International Journal of Operations Research and Information Systems
Volume 12 • Issue 4

Fuzzy Clustering With Derivative–Free Search Algorithm for Location of Biogas Energy Systems

Gökçe Kiliçkaya, Istanbul University-Cerrahpaşa, Turkey*
Tarik Küçükdeniz, Istanbul University-Cerrahpaşa, Turkey
https://orcid.org/0000-0002-6670-1809
Şakir Esnaf, Istanbul University-Cerrahpasa, Turkey
https://orcid.org/0000-0001-6261-3118

ABSTRACT

In the past decades, new models and algorithms have been developed for solving various types of facility location problems using different versions of the fuzzy c-means algorithm and its hybrid combinations. On the other hand, the need for renewable energy sources has become even more important due to the increasing population, environmental pollution, and climate change. In this study, the authors proposed two revised weighted fuzzy c-means clustering-based hybrid algorithms for solving real-life biogas facility location problem. The first algorithm is Nelder-Mead simplex algorithm, and the second is center-of-gravity approach. The problem is solved as multi-facility Weber problem, and results have been analyzed.

KEYWORDS

Biogas Facility Location, Center-of-Gravity Method, Multi-Facility Weber Problem, Nelder-Mead Simplex Algorithm, Revised Weighted Fuzzy C-Means

1. INTRODUCTION

The rapid growth of the world's population and the new dimensions of industrialization are rapidly increasing the need for energy. For this reason, the developed and developing countries which could not solve the energy problem, tried to develop new energy resources and new technologies for energy needs. As in all developing countries, our country must have sufficient energy to reach the level of developed countries. Nowadays, the need for energy and the negative effects of fossil fuels on the environment, as well as the tendency of fossil fuels to run out, have led researchers to research renewable energies. Biofuels can be produced from agricultural biomass and include bioethanol, biodiesel, bioethanol, biogas (methane and carbon dioxide mixture), and bio-oil components (Demirbaş, 2009). Turkey has a significant bioenergy potential because of its high number of animals and large farmland area. Therefore, an increase in the number of biogas facilities might contribute to the region's energy challenges. The environmental characteristics and the location problems of a biogas facility are important features to ensure maximum profitability (Derse, 2018).

DOI: 10.4018/IJORIS.294118
*Corresponding Author

To solve the facility location problems several methods from the center of gravity to clustering have been purposed. The center of gravity (COG) is a mathematical method used to locate the distribution center in such a way as to minimize the distribution costs. The *p*-median problem is the location problem of *p* number of facilities to minimize the total transportation cost (Sule, 2001). One of the methods used in the solution of the facility location problem is clustering. The clustering method, with its simplest definition, is the grouping of data with similar characteristics. The overall objective is to ensure homogeneity within the cluster, and heterogeneity among clusters. While the data in the clusters are very close to each other, the distance between the two different clusters is very large. The clustering method in facility location problems is related to the current positions and similarities of individuals in space. Individuals who are near to each other are gathered in the same cluster.

This study has three important contributions. The first contribution is that fuzzy clustering-based hybrid methods are first applied to the location of renewable energy systems. No study has been found in the literature yet. The second important contribution is that the Revised Weighted Fuzzy C-Means and Center-of-Gravity hybrid method developed for the solution of the multi-facility Weber problem. This new method adaptation to the facility location of biogas plants are proposed for the first time in this study. The third important contribution is that Revised Weighted Fuzzy C-Means and Nelder-Mead hybrid method developed by Küçükdeniz and Esnaf (2018), which is the core of the proposed method, was also first used for biogas plant location problem.

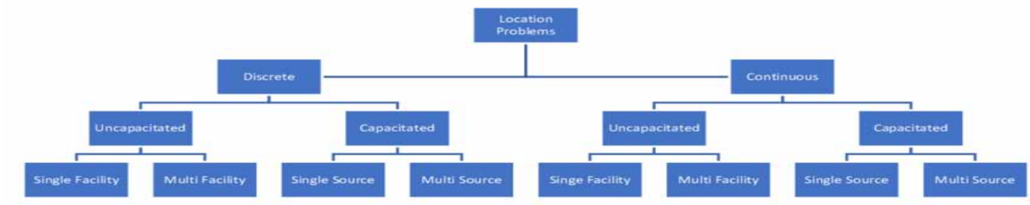
Facility location and modelling of biogas, one of the renewable energy sources, is an increasingly important issue. With the establishment of a biogas facility in a suitable location, attention is drawn to the savings in transportation costs and sustainability. Determination of location selection is important for facilities as it greatly affects fixed and variable costs. The aim of the study both the cost will be reduced and the efficiency and profit to be obtained from the biogas facilities will be maximized. Determining the optimum location of biogas facilities benefits many social, environmental, geographical, legal and economic areas. The proposed model was applied for the first time in renewable energy sources. The developed hybrid method is one of rare studies in the literature for biogas facilities. With the proposed model, both optimum location of renewable energy sources are provided and it provides an environmental contribution with the decrease in transportation costs.

The rest of the sections is as follows. In the second section, multi-facility Weber problem is explained. In the third section, studies in the literature are analyzed. In the fourth section, hybrid revised weighted fuzzy c-means (RWFCM), Nelder-Mead (NM) and its hybrid RWFCM and NM methods are examined. The fifth section is about the application of the problem. In this section, with the help of the hybrid RWFCM and NM method, facility locations in Konya province are determined, and then multi-facility Weber problem (MFWP) is used in order to minimize the total transportation cost. The application was designated as the location of biogas plants, and alternative solutions were suggested using a real-world problem. Also, the results obtained from the methods are discussed and benchmarked. The last section is the conclusions of this study.

2. PROBLEM DEFINITION

Among facility location problems, the problems seeking to find a facility location in solution space are called the Weber Problem. This classification of four sub-classes is shown in Figure 1 (Tunçbilek, 2018).

Figure 1. Clusters of location problems (Tunçbilek,2018)



Multi-Facility Weber Problem (MFWP)

The Multi-facility Weber Problem (MFWP), which is an advanced form of the Weber Problem, deals with the establishment of multiple facilities to meet the demands (w_i) of customers located at the points (a_i) on a plane with the minimum total transportation cost. The capacities of the facilities are considered unlimited. Another purpose of the MFWP is to determine the location of each facility and the allocation of each customer to a facility to meet its demand. The investment costs of facilities are not involved in the total cost, and the only objective function is to minimize the total transportation cost. The number of facilities is predetermined. In MWFP, the total capacity of the facilities is greater than the total amount of demand. Since facility capacities are unlimited, in the optimum solution, each customer is assigned to the facility that is closest to it, and each customer receives service from only one facility. MFWP has an objective function which is nonlinear, neither concave nor convex, and it usually contains a great number of local minimum points. The details of the problem are given below.

