*Pol. J. Environ. Stud. Vol. 32, No. 4 (2023), 3053-3062*
DOI: *10.15244/pjoes/162671* ONLINE PUBLICATION DATE: 2023-05-10

*Original Research*

# Analysis of Biogas Sources in the Context of Renewable Energy; Erzurum Province as an Example

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*Received: 23 December 2022*
*Accepted: 27 March 2023*

**Abstract**

Energy consumption is an essential criterion in determining countries' development levels in light of developments in technology and industry. Fossil fuels in the world are scarce and available only in specific locations. Using fossil fuels significantly increases the emission of harmful gases and particles into the atmosphere, which causes many environmental problems. Erzurum has excellent potential in terms of animal, vegetable, and urban organic wastes that constitute a source for bioenergy production. Within the scope of this study, in the light of the data obtained from the Turkish Statistical Institute (TSI), the amount of biogas that can be generated from the potential animal wastes of Erzurum province between 2002-2021 was calculated. The amount of energy that can be obtained from this biogas has been determined, and the ratio of the energy that can be produced to electricity consumption and its benefit in reducing the amount of carbon dioxide to be given to the atmosphere have been examined. As a result, the amount of collectible manure was figured out as 9.582.132,01 tons/year. It has been found that the amount of potential energy obtained from this amount of animal waste would meet the 96% of annual electricity consumption of Erzurum province. The increase in livestock activities and investments in Erzurum, especially in the last two decades, shows that the biogas energy produced from animal waste is sustainable. It has been calculated that the emission of a significant amount of carbon dioxide into the atmosphere can be reduced thanks to the electrical energy produced by methane gas. In addition, it has been concluded that the wastes generated after energy production from biogas facilities are significant in terms of being usable as manure in agricultural areas, contributing to employment and rural development, and keeping the environment clean.

**Keywords**: renewable energy, biomass, biogas, Erzurum

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## Introduction

Today, energy has become an indispensable resource in all areas of our lives in many sectors, such as industry, transportation, health, heating, etc. The need for energy is increasing day by day. Energy is divided into renewable and non-renewable in terms of the source from which it is obtained. Fossil fuels like oil, coal, natural gas, etc., are defined as non-renewable energy sources [1-3]. Energy sources such as hydro, solar, wind, biomass, and geothermal are renewable. In today's world, countries obtain most of the energy they use from fossil fuels. However, the reserves of fossil fuels are scarce. It is reported that oil will run out in about 50 years, natural gas in 70 years, and coal in 150 years [4-6]. In addition, the use of fossil fuels in energy production causes major environmental problems [7]. Therefore, countries have turned to renewable and clean energy sources to maintain their energy supplies. Developed countries have recently started many projects and studies to ensure energy continuity with hydroelectric, solar, wind, geothermal, and biomass energy resources [8].

## Literature Review

Biogas is a clean and sustainable energy source. It is a flammable gas that is lighter than air, colorless, odorless, and contains large amounts of methane and carbon dioxide, which is produced by the decomposition of wastes used as raw materials in an airless environment by various bacterial groups. Biogas, which is an economic resource, has a very important potential for rural development. [8]. Biogas, which is a very economical resource, also contains an important potential for rural development.

Biomass energy is one of the renewable energy sources that has gained importance in recent years. Benefiting from biomass energy, in addition to benefiting the energy supply, makes significant contributions to the prevention of environmental pollution and the reduction of the greenhouse effect.

The development levels of countries are similar to the sustainable use of natural resources. Even if underdeveloped countries have rich natural resources, they realize the use of natural resources by methods far from sustainable utilization due to technological impossibilities.

Energy has become one of the most vital needs for humanity today. Each production requires a type of energy. The development of technologies due to the changing world has mandated the use of the natural resources, energies harmless to the environment and natural resources have become important. In order to meet the growing energy needs of the world, many countries tend to use renewable energy sources instead of depletable fossil fuels that cause global warming [9, 10].

Many European countries have modified their regulations to utilize bio-electricity in their energy sectors. For instance, Norway derives virtually 100% of its electricity from renewable sources. As of 2016, the total installed biomass power plants were about 3600 with the capacity of 51 GW. bioelectricity supplied from renewable energy accounts for around 26,5% of total electricity in the world, of which only 2,2% is provided by biomass [11].

Biomass wastes used as raw materials in biogas production are examined under three headings;

Animal waste; Manures of farm animals (cattle, sheep, goat, chicken, horse) are wastes accumulated in slaughterhouses and animal product processing facilities.

Vegetable wastes: Agricultural products grown for bioenergy, wastes from agricultural production, forest, park, and garden wastes, production wastes from agricultural product processing facilities, and vegetable biomass wastes are some examples of vegetable wastes.

Organic urban and industrial wastes: Organic urban and industrial wastes [8, 12].

One of the world's most important debates in recent years is the effect of global climate change on water resources. This threatens ecological stability, human and environmental health [13].

The negative effects of these wastes on the environment, animal waste from livestock production facilities is often applied to land without prior treatment. Biosolids (treated municipal wastewater sludge) from large wastewater facilities in urban areas are often transported and applied to land in rural areas. This situation introduces a potential for risk of human exposure to waterborne contaminants such as human and zoonotic pathogens originating from manure, biosolids, and leaking septic systems [14].

