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Investigation of Biogas Production Potential from Livestock Manure by Anaerobic Digestion in Bingöl Province

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Alternative energy, Anaerobic digestion, Organic waste, Animal feces, Energy of household appliances

Abstract: Biogas is one of the sustained alternative energy sources. The annual biogas potential of Bingöl province was calculated according to the data of bovine, ovine and poultry animals between 2015-2020 years which were obtained from the Turkish Statistical Institute (TSI). In addition, liquid and available manure amount, biogas potential, electrical energy and heat energy amounts were determined according to the animal data of the districts in Bingöl province for 2020. It is estimated that the biogas energy potential between 2015-2020 years with 39.02 million m^3 will be the most in 2018, with 36.1 m^3 the least in 2019 and 36.5 million m^3 in 2020. In 2020, the biogas energy potential of the districts were found among; 263 thousand m^3-12.65 million m^3. It is clear that in Bingöl province in 2020 from a total number of 5694302 livestock, 865202 of which are bovine and ovine that approximately 754 thousand tons of utilizable manure, 36.5 million m^3 biogas, 171.4 GWh electrical energy and 171449*10^6 kcal m^{-3} heat energy can be obtained. A facility to be established in Bingöl will enable to increase the use of renewable energy sources, decrease methane gas emissions and meet energy needs of farmers or householders.

Bingöl İli Hayvancılık Gübresinden Anaerobik Çürütme ile Biyogaz Üretim Potansiyelinin Araştırılması

Anahtar Kelimeler
Alternatif enerji, Anaerobik çürüme, Organik atık, Hayvan gübresi, Ev aletleri enerjisi

Öz: Biyogaz, sürekliliği olan alternatif enerji kaynaklarından biridir. Türkiye İstatistik Kurumu (TÜİK)'ndan alınan Bingöl iline ait 2015-2020 yılları arasındaki büyükbaş, küçükbaş ve kanatlı hayvan sayıları verilerine göre yıllık biyogaz potansiyeli hesaplanmıştır. Ayrıca, Bingöl ilinde bulunan ilçelerin 2020 yılı hayvan verilerine göre yaş ve kullanılabilir gübre miktarı, biyogaz potansiyeli, elektrik enerjisi ve ısı enerjisi miktarları belirlenmiştir. Elde edilen verilere göre, 2015-2020 yılları arasında biyogaz enerjisi potansiyelinin 39.02 milyon m^3 ile en fazla 2018 yılında, 36.1 m^3 ile en az 2019 yılında, 2020 yılında ise 36.5 milyon m^3 olabileceği görülmüştür. 2020 yılında Bingöl ilçelerindeki biyogaz enerjisi potansiyeli 263 bin m^3 - 12.65 milyon m^3 arasında değişmiştir. 2020 yılı içerisinde Bingöl ilindeki 865202'si büyükbaş ve küçükbaş olmak üzere toplam 5694302 hayvandan, yaklaşık 754 bin ton kullanılabilir gübre, 36.5 milyon m^3 biyogaz, 171.4 GWh elektrik enerjisi ve 171449*10^6 kcal m^{-3} ısı enerjisi elde edilebilecektir. Bingöl'de kurulacak biyogaz enerji üretim tesisleri, yenilenebilir enerji kaynaklarının kullanımının artırılmasına, metan gazı emisyonlarının azaltılmasına, çiftçilerin veya hanelerin bazı enerji ihtiyaçlarının karşılanmasına olanak sağlayacaktır.

1. INTRODUCTION

Depending on population growth and industrial development, energy demand is constantly increasing. The current amount of energy has become unable to meet this demand. This situation causes a continuous increase in energy prices. In addition, due to limited fossil fuel reserves, there will be difficulties in meeting energy needs in the coming years. Therefore, the demand for new and renewable energy sources has been increasing rapidly in the world as well as in Turkey in recent years, and many studies have been carried out seriously. Since using of renewable energy sources, there has been less damage to the nature and the use of fossil fuels is reduced [1, 2].

