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ORIGINAL ARTICLE

Mapping of biogas potential of animal and agricultural wastes in Turkey

Mehmet Volkan Aksay[1] · **Abdulsamed Tabak**[2]

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Abstract
This paper presents the biogas potential of animal manure and agricultural waste in Turkey. In the study, results such as the amount of animal manure and agricultural wastes, biogas potential, and electricity generation from biogas are mapped for 12 regions and 81 cities. Additionally, the rate of meeting the electricity demands of cities is found if the biogas potential is converted into electrical energy. Besides, the costs of biogas plant installations for the cities with the highest biogas potential in each region are calculated according to the highest investment conditions. Later, as a result of using biogas for electrical energy, the reduced CO_2 emissions are calculated. According to the results, Turkey's total collectible manure, total collectible agricultural waste, and biogas potential are more than 176 million tons, 17 million tons, and 17 billion m^3 per year, respectively. Turkey's electricity generation potential and total CO_2 emission reduction are more than 38 GWh and 174 million tons per year, respectively. The lowest payback period on investment is determined in the selected city of the Mediterranean region with 5.14 years, while the highest is in the Northeastern Anatolia region with 7.55 years. The results obtained will guide the priority given to the region and type of waste in biogas plant installation. Moreover, it will enable comparison with the investment costs of other renewable energy sources.

Keywords Biogas potential of Turkey · Animal manure · Agricultural waste · Electricity generation · CO_2 emission · Biogas plant · Investment cost

Nomenclature

B_{CO2}	CO_2 Emissions by Storage and Land spread of Biowaste, kg
BP	Biogas Potential, m^3
c	Energy Content of methane, 9.94 kWh/ m^3CH_4
CHP	Combined Heat and Power plants
*CHPCO*2	CO2 emission from CHP, kg /kWh
*COALCO*2	CO2 emission produced by Coal fired plant, kg CO_2/kWh
CRi	Collection Ratio for waste type i, %
EE	Electricity generation from methane, kWh/year
HAi	Harvested Area for cereal type *i*, decare (da)/year
NAi	Number of Animals for type *i*
SMYi	Specific Methane Yield of manure for animal type *i*, m^3 CH_4/tonnes VS
TCA	Total Collectible Agricultural residue, tonnes/year
TCM	Total Collectible Manure for all types of animal, tonnes/year
TMPar	Total Methane Potential of Agricultural Residue, m^3 CH4/year
TMPm	Total methane potential of animal manure, m^3 CH4/year
TMPt	Total Methane Potential, m^3 CH4/year
TSi	Total Solid value for type *i*, %
*TTLCO*2	Total CO_2 emission reduction
UMP	Unit Manure Production, Tonnes manure/year
UMPi	Unit Manure Potential by animal type *i*, tonnes/ animal.year
UMPiar	Unit Methane Potential of agricultural residue for cereal type *i*, m^3CH_4/ tonnes

✉ Mehmet Volkan Aksay
volkanaksay@karabuk.edu.tr

[1] Department of Electricity and Energy, TOBB Tech. Sciences Vocational School, Karabuk University, Karabuk 78050, Turkey

[2] Department of Mechatronics Engineering, Faculty of Engineering, Necmettin Erbakan University, Konya 42090, Turkey

URP_i	Unit Residue Potential for cereal type *i*, tonnes /da
VSi	Volatile Solid value for type *i.*

Abbreviations

ARCGIS	Geographical Information System software
FAO	Food and Agriculture Organization of the United Nations
IDBT	Industrial development bank of Turkey
IRENA	The International Renewable Energy Agency
OECD	Organisation for Economic Co-operation and Development
RES	Renewable energy sources
TETC	Turkish Electricity Transmission Corporation
TPSBO	Turkish Presidency Strategy and Budget Office,
TSI	Turkish Statistical Institute
WBA	World Biogas Association

1 Introduction

Researchers and energy-producing industries switch to alternative energy sources due to environmental pollution created by fossil resources and the decrease in reserves. Renewable energy sources (RES) have started to be preferred more for reasons such as being available in every country in different forms, not releasing carbon, and rapidly decreasing costs in recent years [1, 2].

Especially, developing and developed countries tend to diversify resources while planning their energy supply and making arrangements for the widespread use of RES. The Turkish government plans to increase the share of RES in electricity generation to at least 40% in 2023 [3].

It can benefit from different RES worldwide, such as hydraulic, solar, wind, biomass, and geothermal energy. However, biogas technology has advantages in waste management, partial control of energy production management, environment, and health compared to other RES [4, 5]. Biomass fuels provide baseload power and generate electricity more reliably than intermittent renewable energy sources such as wind and solar since the fuel can be stored and used when in demand [6]. Another advantage of biomass energy is reducing the greenhouse gas effect [7–9].