MFWP:

$$\min_{Z,X} \sum_{i=1}^{n} \sum_{j=1}^{m} w_i z_{ij} d\left(X_j, a_i\right) \tag{1}$$

Subject to

$$\sum_{i=1}^{m} z_{ij} = 1 \qquad i = 1, \ldots, n \tag{2}$$

m: number of facilities
n: number of districts
$a_i = (a_{i1}, a_{i2})$: coordinates of the i^{th} district ***i****=1,...,n*
$X = (x_1, \ldots, x_m)$: coordinates of the j^{th} facility [x_j: (x_{j1}, x_{j2})] decision variables $j=1,\ldots,m$
w_i: manure supply of the i^{th} district
$Z = (z_{ij})$: 1; if the i^{th} district is allocated to the j^{th} facility, 0; otherwise
$d(X_j, a_i)$: Euclidean distance between district *i* and facility *j*.

The objective function (1) is a minisum (location problem) function that minimizes the sum of weighted distances from the demand points to the nearest facilities. Constraint (2) guarantees that the total production of each district of each customer is satisfied. *X*, and z_{ij} are the decision variables of the model. Finally, constraint (3) gives the conditions of decision variables, if $z_{ij} = 1$: district *i* is served by facility *j*, otherwise $z_{ij} = 0$.

z_{ij} values, which represents the assignment of district to facilities, is determined by the assignment of each district to its nearest facility. Also, a district gives service to only one facility. If a district has the same distance from more than one facility, it supplies to any facility. In this study, all facilities have unlimited capacities.

3. LITERATURE REVIEW

Esnaf and Küçükdeniz (2006, 2009), Esnaf et al. (2009), and Küçükdeniz et al.(2019) applied a hybrid-clustering model of fuzzy c-means and Gustafson-Kessel methods on some multi-source facility location problems.

Celli et al. (2008) applied optimization algorithm for the effectiveness of biogas production to take into biogas availability, transportation, and power facilities as well as constraints. The Geographic Information System (GIS) was used to get better results. In this study used hybrid revised weighted fuzzy c-means methods for finding the optimal biogas power plants by minimizing the transportation cost. According to Esnaf et al. (2008), multi-facility location problems can be seen widely in real life situations such as garbage collection systems and emergency services. In this study, fuzzy c-means based methods are proposed for the solution of a problem in which the points of capacity constrained supplier centers and demand centers are known.

Rentizelas and Tatsiopoulos (2010) examined the optimum location for energy applications of the bioenergy production plant. In this study, due to the complexity of the optimization problem, the hybrid optimization method was used to overcome in constraints. In a study by Esnaf and Küçükdeniz (2013), fuzzy c-means algorithm is modified for uncapacitated planar multi-facility location problems. Modified version considers weights in every iteration to update the cluster centers. Thus the use of the center of gravity method, and convex programming, etc. after fuzzy c-means algorithm is not necessary anymore.

Büyüksaatçi and Esnaf (2014) proposed a new approach to solving the problem of carbon emission based facility location problem. In this study, a novel hybrid model that aims to reduce CO_2 emissions in distribution channels is developed. Clustering analysis was performed by using fuzzy C-means and Gustafson-Kessel algorithms. Esnaf et al. (2014) proposed a new algorithm to solve uncapacitated facility location problems. This algorithm is a special form of the original fuzzy c-means algorithm. By this algorithm, demand points are assigned to clusters using the membership values of the demand points in one iteration. Silva et al. (2014) apply a Multicriteria Spatial Decision Support System determine the suitable sites for placement of biogas plants. In this method used is ELECTRE TRI to yields of a possible alternative and use of a Geographic Information System (GIS) to assess with more subjective information.

Franco et al. (2015) formulated the facility location problem as a multi-criteria decision problem to identify and rank suitable alternatives for biogas plants. Also, in their study present the Geographical Information System (GIS) for measuring according to a given set of criteria. Yürük and Erdoğmuş (2015) analyzed the problem of where a biogas facility would be located if biogas was produced from poultry manure in Düzce province of Turkey. In this study, the biogas potential of Düzce province were calculated and the poultry manure facilities were divided into clusters by K-means clustering method.

Ciapala et al. (2017) present to choose optimal location and crucial customers to optimization three approaches. In order to obtain the optimal location for the biogas power plant used mixed integer nonlinear mathematical model. In this study, discuss obtained results from three approaches to optimization process and further improvements. Derinkuyu et al. (2017)-biogas power plant uses animal waste to reach energy production therefore in this study is used to collaborate with about 150 farms within the area. They proposed mathematical model to supply the waste needs of the plant form the farms and 4 step heuristic model has been developed.

Kim et al. (2018) propose a two-stage simulation-based structure to find optimal locations of biomass storage facilities that can help solve concerns about bio-refinery. Geographical Information System was used to minimize transportation costs. Jeong and Gomez (2018) examine the selection of biomass plants is important case because biomass depots are geographically dispersed. Geographic

Information System-Multi-Criteria Decision Analysis (GIS-MCDA) techniques are suitable for solving such problems. The authors are used Geographic Information System-Multi-Criteria Decision Analysis (GIS-MCDA) techniques to identify suitable for biomass facilities. Foncesa et al. (2018), examined limited work has been done on the circular economy. Because of this gap a quantitative research was carried out among 99 Portuguese organizations with online survey. The results obtained show that the circular economy is an important and valuable topic. Zimon et al. (2019) provide analysis and reviews about of sustainable development goals (SDG). In this study, its connection with sustainable supply chain management (SSCM) has been explained and research has contributed to the literature. In summarizing include a new conceptual model, and a dynamic context for a three phase model for implementation of successful sustainable supply chain management initiatives.

Kheybari and Rezaie (2020) discusses to locating biogas, solar and wind power plants with a multi-criteria approach. This paper examined renewable energy power plants depends on economic, social and environmental dimensions. Best-worst method (BWM) designed via an online survey for a sample of experts in Iran. The results indicate that energy saving, effect on resources and natural reserves and wind flow are the most effective factors for determing location of plants. Yücenur et al. (2020), proposed one of the most important sources of renewable energy is the biogas in the world. Biogas provide both ecological balance and environmental safe. Turkey has the resources for the production of biogas. Therefore, this study aims appropriate city selection for a biogas facilitiy location. SWARA method is used in the first phase of the model. After obtaining criteria weights with SWARA method, COPRAS method is used for selecting appropriate city t establish a biogas facility. Coura et al. (2021), examined high volumes of animal manure and sewage sludge have negative impacts. Therefore, this research considers optimization of biomethanization processes for local environmental quality. Multicriteria and multiobjective techniques used for definition of suitable locations.

