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Potential of Biogas and Electricity Production from Animal Waste in Turkey

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Abstract

In this paper, biogas potential produced from animal manure has been calculated using data for various regions of Turkey between 2007 and 2019. Moreover, generation of electricity potential that can be provided using biogas obtained from animal manure resources has been examined. The animal numbers subjected to the study have been reached via the Turkish Statistical Institute. The amount of animal manure, which is the basis for calculating the amount of biogas, has been calculated using the average number of animals and the animal weight. Eastern Anatolia and Central Anatolia Regions have the highest biogas potential with 19% compared with the other regions due to amount of manure obtained from animal. The finding of this study denotes that 76,448 × 10^6 m^3 potential of methane content can be obtained from biogas for the mentioned years, and 2,339,296 × 10^6 MJ potential of heating value can be obtained from this methane value. While the potential of electricity energy, which can be provided from animal manure wastes, has been 231,009 × 10^6 between 2007 and 2019 in Turkey, the total electricity consumption in 2007–2019 is 2,898,040 × 10^6 kWh. The results show that the potential electricity that can be provided from animal manure could meet 7.99% of the electricity consumed in the same years. Furthermore, the cost analysis of biogas facility, which is established in Eastern Anatolia Region, has been performed using circular economy model. According to calculations, the discounted payback period has been found to be 10 years.

Keywords Bioenergy · Energy production · Livestock · Methane · Waste

Nomenclature

Symbols

TPB	Theoretical potency of biogas (m^3/year)
M	Total amount of the manure (kg/year)
TS	Ratio of the total solids of animal manure
AC	Availability coefficient
EB_{TS}	The quantity of estimated biogas produced (m^3 TS/kg)
e_{biogas}	Amount of produced electricity (kWh/year)
E_{biogas}	Unchanged raw energy in biogas (kWh/year)
Energy $content_{biogas}$	Calorific value of biogas (kWh/m^3)
$\dot{m}_{biogas}$	Amount of biogas generated (m^3/year)
x	Independent variables
y	Dependent variables
NCV	Net current valuation
C_i	Discounted cash inflows
C_o	Discounted cash outflows
t	Time of the cash flow
n	Lifetime of investment

Greek Symbols

η Efficiency

Subscript

a Kilotons

Acronyms

COD	Chemical oxygen demand
toe	Tons of oil equivalents
DVS	Department of Veterinary Services

Introduction

As the world globalizes, demands for energy sources increase. Fossil sources meet a large part of this demand. However, these sources emit greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [1], and the increase in these gases causes excess heat in the world. At the

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end of this rise, the world will probably face an irreversible problem known as global warming, implying serious consequences and frightening threats to the world such as climate changes and melting of glaciers. On the other hand, the renewable energy sources have many advantages such as being harmless, cheaper than fossil sources, and inexhaustible. There are various types of renewable energy sources around in the world, the most important of which are solar energy, geothermal energy, wind energy, and biofuel energy. The animal manure is also one of renewable energy sources, which has huge biogas energy potential and readily reachable in every place dealing with animal husbandry. There have been a lot of researches on this subject.

Aziz et al. [2] demonstrated the probability of biogas generation from goat fertilizer, poultry manure, sewage sludge, rice waste, palm oil mill wastewater, and fish waste. The biogas potential produced from these substances was contrasted by the utilization of traditional bokashi catalysts and industrial inoculum. Physicochemical properties were evaluated by laboratory-based analyzes. The potential of bio-methane test was employed to evaluate biogas generation for 20 days in case of mesophilic conditions. The results showed that all of the layers utilizing industrial inoculum had the potency to make biogas based on organic compound content, but methane gas was not generated from the layers by traditional bokashi. Afezeli et al. [3] presented a study regarding possible of biogas generating from manure and poultry wastes in Iran. They used various biomass sources such as abattoir wastes, including rumen, innards, stomach and gore from light, heavy livestock, and poultry blood. The results showed that Tehran and Mazandaran had 9 million m^3 and 828 million m^3 biogas potential obtained from manure and poultry wastes, respectively. Cvetkovic et al. [4] investigated potential and station of biogas as energy sources in the Republic of Serbia. They used various biomass sources such as farming crops, livestock residues, and municipal solid wastes in their study. Their result showed that biogas generation potency obtained from agricultural yields was 0.85 megatons in a year, while biogas production potency obtained from livestock residues was 94.13 ktoe. Blandzija et al. [5] investigated the contemporary farming solid biomass and energy potency in Croatia. The amount of solid biomass and energy potential included post-harvest remains, pruning residues, agricultural industrial solid waste, and biomass from the Miscanthus energy product. According to the results of this study, three scenarios were developed for the introduction of solid biomass in the renewable energy generation sector. They were called progressive—S1, optimistic—S2, and conservative—S3. According to these definitions, Croatia had biomass potential 51.14 PJ (S1), 24.06 PJ (S2), and 12.18 PJ (S3). Khayum et al. [6] studied on biogas potential obtained from spent tea waste. They mixed tea waste with cow manure in different proportions to produce biogas, and they kept samples in different anaerobic digesters in their working. Besides, the impact of significant input parameters such as pH and carbon to nitrogen (C/N) ratio and the duration of digestion in biogas generation were investigated. Gases gathered from diggers were characterized to provide conformity for using as a renewable fuel. Moreover, the digested slurry was withal analyzed for its use in the agricultural sector. According to the conclusion, spent tea waste, after being co-digested with cow manure, was of high value in terms of biogas production and also could be used as a fertilizer.

