Modeling Favorable Locations for Biogas Plants that Generate Electricity from Dairy and Beef Cattle Manure through Mixed Integer Linear Programming

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Mixed integer linear programming (MILP) is known as a type of programming that can combine continuous variables, integer variables, and (0-1) variables in the same algorithm and generate fitting results for the data. Using this technique, it is possible to model and solve complex problems in many different fields such as economics, biology, engineering, *etc.* In the present study, a regional planning model was developed using MILP technique for the conversion of manure from dairy and beef cattle into biogas and electrical energy. For this regional planning study, considering the locations of future facilities, data on dairy and beef cattle in the Isparta province of Türkiye were used. According to the model written and solution outputs, to utilize all manure obtained from dairy and beef cattles in Isparta, 5 biogas plants with a total manure processing capacity of approximately 522,000 tons should be built in different districts. It is possible to produce a total of approximately 21,000,000 m^3 of biogas and 38,500 MW of electricity per year in these biogas plants. This electrical energy obtained can meet 3.83% of the annual electricity consumption of Isparta province.

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INTRODUCTION

The increasing global demand for energy and the associated environmental impacts have had a significant impact on the shift towards sustainable and green energy sources (Sayed *et al.* 2021). Renewable energy has many advantages over fossil energy, such as sustainability, low greenhouse gas emissions, and high economic efficiency (Sarker *et al.* 2019). Increasing the use of renewable energy sources offers a promising solution to minimize the overuse of conventional energy sources and reduce pollution. Biogas technology using renewable energy sources is one of the most important solutions for converting waste into a high value energy source (Addous *et al.* 2017). Biogas from biomass is a potential renewable energy source that can be used in different sectors such as the transportation sector, electricity generation, heat generation, combined heat and power systems, and fuel cells (Abanades *et al.* 2022). The high yield of biogas from traditional feedstocks (*e.g.*, animal manure) has led to many commercial units operating worldwide (Matsakas *et al.* 2016). In 2020, 80% of the total energy supply came from coal, crude oil, and natural gas. The proportion of energy obtained using nuclear power plants is 5%. Renewable energy technologies, such as solar, wind, hydro, biomass, geothermal, *etc.*, have a share of 15% in total energy supply. In 2020, bioenergy-based electricity generation was ranked 4th among renewable energy sources with a production value of 685 TWh (WBA 2022).

Today, to meet the increasing energy demand to the desired extent, renewable energy resources need to be used more efficiently and effectively. In particular, increasing the biogas production obtained from animal manure and the energy produced accordingly will be feasible, not with small-scale solutions but with large-scale planning. In line with this purpose, regional planning models need to be prepared and implemented to produce biogas and electrical energy from animal manure. This can be viewed as the most promising way to increase the share of energy obtained from animal manure as renewable energy sources.

Anaerobic digestion (AD) is a cost-effective method for biogas and biomethane production from waste; besides, it provides great potential in transforming biomass into recyclable and sustainable green energy (Xu *et al.* 2019). Anaerobic processes have been used in agricultural and industrial waste conversion for a long time, and it is a preferred method for wastewater purification as well (Güler 2020). Anaerobic digestion is a well-developed technology used to transform waste into bioenergy (Caiardi *et al.* 2022; Aworanti *et al.* 2023).

Biogas plants used for biogas production vary depending on their capacities. Biogas plants fall into four groups: family type (6 to 12 m^3), farm type (50 to 100 to 150 m^3), village type (100 to 200 m^3), and large-scale industrial biogas plants (1000 to 10000 m^3) (Çelikkaya 2016). Large-scale industrial biogas plants provide several benefits such as waste recycling for society and the relevant industries, reducing the cost of waste disposal, and energy production (Seadi *et al.* 2008). In recent years, large-scale industrial biogas plants used for agricultural waste transformation have developed fast and brought enormous benefits (Lu and Gao 2021). Yet, in order to achieve the sustainable operation of large-scale industrial biogas plants, it is necessary to pay attention to several factors such as technical aspects, operating costs, and subsidies or support provided by the government (Cheng *et al.* 2023).

