Determining the Biogas Potential from Animal Manure in Canakkale and Creating an Electricity Generation Capacity Map

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Abstract- In this study, the biogas production potential from animal manure in Canakkale was determined and the electrical energy production capacity of the province was determined. According to the 2021 cattle, small ruminant, and poultry numbers received from the Provincial Directorate of Agriculture and Forestry, the cattle, small ruminant, and poultry manure amounts of all districts were calculated. Then, the amount of biogas that could be produced was calculated based on this data digital maps of the province were created by calculating the equivalent electrical energy production values of all districts with the biogas energy potentials that can be obtained. It has been calculated that a total of 119,715,927.80 m³ of biogas can be obtained annually throughout the province. The total annual equivalent electrical energy of this potential is 562,664.86 MWh. In line with the data obtained, it has been determined that Canakkale has a 70 MW biogas power plant potential.

Keywords Animal Manure, Biogas Potential, Capacity Map, Electricity Generation Potential, Renewable Energy.

1. Introduction

While the world population is increasing rapidly, industrialization is also rapidly expanding [1]. This situation leads to an increase in global energy demand. In the coming years, energy needs are expected to increase by 47% until 2035 [2]. To meet this increasing demand and reduce energy dependence on foreign energy, countries are increasing their efforts to research and develop new energy sources.

In this context, concerns about the decline of fossil fuels and their environmental impacts cause many countries to prioritize renewable energy sources in their energy policies. [3]. Energy supply security has become an extremely critical issue for our country, especially due to the negative developments in world politics. As an issue of great importance for our future, we should diversify energy sources, use domestic energy resources more, and focus on technology development in the energy sector [4].

Turkey's energy dependency ratio is recorded at a very high level, 72.6% [5]. Therefore, it has to mobilize more domestic resources to reduce energy dependence. More efforts should be made to meet Turkey's increasing energy demand and to use existing energy resources more effectively. Currently, it cannot be used at the desired level in energy production. Biogas, one of the renewable energy sources widely used especially in the agriculture and livestock sectors, has great potential to close this energy gap [6].

Biogas is an energy source known for its high thermal efficiency, environmentally friendly properties, and the advantages of being produced from local resources. Biogas is frequently used worldwide, especially for electricity and heat

production [7]. Installing biogas plants can offer a solution to preventing energy crises and alleviating the potential environmental problems of animal manure. Biogas can also create a healthier living environment by significantly reducing greenhouse gas emissions [8]. Biogas production, which is considered one of the most effective methods of utilizing animal manure, enables the use of biogas obtained as a result of processing animal manure as an important energy source for electricity production [9, 10].

A study carried out by Altikat and Celik in 2011 examined the biogas potential of Igdir from animal waste. The results of this study calculated that 100 million kWh of electrical energy could be produced annually by using biogas in Igdir [11].

In 2013, Kocer and Kurt investigated Malatya's animal population and biogas production potential. The study's results determined that there could be 31,990,425 m3 of biogas production capacity annually in Malatya [12].

A study carried out by Çaglayan and Kocer in 2014 evaluated the animal potential in Muş and examined biogas production. According to the results of this study, it was calculated that there is a potential to produce 49,125,147 m^3 of biogas energy annually in Muş [13].

In 2017, Doruk and Bozdeveci studied the biogas potential that can be obtained from animal waste in rural areas of Denizli. As a result of this research, it was calculated that 192,235 m^3 of biogas could be produced daily in Denizli and 329 million kWh of electrical energy could be obtained annually from this biogas [14]. Additionally, a study by Baran, Lule, and Gokdogan investigated the energy potential that can be obtained from the animal waste of Adiyaman. According to the research results, it was calculated that 264,673.50 m^3 of biogas energy could be produced annually in Adiyaman and 70,560,426.49 kWh of electrical energy could be produced from this biogas [15]. Karaca calculated the biogas potential that can be produced from the animal waste source of Hatay as 14,943,719 m^3/year in total [16].