Özer [7] examined biogas energy potential from animal fertilizer and farming wastes in Ardahan, Turkey, and reported some reduction in CO_2 emission. Özer used a lot of data, such as availability factors and volatile solid ratio of the manure, in this study. The result showed that 323 GWh/year electricity was generated from animal manure, and cultivation waste and CO_2 emission reduced 2 million tons/year approximately. Abdeshahian et al. [8] analyzed biogas probable from organic waste which got from animals and slaughterhouses in Malaysia. They used data, taken from the Department of Veterinary Services (DVS), Ministry of Agriculture and Agro-Based Industry Malaysia, to calculate potential of biogas. In their study, produced biogas was calculated by using number of live animals in Malaysia. According to result of their study, biogas potential was observed at 4589.49 million m^3 in 2012. This meant that electricity energy obtained from animal fertilizer was 8.27×10^9 kWh/year. Noorollahi et al. [9] evaluated biogas generation from livestock manure. Moreover, they examined the evaluations which made for distinct provinces in Iran in their own studies. They used the statistical data number of cows, produced amount of manure, and volume of constituted biogas per kilogram of animal waste in this study. Furthermore, the total amount of biogas generation from livestock waste was computed for each province utilizing experimental and theoretical methods. It was concluded that biogas potential produced from farm animal wastes met some of the country's natural gas request. Arshad [10] prepared a study regarding electricity production from biogas obtained from poultry waste in Pakistan. Their study was based on 25,000 poultry farms in Pakistan. Biogas production obtained from poultry was estimated according to this study. The outcomes showed that 280 MWh/day of electricity could be produced in Pakistan. Dalkılıç and Uğurlu [11] investigated biogas potential obtained from chicken manure. They used the method of mesophilic-thermophilic two-stage anaerobic system to obtain biogas. Also, the biogas production was calculated using semicontinuous mode under different organic loading rates. The conclusion displayed that the methane ingredient of biogas was found at 74%. Avcıoğlu [12] examined position and probable of biogas energy from animal wastes in Turkey. In this study, a number of livestock animals were used and the rate of dry matter and availability were considered. The data based on Turkey's biogas energy potential showed that the last agricultural census was 2.177.553.000 m^3. A total of 68% of this potential was cattle, 5% small ruminant, and 27% poultry. Furthermore, a waste map was prepared for Turkey and more than 1 GJ of biogas energy potential were seen to be achievable in varies cities of Turkey. Ozcan et al. [13] investigated electrical energy potential from biomass sources which were energy crops, municipal solid wastes, animal manure, and urban wastewater treatment sludge in Turkey. They used applicable, technical, and economic conditions of Turkey in this study. Outcomes of this study showed that the entire main energy value of biogas attainable from the observed sources was 188.21 TWh/year, and the total primary energy value linked to the probable of the appraised biomass sources was 278. 40 TWh/year. Ardebili [14] investigated the potential of biogas production by anaerobic digestion to farm animal waste and agricultural residues for Iran. As a result of the analysis, it has been determined that Iran can produce 62,808 × 10^6 kWh/year electricity with these wastes and has the potential to meet 27% of the country's energy needs. Cucchiella et al. [15] examined the economic effects of biogas and bio-methane plants using various animal wastes in Italy. By comparing biogas and bio-methane plants of different capacities, they provided an economic perspective to investors. Khalil et al. [16] investigated the potential for biogas production using animal waste in Indonesia. As a result of this research, they determined that with these wastes, there is about 9597.4 Mm^3/year biogas production potential and it can be produced electricity of 1.7 × 10^6 KWh/year using biogas energy. Melikoglu and Menekse [17] developed a model to predict bio-methane production potential from cattle and sheep waste. They estimated that the cattle and sheep population would reach 18.7 and 39.2 million, respectively, in 2026, and these wastes had potential for production of 1.99 billion m^3 and 0.15 billion m^3 of bio-methane.