This study aims to find near-optimum points for biogas facilities by using the fuzzy clustering analysis hybridized with derivative-free and derivative search. When the literature is reviewed, it is seen that there is no study using Revised Weighted Fuzzy C-means with Center-of-Gravity and Nelder-Mead hybrid methods for the biogas facility location problem. Revised Weighted Fuzzy C-means and Center-of-Gravity hybrid method was also first proposed for facility location-allocation problems, especially for the most searched one known as multi-facility Weber problem and biogas facility location. According to the best of our knowledge, our study is a novel and pioneer work in this respect.

4. REVISED WEIGHTED FUZZY C-MEANS HYBRIDIZED WITH NELDER-MEAD AND CENTER-OF-GRAVITY METHODS FOR MULTI-FACILITY WEBER PROBLEM

In this section, RWFCM, Center-of-Gravity, NM, and their hybrid usages, RWFCM-COG, and RWFCM-NM methods will be explained. The use of demands as weight parameters added to the solution stages of FCM algorithm in RWFCM improves the quality of the solution. After the Revised Weighted Fuzzy C-Means (RWFCM) algorithm finds cluster centers, they are accepted as starting points and further improved using Center-of-Gravity and Nelder-Mead (NM) algorithms. The optimization of formula (1) is the aim of both versions (Küçükdeniz and Esnaf, 2018). In this study, the RWFCM algorithm will firstly solve the problem as described above, and then the NM simplex algorithm will be applied to get better results.

4.1. Revised Weighted Fuzzy C-Means Algorithm (RWFCM)

Esnaf and Küçükdeniz (2013) have proposed this method. This algorithm considers the weights of each data vector, which will be clustered. It is the weighted type of classical FCM algorithm. Unlike other weighted FCM methods, weights are not calculated during clustering iterations and do not exist artificially. In this method, the objective function of the RWFCM method such that $\nu = \{ \left[V_i \right]$, $1 \leq$

$i \leq c$ } | with $\nu_i \epsilon \mathfrak{R}^m$ vector of the final cluster prototypes, and p ϵ $(1,\infty)$ is a factor to adjust the weighting exponent of membership degree is as follows:

$$J_p(U,\nu) = \sum_{k=1}^{n}\sum_{i=1}^{c} w_k (u_{ik})^p a^k - \nu_i^{\,2} \tag{4}$$

U is the partition matrix with $\left[u_{ik}\right]$, c defines the cluster centers, a^k, $(1 \leq k \leq n)$, is the data to be clustered, and w_k is assigned weights to a^k.

The objective function of $J_p(U,\nu)$ under the following constraint is minimized.

$$\sum_{i=1}^{c} u_{ik} = 1 \ \forall k \tag{5}$$

The final cluster centers and respective membership functions are given by the following formulas;

$$v_i = \sum_{k=1}^{n} w_k (u_{ik})^p a_k \Big/ \sum_{k=1}^{n} (u_{ik})^p \quad 1 \leq \mathrm{i} \leq \mathrm{c} \tag{6}$$

$$u_{ik} = 1 \Big/ \sum\nolimits_{J=1}^{C} \left(\frac{a^k - v_i}{a^k - v_j} \right)^{2/(p-1)}, \ 1 \leq \mathrm{i} \leq \mathrm{c}, \quad 1 \leq \mathrm{k} \leq \mathrm{n} \tag{7}$$

Steps of the RWFCM algorithm;

Step 1: determine the number of clusters c, the weighting exponent p and initial values for cluster centers $\nu_1, \nu_2 \ldots\ldots \nu_c$.
Step 2: use formula (7) to calculate the membership values u_{ik} $(1 \leq \mathrm{i} \leq \mathrm{c},\ 1 \leq \mathrm{k} \leq \mathrm{n})$
Step 3: compute the updated cluster center values $\nu_1^{new}, \nu_2^{new} \ldots \nu_c^{new}$ with formula (6).
Step 4: if $\max_i \left\{ v_i - v_i^{new}{}_{err} \right\} < \varepsilon$ then stop else go to Step 2.

4.2. Nelder-Mead Simplex Algorithm (NM)

The simplex search method, first proposed by Spendley, Hext and Himsworth (1962) and later refined by Nelder and Mead (1965), is a derivative-free search method that was particularly designed for unconstrained minimization scenarios, such as nonlinear least squares, nonlinear simultaneous equations, and other types of function minimization (Fan et.al 2006).

Lagarias et al. (1998) introduced the NM algorithm aiming to minimize a function f(x) for $X \in \mathrm{R}^n$. A simplex is a geometric form in n dimensions with a convex hull of $n + 1$ corner. A simplex with vertices are expressed as $x_1, x_2, x_3 \ldots x_{n+1}$ by Δ.

The Nelder-Mead method iteratively produces a sequence of simplices to approximate an optimal point of f(x). At each iteration, the vertices $\left\{x_j\right\}_{j=1}^{n+1}$ of the simplex are ordered, according to the objective function.

$$f(x_1) \leq f(x_2) \leq f(x_3) \ldots \leq f(x_{n+1}). \tag{8}$$

Here x_1 is the best vertex, x_{n+1} is the worst vertex. If many vertexes have the same objective values, coherent tie-breaking rules as given by Lagarias *et al.* (1998) are required to well define the method (Gao and Han, 2012).

NM algorithm uses four parameters: coefficients of reflection (α), expansion (β), contraction (γ) and shrink (δ). Constraints of these parameters are: $\alpha > 0$, $\beta > 1$, $0 < \gamma < 1$ and $0 < \delta < 1$. In addition, $\alpha = 1$, $\beta = 2$, $\gamma = (1/2)$, and $\delta = (1/2)$ are the standard values of these parameters (Lagarias et al., 1998; Gao and Han, 2012; Nesamalar et al., 2016). $\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$ is the formula that finds the centroid of the n best vertices.

The Nelder-Mead algorithm which is the version of Lagarias et al. (1998) and Gao and Han (2012) is employed in this study. The algorithm has six steps and starts with sort step that holds formula (8) then do reflection (9) step. After the reflection, expansion (10) step is executed. Outside contraction (11) step follows the expansion. If replacement of evaluated point is required, inside contraction (12) step follows the outside contraction, otherwise shrink (12) step is performed. After inside contraction shrink step is executed again. Iterations end when predetermined error value is reached. Formulas of the steps are as follows.

