Yalvaç Akademi Dergisi

https://dergipark.org.tr/tr/pub/yalvac

IDENTIFYING OPTIMAL BIOGAS PLANT INSTALLATION IN EASTERN ANATOLIA REGION USING CLUSTERING TECHNIQUES

Onur İNAN[*1],

[1]Mehmet Akif Ersoy University, Bucak Emin Gulmez Vocational School of Technical Sciences

E-posta: oinan@mehmetakif.edu.tr

ABSTRACT: The increasing depletion of fossil fuels and their contribution to environmental issues have prompted energy managers and planners to shift their focus toward renewable energy sources to meet energy demands. Biogas produced through anaerobic digestion or fermentation of organic materials, stands out as a key energy source for converting agricultural, animal, industrial, and municipal waste into usable energy. This renewable energy is applied across various domains, including heating, transportation, and electricity generation. Biogas plants are crucial in efficiently processing agricultural, industrial, and urban waste. Therefore, optimizing the location and capacity of biogas plants during their installation is essential to maximize their efficiency and potential. In this study, to determine the biogas plant installation with the most suitable location and capacity according to the 2021 data of the Eastern Anatolia Region, firstly, the number of cattle, sheep, and poultry raised in the provinces and districts of the region, the amount of biogas produced accordingly, and the latitude and longitude values of the relevant settlement were achieved. The collected data were evaluated with the K-means clustering method, and the most suitable location for the biogas plant installation was found together with the production capacity. The results obtained from this study are anticipated to guide researchers operating in the relevant field and pave the way for similar studies.

Keywords: *Biogas Production, Plant Installation, K-means Clustering*

1. INTRODUCTION

In recent years, significant investments have been made in renewable energy sources in Türkiye to reduce the increasing demand for energy imports and to meet the energy supply without harming the environment in line with sustainability policies. The gradual depletion of non-renewable resources has provided an impetus for the development of renewable energy alternatives. For this purpose, the potential for biogas production from animal waste throughout Türkiye was evaluated and a feasibility analysis was conducted for biogas facilities that could be established in each province. In addition, the economic viability of biogas facilities and carbon dioxide savings were analyzed [1]. In another study, the spatial distribution of hydraulic, wind, geothermal, solar and biomass energy potential in Türkiye was evaluated and data were presented for the effective planning and use of renewable energy sources [2]. In another publication, the biogas potential in Düzce province was assessed and the most suitable location for the biogas plant was determined using the K-means clustering algorithm. In the relevant study, the optimum plant location was determined to minimize transportation costs, considering the locations of chicken farms and biogas production potentials [3]. In another biogas study, the biogas production potential that can be obtained from cattle, sheep and poultry manure in Muğla province was spatially analyzed and the electricity, heat and coal equivalents of the obtained biogas were calculated [4]. In a similar study, seventeen compost facility clusters were determined for Çorum province utilizing the K-means clustering method and the facilities were positioned by showing the cluster centers on the map [5]. In another study conducted in Konya Closed Basin, optimum areas for biogas plant installation in related region were determined employing Multi-Criteria Decision Making (MDCM) methods and Geographic Information Systems (GIS) [6].

Recently, various studies have been conducted to examine the role and energy potential of animal waste in biogas production in Eastern Anatolia Region. In the first of these studies, the amount of dry biomass in the region and the calorific value of this biomass were computed and suggestions were made on how to utilize the biomass potential effectively and widely [7]. In another study on the Eastern Anatolia Region, the effectiveness of microalgae production opportunities for increasing biogas production was revealed along with evaluating livestock and plant production potential [8]. In another publication, the amount of waste originating from cattle and sheep in 14 provinces in the Eastern Anatolia Region was calculated, and then the biogas energy that could be produced from these wastes and the number of people who could benefit from this energy were determined [9].