Global warming, which is one of the serious problems of nowadays, will have negative effects on our world in the future. Global warming and climate change occur with the increase of greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (NO) and water vapor (H_2O)). The most serious reason for climate change is the uncontrolled increase in the amount of CO_2 in nature. Population growth have led to, the decrease in green areas, the increase in fossil fuel-powered motor vehicles and consequently increase in the amount of CO_2 released into the nature. This problem make policies eager to take an action against CO_2 amount globally. Renewable energy sources play the most important role in reducing the CO_2 emissions [3, 4]. The energy obtained from organic wastes is more advantageous than renewable energy sources such as solar, wind and geothermal. Because these wastes has continuity. Therefore, this energy source will be one of the most common renewable energy sources in the future. Biogas production from organic solid wastes is obtained by anaerobic digestion (AD), which is one of the most widely used and traditional biochemical methods, as shown in Figure 1. In addition, the conversion of AD organic wastes to biogas is the most preferred biotechnological method [5, 6, 7].

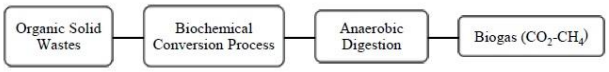

Figure 1. Waste recycling technologies [7].

Anaerobic digestion is a biological process in which anaerobic bacteria decompose organic matter and produce biogas in conditions with little or no oxygen. During the AD, nutrients are retained and digestion residues are made suitable to become an organic fertilizer that can replace mineral fertilizers that require fossil energy [8]. The main by-product of AD is the digested solid fraction, which is rich in nitrogen (N) content and can be used as fertilizer. As a result of AD process, the significant methane emission caused by the uncontrolled decomposition of organic waste into the atmosphere will be stopped and the emission of methane gas, which is 25 times more effective in retaining heat in the atmosphere than carbon dioxide, will be trapped [9, 10]. Anaerobic digestion is possible in principle at temperatures between 3 °C and about 70 °C. The differentiation generally varies between three temperature ranges respectively: the psychrophilic temperature is below 20 °C, the mesophilic temperature is between 20 °C and 40 °C, and the thermophilic temperature is above 40 °C [11-13].

Since the interest in biogas potential obtained from animal manure has increased in recent years, biogas potential has been investigated for many provinces in Turkey as well. These provinces and studies are following as; Adana [14, 15], Ankara [16], Bitlis [17], Burdur [18], Bursa [19], Elazig [20], Erzincan [21], Hatay [22], Isparta [23], Kahramanmaraş [24], Kayseri [25], Muş [26], Tekirdağ [27], Yozgat [28]. Organic matter which is consisted in animal manure are fermented and digested by microorganisms (bacteria, protozoa and archaea) under anaerobic conditions and produce CH_4 in 3 stages. Organic wastes (carbohydrates, proteins and fats) undergo fermentation by micro-organisms and decompose into hydrogen, carbon dioxide, acetic acid, butyric acid, propionic acid, various alcohols and other compounds. In the second stage H_2, CO_2 and acetic acid are reacted by acetogenic bacteria. And in the final stage, methane and carbon dioxide gases are formed by methanogenic bacteria [12].

Biogas energy is a variable renewable that can be used to replace fossil fuels in energy and heat generation and can also be converted into transportation fuel after its purification. It is rich in methane and carbon dioxide can replace natural gas as a raw material for the production of other biochemicals [29, 30]. In addition, it has been preferred as one of the most energy productive and environmentally advantageous technologies for bioenergy production [31].

Biogas is a fuel gas which containing 50-70% methane (CH_4), 25-50% carbon dioxide (CO_2), 1-5% hydrogen (H_2), 0.3-3% nitrogen (N_2), traces of ammonia (NH_3) and hydrogen sulfide (H_2S) [32-34]. It can be produced from raw materials such as agricultural wastes, animal manure, municipal wastes, plant materials, sewages, green wastes or food wastes. And it is a renewable energy source and in mostly exerts a very small carbon footprint. It can be also used as a fuel to generate heat and electricity, or it can be injected into the gas grid as biomethane. This energy production creates more employment and livelihood in rural areas. It also plays a major role in reducing important greenhouse gases such as CO_2 and CH_4 [35]. By converting these two gases into biogas production instead of dispersing them into the atmosphere, the energy we need will be met without harming the environment, thus contributing to the reduction of global warming. The use of biogas energy may become advantageous when designing sustainable energy solutions in industrial applications, farms and households as seen in developing countries [31, 36].

The production of biogas is a process of gas formation as a result of biological decomposition of organic materials in anaerobic conditions. In a biogas production facility, livestock manure is diluted with water and transferred to an on–off tank. AD is carried out by bacteria, protozoa and archaea (microbiological flora) which are in different amount and in the structure of animal manure. Biogas is formed 10-15 days after the filling of the tank and this

production continues for about 60 days and then decreases. As a result of AD, gases accumulate in the upper part of the tank and organic fertilizers in the lower parts [12, 16].