Reflection. The reflection point x_r is computed using the formula (9);

$$x_r = (1+\alpha)\, \bar{x} - \alpha\, x_{n+1} \tag{9}$$

Expansion. The expansion point x_e is calculated using the formula (10);

$$x_e = \beta\, x_r - (1-\beta)\, \bar{x} \tag{10}$$

Outside contraction. The outside contraction point (x_{oc}) from;

$$x_{oc} = \gamma\, x_r + (1-\gamma)\, \bar{x} \tag{11}$$

Inside contraction. Calculate the inside contraction point (x_{ic}) from;

$$x_{ic} = (1+\gamma)\, \bar{x} - \gamma\, x_{n+1} \tag{12}$$

Shrink. For $2 \leq i \leq n + 1$, determine;

$$x_i = \delta\, x_i + (1-\delta)\, x_1 \tag{13}$$

The stopping criterion of the simplex is a distance between iteration *k* and iteration *(k +1)* . If $\frac{1}{2} \sum_{j=1}^{n} x_i^k - x_i^{k+12} < \varepsilon$, then the algorithm stops, where x^{k+1} is the vertex changing x^k at the iteration (k+1) and ε is a given "small" positive real number.

4.3. The Center-of-Gravity Method

The center-of-gravity (COG) is used for locating a single plant. COG aims to minimize transport costs between the known location of customers and geographical coordinates of facilities. The objective function of the COG is (Ballou,1999),

$$Min\sum_{i=1}^{n} w_i d\left(x_j, a_i\right) \tag{14}$$

Euclidean distance between demand point *i* and facility *j* is

$$\mathrm{d}\left(X_j, a_i\right) = \sqrt{\left(x_j - a_{i1}\right)^2 + \left(y_j - a_{i2}\right)^2} \tag{15}$$

Following facility location formulas are derived from formula (14) and (15) by taking the partial derivatives of (14) with respect to x_j and y_j, setting them equal to zero, and rearranging them.

$$\overline{x_j} = \frac{\sum_i w_i a_{i1} / d_i}{\sum_i w_i / d_i} \tag{16}$$

$$\overline{y_j} = \frac{\sum_i w_i a_{i2} / d_i}{\sum_i w_i / d_i} \tag{17}$$

At the first iteration of this method, formula (16) and (17) calculate the initial (X, Y) coordinates of each facility without taking into consideration of distances. These are approximate coordinates and using these coordinates' distances between customers and facilities are found. Substituting distance values into formula (16) and (17), new x_j and y_j coordinates are calculated. Using the latest coordinates, the *d* is recalculated, and iterations are continued until the difference between the last two values of the x_j and y_j coordinates is lower than a certain error value.

4.4. The Hybrid RWFCM-NM and RWFCM-COG Methods for MFWPs

Using the RWFCM algorithm, the most appropriate facility locations might be determined and therefore total transportation costs are minimized. In this section, we explained how the RWFCM algorithm combine with Nelder-Mead and Center of Gravity methods to solve the MFWP. A customer or a demand point with coordinates x_j and y_j is considered as a data point (a^k). The demand quantities of demand points constitute weights and they are symbolized by w_k. The transportation costs are the product of the demand quantities of demand locations and distances between facilities and demand locations. The facilities have infinite capacities.

The RWFCM algorithm gives the cluster centers for generalized MFWP, and these centers are the facility locations to be opened. Customers are assigned to facilities taking into account the membership value of the clustering algorithm. After RWFCM, final locations of the facilities are defined using the NM simplex algorithm.

RWFCM and COG hybrid method is a two-stage sequential approach that primarily clusters the customers and then applies COG to each cluster like hybrid RWFCM-NM method. Instead of NM, the COG approach is used. As a fine-tuning algorithm, COG is proposed in Esnaf and Küçükdeniz (2009) and used as benchmark algorithms in Gergin and Esnaf (2013), Büyüksaatçi and Esnaf (2014), Küçükdeniz and Esnaf (2018), and Gergin et al. (2019).

The implementation of the RWFCM-NM hybrid and RWFCM-COG methods is itemized as follows (Küçükdeniz and Esnaf, 2018):

1. Location of customers: $a^k = (x_k, y_k)$ where k denotes the number of customer, k =1,2,….,n;
2. Calculate the cluster centers v_i for all facilities using the RWFCM;
3. Determine the cluster (facility) of each customer according to the membership values u_{ik};
4. For each cluster, compute the cluster centers(location of facilities) with the selected algorithm. Options are Nelder-Mead explained in subsection 4.2. and Center-of-Gravity given in 4.3. and finalize v_i, a^k, w_k; and
5. $X_j \to v_i$, $a_i \to a^k$, $w_i \to w_k$, taking into account the last assignments made by NM or COG algorithms, determines w_{ij} and calculates the cost function given in the first section by formula (1).

5. APPLICATION

Afyon, Amasya, Balıkesir, Çorum, Erzurum, Isparta, Izmir, Kars, Konya, Malatya, Samsun, Sivas, Şanlıurfa, Tokat, and Yozgat are the provinces in Turkey that have facilities in which milk is produced and processed. Konya province has a 15% share in milk production together with Aksaray province, and this rate is higher than that of Balıkesir province. In addition, Konya has become one of the most active markets where milk price is determined without a tender. This region has become even more attractive with the investments of big industrialists. Therefore, Konya province appears to be one of the most effective places in milk production in the near future (TZOD, Agricultural Economics Reports).

Considering the reasons mentioned above, it can be argued that Konya is one of the most suitable provinces for biogas production. For this reason, this study will deal with the biogas multi-facility location-allocation problem in Konya province. The purpose is to find biogas facility locations that are close to dairy farms so that the transportation cost is minimum. Therefore, we will first use the hybrid RWFCM-NM and RWFCM-COG (Revised Weighted Fuzzy C-Means-Center-of-Gravity) methods for the solution of the problem. Then, the problem will be solved using FCM (Fuzzy C-Means), FCM-COG (Fuzzy C-Means-Center-of-Gravity), RWFCM (Revised Weighted Fuzzy C-Means), and FCM-NM (Fuzzy C-Means Nelder-Mead) methods. Finally, the results taken from all the methods will be benchmarked.

5.1. Data Set

In this study, the most suitable biogas facility locations found, taking into account the total amount of dairy manure in each district of Konya province. For each district, the amount of dairy manure was calculated using the amount of milk produced. 1.75 kg of dairy manure is obtained, producing 1 kg of milk (Yurtseven, 2013), and 1 kg of dairy manure equals 33-meter cube of biogas (Ergür and Okumuş, 2010). The data set of this study consists of *X* and *Y* coordinates and the dairy manure produced in each district. Coordinates of 31 districts are given in Table 1.

