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Catching the biogas opportunity: Determining the animal waste-based biogas potential and environmental effects for Sirnak

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ABSTRACT

Anaerobic digestion of renewable feedstocks into biogas is an important technological approach for sustainable and reliable energy supply. Biogas is produced from biomass and is defined as a gaseous energy carrier containing 60% methane and 35-40% carbon dioxide. Among many different types of biomass, the use of animal wastes in biogas production is more preferred than others. The region selected in the study is a city with a significant amount of animal waste production and, thus, biogas potential due to intensive livestock. In this study, the animal waste potentials that can be produced from cattle, sheep, and poultry in Sirnak province and their effects in terms of biogas equivalents and carbon emissions were analyzed. The results of the study show that a total of 23.4] million m^3 $year^{-1}$ of biogas can be produced from animal wastes in Sirnak province from all districts, while total electricity production may be 44,238,955.45 kWh $year^{-1}$. As an environmental impact, it has been determined that total CO_2 emissions can be 276,356,209.6 kg CO_2 $year^{-1}$, on the other hand, a reduction in total CO_2 emissions up to 209,809,869.8 kg CO_2 $year^{-1}$ can be achieved.

I. INTRODUCTION

Energy demand has been increasing rapidly in recent years due to the increase in the world population and rapidly developing industrial production. A significant portion of this intensive energy demand is met by fossil resources, which have limited reserves and create climate change problems by causing greenhouse gas emissions. As an alternative to this situation, awareness of sustainable clean energy production and supply and environmental pollution issues has increased. The trend towards renewable energy sources to meet energy demand has recently gained momentum [1, 2]. Among these renewable energy sources, biomass has attracted more and more attention in recent years in terms of energy efficiency and climate change with its energy potential [2, 3]. Biomass resources can be used to meet different energy demands such as generating electricity, heating homes, fuelling vehicles, and supplying process heat for industrial plants [4]. Biomass has a wide portfolio including a wide variety of organic wastes such as animal manure, agricultural waste, municipal-industrial waste, and sewage sludge [4, 5]. Biomass energy is utilized by direct combustion for heating and cooking, or by anaerobic digestion, pyrolysis, gasification, etc. to produce heat, electricity, and liquid and gaseous fuels [6]. Accordingly, biogas/biomethane production from organic wastes has been increasingly realized as a sustainable energy source in recent years [7]. Animal wastes, which are one of the alternative sources for biogas production, are no longer considered an environmental problem and are preferred an important alternative to meet energy needs [1, 7, 8].

The breakdown of organic matter (biomass) in a humid, oxygen-free environment with the help of the right microorganisms leads to biogas formation, which is a microbiological process. Biogas can be produced naturally [9, 10] or in facilities such as landfills, sewage treatment plants, or anaerobic digestion plants. The chemical composition, energy content, or fuel equivalent of the biogas produced varies depending on the type of biomass selected [11]. Along with the substrate, other factors also affect the biogas composition [12, 13]. Biogas mainly contains 55-70% methane and 30-45% carbon dioxide, but also hydrogen sulfide (mostly 50-2000 mg/l), water vapor (saturated), oxygen (less than 1% by volume), nitrogen (less than 2% by volume), and trace amounts of

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hydrogen, ammonia, carbon monoxide, oxygen, and various hydrocarbons (e.g., benzene up to 2.5 mg/m^3 or toluene up to 11.8 mg/m^3) [11, 14-16].

Anaerobic degradation of agricultural residues, animal wastes, energy crops, and biodegradable industrial by-products is considered a technology that can reduce greenhouse gas (GHG) emissions and contribute to the development of sustainable energy supply and has recently attracted much attention [17]. Anaerobic degradation is defined as the breakdown of organic compounds into more basic products by producing biogas through microorganisms in the absence of oxygen [18, 19]. The advantages of anaerobic digestion on various issues are seen at local, national, and even global scales [11]. Biogas production by anaerobic digestion in bio-based energy production is more advantageous than other methods and is also one of the most energy-efficient and environmentally friendly technologies [13]. Animal waste, often used in anaerobic digestion, is one of the most frequently used feedstocks for biogas production worldwide [16]. In recent years, a significant amount of animal waste has been generated due to the large increase in the number of livestock. This situation offers a very large biogas supply opportunity. In regions where livestock is intensively carried out, animal wastes become an important problem, such as environmental pollution, when they are not disposed of properly, and at the same time, their disposal also creates an economic burden [16, 20]. For these reasons, anaerobic digestion of animal manure is mostly carried out both to obtain organic fertilizer and to convert the waste into basic molecules such as methane and carbon dioxide by removing odor and microbial pathogens for energy production. [21-23].

Since animal wastes are at the forefront of biogas production for the reasons mentioned above, countries where livestock are developing offer an important potential for biogas production. Thanks to the climate, ecological characteristics, and topographical diversity, livestock is very developed in Turkey. Cattle, ovine, poultry, beekeeping, sericulture, and sericulture are the main types of livestock [24]. Cattle breeding is in the form of pasture and fattening and is carried out with modern methods. The number of large-scale facilities engaged in cattle and sheep breeding has increased in recent years, especially in or close to large cities, which are more intensive consumption centers. Sheep, hair goats, and mohair goats are raised within the scope of ovine husbandry in Turkey [7, 25]. In Turkey, the number of registered cattle breeding enterprises is 1,164,673, while the number of sheep and goat breeding enterprises is 385,125 [26]. Significant number of animals are raised and cared for in these facilities or in rural areas [27]. Accordingly, the amount of animal waste is also quite high [28]. Animal manure cannot be directly removed due to sanitation-based restrictions. A significant portion of animal manure is stored near livestock facilities for fertilizer use [29, 30] or around houses or fields in rural areas. However, storage of animal manure under inappropriate conditions not only creates odor and hygiene-based problems but also generates significant greenhouse gas emissions [31-33]. This situation causes livestock farming to account for a significant percentage of Turkey's greenhouse gas emissions. Therefore, it is aimed at develop innovative approaches to reduce greenhouse gas emissions from fertilizers [28, 33]. Animal manure that is not stored under the right conditions can mix with surface water or groundwater through leaks [25, 34]. For all these reasons, sustainable manure management systems that reduce environmental impacts and allow for the storage, transport, and efficient utilization of manure should be implemented on animal farms. As mentioned before, animal manure is an important biomass source, and biogas can be produced [8, 32, 35, 36]. While the biogas produced is used as an energy source, the remaining substrate or decomposition product waste can be used as fertilizer [37- 39].

