Management of Rural Biogas from Manure Waste Using Multi-Criteria Analysis and Geographical Information System (GIS) Approach

C. Meidiana, S. D. K. Uma, and W. P. Wijayanti

***Abstract*—The objective of this study was to identify the renewable energy source potential anddetermining appropriate anaerobic digester (AD) scale and site in a rural area. The AD uses cow manure as feedstock. This study undertakes a multi-criteria analysis and a geographical information system (GIS) approach to allow the assessment of real information (climate, soil condition, land use, manure waste distribution) with subjective information from expert judgement. GIS was used to identify the settlement pattern of the village required for spatial cluster analysis, while analytical hierarchy process (AHP) was used to determine AD scale for each cluster (totally 27 cluster in the study area). There are 4 criteria and 11 sub-criteria have been used in a two level hierarchy to conduct the AHP. The results show that communal AD with capacity of 15 – 37.5 m3 are the most appropriate. The energy production potential depends on the size of the communal AD. The energy production ranges between is higher for the first assumptions and lower for the second one amounting to 24.92kWh/h and 47.28 kWh/h. The combination of GIS approach and MCA shows adequate for determining the AD scale and AD location. The methodology can further be used in profitability and environmental valuation.**

***Index Terms*—Anaerobic digester, spatial cluster analysis, analytical hierarchy process, energy production.**

I. Introduction

Based on Indonesian Outlook Energy 2015, the final energy consumption is increasing 4.9% per year caused mainly by positive population growth 0.8% per year. However, the energy supply is inversely proportional with energy demand because there was an energy consumption increase of 1.9% per year in average from 2010 until 2015 (this number is predicted to be continued in the next decades) while oil production declines 2.2 % per year and the price inclines 2.3% per year. Moreover, petroleum reserves declines 1.2% per year and final consumption of energy in Indonesia is 79% dominated by petroleum fuel [1]. It is predicted that in the next two decades, Indonesia will experience an era of fuel crisis, higher fossil fuel prices and energy insecurity. Currently, interest in biogas technology is revived by increasing awareness of sustainable energy management. Sustainable energy management should not only consider the balance between energy demand and supply but also energy distribution in urban and rural areas. Therefore, need for reliable renewable energy planning is expected to improve by providing clear scheme of renewable energy development. In 2006, Government of Indonesia (GoI) has enacted the Presidential Regulation no. 5/2006 focusing on promoting the use of renewable energy. Some targets are set to decrease the dependence on fossil fuel, to increase the share of the final energy consumption and to minimize carbon emissions.

Biogas from biomass (manure waste) is one of the promising renewable energies in Indonesia because it is inexpensive for abundant sources and substitution of firewood. Biogas utilization for household purposes (cooking, heating, cooling and lighting) tends to increase tremendously. This increase is affected by advantages of biogas compared to other renewable energies, such as robustness, simple storage, various end uses and flexibility of production time as well as direct economic effect [2]-[4]. Furthermore, biogas production process contributes environmental benefits such as odor release reduction, pathogens decrease and organic fertilizer generation [5]-[9]. Nevertheless, there are factors retarding biogas technology application in rural areas. Low affordability, technical limitations, lack of skilled human resources, and lack of information are the common problems of rural biogas development [10]-[12]. According to [10], affordability is the most important factor influencing the low interest of farmers to construct the AD. Most farmers have annual net income which cannot cover the total AD cost. Currently, financial support for rural biogas are provided by the government through a self-sufficient energy village (SSEV) program and household biogas (BIRU) program. Non-biogas farmers are supported to construct small-scale anaerobic digesters (ADs). Yet, the affordability is low for the relatively high AD cost.

In the area of study, land availability is another factor beside affordability since the village is situated in mountainous area and the settlement tend to be situated in cluster. Therefore, the housing is relatively dense. This conditions is problematic for determining the AD location because it is highly geographically dependent and there is a minimum area required for AD construction [13], [14].

