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An Optimization Approach for a Biogas Supply Chain using Goal Programming and Mixed Integer Linear Programming

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Abstract
Environmental concerns prompt the world for a transition to renewable energy sources from fossil energy. Reducing the dependency on non-renewable energy sources is needed for the sustainable world and less environmental pollution. Biogas energy, which is one of the most important renewable energy sources, is produced by burning organic wastes and can be used in many different fields. In this study, a two-stage approach was presented to optimize a biogas supply chain problem by incorporating of 30 districts in Izmir. In the first stage, the selection of the most suitable biogas plants was considered by the goal programming approach, which is of great importance to decide the optimal location with high energy potential. The most suitable sites for the biogas plants were obtained as Konak and Narlıdere districts. In the second stage, the location problem of the biogas vehicle charging stations (BVS) for biogas vehicles was handled considering the results of the first stage using mixed integer linear programming (MILP) approach. Computational results demonstrate that it would be more appropriate to establish BVS in 12 districts of İzmir. The model and solution approach are pioneering for supply chain problems and an efficient tool for renewable energy plans.
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1. Introduction

In response to global warming, the optimal option for the green challenge is to reduce the dependency on fossil fuels and transition to renewable energy sources. Alternative energy sources have been gained attraction since the utilization of fossil fuels threatens human health and the environment. There has been a considerable impact on the alternative energy systems and most countries have attempted new energy policies such as bio-sources [1]. Biogas is one of the cleanest energy sources for human living and energy production is carried out using manure. Animal manure, which is the source of biogas production, ensures an environmentally friendly way to produce clean energy [2]. This energy can reduce the harmful effects of fossil fuels in various sectors including the transportation sector [3]. However, biogas is an alternative source of energy, which can be used instead of diesel, LPG, and natural gas. The integration of the biogas energy and transportation sector is important in the context of economic and environmental aspects. The optimal planning of the BVS should be conducted by incorporating these aspects. The usage of biogas for the transport sector increases in EU countries [4]. Considering the environmental view, the location problem of the BVS should be handled with the city traffic situations. Candidate locations of BVS should be decided with the environmental factors. Considering the economic aspect, the candidate BVS should meet the requirements including minimum investment, operation, and maintenance costs.

Although biogas is getting attractive in recent years, biogas technology requires financial support due to the expensive feedstock, feedstock availability, and limited innovations [5]. This innovation is associated with the improvement of products,

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processes, and marketing and organization systems. This study includes innovations in the context of location and distribution systems. The main challenge is to demonstrate the effectiveness of a potential biogas supply chain system for a real case study.

The present paper provides the interactions between location of biogas production sites and the location of the BVS for a biogas supply chain. A BVS is a structure that supplies biogas energy for the recharging of vehicles. In the first step, optimal biogas production locations were decided by incorporating the minimization of the costs and maximizing of the biogas energy of cities using the set-covering model. During the second step, BVS location problem, in which population density ~~is~~ was included to reduce the total costs, is conducted.

The main contributions of the paper, to the best of our knowledge, it is the first paper to provide a biogas network system including biogas production, distribution, charging of the vehicles with a two-stage approach. New modelling optimization approaches ~~are~~ were provided using real-world data. Furthermore, this paper contributes to the literature by regarding maximizing the animal manure amount in addition to the economic benefit for biogas plant production problems. Impacts of vehicle congestion on the optimal BVS location were also investigated.

The rest of the study is organized as follows. Biogas potential for the study area is mentioned. Then, the literature review is examined in detail. Material and method section provide the data used in the case study and methods carried out to solve the problems. The obtained results are presented in the Results and Discussion, Conclusion sections.