Mathematical programming, especially mixed integer linear programming (MILP), has become one of the most researched methods for process planning problems due to its rigor, flexibility, and comprehensive modeling capability (Floudas and Lin 2005). The MILP paradigm has been applied to many problems in the process systems engineering. Typical applications include supply chain optimization, process network design and operation, production planning and scheduling, *etc.* (Ogbea and Lia 2015). MILP is often used for systems analysis and optimization as it offers a flexible and powerful method to solve large, complex problems such as industrial symbiosis and process integration (Kantor *et al.* 2020). The MILP is the most advanced mathematical framework for optimization of energy systems (Weimann *et al.* 2019).

There are several biogas plant regional planning model studies for transforming animal manure produced in Türkiye into biogas and electrical energy. Unal *et al.* (2011) carried out work in the Tire district of İzmir province of Türkiye. They developed a regional planning model aimed at utilizing the existing dairy cattle wastes in the region and converting them into biogas and electrical energy. According to the model output results, they found that it is possible to produce around 35,000,000 m^3 of biogas annually by recycling the dairy cattle wastes in the Tire district. They calculated that an annual electrical energy production of around 165,000 MW is possible by converting this amount of biogas produced into electrical energy. Karadağ (2019), who worked in Bursa province of

Türkiye, developed a regional planning model aimed at utilizing the dairy and beef cattle wastes and converting them into biogas and electrical energy. This planning model showed that an annual biogas and electrical energy production of around 67,800,000 m^3 and 128,000 MW is possible by recycling the dairy and beef cattle wastes. Another similar study was conducted in Şanlıurfa province of Türkiye. In his study, Yıldırım (2019) calculated the amount of biogas and electrical energy that can be produced by recycling dairy and beef cattle wastes by an optimization study. This study indicated that an annual biogas and electrical energy production of around 116,000,000 m^3 and 216,000 MW is possible by recycling the dairy and beef cattle wastes in Şanlıurfa province.

The present work did not consider the detailed composition of biomass used in the process. It is well known that the addition of cellulosic biomass, adding to the amount already present in typical manure, can help to achieve optimized conditions for anaerobic digestion (Neshat *et al.* 2017). Such addition can achieve a more favorable ratio between carbon and nitrogen, thus helping to support biological processes in the reactor. Cellulosic biomass, of various types, is often available at low cost near to sources of manure. Future studies may consider these issues with respect to the location of biogas plants.

These academic studies conducted in Türkiye reveal that it is possible to produce considerable amounts of biogas and electrical energy if the existing animal waste potential of Türkiye is utilized.

EXPERIMENTAL

Materials

While writing the planning model and obtaining solutions, the livestock data of Isparta province of Türkiye was used as a sample model. Isparta province is located in the Mediterranean region of Türkiye. The surface area of Isparta is 8933 km^2 and its altitude is 1050 m above sea level (TSI 1999). The location of Isparta province in Türkiye is shown in Fig. 1.

Fig. 1. Location of Isparta province within Türkiye

Data on dairy and beef cattle breeding in Isparta province, which constitutes the material of the planning model, was obtained from the Turkish Statistical Institute database. All the livestock data obtained were included in the study according to the complete census method. In Türkiye, bull breeding is not used commonly due to the use of artificial insemination methods in dairy cattle breeding. Therefore, bulls were excluded from the study. Dairy and beef cattle breeding data in 2022 for Isparta are given in Table 1.

