

Based on the final score, small scale AD is the most suit-able type to be constructed in study area since it has the highest percentage. Medium and large scale may be adopted but it is not necessarily appropriate since the per-centage is lower (Fig.2). However, further study must be conducted to identify the location for such scales.

The next step is clustering the farmers through spatial cluster analysis since land availability is the main factor hindering AD construction. Table 6 shows the result from spatial cluster analysis requiring for clustering the objects where in this case is non-biogas farmer's house. All values meet the criteria for clustering which is 0.89, -2.7841, and 0.005368 for nearest neighbor ratio, z-score, and p-value respectively indicating that the settlement pattern in study area is clustered. This pattern enables the grouping of non-biogas farmers easier. The observed and expected mean distance is 12.95 meter and 14.53 meter respectively. Clus-ter is formed with maximum radius of 14.53 meter instead of 12.95 meter considering that longer distance includes more houses to be one cluster allowing inclusion of more non-biogas farmers.

Table 2. Standards for typical anaerobic digester (fixed dome type)

Type	Capacity (m^3)	Gas production (m3/d)	Feedstock (kg/d)	Water (liter/d)	No. of cows	Price (Rp) in million
Small	4 – 12	0,7 – 4	20 – 120	20 – 120	2 – 6	4.5 – 6
Medi um	>12 – 25	2.2 – 8,5	60 – 250	60 – 250	6 – 12	6 – 12
Large	>25 – 50	4.5 - 17	125 – 500	125 – 500	12 – 25	>12

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 3. Criteria weighing by each expert

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Total Value
LS	0,0554	0,0449	0,1257	0,4551	0,0539	0,1678	0,1686	1,0714
LA	0,6930	0,5418	0,2999	0,3494	0,6774	0,1911	0,1323	2,8850
SR	0,1414	0,1697	0,1906	0,1368	0,1122	0,0538	0,0525	0,8569
FC	0,1102	0,2435	0,3838	0,0587	0,1565	0,5873	0,6466	2,1866
Total	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	7,0000

Table 4. Aggregate value of weight from all experts

Criteria	**LS**	**LA**	**SR**	**FC**	**Total**	**Priority Vector**
Land Suitability (LS)	0,0212	0,0243	0,0040	0,0159	0,0653	0,0165
Land Availability (LA)	0,6602	0,7570	0,8937	0,7565	3,0673	0,7703
Safety Requirement (SR)	0,0346	0,0055	0,0065	0,0145	0,0611	0,0155
Farmer's Characteristic (FC)	0,2841	0,2132	0,0958	0,2131	0,8062	0,1977

Table 5. Weight of sub-criteria

No	Sub-criteria	Value
1	Minimum land area (14 m2)	0,7144
2	Number of cow (2 – 5 heads)	0,1633
3	Stall proximity to AD	0,0559
4	Interest to use biogas	0,0302
5	Distance between houses (min. 2 m)	0,0157
6	Average ambient temperature (26°C)	0,0131
7	Soil type	0,0063
8	Number of HH's member	0,0042
9	Land use	0,0034
10	Maximum distance from AD to kitchen (30 m)	0,0013

Based on these value, the group is formed and land availability for small scale AD within the group is identified. The location for AD is determined when it meets the re-quired minimum area for AD.

The next step is clustering the farmers through spatial cluster analysis since land availability is the main factor hindering AD construction. Table 6 shows the result from spatial cluster analysis requiring for clustering the objects where in this case is non-biogas farmer's house. All values meet the criteria for clustering which is 0.89, -2.7841, and 0.005368 for nearest neighbor ratio, z-score, and p-value respectively indicating that the settlement pattern in study area is clustered. This pattern enables the grouping of non-biogas farmers easier. The observed and expected mean distance is 12.95 meter and 14.53 meter respectively.

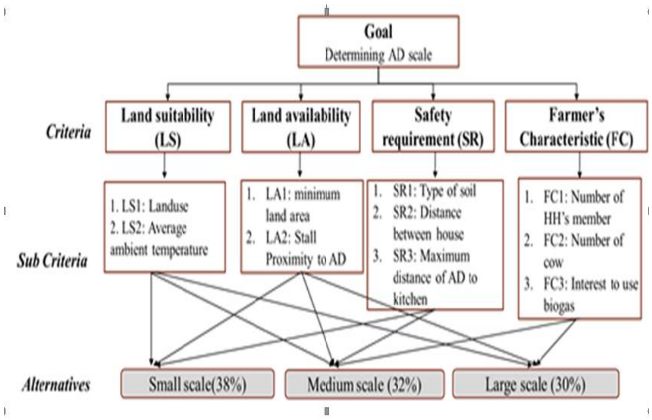

Figure 2. Result of Analytical Hierarchy Process for determining the priority of AD scale

Table 6. The value gained from the Spatial cluster analysis

Parameters	**Criteria**	**Value**
Observed Mean Distance	-	12.953599
Expected Mean Distance	-	14.529663
Nearest Neighbor Ratio	< 1	0,891528
z-score	< 2.38	-2,784103
P-value	< 0.01	0,005368

Cluster is formed with maximum radius of 14.53 me-ter instead of 12.95 meter considering that longer distance includes more houses to be one cluster allowing inclusion of more non-biogas farmers. Based on these value, the group is formed and land availability for small scale AD within the group is identified. The location for AD is determined when it meets the required minimum area for AD.