A study carried out by Kocabey in 2019 examined the biogas potential resulting from animal waste in Balikesir. It determined that 390,114,719 m^3 of biogas could be produced annually and its equivalent electrical energy potential was 893,363 MWh [4]. Kalaycı et al. investigated the biogas production potential from animal waste in Kirklareli. As a result of their study, they revealed that there is a total annual biogas production potential of 86,503,832 m^3 in Kirklareli [17].

In 2020, Nuralan and etc all investigated the potential for biogas and electricity production from cattle waste in Kocasinan and Melikgazi districts of Kayseri. In the study, they calculated that 2,134,638 m^3 of biogas could be obtained annually [18]. On the other hand, Ay and Kaya carried out a study in which they examined the biogas potential resulting from animal waste in Kahramanmaras. In this study, they calculated that the annual biogas production is approximately 70 million m^3 and the electrical energy that can be produced with this potential is 326 GWh [19].

In 2021, Atilgan and Yilmaz carried out a study to determine the biogas potential of animal waste using Mardin's 2019 data. According to the results of this research, they calculated that the amount of biogas that can be produced annually in Mardin is 56,778,608.24 m^3 and that 266,859,488.7 kWh of electrical energy can be produced from it [10].

In the first part of the study, a literature review was carried out on the importance of renewable energy and the potential for energy production from animal manure-derived biogas. The second part gave general information about biogas and the process of obtaining biogas. In the third part, using 2021 data, the biogas potentials of Canakkale resulting from animal manure were determined, and digital maps regarding electricity production were created.

2. Materials and Method

In this study, Canakkale Provincial Directorate of Agriculture and Forestry provided cattle, small ruminant and poultry data for 2021. In the first step, the animal distribution of Canakkale according to districts was analyzed. Then, the annual manure production amount was calculated by considering the number of cattle, small ruminants, and poultry in each district. Then, the biogas production amounts that could potentially be obtained from these manures were determined, and the amounts of electrical energy that could be produced from this biogas were calculated.

2.1. General Information and Assumptions about Biogas

Biogas is a gas formed by the anaerobic fermentation of vegetable, animal, and industrial organic wastes. This gas is odorless, colorless, flammable, and burns with a bright blue flame. Biogas is a gas lighter than air and has a density of 0.83 relative to air. While the methane (CH_4) rate in its formation generally varies between 40% and 75%, the carbon dioxide (CO_2) rate is generally between 15% and 60%. It contains ammonia (NH_3), nitrogen (N), hydrogen sulfide (H_2S), carbon monoxide (CO), oxygen (O) and water vapor (H_2O) in its structure. The conversion rate of organic matter to biogas varies between 40% and 60% [20]. The thermal equivalent of biogas ranges from 20 to 25 MJ/m^3, depending on the methane content [21].

Table 1. Basic components of biogas [20]

Component Name	Volumetric Ratio	Unit
Methane (CH_4)	40-75	%
Carbon Dioxide (CO_2)	15-60	%
Water Vapor (H_2O)	1-5	%
Nitrogen (N_2)	0-5	%
Oxygen (O_2)	<2	%
Hydrogen (H_2)	<1	%
Ammonia (NH_3)	0-500	ppm
Hydrogen Sulfur (H_2S)	0-5000	ppm

Anaerobic fermentation is examined in three different groups depending on the temperature of the environment. These are acrophobic fermentation in the range of 5-25°C, mesophilic fermentation in the range of 30-40°C, and thermophilic fermentation in the range of 50-62°C [22]. Methane gas production and ambient temperature are the most important factors [23]. Because sudden temperature changes and the temperature difference between day and night contain methane properties. For this reason, the internal temperature of the generator is kept constant by using the cooling water of the biogas combustion engine. Bacteria can produce methane between 4.5 and 75°C above the ambient temperature inside the generator [24]. Therefore, the success rate of biogas production facilities in hot climate regions is quite high. The solids content of animal manure of the products is over 10%. For optimal biogas production, the solid content of the manure-water mixture in the generator should be between 7% and 9%. To achieve this goal, animal manures placed in the generator are usually diluted [25].