Although there are some studies pertaining to with biogas production from various wastes in the world, there is huge amount of gap about biogas production from animal manure in Turkey. Moreover, in many studies, biogas energy has been researched for only one year for some countries as can be seen from above literature survey. Furthermore, Turkey has rich biogas potential, but there is not enough study regarding the evaluation of this potential and the contribution to the economy has not been calculated. The purpose of this study is to examine the annually biogas production obtained from animal manure between 2007 and 2019 to fulfill this gap and suggest a circular economy model for further studies. This study can give a whole picture on the capacity of electric generation from biogas energy every year for Turkey.

Methodology and Analysis

Overview

For this study, the number of animals used for biogas production was taken from Turkish Statistical Institute from 2007 to 2019 [18]. These data included the number of livestock bovine animal, sheep and goats, and poultry in different regions of Turkey.

The biogas obtained from the animal waste is influenced by the various factors such as the proportion of total solids, the feeding regime, the body weight, the animal type, and the waste availability [19]. The collection of the manure may not be realized efficiently every time for the generation of biogas, and the availability of the manure is various. Therefore, the estimation of biogas generation from the animal manure and the availability coefficient were considered when the total biogas volume was computed. The generation of biogas can be easily maximized by managing the process at optimum conditions [16]. The total solids of the waste are a significant indicator for the generation of biogas from the animal waste. Biogas is produced with optimum pH and temperature values from animal wastes with anaerobic digestion. In addition, it can be emphasized that there is a different amount of biogas production according to the animal type. This is because the amount and component of the fertilizer are different. According to a recent report by Khalil et al. [16], the ideal amount of methane production could be achieved by controlling several parameters such as temperature (35–60 °C) and pH (optimum at 6.8–7.2).

Biogas generated from animal manure was calculated with the estimated value in relation to the weight of the animal in this study. The other parameters were the ratio of the total solids of the animal manure, quantity of approximate biogas generated, and availability coefficient. In accordance with these values, biogas was converted into electrical energy. Calculations were shown clearly below for electricity generation and the biogas potential.

Livestock Population

Most of the people living in turkey provide livelihood from livestock. Therefore, Turkey is rich in animal waste and animal manure. According to the Turkish Statistical Institution data (TÜİK), Turkey has a total of 75,178 culture cattle, 73,716 breed cattle, 28,784 domestic cattle, and 1588 buffalos in 2007–2019 while Turkey has a total of 41,311 turkeys, 2,525,385 meat-hen, 11,769 goose, 1,184,814 egg-hen, and 5624 ducks in 2007–2019. Table 1 indicates the distribution of the total number of bovine animals, total number of sheep and goats, and total number of poultries for regions of Turkey.

Livestock Waste

Biogas is obtained by fermentation of waste such as animal manure, blood, crop waste, and domestic and industrial wastes in an airless environment. Animal manure is used to produce biogas due to huge amount of request of energy in Turkey.

Table 1 Regional distribution of livestock of bovine animals, sheep and goats, and poultry population in Turkey for years 2007–2019 [18]

Regions	Total bovine animals*	Total sheep and goats*	Total poultry*	Total animal numbers*
Aegean Region	27,488	55,771	1000,850	1,084,109
Black Sea Region	29,358	21,747	721,447	772,552
Central Anatolia Region	34,467	79,003	490,959	604,429
Eastern Anatolia Region	37,067	132,122	123,139	292,328
Marmara Region	22,617	52,361	1,089,450	1,164,428
Southeastern Anatolia Region	13,502	90,565	146,884	250,950
Mediterranean Region	14,767	56,261	196,174	267,201
Total	179,266	487,829	3,768,903	4,435,998

*Thousand

Some assumptions are made in the amount of animal manure required for calculation of biogas production in this study.

- Body weight has been assumed at 250 kg for bovine animals, 40 kg for sheep and goats, and 1.5 kg for poultry for this study [19].
- The amount of fertilizer of bovine animals, sheep and goats, and poultry has been calculated in proportion to their body weights of 0.09 and 0.04 and 0.03, respectively [19].

Calculation of Biogas Potential Produced from Manure

Biogas occurs in three phases. These are hydrolysis, acid formation, and methane formation. In general, every factor that microbiological bacteria affecting biogas formation are affected also affects biogas production. A bacterium needs certain temperature and pH values to continue its vital activities.

Methanogenic bacteria are not active at very high and very low temperatures. Therefore, the reactor temperature where biogas production takes place directly affects the production or speed of biogas. The temperature inside the reactor also determines the waiting time and the reactor volume. Classification of temperature according to its level can be done in three ways.