When agricultural and animal wastes are utilized efficiently in Turkey, large-scale natural gas savings can be achieved, and imports have been expected to be significantly reduced [7, 28, 40]. In order to utilize the full potential of animal waste-based biomass in Turkey and to produce more biogas, biogas contents in various regions should be calculated and planning should be made. However, from an energy source perspective, biogas production in Turkey is not controlled enough to be properly utilized. At this stage, it is important to provide information about local biogas resources, as stated in the literature [7, 28]. It is particularly important to study cities or regions where livestock farming is intensive but the utilization of the available potential has not been calculated. This will contribute to the provision of information and the development of biogas and energy supply plans and strategies. In addition, as stated in Aksay and Tabak (2022) [33], it is very important to calculate the data on feedstock and electricity production close to reality in terms of the installation and operation of such costly biogas plants. For these reasons, this study analyzed the biogas production potential for Sirnak province, where livestock breeding is intensively carried out and therefore has a significant waste potential. Several calculations on the biogas potential of Sirnak province have been made in different studies [33, 41-44]. However, this study is a pioneer in terms of calculating the districts and animal wastes one by one and analyzing them together with their environmental impacts more comprehensively than others. In addition, compared to previous studies, an increase in capacity in terms of increased waste and thus biogas amount as a result of the support for livestock in recent years has been identified. Within the scope of the study, biogas production potential and the amount of electricity that can be generated from bovine, ovine, and poultry manure were calculated. In addition, CO_2 emissions and how much reduction in CO_2 emissions can be achieved were also determined. The calculation of possible CO_2 reduction also reveals the greenhouse gas effect.

II. THEORETICAL METHOD

In this study, the biogas production potential that can be produced from the wastes of existing ovine, bovine, and poultry animals in Sirnak province in 2022 was determined. In addition, the amount of electricity that can be obtained from this biogas, the determination of the amount of CO_2 emission, and the reduction in CO_2 emission were also presented [45].

2.1 Determination of Biogas Potential and Electricity Generation Equivalent

In order to calculate the biogas production potential of Sirnak province from animal waste, it is necessary to know the amount of organic material available. Therefore, the number of cattles, sheep, goats, egg-hens, turkeys, ducks, and geese was investigated on the basis of districts. The animal number statistics for the year 2022 in the Turkey Biomass Energy Potential Atlas (BEPA) were used (BEPA Statistics, 2022) [46]. BEPA statistics were preferred because they also provide animal numbers on a district basis. While the districts within the borders of Sirnak province are shown in Figure 1, animal number data are given in Figure 2 and Figure 3.

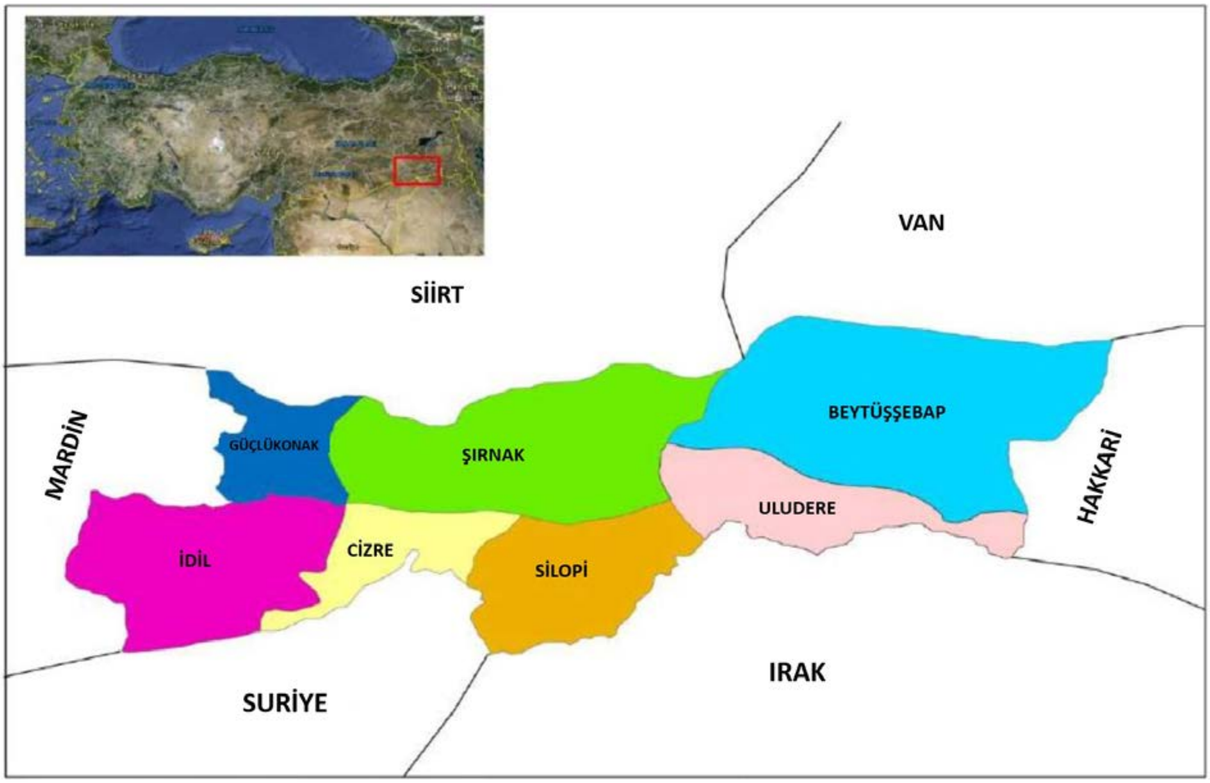

Figure 1. Map of Sirnak province and its districts [47]