In determining the biogas production potential, when calculating daily manure amounts, 5% to 6% of the total weight of cattle, 4% to 5% of the total weight of ovine, and 3% to 4% of the total weight of poultry are used [26]. According to these rates, the annual amount of manure for cattle is calculated as 3600 kg, for small ruminants, 700 kg, and for poultry, 22 kg. Based on these data, the amount of biogas that can be obtained annually from 1000 kg of wet manure is calculated as 33 m^3 for cattle, 58 m^3 for ovine, and 78 m^3 for poultry [27].

Table 2. Production values used in admissions [28-29]

Type of Animal	The Average Annual Amount of Wet Manure (Ton)	Average Annual Biogas Potential from Wet Manure (m^3/ton)	Thermal Equivalent (MJ/ m^3)	Electrical Equivalent (kWh/ m^3)
Cattle	3.6	33	22.5	4.7
Small ruminant	0.7	58		
Poultry	0.022	78		

Combustion of one cubic meter of biogas produces the same amount of energy that can be obtained from 1.46 kg of coal, 0.66 L of diesel or 3.47 kg of wood. Biogas energy is also used to produce electrical energy. 4.7 kWh of electrical energy can be produced from 1 m^3 of [30].

Table 3. Energy equivalents of 1 m^3 of biogas for different fuel types [31]

	Butane	Coal	Diesel	Electric	Gas	Propane	Wood
1 m^3 Biogas	0.43 kg	1.46 kg	0.66 L	4.7 kWh	0.62 L	0.25 m^3	3.47 kg

Biogas is an energy source produced mainly in three stages: Hydrolysis, acid formation and methane production. The first stage involves the breakdown of insoluble substances by enzymes secreted by microorganisms. The second stage involves the conversion of organic substances into acids, hydrogen and small molecules such as carbon dioxide. In the third stage, carbon dioxide (CO_2) and methane (CH_4) gases, and small amounts of nitrogen (N_2) and oxygen (O_2) gases are formed [32].

The following factors must be considered to be successful in biogas production through the anaerobic fermentation process [24, 33].

- Manures from animals treated with antibiotics should not be added to the production tank and these manures should be prevented from affecting the biogas production process.
- Organic manures containing detergents should not be added to the production tank, and such chemicals should be prevented from adversely affecting biogas production.
- There should be no oxygen in the fermentor or generator should be kept away from this environment.
- Optimal fermentation time should be maintained.
- The environment's acidity level (pH) should be kept between 6.8 and 7.8, as this pH range represents a suitable environment for biogas production.
- Appropriate carbon-nitrogen ratio (C/N ratio) must be ensured, maintaining this balance is important for biogas production.
- The generator should not be exposed to sunlight and should be in a dark environment.
- The raw material used in the generator must be properly diluted and processed so that the biogas production process can proceed effectively.
- Depending on the production method, the temperature inside the generator must be kept consistently at either 35°C or 56°C, these temperature conditions ensure efficient biogas production.

2.2. Work Area

Canakkale is a city located in northwestern Turkey and takes its name from the Bosphorus that bears its name and separates the European and Asian continents. Geographically, the province covers an area of 9,817 km^2 between 25° 40′ and 27° 30′ east longitudes and 39° 27′ and 40° 45′ north latitudes [34]. The eastern and southeastern borders of the province are neighbors with Balıkesir, and it is surrounded by the Aegean Sea in the west, Edirne in the northwest, Tekirdağ and the Marmara Sea in the north. Due to this unique geographical location, a transition climate between the Mediterranean and Black Sea climates is active.