Table 1. Coordinates and demands of 31 districts of Konya province

Number	District	X	Y	Milk Produced (Tons)	Produced Manure (Tons)
1	Ahırlı	37.24	32.12	11792	20636
2	Akören	37.45	32.37	6935	12136
3	Akşehir	38.36	31.42	18312	32046
4	Altınekin	38.31	32.87	15163	26535
5	Beyşehir	37.68	31.72	40051	70089
6	Bozkır	37.19	32.25	14093	24662
7	Cihanbeyli	38.66	32.92	43112	75446
8	Çeltik	39.02	31.79	7074	12379
9	Çumra	37.57	32.78	117589	205780
10	Derbent	38.01	32.02	8718	15256
11	Derebucak	37.39	31.51	3710	6492
12	Doğanhisar	38.15	31.68	10650	18637
13	Emirgazi	37.9	33.84	37165	65038
14	Ereğli	37.51	34.05	129283	226245
15	Güneysınır	37.27	32.73	14731	25779
16	Hadim	36.99	32.46	6144	10752
17	Halkapınar	37.43	34.19	9781	17116
18	Hüyük	37.95	31.6	9851	17239
19	Ilgın	38.28	31.91	69925	122368
20	Kadınhanı	38.24	32.21	53222	93138
21	Karapınar	37.72	33.55	102319	179058
22	Karatay	37.87	32.5	82410	144217
23	Kulu	39.09	33.08	16881	29541
24	Meram	37.86	32.47	24597	43044
25	Sarayönü	38.27	32.41	21358	37376
26	Selçuklu	37.93	32.51	18753	32817
27	Seydişehir	37.42	31.85	30168	52794
28	Taşkent	36.92	32.49	1972	3451
29	Tuzlukçu	38.48	31.63	13072	22876
30	Yalıhüyük	37.3	32.09	1798	3146
31	Yunak	38.81	31.73	22175	38806

5.2. Solving the Problem

It should not be forgotten that demand, as mentioned in the problem description and methods above, is the amount of manure that is to be supplied from the diary farms in each district to the biogas facilities.

The RWFCM algorithm handles the manure as weight, v_i are calculated for each cluster. Afterward, facility locations are considered as decision variables, and the total transportation cost is minimized running the NM simplex algorithm for each cluster. The NM algorithm accepts the coordinates of facilities determined by the last iteration of the Revised WFCM algorithm as the initial points, and it reaches to ultimate cluster centers (facility locations). Finally, multiplying the produced manure of each district with the distance to its cluster center (facility location) gives the total transportation cost. The COG method is used similarly as the NM algorithm.

In this study, for the application of the RWFCM algorithm, the codes adapted by Balasko et al., (2005) for MATLAB is used. Membership degree weighting effect (p) and, termination tolerance of the clusters (ε) are same as in Küçükdeniz and Esnaf (2018).

5.3. Comparing the Performances of the RWFCM-NM and RWFCM-COG With Benchmark Methods

This section is regarding the comparison of the performance of the RWFCM-NM and RWFCM-COG methods with other clustering based facility location methods. Firstly, benchmark methods will briefly be summarized. Then, there will be a comparison between benchmark methods. MATLAB R2015a was used to run the codes of the FCM, the FCM-COG, the RWFCM, the FCM-NM, the RWFCM-NM and the RWFCM-COG. FCM, FCM-COG, and, RWFCM algorithms' details are referred in Esnaf and Küçükdeniz (2009) and Küçükdeniz and Esnaf (2018).

FCM based Nelder-Mead method (Küçükdeniz and Esnaf, 2018): Cluster centers obtained by FCM method is fine-tuned using NM method. The NM simplex algorithm performs a direct-search to minimize the total transport cost of each problem by changing the location of facilities until it reaches final and optimal locations.

Self Organizing Maps (SOM) is represented high dimension inputs with lower dimension outputs that is special type of neural networks. Another name is known as Kohonen Maps because initially examined by Teuvo Kohonen. Firstly, system trains itself and new inputs are mapped. SOM algorithm benefits from competitive learning during that phase. Haykin (1999) presents that SOM run very similar to C-Means algorithm for small number of neurons (Gergin et al. 2019).

In this study, the RWFCM algorithm which allocates demand with the degree of their memberships proposed by Küçükdeniz and Esnaf (2018) for the Multi-Source Weber problem was adapted to the multi-facility Weber problem by taking into consideration the assumption that each the manure of each district is received by only one facility.

The predefined numbers of the cluster centers are two, three, four, and five, respectively. Table 2 depicts the coordinates of each cluster center of all algorithms. Table 3 shows the location of facilities and allocation of customers obtained for two, three, four, and five facility options using the RWFCM-NM and RWFCM-COG hybrid methods. Table 4 demonstrates the total transportation costs of all methods calculated according to the coordinate values given in Table 2.

Table 2. Benchmark Results for Coordinates of Clusters Centers

Number of Clusters-Facilities	FCM X Y		SOM X Y	RWFCM X Y		FCM-COG X Y		RWFCM-COG X Y		FCM-NM X Y		RWFCM-NM X Y	
2	37.97	31.99	37.81 32.09	37.67	33.71	38.06	32.12	37.51	34.05	37.89	32.45	37.51	34.05
	37.74	33.20	38.08 33.49	38.00	32.22	37.72	33.55	37.89	32.45	37.51	34.05	37.89	32.45
3													
	38.33	31.91	37.43 32.27	38.24	31.94	38.31	32.09	38.28	31.91	38.28	31.91	38.28	31.91
	37.74	33.78	37.64 33.90	37.65	33.83	37.51	34.05	37.51	34.05	37.51	34.05	37.51	34.05
	37.41	32.3	38.43 32.09	37.73	32.58	37.72	32.52	37.82	32.53	37.87	32.5	37.87	32.50
4													
	38.13	32.53	37.64 33.90	38.63	32.88	37.87	32.5	38.66	32.92	37.87	32.5	38.66	32.92
	37.66	33.89	38.30 31.72	37.62	33.87	37.51	34.05	37.51	34.05	37.55	34.00	37.54	34.01
	37.27	32.24	37.27 32.26	37.67	32.58	37.43	31.86	37.68	32.59	37.57	32.78	37.71	32.55
	38.35	31.72	38.27 32.62	38.2	31.87	38.28	31.91	38.28	31.91	38.27	31.91	38.28	31.91
5													
	38.49	32.82	37.64 33.90	38.66	32.91	38.66	32.92	38.66	32.92	38.66	32.92	38.66	32.92
	37.26	32.38	38.66 31.64	37.67	32.66	37.57	32.78	37.59	32.75	37.86	32.51	37.68	32.66
	37.74	31.81	37.93 31.94	37.56	31.84	37.68	31.72	37.42	31.85	37.42	31.85	37.42	31.85
	37.63	33.92	38.68 32.95	37.62	33.89	37.51	34.05	37.51	34.05	37.64	33.85	37.62	33.9
	38.51	31.73	37.36 32.42	38.31	31.92	38.28	31.91	38.28	31.91	38.28	31.91	38.28	31.91

Total transportation cost defined with formula (1) is to minimize the sum of weighted distances from the districts to the nearest biogas facilities. As seen in Table 4, the proposed RWFCM-based hybrid methods gave the best results when compared to the other methods. For two and three clusters or facilities, the RWFCM-NM method gives better results than the RWFCM-COG. On the other hand, for four and five facilities, the opposite situation occurs. RWFCM-COG is slightly better than the RWFCM-NM method. When we look at Table 4, we also can see that the results of the hybridized RWFCM methods with using the NM algorithm and COG method are better than the original RWFCM method. Thus, it can be stated that the RWFCM-NM and RWFCM-COG hybrids give better results.