Table 1. Number of Dairy and Beef Cattle in Isparta and Its Districts

Districts	Dairy Cattle Age Groups* (Month)			Beef Cattle Age Groups* (Month)		Number of Cattle* (Head)	Ratio in Total Cattle (%)
	Calf (<12)	Heifer (12 to 24)	Cow (>24)	Calf (<12)	Heifer (12 to 24)		
Şarkikaraağaç	6170	6001	10422	6136	2991	31720	22.6
Merkez	2218	2703	12202	2589	2858	22570	16.1
Yalvaç	2879	3192	10897	2653	2775	22396	16.0
Eğirdir	2053	3310	7924	1848	1651	16786	12.0
Sütçüler	1440	1190	4673	1335	813	9451	6.7
Keçiborlu	1171	1154	2836	1823	1401	8385	6.0
Aksu	932	1146	3163	927	967	7135	5.1
Gelendost	792	873	2967	739	707	6078	4.3
Atabey	710	770	2470	827	715	5492	3.9
Gönen	819	561	1856	722	360	4318	3.1
Senirkent	363	426	1418	267	271	2745	2.0
Uluborlu	177	167	1038	197	219	1798	1.3
Yenişarbademli	190	250	705	154	68	1367	1.0
Total	19914	21743	62571	20217	15796	140241	100.0
*These data were obtained from the Turkish Statistical Institute database TSI (2022)							

Mathematical Formulation of the Planning Model

A large number of real-life problems arising in various fields, such as production planning, resource allocation, programming, transportation planning, and management, can be formulated and solved using MILP models (Lia *et al.* 2023). Linear programming problems involve an unknown number of decision variables to be optimized. Mixed integer programming is a subset of the broader field of mathematical programming. Mixed integer programming techniques do not explicitly examine every possible combination of discrete solutions, but instead examine a subset of possible solutions and use optimization theory to find the solution that no other solution can find (Lyqs *et al.* 2008).

Lingo 11.0 software, whose original license belongs to Assoc. Prof. Dr. Murat Kılıç, a faculty member at Ege University, Faculty of Agriculture, was used in the solution of the written planning model.

The algorithm of the MILP model is presented below.

Objective function:

$$\text{Min} \quad a_1x_1 + a_2x_2 +,\ldots,+ a_nx_n + m_1e_1y_1 + m_1e_2y_2 +,\ldots,+ m_1e_ny_n \tag{1}$$

In this equation, $x_j = 0$ or 1, $\forall j = 1,\ldots,n$ refers to alternative biogas plants to be established in the districts. x_j is defined as (0-1) variable in the model. In the model, xj is a decision variable. aj, $\forall j = 1,\ldots,n$ denotes the investment cost coefficients of alternative biogas plants.

For $y_j \geq 0$, the term $\forall j = 1,\ldots,n$ denotes the annual amount of manure produced in the districts and sent to biogas plants for processing. y_j is defined as an integer variable in the model. y_j is a decision variable. $e_j \geq 0$, $\forall j = 1,\ldots,n$ is the round-trip distance traveled when transporting biogas produced in districts to biogas plants for processing. m_1 is the transportation cost coefficient and is a constant value.

The objective function is designed to minimize the total investment cost of the biogas plants to be established in the region and the transportation cost of manure to the biogas plants. Constraints were defined as follows:

$$b_1x_1 + b_2x_2 + \ldots\ldots\ldots\ldots + b_nx_n \leq c_1 \quad (2)$$

$$b_1x_1 + b_2x_2 + \ldots\ldots\ldots\ldots + b_nx_n \geq c_2 \quad (3)$$

For $x_j = 0$ or 1, $\forall j = 1,.....,n$ refers to alternative biogas systems to be established in districts and x_j is defined as a (0-1) variable in the model. $b_j \geq 0$, $\forall j = 1,.....,n$ denotes the annual manure processing capacity of alternative biogas systems to be established in the districts. c_1 and c_2 denote the upper and lower limits of the amount of manure produced in the region. c_1 and c_2 are right-hand side variables.

$$y_1 + y_2 + \ldots\ldots\ldots\ldots + y_n \leq d_1 \quad (4)$$

$$y_1 + y_2 + \ldots\ldots\ldots\ldots + y_n \geq d_2 \quad (5)$$

$y_j \geq 0$, $\forall j = 1,.....,n$ denotes the annual amount of manure produced in the districts and sent to biogas systems for processing. y_j is defined as an integer variable in the model. d_1 and d_2 denote the upper and lower bounds of the amount of manure produced in the districts. d_1 and d_2 are right-hand side variables.

$$b_1x_1 + b_2x_2 + \ldots\ldots\ldots\ldots + b_nx_n - y_1 - y_2 - \ldots\ldots\ldots\ldots - y_n = 0 \quad (6)$$

The annual amount of manure sent to biogas systems is equal to the annual amount of manure produced in the districts and sent to biogas systems for processing. According to the algorithm of the model, the amount of manure produced should be equal to the amount of manure processed in biogas plants.