In this study, the biogas potential that can be obtained from livestock manure in Bingöl province and its districts according to 2020 datas were determined. In addition, the biogas potential of Bingöl province the years between 2015-2020 was also calculated. The data of this study were obtained from Bingöl Provincial Directorate of Agriculture Forestry and Turkish Statistical Institute [38, 39]. By determining the number of animals in the provinces and districts, the amount of livestock manure that can be obtained according to the animal type was calculated. Hence the annual biogas and electricity potential of Bingöl province and energy savings were calculated theoretically.

2. MATERIALS AND METHODS

2.1. Geographical Characteristics of Bingöl Province

This study includes the borders of Bingöl province, which is located between 41-20° and 39-56° east longitudes and 39-31° and 36-28° north latitudes. Bingöl province, is located in the Eastern Anatolia Region of Turkey, has a total population of 281768, 165867 of which are in the central district, according to 2020 TSI datas. And that means 67.7% of the population lives in central district [40]. It has an area of 8004 km^2 , of which 3 million 137 thousand 710 decares (approximately 42% of the surface area) covers pastureland and 300 thousand decares of agricultural land [39]. As seen in Figure 2, Bingöl province consists of 8 districts in total namely; Adaklı, Genç, Karlıova, Kiğı, Center, Solhan, Yayladere and Yedisu. Livelihood of the province is animal husbandry. Locals earn a good income from the beekeeping sector with the sale of livestock and dairy products.

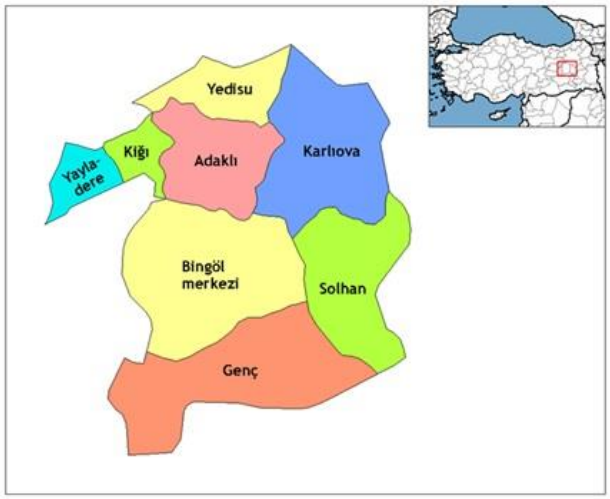

Figure 2. Geographic map of Bingöl province [40].

2.2. Animal Data

The animal data of Bingöl province for the year 2020 which is obtained from the Ministry of Agriculture and Forestry are given in Table 1. The number of animals was determined, based on this informations. The total number of ovine make up sheep with 73.4% and cattle make up with 99.95% of bovine. According to TSI datas, in 2020 when animal husbandry was the highest numbers, the number of bovine decreased compared to the previous year, while the number of ovine and poultry increased compared to the previous years (Table 1). As it is clear that in Table 1, poultry constitute the majority of the number of animals in the province [39].

Table 1. The total number of livestocks in Bingöl province between 2015–2020 [38, 39].

Years	Bovine	Ovine	Poultry	Total
2015	166695	817548	904404	1888647
2016	165849	859668	1832055	2857572
2017	182892	783043	2624772	3590707
2018	184670	792160	2582922	3559752
2019	197689	635603	2847660	3680952
2020	144550	720652	4829100	5694302

The district where sheep and goats breeding is carried out the most in 2020 is Karlıova with 348375 ovine numbers as mentioned in Figure 3. Karlıova is followed by Solhan with 147291 sheep and then Central districts with 101198 sheep and goats. The majority of bovine breeding is carried out in Bingöl central (60087), Karlıova (20986) and Solhan (19984) districts, respectively (Figure 3). Since the majority of poultry are in the Central district, it is considered the place where animal husbandry is most engaged in terms of the total number of bovine, ovine and poultry, with approximately 4.7 million animals [38]. Poultry breeding is more preferred in areas close to transit centers where transportation is easy, rather than rural areas [41]. Therefore, the number of poultry in the central district of Bingöl has a considerably higher number than other districts. It is also reported that the reason for the huge differences in the number of total animals by years is due to the grants given by the Ministry of Agriculture and Forestry in the relevant years [39]. Animal husbandry is carried out the least in Yayladere district with a total number of 8845 animals, including bovine, ovine and poultry. It is considered that the reason Kiğı, Yayladere and Yedisu total animal assets are less than other districts is to be proportional to the number of populations they have. In addition, the fact that there is such a great number of sheep and goats in Karlıova district can be shown among the results that the geographical structure of the district is more suitable for these type of animal breeding and the improvement projects carried out by the public [42].