Geographical information system (GIS) is a tool can meet this demand. A study by [15] used GIS to determine the location of AD system. GIS approach combines with multi criteria analysis (MCA) may be used to determine AD location. There were some studies using MCA-GIS technique in the context of renewable energy development. [16], [17] assessed the viability of local renewable energy sources, while [18] analyzed sustainability of bio-energy project by determining criteria and weighing them. [19] combined MCA with GIS for deciding the suitable location for biogas plants, while [20] used it to determine location of biomass. Evaluation of Renewable energy source may be conducted using MCA as proposed by [21]. Nevertheless, all these

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studies observed the management of large scale biogas/biomass management and none of them proposed a small scale biogas/biomass management. Hence, the study analyzed suitable anaerobic digester with some limitations for implementing medium or 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 aspect.

II. Method and Material of Research

There are many attributes, both quantitative and qualitative, to be analysed in multiple-phase evaluation when planning biogas management. Planning biogas management in Toyomerto has been accomplished through two phases i.e., scaling biogas management and siting AD. Some indicators were used and evaluated using multiple criteria decision aid method so called multi-criteria analysis (MCA). MCA allows decision makers to make well-informed decisions and achieve optimum outputs. Questionnaires were distributed to collect the data for MCA and some interviews with non-biogas farmers were conducted. Meanwhile, the geographical data is collected and analyzed using ArcGIS 10.5 software is required for spatial cluster analysis. Secondary data was gained from documents provided by local authorities and key persons engaging in rural biogas management. Related scientific research papers were used as references.

A. *Area of Study*

Toyomerto Village has mild climate because it is located 1187.5 – 1300 m above sea level with a measured rainfall of 2000 – 3000 mm per year and average temperature of 26*C. The main livelihood in the village is agriculture and animal farming. According to the data reported by the rural authorities in 2016, the village have a total of 1,348 cows owned by 300 households. Currently, 147 AD owned individually by the farmers are constructed to process manure waste into biogas for cooking as showed in Fig. 1. All ADs are fixed dome with the capacity between 4 m3 and 12 m3. Meanwhile, 167 farmers use the manure waste either for fertilizer or throw away to ditches or streams. Fig. 2 describes the system boundary of the study including the current practices of biogas management.