In studies close to present day, it is seen that studies on biogas production and biogas plant installation have been carried out intensively. In the first of these studies, a new hybrid modeling and optimization approach was developed to determine the most suitable installation location for a biogas plant in Manisa province. As a result of the analyses conducted using different optimization methods, it was determined that the establishment of a biogas plant in Gölmarmara, Salihli and Ahmetli regions would provide an annual electricity production of 68 GWh [10]. In another study, the biogas potential that can be obtained from agricultural waste in Hubei Province of China was estimated and the reasons for the low utilization rate were investigated by analyzing the difference with the current biogas production. The results revealed that the current production reached only 3.17% of this potential [11]. In another study conducted in the Haryana state of India, the biomass potential that can be obtained from animal manure was estimated and its effects on reducing greenhouse gas emissions were evaluated [12]. In another study implemented in Denizli, Türkiye, an innovative method was applied for biomass supply chain network design using artificial intelligence, Geographic Information Systems (GIS), Multi-Criteria Decision Making (MCDM) and mathematical modeling. The results showed that nine biogas plants with a capacity of 2000 kWh could be established, 83.2% of the net income would come from electricity sales and the rest from fertilizer sales, and it was determined that the biggest financial factor was the fertilizer sales price [13]. Another study computed the potential of converting agricultural and forestry waste into biomass energy in China and analyzed the energy production capacity and carbon emission reduction effect for 2020. According to the results, the use of biomass energy can replace 256 million tons of standard coal and reduce approximately 520 million tons of carbon dioxide emissions, which has an impact of 4–6% on the carbon peak [14].

Clustering is a process that involves automatically grouping similar objects into distinct clusters. This method of extracting data is one of the most widely used techniques in data analysis to uncover patterns and insights within a dataset. In essence, clustering seeks to discover subgroups in the data such that points within the same cluster are highly similar, whereas points in different clusters are notably distinct. This technique has been particularly effective for analyzing high-dimensional datasets, which are often challenging to visualize [15]. K-means clustering is a straightforward, efficient, and easy-to-implement technique for addressing various data analysis challenges. As an unsupervised machine learning algorithm, it aims to divide a dataset into *k* distinct clusters based on predefined criteria. It groups data points based on their proximity to the centroid of each cluster. The algorithm operates iteratively by associating each data point with the nearest cluster and recomputing the cluster centroids. Consequently, data points within the same cluster exhibit greater similarity while the distinction between clusters is optimized. It has been stated that K-means clustering is suitable for many analysis applications and is a useful tool for large data sets [16]. Another study showed that K-means clustering can achieve successful results even in high-dimensional data sets [17]. Recently, K-means clustering was employed to compute biogas yield and determine the best location for the biogas production facility [18,19].

The Eastern Anatolia Region is one of the most important regions of Türkiye in terms of biogas production from animal waste due to its large pasture areas and intensive animal husbandry activities. Previously in literature, the biogas potential in the Eastern Anatolia Region was previously obtained by taking into account basic approaches. However, in these studies, physical parameters such as age, weight, etc. of animal species were not taken into account [20,21]. Determining suitable biogas production plant locations in this region will help meet the energy needs in agricultural and rural areas and also support environmental sustainability by improving waste management. In economic terms, electricity and heat energy can be acquired through biogas production, contributing to the local economy. In addition, organic fertilizer production that can be utilized in agricultural production can be increased and dependence on fossil fuels can be reduced. A study to find the most suitable biogas production plant location in the region can accelerate regional development, increase energy supply security and provide environmental benefits by reducing carbon emissions.

This study aimed to assess the biogas potential derived from cattle, sheep, and poultry manure in the Eastern Anatolia Region and its districts (these potential values were calculated using the calculation technique of references [22,23]) and to identify the most optimal plant location using the K-means clustering method. For this purpose, the biogas potential and the ideal plant location were specified based on livestock data, including the number of cattle, sheep, and poultry obtained from TUIK for the Eastern Anatolia Region in 2021.

2. FUNDAMENTALS OF K-MEANS CLUSTERING METHOD

The k-means algorithm is one of the most straightforward unsupervised learning methods to address clustering tasks [24]. K-means, a popular partitioning-based clustering technique, is extensively utilized in scientific research and industrial applications as one of the most common clustering algorithms [25]. The core idea behind the K-means algorithm is to partition a dataset of n data points into k clusters, as determined by the provided input parameters. The objective is to enhance the similarity of data points within each cluster while reducing the similarity between points in different clusters. Cluster similarity is determined by calculating the average distance between the cluster's centroid, which is the center of gravity, and the other data points within the same cluster [26]. In the K-means method, clustering is generally done based on Euclidean distance:

$$p = (p_1, p_2, ..., p_n)\, and\, q = (q_1, q_2, ..., q_n)$$

$$d(p,q) = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2} = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + ... + (p_n - q_n)^2} \tag{1}$$