Psychophilic temperature range = 12−20°C

Mesophilic temperature range = 20−40°C

Thermophilic temperature range = 40−65°C

The optimum pH values for methane-forming bacteria are neutral or slightly alkaline values. While the fermentation process continues in anaerobic conditions, it varies between 7 and 7.5.

The amount of dry matter is an element that directly affects the biogas yield. Biogas yield varies according to the dryness rate of the organic substance used. The amount of water to be used is determined according to the dryness rate of the wastes used. The dryness rate in wet fermentation is in the range of 7.5–11. The most important factor is ratio of the total solids.

The determined of biogas production from fertilizer is given in the equivalence (Eq. 1).

$$TPB = M \times TS \times AC \times EB_{TS} \quad (1)$$

TPB is theoretical potency of biogas (m^3/year) while M is total amount of the manure generated for each region in 2007–2019 (kg/year). TS refers to ratio of the total solids of animal manure while AC is availability coefficient. TS value has been assumed at 25% for bovine animals and sheep and goats while it has been assumed at 29% for poultry in distinct type animal [3, 12, 19]. On the other hand, in this study, AC has been assumed at 50%, 13%, and 99% for bovine animals, sheep and goats, and poultry, respectively. And lastly, EB_{TS} refers to the quantity of estimated biogas produced (m^3 TS/kg). EB_{TS} value has been assumed at 0.6, 0.4, and 0.8 for bovine animals, sheep and goats, and poultry, respectively [19].

Methane Content and Heating Value of Biogas Obtained

Anaerobic digestion of livestock manure shows that the proportion of methane content in biogas improved from various livestock manures based on source manure. In this study, methane content is 60%, 45% and 60% for the bovine animals, sheep and goats, and poultry, respectively [19]. Also, heating value calculated from methane is presumed that 85% of the methane derived could be transformed to heat in the boiler by seeing a calorific value of 36 MJ/m^3 [19].

Calculation of Electricity Potential from Biogas

Calculations required to generate electricity from biogas have been given in below equations.

$$E_{biogas} = \text{Energy content}_{biogas} \times \dot{m}_{biogas} \quad (2)$$

Energy content_{biogas}: calorific value of biogas (kWh/m^3).

Table 2 Regional distribution of animal manure obtained in Turkey for years 2007–2019

Regions	Bovine animal manure (Kt)[a]	Sheep and goats manure (Kt)[a]	Poultry manure (Kt)[a]	Total animal manure(Kt)[a]	Total amount of methane content (m^3)	Total amount of heating value (MJ)
Aegean Region	225,744	32,570	16,439	274,753	$12,614 \times 10^6$	386,001 × 106
Black Sea Region	241,102	12,700	11,850	265,652	$12,557 \times 10^6$	384,241 × 106
Central Anatolia Region	283,064	46,138	8064	337,266	$14,119 \times 10^6$	432,044 × 106
Eastern Anatolia Region	304,414	77,159	2023	383,596	$14,429 \times 10^6$	441,520 × 106
Marmara Region	185,746	30,579	17,894	234,219	$11,004 \times 10^6$	336,705 × 106
Southeastern Anatolia Region	110,882	52,890	2413	166,184	5631×10^6	172,326 × 106
Mediterranean Region	121,271	32,856	3222	157,349	6093×10^6	186,460 × 106
Total	1,472,223	284,892	61,904	1,819,019	$76,448 \times 10^6$	$2,339,296 \times 10^6$

[a] Kilotons

$\dot{m}_{biogas}$: amount of biogas generated per year (m^3/year).

E_{biogas}: the untransformed raw energy in the biogas and it is determined from Eq. 2.

Energy content biogas is assumed 6 kWh/m^3 by taking into account the biogas calorific value at 21.5 MJ/m^3 biogas (1 kWh = 3.6 MJ) [19].

Equation 3 is used to calculate potential electrical energy using the generated biogas.

$$e_{biogas} = E_{biogas} \times \eta \qquad (3)$$

e_{biogas}: the amount of electricity produced (kWh/year).

E_{biogas}: the untransformed raw energy in biogas (kWh/year).

η: the overall efficiency of biogas conversion, and η value is assumed at 30% for this study [19].

Multiple Nonlinear Regression Analysis

Nonlinear regression analysis models some data by a function. This function is a nonlinear composition of the parameters, and the function depends on independent variables. The data are placed by a process of consecutive approximations. Nonlinear regression refers the below statistical model of the form. The software used for the calculation is Microsoft Excel. Macro has been created for this calculation. Independent variables are animal number and biogas amount obtained while dependent variable is electricity generation.

$$y \sim f(x, \beta)$$

In the above form, x refers to independent variables while y refers to observed dependent variable.