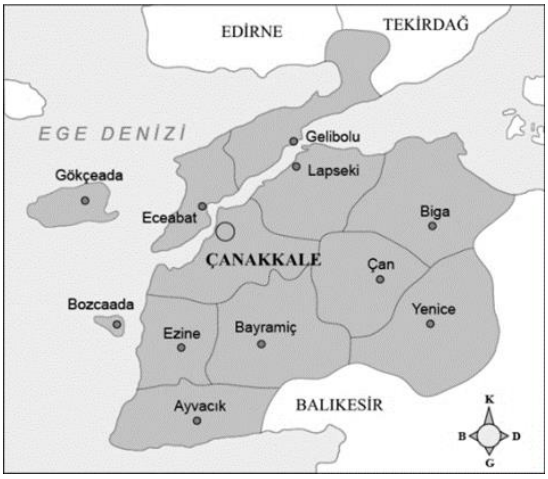

Fig. 1. Borders of Canakkale and districts [35-36].

There are a total of 12 districts, 23 municipalities and 576 villages within the municipal borders of Canakkale. This province consists of a total of 12 districts, including the center of Canakkale. These districts are Ayvacık, Bayramiç, Biga, Bozcaada, Çan, Eceabat, Ezine, Gelibolu, Gökçeada, Lapseki and Yenice [37]. The rural population ratio in the province to the general population is approximately 38.27%. This rate is approximately 6 times higher than the similar rate in Turkey. Since the main source of income of the population living in rural areas is generally agricultural activities, agriculture has great importance in the economy of Canakkale. The large rural population further supports this. Half the total surface area of 981,700 hectares of Canakkale province is covered with forests, one-third is devoted to agricultural areas, and the remaining 17 percent is non-agricultural land. Soil fertility divides agricultural soils into 8 classes, starting with class I and ending in VIII. It shows a decreasing order of efficiency towards class. Approximately one-third of the province's agricultural land is from I. to IV. It has a significant advantage in terms of agriculture due to its presence in the soil class [38]. Table 4 below shows the population information, number of settlements and surface areas of our country and the study area for 2021.

Table 4. Land areas, number of settlements and population information of Canakkale and Turkey [38]

Year: 2021		Canakkale	Turkey
Area, km^2		9,817	783,562
Number of settlements, units	District	12	973
	Municipality	23	1,359
	Village	576	18,211
Population, person		557,276	84,680,273
Population of provincial and district centers, persons		344,008	78,908,631
Town and village population, person		213,268	5,771,642
Ratio of provincial and district centers to total population, %		61.73	93.18
Ratio of towns and villages to total population, %		38.27	6.82

3. Results

3.1. Animal Data

According to the Provincial Directorate of Agriculture and Forestry data for 2021, the number of animals in Canakkale and its districts is given in Table 5. The table is based on the numbers of cattle species other than buffalo in the cattle category, goats and sheep in the small ruminant category, and laying hens and broiler chickens in the poultry category.

Table 5. Number of cattle, small ruminant and poultry in the districts [39]

	Cattle				Small ruminant			Poultry		
	Culture	Crossbreed	Local	Total	Sheep	Goat	Total	Laying Hen	Broiler Chicken	Total
Merkez	7,905	1,093	2,149	11,147	50,110	40,020	90,130	33,280	2,515,220	2,548,500
Ayvacık	7,940	4,860	3,940	16,740	93,955	24,070	118,025	6,500	0	6,500
Bayramiç	13,750	1.944	0	15,694	43,995	35,560	79,555	35,650	510,330	545,980
Biga	56,999	0	1,639	58,638	65,120	24,510	89,630	107,500	27,787,245	27,894,745
Bozcaada	29	0	0	29	1,775	680	2,455	450	0	450
Çan	26,912	0	0	26,912	52,629	15,389	68,018	28,650	447,230	475,880
Eceabat	823	0	0	823	9,835	4,605	14,440	9,625	0	9,625
Ezine	14,091	1,643	225	15,959	95,093	22,795	117,888	14,250	1,144,933	1,159,183
Gelibolu	5,835	2,118	335	8,288	42,615	34,615	77,230	30,250	0	30,250
Gökçeada	1,309	93	98	1,500	54,034	23,932	77,966	2,865	0	2,865
Lapseki	10.892	1,204	1,963	14,059	34,102	22,244	56,346	17,252	1,509,303	1,526,555
Yenice	41,078	7,304	4,438	52,820	48,848	9,935	58,783	30,854	0	30,854
Total	187,563	20,259	14,787	222,609	592,111	258,355	850,466	317,126	33,914,261	34,231,387