K-Means algorithm begins by randomly selecting *k* initial centroids, where *k* refers to the number of clusters. Each data point in the dataset is then assigned to the cluster whose centroid is nearest to it. The cluster center value is determined by computing the average of the points within the cluster. This process continues until the center values remain constant. [27]. The steps of the K-means method are carried out in the following sequence:

Step 1: *k* objects are randomly chosen and designated as the initial cluster centers. M_1, $M_2, ...,$ M_k The midpoints are computed as follows [28]:

$$M_k = \frac{1}{n_k}\sum_{i=1}^{n_k} x_{ik} \tag{2}$$

Step2: Intra-cluster changes are computed with the Squared Error Formula [29]:

$$e_i^{\,2} = \sum_{i=1}^{n_k}(x_{ik} - M_k)^2 \tag{3}$$

For the space of all sets containing set *K*, the squared error is the sum of the variations within the set. Therefore, the squared error value is computed as follows:

$$E_k^{\,2} = \sum_{k=1}^{K} e_k^{\,2} \tag{4}$$

Step 3: Each data point is allocated to the cluster that is most proximate to it.

Step 4: Once all the data points have been assigned to their nearest clusters, the centroids are recalculated for each k cluster.

Step 5: Steps 2 and 3 are repeated until the Cluster Centers remain same [30].

3.MATERIAL AND METHOD

This study used data on the number of cattle, sheep, and poultry produced and the amount of biogas produced from TUIK in 2021 from 14 provinces and 125 districts of the Eastern Anatolia Region. According to TUIK, cattle are categorized into domestic, buffalo, culture, and hybrid breeds. Similarly, sheep are classified as merino, domestic sheep, hair goat, and Angora goat. Lastly, in the poultry category, egg and meat chickens, ducks, turkeys, and geese are included [31]. Due to TUIK's data 2021, the total number of cattle, sheep, and poultry in the Eastern Anatolia Region on a provincial basis and the corresponding total biogas values produced are given in Table 1.

In this study, biogas potential was computed by evaluating each animal species individually within its respective category, with calculations based on the quantity of manure produced, as informed by relevant publications [22,23]. To approximate manure production, live mass values of each animal according to its species, breed and age group were taken into account. The daily fresh manure output was determined using a percentage of live weight. These values were assigned as 6% for cattle, 5% for small ruminants and 4% for poultry. These percentages were applied to calculate daily manure amounts for each province, accounting for differences in age, breed, and species. Separate calculations were performed for cattle, small ruminants, and poultry, and the total manure volume was subsequently derived. It is important to note that manure production can fluctuate depending on factors such as climate, nutrition, and breeding practices. Accordingly, species-specific usability coefficients were applied. These coefficients were determined as 50% for cattle, 13% for small ruminants and 99% for poultry. In summary, the relevant parameters for each animal species expressed in Table 2 were calculated by the following formula [23], taking into account the reference [22]:

$$BP = TM.SR.AC.EB \tag{5}$$

Here, BP represents the annual gas potential (m^3), SR denotes for the fertilizer solid ratio (%), AC expresses the usability coefficient (%) and EB symbolizes the estimated biogas value of total solid fertilizer (m^3/kg).

Table 1. Total number of animals and the corresponding total biogas values produced in the provinces of Eastern Anatolia Region

Province	Cattle	Sheep/Goat	Poultry	Biogas Value (m^3)
Ardahan	331468	118527	295053	172994417
Ağrı	413012	1427144	236455	85782794
Bingöl	132307	696131	808614	36275883
Bitlis	88991	795230	95534	25244037
Elâzığ	187326	1089120	6844851	103849194
Erzincan	128289	550077	1354928	34089619
Erzurum	860404	900623	213061	184190375
Hakkâri	37923	676719	59673	14425098
Iğdır	100400	1402380	132059	31842530
Kars	620723	604755	893192	129277243
Malatya	174986	367606	6085786	61701154
Muş	335798	1250000	467007	81853187
Tunceli	25749	354337	81810	8821344
Van	166401	3384220	462032	58450998
Total	**3603777**	**13616869**	**18030055**	**1028797881**

Table 2. Biogas production and manure properties across different animal breeds [22]

Animal Type	Age Range by Category (in Months)	Live Mass Amount	Manure Amount		Solid Manure (SM) (%)	Availability (AC) Duration of stay in barn	Efficiency of biogas (l/kg)
			% mass	kg/day			
Cattle	x<12 12<x<24 X>24	200–900	5–6	10–20	5–25	Dairy 65 Beef 25	200–350
Small ruminant	x<6 6<x<12 12<x<24 X>24	20-100	4-5	2	30	13	100-310
Poultry		2-10	3-5	0.08-0.1	10-35 50-90	99	310-620 550-650