Discounted Payback Period

Discounted payback period is a technique which sizes up a project through the notion of the time value of money. Net current valuation (NCV), symbolizing the volume of the current values of individual liquidity flows, is an indicator utilized to score profitability [20]. The construction of the plant is

Table 3 Annually biogas potential for animal kinds (m^3/year) in years 2007–2019

Years	Bovine animal potential of biogas	Sheep and goats potential of biogas	Poultry potential of biogas	Total amount of biogas potential
2007	6850×10^6	241×10^6	1032×10^6	8123×10^6
2008	6742×10^6	224×10^6	940×10^6	7906×10^6
2009	6659×10^6	204×10^6	883×10^6	7746×10^6
2010	7055×10^6	223×10^6	902×10^6	8180×10^6
2011	7689×10^6	245×10^6	911×10^6	8846×10^6
2012	8637×10^6	272×10^6	971×10^6	9880×10^6
2013	8951×10^6	292×10^6	1019×10^6	$10,263 \times 10^6$
2014	8836×10^6	315×10^6	1124×10^6	$10,275 \times 10^6$
2015	8702×10^6	318×10^6	1193×10^6	$10,214 \times 10^6$
2016	8760×10^6	314×10^6	1258×10^6	$10,332 \times 10^6$
2017	9920×10^6	336×10^6	1313×10^6	$11,569 \times 10^6$
2018	$10,607 \times 10^6$	350×10^6	1355×10^6	$12,312 \times 10^6$
2019	$11,008 \times 10^6$	368×10^6	1316×10^6	$12,692 \times 10^6$
Total	$110,417 \times 10^6$	3704×10^6	$14,218 \times 10^6$	$128,338 \times 10^6$

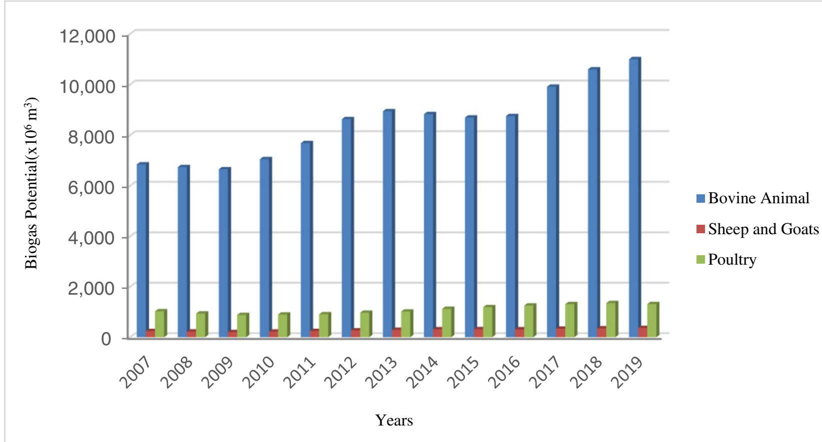

Fig. 1 Total biogas potential obtained from animal manure (m^3/year) for years 2007–2019 in Turkey

assumed at 6 months while the lifetime (n) is assumed at 20 years to calculate the discounted payback period. The opportunity cost of capital (r) is accepted to 5% by D'Adamo et al. [20].

$$\mathrm{NCV} = \sum_{t=0}^{n} (C_i - C_o)/(1+r)^t$$

While NCV represents net current valuation, C_i and C_o refer discounted cash inflows and discounted cash outflows, respectively. Moreover, t refers to time of the cash flow.

Results and Discussion

Distribution of Animal Manure, Biogas, and Electricity Generation in Regions of Turkey

The total amount of wet manure is calculated to be 1,472,223 kt of bovine animal, 284,892 kt of sheep and goats, and 61,904 kt of poultry for Turkey between 2007 and 2019 as shown in Table 2. In comparison with other animals, the maximum amount of manure is observed for the bovine animal with 81% and followed by sheep and goats with 16% and lastly poultry with 3% due to the number of animals and the animal weight. Furthermore, considering the number of cattle and sheep and goats, the most animal manure has been obtained from the Eastern Anatolia Region with 383,596 kt. Due to the terrestrial and climatic characteristics of the region, grassland and meadow areas take up more space. Therefore, animal numbers and manure produced from these animals are higher for Eastern Anatolia Region. On the other hand, due to the suitability of the land in the Marmara Region to agricultural machinery and the limitation of pasture areas, the producer focused on poultry breeding. Moreover, Table 2 indicates the potential of methane (m^3) obtained from biogas and heating value (MJ) from methane. Methane content and heating value of bovine animal are higher than sheep and goats and poultry. Because of this, the amount of biogas of the bovine animal is higher than other animals.