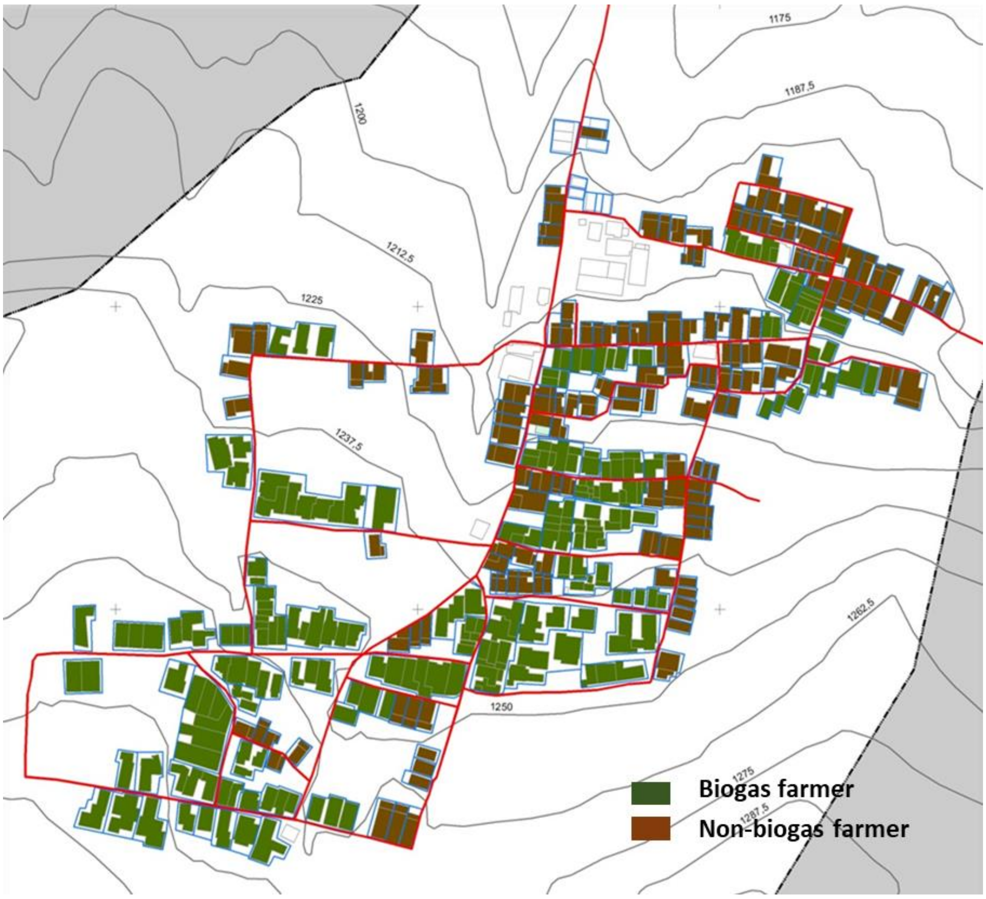

Fig. 1. Biogas and Non-biogas farmers in area of study.

B. *Determination of Relevant Criteria*

As Criteria for MCA is chosen based on some local parameters, i.e.(i) Climate, (ii) Land Availability, (ii) Safety Requirement, (iv) Energy Network and derived into 11 sub-criteria (Fig. 3). According to [22], MCA comprises problem definition, 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.

Analytical Hierarchy Process (AHP) developed by [23] 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 proposed by [23] (Table I). A matrix for pairwise comparison is constructed to determine the priority weight. 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 (λ_{max} – n)/(n– 1). Here, λ_{max} 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.

C. 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 (Fig. 4) [24]. The results should be less than 1, less than 2.58 and less than 0.01 for nearest neighbor ratio, z-score, and p-value respectively. The mean distance is calculated afterwards comprising observed mean distance and expected mean distance. The decision of applied value (observed or expected mean distance) is arbitrary based on certain considerations to create the cluster of farmers for communal AD according to [10].

D. Energy Production Calculation

Heat energy generated from the anaerobic digestion process is calculated by the following equation (Eq.1) [25]:

$$E_{th} = \frac{m_{manure} \times DM_{manure} \times ODM_{manure} \times BY_{manure} \times 5.5 \times \eta_{th}}{t} \quad (1)$$

where E_{th} (kWh/h), 5.5 (kWh/m^3), BY (m^3/t$_{ODM}$)and η^{el} (45%) are the amount of thermal energy from biogas, total energy value of biogas, conversion index and thermal efficiency value, respectively. Operating time parameter, t (h/yr) usually ranges from 8000 to 8760. In this study, the minimum operating time parameter was used which is 8000 (h/yr).

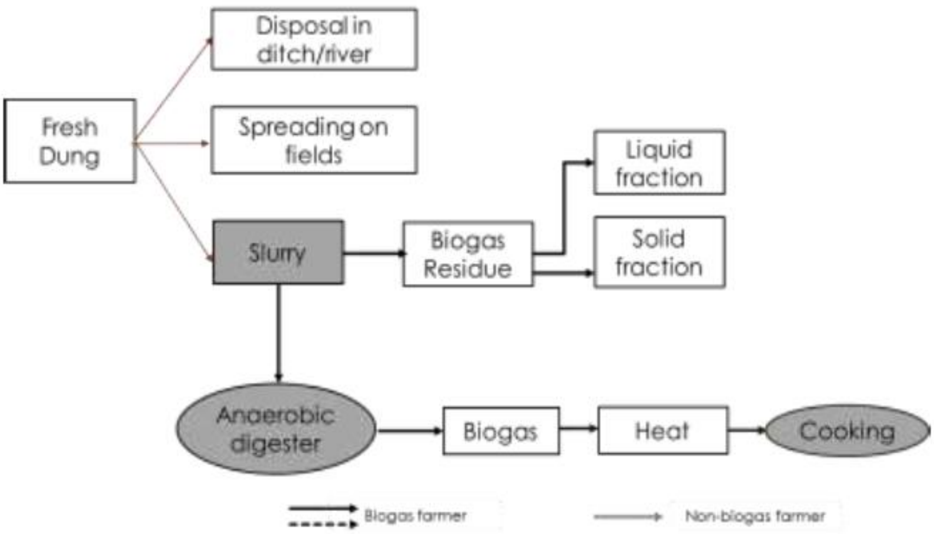

Fig. 2. System boundary of manure waste management in area of study.