In this study, the Elbow method determined the most appropriate number of clusters. The Elbow method is used to determine the most appropriate number of clusters (k) in the K-means algorithm. This method is based on computing the sum of the squared distances of each data point to the cluster center it belongs to for different k values and analyzing how this value changes depending on k. The aim is to determine the optimal number of clusters by detecting the point where the total variance decreases rapidly [32]. The Elbow method algorithm is implemented briefly as follows:

Step 1: For different k values, the K-means algorithm is applied, and clustering is performed.

Step2: Within-Cluster Sum of Squares (WCSS), that is, the sum of the squares of the distances of the points in each cluster to the cluster center (centroid), is computed as follows:

$$WCSS = \sum_{i=1}^{k} \sum_{x \in C_i} \left\| x - \mu_i \right\|^2 \tag{6}$$

Here, k is the number of clusters; Ci represents the ith cluster. In addition, x is a data point in the cluster, and μ_i exemplifies the center of the ith cluster (centroid). In the equation above, WCSS is calculated by taking the square of the Euclidean distance between the data point x and the cluster center μ_i.

Step 3: The point where the rate of decline of WCSS slows significantly (elbow point) is found. This point is accepted as the k optimum value.

Based on 2021 TUIK data, the optimum number of clusters was determined using the elbow method, as shown in Figure 1. The point k=4 in the graph was selected as the most appropriate value.

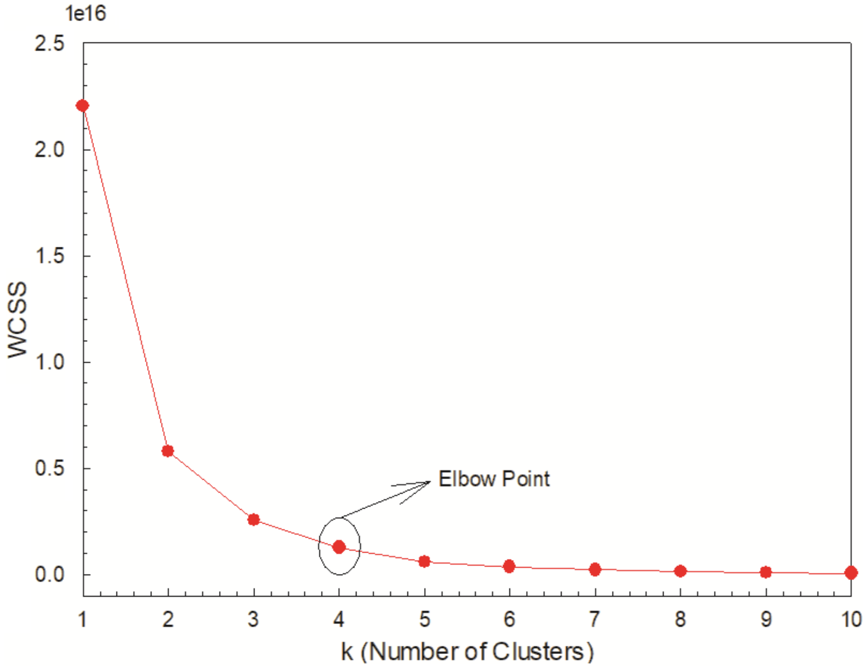

Figure 1. Implementation of the Elbow method to determine the optimum number of clusters

4. DETERMINING MOST APPROPRIATE PLANT LOCATIONS BY K-MEANS CLUSTERING

The biogas production potential of 14 provinces and 125 districts in the Eastern Anatolia Region was achieved as in Figure 2, depending on the latitude and longitude values, when the cluster number value was taken as 4 in the K-Means clustering method.