Table 3. Location of facilities and allocation of customers of RWFCM-NM and RWFCM-COG hybrid methods

Number of Clusters Facilities	Facility number	Districts (As Numbers)	Total Manure (Tons)
	1	13,14,17,21	487457
2			
	2	1,2,3,4,5,6,7,8,9,10,11,12,15,16,18,19,20,22,23,24,25,26 27,28,29,30,31	1197438
	1	3,5,8,10,11,12,18,19,20,23,25,29,31	516243

Table 3 continued on next page

Table 3 continued

Number of Clusters Facilities	Facility number	Districts (As Numbers)	Total Manure (Tons)
3	2	13,14,17,21	487457
	3	1,2,4,6,7,9,15,16,22,24,26,27,28,30	681195
	1	4,7,23	131522
4	2	13,14,17,21,23	516998
	3	1,2,6,9,15,16,22,24,26,27,28,29,30	602090
	4	3,5,8,10,12,18,19,20,25,29,31	480210
	1	4,7,23	131522
	2	2,9,15,16,22,24,26,28	477976
5	3	1,5,6,11,18,27,30	195058
	4	13,14,17,21	487457
	5	3,8,10,12,19,20,25,29,31	392882

Table 4. Benchmark Results for Total Transportation Costs

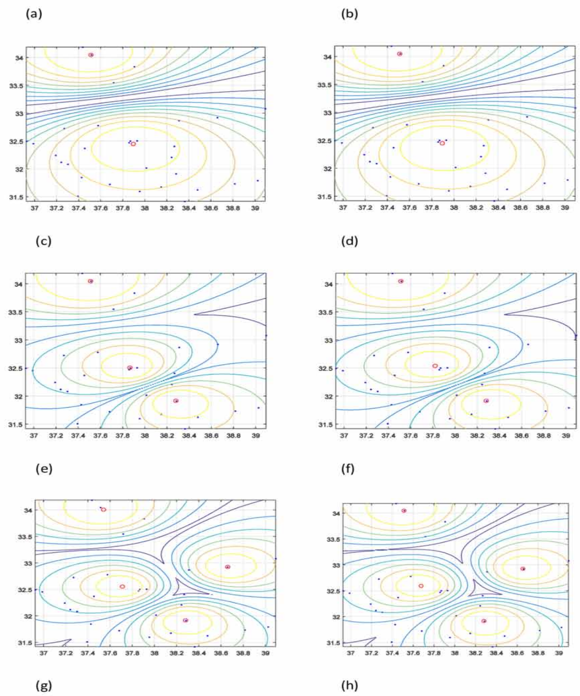
Number of biogas facilities	FCM (TRY*)	SOM (TRY*)		RWFCM (TRY*)	FCM-COG (TRY*)	FCM-NM (TRY*)	RWFCM-NM (TRY*)	RWFCM-COG (TRY*)
2	985637.102	859847.372		858099.749	890757.576	822381.006	822381.005	822381.005
3	730895.953	723828.489		630508.505	637787.972	615305.647	615284.203	617072.807
4	628634.256	645783.992		528238.535	527496.654	520488.259	511143.126	509764.316
5	617394.148	584778.881		436481.739	428642.156	431890.312	428903.864	424973.766

*Turkish Liras

Figure 2 shows the cluster map solutions of RWFCM-NM and RWFCM-COG hybrid methods.

Note: (a)RWFCM-NM for 2 clusters; (b)RWFCM-COG for 2 clusters; (c)RWFCM-NM for 3 clusters; (d) RWFCM-COG for 3 clusters; (e)RWFCM-NM for 4 clusters; (f) RWFCM-COG for 4 clusters; (g) RWFCM-NM for 5 clusters; (h)RWFCM-COG for 5 clusters.

Figure 2. Cluster map solutions of the RWFCM-NM and RWFCM-COG hybrid methods for 2,3,4,5 clusters



The percentages of the transport cost differences,D, for each group of facilities of FCM, RWFCM, FCM-COG, FCM-NM, RWFCM-COG and the RWFCM-NM hybrid method are computed with the following formula:

$$D = \left(\frac{O - Y}{O} \right) \tag{18}$$

Where O denotes the objective function value, i.e., transportation cost, generated by benchmark methods for each data set, Y is the transportation cost generated by the RWFCM method for the corresponding data set.

According to formula (18), the percentage differences of the RWCM-NM hybrid method compared to the other methods is as shown in Table 5, and percentages of the RWFCM-COG hybrid method regarding other methods are presented in Table 6.

Table 5. Percentages of transportation costs differences of the RWFCM-NM method from the FCM, the RWFCM, FCM-COG, FCM-NM, and the RWFCM-COG methods.

Number of biogas facilities	FCM	SOM	RWFCM	FCM-COG	FCM-NM	RWFCM-COG
2	16.564%	3.746%	4.163%	7.676%	0.000%	0.000%
3	15.818%	14.675%	2.415%	3.528%	0.003%	0.290%

For two and three facilities, RWFCM-NM is better than FCM, RWFCM, and FCM-COG methods. For two facility, the cost of the RWFCM-NM is equal to FCM-NM and RWFCM-COG methods. For three facilities, the RWFCM-NM method is slightly better than FCM-NM and just 0.29% lower than RWFCM-COG.

Table 6. Percentages of transportation costs differences of the RWFCM-COG method from FCM, the RWFCM, FCM-COG, FCM-NM, and the RWFCM-NM methods.

Number of biogas facilities	*FCM*	*SOM*	*RWFCM*	*FCM-COG*	*FCM-NM*	*RWFCM-NM*
4	18.909%	20.601%	3.497%	3.362%	2.060%	0.270%
5	31.167%	26.980%	2.637%	0.856%	1.601%	0.916%

For four and five facilities, RWFCM-COG is better than FCM, RWFCM, FCM-COG, FCM-COG, and RWFCM-NM methods.

6. CONCLUSIONS

This study has three contributions to the literature. The first contribution is the application of a known method to a new application area. Revised Weighted Fuzzy C-Means and Nelder-Mead hybrid method (RWFCM-NM) proposed by Küçükdeniz and Esnaf (2018) are used to locate and allocate renewable energy systems or resources. The RWFCM-NM hybrid method finds near-optimal solution to a real-life problem of location-allocation of biogas facilities in a Turkish city.