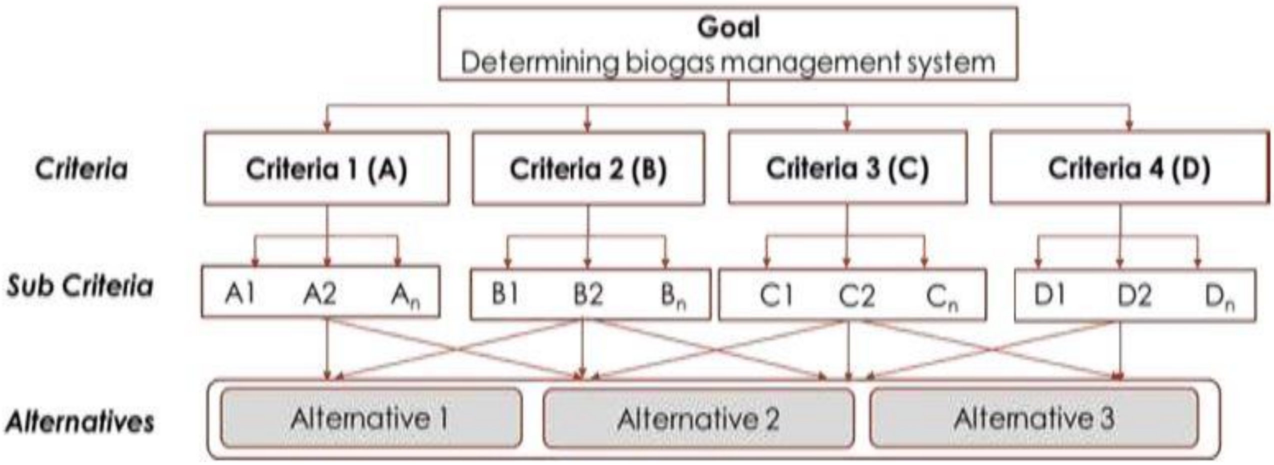

Fig. 3. Analytical hierarchy process diagram.

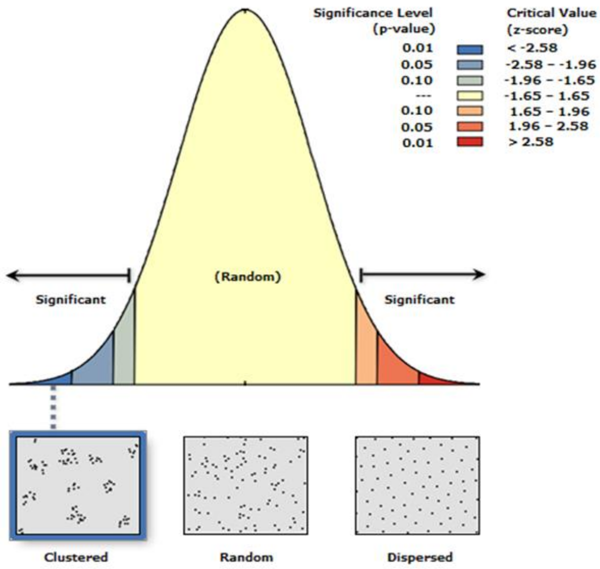

Fig. 4. Critical values in spatial cluster analysis [24].

TABLE I: 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

TABLE II: STANDARDS FOR TYPICAL ANAEROBIC DIGESTER

AD Type	Capacity (m^3)	Gas production (m3/d)	Water (liter/d)	No. of cows
A	4.0	0,8 – 1,6	20 – 40	3 – 4
B	15.0	4.2 – 4.8	20 – 120	10
C	37.5	12.2 – 13,5	60 – 250	25
D	48.0	18.3 – 19.6	100 – 120	32

TABLE III: S CRITERIA WEIGHING BY THE EXPERTS

	Sub-criteria	Vector Weight	Priority Vector
Climate (0.049)	C1	0,500	0,026
	C2	0,500	0,026
Safety Requirement (0.225)	SR1	0,365	0,083
	SR2	0,172	0,039
	SR3	0,099	0,023
	SR4	0,365	0,083
Land Availability (0.590)	LA1	0,777	0,081
	LA2	0,069	0,036
	LA3	0,155	0,405
Energy Network (0.134)	EN 1	0,500	0,099
	EN2	0,500	0,099