Features of Alternative Biogas Plants in the Planning Model

Within the planning model, 4 different alternative biogas plant options, namely A, B, C and D, were included. The information on the technical specifications and costs of alternative biogas plants was obtained from the firms that operate in Türkiye and operate biogas plant installations. In line with the information obtained from the firms, it was determined that the annual manure processing capacity of the standard type biogas facilities preferred in Türkiye are around 50000 tons (type A), 100000 tons (type B), 150000 tons (type C), and 200000 tons (type D).

In the planning model, to simulate the existing conditions in Türkiye, four different biogas plant options (type A, B, C, and D) with different waste processing capacities, which are generally used in Türkiye, were used. It was aimed thereby to obtain suitable solutions for the existing conditions.

All alternative biogas plants have a continuous operation period except for mandatory maintenance. Technical specifications and costs of alternative biogas plants have been obtained from the companies producing biogas plants operating in Türkiye. Information on alternative biogas plants is given in Table 2.

The sum of the installation, construction and co-generator costs of the 4 different alternative biogas plants in the planning model determines the total cost of the biogas systems. The data on the costs of alternative biogas plants are given in Table 3.

Table 2. Technical Specifications of Alternative Biogas Plants

Description	Unit Abbreviation	Alternative Biogas Plant Options			
		Type A	Type B	Type C	Type D
Facility operating time	h days^{-1}	24/7	24/7	24/7	24/7
Biogas production	m^3 year^{-1}	2406455	4204800	6004250	7801875
Biogas methane content	%	55	55	55	55
Electricity generation	kWh	619	1000	1500	2.008
Electricity generation	kWh year^{-1}	4546440	7344814	11017221	17590080
Manure processing amount	tons year^{-1}	58400	105000	150000	192720

Table 3. Installation, Construction, and Ko-Generator Costs of Biogas Plants

Description	Biogas Plant Costs (€)			
	Type A	Type B	Type C	Type C
Biogas plant installation costs	1471000	2400000	2850000	3500000
Construction costs	518000	850000	1250000	2000000
Ko-Generator	330000	650000	850000	1000000
Total	2319000	3900000	4950000	6500000

Determination of Manure Transportation Costs in the Planning Model

In the planning model, manure transportation costs are another decisive factor in determining the amount of manure to be sent from manure production centers to biogas plants. The model algorithm minimizes the investment costs of biogas plants while also minimizing the transportation costs of the manure sent to these plants. While the model determines the installation centers of biogas plants, it also plans the distribution of manure to be sent to these plants.

To determine manure transportation costs in the planning model, first, there is a need for a road map that reveals the distances of the districts in the region from each other and is added as a coefficient to the model. While creating this road map, the distance to be traveled was determined as the round-trip distance. In this road map, the distance to be covered by manure from one district to the biogas plant in the same district is assumed to be a minimum of 10 km. The round-trip distance of manure from one district to the biogas plant in the same district was determined as 20 km. The transportation network that will be used to send the manure to be produced in the districts of Isparta to the potential biogas plant installation centers is given in Table 4.

When calculating the transportation costs, the transportation cost coefficient that will enable the calculation of the total transportation cost as well as the distance traveled by the manure should be known and entered into the model. To determine this coefficient, studies on the subject were examined. In a study, it was stated that the amount of fuel to be consumed as a result of transporting a ton of agricultural products for 1 km on a straight road is 0.05 L (Liter). In the same study, it is stated that the amount of fuel to be spent along the wavy road is 0.10 L and the amount of fuel to be spent along the bumpy road is 0.15 L. In the present planning model study, the average amount of fuel to be consumed during this transportation (0.10 L) was used; its equivalent in euro was calculated (0.1267 €) and added as a coefficient to the model. The calculation of the transportation cost coefficient and its value in Euro is given in Table 5.