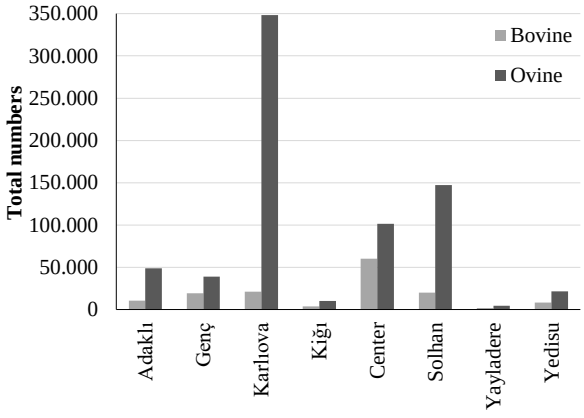

Figure 3. Ruminants distribution by districts in 2020.

The average accepted values of calculation the biogas energy potential are given in Table 2 below [20, 43]. It is accepted that approximately 1:3 of the manure obtained from animal wastes are destroyed by mixing with nature in the pastures, and only 2:3 is usable [20]. In the calculation; equations given in between Eq. 1-11 below are used [14-28].

Table 2. Acceptances for biogas energy potential [16, 37, 43, 44].

Animal Species	Annual Manure (tons an^{-1})	Biogas obtained from 1 tons of manure (m^3)
Bovine	3.6 t	33 m^3
Ovine	0.7 t	58 m^3
Poultry	0.022 t	78 m^3

Annual amount of liquid manure that animals can produce;

$$M_b = n*3.6 \text{ tons an.}^{-1} \quad (1)$$

$$M_o = n*0.7 \text{ tons an.}^{-1} \quad (2)$$

$$M_p = n*0.022 \text{ tons an.}^{-1} \quad (3)$$

$$M_t = M_b + M_o + M_p \text{ tons an.}^{-1} \quad (4)$$

In the equations; *n:* Number of animals, M_b : Amount of liquid manure obtained from bovine animals, M_o : Amount of liquid manure obtained from ovine animals, M_p : Amount of liquid manure obtained from poultry, M_t : It expresses the total amount of liquid manure. Usable amount of liquid manure. *(M_u)*;

$$M_u = M_t*2*3^{-1} \text{ tons an.}^{-1} \quad (5)$$

Potential biogas energy *(PB_e)*;

$$PB_{eb} = M_b *2*3^{-1}*33 \text{ m}^3 \text{ an.}^{-1} \quad (6)$$

$$PB_{eo} = M_o*2*3^{-1}*58 \text{ m}^3 \text{ an.}^{-1} \quad (7)$$

$$PB_{ep} = M_p*2*3^{-1}*78 \text{ m}^3 \text{ an.}^{-1} \quad (8)$$

$$PB_{et} = PB_{eb} + PB_{eo} + PB_{ep} \text{ m}^3 \text{ an.}^{-1} \quad (9)$$

In the equations given above; PB_{eb}*:* Biogas energy obtained from bovine, PB_{eo}*:* Biogas energy obtained from ovine, PB_{ep}*:* It refers to biogas energy obtained from poultry and PB_{et}*:* Total potential biogas energy.

Total potential electrical energy (PEE_t);

$$PEE_t = PB_{et} *4.70 \text{ kWh an.}^{-1} \quad (10)$$

Total potential thermal energy (TPT_e) is between values given below [14-28];

$$TPT_e = PB_{et} *4700 \text{ kcal } m^{-3} - 5700 \text{ kcal } m^{-3} \text{ (approximately)} \quad (11)$$

3. RESULTS AND DISCUSSION

3.1. Biogas Energy

The biogas potential according to the amount of manure that can be obtained from bovine, ovine and poultry between 2015-2020 in Bingöl province is given in Figure 4. It is seen in Figure 4 that the biogas production potential between these years could be at most in 2018 with 39.02 million m^3 and at least in 2019 with 36.1 million m^3.