TABLE IV: COMBINING ALTERNATIVE WEIGHT AND MEAN OF GEOMETRIC FROM FIVE EXPERTS

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Communal	0.536	0.527	0.500	0.527	0.536
Individual	0.464	0.473	0.500	0.473	0.464

III. ANALYSIS AND DISCUSSION

Data of socio-economic and demographic of non-biogas farmer households (HHs) in Toyomerto Village were collected through primary and secondary survey. Generally, there are three different scale for AD, i.e. small, medium, and large with the capacity between 4 – 50 m3 and the price is proportional to the capacity (Table II). The capacity of individual AD is 4 m3, while capacity of communal AD is divided into three type i.e. small, medium and large with volume of 48 m^3, 37.5 m^3, and 15 m^3 respectively. The value of priority vector (CR) is used to calculate the value of CI and RI. Calculation for all criteria and sub criteria using ratio between CI and RI comes to CR value which is less than 0.1 indicating that AHP result is valid and can be used for decision making. Table III shows that land availability has the highest value of priority vector followed by safety requirement, energy network and climate with priority vector value of 0.590, 0.225, 0.134, and 0.049 respectively. The values indicate that land availability is the most important criteria. The same procedure is conducted for weighing the sub criteria. Based on the final score, communal AD is the most suitable type to be constructed in study area as described in Table IV and showed in Fig. 5. Clustering farmers through spatial cluster analysis is the next step since land availability is the main factor hindering AD construction. Table V 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 0.90453, -3.68254, and 0.00023 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 8.30 meter and 9.05 meter respectively. Cluster is formed with maximum radius of 9.05 meter instead of 8.30 meter considering that longer distance includes more houses to be one cluster allowing inclusion of more non- biogas farmers. Based on these values, the groups are formed and land availability for communal AD within the group is identified. The location for AD is determined when it meets the required minimum area for AD. Locations of communal AD are showed in Fig. 6.

The location for AD is determined when it meets the required minimum area for AD. Using overlay technique, 27 units of communal AD involving 84 non-biogas farmers. These ADs include 2 units with medium scale and 25 units with small scale. Meanwhile, 73 units of individual AD with capacity of 4 m3 and 6 m3 can be constructed where there is no adequate land for both capacities. Solution for such case is constructing the AD either next to the stall or under the stall.

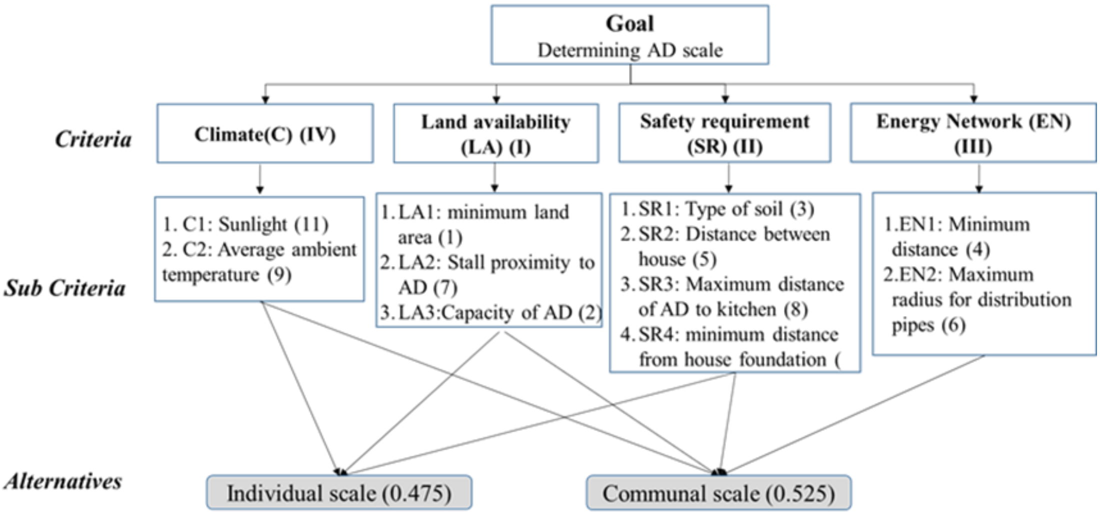

Fig. 5. Result of analytical hierarchy process for determining the most appropriate AD scale.