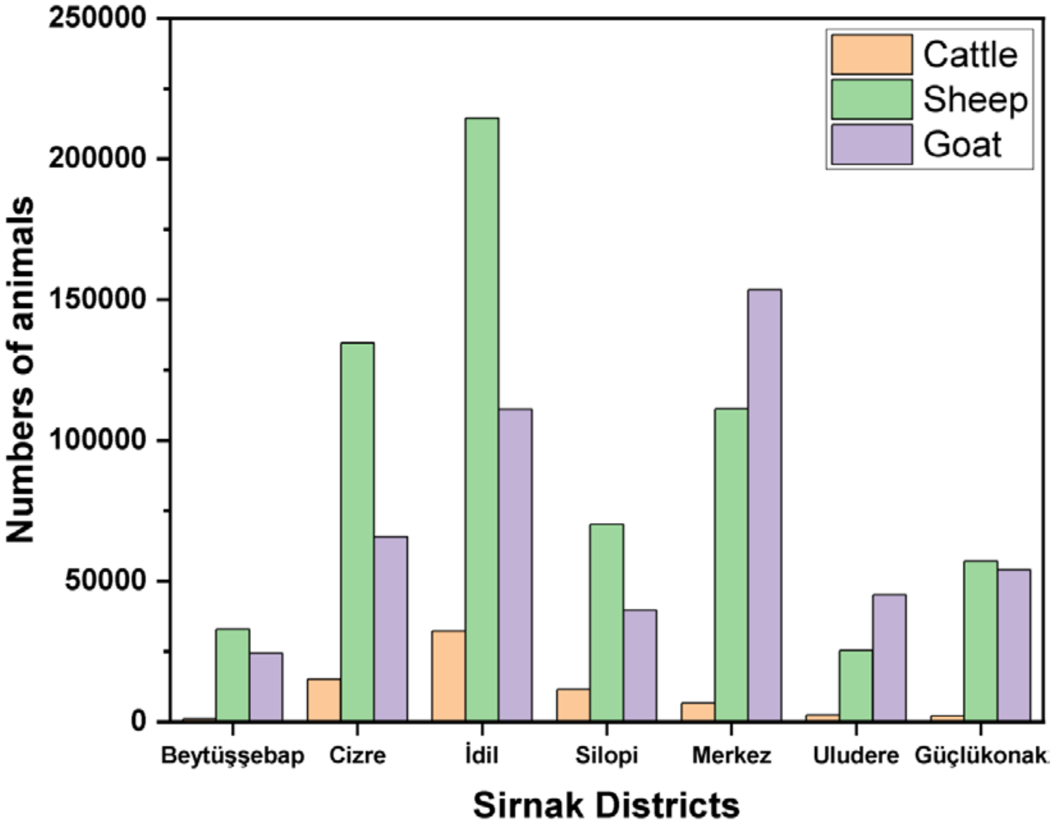

Figure 2. Numbers of cattles, sheep, and goats in Sirnak districts [46]

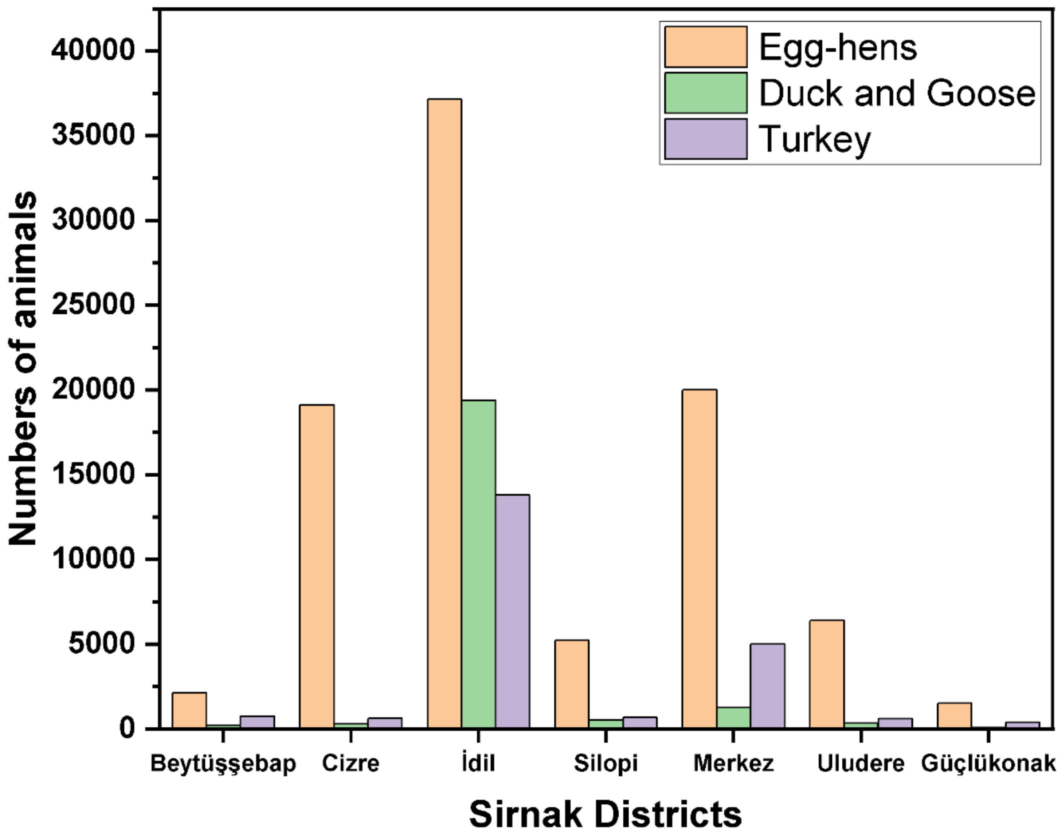

Figure 3. Numbers of egg-hens, ducks, goose and turkeys in Sirnak districts [46]