The patterns of occurrence of the highest and lowest animal population by district are given in Fig. 2. The district with the highest cattle population in Canakkale is Biga with a rate of 26% and 58,638 animals. The district with the lowest cattle population is Bozcaada with a rate of 0.013% and the number of animals is 29. The district with the highest population of small ruminant in Canakkale is Ezine, with a rate of 14% and 117,888 animals. The district with the lowest small ruminant population is Bozcaada with a rate of 0.29%. The district with the highest poultry population throughout the province is Biga, with a rate of 82% and 27,894,745 animals. The district with the lowest poultry population is Bozcaada with a rate of 0.0013% and the number of animals is 450.

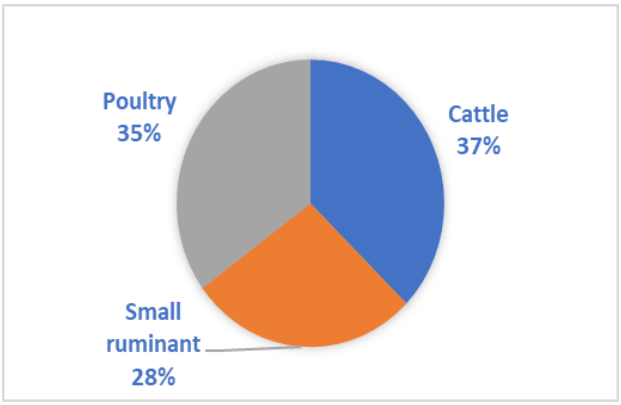

Fig.3. Total wet manure spread across the province.