Table 4. Transportation Network Between Manure Production Centers and Potential Biogas Plant Installation Centers

Round Trip Road Distance (km) / Manure production centres	Potential Biogas Plant İnstallation Centers												
	Aksu	Atabey	Eğirdir	Gelendost	Gönen	Keçiborlu	Merkez	Senirkent	Sütçüler	Şarkikaraağaç	Uluborlu	Yalvaç	Yenişarbademli
Aksu	**20.0**	104.2	54.6	127.6	132.4	199.2	127.4	193.8	90.2	188.0	214.0	182.8	85.2
Atabey	104.2	**20.0**	50.2	141.2	28.2	77.4	48.8	148.8	156.0	218.0	129.6	196.4	189.2
Eğirdir	54.6	50.2	**20.0**	87.8	78.4	127.6	73.0	139.8	106.4	168.4	159.4	147.0	139.8
Gelendost	127.6	141.2	87.8	**20.0**	167.4	216.0	160.8	148.2	178.0	80.8	167.6	59.4	184.0
Gönen	132.4	28.2	78.4	167.4	**20.0**	52.0	47.4	83.8	184.2	246.0	104.2	224.0	218.0
Keçiborlu	199.2	77.4	127.6	216.0	52.0	**20.0**	68.6	71.8	212.0	266.0	52.4	204.0	268.0
Merkez	127.4	48.8	73.0	160.8	47.4	68.6	**20.0**	152.0	147.0	242.0	124.0	220.0	212.0
Senirkent	193.8	148.8	139.8	148.2	83.8	71.8	152.0	**20.0**	246.0	194.4	20.0	131.2	298.0
Sütçüler	90.2	156.0	106.4	178.0	184.2	212.0	147.0	246.0	**20.0**	256.0	266.0	236.0	158.2
Şarkikaraağaç	188.0	218.0	168.4	80.8	246.0	266.0	242.0	194.4	256.0	**20.0**	214.0	68.4	103.4
Uluborlu	214.0	129.6	159.4	167.6	104.2	52.4	124.0	20.0	266.0	214.0	**20.0**	151.4	318.0
Yalvaç	182.8	196.4	147.0	59.4	224.0	204.0	220.0	131.2	236.0	68.4	151.4	**20.0**	168.2
Yenişarbademli	85.2	189.2	139.8	184.0	218.0	268.0	212.0	298.0	158.2	103.4	318.0	168.2	**20.0**

Table 5. Transportation Cost Coefficient

Structure of the Road	Fuel Consumption* (L $ton^{-1}km^{-1}$)	Fuel Consumption (€ $ton^{-1}km^{-1}$)
Flat road	0.05	0.0634
Undulating road	0.10	0.1267
Hilly road	0.15	0.1900
Average	0.10	0.1267
*These data were obtained from the DAFF (2014)		

RESULTS AND DISCUSSION

To determine the amount of manure production to be included as a constraint factor in the planning model, tables determined and published by the studies of international organizations were used. In these tables, the manure production values close to the age and average weight ratios of animals raised in Türkiye were used.

In addition, academic studies have indicated that only 50% of the manure from dairy and beef cattle can be collected and used for biogas production under conditions that are prevalent in Türkiye. Daily manure production amounts and collectable manure rates of dairy and beef cattle according to various age groups under Türkiye conditions are given in Table 6.

When the manure amounts of dairy and beef cattle in Isparta in 2022 were evaluated, it was calculated that the total annual amount of manure to be obtained from dairy and beef cattle in Isparta province in 2022 was calculated to be about 1,080,000 tons. The total annual manure amount for dairy and beef cattle in Isparta province in 2022 is given in Table 7.