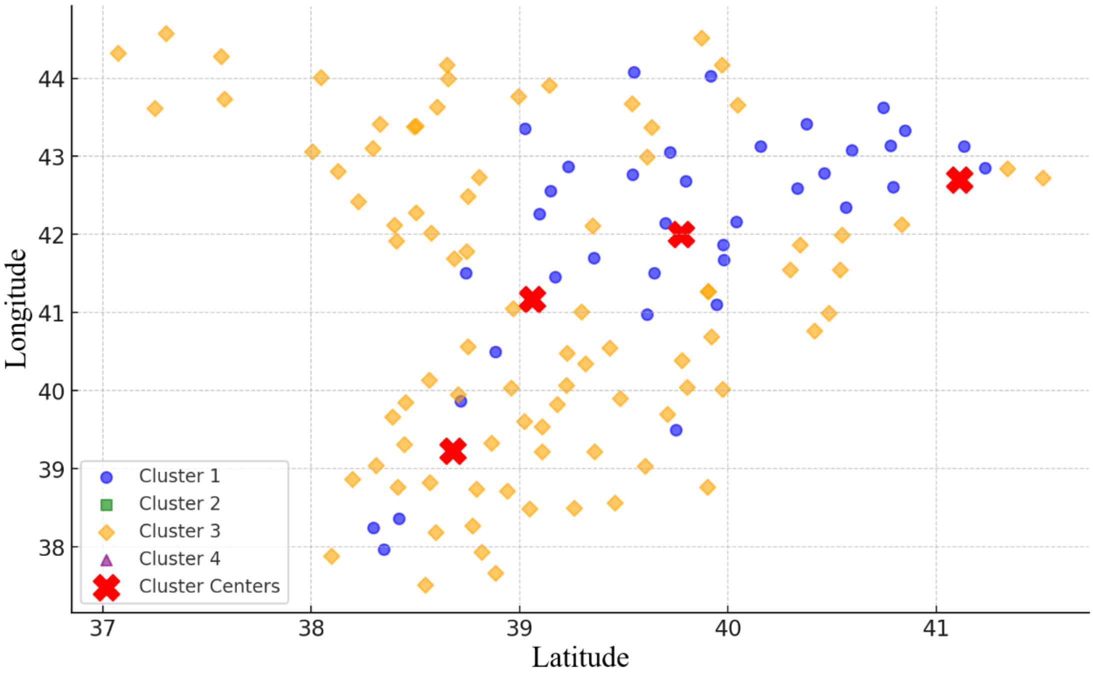

Figure 2. Eastern Anatolia Region biogas production potential K-Means clustering results

Depending on this distribution, Table 3 shows the number of data points, average latitude, average longitude, total biogas production, and average biogas production values of the 4 clusters attained depending on K-Means clustering, respectively.

Table 3. Latitude, longitude, and biogas production values obtained by K-Means clustering

Cluster	**Number of Data Points**	**Avg Latitude**	**Avg Longitude**	**Total Biogas Production**	**Avg Biogas Production (m^3)**
Cluster 1	37	39.774097	42.007117	539131945.6950	14571133.6674
Cluster 2	1	41.110481	42.702171	123105834.2977	123105834.2977
Cluster 3	86	39.059853	41.167441	294401750.7379	3423276.1713
Cluster 4	1	38.680969	39.226398	72158350.4887	72158350.4887

In addition, a heat map was generated, as in Figure 3, to specify the correlation of the amount of biogas produced with the number of cattle, sheep, and poultry. Based on the heat map achieved, the following conclusions were reached:

- The correlation between the number of livestock and biogas production was 0.67. Based on this, it can be concluded that there is a medium-high level positive relationship between the amount of biogas and the number of cattle.
- The correlation between the number of small cattle and biogas production was determined as 0.20. Based on this, it can be stated that there is a weak relationship between the amount of biogas and the number of small cattle.
- The correlation between the number of poultry and biogas production was found to be 0.44. This result indicates a moderate positive relationship between the quantity of biogas produced and the poultry count.