The heat, electricity, gas, and liquid fuels obtained by the classical and modern processing of these resources are called as biomass energy [15-18]. Fuel obtained from biomass sources is defined as biogas. The main benefits of biogas energy are as follows [19-24];

- It is a clean energy source.
- It can be characterized as an environmentally friendly and inexpensive source of energy and manure.
- It ensures the recycling of waste.
- Organic manure formed by biogas production, weed seeds in animal manure lose their germination feature.
- As a result of biogas production, the undesirable odor in animal manure is wholly eliminated.
- A valuable organic manure output occurs as a result of biogas production.
- Foreign components in animal sources threaten groundwater. These threats are eliminated by biogas production. Because biogas produced from organic components has a very clean side-product.
- Biogas is a versatile energy source and can be used for both heating and electricity generation. Biogas

containing 95% CH4 can be used instead of natural gas.
- Biogas can be easily used by making pressure adjustments in the nozzle diameters of stoves operating with liquefied petroleum gas.

According to literature research: Biogas facilities can be used as exemplary regions in terms of both energy production and environmental protection in regions such as Afyon, Kayseri, Çorum, Manyas, Bursa, Erzurum, Kars, Niğde, Ağrı, Edirne, Tekirdağ where both cattle and poultry production are concentrated [25].

In this study, the amount of energy that can be produced from the biogas obtained from the wastes of bovine, ovine, poultry, and equidae in Erzurum was determined. In addition, the ratio of this energy to electricity consumption in Erzurum and its benefits for $CO_2$ emissions were examined.

## Materials and Methods

The primary material of the study includes cattle, ovine, poultry, and equidae animals in Erzurum province between 2002-2021 (Fig. 1). The data on the number of animals in the city were obtained from the Turkish Statistical Institute (TSI). Although it is not possible to collect animal waste altogether, the energy amount of methane gas was calculated by using the biogas potential in methane, the average amount of manure that can be collected per animal, the amount of solid matter (SM), the rate of solid matter in manure, the amount of volatile solids (VS) and volatile solids in manure.

The total amount of wet manure that animals can produce annually is found by the equation of $M_{AWM} = M_{AM}*N*365$. The equation expansion is; $M_{AWM}$ represents the total amount of manure that animals can produce per year (kg/year), $M_{AM}$ represents the amount of manure an animal can produce in a year (kg/year) and $S$ is the number of animals. The equation of $M_{AVWM}$ finds the annual amount of collectible valuable wet manure produced by animals $M_{AVWM} = M_{AWM}*C$. $M_{AVWM}$ refers to the annual amount of collectible beneficial wet manure (kg/year), $M_{AWM}$ refers to the total amount of manure that animals can produce per year (kg/year) and $C$ refers to the amount of beneficial collectible manure (%). The amount of solid matter in the amount of wet manure produced is found by the equation of $M_{SM} = M_{AVWM}*SM$. $M_{SM}$ refers to the total amount of solid matter (kg/year) in the annual amount of collectible beneficial manure produced by animals, and $SM$ refers to the solid matter ratio (%) in wet manure [26].

The amount of volatile solids in the solid is found by the equation $M_{VS} = M_{SM}*VS$. $M_{VS}$ expresses the annual total amount of volatile solids (kg/year) in the wet manure produced by the animals, and $VS$ expresses the percentage of volatile solids in the amount of solid matter (%). The total annual amount of methane that can be produced from the collectible, beneficial manure is found by the equation $M_{METHANE} = M_{VS}*MO$. $M_{METHANE}$ is the total annual amount of methane that can be produced from the collectible useful manure produced by animals ($m^3$ $CH_4$/year), $MO$ is the amount of methane produced from 1 kg of volatile solids. Suppose the methane content of the produced biogas is 60%. In that case, the energy value of the biogas produced

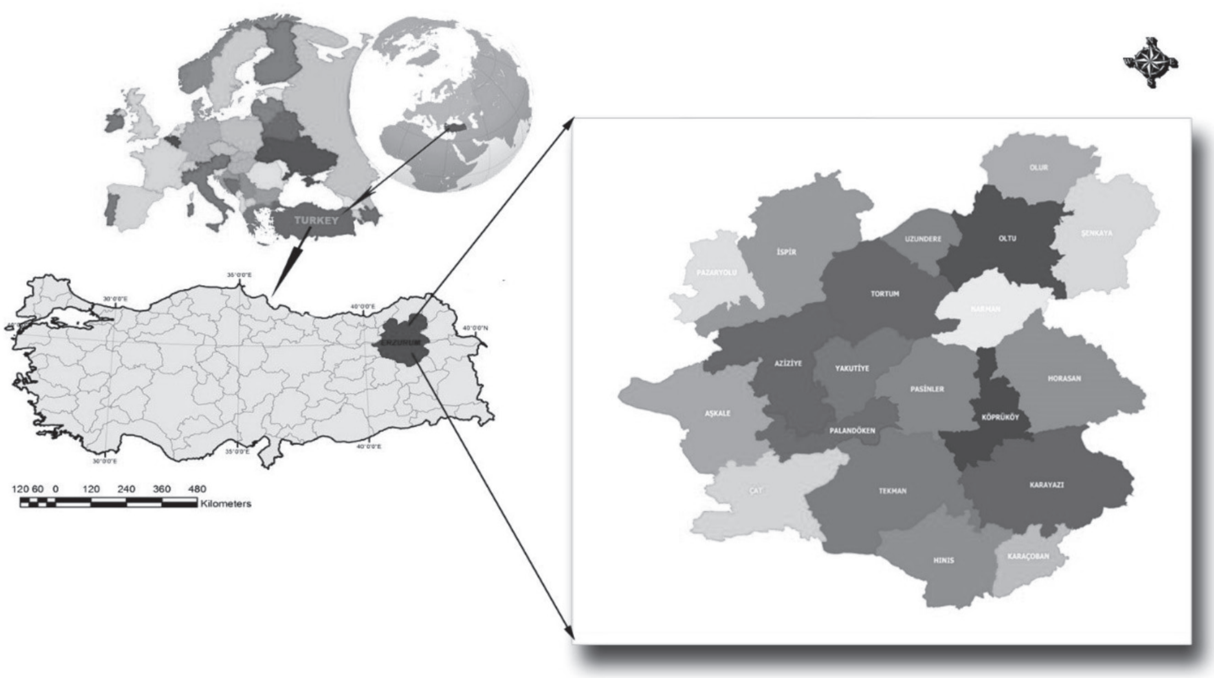


Fig. 1. Location map.