Table 6. The Daily Amount of Manure Produced by Dairy and Beef Cattle

Dairy and Beef Cattle		Age Groups* (month)	Average Live Weight* (kg)	Manure Production* (kg day^{-1})	Ratio of Collectable Animal Manure** (%)
Dairy cattle	Calf	<12	150	8.62	50
	Heifer	12 to 24	350	20.41	50
	Cow	>24	450	28.12	50
Beef cattle	Calf	<12	200	11.79	50
	Heifer	12 to 24	350	22.68	50

* These data were obtained from MCARD (2022); MWPS (2004); OSU (2006)
** These data were obtained from (Ekinci *et al*. 2010); Kulcu (2002)

Table 7. The Annual Amount of Manure Produced by Dairy and Beef Cattle

Districts	Manure Production (tons year^{-1})					Total Manure Production (tons year^{-1})
	Dairy Cattle Age Groups (month)			Beef Cattle Age Groups (month)		
	Calf (<12)	Heifer (12 to 24)	Cow (>12)	Calf (<12)	Heifer (12 to 24)	
Şarkikaraağaç	19412.67	44705.35	106969.32	26405.36	24760.10	222252.80
Merkez	6978.49	20136.40	125238.89	11141.37	23659.10	187154.25
Yalvaç	9058.20	23779.28	111844.63	11416.79	22972.01	179070.90
Eğirdir	6459.35	24658.34	81330.35	7952.59	13667.31	134067.95
Sütçüler	4530.67	8865.08	47962.74	5744.97	6730.18	73833.64
Keçiborlu	3684.32	8596.90	29108.14	7845.01	11597.76	60832.12
Aksu	2932.35	8537.30	32464.40	3989.21	8005.02	55928.27
Gelendost	2491.87	6503.54	30452.69	3180.18	5852.69	48480.97
Atabey	2233.87	5736.23	25351.59	3558.87	5918.91	42799.47
Gönen	2576.82	4179.25	19049.61	3107.02	2980.15	31892.86
Senirkent	1142.11	3173.55	14554.07	1148.99	2243.39	22262.11
Uluborlu	556.90	1244.09	10653.82	847.76	1812.93	15115.50
Yenişarbademli	597.80	1862.41	7235.98	662.72	562.92	10921.82
Total	62655.42	161977.74	642216.23	87000.83	130762.45	1084612.66

Within the algorithm of the planning model, the manure produced in the districts and sent to the biogas plants for processing should be equal to the total manure processing capacity of the biogas plants to be established in the region. For ease of operation and to find more comfortable solution outputs in the solution of the model, ± 5% limit values were used for manure amounts. In addition, because the solutions to be obtained in the solution outputs are desired to be integer, the lower and upper limit values of the district manure production amounts are defined as integer variables in the model. Collectable manure amounts and optimization model boundary values are given in Table 8.

When the solution outputs of the planning model were evaluated, the model calculated that it would be appropriate to install 5 biogas plant (A, B and C type) with a total annual manure processing total capacity of about 522,000 tons in Eğirdir, Keçiborlu, Merkez, Şarkikaraağaç, and Yalvaç districts. The planning model did not recommend the installation of a type D biogas plant. The total investment cost of these 5 biogas plants will be about 18,400,000 €. The types, capacities, and costs of biogas plants to be established are given in Table 9. A map showing the types of biogas plants to be established and the districts where they will be established is given in Fig. 2.

Table 8. Collectable Animal Manure and Optimization Model Limit Values

Districts	Total Manure Production (tons year^{-1})	Amount of Collectable Animal Manure (tons year^{-1})	Optimization Model Limit Values (tons year^{-1})	
			Lower Limit (-5%)	Upper Limit (+5%)
Şarkikaraağaç	222252.80	111126.40	105570	116683
Merkez	187154.25	93577.13	88898	98256
Yalvaç	179070.90	89535.45	85059	94012
Eğirdir	134067.95	67033.97	63682	70386
Sütçüler	73833.64	36916.82	35071	38763
Keçiborlu	60832.12	30416.06	28895	31937
Aksu	55928.27	27964.14	26566	29362
Gelendost	48480.97	24240.49	23028	25453
Atabey	42799.47	21399.74	20330	22470
Gönen	31892.86	15946.43	15149	16744
Senirkent	22262.11	11131.06	10575	11688
Uluborlu	15115.50	7557.75	7180	7936
Yenişarbademli	10921.82	5460.91	5188	5734
Total	1084612.66	542306.33	515191	569422