Biogas potential produced from bovine animal, sheep and goats, and poultry was $110{,}417 \times 10^6$ m^3, 3704×10^6, and $14{,}218 \times 10^6$ m^3, respectively. Although sheep and goats have higher amount of the wet manure than poultry, they have less amount of biogas potential than that of poultry. Because of this, poultry has higher value of TS, AC, and EB_{TS} than those

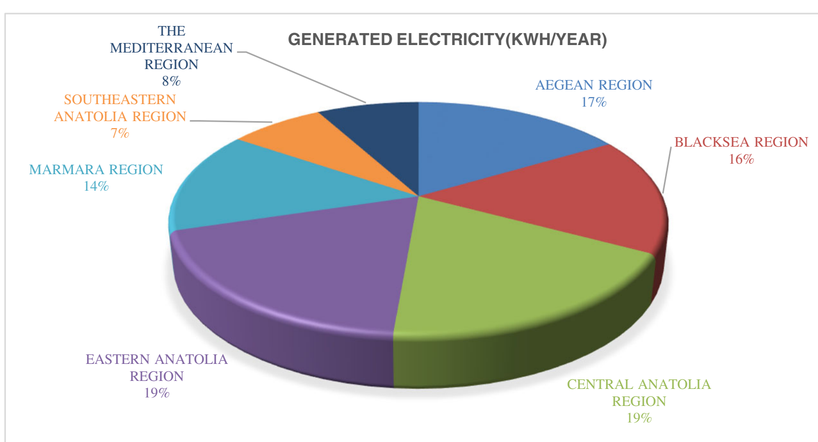

Fig. 2 Regional distribution of electricity generation potential (kWh) obtained from biogas for 2007–2019

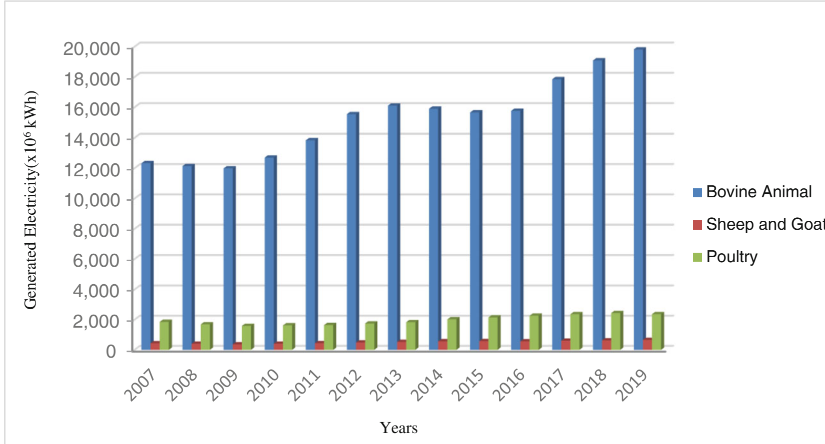

Fig. 3 Comparison of electricity generation for animal kinds (kWh/year) in years 2007–2019

of the other animal types. As clearly seen, TS, AC, and EB_{TS} values are very important factors for biogas potential as well as amount of animal manure.

The results, shown in Fig. 1 and Table 3, are calculated using abovementioned equation. This figure demonstrates the biogas potential produced from animal manure for Turkey from 2007 to 2019. As can be seen in Table 3, the highest value of biogas potential is obtained in 2019 from bovine animals with $11{,}008 \times 10^6$ m^3/year compared with both animal kinds and biogas value of the other years. Furthermore, the highest biogas potential is also observed in 2019 for sheep and goats like bovine animals compared with previous years. However, the highest value of biogas generation is 1355×10^6 m^3/year for poultry in 2018 compared with biogas value of the other years. The reason of it is the number of animals in those years, namely that the number of animals in biogas production is an important factor.

In Fig. 2, the regional distribution of electricity generation potential (kWh) obtained from biogas for the years 2007 and 2019 is presented for Turkey. The potential of generated electricity from animal manure is totally $231{,}009 \times 10^6$ kWh for 2007–2019. Due to direct proportion of biogas amount, the highest amount of electricity potential is determined in Eastern Anatolia Region with the value of $43{,}738 \times 10^6$ kWh. Due to the geographical and climatic conditions of Eastern Anatolia Region and Central Anatolia Region and people's livelihoods, the total number of bovine animals and sheep and goats and also the electricity production potential are higher than other regions. On the other hand, Fig. 3 shows the potency of the electricity generation from the manure of bovine animals, sheep and goats, and poultry for the years 2007 and 2019. The highest value of electricity production potential is observed for bovine animals with about 86%, followed by poultry and sheep and goat with 11% and 3%, respectively.