from animal manure can be calculated by taking the energy value of 22,7 MJ/Nm³ and the value of the methane gas as 36 MJ/Nm³. The amount of energy that can be produced from methane gas is found by the equation $Q = M_{METHANE} * H_{METHANE}$. $Q$ is the energy equivalent of methane gas that can be produced annually (MJ/year), and $H_{METHANE}$ is the heating value of methane, which is taken as 36 MJ/m³. The amount of electricity to be obtained by generating electrical energy from methane gas with an internal combustion engine is found by the equation $E = M_{METHANE} * \eta e * W$. $E$ is the annual electricity production of the internal combustion engine (MWhe/year), Ƞe is the electrical efficiency of the internal combustion engine (35%) and W is the energy value of methane gas in kWh, and is taken as 10 kWh/m³ [26, 27].

## Results and Discussion

Biogas is a flammable gas that is lighter than air, colorless, odorless, and contains large amounts of methane and carbon dioxide, which is produced by the decomposition of biomass resources by various bacterial groups in an airless environment [19]. Biogas, which is close to natural gas in terms of energy value, is crucial for developing rural areas where livestock activities are carried out. Within the scope of the study, animal wastes, one of the three primary sources of biogas production, were examined.

In biogas production, the amount and efficiency of manure vary according to animal species. Table 1 shows the acceptable amount and properties of manures in the biogas process according to animal species.

The last ten-year animal number data of Erzurum province between 2002-2021 were obtained from Turkish Statistical Institute (TSI). According to these data, when the animal existence of the province is examined, As of 2021, there are 858.506 cattle, 1.898 water ox, 809.771 sheep, 90.852 goats, 214.061 poultry and 8.545 equidae. Table 2. shows the animal assets of Erzurum province between 2002-2021 according to their species.

In the period between 2002-2021, when we examine the animal data in Erzurum province, the total animal population has increased yearly. In light of these data, it shows that the amount of animal waste needed in biogas production can be met by increasing in the coming years and that biogas production is sustainable with animal wastes.

### Biogas Potential in Erzurum Province

The amount of potential manure produced by the animals and the amount of manure obtained in the case of the collection is different. To explain with an example, Large-scale animal breeders have larger farms than rural farmers, and animals are fed without being taken to grazing areas such as meadows and pastures. On the other hand, animal owners in rural areas feed their animals, generally small cattle, in fields such as pastures and meadows, and the manures in these areas cannot be collected. However, grazing areas such as pastures and meadows are used only for some months of the year. In short, how long the animals are kept indoors and how much of the manure they produce can be collected is an essential factors [28]. Table 3. shows the accepted values for calculating the amount of biogas, depending on the type of animals and considering the time they stay indoors.

Although it is impossible to collect animal waste completely, it is necessary to calculate the biogas potential in terms of methane gas and the energy amount of methane gas with more detailed data. In this part of the study, the energy amount of methane gas was calculated by using the data of the average amount of manure that can be collected per animal, Solid Matter Amount (SM), SM Ratio in Manure, Volatile Solids Amount (VS) and VS Ratio in Manure for 2021 in Erzurum.

Table 4. shows the amount of methane gas that Erzurum province can produce with animal stock in 2021, calculated with the values in Table 3. The manure harvestability they produce for cattle and water ox is 70%, and 13% for sheep and goats. Since sheep and goats are fed in pastures and grasslands, the manure

Table 1. Amount and properties of manure by animal species [8, 26, 28].

| Accepted Values For Calculatıng The Amount Of Biogas | | | | | |
|---|---|---|---|---|---|
| Anımal Breed | Daily Manure Production Per Animal | Collectible Useful Manure (C) | Solid Matter Ratio in Wet Manure (SM) | Volatile Solids Ratio in Solids (VS) | Methane Production (MO) |
| | kg/day-animal | % | % | % | $m^3CH_4$/kg-VS |
| Cattle | 43,00 | 70,00 | 17,27 | 83,36 | 0,18 |
| Water Ox | 43,00 | 70,00 | 17,27 | 83,36 | 0,18 |
| Sheep | 2,40 | 13,00 | 23,00 | 83,63 | 0,30 |
| Goat | 2,05 | 13,00 | 23,17 | 73,06 | 0,30 |
| Poultry | 0,19 | 66,00 | 20,00 | 77,27 | 0,35 |
| Equidae | 20,40 | 29,00 | 19,61 | 66,67 | 0,30 |

they produce stays in the land where they are grazed. The collectability of the manure is 29% in equidae and 66% in poultry. In light of these data, the total amount of manure that the livestock can produce in 2021 is 14.359.851,39 tons/year; the amount of collectible manure, that is, the manure that can be converted into biogas, is 9.582.132,01 tons/year. The total amount of solid matter (SM) in the total collectible manure is 1.661.338,87 tons/year. The total amount of volatile matter (VS) in the total solid matter is 1.384.015,20 tons/year. The largest share in the solid matter (SM) ratio in the total manure belongs to the cattle species with 98,05%. The volatile matter (VS) ratio in the solid matter (SM) ratio in the total manure is also 98,11% belonging to the cattle species.