Table 9. Types of Biogas Plants, their Capacities, and Costs

Districts Where Biogas Plants are Established	Type of Biogas Plants	Capacity of Biogas Plants (tons year^{-1})	Number of Biogas Plants (piece)	Biogas Plants Total Costs (€)
Eğirdir	C	150000	1	4950000
Keçiborlu	A	58400	1	2319000
Merkez	B	105000	1	3900000
Şarkikaraağaç	C	150000	1	4950000
Yalvaç	A	58400	1	2319000
Total		521800	5	18438000

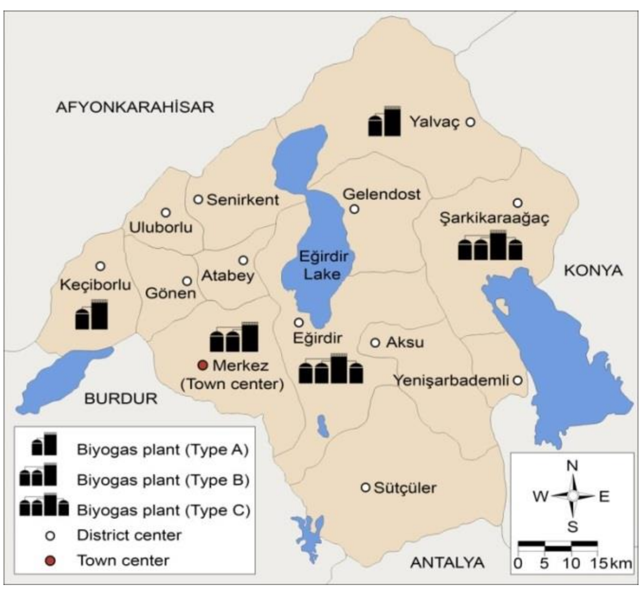

Fig. 2. Biogas plant types and locations

The planning model not only determined in which districts, how many, and at what capacities biogas plants would be established, but also provided a manure distribution plan to minimize manure transportation costs. Manure distribution planning according to the results of the planning model is given in Table 10.

According to the planning model solution output, the total transportation cost resulting from the transportation of manure produced in the districts and sent to the biogas plants is calculated as about 2,460,000 € per year. The transportation costs incurred because of sending manure to biogas plants are given in Table 11.

According to the outputs of the planning model, the total annual amount of biogas that can be produced in Isparta province is around 21,000,000 m^3 and the amount of electrical energy is around 38,500,000 kW. The amount of biogas and electricity that can be obtained from manure collected in Isparta province is given in Table 12.

Table 10. Manure Distribution Planning

Manure Production Centers	Biogas Plants İnstallation Centres					Manure Production Amounts of Districts (tons year^{-1})
	Eğirdir	Keçiborlu	Merkez	Şarkikaraağaç	Yalvaç	
Aksu	26566	-	-	-	-	26566
Atabey	10669	-	9661	-	-	20330
Eğirdir	67249	-	-	-	-	67249
Gelendost	10445	-	-	12583	-	23028
Gönen	-	8708	6441	-	-	15149
Keçiborlu	-	31937	-	-	-	31937
Merkez	-	-	88898	-	-	88898
Senirkent	-	10575	-	-	-	10575
Sütçüler	35071	-	-	-	-	35071
Şarkikaraağaç	-	-	-	105570	-	105570
Uluborlu	-	7180	-	-	-	7180
Yalvaç	-	-	-	26659	58400	85059
Yenişarbademli	-	-	-	5188	-	5188
Total capacities of biogas plants (tons year^{-1})	150000	58400	105000	150000	58400	521800