2. Literature Review

One of the critical aims in the context of the biogas subject is where to establish the biogas production sites and charging stations. A location problem of biogas reactors was studied in a work [6]. They proposed a mixed-integer nonlinear problem for a biogas supply chain system. They developed a heuristic to obtain the locations of the reactors. A four-stage biogas network was also presented in another work [7]. They developed a mixed-integer mathematical model to decide the locations of hubs and reactors. The paper comprised from collection of the feedstock to delivery of biogas. A linear programming model was provided for the supply chain of bio-fuel production. They also decided feedstock amounts in the model [8]. A biogas network was presented by incorporating energy and mass losses. They proposed a mixed-integer programming to optimize production and investment decisions [9]. The bioenergy supply chain problem was addressed. A mixed-integer linear programming was used to optimize the biogas network considering seasonal and available resource, product recycling [10]. A nonlinear mixed integer model was proposed to locate biogas plants. The model aimed to minimize construction, transportation, labor costs. The model consisted of the collection and storing feedstock and production of the biogas from the feedstock [11]. A facility location selection for biogas energy was provided [12]. Yuruk and Erdogmus [13] addressed optimum location for biogas plant in Düzce, Turkey. The problem including various parameters such as animal species, biogas amounts, agricultural lands, etc. was solved using a goal programming approach.

In recent years, many studies have been conducted to locate the charging stations of alternative energy sources. Many researchers provided location problems of electric vehicle charging stations. A Bayesian model has been developed for the optimal electric vehicle charging station by incorporating sustainability and technical aspects [14]. The problem of the electric vehicle charging stations was addressed by using a genetic algorithm. They also considered the demands and generation of electric vehicles by using the Monte Carlo method [15]. A mathematical model was developed for the optimal location of electric vehicle charging stations and the problem is solved with a modified algorithm. They used k-means clustering to show the relation between charging distance and satisfaction. The results showed that satisfaction increases with the increasing number of electric vehicle stations [16]. A mathematical model was developed to find the optimum location of an electric vehicle charging station. They aimed to provide minimum waiting time, cost, and travel time [17]. P-median model, set covering model, and maximal covering location model are used to compare for the optimal location of electric vehicle stations considering driver behaviors. The P-median model gave better results than other models [18]. An optimization problem was studied for the optimal electric vehicle charging station. They firstly considered the station accessibility and electric vehicle capacity. Four methods including iterative mixed-integer linear programming (MILP), greedy approach, effective MILP, and chemical reaction optimization were used in the study [19]. A mixed-integer nonlinear problem was proposed for optimal electric vehicle charging stations. They aimed to minimize the total costs comprising location costs and electric costs. The problem was solved by a genetic algorithm [20]. A multiple criteria decision-making method was presented to choose the optimal electric vehicle charging station. Environmental, economic, and social criteria were examined with the Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) method [21]. Hydrogen energy was also a clean energy source considered as an alternative to other fossil fuels in automotive applications. Therefore, hydrogen-fuelling stations are examined in the context of setup and energy costs [22]. A hydrogen production facility location problem integrating various decisions such as production, storage and transportation, safety, location, and staff assignment was provided in a hydrogen network study [23].

The main novelty of this paper is to present a biogas network system using a developed two-stage mathematical modelling approach for the location of biogas production plant and charging stations of the biogas vehicles. The paper is first dealing with the biogas network in Turkey and a guide for the decision-makers in the energy sector.

The present work contributes to the literature by presenting both maximizing the animal mature term and minimizing the cost for a location decision. Vehicle congestion has not been addressed in the BVS literature. Considering the integration of both biogas production facility and BVS location decisions overcomes the gap.

3. Material and Method

In this section, the first stage considers the location of biogas production facilities using a goal programming approach to handle the two objectives which are minimization of the costs and maximizing of the biogas energy obtained from the sources. During the second stage, BVS location selection is handled considering population, capacity, cost, density. A simple illustration is given in Figure 1.

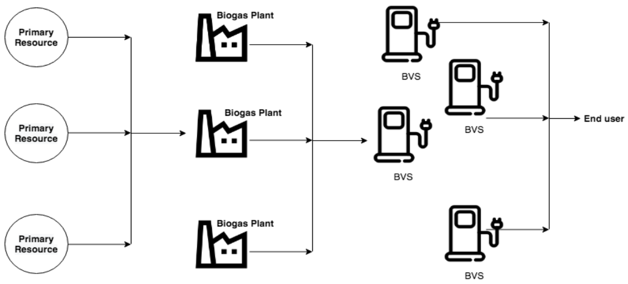

Figure 1. Biogas network proposed in the presented work

Izmir has a high potential with the climate and vegetation geography in terms of agriculture and livestock in Turkey. In addition, İzmir has the potential of biogas with poultry farming [24]. Table 1 demonstrates the total agricultural area, total number of animals (cattle and sheep) of Izmir's districts in 2018.