Table 2. Animal Stock in Erzurum province between 2002-2021 [31].

| Animal Stock Between 2002-2021 in Erzurum Province | | | | | | |
|---|---|---|---|---|---|---|
| Year | Cattle | Water Ox | Sheep | Goat | Poultry | Equidae |
| 2002 | 556.087 | 2.308 | 747.857 | 82.421 | 631.356 | 19.179 |
| 2003 | 523.115 | 1.575 | 734.354 | 85.866 | 498.020 | 18.541 |
| 2004 | 538.652 | 1.504 | 763.800 | 85.346 | 596.640 | 18.526 |
| 2005 | 528.797 | 1.288 | 734.998 | 83.974 | 386.506 | 17.885 |
| 2006 | 534.302 | 1.086 | 746.934 | 82.613 | 337.479 | 17.552 |
| 2007 | 556.039 | 698 | 684.315 | 75.693 | 355.933 | 18.494 |
| 2008 | 528.969 | 807 | 590.964 | 60.289 | 391.517 | 15.286 |
| 2009 | 531.249 | 1.215 | 358.669 | 43.987 | 255.210 | 12.355 |
| 2010 | 536.982 | 1.032 | 457.159 | 39.191 | 225.957 | 13.094 |
| 2011 | 586.891 | 1.116 | 514.488 | 47.754 | 234.448 | 12.577 |
| 2012 | 623.869 | 1.113 | 514.413 | 60.070 | 226.761 | 12.161 |
| 2013 | 669.524 | 1.159 | 565.371 | 63.694 | 245.752 | 11.820 |
| 2014 | 654.568 | 1.268 | 633.390 | 84.453 | 183.107 | 10.976 |
| 2015 | 640.220 | 1.591 | 697.539 | 92.928 | 236.747 | 10.644 |
| 2016 | 649.473 | 1.490 | 617.266 | 88.687 | 174.203 | 10.485 |
| 2017 | 729.552 | 1.730 | 614.528 | 99.701 | 178.252 | 10.787 |
| 2018 | 767.121 | 1.844 | 649.716 | 97.017 | 189.135 | 10.613 |
| 2019 | 825.725 | 2.081 | 689.158 | 92.536 | 179.453 | 10.067 |
| 2020 | 866.891 | 2.118 | 799.154 | 105.433 | 181.504 | 8.983 |
| 2021 | 858.506 | 1.898 | 809.771 | 90.852 | 214.061 | 8.545 |

Table 3. Accepted values for calculating the amount of biogas [8, 26, 28].

| Accepted Values For Calculating The Amount Of Biogas | | | | | |
|---|---|---|---|---|---|
| Animal breed | Daily manure productıon per animal | Collectible useful manure (C) | Solid matter ratio in wet manure (SM) | Volatile solids ratio in solids (VS) | Methane productıon (MO) |
| | kg/day-animal | % | % | % | $m^3CH_4/kg$-VS |
| Cattle | 43,00 | 70,00 | 17,27 | 83,36 | 0,18 |
| Water Ox | 43,00 | 70,00 | 17,27 | 83,36 | 0,18 |
| Sheep | 2,40 | 13,00 | 23,00 | 83,63 | 0,30 |
| Goat | 2,05 | 13,00 | 23,17 | 73,06 | 0,30 |
| Poultry | 0,19 | 66,00 | 20,00 | 77,27 | 0,35 |
| Equidae | 20,40 | 29,00 | 19,61 | 66,67 | 0,30 |

Table 4. The amount of manure, SM and VS that can be collected by animal species in Erzurum province in 2021.

| Erzurum Province 2021 Collectible Manure by Animal Breed, SM Amount and VS Amount | | | | | | |
|---|---|---|---|---|---|---|
| Animal type | Number of animals in 2021 | Collectible useful manure amount (C) | Amount of solid material (SM) | SM ratio in manure | Amount of volatile solid material (VS) | VS rate in manure |
| | Number | Tone/year | Tone/year | % | Tone/year | % |
| Cattle | 858.506 | 9.431.976,17 | 1.628.902,28 | 98,05 | 1.357.852,94 | 98,11 |
| Water Ox | 1.898 | 20.852,38 | 3.601,21 | 0,22 | 3.001,96 | 0,22 |
| Sheep | 809.771 | 92.216,72 | 21.209,85 | 1,28 | 17.737,79 | 1,28 |
| Goat | 90.852 | 8.837,40 | 2.047,63 | 0,12 | 1.496,00 | 0,11 |
| Poultry | 214.061 | 9.797,79 | 1.959,56 | 0,12 | 1.514,15 | 0,11 |
| Equidae | 8.545 | 18.451,56 | 3.618,35 | 0,22 | 2.412,35 | 0,17 |
| Total | 1.983.633 | 9.582.132,01 | 1.661.338,87 | 100,00 | 1.384.015,20 | 100,00 |

Table 5. The amount of methane, energy, TOE and electricity that can be produced with animal waste in Erzurum province in 2021.