Table 4 Annually electricity generation potential from biogas obtained from animal manure

Years	Total animal number*	Potential of biogas (m^3)	Calorific value of biogas (kWh/m^3)	Efficiency of the conversion (%)	Generated electricity (kWh)
2007	316,419	8123×10^6	6	0.3	$14{,}622 \times 10^6$
2008	289,558	7906×10^6	6	0.3	$14{,}231 \times 10^6$
2009	271,771	7746×10^6	6	0.3	$13{,}943 \times 10^6$
2010	279,810	8180×10^6	6	0.3	$14{,}724 \times 10^6$
2011	286,292	8846×10^6	6	0.3	$15{,}922 \times 10^6$
2012	307,310	9880×10^6	6	0.3	$17{,}784 \times 10^6$
2013	323,245	$10{,}263 \times 10^6$	6	0.3	$18{,}473 \times 10^6$
2014	353,860	$10{,}275 \times 10^6$	6	0.3	$18{,}495 \times 10^6$
2015	372,384	$10{,}214 \times 10^6$	6	0.3	$18{,}384 \times 10^6$
2016	389,093	$10{,}332 \times 10^6$	6	0.3	$18{,}598 \times 10^6$
2017	408,561	$11{,}569 \times 10^6$	6	0.3	$20{,}825 \times 10^6$
2018	422,556	$12{,}312 \times 10^6$	6	0.3	$22{,}162 \times 10^6$
2019	415,139	$12{,}692 \times 10^6$	6	0.3	$22{,}846 \times 10^6$
Total	4,435,998	$128{,}338 \times 10^6$			$231{,}009 \times 10^6$

*Thousand

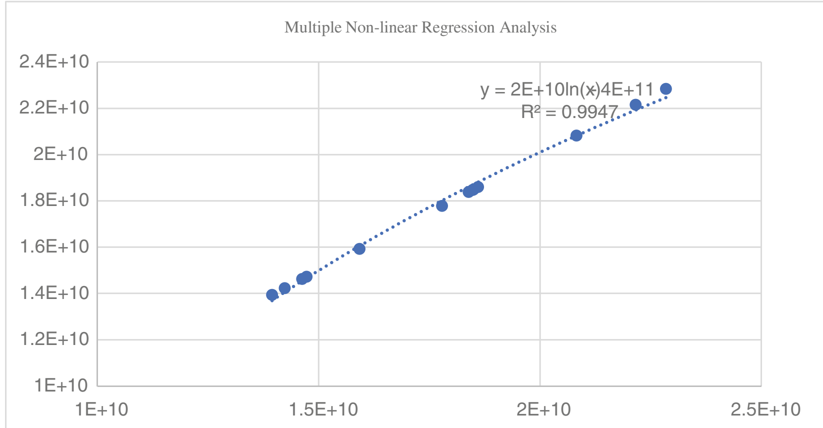

Fig. 4 Multiple nonlinear regression analysis

According to the data obtained from Turkish Electric Institute, electricity consumption in Turkey for the years 2007–2019 is 2,898,040 × 10^6 kWh of which 30% is obtained from natural gas, 34% from coal, 23% from hydraulic energy, 2% from wind, and 11% from other sources [21, 22]. However, the potency of electricity produced from biogas, obtained from animal manure, is 231,009 × 10^6 kWh for the same years as can be seen from Table 4. Namely, 7.97% of the mentioned electricity consumption could be met from biogas, obtained from animal manure as can be seen from this study.

When the data calculated is taken into consideration, the amount of electricity produced from biogas meets the important part of the need. The other important point is the positive environmental effect of this study. Because, when animal manure is not gathered and is not processed to produce biogas, the released methane will damage the atmosphere and the influence of methane on global warming is 25 times higher than CO_2 [9, 21, 22]. So, compared with other renewable energy sources, animal-based biogas production prevents the release of methane and provides an important part of required energy. In other words, producing biogas from manure becomes a necessity to protect nature.

A statistical analysis, which is a multiple nonlinear regression with 2 variables, has been performed for biogas estimation in Microsoft Excel. Animal number and biogas amount obtained have been selected as independent variables while electricity generation is dependent variable. The dependent variable and predicted values converge quite closely as can be seen Fig. 4.