Table 11. Manure Transportation Costs

Manure Production Centers	Districts Where Biogas Plants Were Established	Amount of Manure Sent to Biogas Plants (tons year^{-1})	Total Manure Transport Cost (€ year^{-1})
Aksu, Atabey, Eğirdir, Gelendost, Sütçüler	Eğirdir	150000	1011027.1
Gönen, Keçiborlu, Senirkent, Uluborlu	Keçiborlu	58400	282170.1
Atabey, Gönen, Merkez	Merkez	105000	323683.0
Gelendost, Şarkikaraağaç, Yalvaç, Yenişarbademli	Şarkikaraağaç	150000	695332.3
Yalvaç	Yalvaç	58400	147985.6
	Total	521800	2460198.1

Table 12. Amount of Biogas and Electricity to be Produced from Biogas Plants

Districts Where Biogas Plants Were Established	Type of Biogas Plants	Capacity of Biogas Plants (tons year^{-1})	Number of Biogas Plants (piece)	Biogas Production (m^3 year^{-1})	Electricity Generation (kW year^{-1})
Eğirdir	C	150000	1	6004250	11017221
Keçiborlu	A	58400	1	2406455	4546440
Merkez	B	105000	1	4204800	7344814
Şarkikaraağaç	C	150000	1	6004250	11017221
Yalvaç	A	58400	1	2406455	4546440
Total		521800	5	21026210	38472136

The annual electricity consumption of Isparta province in 2022 was around 1,000,000 MW in total. According to the data obtained from the planning model, the amount of electrical energy that can be obtained as a result of the utilization of the manure of dairy and beef cattle in Isparta province will be about 38,500 MW in total for the year 2022. With this production amount, it is determined that it is possible to meet 3.83% of the electrical energy consumed in Isparta province in 2022 with the electrical energy to be obtained from biogas. 2022 electricity energy consumption data for Isparta province and electricity energy to be obtained from biogas are given in Table 13.

Table 13. Isparta Province's Electrical Energy Consumption and the Amount of Electrical Energy to be Obtained from Biogas

Total Electricity Consumption in Isparta Province* (MW year^{-1})	Total Amount of Electricity to be Produced From Biogas (MW year^{-1})	Ratio of Production to Consumption (%)
1003556.11	38472.14	3.83
*Electricity consumption value of 2022, data were obtained from EMRA (2022)		

CONCLUSIONS

1. The mixed integer linear programming (MILP) method allows for the development of regional planning models. This method makes it possible to use different variables in the same algorithm and get solution outputs.
2. According to the results of the planning model, to process and convert approximately 522,000 tons of manure into biogas in 2022 in Isparta province, a total of 5 biogas plants, 2 type A plants with an annual manure processing capacity of 58,400 tons, 1 type B plant with an annual manure processing capacity of 105,000 tons and 2 type C plants with an annual manure processing capacity of 150,000 tons, should be built.
3. According to the results of the planning model, it will be possible to produce approximately about 21,000,000 m^3 of biogas and 38,500,000 kW of electrical energy annually with 5 biogas plants of different capacities to be established in various districts of Isparta province.
4. The annual about 38,500 MW of electricity to be produced by the future biogas facilities will be able to meet 3.83% of the annual electricity requirement of Isparta province.

5. The biogas plant planning model studies conducted in different regions of Türkiye concerning the recycling of animal waste have revealed that an annual biogas production between around 21,000,000 m^3 and 116,000,000 m^3 is possible if the existing animal waste is utilized. It was calculated that an amount of electrical energy production ranging between around 38,500 and 216,000 MW is possible if this amount of biogas is converted into electrical energy. Considering that Türkiye is dependent on outside sources in terms of electrical energy, the utilization of its potential for animal waste has become a necessity for Türkiye.
6. In order to utilize Türkiye's animal waste potential effectively and efficiently and convert it into biogas and electrical energy, it is necessary to make plans on a national scale and put them into practice. For this purpose, the breeders engaged in agricultural production should be guided and supported with incentives on a country basis. These plans to be made and incentives to be granted will increase the share of agricultural waste within renewable and sustainable energy production and greatly contribute to reducing the dependency of Türkiye on the outside in terms of energy.

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