| Erzurum Province The Amount Of Methane, Energy, TOE And Electricity That Can Be Produced With The Animal Stock's Waste In 2021 | | | | | |
|---|---|---|---|---|---|
| Animal breed | Number of animals in 2021 | Methane production (MO) | Energy value | TOE energy | Electric energy |
| | Number | $m^3CH_4$/kg-SM | GJ/Year | TOE/Year | MWhe/Year |
| Cattle | 858.506 | 244.413.529,97 | 8.798.887,08 | 210.157,81 | 855.447,35 |
| Water Ox | 1.898 | 540.353,68 | 19.452,73 | 464,62 | 1.891,24 |
| Sheep | 809.771 | 5.321.338,25 | 191.568,18 | 4.575,53 | 18.624,68 |
| Goat | 90.852 | 448.798,63 | 16.156,75 | 385,90 | 1.570,80 |
| Poultry | 214.061 | 529.952,45 | 19.078,29 | 455,68 | 1.854,83 |
| Equidae | 8.545 | 723.706,38 | 26.053,43 | 622,28 | 2.532,97 |
| Total | 1.983.633 | 251.977.679,36 | 9.071.196,46 | 216.661,81 | 881.921,88 |

With the values in Table 4, the methane gas production amount ($m^3$-$CH_4$/year), the energy value of the produced methane gas (GJ/year), the ton equivalent oil equivalent of the produced methane gas energy (TOE/year) and electrical energy equivalent (MWhe/year) were calculated and shown in Table 5. The amount of methane gas produced was calculated with the methane gas production (MO) value in Table 3. MO is the amount of methane gas produced from 1 kg VS. If the methane gas content of the produced biogas is 60%, the energy value is 22,7 MJ/$Nm^3$ and the value of the methane gas is 36 MJ/$Nm^3$ [26]. Accordingly, the energy value of the produced methane gas was calculated by multiplying the amount of methane gas produced with 36. The calculated methane gas energy is converted to TEO. *1 TOE = 41,868 GJ* [8, 29]. The kWh energy value of methane gas is taken as 10 kWh, and its electrical efficiency is 35%, and the electrical energy equivalent is calculated.

The total amount of methane gas that Erzurum can obtain from the total livestock in 2021 is 251.977.679,36 $m^3$. The amount of methane gas production in cattle is 244.413.529,97 $m^3$, in water ox 540.353,68 $m^3$, in sheep 5.321.338,25 $m^3$, in goat 448.798,63 $m^3$, in poultry 529.952,45 $m^3$, in equine 723.706,38 $m^3$.

The amount of electrical energy that methane gas can obtain with an internal combustion engine with an average electrical efficiency of 35% is 881.921,88 MWh. In addition, the total methane gas produced is 216.661,81 TOE.

When Table 6. is examined, it is seen that the amount of methane gas that Erzurum can obtain from the total animal waste in the last twenty years is 3.755.790.944,24 $m^3$-$CH_4$. The energy value of the methane gas obtained is 135.208.473,99 GJ/year, the crude oil equivalent is 3.229.398,92 TOE/year, and the electrical energy equivalent is 13.145.268,30 MWhe/year. When the data is examined in general, the produced methane gas and energy equivalent values tend to increase in the twenty years.

According to the information received from Aras Electricity Retail Sales Inc, which distributes

Table 6. Amount of Methane, Energy, TOE and Electricity that Erzurum province can produce with animal waste in the last twenty years.

| The Amount of Methane, Energy, TOE, and Electricity That Erzurum Provides with The Last 20 Years Of Animal Waste | | | | | |
|---|---|---|---|---|---|
| Year | Number of animals | Methane production (MO) | Energy value | TOE energy | Electric energy |
| | Number | $m^3CH_4$/kg-SM | GJ/Year | TOE/Year | MWhe/Year |
| 2002 | 2.039.208 | 167.482.038,59 | 6.029.353,39 | 144.008,63 | 586.187,14 |
| 2003 | 1.861.471 | 157.430.496,62 | 5.667.497,88 | 135.365,86 | 551.006,74 |
| 2004 | 2.004.468 | 162.267.427,38 | 5.841.627,39 | 139.524,87 | 567.936,00 |
| 2005 | 1.753.448 | 158.629.684,15 | 5.710.668,63 | 136.396,98 | 555.203,89 |
| 2006 | 1.719.966 | 160.061.562,64 | 5.762.216,26 | 137.628,17 | 560.215,47 |
| 2007 | 1.691.172 | 165.819.333,96 | 5.969.496,02 | 142.578,96 | 580.367,67 |
| 2008 | 1.587.832 | 157.270.492,34 | 5.661.737,72 | 135.228,28 | 550.446,72 |
| 2009 | 1.202.685 | 155.843.027,06 | 5.610.348,97 | 134.000,88 | 545.450,59 |
| 2010 | 1.273.415 | 158.036.785,09 | 5.689.324,26 | 135.887,18 | 553.128,75 |
| 2011 | 1.397.274 | 172.665.877,38 | 6.215.971,59 | 148.465,93 | 604.330,57 |
| 2012 | 1.438.387 | 183.198.608,67 | 6.595.149,91 | 157.522,45 | 641.195,13 |
| 2013 | 1.557.320 | 196.580.420,63 | 7.076.895,14 | 169.028,74 | 688.031,47 |
| 2014 | 1.567.762 | 192.676.489,71 | 6.936.353,63 | 165.671,96 | 674.367,71 |
| 2015 | 1.679.669 | 189.251.717,02 | 6.813.061,81 | 162.727,19 | 662.381,01 |
| 2016 | 1.541.604 | 191.140.494,18 | 6.881.057,79 | 164.351,24 | 668.991,73 |
| 2017 | 1.634.550 | 214.079.037,80 | 7.706.845,36 | 184.074,84 | 749.276,63 |
| 2018 | 1.715.446 | 225.037.433,20 | 8.101.347,60 | 193.497,36 | 787.631,02 |
| 2019 | 1.799.020 | 241.956.092,98 | 8.710.419,35 | 208.044,79 | 846.846,33 |
| 2020 | 1.964.083 | 254.386.245,49 | 9.157.904,84 | 218.732,80 | 890.351,86 |
| 2021 | 1.983.633 | 251.977.679,36 | 9.071.196,46 | 216.661,81 | 881.921,88 |
| TOTAL | 33.412.413 | 3.755.790.944,24 | 135.208.473,99 | 3.229.398,92 | 13.145.268,30 |

and transmits electricity in Erzurum, the electricity consumption of Erzurum province in 2021 is 919.749 MWh in total for lighting, residential, industry, agricultural irrigation, and business subscriber groups. In Table 7., the electricity consumption values of Erzurum province for 2021 are given.