With the upward growth of population and welfare, the demand for animal food such as meat, milk, dairy products, and eggs increases. Simultaneously with the government's support for farming, animals are advancing in number each year. The increase in animals and agricultural production causes environmental pollution problems. In addition, in developing countries where the agricultural waste management is weak, burning or leaving the post-harvest waste in the field harms the chemical and physical structure of the soil. Biomass energy can be obtained from these biomass sources, reducing the environmental pollution [8–10].

Animal manures and agricultural wastes have been included in many studies in the literature. Ali et al. (2020) [11] investigated the biogas potential from wastes obtained from animal manure and slaughterhouses in Mauritania of Africa. The study indicated that the country's southern regions have high potential, while the northern regions have low potential. Neto and Gallo (2021) [12] presented the biogas potential for anaerobic digestion of vinasse in Brazil. The greenhouse gas emissions prevented by generating electricity from biogas were evaluated by considering fossil-based power plants. Calculations for replacing fossil-based plants with biogas power plants were carried out. Yan et al. (2021) [13] demonstrated the theoretical potential of agricultural wastes of cities in China, and they revealed the rate of utilizing this potential as biogas. Manesh et al. (2020) [14] searched the biogas potential of poultry manure in Iran. Economic analysis, environmental analysis, and environmental impacts in different regions of the country were presented. In the literature, there are few studies on the biogas potential of Turkey. Abusoglu et al. (2021) [15] evaluated the biogas potential of municipal wastewater treatment plants in terms of heating and electricity generation. Özer (2017) [16] determined the biogas potential for animal waste in Ardahan city of Turkey and calculated the reduced CO_2 emissions due to the electrical energy generated from biogas. Çalışkan and Ozdil (2020) [17] demonstrated the potential of biogas obtained from animal wastes in Turkey between 2007 and 2019. According to the results, electricity potential supplied from wastes meets 7.99% of the electricity consumption between 2007 and 2019. Akyürek and Coşkun (2018) [18] revealed the biogas potential obtained from animal waste for the Aegean Region (the western part of Turkey). The study specifies the possible electrical energy produced with this potential and the reduction in CO_2 emissions. Kızılaslan and Kızılaslan (2007) [19] investigated the biogas potential obtained from the waste of different animals. They determined the biogas potential of these animals as 3 billion m^3/year. They have pointed out that Turkey's potential is satisfactory compared with European and middle eastern countries.

When studies on the biogas potential of Turkey are examined, it is seen that a more detailed and comprehensive calculation is required. Since the investment will be around millions of dollars, it is essential to determine the raw material and electricity generation potential closest to the actual values.

Regarding the previous studies, the biogas potential obtained for Turkey is often calculated over animal wastes for specific regions or cities. However, in this study, the amounts of animal manure, agricultural waste, and electricity generation for 12 regions and 81 cities are revealed separately. Additionally, unlike the previous studies, the amount of manure obtained from cattle is determined according to the animal's age. Besides, goat and sheep, laying hen, and broiler chicken were calculated separately instead of categorized as small ruminants and poultry.

Figure 1 shows the level-1 regions of Turkey. Unlike Turkey's geographical regions, this map has been prepared by considering more parameters and in line with the European Union harmonization period. Accordingly, as can be seen from the map, there are 12 regions in Turkey [20].

As a result of the evaluation of biogas potential in Turkey, the possible CO_2 reduction is calculated to reveal the greenhouse gas effect. Furthermore, the cost of biogas plant installation is predicted for the city with the highest potential in each region. Since the study is comprehensive and the results are explained in detail, it benefits academicians and guides the investors.

The rest of the article is designed as follows: Section 2 presents the mathematical expressions used in theoretical calculations, Section 3 gives the results obtained after the calculations, and Section 4 expresses the conclusion.

2 Materials and methods

In this section, mathematical expressions related to obtaining the amount of biogas derived from animal and agricultural wastes, reducing CO_2 emission, and calculating facility costs are explained. ARCGIS software is used to acquire the maps.

2.1 Calculation of manure and biogas potential of animals

To determine the biogas potential, obtaining the collectible animal manure is essential. Calculation of collectible animal manure amount is given in Eq. (1) [16–18].

$$TCM = \sum NA_i \times UMP_i \times CR_i \quad (1)$$

TCM represents total collectible manure for all types of animal (tonnes/year), NA_i is the number of animals for type i, UMP_i is unit manure potential by animal type i, (tonnes/animal-year), CR_i is collection ratio.

Since it is practically not possible to collect all the manures, in this study, the collection ratio parameter is used in Eq. (1) to make a more realistic calculation. Calculation of theoretical biogas potentials is given in Eq. (2) [16–18, 21].

$$TMP_m = \sum TCM_i \times TS_i \times VS_i \times SMY_i \quad (2)$$

TMP_m is total methane (CH_4) potential of animal manure (m^3 CH_4/year), TS_i is total solid value for animal type i, VS_i is volatile solid value for animal type i, SMY_i is specific methane (CH_4) yield of manure for animal type i (m^3 CH_4/tonnes VS).