Table 2 depicts the total cost to install a biogas facility. The data was obtained from the work of [25].

The goal programming approach was used to achieve more than one goal. Since it is a problem involving binary and integer decision variables, MILP approach was used. During the first stage, a location problem was provided for a biogas production facility. In the second stage, a location problem was provided for a BVS. Nomenclature for the models is demonstrated in Table 3

Table 1. Total agricultural area, total number of animals of Izmir's districts

Districts	Total Agricultural Area (decare)	Total Number of Animals (Cattle)	Total Number of Animals (Sheep)
Balçova	4.642,6	249	319
Bornova	27.728,4	3.051	5.059
Buca	29.634,0	4.907	5.000
Çiğli	13.504,0	2.615	1.225
Gaziemir	2.704,5	351	399
Güzelbahçe	14.569,3	1.840	5.273
Karşiyaka	3.765,0	189	1.250
Konak	100,0	0	0
Narlidere	1.787,5	68	306

Aliağa	121.388,0	7.510	5.770
Bayindir	305.593,0	95.264	6.408
Bergama	424.361,0	231	50
Beydağ	49.366,0	67.880	12.565
Çeşme	18.667,0	24.321	489
Dikili	120.967,0	1.824	3.556
Foça	48.222,0	10.507	20.346
Karaburun	38.473,0	18.921	5.412
Kemalpaşa	226.831,0	28	4.517
Kinik	90.791,0	191	30.277
Kiraz	184.152,6	35.099	18.538
Menderes	236.083,0	10.280	14.750
Menemen	232.236,0	99.893	2.747
Ödemiş	336.214,0	25.016	13.326
Seferihisar	87.430,0	16.481	19.521
Selçuk	153.108,0	172.550	13.145
Tire	276.975,0	4.750	22.766
Torbali	309.933,0	3.766	5.559
Urla	86.011,0	127.662	9.530
Bayrakli	215,7	22.280	9.735
Karabağlar	4.771,0	4.850	12.107
Total	3.450.223,6	762.574	249.945

Table 2. Installation cost of biogas facility

Biogas Capacity	250 m^3/h	500 m^3/h	750 m^3/h	1000 m^3/h	2000 m^3/h
Installation (Euro)	72.500	97.000	120.000	145.000	195.000
Maintenance	25.000	40.000	60.000	75.000	100.000
Management	10.000	12.000	15.000	17.500	20.000
Electricity	30.000	55.000	86.000	107.500	193.500
Water	8.050	16.125	24.188	32.250	64.500
Chemicals	1.250	2.500	3.750	5.000	10.000
Feedstock	350	625	950	1.205	2.500

Table 3. Nomenclature of the first stage's model

Nomenclature	Description

I, J, R	set of biogas facilities, potential districts, primary resources
$demand_j$	demand for biogas of distrcit j
c_i	installation cost (TL)
d_{ij}	distance between cities
b_i	maintenance cost (TL)
s_i	operating cost (TL)
e_i	electricity cost (TL)
f_i	chemical cost (TL)
h_i	water cost (TL)
a_i	substance cost (TL)
anb_{jr}	source number
ax_r	animal manure amount obtained the sources
ay_r	biogas energy obtained from the sources
azr	processing cost of the animal manure obtained from the source (TL)
sbt	waste transportation cost (TL)
pwri	the amount of power potential of the station to be installed
wj	district population
vhc	gasoline vehicles per person
eu	daily euro rate
prc	percentage of all demand to be met
pt	BVS numbers (unit)
km	BVS installation cost
Md	Maximum distance
cpti	biogas facility capacity
vj	vehicle density
cap	BVS capacity
fp	unit price of fuel divided by euro's fixed rate
goal1	goal 1 value
goal2	goal 2 value
d1, d2	positive and negative deviation values from goal 1, respectively
d3, d4	positive and negative deviation values from goal 2, respectively
x_{ij}	binary decision variable indicating whether the facility i has been decided to be established in district j
y_{ji}	binary decision variable indicating whether the facility i has been decided to be assigned in district j