The most basic information required for the calculation of biogas production potential is the amount of waste per animal [33, 41]. The assumptions taken into account to calculate the amount of waste per animal are shown in Table 1. Animal waste amounts were calculated on the basis of districts by multiplying the number of animals by the corresponding ratios. The waste amounts (M) found are not fully achievable or permissible to use. Therefore, the total amount of waste (M) (kg/day) and the percentage of access to the amount of manure (AC) (availability coefficient) were taken into account when calculating the total amount of biogas. The product of these two gives the total amount of accessible waste in a day for each animal.

Table 1. Assumptions of animal wastes in Sirnak districts

Livestock	**Manure** *(kg/day)*	**AC** *(%)*	**References**
Cattle	29.00	50	[48-50]
Sheep	2.40	13	
Goat	2.05	13	
Egg-Hen	0.13	99	
Duck and Goose	0.33	99	
Turkey	0.38	99	

The total solids (TS) of animal waste is another basic parameter for biogas production from animal waste. The total solids ratio varies according to different factors such as the amount of nutrition, body weight, type of animal, and waste availability [1]. The ratio of solids (TS) (%) and volatile solids (VTS) (%) in wet manure is the basic structure of manure for biogas production and varies according to animal species. In addition, the estimated amount of biogas produced per kg of total volatile solids (EB_{TS}) (m^3/kg VTS or l/kg VTS) was also used in the calculations. However, the waste supply before biogas production may not always be in the desired amount, and the amount of manure may vary. These values are different for each animal and the accepted sizes for each animal, are given in Table 2.

Table 2. TS (%), VTS (%), and EB_{TS} (l/kg VTS) values by livestock

Livestock	**TS** *(%)*	**VTS** *(%)*	**EB_{TS}** *(l/kg VTS)*	**References**
Cattle	14.00	83.33	330	[6, 48, 49]
Sheep	27.50	83.36	300	
Goat	31.71	73.06	300	
Egg-Hen	25.00	75.00	350	
Duck and Goose	28.18	61.28	350	
Turkey	25.53	75.83	350	

According to these values, biogas production was calculated as shown in Eq. 1. For each animal, the amount of biogas calculated varied due to variations in the number of animals, manure amount, and other parameters. The theoretical potential of biogas produced (TPB) (m^3/day) [51, 52]:

$$TPB = MxACxTSxVTSxEB_{TS} \quad (1)$$

Biogas production can be achieved with high efficiency by adjusting the pH and temperature values of the process to optimum conditions [53]. In biogas production, bovine manure is mostly used due to the high amount of manure compared to other animals. The biogas yield produced by mixing sheep and goat manure with cattle manure is slightly more efficient. Poultry manure can be preferred as an important biogas source due to its high biodegradation rate [54]. In this study, no meat chicken was found for Sirnak province, and egg chicken was taken into consideration for the assumptions and calculations made for chicken. On the other hand, animal manure that can be used for biogas production was calculated by taking into account the duration of the animals' stay in the shelter. It is assumed that 50% of cattle, 13% of ovine, and 99% of poultry produce an average of 29 kg, ovine

2.40 kg, and poultry 0.13 kg of manure per day. The estimated amount of biogas produced per kg of volatile solids in total wet manure was assumed to be in the range of 200-350 l/kg VTS in cattle, 100-310 l/kg VTS in ovine animals, and 310-620 l/kg VTS in egg-hens [49]. The access rate to manure, the amount of manure production for each animal, the dry matter and volatile dry matter ratios of manure, and the methane production rate of manure were calculated by considering different studies in the calculation of biogas production potential.

The methane content in the biogas formed as a result of the anaerobic digestion of animal manure is important in terms of the electricity potential that can be generated from biogas. The percentage of methane in biogas varies according to the source of the manure. It has been determined that 50-70% of the biogas formed as a result of anaerobic digestion from cattle manure consists of methane [16, 22, 23, 55]. On the other hand, the methane content of biogas produced from sheep manure is between 40% and 50% [16], while biogas production using chicken manure contains methane in the range of 50%-70% [55, 56]. In this study, the amount of methane content for cattle, sheep, and poultry was accepted as 60%, 45%, and 60%, respectively.

Considering the calorific value of methane is 36 MJ/m^3, it is accepted that 85% of the produced methane can be converted into heat in the boiler in terms of heat and power efficiency (85% heating conversion efficiency) while electricity efficiency is between 35-40% [21]. Energy content of methane unit and cogeneration electricity efficiency are taken as 10 kWh/m^3 and is 40%, respectively [52]. The electricity generation potential from biogas is shown in Eq. 2.

$$Biogas\ plant\ capacity\ (kWh/year) = Biogas\ production\ amount\ (m^3/hour)\ x\ Methane\ rate\ (\%)\ x\ Methane\ unit\ energy\ content\ (kWh/m^3)\ x\ Cogeneration\ electricity\ efficiency\ (\%) \quad (2)$$

2.2 Determination of CO_2 Emission and CO_2 Emission Reduction

There are three separate parts in the calculation of CO_2 emission [33, 48].