Fig. 1 Level-1 regions of Turkey

2.2 Calculation of waste and biogas potential of agricultural crops

Equation (3) is used to calculate the amount of collectible agricultural waste [16, 22, 23].

$$TCA = \sum HA_i \times URP_i \times CR_i \quad (3)$$

where *TCA* represents total collectible agricultural residue (tonnes/year), i is type of cereal, HA_i is annual harvested area for cereal type i (decare (da)), URP_i is unit residue potential for cereal type i (tonnes /da), CR_i is collection ratio of agricultural residue.

Calculation of biogas potential obtained from agricultural wastes is given in Eq. (4) [16, 22–24]

$$TMP_{ar} = \sum TCA_i \times UMP_{iar} \quad (4)$$

TMP_{ar} denotes total CH_4 potential of agricultural residue (m^3 CH_4/year), UMP_{iar} is unit CH_4 potential of agricultural residue for cereal type i (m^3CH_4/ tonnes).

2.3 Calculation of energy production from methane

The total methane production obtained from animal and agricultural wastes are calculated by Eq. (5) [16].

$$TMP_t = TMP_m + TMP_{ar} \quad (5)$$

TMP_t is total CH_4 potential (m^3 CH_4/year). The possible electricity generation from methane potential is calculated by Eq. (6) [16, 17, 25, 26].

$$EE = TMP_t \times c \times \eta \quad (6)$$

EE is the amount of possible electricity generation from methane (kWh/year), c is energy content of methane (9.94 kWh/ m^3CH_4) is assumed according to [25], η is Combined Heat and Power (CHP) efficiency. The energy efficiency of cogeneration units is accepted as 90% (40% electrical and 50% thermal) [26].

2.4 *Reduction of CO_2 emissions*

In this study, the data based on the biogas potential are calculated as m^3CH_4/tonnes waste. In the calculations, it is assumed that the biogas contains 55% methane. Equation (7) shows the emissions by storage and land spread of waste (kg) [16, 27].

$$B_{CO_2} = BP \times 9.2 \quad (7)$$

where, *BP* is biogas potential (m^3) and given in Eq. (8). In Eq. (7), the value of 9.2 is CO_2 emission coefficient of directly released biogas to the atmosphere (kg CO_2/m^3 biogas) [16, 27].

$$BP = \frac{TMP_t}{55\%} \quad (8)$$

Equation (9) gives the CO_2 emission from CHP (kg) [16, 27, 28].

$$CHP_{CO_2} = EE \times 0.734 \quad (9)$$

where *EE* is the amount of possible electricity generation from methane (kWh/year), 0.734 is the emission coefficient of electricity production by CHP plants (kg CO_2/kWh).

Equation (10) shows the emission produced by coal fired plant for the same amount of electricity production (kgCO_2/kWh). The emission factor for Turkish coal is assumed as 1 kg of CO_2 per kWh [16, 28].

$$COAL_{CO_2} = EE \times 1 \quad (10)$$

Equation (11) gives the total CO_2 emission (TTL_{CO_2}) reduction achieved using Eq. (7), (9)–(10) [16].

$$TTL_{CO_2} = B_{CO_2} + COAL_{CO_2} - CHP_{CO_2} \quad (11)$$

2.5 Cost analyses for biogas plant installation

The main factors that constitute the costs of biogas plants can be expressed as initial investment costs and annual operating expenses. Annual operating expenses include fermenter utilization and maintenance, cogeneration unit use and maintenance, labor expenses, insurance and taxes, raw material procurement, and transportation expenses. Annual revenues are determined as electricity sales, heat usage, carbon trade, organic fertilizer sales. Table 1 gives the coefficients of cost analyses [17, 29–32]. The coefficients are precisely identified in Table 1 according to Turkey's conditions and data from the literature.

3 Results and discussion

This section includes results of biogas and electricity potentials, greenhouse gas emission reduction, and the installation costs predictions of the facilities planned to be built in selected regions. Results are expressed and interpreted through tables, graphs, and maps.

3.1 Assessment of Turkey's animal manure and biogas potential

Despite the growth in the number of animals leading to waste and environmental pollution issues, biogas, energy, and organic fertilizer can be obtained by appropriate waste management.