3.1. First Stage Model

In the first objective function, Equation 1 shows the goal equation. Animal manure amount obtained is maximized (Equation 2), while total costs in which main costs regarding installation costs, animal manure processing cost, and waste transportation cost are available, are minimized Equation (3). Equation (4) shows that all demands must be met. Equation (5) provides a maximum of one plant for the region. Equation (6) calculates the demand parameter. Equation (7) is the non-negativity constraint for decision variables and binary variable constraint.

$$Z = d_1 + d_4 \tag{1}$$

$$\sum_{j=1}^{J}\sum_{r=1}^{R} anb_{jr} * ax_r * ay_r * x_{ij} + d_1 - d_2 = goal1 \tag{2}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(c_i + b_i + s_i + e_i + h_i + f_i + a_i) * x_{ij} + \sum_{j=1}^{J}\sum_{r=1}^{R} anb_{jr} * ax_r * ay_r * x_{ij} * \left(\frac{az_r}{eu}\right) + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} d_{ij} * x_{ij} * sbt + d_3 - d_4 = goal2 \tag{3}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{I} pwr_i * x_{ij} \geq \sum_{j=1}^{J} demand_j * prc \tag{4}$$

$$\sum_{i=1}^{I} x_{ij} \leq 1 \quad ,\forall j \tag{5}$$

$$demand_j = vhc * w_j \qquad j = 1, \dots, J \tag{6}$$

$$x_{ij} \in (0, 1) \tag{7}$$

3.2. Second Stage Model

In the objective function, the total transport cost, the total BVS installation cost are minimized and the profit to be gained from the vehicle density is maximized in Equation (8). Equation (9) ensures that minimum one BVS is installed for each region in which a biogas plant is available. Equation (10) defines the vehicle density in the region. Equation (11) ensures that the distance between biogas plant and BVS should be under the given maximum distance constraint. Equation (12) ensures that each BVS is assigned to a biogas plant. Equation (13) is a capacity constraint between the biogas plant and BVS. Equation (14) addresses the total BVS numbers. Equation (15) is the non-negativity constraint for decision variables and binary variable constraint.

$$\min z = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} * sbt * y_{ji} + \sum_{i=1}^{I}\sum_{j=1}^{J} y_{ji} * (km)/eu - \sum_{i=1}^{I}\sum_{j=1}^{J} v_j * y_{ji} * fp \tag{8}$$

$$\sum_{j=1}^{J} y_{ji} \geq 1 \quad ,\forall i \tag{9}$$

$$v_j = vhc * w_j \quad ,\forall j \tag{10}$$

$$d_{ij} * y_{ji} \leq Md \quad ,\forall j ,\forall i \tag{11}$$

$$\sum_{i=1}^{I} y_{ji} \leq 1 \quad ,\forall j \tag{12}$$

$$\sum_{j=1}^{J} y_{ji} * cap \geq cpt_i \quad ,\forall i \tag{13}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} y_{ji} = pt \tag{14}$$

$$y_{ji} \in (0, 1), pt \geq 0 \tag{15}$$

4. Results and Discussion

During the first stage, a location problem of biogas production plants was solved. Goal 1 value as 2*106 and Goal 2 value as 5*107 were incorporated into the system at first. Obtained results demonstrated that defined goals were achieved. d2 and d3 deviations were obtained as 18.510 and 260.399, respectively. Decision variable p, which is the number of the facilities to be opened, was obtained as 2. xij, which is the binary decision variable that gives the status of the plants, implies that 5th type plant which represents 2000 m^3 capacity in the Konak region should be installed, 5th type plant which represents 2000 m^3 capacity in the Narlidere region should be installed. Table 4 depicts the demands of the districts. demandj was obtained as a need for gasoline per vehicle as a result of multiplying the number of populations in the region (w_j), the average number of vehicles per head and the number of gasoline vehicles.