Table 7. Electricity consumption distribution in Erzurum in 2021

| Erzurum Province Electricity Consumption in 2021 | |
|---|---|
| | MWhe |
| Lighting | 67.232,00 |
| Housing | 393.444,00 |
| Industry | 40.961,00 |
| Agricultural Irrigation | 6.901,00 |
| Trade | 411.211,00 |
| Total | 919.749,00 |

In Table 8., the ratios of 881.921,88 MWhe/year electrical energy, which has the potential to be produced with animal waste by Erzurum in 2021, to the electricity consumption in 2021 are given. The electrical energy that Erzurum province can produce with animal waste in 2021 can meet approximately 96% of the total electricity consumption in 2021, approximately 13 times of the lighting consumption at 1.311,76%, approximately 2,2 times of the residential consumption with 224,15%, and 2153% of the industrial consumption 21,5 times and, approximately 2,1 times of trade consumption with 214,47.

$CO_2$ emissions into the atmosphere occur from the energy sources used for electrical energy production [30]. The amount of $CO_2$ emission varies according to the source of electricity generation. In Table 9., $CO_2$ emission values according to energy sources are given.

Table 9. shows that biomass energy is the third energy source with the most negligible $CO_2$ emission value, together with hydroelectricity.

Table 8. Contribution of electrical energy to be produced from biogas to annual consumption in Erzurum in 2021.

| The Contribution of Electric Energy to be Produced From Biogas in 2021 in Erzurum Province | | | |
|---|---|---|---|
| | TEDAS Consumption MWhe | Produced By Biogas Mwhe | Rate % |
| Lighting | 67.232,00 | 881.921,88 | 1.311,76 |
| Housing | 393.444,00 | | 224,15 |
| Industry | 40.961,00 | | 2.153,08 |
| Agricultural Irrigation | 6.901,00 | | 12.779,62 |
| Trade | 411.211,00 | | 214,47 |
| Total | 919.749,00 | | 95,89 |

Table 9. Carbon emission values by energy sources [32].

| Carbon Emission Values By Energy Sources | | |
|---|---|---|
| Source | Min.-Max. Greenhouse Gas Emission (ton-$CO_2$/GWh) | Average Greenhouse Gas Emission (ton-$CO_2$/GWh) |
| Lignite | 790-1372 | 1054 |
| Stone coal | 756-1310 | 888 |
| Fuel-oil | 547-935 | 733 |
| Natural gas | 362-981 | 499 |
| Nuclear | 2-130 | 66 |
| Geothermal | | 38 |
| Biomass | 10-101 | 26 |
| Hydroelectric | 2-237 | 26 |
| Sun | 13-731 | 23 |
| Wind | 6-124 | 10 |

According to this table, with the biogas sourced 881.921,88 MWhe/year electricity that Erzurum province can produce from animal wastes in 2021; 906.615,69 tons/$CO_2$ according to lignite, 760.216,66 tons/$CO_2$ according to imported and hard coal, 623.518,77 tons/$CO_2$ according to to fuel oil, 417.149,05 tons/$CO_2$ according to natural gas, 35.276,88 tons/$CO_2$ according to nuclear energy, according tons/$CO_2$ and geothermal energy, 10.583,06 tons/$CO_2$ emission will be prevented.

## Conclusions

Increasing energy demand in a developing country such as Turkey and external dependence on energy today are reality. Today, where global warming and climate change increase their negative effects, the importance of renewable energy sources has been understood more. In addition, it has become necessary to develop renewable energy sources to meet the ever-increasing energy needs and ensure energy supply and security [10].

In the study, in which the gains to be obtained from the use of biogas energy, one of the renewable energy sources, are explained, some suggestions have been made about adopting a structure compatible with the requirements of age and sustainable development.

As a country with sizeable rural geography and population, Turkey has a significant amount of biogas potential that will accelerate national development. Activating this potential requires a detailed and holistic planning study. In this context, the critical point to be underlined in the realization of policies for disseminating biogas, one of the sources of renewable energies, is that the state plays a regulatory role at every stage of the policies. In financing such projects, the government should consider the cost of imported inputs of fossil fuels, the damage they cause to the environment in energy production, and the contribution that the increased efficiency of renewable energy production will make to the national income of the country.