Table 1 Coefficients of cost analyses

	Costs	Method	Ref
Initial cost	Installation cost	Installed capacity (kW) × invesment cost (4000 €/kW)	[17, 29, 32]
Expenses	Utilization and maintenance of fermenter	(Total installation cost – Cogenaration invesment costs) × 3%	[17, 29, 31]
	Utilization and maintenance of cogeneration unit	Operating hours (8000 h/year) × (0.8–1.1) € /h	[17, 29]
	Labor expenses	10 people × 12 months × 1500 €	[17, 29]
	Insurance and taxes	Total installation cost × (5–10%)	[17, 29]
	Raw material supply and transport	Annual raw material (tonnes) × 3–6 €/tonnes	[17, 29, 30]
Revenues	Electricity sales	Installed capacity (kW) × 80% operating hours (8000 h/year) × Electricity price (0.113 €/kWh)	[17, 29]
	Heat usage	Installed heat capacity (kW_{heat}) × Operating hours (8000 h/year) × 0.03 €/kWh	[17, 29]
	Organic fertilizer sale	Organic fertilizer production × 30 €/tonnes	[17, 29]
	Carbon trade	Installed capacity (kW) × (− 5%) Operating hours (8000 h/year) × Green certificate payment (0.02 €/kWh)	[17, 29]

The number of animals used in calculations relating to manure is acquired from data provided by Turkish Statistical Institute (2020) and classified as cattle, goat, sheep, poultry (egg), poultry (broiler) [33].The total amount of manure that can be obtained depends on the number of animals, type, size, unit manure production, and collection rate; moreover, the amount of biogas varies according to the amount of manure, total solids, volatile solids, and methane yield. These values are obtained from studies in the literature and are shown in Table 2 [16, 18, 24, 34, 35].

The unit manure production amount for cattle 2 years and older is assumed as 13.7 kg/day, and the unit coefficients of animals for 2 years and over, 1–2 years, and less than 1 year old are considered as 1.0.7 and 0.3, respectively. [24]. The unit manure production of goats and sheep is mostly stated under a single value under the name of small ruminants in related studies, but in this study, these data are indicated separately. Likewise, broiler and laying hens are also mentioned as poultry in the literature, and unit manure productions are frequently stated under a single value. Still, in this study, these data are given individually. Since the unit manure production amount of goats, sheep, and especially poultry is relatively low compared to cattle and does not show a significant difference according to the animal's age, it is not calculated separately according to their age. Animals other than those specified above are not evaluated owing to their small population or the futility of gathering their manure.

Table 3 gives the total manure and biogas potential of Turkey. It is clear from Table 3 that the maximum methane is supplied with a volume of 2.22 billion m^3 CH_4 from cattle over 2 years old. This yield is followed by a 1–2-year-old cow and poultry (broiler), respectively. Goats with 24 million m^3 CH_4 have the minimum methane potential.

Important factors in biogas production, such as total solids, volatile solids and methane yield, vary according to animal species. Maximum methane potential in Turkey can be obtained from the manure of cattle, poultry, and small ruminants, respectively. In animal husbandry, issues such as climatic conditions that animals require, the growing potential of forage crops, the population of the region and the balance of demand and supply for animal products, the public's interest in agriculture and animal husbandry, and livelihoods of residents are significant [36].

Figure 2 shows the manure potential by region in Turkey. As shown in Fig. 2, cattle manure potential is predominantly formed in Northeastern Anatolia and Aegean

Table 2 Manure characteristics for methane production

Type of animal	Unit manure production (tonnes manure/year)	Collection ratio (%)	Total solids (%)	Volatile solids (%)	Specific methane yield m^3CH_4 /tonnes VS	d
Cattle 0–1 yo	4.11	0.5	0.15	0.8	200	[24, 25]
Cattle 1–2 yo	9.59	0.5	0.15	0.8	200	
Cattle > 2 yo	13.7	0.5	0.15	0.8	200	
Sheep	0.75	0.13	0.25	0.2	300	[17, 18, 25, 34, 35]
Goat	0.87	0.13	0.3	0.2	300	
Poultry (broiler)	0.069	0.99	0.25	0.7	350	[16, 18, 25]
Poultry (egg)	0.047	0.99	0.25	0.7	350	

Table 3 Total manure and biogas potential of Turkey

Type of animal	Number of animals in Turkey-2020	Total collectible manure (tonnes manure/year)	Total methane potential (m^3 CH_4)
Cattle 0–1 yo	4,617,821	9,489,622.15	227,750,931.7
Cattle 1–2 yo	9,575,530	45,914,666.35	1,101,951,992
Cattle > 2 yo	13,524,891	92,645,503.35	2,223,492,080
Sheep	42,126,781	4,107,361.15	61,610,417.21
Goat	11,985,845	1,355,599.07	24,400,783.25
Poultry (broiler)	258,046,340	17,627,145.49	1,079,662,661
Poultry (egg)	121,302,869	5,644,222.49	345,708,627.8
Total	461,180,077	176,784,120.10	5,064,577,494

Region. The Northeastern Anatolia region is leading due to its provincial location and the great number of meadow fields [17, 37]. Istanbul is a metropolitan city where about 20% of Turkey's population lives; animal husbandry is not common because of the high population and lack of space. Consequently, it is the region with minimum potential for animal manure [38].