The second contribution is the application of newly developed method which stems from this study to the new area. The new algorithm called Revised Weighted Fuzzy C-Means and Center-of-Gravity (RWFCM-COG) hybrid, was first proposed in this study for facility location-allocation problems. The third and final contribution is the application of the RWFCM-COG, a new method, to a real-life biogas facility location-allocation problem, new application area.

It can be said that our study is a novel and pioneering study in the fields of location-allocation and renewable energy areas, which brings a solution to the biogas facility location. Benchmark analysis was carried out using the dataset of Konya province and its districts that produces the highest amount of milk in Turkey.

Results show, the maximum cost difference that is 31.67% was obtained by RWFCM-COG hybrid method against the FCM method in case of 5 plants. In the case of 5-facility location, the solution obtained by the RWFCM-COG hybrid method is the most cost-effective solution. In the case of two biogas plants, the costs of FCM-NM, RWFCM-NM and RWFCM-COG methods are equal to each other and this gives the lowest cost solution for the number of plants. In the case of three plants, the RWFCM-NM has a lower cost solution compared to the RWFCM-COG method. In the case of 4 and five plants, the RWFCM-COG method has 0.27% and 0.916% lower costs, respectively, according to the RWFCM-NM method.

Comparative results show that proposed hybrid method gives optimized results. Although the RWFCM-NM and RWFCM-COG methods do not provide each other a clear advantage, the RWFCM-COG gives the same results as RWFCM-NM when in the case of two facilities. Also, better performance than RWFCM-NM in 4 and 5 plant alternatives show that this hybrid method is one step ahead. To sum up, a real world facility location problem is solved for coordinates data of 31 districts of Konya province. Transportation costs are minimized by clustering-based hybrid methods, taking into account the milk quantities for each district. The proposed RWFCM-COG algorithm based method is benchmarked with FCM, FCM-COG, FCM-NM, RWFCM, RWFCM-NM methods. The RWFCM-COG and RWFCM-NM have been given better results in all instances.

The model proposed in our study was applied for the first time in biogas facility location. Transportation costs are minimized with optimum facility location. The aim of the study is to provide both renewable energy production and cost minimization. The best results were obtained with the proposed model. Therefore, the efficiency of the model applied for the first time in renewable energy has been demonstrated. In our study, attention was drawn to renewable energy which is an important issue in terms of sustainability.

As a future study, green route planning can be developed that optimizes the routes of clustered biomass production points in each set of plants determined by RWFCM-based methods, that also considers low carbon emissions. Also, future research might be focused on social impact. Employment to be provided to the region with biogas facilities can be examined. Labor benefit cost can be calculated for the development of the region. Analysis can be developed taking into account the population of the region. In addition, the response of the local people in the selected region to the biogas plants can be examined. The effect of reducing environmental pollution and getting rid of solid wastes on the people of the regipn can be examined.

REFERENCES

Balasko, B., Abony, J., & Feil, B. (2005). *Fuzzy clustering and data analysis toolbox*. Academic Press.

Ballou, R. (1999). *Business Logistics Management* (4th ed.). Prentice-Hall Inc.

Büyüksaatçi, S., & Esnaf, Ş. (2014). Carbon Emission Based Optimization Approach for the Facility Location Problem. *The Online Journal of Science and Technology*, *4*(1).

Celli, G., Ghiani, E., Loddo, M., Pilo, F., & Pani, S. (2008). Optimal location of biogas and biomass generation plants. In *2008 43rd International Universities Power Engineering Conference* (pp. 1-6). IEEE. doi:10.1109/UPEC.2008.4651490

Ciapała, B., Jurasz, J., & Janowski, M. (2017). Decision support for optimal location of local heat source for small district heating system on the example of the biogas plant. In *E3S Web of Conferences* (Vol. 17, p. 00016). EDP Sciences. doi:10.1051/e3sconf/20171700016

Coura, R., Alonso, J. M., Rodrigues, A. C., Ferraz, A. I., Mouta, N., Silva, R., & Brito, A. G. D. (2021). Spatially Explicit Model for Anaerobic Co-Digestion Facilities Location and Pre-Dimensioning Considering Spatial Distribution of Resource Supply and Biogas Yield in Northwest Portugal. *Applied Sciences (Basel, Switzerland)*, *11*(4), 1841. doi:10.3390/app11041841

Demirbaş, A. (2009). Biofuels from agricultural biomass. Energy Sources. *Part A*, *31*(17), 1573–1582.

Derinkuyu, K., Tarakçıoğlu, B., İrem Melis, K. O. Ç., Sazak, E., & Zengin, D. (2017). Biomass Logistics Management for Biogas Power Production Facility. *Journal of Industrial Engineering, 28*(3), 20-34.

Derse, O. (2018). Facility Location Selection Problem for Biogas Energy Plant by Goal Programming. *Süleyman Demirel University Journal of Natural and Applied Sciences.*

Ergür, H. S., & Okumuş, F. (2010). Cost and potential analysis of biogas in Eskisehir. *Uludağ University Journal of The Faculty of Engineering, 15*(2).

Esnaf, Ş., & Küçükdeniz, T. (2006). A Fuzzy Clustering-Based Hybrid Method for A Multi-Facility Location Problem. *Proceedings of the 5th International Symposium on Intelligent Manufacturing Systems*, 304-317.

Esnaf, Ş., & Küçükdeniz, T. (2009). A Fuzzy Clustering-Based Hybrid Method for A Multi-Facility Location Problem. *Journal of Intelligent Manufacturing*, *20*(2), 259–265. doi:10.1007/s10845-008-0233-y

Esnaf, Ş., & Küçükdeniz, T. (2013). Solving Uncapacitated Planar Multi-facility Location Problems by a Revised Weighted Fuzzy c-means Clustering Algorithm. *Journal of Multiple-Valued Logic & Soft Computing*, *21*(1-2), 147–164.

Esnaf, Ş., Küçükdeniz, T., & Büyüksaatçi, S. (2008). Fuzzy C-Means and Center of Gravity Combined Model for a Capacitated Planar Multiple Facility Location Problem. *International Conference on Multivariate Statistical Modeling and High dimensional Data Mining*, 131.

Esnaf, S., Küçükdeniz T., & Tunçbilek, N. (2014). Fuzzy C-Means Algorithm with Fixed Cluster Centers for Uncapacitated Facility Location Problems: Turkish Case Study. *Supply Chain Management Under Fuzziness*.