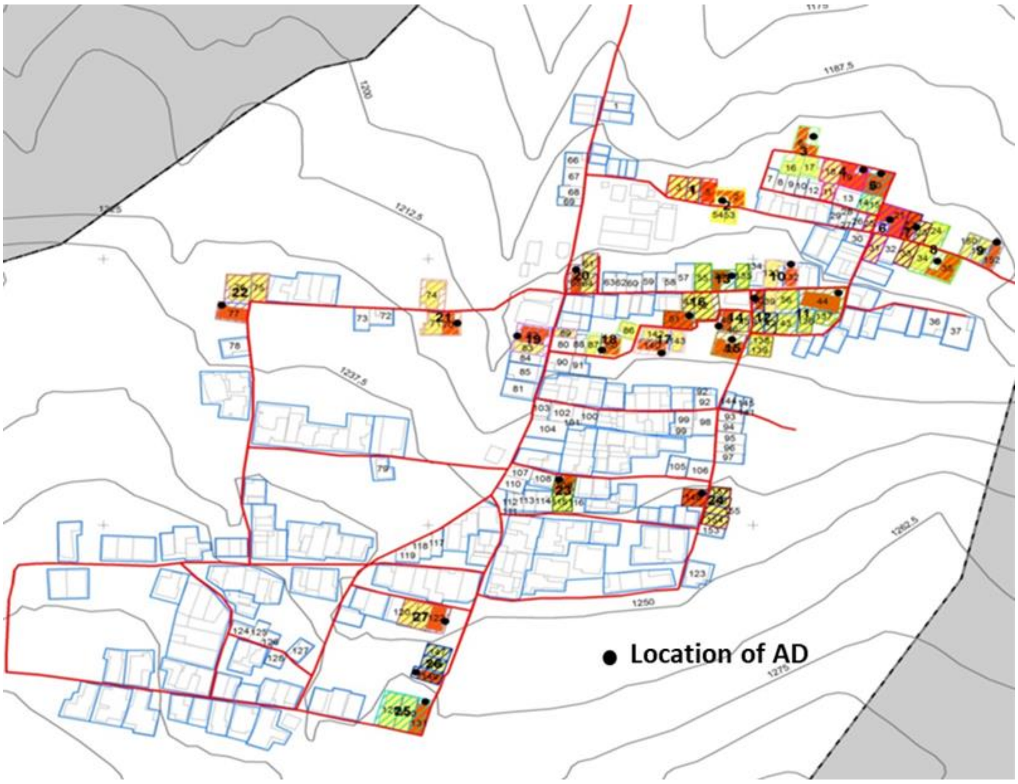

Fig. 6. Location of communal AD.

TABLE V: INTEGER VALUES OF IN SPATIAL CLUSTER ANALYSIS

. Parameters	Criteria	Value
Observed Mean Distance	-	8.297484 m
Expected Mean Distance	-	9.045385 m
Nearest Neighbor Ratio	< 1	0.917317
z-score	< 2.38	-3.682541
p-value	< 0.01	0.000231

IV. CONCLUSION

The Analytical Hierarchy Process come to the result that communal AD is the most suitable type to treat the manure waste in the study area. The optimum capacity of AD ranging between 15 –37.5 m^3. However, since the main restriction is the land avalibaility, the spatial cluster anlysis is conducted to determine the size of the non-biogas farmer groups. Furthermore, map of land availability and cow ownership is overlaid to produce the location of the cluster based on the group's size. The output of these analysis are the number of the cluster with each type i.e. 27 communal AD and 73 individual AD. Totally, 84 non-biogas farmers can be served by 27 communal ADs. Meanwhile, based on land availability analysis, 41 individual ADs can be constructed next to the stall. Yet, 32 individual ADs must be constructed under the stall for land unavailability. The energy production potential depends on the size of the communal AD installed in each cluster. The energy production of each cluster ranges between 11.92 kWh/h and 27.28 kWh/h.

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