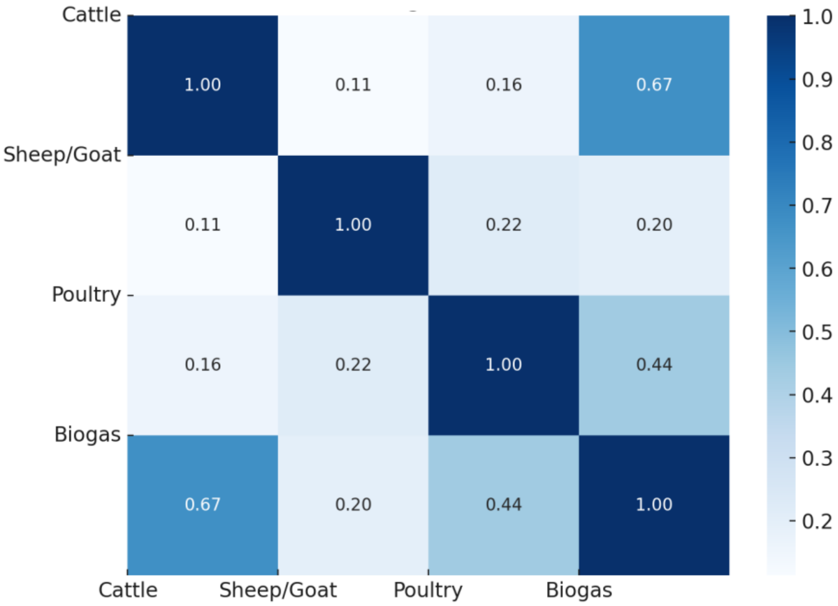

Figure 3. Correlation between biogas and livestock numbers

As can be seen in the heat map, the species with the highest correlation with biogas production among animal species is cattle. This is because the calculation of biogas potential based on manure amount includes a wide range of factors such as age, weight and the duration of stay of each animal in the place where it is housed. Similar results were obtained in previous biogas potential studies conducted throughout Türkiye [33,34].

Finally, the nearest cities and districts were determined by looking at latitude and longitude values, and the most suitable biogas power plant location was found. The province/district location with the finest biogas production potential for each cluster, latitude-longitude values , and estimated biogas production amounts are displayed in Table 3. As can be seen from Table 4, Cluster 2 and Cluster 4 have extremely large values in terms of biogas production. Since K-Means uses average values when determining cluster centers, the centers are concentrated in a single point due to these large values. Therefore, these points with very high biogas production form a single cluster.

Table 4. Locations having the best biogas production potentials with their respective production amounts

Cluster	Province/District Location	Latitude/Longitude Values	Estimated Biogas Production Amount (m^3)
Cluster 1	Erzurum/Karayazı	39.70/42.14	19.2 million
Cluster 2	Ardahan/Center	41.11/42.70	123.1 million
Cluster 3	Bingöl/Solhan	38.96/41.05	4.25 million
Cluster 4	Elazığ/Center	38.68/39.23	72.1 million

According to Table 4, Ardahan Central district has the highest potential for biogas production. A biogas power plant established here will achieve the highest efficiency in the Eastern Anatolia Region.

5. CONCLUSION

Biogas technology has gained significance in generating renewable energy by converting and disposing of wastes that contribute to environmental issues, thereby transforming them into valuable energy resources. Despite Türkiye having substantial potential for utilizing organic waste, this resource remains underutilized. Additionally, investments in energy projects centered on organic waste have not seen sufficient demand in Türkiye. In this context, a study was carried out on the most suitable biogas production location and potential for the Eastern Anatolia region, where animal husbandry is among the main sources of income.

According to TUIK 2021 data in the Eastern Anatolia Region, there are 3603777 Cattle, 13616869 Sheep/Goats, and 18030055 Poultry. These numbers indicate that the region has significant potential for biogas production. Hence, it is crucial to identify the most suitable location data to optimize energy production for a potential biogas plant in the Eastern Anatolia Region.

For this reason, the most suitable number of clusters for implementing the K-Means algorithm was determined first. Subsequently, the K-Means clustering algorithm was employed to determine the optimal location for a plant that would meet the highest biogas production. As a result of applying the clustering algorithm, four settlements were identified with their excessive biogas production potential. Among these, it was concluded that the central district of Ardahan province is the most suitable settlement for establishing a biogas power plant with million production capacity 123.1 million. Furthermore, the relationship between the quantity of biogas produced and the numbers of cattle, sheep, and poultry was mentioned.

As a result of the K-means clustering algorithm, Ardahan (Center) district was found to be the settlement with the highest biogas potential. Therefore, since it has the highest animal waste source, continuous and efficient biogas production can be provided. Accordingly, large-scale facilities can be established. In addition, Ardahan (Center) district is a settlement with completed double roads, so it has the advantage of transporting raw materials to the biogas facility with ease. The produced biogas can be distributed more easily to the city center and industrial zones. If electricity production is to be made, connection to the grid can be achieved at a lower cost. On the other hand, due to the harsh winter conditions of Ardahan (Center) district, its location on a high altitude and rugged terrain, and the difficulties of storage and waste management, additional facility or infrastructure investments may be required in addition to the biogas facility installation.