When Fig. 2 is evaluated in terms of small ruminants, it is seen that manure potentials emerging from small ruminants are at significant levels in Southeastern Anatolia, Mid-Eastern Anatolia, Mediterranean, Aegean, and Western Anatolia, respectively. One of the remarkable reasons the Southeastern Anatolia Region is the leader is owing to the cuisine culture of the region. Climatic conditions and the abundance of sheep and goat fodder plants are other critical conditions for animal husbandry [17, 39].

When evaluating the poultry manure potential in Fig. 2, it is clear that the regions with the highest percentage of poultry manure potential are Eastern Marmara, Aegean, West Marmara, and Mediterranean regions, respectively. The most prominent reason is that Istanbul is neighbor to the East and the West Marmara, and a substantial part of Turkey's population lives in these regions. In addition, unfortunately, because of the increasing demand and rapid production in poultry farming, animals are usually held in closed areas, and there is no demand for as much space as cattle and sheep. For this reason, the number of poultry farms is high, close to big cities [40].

In Fig. 3, where biogas yields from animal waste are shown, the Aegean region is the leader in total methane potential. Aegean possesses tremendous potential due to having a convenient climate for agriculture and animal husbandry and owning Turkey's 3rd most populated city (Izmir). It has a high demand for animal products, consequent high tourism potential of the region and people's interest in agriculture and animal husbandry [18]. The yields of other regions seem in balance. Nevertheless, the reason for the poor potential of the eastern Black Sea region is a sparse population of animals because of the mountainous nature of the region [41]. Due to the surplus amount of manure, the most substantial yield is generated from cattle manure. The low methane yield obtained from

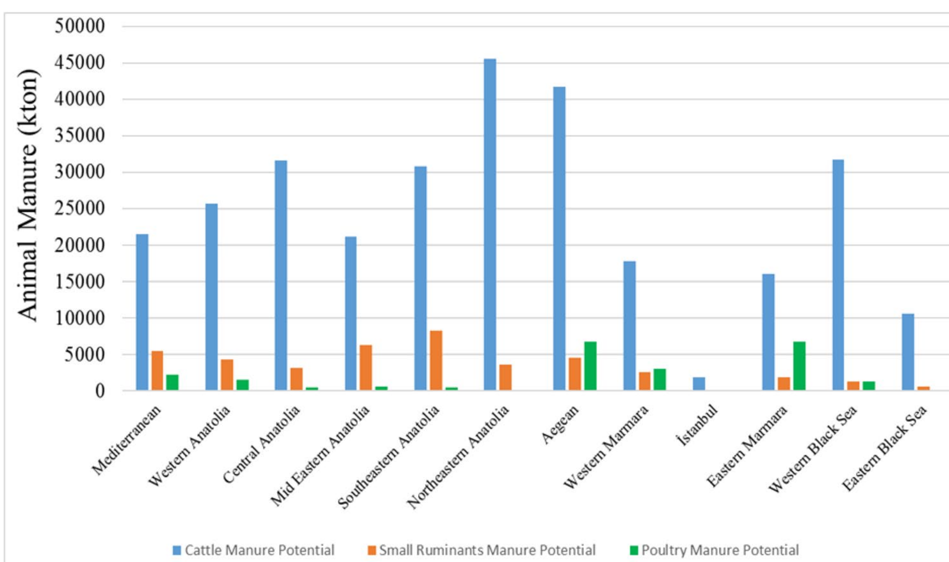
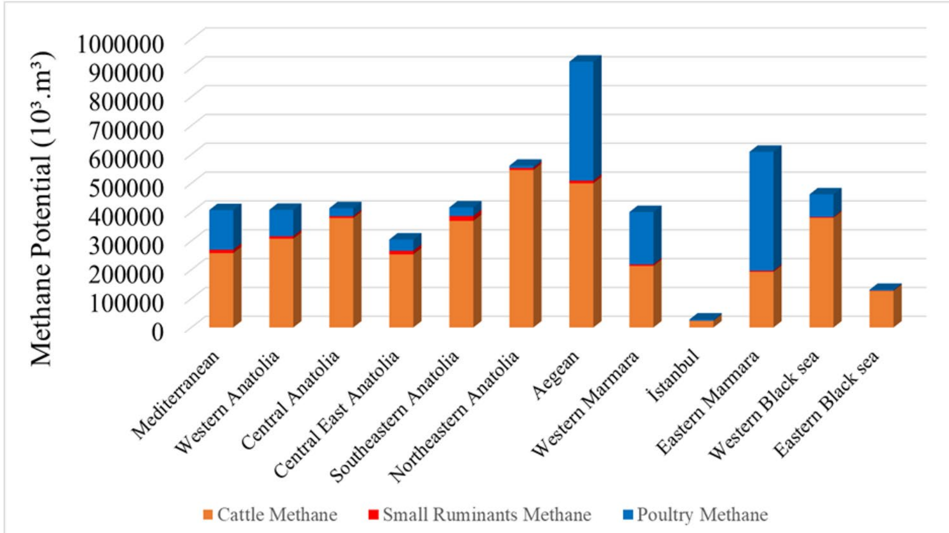


Fig. 2 Manure potential by region in Turkey

Fig. 3 Methane potential from manures by region in Turkey



small ruminants is because of the collectibility, low total solids, volatile solids ratios, and the small number of animals and manures.