In the study, the biogas potential that can be obtained from the animal waste potential of Erzurum province was examined, and the amount of electrical energy that could be produced from these wastes was calculated. The amount of waste that can be produced from animal existence is 14.359.851,39 tons/year. However, collecting all of this animal waste manure is impossible. Most poultry manure remains in the grazing land, except for small ruminants, equids and laying hens. The total amount of manure that can be collected is 9.582.132,01 tons/year. It has been calculated that 251.977.679,36 $m^3$-$CH_4$/year of methane gas can be produced from a total of 9.582.132,01 tons/year of animal waste. It has been calculated that the energy value of the methane gas that can be produced is 9.071.196,46 GJ/year, the crude oil equivalent of this energy is 216.661,81 TOE, and that 881.921,88 MWhe of electrical energy (with 35% efficiency) can be produced with the methane gas that can be produced. This amount is approximately 96% of the annual total electricity consumption of Erzurum, which has a population of 756.893. According to the results obtained, when the year 2021 is taken as a reference, almost all of the electrical energy needed by the province of Erzurum is met with biogas energy obtained from animal waste. By generating electricity from the methane gas that can be produced, it has been calculated that carbon dioxide emissions can be prevented from at least 10.583,06 tons/$CO_2$ to 906.615,69 tons/$CO_2$ compared to other energy sources. These values are also very important in Erzurum scale in reducing the amount of harmful gas released into the atmosphere in today's world where the danger of global warming is felt.

In the examination of the last 10 years of animal waste in Erzurum, it has been calculated that a total of 3.755.790.944,24 $m^3$-$CH_4$ can be produced, this amount is equivalent to 3.229.398,92 TOE crude oil and 13.145.268,30 MWhe electrical energy can be produced.

In addition, as a result of the study, it is predicted that the utilizing the animal waste potential of Erzurum will make a considerable economic contribution both on a provincial basis and in Turkey. Anaerobic digestion of animal manure offers several environmental, agricultural and socio-economic benefits throughout improved fertilizer quality of manure, considerable reduction of odors and inactivation of pathogens and last but not least production of biogas production, as clean, renewable fuel, for multiple utilizations.

Biogas production contributes to more sustainable livestock operations by substantially reducing other environmental impacts related to manure management. It reduces the risk of water pollution associated with animal manure slurries (i.e., eutrophication). In addition, in terms of its benefit in reducing the amount of $CO_2$ released into the atmosphere, biogas is one of the nature-friendly energy resource investments and is thought to be one of the most suitable methods for reducing global warming. When the animal wealth of Erzurum for the last twenty years is examined, it is seen that the number of cattle has a constantly increasing trend. The numbers of ovine, poultry and equidae have followed a fluctuating course in the twenty years. On the other hand, since the useful manure required for biogas production is obtained chiefly from cattle, the annual biogas energy potential tends to increase continuously over twenty years. This means that there will be continuity for biogas production and it is sustainable. With the establishment of biogas facilities, it will be ensured that the animal wastes generated from animal husbandry activities, which are the main livelihoods of Erzurum province, will be brought into the economy. In addition, environmental pollution caused by wastes will be prevented and it will be a new source of income for the rural people who are engaged in animal husbandry activities. Thanks to these added values, migration from the village to the city will be prevented to some extent and the continuity of animal husbandry activities will be ensured for the city in the short term.

Generating electrical energy from biogas means biogas can benefit approximately 35% to 40%. Using biogas only to generate electrical energy is also not suitable in terms of energy efficiency. The benefit of using biogas in cogeneration or trigeneration power plants can reach 90%. Since electrical energy, heating and cooling energies are produced simultaneously in these power plants, 3 units of energy from 1 unit of biogas energy are obtained and energy efficiency reaches the maximum rate.

The benefits of biogas facilities on environmental cleanliness and human health are substantial. The establishment of biogas facilities also provides benefits in socio-economic terms. In addition to the employment to be provided in the biogas plants, the provision of services such as workers and transportation for the wastes to be brought from the farms is also crucial in terms of business and income. Wastes from cattle and sheep production facilities, animal shelters, farms, barns, zoos, animal hospitals and other animal waste-producing facilities can be collected and disposed of in biogas facilities. While these wastes are essential raw materials for biogas production, these wastes are prevented from causing environmental pollution, thus fulfilling their social and environmental responsibility. The waste generated after biogas production can be used in agricultural areas as liquid manure, which has lost its foul smell and has become more efficient. The use of manure, which comes out of the facility as waste, in agricultural areas ensures efficient and healthy farming and reduces the use of chemical manures and the cost of fertilization. Also improves human/farm cohabitation in rural regions by reducing odour emissions by 70-95%.

The study shows that there are many opportunities in terms of biogas production and conversion of animal wastes into energy in Erzurum province. In this context, establishing a biogas facility in the region in line with a specific planning study will be beneficial both locally and nationally. Rewording manure processing for biogas production and for the environmental benefits provided by this would ensure the future development of the manure based biogas systems.

### Conflict of Interest

The authors declare no conflict of interest.