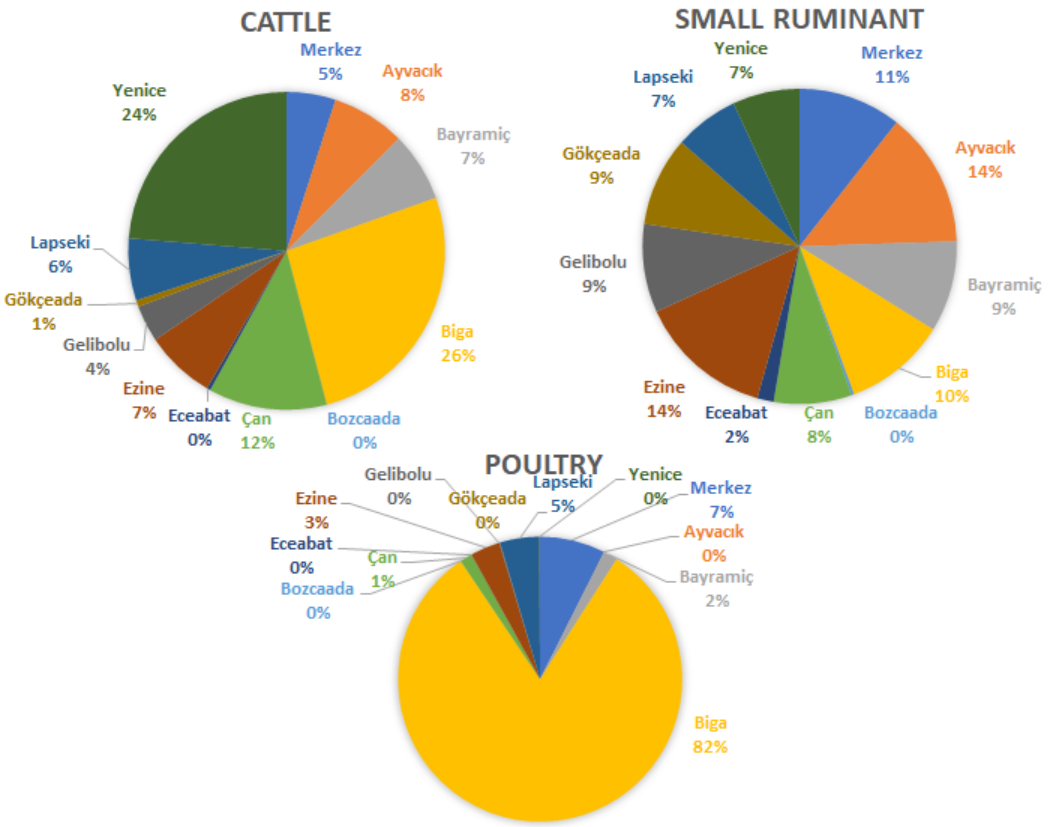

Fig. 2. Distribution of cattle, small ruminants, and poultry by districts.

3.2. Manure Potential

Annual manure amounts calculated according to the number of animals throughout the province are presented in Table 6. While it was determined that there was a total waste generation potential of 2,149,809.1 tons throughout the province, according to the calculations, Biga was the district where the most manure was given. The district with the lowest manure production potential was determined as Bozcaada. While Biga is the district where cattle and poultry manure can be accumulated the most, the districts with the highest potential for collecting small animal manure are Ayvacık and Ezine. The province-wide annual manure amount distribution chart is given in Fig. 3, and the distribution chart by districts is given in Fig. 4.

Table 6. The amount of manure that may consist of cattle, small ruminant and poultry in the districts (Tons)

	Cattle	Small ruminant	Poultry	Total
Merkez	40,129.2	63,091	56,067	159,287.2
Ayvacık	60,264	82,617.5	143	143,024.5
Bayramiç	56,498.4	55,688.5	12,011.56	124,198.46
Biga	211,096.8	62,741	613,684.4	887,522.2
Bozcaada	104.4	1,718.5	9.9	1,832.8
Çan	96,883.2	47,612.6	10,469.36	154,965.16
Eceabat	2,962.8	10,108	211.75	13,282.55
Ezine	57,452.4	82,521.6	25,502.03	165,476.03
Gelibolu	29,836.8	54,061	665.5	84,563.3
Gökçeada	5,400	54,576.2	63.03	60,039.23
Lapseki	50,612.4	39,442.2	33,584.21	123,638.81
Yenice	190,152	41,148.1	678,788	231,978.89
Total	801,392.4	595,326.2	753,090.5	2,149,809.1

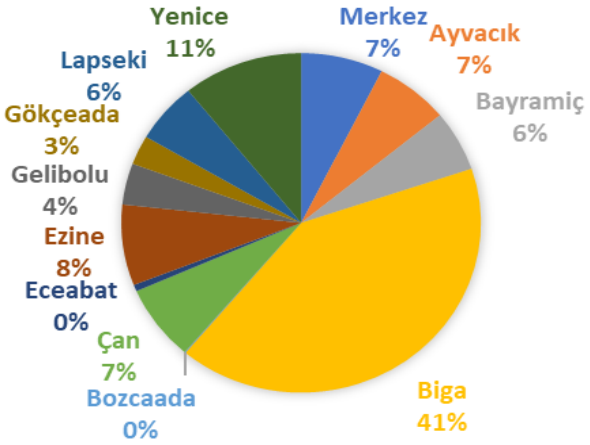

Fig. 4. Distribution of wet manures by districts.

3.3. Manure Sourced Biogas Production Potential

The annual amount of biogas is calculated according to the amount of animal manure found throughout the province and is presented in Table 7. Accordingly, it has been calculated that a total of 119,715,927.8 m^3 of biogas can be produced annually: 26,445,949.2 m3 from cattle, 34,528,919.6 m3 from small ruminants, and 58,741,059 m^3 from poultry. Across the province, poultry appears to have the greatest potential for biogas production.