In this study, K-Means clustering method was used to determine the spatial distribution of biogas production potential and the obtained results were presented with a data-driven analysis approach. Since the aim of the study was to determine the most suitable facility locations for biogas production in the Eastern Anatolia Region, alternative analysis methods such as methodological comparison or multi-criteria decision making (MCDM) were excluded from the scope. In terms of spatial visualization, clustering results were expressed numerically and considering the data-driven approach of the study, additional mapping studies were not considered a necessity. In future studies, more comprehensive analyses with different methodologies will be evaluated based on this study.

The findings of this study provide an important decision mechanism in terms of evaluating the biogas production potential in the Eastern Anatolia Region and determining the most suitable power plant locations. The results obtained can contribute to strategic planning for biogas plants in the region and to direct energy policies. When the applicability of the study is evaluated in terms of animal waste management and renewable energy investments, it can be expanded by integrating with logistics and infrastructure conditions. For future studies, it is planned to further detail the spatial analyses, to conduct comparative analyses with multi-criteria decision making (MCDM) methods, and to evaluate the effects of infrastructure and logistics factors on biogas power plant location selection. In addition, modeling studies are considered to increase the economic and environmental sustainability of biogas production processes.

This study is thought to contribute to increasing the amount of biogas production from animal waste in the Eastern Anatolia Region, increasing the efficiency of regional livestock enterprises, and inspiring studies on similar renewable energy studies.

REFERENCES

[1]. Ekinci, K., Kulcu, R., Kaya, D., Yaldız, O., Ertekin, C., Ozturk, H. H. (2010). The prospective of potential biogas plants that can utilize animal manure in Turkey, Energy Exploration & Exploitation, 28 (3), 187-206.

[2]. Güngör-Demirci, D. (2015). Spatial analysis of renewable energy potential and use in Turkey, Journal of Renewable and Sustainable Energy, 7(1):13126.

[3]. Yuruk, F., Erdogmus, P. (2018). Finding an optimum location for biogas plant: a case study for Duzce, Turkey, Neural Computing and Applications, 29(1), 157-165.

[4]. Aksu, H. H., Kumas, K., Inan, O., Akyuz, A., Gungor, A. (2019). Determination and spatial analysis of Muğla, Turkey biogas potential by tier methodologies, AIP Conference Proceedings 2178(1),030044.

[5]. Dundar, S., Bircan H., Eleroglu, H. (2021). Optimal Ranking of Compost Facilities that Can Be Established in Çorum with COPRAS and MAIRCA Methods, 2nd International Congress of the Turkish Journal of Agriculture – Food Science and Technology, 2523-2531.

[6]. Tulun, S., Arsu, T., Gurbuz, E. (2023). Selection of the most suitable biogas facility location with the geographical information system and multi-criteria decision-making methods: a case study of Konya Closed Basin, Turkey, Biomass Conversion and Biorefinery, 13, 3439–3461.

[7]. Nacar-Kocer, N. and Unlu, A., Biomass Potential of East Anatolia Region and Energy Production, Research of Eastern Anatolia Region, 5(2), 175-181, 2007.

[8]. Asla, F., Ozgen, I., Esen, H. (2016). The Opportunities for Utilization from Biogas and Microalgae in Energy Planning and the Potential of Eastern Anatolia Region, International Conference on Natural Science and Engineering (ICNASE'16), 1289-1299.

[9]. Caglayan, G. H. (2020). Investigation of Biogas Potential of Cattle and Sheep Waste in Eastern Anatolia Region, Turkish Journal of Agricultural and Natural Sciences, 7(3), 672 – 681.

[10]. Ceylan, A. B., Aydın, L., Nil M., Mamur, H, Polatoglu, I and Sozen, H. (2023). A new hybrid approach in selection of optimum establishment location of the biogas energy production plant, Biomass Conversion and Biorefinery, 13:5771–5786.

[11]. Liu, T., Ferrari, G., Pezzuolo, A., Alengebawy, A., Jin, K., Yang, G., Li, Q. and Ai, P. (2023). Evaluation and analysis of biogas potential from agricultural waste in Hubei Province, China, Agricultural Systems, 205:103577.

[12]. Nehra, M. and Jain, S. (2023) Estimation of renewable biogas energy potential from livestock manure: a case study of India, Bioresource Technology Reports, 22:101432.

[13]. Senocak, A. A, Guner Goren, H. (2023). Three-phase artificial intelligence-geographic information systems-based biomass network design approach: a case study in Denizli, Applied Energy, 343:121214.