Overlay technique using 3 different variables, i.e. in-terest, land availability, quantity suitability of cow, is used to identify the appropriate location and AD type.

The analysis produces the following result:

1. There are 64 farmers which can construct individual AD since the land is available. However, only 39 farmers have interest to implement it.

2. There 67 farmers do not meet the requirement of minimum land area. However, 32 farmers want to build the AD under the stall

3. There are 12 farmers cannot meet the suitability quantity of cow and land availability. Communal AD is the best alternative for this group

IV. CONCLUSION

1. Based on AHP, the most suitable AD for study area is small scale AD (individual) with the capacity ranges between 4 – 12 m3.

2. Based on MCA, sub criteria of minimum land area and number of cows is the most dominant indicator in determining the location of AD.

3. Based on land availability analysis, 75 farmers (out of 155) have minimum land area for the smallest AD's capacity(13.75 m2), while 80 farmers do not.

4. Based on the spatial cluster analysis and overlay of map of interest, land availability and cows ownership, 66 AD can be constructed. (39 individual ADs and 27 communal ADs.

REFERENCES

1. REN21 (2012). Renewables 2012. Global status report. Renewable Energy Policy Network for the 21st Century (REN21). Paris: REN21 Secretariat.
2. Al Garni, H., Kassem, A., Awasthi, A., Komljenovic, D., Al-Haddad , K., (2016). A Multi Criteria Decision Making Approach for Evaluating Renewable Power Generation Sources in Saudi Arabia. Sustainable Energy Technologies and Assessments. 16: 137–150.
3. Taleghani G, Kia AS (2005). Technical-economical Anal-ysis of the Saveh Biogas Power Plant. Renewable Energy. 30(3): 441 – 446.
4. Ma J, Scott NR, DeGloria S, Lembo AJL. (2005). Siting Analysis of Farm-based Centralized Anaerobic Digester Systems for Distributed Generation using GIS. Biomass and Bioenergy. 28(6): 591 – 600.
5. Silva, S., Luı´s A¸ ada-Almeida, Dias, LC. (2014). Biogas Plants Site Selection. Integrating Multi Criteria Decision Aid methods and GIS techniques: A case study in a Portu-guese region. Biomass and Bioenergy. 71. 58 – 68.
6. Peter NW, Drake L , Johnny M. (2014). Economic Viabil-ity of Biogas Energy Production from Family-sized Di-gesters in Uganda. Biomass and Bioenergy . 70. 26 – 39
7. Meidiana, C., Rafsanjani, A. (2015). The Spatial-economic Approach for Determining Biogas Management in Rural Area. International Journal of Applied Engineering Re-search. 10 (95). 31-35
8. Owen, Anthony D. (2006). Renewable energy: Externality Costs as Market Barriers. Energy Policy, 34 (5): 632-642.
9. Pegels, A. (2010). Renewable Energy in South Africa: Po-tentials, Barriers and Options for Support. Energy Policy; 38 (9):4945-4954 Cheng-Dar, Y., Grant Gwo-Liang, Y. (2007). Decision Support System for Exploiting Local Renewable Energy Sources: a Case Study of the Chigu Ar-ea of Southwestern Taiwan. Energy Policy, 35: 383–394.
10. Butchholz, T., Rametsteiner, E., Volk, T.A., Luzadis, V.A. (2009). Multi-criteria Analysis for Bioenergy Systems As-sessments. Energy Policy, 37: 484–495.
11. Perpi˜na, C., Martinez-Llariob, JC., Perez-Navarroa Angel. (2013). Multi-criteria Assessment in GIS Environments for Siting Biomass Plants. Land Use Policy, 31: 326– 335
12. Franco, C., Bojesen, M., Hougaard, Jens Leth., Nielsen, K. (2015). A Fuzzy Approach to a Multiple Criteria and Geo-graphical Information System for Decision Support on Suitable Locations for Biogas Plants. Applied Energy, 140: 304–315
13. ESRI 2012 (2011). ArcGIS Desktop: Release 10.1. Red-lands: Environmental Systems Research Institute.
14. Mateo, JRSC. (2012). Multi-criteria Analysis in the Re-newable Energy Industry. Santander: Springer Science & Business Media;
15. Saaty TL, Vargas LG. (2012). Models, Methods, Concepts and Applications of the Analytic Hierarchy Process. 2nd ed. New York: Springer;
16. Peter NW, Drake L , Johnny M. (2014). Economic Viabil-ity of Biogas Energy Production from Family-sized Di-gesters in Uganda. Biomass and Bioenergy . 70. 26 – 39