The methane potential of cities from cattle manure is shown in Fig. 4. The wealthiest cities in terms of methane potential arising from cattle manure are considered as Erzurum (Northeastern Anatolia) with 182 million m^3CH_4/year, Konya (Western Anatolia) with 167 million m^3CH_4/year, Diyarbakır (Southeastern Anatolia) with 143 million m^3CH_4/year, Izmir (Aegean) with 133 million m^3CH_4/year, Kars (Northeastern Anatolia) with 126 million m^3CH_4/year, and Ankara (Western Anatolia) with 125 million m^3CH_4/year, respectively. In the predictions carried out for other regions, the cities with the most significant potential and their values are as follows; Balıkesir (Western Marmara) with 96 million m^3CH_4/year, Samsun (Western Black Sea) with 80.8 million m^3CH_4/year, Sivas (Central Anatolia) with 80 million m^3 CH_4 /year, Muş (Mid-Eastern Anatolia) with 69 million m^3 CH_4/year, Adana (Mediterranean) 50 million m^3 CH_4/year, Bursa (Eastern Marmara) with 45 million m^3

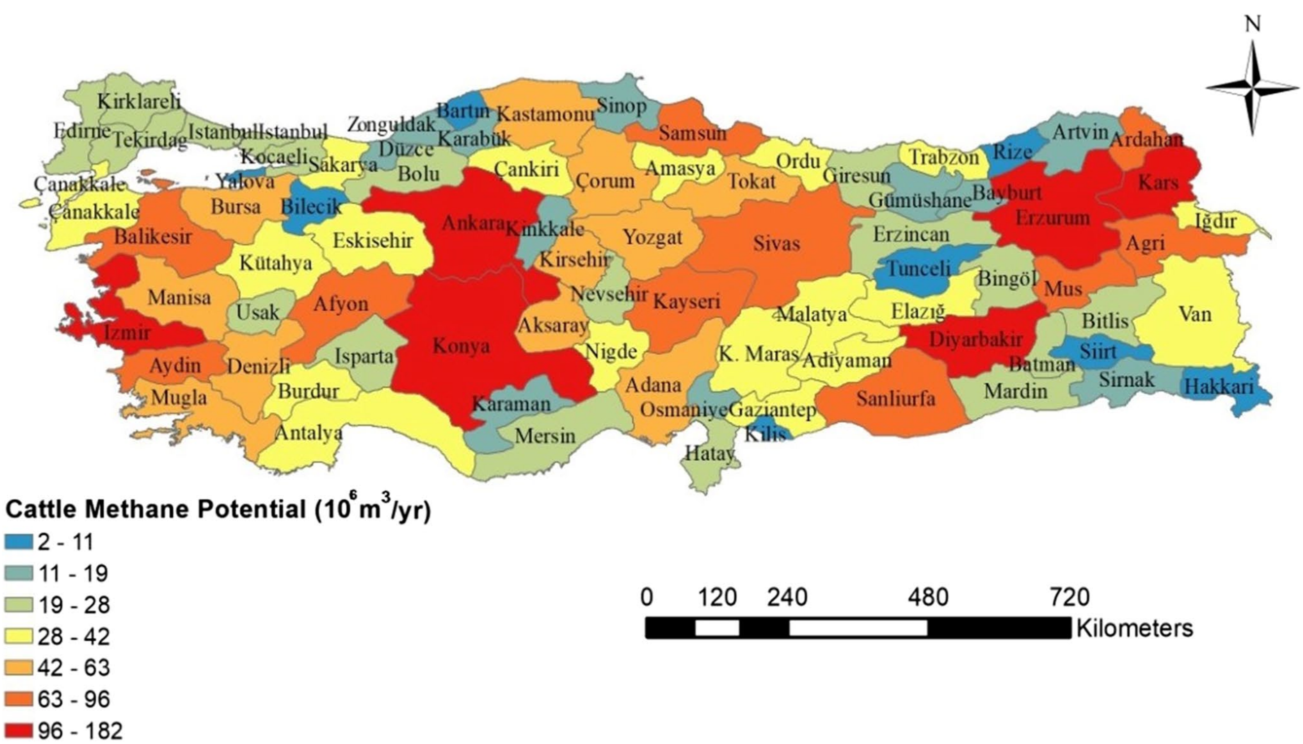


Fig. 4 Methane potential of cities from cattle manure

CH_4/year, Trabzon (Eastern Black Sea) with 32 million m^3 CH_4/year, İstanbul with 23 million m^3 CH_4/year.