Part 1: CO_2 emission to the environment when animal manure is not treated, i.e. anaerobic digestion is not applied;

$$B_{CO_2} = TBBP\ x\ a_{CO_2} \quad (3)$$

is calculated by using the Eq. 3. Where TBBP is the total amount of biogas produced (m^3/year); a_{CO2} is the CO_2 emission equivalent (kg CO_2/m^3) which is equal to the emission of 1 m^3 of biogas to the atmosphere (9.19 value is accepted in this study).

Part 2: When electricity is produced from biogas, the CO_2 equivalent value (CHP) that will be released to the atmosphere as a result of the combustion of biomethane is ;

$$CHP_{CO_2} = TBMP\ x\ b_{CH_4} x\ EI \quad \textbf{(4)}$$

is determined from the equation. TBMP is the total amount of methane produced per year (m^3/year); b_{CH_4} is the CO_2 equivalent of the gases emitted to the atmosphere (kg CO_2/kWh) if methane gas is used to generate 1 kWh of electrical energy (0.8 value is taken in this study); EI is the energy content of biogas (kWh/m^3).

Part 3: The amount of CO_2 to be emitted if the amount of electricity produced from biogas is produced using coal;

$$Coal_{CO_2} = TBBP\ x\ EI\ x\ n\ x\ C_{coal} \quad (5)$$

is calculated by using the equation. Where TBBP is the total amount of biogas produced per year (m^3/year); EI is the energy content of biogas (kWh/year); n is the conversion efficiency to electricity (%); C_{coal} is the amount of CO_2 emitted by the coal used to produce 1 kWh of energy (kg CO_2/ kWh) (1 kg CO_2 per kWh is accepted for the coals in Turkey) [17].

Total CO_2 emission and reduction in Total CO_2 emission are expressed by the following equations:

$$Total\ CO_2\ Emission:\ TE_{CO_2} = Coal_{CO_2} + B_{CO_2} \quad (6)$$

$$Reduction\ in\ Total\ CO_2\ Emission = RTE_{CO_2} = Coal_{CO_2} + B_{CO_2}\text{-}CHP_{CO_2} \quad (7)$$

III. RESULTS AND DISCUSSIONS

According to 2022 BEPA data, there are 59,347 cattle, 1,138,629 ovine (sheep and goats), and 135,332 poultry, totaling 1,333,308 animals in Şırnak province. The relevant equations in the theoretical calculation section were used for the biogas potential that can be produced from collectible animal wastes. The possible biogas potentials in all districts, including the central district, are given in Figures 4 and 5 for each animal waste. If the wastes in the region are used for biogas production, it has been determined that a total of 64,234.218 m^3/day of biogas can be produced from animal wastes per day. Of this value, 39,516.1 m^3/day is from cattle, 21,863.801 m^3/day from ovine, and 1,754.314 m^3/day from poultry. In another study conducted six years ago by Lüle (2017), it was calculated that 5,479.452 m^3/day and 273.972 m^3/day of biogas could be produced from cattle and poultry wastes, respectively, while in our study, it was determined that these values increased in this time interval. Compared to the same study, the amount of biogas that can be produced from ovine wastes is 82,191.78082 m^3/day, while in our study it was 23,301.67529 m^3/day. These results are in line with the increase in the number of cattle in the region in recent years and the government's desire to encourage small cattle breeding in Şırnak. Additionally, in the study of Aksay and Tabak (2022) [33], the amount of biogas obtained from animal waste was calculated as 55,890.410 million m^3/year for Sirnak. When it is considered that their data belongs to the year before 2022 and compared with the results in the present study, it is seen that an increase of 8,343.808 million m^3/day has been achieved in about two years. This increase shows that the biogas potential in Sirnak is sustainable and can be further increased by increasing livestock production and other incentives. Using 2021 data, Aydın and Üren (2022) [43] calculated the total amount of biogas produced based on animal waste for Sirnak as 108,472.251 m^3/day. The reason for calculating higher compared to the previous study and ours, which were conducted in the same periods, may be that all wastes were included in the calculation considering that all of them were accessible and all of them were used.

Although Artun et al. (2017) [41] stated that no suitable biogas energy production area could be identified in Şırnak, investments in the field of livestock have accelerated with government support since their study. This has increased the number of animals and, therefore, the amount of waste. The results of our current study indicate that there is a significant potential for sustainable biogas production in Sirnak province. Sirnak is a city with a higher cattle content, the highest rate of biogas production from cattle is due to the higher amount of waste and methane content, as mentioned before. Abdeshahian et al. (2016) also found that more biogas will be obtained from cattle wastes in support of this situation [1]. On the other hand, although this value is the highest for poultry in terms of waste accessibility, the amount of biogas produced is the lowest. This is due to the difference in the volatile dry matter content and methane percentage per waste and the fact that the amount of waste is less in volume compared to cattle and sheep. The amount of biogas production varies from animal to animal according to the changes in the waste and its properties, as well as the amount of biogas that can be produced between the districts for the same animal due to the different animal data in the seven districts of Sirnak province. When Figure 4 is examined, İdil district ranks first in sheep and cattle waste-based biogas production, while it ranks second after the central district in the production of goat waste. This situation is due to the high number of animals, as stated by Bulut et al. (2017) in their study. Artun et al. (2017) [41] also stated that İdil district has approximately 2/3 of the total number of animals in the province with 59.83%. Beytüşşebap district was found to have the lowest value in biogas production based on cattle and goat waste, while Uludere district was calculated to have the lowest potential in sheep waste production. On the other hand, when the biogas production data based on egg-hen, duck, goose, and turkey wastes is analyzed according to Figure 5, it is determined that the lowest amount belongs to Güçlükonak district except for turkey waste-based biogas production. In turkey waste-based biogas production, the lowest value was calculated in Beytüşşebap district. In general, the lower biogas potential in Beytüşşebap district is due to the fact that animal waste is not high compared to other districts due to the decrease in population in recent years and the decrease in livestock activities. Similarly, the low number of animals in Güçlükonak district caused the amount of biogas produced to be less than the other districts.