Table 4. Demand results of the districts

Districts	Biomass demand of the region	Districts	Biomass demand of the region
Balçova	3.539,64	Foça	1.477,775
Bornova	19.859,128	Karaburun	472,936
Buca	22.271,892	Kemalpaşa	4.741,316
Çiğli	8.676,593	Kinik	1.329,333
Gaziemir	6.135,414	Kiraz	1.962,085
Güzelbahçe	1.587,546	Menderes	4.183,677
Karşiyaka	15.350,021	Menemen	7.786,253
Konak	15.904,136	Ödemiş	5.910,521
Narlidere	2.952,919	Seferihisar	1.942,326
Aliağa	4.254,865	Selçuk	1.621,801
Bayindir	1.810,209	Tire	3.767,12
Bergama	4.602,464	Torbali	7.973,946
Beydağ	557,862	Urla	2.959,921
Çeşme	1.939,783	Bayrakli	13.895,216
Dikili	1.970,248	Karabağlar	21.409,296

The number of stations was obtained as 12. The z function, which is the objective function, shows that at the end of one year, the station installation by the value 9952.154 TL will provide the profit rate. Güzelbahçe, Çeşme, Dikili, Seferhisar and Urla districts should obtain biomass resources from the Konak region, while Narlıdere, Balçova, Bayındır, Foça, Karaburun, Kınık and Selçuk should take these resources from the Narlıdere. As a result of the pt decision variable, a total of 12 BVS has been installed.

4.1. Sensitivity Analysis

At the beginning of the model, it ~~is~~ was planned to meet 2% of all demand with biofuels. The effects of the coverage rate on the chosen regions are presented in Table 5. When the planning is decided to meet 2,5% of all demand, x_{ij} results as 5th type plant which represents 2000 m^3 capacity in the Narlidere and Bergama regions, as 4th type plant which represents 1000 m^3 capacity in the Konak region. When the planning is decided to meet 3% of all demand, x_{ij} results as 5th type plant which represents 2000 m^3 capacity in the Konak, Narlidere and Bergama regions. When the planning is decided to meet 3,5% of all demand, x_{ij} results as 5th type plant which represents 2000 m3 capacity in the Balçova, Narlidere and Bergama regions and as 3th type plant which represents 750 m^3 capacity in the Konak region. When the planning is decided to meet 4% of all demand, x_{ij} results as 5th type plant which represents 2000 m^3 capacity in the Balçova, Konak, Narlidere and Bergama.

Table 5. The effect of demand coverage rate change on the selected region and its structure

prc value	Districts	pwr_i
%2	Konak	5
	Narlıdere	5
%2,5	Konak	4
	Narlıdere	5

	Bergama	5
	Konak	5
	Narlıdere	5
%3	Bergama	5
	Balçova	5
	Konak	3
	Narlıdere	5
%3,5	Bergama	5
	Balçova	5
	Konak	5
	Narlıdere	5
%4	Bergama	5

4.2. Discussion

The usage of biofuels provides both the elimination of wastes and the emergence of clean energy by burning organic wastes. In this study, the location of biogas plant sites and BVS were considered in the province of İzmir in Turkey. In the study, installation decisions were decided for Konak and Narlidere with a capacity of 2000 m3 and a total capacity of 4000 m3. In the Durmaz and Bilgen [26] study, in which the province of Izmir was discussed and the MILP model was developed, for a 60 km coverage area, Aliağa (150 capacity (1), 1000 capacity (1)), Bayındır (1000 capacity (1)), Foça (1000 capacity (2)), Kemalpaşa (1000 capacity (3)), Seferihisar (150 capacity (1)), Tire (500 capacity (1)), Urla (500 capacity (1)) were obtained. Installing a total capacity of 8300 m3 was decided in this study. Since the share of 2% in total usage was considered in our study, installation of 4000 m3 capacity was decided. However, using the sensitivity analysis, the share of 4% in total usage resulted as the installation in the Balçova, Bergama, Konak, Narlidere and total 8000 m3 capacity.

5. Conclusion

In this paper, the presenting problem provided a biogas supply chain network problem integrating biogas plant production problems to minimize the installation costs and to maximize the animal manure amount and BVS installation problem. It is worthy to note that various studies related to the optimization of biogas networks are available in the literature. However, the novelty of this paper lies in maximizing the animal manure amount and impacts of vehicle congestion on the optimal BVS location. The limitation of the study is to consider only İzmir district in Turkey. Since Turkey has a goal to reduce emissions, other cities can be included to generalize the problem. Also, the stochastic optimization approach [27] and fuzzy logic [28] can be considered for the uncertain criteria to decide the biogas plant locations. Considering designing a novel biogas network with low installation, maintenance, process costs and carbon prices [29] is a need for future research.

Data availability

All data and materials are available in manuscript.

Conflict of Interest Statement

All authors declare that they have no conflicts of interest.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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