Although the values given in Figs. 2 and 3 differ from the relevant studies in the literature due to the number of animals in the selected year, it is still seen that they are compatible in determining the city with high potential. Caglayan (2020) evaluated the biogas potential of cattle manure in the Northeastern Anatolia region and pointed out that Erzurum and Kars have the greatest potential in the region, respectively [42]. Caliskan and Ozdil (2020) investigated the biogas and electricity production potential of Turkey and indicated that the Eastern Anatolia and the Western Anatolia regions have higher potential with 19% compared to the rest of Turkey [17]. Lule (2019) determined the biogas potential of animal manures in the Southeastern Anatolia Region, and according to the results, Diyarbakır had the most potential, whereas Kilis has the least [43]. In another study, Karaca (2018) investigated the biogas potential of animal manures in Turkey with 2015 data. The most remarkable cities were Konya, Izmir, Erzurum, Balikesir, Afyon and Kars, respectively [44].

Figure 5 shows the methane potential of cities from small ruminants. The wealthiest cities in terms of methane potential from small ruminants manure are noted as Van (Mid-Eastern Anatolia) with 4.7 million m^3CH_4/year, Konya (Western Anatolia) with 4.3 million m^3CH_4/year, Şanlıurfa (Southeastern Anatolia) with 3.9 million m^3CH_4/year, Diyarbakır (Southeastern Anatolia) with 3.3 million m^3CH_4/year, Mersin (Mediterranean) with 3.2 million m^3CH_4/year, Ankara (Western Anatolia) with 3.1 million m^3CH_4/year, respectively.

In other regions, the cities with the highest potential in their regions are listed as follows; Balıkesir (Western Marmara), with 2.2 million m^3CH_4/year, Ağrı (Northeastern Anatolia), with 2 million m^3 CH_4/year, Afyon (Aegean), with 1.8 million m^3CH_4/year, Eskişehir (Eastern Marmara), with 1.7 million m^3 CH_4/year, Aksaray (Central Anatolia), with 1.5 million m^3CH_4/year, Tokat (Western Black Sea), with 0.7 million m^3CH_4/year, Trabzon (Eastern Black Sea), with 0.27 million m^3CH_4/year, İstanbul, with 0.25 million m^3CH_4/year.

In relevant studies, Yılmaz and Saka (2017) examined the biogas potential from small ruminants in the Southeastern region. They pointed out that Diyarbakır and Şanlıurfa have the highest biogas potentials in the region [45]. Caglayan (2020) studied Mid-Eastern Anatolia region biogas potentials, and results showed that Van was the wealthiest city on small ruminants-based biogas potential [42]. Thus, it is seen that the data given above are compatible with the literature. In addition, there are no similar studies related to other cities.

It has been observed that the methane potential derived from small ruminant manure is slighter than the cattle manure potential due to the small amount of livestock and