Fan, S. K. S., Liang, Y. C., & Zahara, E. (2006). A genetic algorithm and a particle swarm optimizer hybridized with Nelder–Mead simplex search. *Computers & Industrial Engineering*, *50*(4), 401–425. doi:10.1016/j.cie.2005.01.022

Fonseca, L. M., Domingues, J. P., Pereira, M. T., Martins, F. F., & Zimon, D. (2018). Assessment of circular economy within Portuguese organizations. *Sustainability*, *10*(7), 2521. doi:10.3390/su10072521

Franco, C., Bojesen, M., Hougaard, J. L., & Nielsen, K. (2015). A fuzzy approach to a multiple criteria and Geographical Information System for decision support on suitable locations for biogas plants. *Applied Energy*, *140*, 304–315. doi:10.1016/j.apenergy.2014.11.060

Gao, F., & Han, L. (2012). Implementing the Nelder-Mead simplex algorithm with adaptive parameters. *Computational Optimization and Applications*, *51*(1), 259–277. doi:10.1007/s10589-010-9329-3

Gergin, Z., & Esnaf, Ş. (2013, July). Comparing the performance of different artificial intelligence based clustering algorithms in healthcare waste disposal location. In *Intelligent Systems and Decision Making for Risk Analysis and Crisis Response: Proceedings of the 4th International Conference on Risk Analysis and Crisis Response*, *Istanbul, Turkey*, *27-29 August 2013* (p. 161). CRC Press.

Gergin, Z., Tunçbilek, N., & Esnaf, Ş. (2019). Clustering Approach Using Artificial Bee Colony Algorithm for Healthcare Waste Disposal Facility Location Problem. *International Journal of Operations Research and Information Systems*, *10*(1), 56–75. doi:10.4018/IJORIS.2019010104

Jeong, J. S., & Ramírez-Gómez, Á. (2018). Optimizing the location of a biomass plant with a fuzzy-Decision-Making Trial and Evaluation Laboratory (F-DEMATEL) and multi-criteria spatial decision assessment for renewable energy management and long-term sustainability. *Journal of Cleaner Production*, *182*, 509–520. doi:10.1016/j.jclepro.2017.12.072

Kheybari, S., & Rezaie, F. M. (2020). Selection of biogas, solar, and wind power plants' locations: An MCDA approach. *Journal of Supply Chain Management Science*, *1*(1-2), 45–71.

Kim, S., Kim, S., & Kiniry, J. R. (2018). Two-phase simulation-based location-allocation optimization of biomass storage distribution. *Simulation Modelling Practice and Theory*, *86*, 155–168. doi:10.1016/j.simpat.2018.05.006

Küçükdeniz, T., & Esnaf, S. (2018). Hybrid revised weighted fuzzy c-means clustering with Nelder-Mead simplex algorithm for generalized multisource Weber problem. *Journal of Enterprise Information Management*, *31*(6), 908–924. doi:10.1108/JEIM-01-2018-0002

Küçükdeniz, T., Esnaf, S., & Baytürk, E. (2019). Extended Single-Iteration Fuzzy C-Means, and Gustafson-Kessel Algorithms for Medium-Sized (10^6) Multisource Weber Problem, International Journal of Operations Research and Information Systems (IJORIS). *SpVol.*, *10*(3), 1–15.

Lagarias, J. C., Reeds, J. A., Wright, M. H., & Wright, P. E. (1998). Convergence properties of the Nelder-Mead simplex method in low dimensions. *SIAM Journal on Optimization*, *9*(1), 112–147. doi:10.1137/S1052623496303470

Nelder, J. A., & Mead, R. (1965). A simplex method for function minimization. *The Computer Journal*, *7*(4), 308–313. doi:10.1093/comjnl/7.4.308

Nesamalar, J. J. D., Venkatesh, P., & Raja, S. C. (2016). Managing multi-line power congestion by using hybrid Nelder-Mead-fuzzy adaptive particle swarm optimization (HNM-FAPSO). *Applied Soft Computing*, *43*, 222–234. doi:10.1016/j.asoc.2016.02.013

Rentizelas, A. A., & Tatsiopoulos, I. P. (2010). Locating a bioenergy facility using a hybrid optimization method. *International Journal of Production Economics*, *123*(1), 196–209. doi:10.1016/j.ijpe.2009.08.013

Silva, S., Alçada-Almeida, L., & Dias, L. C. (2014). Biogas Plants Site Selection Integrating Multicriteria Decision Aid Methods and GIS Techniques: A Case Study in a Portuguese Region. *Biomass and Bioenergy*, *71*, 58–68. doi:10.1016/j.biombioe.2014.10.025

Spendley, W. G. R. F. R., Hext, G. R., & Himsworth, F. R. (1962). Sequential application of simplex designs in optimization and evolutionary operation. *Technometrics*, *4*(4), 441–461. doi:10.1080/00401706.1962.10490033

Sule, D. R. (2001). *Logistics of Facility Location and Allocation*. Marcel Dekker Inc. doi:10.1201/9780203910405

Tunçbilek, N. (2018). *Modıfied Artificial Bee Colony Algorıthm for The Capacıtated Multı-Facılıty Weber Problem*. Ph.D. Thesis.

Turkey Union of Chambers of Agriculture. (2010). Agricultural Economics Reports. Author.

Yücenur, G. N., Çaylak, Ş., Gönül, G., & Postalcıoğlu, M. (2020). An integrated solution with SWARA&COPRAS methods in renewable energy production: City selection for biogas facility. *Renewable Energy*, *145*, 2587–2597. doi:10.1016/j.renene.2019.08.011

Yurtseven, S. (2013). Manure as Final Product of Animal Feeding and its Potential of Gas Production. *Journal of Nature and Science*, *16*(1), 62–69.

Yürük, F., & Erdoğmuş, P. (2015). Biogas Potential of Düzce Which Can Be Produced by Anımal Waste and Determınatıon of Optımum Plant Locatıon Wıth K-Means Clusterıng. *Journal of Advanced Technology Sciences*, *4*(1), 47–56.

Zimon, D., Tyan, J., & Sroufe, R. (2020). Drivers of sustainable supply chain management: Practices to alignment with un sustainable development goals. *International Journal for Quality Research, 14*(1).

Gökçe Kılıçkaya is a PhD student of Department of Industrial Engineering at Istanbul University-Cerrahpaşa. Department of Industrial Engineering, Faculty of Engineering, Istanbul University-Cerrahpaşa, Avcılar, Istanbul, Turkey Sakir Esnaf is a Professor of Department of Industrial Engineering at Istanbul University-Cerrahpasa. He graduated from Istanbul Technical University, Department of Industrial Engineering in 1986. He received his M.Sc and Ph.D degrees in Production Management from Istanbul University. He worked as a postdoctoral research fellow at the Intelligent Fuzzy Systems Laboratory, Department of Mechanical and Industrial Engineering at University of Toronto, Canada. His current research topics are facility location, fuzzy clustering, metaheuristics, big data analytics and revenue management. He has several national and international papers published.