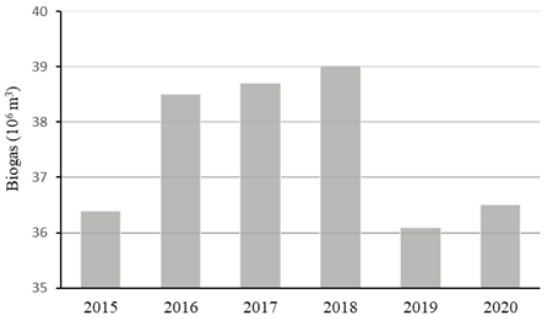

Figure 4. Distribution of biogas production potential of Bingöl province by years.

In 2020, approximately 36.5 million m^3 of biogas will be obtained from a total of 5694302 animal population. In Figure 5 below is given, the percentage (%) potential distribution of biogas that can be produced in the central and the other districts of Bingöl province in 2020. The majority of biogas energy in Bingöl province, 34.68% can be obtained from the Central, 30.73% Karlıova and 15.39% Solhan districts (Figure 5). The minimum biogas production potential in the province can be obtained in Yayladere district with 0.72% (Figure 5).

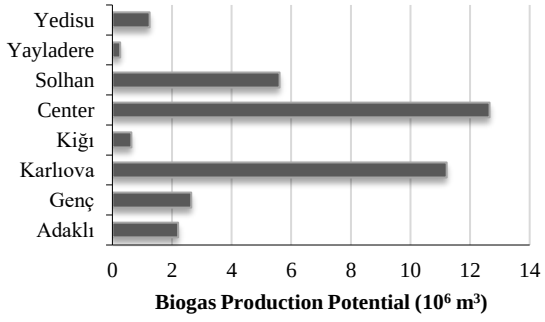

Figure 5. Distribution of biogas production potential by districts in 2020.

The Central district with a total number of 4665425 animals, including 60087 bovine, 101198 ovine and 4504140 poultry is the highest in number of animals. According to datas $12650.7*10^3$ m^3 of biogas energy is generated from $257.5*10^3$ tons of usable manure per year that can be obtained from the central district. In addition, the obtained biogas energy is equivalent to $59458.4*10^3$ kWh electrical energy or $59.5*10^9$ kcal thermal energy (Table 3).

Table 3. Theoretical biogas potential produced by animal species in the province and districts of Bingöl in 2020.

Districs	Num. of Animals	Usable Manure Amount	Biogas Potential	Electrical Energy	Heat Energy
	Head	10^3 t an^{-1}	10^3 m^3 an^{-1}	10^3 kWh an^{-1}	10^9 kcal m^{-3}
Adaklı	111356	48.5	2206.2	10369.2	10.4
Genç	107918	65.4	2647.4	12442.8	12.4
Karlıova	473047	214.5	11210	52687.3	52.7
Kiğı	80516	14.4	637.1	2994.7	2.9
Center	4665425	257.5	12650.7	59458.4	59.5
Solhan	204877	117.2	5612.4	26378.4	26.4
Yayladere	8845	6.4	262.9	1236	1.2
Yedisu	42318	30.1	1251.4	5881.9	5.9
Total	**5694302**	**754**	**36478.1**	**171448.7**	**171.4**

3.2. Energy Conversions

Bingöl with its all districts have a potential of 754051.1 tons liquid manure production per year from bovine, ovine and poultry. The comparison with other fuel types of 36478.5*10^3 m^3 biogas which can be obtained from liquid manure in 2020 was made based on the following assumptions. According to the assumptions stated below, approximately 171.4 GWh of electrical energy and 171449-207927.4 x106 kcal m^{-3} of heat energy are revealed from 36478.5*10^3 m^3 of biogas (Figure 6). The energy equivalents obtained from 1 m^3 biogas are given in Table 4 below.

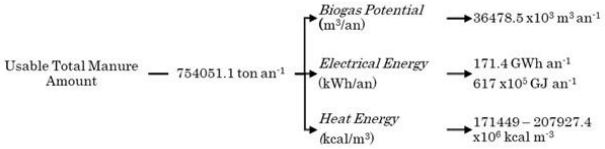

Figure 6. Energy conversions according to the total amount of biogas in 2020.