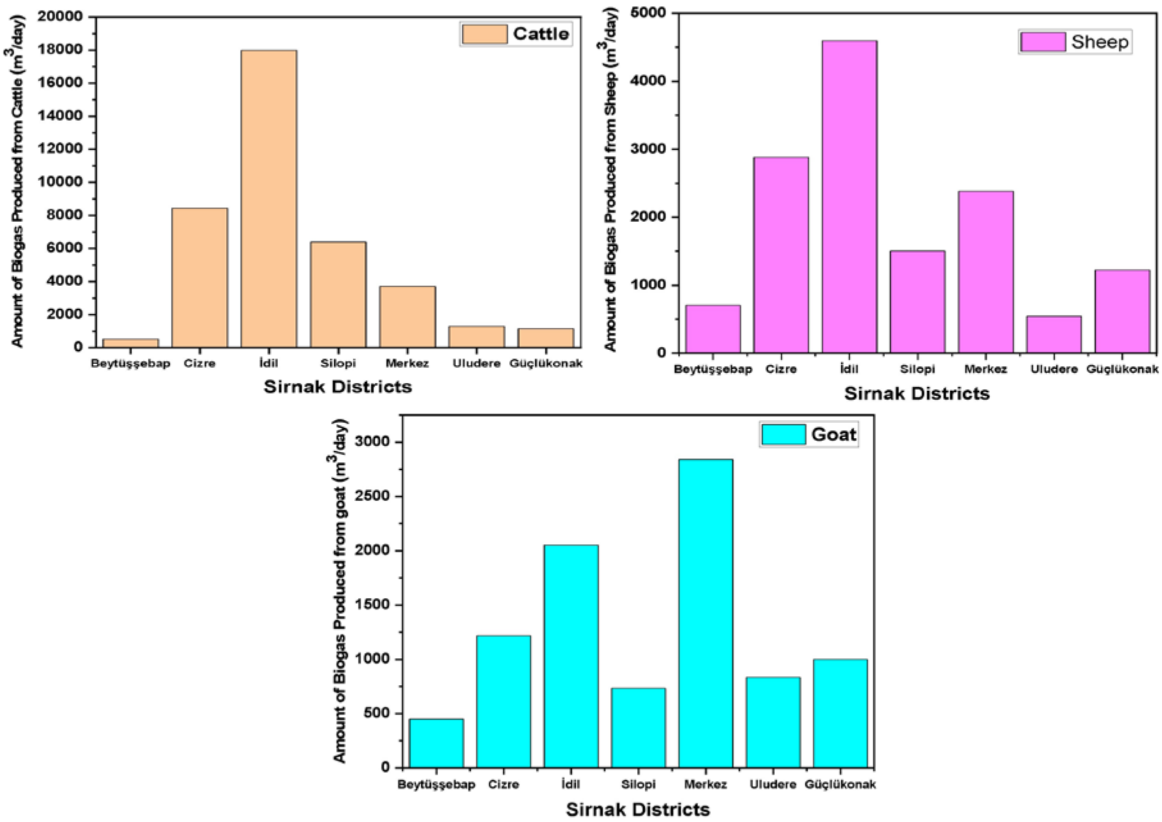

Figure 4. Amounts of Biogas Produced from cattles, sheep and goats in Sirnak districts

Approximately 55-70% of the biogas potential produced consists of methane. In this study, 60% is accepted for cattle and poultry and 45% for ovine animals. Using the equation given for electricity generation in the theoretical method section, according to the 2022 data for Şırnak province, the amount of electricity that can be produced when methane gas is burned in a CHP engine with an average electricity efficiency of 40% is predicted at 4,423,895,555.45 kWh (44.238 GWh/year). On the other hand, Ertop et al. (2022) [44] determined the amount of electricity that can be obtained from biogas produced from cattle wastes as 2,833,010 kWh/year using Sirnak 2020 animal data. In our study, electricity production from cattle waste increased in three years and was calculated at 34,616,103.6 kWh/year. This can be considered a result of the increase in state support for livestock in the region in recent years. Data on the amount of electricity that can be obtained by using biogas that can be produced from waste according to each animal species on the basis of districts is given in Table 3.

Table 3. Amounts of Electricity Produced (kWh/year) from biogas in Sirnak districts

Districts	Cattle	Sheep	Goat	Egg-Hen	Duck and Goose	Turkey
Beytüşşebap	466,344.73	462,899.20	295,653.28	15,536.73	3,823.74	16,720.21
Cizre	7,403,351.06	1,895,125.69	799,344.96	141,461.73	4,702.36	13,822.40
İdil	15,748,191.89	3,020,311.78	1,348,460.96	274,837.11	333,680.66	301,545.48
Silopi	5,605,429.39	988,203.55	480,900.34	38,561.52	9,008.78	15,115.38
Merkez	3,254,638.71	1,564,982.54	1,866,398.37	147,972.16	21,532.08	111,472.75
Uludere	1,135,555.29	356,682.67	547,499.12	47,351.30	5,681.73	13,376.52
Güçlükonak	1,002,592.51	804,368.38	656,386.36	11,097.16	1,119.52	8,359.66