Table 7. Biogas potential that may occur according to the animal species found in the districts (m^3/year)

	Cattle	Small ruminant	Poultry	Total
Merkez	1,324,263.6	3,659,278	43,73,226	9,356,767.6
Ayvacık	1,988,712	4,791,815	11,154	6,791,681
Bayramiç	1,864,447.2	3,229,933	936,901.68	6,031,281.88
Biga	6,966,194.4	3,638,978	47,867,383.2	58,472,555.6
Bozcaada	3,445.2	99,673	772.2	103,890.4
Çan	3,197,145.6	2,761,530.8	816,610.08	6,775,286.48
Eceabat	97,772.4	586,264	16,516.5	700,552.9
Ezine	1,895,929.2	4,786,252.8	1,989,158.34	8,671,340.34
Gelibolu	984,614.4	3,135,538	51,909	4,172,061.4
Gökçeada	178,200	3,165,419.6	4,916.34	3,348,535.94
Lapseki	1,670,209.2	2,287,647.6	2,619,568.38	6,577,425.18
Yenice	6,275,016	2,386,589.8	52,945.464	8,714,551.264
Total	26,445,949.2	34,528,919.6	58,741,059	119,715,927.8

The distribution graph of the annual amount of biogas recorded in the districts appears in Fig. 5. It can be easily seen from the graph that the district with the highest biogas production potential is Biga and the district with the lowest potential is Bozcaada.

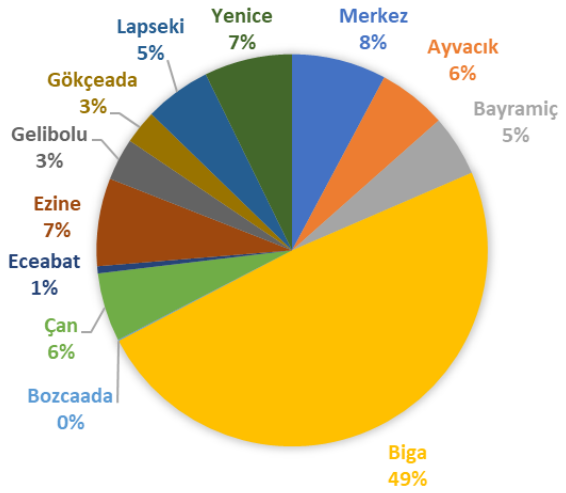

Fig. 5. Distribution of biogas potential by districts.

3.4. Electricity Generation Potential from Biogas

Fig. 6 shows the equivalent electrical energy amount of biogas that can be produced from cattle, small ruminants, and poultry manure. The province's poultry population has a great potential for generating electrical energy, with 49%.

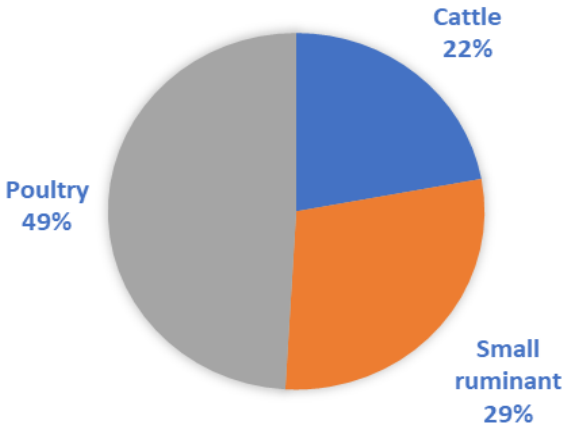

Fig. 6. Distribution of electric energy production in the province according to animal groups.

Table 8 presents the electrical energy production potential by district, and it is understood from these data that the electrical energy production potential has a positive relationship with the biogas production potential. As can be seen in the location chart in Fig. 7, the district with the highest electrical energy production potential is Biga with 274,821 MWh annually, while the district with the lowest production potential is Bozcaada with 488.28 MWh annually.