## References


1. KULEKCI O.C. Place of Geothermal Energy in The Content of Renewable Energy Sources and It's Importance for Turkey. Ankara University Journal of Environmental Sciences. **1** (2), 83, **2009**.
2. JEBLI M.B., YOUSSEF S.B. The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. Renewable and Sustainable Energy Reviews. **47**, 173, **2015**.
3. PATA U.K. Renewable and non-renewable energy consumption, economic complexity, $CO_2$ emissions, and ecological footprint in the USA: testing the EKC hypothesis with a structural break. Environmental Science and Pollution Research. **28**, 846, **2021**.
4. ABAS N., KALAIR A., KHAN N. Review of fossil fuels and future energy Technologies. Futures. **69**, 31, **2015**.
5. YILMAZ A., UNVAR S., KOCA T., KOCER A. Biogas Production and Statistical Information Of Biogas Production. Technological Applied Sciences (NWSATAS). **12** (4), 218, **2017**.
6. KALAIR A., ABAS N., SALEEM M.S., KALAIR A.R., KHAN N. Role of energy storage systems in energy transition from fossil fuels to renewables. Energy Storage. **2**, 135, **2021**.
7. MARTINS F., FELGUEIRAS C., SMITKOVA M., CAETANO N. Analysis of Fossil Fuel Energy Consumption and Environmental Impacts in European Countries Energies. **12**, 964, **2019**.
8. KAYNARCA H., KILIC T., ACIKKALP E., KANDEMIR S.Y. Assessment of Biogas Potential in Eskisehir. Journal of Geography. **42**, 271, **2021**.
9. DEMIR M., OKUTUCU M.A., GUVEN M., CANKURT, M. The Importance of Solar Energy, a Renewable Energy Source, on Nature Conservation. Austrian Journal of Forest Science (ISI). **4**, 219, **2013**.
10. DEMIR M., GUVEN M. In The Context Of Energy Polıcy On Turkey; Evaluatıon Of Envıronmental Impact Of Hydroelectrıc Power Plants (HPP). 19th International Academic Conference, Florence, Italy. **2015**.
11. ARDEBILI S.M.S. Green electricity generation potential from biogas produced by anaerobic digestion of farm animal waste and agriculture residues in Iran. Renewable Energy. **154**, 2, **2020**.
12. GULSEN H.E., TURKAY G.K., AKARSU C., KUMBUR H., DIZGE N. The Effect of Biogas Production from Various Wastes on Sustainable Environmental Management. Journal of Environmental Science and Technology Technical. **3** (2), 1, **2019**.
13. DEMIR M., GOKTUG T.H., BULUT Y. Human-Induced Water Pollution and Management. Fresenius Environmental Bulletin. **23** (1), 1, **2014**.
14. OUN A., KUMAR A., HARRIGAN T., ANGELAKIS A., XAGORARAKI I. Effects of Biosolids and Manure Application on Microbial Water Quality in Rural Areas in the US, Water. **6**, 3701, **2014**.
15. TILKI F., CICEK E. Biomass Energy and Energy Forestry. Journal of Kafkas University Artvin Faculty of Forestry. **1** (2), 33, **2003**.
16. BALAT M., AYAR G. Biomass energy in the world, use of biomass and potential trends. Energy Sources. **27** (10), 931, **2005**.
17. MAO G., HUANG N., CHEN L., WANG H. Research on biomass energy and environment from the past to the future: A bibliometric analysis. Science of the Total Environment. **635**, 1081, **2018**.
18. SIWAL S.S., ZHANG Q., DEVI N., SAINI A.K., SAINI V., PAREEK B., THAKUR V.K. Recovery processes of sustainable energy using different biomass and wastes. Renewable and Sustainable Energy Reviews. **150**, 111483, **2021**.
19. CANKA K.F. General Outlook of Biogas, the Importance of Its Usage, and Biogas in Turkey. **52** (617), 94, **2011**.
20. HAKAWATIA R.M., SMYTHB B., GEOFFREY MCCULLOUGHB G., ROSAA F., ROONEY D. What is the most energy efficient route for biogas utilization: Heat, electricity or transport Applied Energy. **206**, 1076, **2017**.
21. CEBULA J., CHYGRYN O., CHAYEN S., PIMONENKO T. International Journal of Environmental Technology and Management. **21**, 5, **2019**.
22. MENGISTU M.G., SIMANE B., ESHETE G., WORKNEH T.S. The environmental benefits of domestic biogas technology in rural Ethiopia. Biomass and Bioenergy. **90**, 131, **2016**.
23. TORQUATI B., VENANZI S., CIANI A., DIOTALLEVI F., TAMBURI V. Environmental sustainability and economic benefits of dairy farm biogas energy production: A case study in Umbria. Sustainability. **6** (10), 6696, **2014**.
24. WANG Y., ZHANG Y., LI J., LIN J.G., ZHANG N., CAO W. Biogas energy generated from livestock manure in China: Current situation and future trends. Journal of Environmental Management. **297**, 113324, **2021**.
25. TOLAY M., YAMANKARADENIZ H., YARDIMCI S., REITER R. Biogas Production from Animal Wastes. VII. National Clean Energy Symposium; UTES 2008, İstanbul. **2008**.
26. YAGLI H., KOC Y. Determination of Biogas Production Potential from Animal Manure: A Case Calculation for Adana Province. Cukurova University Journal of the Faculty of Engineering and Architecture. **34** (3), 35, **2019**.
27. KOZŁOWSKI K., DACH J., LEWICKI A., MALIŃSKA K., DO CARMO I.E.P., CZEKAŁA W. Potential of biogas production from animal manure in Poland. Archives of Environmental Protection. **45** (3), **2019**.
28. EKINCI K., KULCU R., KAYA D., YALDIZ O., ERTEKIN C., OZTURK H.H. The Prospective of potential biogas plants that can utilize animal manure in Turkey. Energy Exploration & Exploitation. **28** (3), 187, **2010**.
29. KUCUKKAYA E. What are Energy Units, Energy Portal. Available online: https://www.enerjiportali.com/ (accessed on 3th January 2021).
30. MOHTASHAM J. Review Article-Renewable Energies. Energy Procedia. **74**, 1289, **2015**.
31. TURKISH STATISTICAL INSTITUTE (TSI). Animal Stock in Erzurum province between 2002-2021. Available online: https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111 (accessed on 3th March **2022**).
32. ENERGY ATLAS. Carbon emission values by energy sources. Available online: https://www.enerjiatlasi.com/haber/elektrik-uretiminde-karbon-salinimi (accessed on 3th March **2022**).