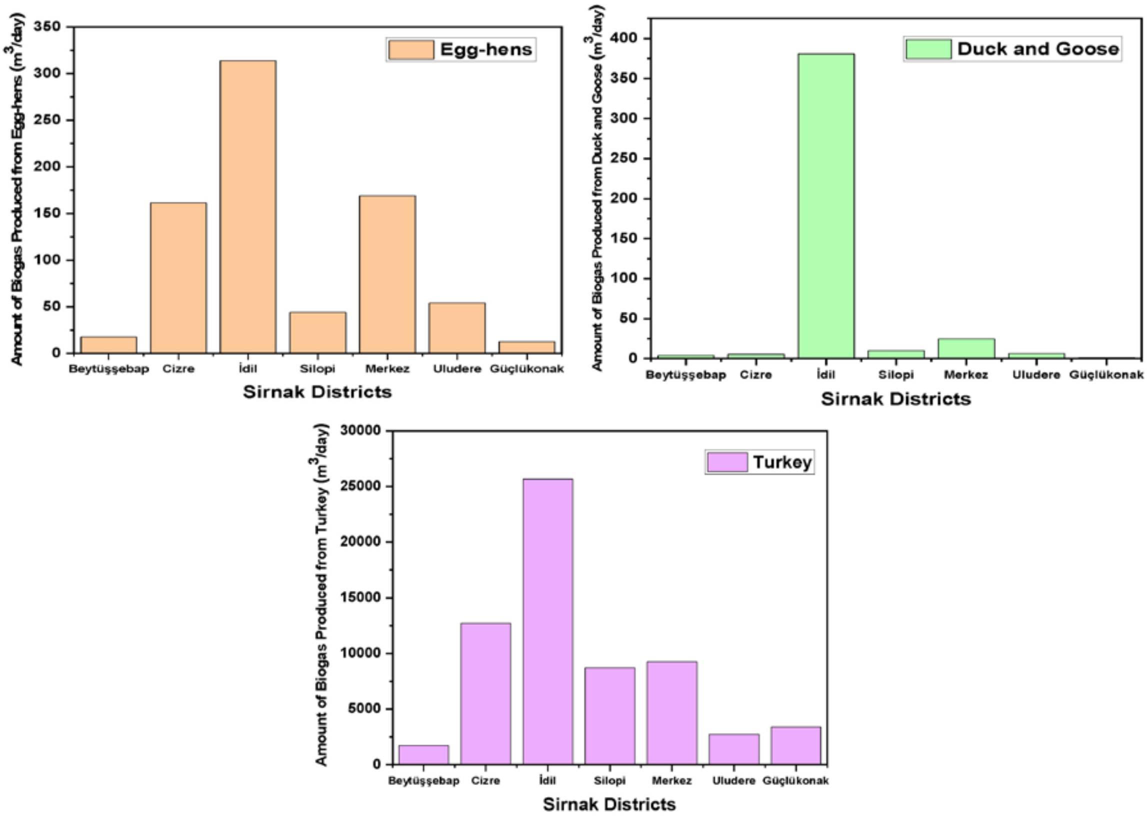

Figure 5. Amounts of Biogas Produced from egg-hens, goose, ducks and turkeys in Sirnak districts

It has been determined that the highest electricity production can be provided from cattle manure [48]. Since cattle produce more manure compared to other animals in terms of the daily manure amount [54], this increases biogas production and thus electricity production. Compared to other districts, cattle breeding, which is intensively active in İdil and Cizre districts compared to other districts, may contribute to the higher amount of biogas and electricity production compared to other districts. Another reason for the high total amount of biogas production and electricity generation in İdil district is the high amount of poultry. Poultry are the most suitable animals for the biological transformation process because of the manure they produce daily. Poultry manure is considered the most suitable and efficient raw material for biogas production. This manure can be easily processed and converted into biogas in biogas plants [54]. This increases biogas production and, thus, electricity production in Idil district. The density of poultry ensures that the amount of manure is high and allows for more biogas production in biogas plants. For these reasons, both the presence of cattle, sheep, and goats and the density of poultry in the İdil district contribute to the higher amount of biogas and electricity production compared to other districts. It has been determined that the amount of electricity generated is the lowest in Beytüşşebap and Uludere districts. The main reason for this is that the number of animals is generally lower than in other districts, as mentioned when analyzing biogas production data.

In our country, most of the electricity generation is provided by fossil resources. However, this situation causes an increase in CO_2 emissions [21]. As in this study, the environmental impact of utilizing biogas in electricity generation as an alternative was also calculated. The total CO_2 emission and the possible reduction in CO_2 emission were calculated using the equations given for them in the theoretical methodology section and given together in Table 4.

Table 4. Amounts of CO_2 Emissions (kg CO_2/year) and Reduction of CO_2 Emissions (kg CO_2/year) thanks to biogas potential in Sirnak districts

Districts /CO_2 Emissions *(kg CO_2/year)*	**Cattle**	**Sheep**	**Goat**	**Egg-Hen**	**Duck and Goose**	**Turkey**
Beytüşşebap	2,290,918.49	3,031,989.79	1,936,529.01	76,324.21	18,784.12	82,138.04
Cizre	36,368,962.11	12,413,072.32	5,235,322.20	694,930.77	23,100.38	67,902.55
İdil	77,362,992.65	19,783,042.17	8,832,419.31	1,350,137.33	1,639,206.26	1,481,342.17
Silopi	27,536,671.89	6,472,733.28	3,149,897.27	189,433.46	44,255.65	74,254.30
Merkez	15,988,412.69	10,250,635.64	12,224,909.34	726,913.27	105,776.34	547,609.89
Uludere	5,578,415.35	2,336,271.51	3,586,119.26	232,613.28	27,911.52	65,712.15
Güçlükonak	4,925,235.71	5,268,612.92	4,299,330.67	54,514.83	5,499.68	41,066.86
Districts /Reduction of CO_2 Emissions *(kg CO_2/year)*	**Cattle**	**Sheep**	**Goat**	**Egg-Hen**	**Duck and Goose**	**Turkey**
Beytüşşebap	1,684,671.29	2,430,220.82	1,552,179.74	56,126.45	13,813.26	60,401.76
Cizre	26,744,605.72	9,949,409.91	4,196,250.62	511,030.52	16,987.30	49,933.43
İdil	56,890,343.20	15,856,636.86	7,079,420.06	992,849.08	1,205,421.39	1,089,333.04
Silopi	20,249,613.68	5,188,068.66	2,524,726.82	139,303.49	32,544.23	54,604.31
Merkez	11,757,382.36	8,216,158.34	9,798,591.45	534,549.45	77,784.63	402,695.31
Uludere	4,102,193.46	1,872,584.04	2,874,370.40	171,056.58	20,525.27	48,322.67
Güçlükonak	3,621,865.44	4,222,934.02	3,446,028.40	40,088.51	4,044.29	30,199.30