Table 4. The energy equivalents obtained from 1 m^3 of biogas [16, 20, 37, 43-46]:

1 m^3 biogas	4.70 kWh electrical energy
	4.700 – 5.700 kcal m^{-3} heat energy
	0.43 kg butane gas
	12.3 kg turd
	3.47 kg wood
	0.8 L gasoline
	0.63 L gas oil
	1.46 kg charcoal energy

3.3. Electrical Energy

According to our calcultions a house of 4 people consumes approximately 21.3 kWh electrical energy per day and 72.4 kWh per week, as shown in Table 5 below. And this consumption reaches about 7774.5 kWh per year. The electrical energy that can be obtained from animal manure in Bingöl province is 171448.7*10^3 kWh $year^{-1}$ according to 2020 datas. This amount of electrical energy that can be obtained annually from biogas energy in Bingöl, has the power to meet the electricity approximate of 22052 households.

According to the January 2021 residential tariffs, 1 kWh of electricity is 0.7102 TL (Turkish lira) taxes included [47]. Accordingly, the annual electricity bill of a household is approximately 5521.4 TL. Thanks to biogas energy, Bingöl province has the potential to meet 121.7 million TL the electricity bill of per year.

Table 5. Electricity consumption of a household per week.

Household Appliances	P	Num.	DWT	DC	NWU	WC
	Watt-hour	1-10	Hours	Watt-hour	1-10	Watt-hour
Refrigerator (A+)	46	1	24	1104	7	7728
Dishwasher (A+)	1800	1	2	3600	5	18000
Wash. Machine (A+)	800	1	2	1600	3	4800
LCD TV (A+)	65	1	5	325	7	2275
Iron	2600	1	2	5200	2	10400
Vacumm Cleaner	2000	1	2	4000	3	12000
Bakery	2500	1	1.5	3750	2	7500
Led Lamp	12	5	5	300	7	2100
Kettle	2200	1	0.2	440	7	3080
Toast Machine	2000	1	0.2	400	3	1200
Microwave Oven	800	1	0.1	80	7	560
Laptop	90	1	3	270	7	1890
Hair Dryer	1300	1	0.2	260	3	780
Other (Charging etc.)	10	1	2	20	7	140
Total				**21349**		**72453**

P: Power, DWT: Daily working time, DC:Daily consumption, NWU: Number of weekly use, WC: Weekly consumption

4. CONCLUSIONS

Global warming, which has been caused by the accumulation of greenhouse gases in the atmosphere in recent years, has become the biggest problem of nowadays [48, 49]. This will cause serious drought and water problems in the future. In order to meet the needs of the increasing the world population, the demand for agriculture and industry will increase and the number of animals will need to increase as well. This will accelerate global warming by increasing the amount of methane and carbon dioxide gas day by day. In order to reduce global warming, the use of alternative energy sources should be risen. In particular, studies on biogas energy should be focused. Moreover, continuity should be ensured in the source of raw materials in biogas plants.

Biogas is an alternative energy source to meet the increasing energy needs in the world as well as in Turkey. Biogas production will reduce the use of fossil fuels and reduce CO_2 emissions. Biogas is a combustible gas that is produced from waste materials under anaerobic conditions by AD method, similar to natural gas and mostly consisting of CH_4 and CO_2.

In this study, the amount of manure that can be obtained from bovine, ovine and poultry in Bingöl province and accordingly the biogas production potential was determined. According to 2015-2020 year data, depending on the total number of animals in Bingöl province, the highest biogas production was obtained in 2018 with 39.02 million m^3. As can be seen in 2020 data, the amount of manure that can be obtained from total of 5694302 animals (bovine, ovine and poultry) in Bingöl has the potential to produce approximately 36.5 million m^3 of biogas energy. The total biogas production potential of the province is max. as following respectively; Central district (12.6 million m^3), Karlıova (11.2 million m^3) and Solhan (5.6 million m^3). The min. biogas production potential has been determined in Yayladere with approximately 263 thousand m^3. According to 2020 data (bovine, ovine and poultry) in Bingöl province, 36.5 million m^3 of biogas can be produced with 754051.1 tons of annually usable manure. In addition, this 36.5 million m^3 of biogas has been determined that it is equivalent to 171.4 GWh of electrical energy, 171449 million kcal m^{-3} of heat energy, 126.6 kg of wood and 29.2 million liters of gasoline.

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