[14]. Zhang, C., Nie, J. and Yan, X. (2023) Estimation of biomass utilization potential in China and the impact on carbon peaking, Environmental Science and Pollution Research, 30:94255–94275.

[15]. Du, KL., Angelov P. (2014). Data density-based clustering, 14th UK Workshop on Computational Intelligence (UKCI), 1-7.

[16]. Wagstaff, K., Cardie, C., Rogers, S. and Schrödl, S. (2001). Constrained K-means Clustering with Background Knowledge, ICML '01: Proceedings of the Eighteenth International Conference on Machine Learning, 577 – 584.

[17]. Kanungo, T., Mount, D. M., Netanyahu, N. S., Piatko, C. D., Silverman R., Wu A. Y., (2004). A local search approximation algorithm for k-means clustering, Computational Geometry, 28(2-3), 89-112.

[18]. Dhavaleswarapu, R.K., Hoysall, C.N. and Srinivasaiah, D. (2023). Statistical clustering of biomass to predict biogas yields, Bioresource Technology Reports, 23: 101557.

[19] Obal, T.M., Souza, J.T., Florentino, H.O., Francisco, A.C. and Soler, E.M. (2024). A matheuristic applied to clustering rural properties and allocating plants for biogas generation, Energy, 305:132249

[20]. Karakuzulu, Z., Arici, F. and Dumansizoglu, M. (2017). Biogas Energy Potential of Eastern Anatolian Regıon, The Journal of Academic Social Science, 39, 541-554.

[21]. Caglayan, G.H. (2020). Investigation of Biogas Potential of Cattle and Sheep Waste in Eastern Anatolia Region, Turkish Journal Of Agricultural And Natural Sciences, 7(3): 672–681.

[22]. Pence, I., Kumaş, K., Siseci Çeşmeli, M., Akyüz, A. (2023). Modeling of energy and emissions from animal manure using machine learning methods: the case of the Western Mediterranean Region, Turkey. Environ Sci Pollut Res 30, 22631–22652 https://doi.org/10.1007/s11356-022-23780-5

[23]. Pence, I., Kumaş, K., Cesmeli, M.S. Akyüz, A. (2024). Future prediction of biogas potential and CH_4 emission with boosting algorithms: the case of cattle, small ruminant, and poultry manure from Turkey. Environ Sci Pollut Res 31, 24461–24479. https://doi.org/10.1007/s11356-024-32666-7

[24]. MacQueen, J. (1967). Some Methods for Classification and Analysis of Multivariate Observations, Proceedings of the fifth Berkeley symposium on mathematical statistics and probability, 1, 281 – 297.

[25]. Berkhin, P. (2002). Survey of Clustering Data Mining Techniques, Technical Report, Accrue Software, Inc.,

[26]. Han, J., Kamber, M., Tung, A. (2001). Spatial Clustering Methods in Data Mining: A Survey, Geographic Data Mining and Knowledge Discovery, Research Monographs in GIS.

[27]. Amasyali, M. F., Ersoy, O. (2008). The Performance Factors of Clustering Ensembles, IEEE 16th Signal Processing, Communication and Applications Conference.

[28]. Gersho, A., Gray, R. M. (1992). Vector Quantization and Signal Compression, The Springer International Series in Engineering and Computer Science 1st edition.

[29]. Linde, Y., Buzo, A., Gray R. (1980). An Algorithm for Vector Quantizer Design, IEEE Transactions on Communications, 28(1), 84-95.

[30]. Sariman, G. (2011). A Study of Clustering Techniques in Data Mining: Comparison of The K-Means and K-Medoids Clustering Algorithms, Suleyman Demirel University Science Institute Journal, 15(3), 192–202.

[31]. Turkish Statistical Institute (TUİK-2021 data), https://data.tuik.gov.tr.

[32]. Tibshirani, R., Walther, G., Hastie, T. (2001). Estimating the Number of Clusters in a Data Set via the Gap Statistic, Journal of the Royal Statistical Society. Series B (Statistical Methodology), 63(2), 411–423.

[33]. Avcioğlu, A.O. and Turker, U. (2012). Status and potential of biogas energy from animal wastes in Turkey, Renewable and Sustainable Energy Reviews, 16:1557–1561.

[34]. Melikoglu, M. and Menekse, Z.K. (2020). Forecasting Turkey's cattle and sheep manure based biomethane potentials till 2026, Biomass and Bioenergy, 132:105440.