The results show that CO_2 emissions are high in Idil and Cizre districts, and this may be due to the fact that animal wastes are not sufficiently utilized for biogas production. Because livestock breeding activities are quite common in these districts, there are more cattle and ovine animals. The manure produced by cattle on a daily basis constitutes a potential source for biogas production [54]. However, there may be cases where animal wastes are not collected and processed sufficiently for biogas production. This may cause animal waste to be released directly into the environment and increase CO_2 emissions. Total biogas production, total electricity production, total CO_2 emission, and reduction in total CO_2 emission corresponding to the total number of animals in each district are given in Table 5.

Table 5. Total Energy Potential and Environmental Effects in Sirnak districts

Districts	**Total Number of Animals *(Quantity)***	**Total Biogas Potential *(m^3/year)***	**Total Electricity Production *(kWh/year)***	**Total CO_2 Emission *(kg CO_2/year)***	**Total CO_2 Emission *(kg CO_2/year)***
Beytüşşebap	61,209	630,761.97	1,260,977.91	7,436,683.68	5,797,413.35
Cizre	235,449	4,648,317.70	10,257,808.23	54,803,291.36	41,468,217.52
İdil	427,87	9,368,035.61	21,027,027.90	110,449,139.9	83,114,003.65
Silopi	127,590	3,177,883.45	7,137,218.97	37,467,245.88	28,188,861.20
Merkez	297,543	3,379,495.94	6,966,996.63	39,844,257.18	30,787,161.57
Uludere	80,018	1,003,141.91	2,106,146.65	11,827,043.09	9,089,052.44
Güçlükonak	115,091	1,237,850.78	2,483,923.62	14,594,260.70	11,365,159.99

As shown in Table 5, the highest number of animals is found in İdil district. The higher the number of animals, the higher the amount of biogas produced and the higher the electricity capacity. If animal manure is not handled properly, Idil is the district where the most carbon emissions will occur. The district with the lowest number of animals is Beytüşşebap. Therefore, the amount of biogas and electricity produced is lower than in other districts.

In terms of reducing CO_2 emissions, different sustainable sources such as hydroelectricity and solar energy are used in Sirnak. However, one of the most important production areas that stands out for Sirnak is livestock, and the fact that the waste obtained from this is an important energy input makes biogas more advantageous than other available alternatives. Furthermore, when all social, technical, geographical, and economic factors of Sirnak are taken into account, it could be faster than others to utilize this existing potential in Sirnak for energy production and CO_2 emission reduction. In addition, with the expected increase in support for livestock in recent years, more and more animal waste will be generated and it is important to convert it into biogas in order to reduce its environmental damage and turn it into useful products.

Livestock breeding investments will come to the forefront in Sirnak with the livestock breeding model that will reduce environmental impacts with biogas production. The conversion of animal wastes into organic fertilizer will not only provide environmental gain but also add value to the national economy. These gains will contribute not only to livestock and energy but also to sustainable agriculture with the use of organic fertilizers, thus preventing agricultural emissions and damage to the soil. It will be possible to realize environmentally friendly, modern, and efficient livestock, agriculture, and energy activities in line with the concept of a "sustainable economy" in the region. This will pave the way for economic development that is ecologically, has a high profit margin, and is culturally compatible with the region. This will pave the way for the activities of a large group of individuals or businesses in agriculture and livestock in Sirnak and its districts. On the other hand, this could be an encouraging example for the implementation of rural livestock, agriculture, environment, and energy development goals at the national level.

IV. CONCLUSIONS

As a result of agricultural policies and targets, together with the suitability of geographical conditions, there is a significant livestock potential in Sirnak, which leads to significant amount of organic waste production. The results of the study indicate that the conversion of animal wastes with biogas technology in the selected city can be an important sustainable energy production potential for this developing region. It is also seen that with this realized transformation, it is also possible to provide an advantage in terms of CO_2 emissions, and a reduction can be achieved. With this study, it is given that the total animal waste produced from animals in Sirnak for 2022 is approximately 24.28 Mt. The total biogas potential produced from these animal wastes is 23.445 million m^3 $year^{-1}$, and the heating value and electricity generation potential equivalents are 550,969,004.9 MJ $year^{-1}$ and 44,238,955.45 kWh $year^{-1}$, respectively. On the other hand, the determination that a reduction in total CO_2 emissions by 209,809,870 kg CO_2 $year^{-1}$ can be achieved indicates a significant environmental gain. This study proves that animal wastes are an economic, clean, and promising energy raw material that can be sustainably utilized for biogas production and electricity generation in Sirnak. The results of this study can be used as a reference for identifying alternative project locations urgently, as it is predicted that waste will increase with increasing livestock support. It will be possible to contribute to emission reduction and energy supply by using the waste that may increase as a sustainable energy input without causing more CO_2 emissions. This study also coincides with the objectives of utilizing animal wastes for sustainable energy production in the development goals of agriculture and livestock in Turkey.

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