Circular Economy Model for Biogas Facility

Turkey has rich biogas potential, but there is not enough study regarding the evaluation of this potential, and contribution to the economy has not been calculated. For this reason, cost analysis was done using circular economy model in this study. The circular economy model is based on the zero waste principle, where the source is not only transformed into value-added goods, but also the waste streams produced during the cycle are used sustainably [20, 21]. Cost analysis has been performed for Eastern Anatolia Region using an average value of 13 years, because Eastern Anatolia Region has had the greatest biogas potential among Turkey's regions for years

Table 5 Technical features of biogas facility

Waste/raw material type	Bovine animal	Sheep and goats	Poultry	Total
Waste/raw material amount(tons/year)	2341 × 10^4	593 × 10^4	15 × 10^4	2950 × 10^4
Dry matter (%)	25	25	29	
Volatile matter (%)	75	75	71	
Biogas production (m^3 / year)	1756 × 10^6	77 × 10^6	35 × 10^6	1869 × 10^6
Main biogas system equipment				
Front warehouse (m^3)	1 × 600	1 × 600	1 × 600	
Fermenter (m^3)	2 × 2500	2 × 2500	2 × 2500	
Hydraulic waiting time (day)	< 38	< 38	< 38	
The ultimate fertilizer tank (m^3)	1000	1000	1000	
Net electricity generation (kW)	2893 × 10^6	100 × 10^6	370 × 10^6	3364 × 10^6
Net heat generation (kW)	2893 × 10^6	100 × 10^6	370 × 10^6	3364 × 10^6
Organic dry manure (tons/year)	5854 × 10^3	1483 × 10^3	45 × 10^3	7383 × 10^3

Table 6 Cost calculation of the facility

Plant component	Calculation method	Price	Unit
Installation cost	Built-in capacity (kWh) × investment expense (Euro/KWh)	$134{,}578 \times 10^{13}$	€
Expenses			
Use and care of fermenter	(Total investment expenses cogeneration unit investment costs × 3%)	$403{,}735 \times 10^{11}$	€/year
Use and maintenance of the cogeneration unit	Working hours (8000 h/year) × (0.8–1.1) €/h	7600	€/year
Insurance and taxes	Total investment expenses × 0.05–0.10%	$672{,}892 \times 10^{11}$	€/year
Labor	10 Person × 12 months × 1500 €	180,000	€/year
Raw material expenses	Purchase and transport expenses (3 €/t/year)	88×10^{6}	€/year
Total annual expenses		$107{,}672 \times 10^{12}$	*€/year*
Revenues			
Electricity sales	Built-in capacity (kW) × (− 20%) working hours × electricity price (0.07 €/kWh)	$150{,}728 \times 10^{12}$	€/year
Carbon trading	Built-in capacity (kW) × working hours × (− 5%) × green certificate paid (0.02 €/kWh)	$511{,}398 \times 10^{11}$	€/year
Heat used	Cogeneration temperature (kW) × working hours × 0.03 €/kWh	$807{,}471 \times 10^{11}$	€/year
Organic fertilizer sale	Organic fertilizer quantity × fertilizer price (30 €/tons)	221,492,123,1	€/year
Total annual revenue		$282{,}637 \times 10^{12}$	*€*
Discounted payback period (year)	Total installation cost = net current valuation	*10*	*year*

2007–2019. Also, when Turkey's economic reasons is considered, the most suitable place is Eastern Anatolia Region for the biogas plant because it is where there is weak industry and economy. Generally, waste preparation unit, front warehouse, fermenter, the ultimate fertilizer tank, cogeneration unit, separators, gas pipes, valves and fittings, heating system, pumps and mixers, and heat transfer elements are planned to employ in the biogas facility.

The cost calculation of biogas plant is presented in Tables 5 and 6 given below. According to calculations obtained from Tables 5 and 6 and formula given in "Discounted Payback Period," the discounted payback period has been found to be 10 years, namely, the year, which total installation cost equals net current valuation, is tenth year.

Conclusion

In this paper, the potential of biogas and electricity production from the manure of different kind animals have been calculated for Turkey. Eastern Anatolia Region and Central Anatolia Region are of the highest production potency of biogas with 19% compared with Turkey's other regions in 2007–2019. Moreover, the bovine animals have the highest production potential of biogas with 86% compared with sheep and goats and poultry animals in the same years. According to this study, the total potency of biogas amount, obtained from the animal manure, is $128{,}338 \times 10^6$ m^3, while the potential of methane content is $76{,}448 \times 10^6$ m^3 for 2007–2019. Also, the heating value is $2{,}339{,}296 \times 10^6$ MJ while totally $231{,}009 \times 10^6$ kWh potential of electricity has been generated for the same years. Therefore, the significant portion of the electricity need, to be exact a 7.97%, could be met from biogas obtained from animal manure in 2007–2019. In addition, according to presented circular economy model, discounted payback period is found to be 10 years. Considering this research, it can be said that biogas is the one of the most significant renewable energy sources and a profitable field for Turkey.

Data Availability All data analyzed during this study are included in this published article.

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