Table 8. Total energy production equivalents by districts

	Biogas Equivalent (m^3/year)	Thermal Equivalent (MJ/year)	Electrical Equivalent (MWh/year)	TEP
Merkez	9,356,767.60	210,527,271	43,976.81	5,028.36
Ayvacık	6,791,681	152,812,822.50	31,920.9	3,649.87
Bayramiç	6,031,281.88	135,703,842.30	28,347.02	3,241.23
Biga	58,472,555.60	1,315,632,501	274,821.01	31,423.34
Bozcaada	103,890.40	2,337,534	488.28	55.83
Çan	6,775,286.48	152,443,945.80	31,843.85	3,641.06
Eceabat	700,552.90	15,762,440.25	3,292.6	376.48
Ezine	8,671,340.34	195,105,157.65	40,755.3	4,660.01
Gelibolu	4,172,061.40	93,871,381.5	19,608.69	2,242.08
Gökçeada	3,348,535.94	75,342,058.65	15,738.12	1,799.51
Lapseki	6,577,425.18	147,992,066.55	30,913.90	3,534.73
Yenice	8,714,551.26	196,077,403.44	40,958.39	4,683.23
Total	19,715,927.80	2,693,608,375.50	562,664.86	64,335.73

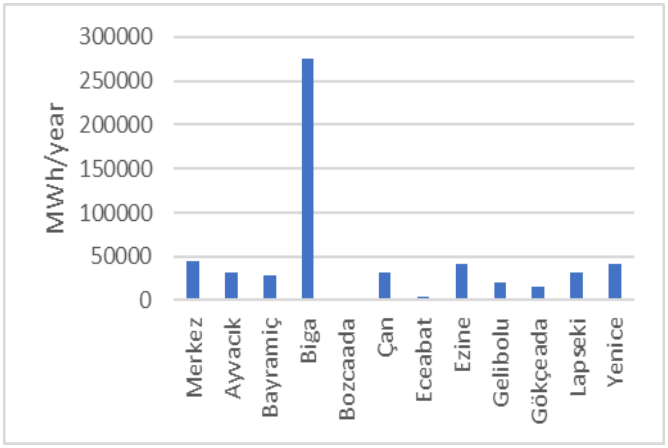

Fig. 7. Distribution of electricity generation potential throughout the province.

4. Conclusion

One of the major reasons for countries' external dependencies is their energy needs. As the population increases and technology advances in countries, the consumption of energy also rises. Therefore, most countries are dependent on external sources for energy.

In order to minimize this external dependence, meet the growing energy demand, achieve low-cost and reliable energy production, and preserve ecological balance, human health, and environmental well-being, the importance of renewable energy sources has become increasingly apparent. Their effective utilization has now become a necessity.

When we look at the current oil reserves used for energy needs, it is estimated that they have a lifespan of 40-45 years, while natural gas reserves are expected to last for 50-60 years. Despite the discovery of new sources every year, the lifespan of these resources is decreasing further due to increasing consumption.

Additionally, due to the pathogens they contain, the large quantities of animal manures pose risks to human and animal health. Furthermore, because of the various compounds they contain, they have adverse effects on the environment, leading to contamination of both underground and surface waters. Therefore, the disposal of these manures is of great importance. Biogas production allows for the elimination of manures, contributing not only to energy production but also making it possible to produce manures as by-products.

In this way, significant contributions can be made to closing Turkey's energy deficit, reducing external dependence, improving soil fertility, which is negatively affected by intensive agricultural activities, and decreasing environmental pollution. Additionally, it should not be overlooked that biogas, when appropriately adapted for use with natural gas or LPG-powered devices, can easily become a viable energy source, helping to mitigate the rapid depletion of energy reserves. Furthermore, the importance of biogas as an energy source capable of significantly reducing carbon emissions should be emphasized. For these reasons, the value of biogas power plants should be better understood.

According to the research findings, it is evident that Canakkale has a significant biogas production potential. Based on data obtained from the Provincial Directorate of Agriculture and Forestry for the year 2021, it has been calculated that a total of 119,715,927.80 m^3 of biogas could be produced annually. The annual equivalent electrical energy of this potential is 562,664.86 MWh. Accordingly, it has been determined that Canakkale has the potential for a 70 MW biogas power plant across the entire province. Particularly, the district of Biga exhibits the highest potential. As of now, there is two biogas facility in Canakkale. The study results indicate that only a limited portion of the province's potential has been utilized. Considering the agricultural and livestock potential of the province, it is envisaged that more biogas production facilities should be established.

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