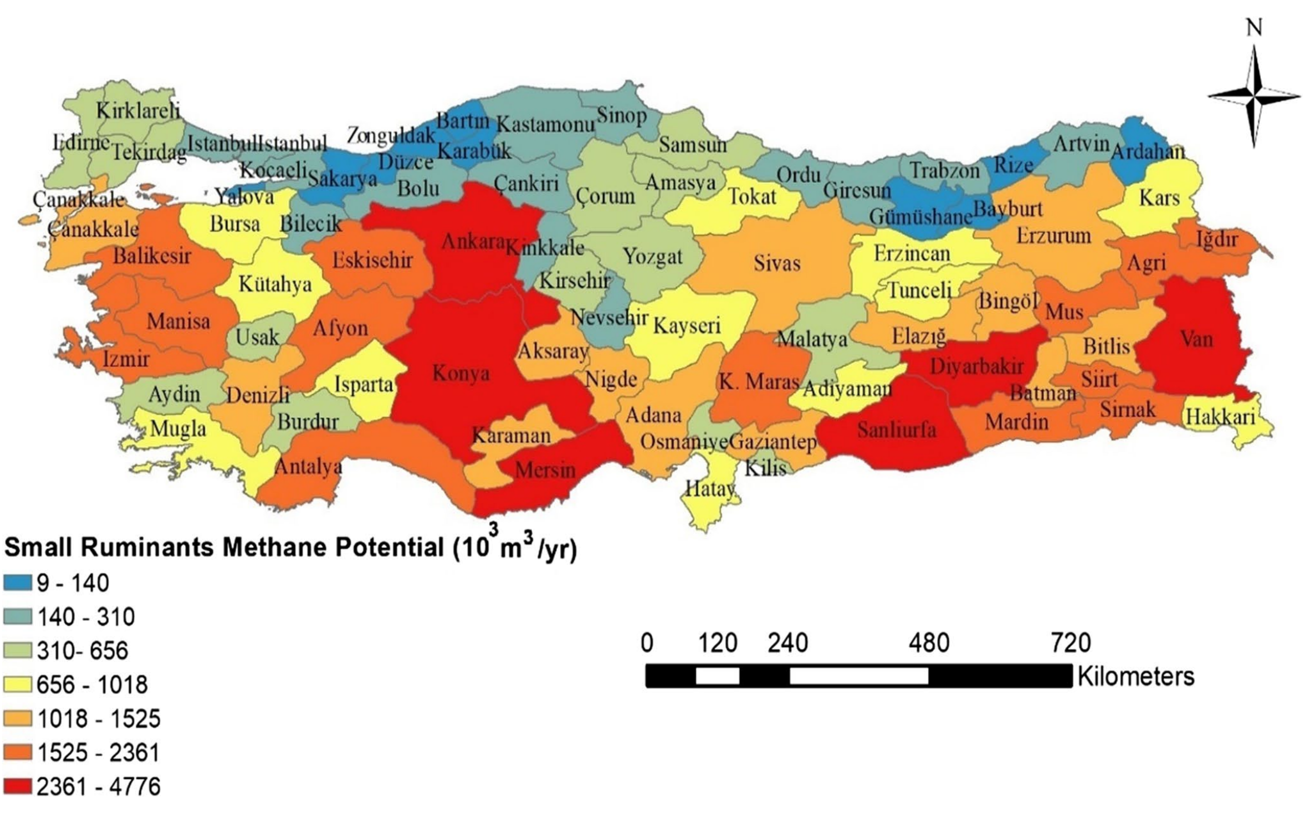


Fig. 5 Methane potential of cities from small ruminants

unit manure production. In line with the data above, it does not seem possible to establish a facility where only sheep and goat manure are handled as raw material. However, in some studies in the literature, it has been stated that this manure increases methane yield due to cofermentation with other animal wastes or agricultural wastes [46–49]. For this reason, it is recommended to establish a facility in places with high potential if the volume and supply of alternative wastes in the region are possible.

Figure 6 demonstrates the methane potential of cities from poultry manure. Regarding the poultry methane potentials given in Fig. 8, it is seen that Manisa (Aegean) with 190 million m^3CH_4/year, Balıkesir (Western Marmara) with 148 million m^3CH_4/year, Bolu (Eastern Marmara) with 136 million m^3CH_4 /year and Sakarya (Eastern Marmara) with 125 million m^3CH_4/year, have a strong capacity, respectively.

The municipalities with the most considerable efficiency in other regions and the data obtained are specified as follows; Ankara (Western Anatolia), with 55 million m^3CH_4/year, Zonguldak (Western Black Sea), with 27 million m^3CH_4/year, Malatya (Mid-Eastern Anatolia), with 16.7 million m^3CH_4/year, Gaziantep (Southeastern Anatolia), with 16.1 million m^3CH_4/year, Erzincan (Northeastern Anatolia), with 4.7 million m^3CH_4/year, Istanbul, with 4.4 million m^3CH_4/year, Ordu (Eastern Black Sea), with 1.5 million m^3CH_4/year, Aksaray (Central Anatolia), with 0.8 million m^3CH_4/year.

Avcioglu et al. (2013) investigated the biogas potential of chicken waste in Turkey with the data of 2009. They listed the provinces with the highest potential as Bolu, Balıkesir, Sakarya, Manisa, Afyon, Konya, İzmir, Ankara, Çorum and Bursa, respectively, according to the waste map they prepared. Comparing data above, the number of animals and biogas potential has increased even more, and some new cities have progressed in this sector [50].

It is clearly observed that the potential is less than the other regions in the east of the map, along the Black Sea and Mediterranean coasts. Intensity is growing in the west of the country, in the Aegean and neighboring Marmara regions. Poultry manure, nevertheless, has valuable potential. However, not as much as the methane potential of cattle manure can be applied as co-substrate by installing cofermentation type systems in cities with high potential or in regions where other animals and agricultural waste are abundant. Research in the literature on this subject has been observed to enhance methane yield [51–55].

In Fig. 7, where methane yields from all animal manures are shown, cities of Balıkesir (Western Marmara) with 247 million m^3CH_4/year, Manisa (Aegean) with 237 million m^3CH_4/year, İzmir (Aegean) with 214 million m^3CH_4/year, Konya (Western Anatolia) with 204,364,467.8 m^3CH_4/year, Erzurum (Northeastern Anatolia) with 184.5 million m^3CH_4/year, Ankara (Western Anatolia) with 184.2 million m^3CH_4/year, Sakarya (Eastern Marmara) with 163 million m^3CH_4/year, Bolu (Eastern Marmara) with 161 million m^3CH_4/year, Diyarbakır (Southeastern Anatolia) with 149 million m^3CH_4/year, are listed as the municipalities with the highest potential, respectively.

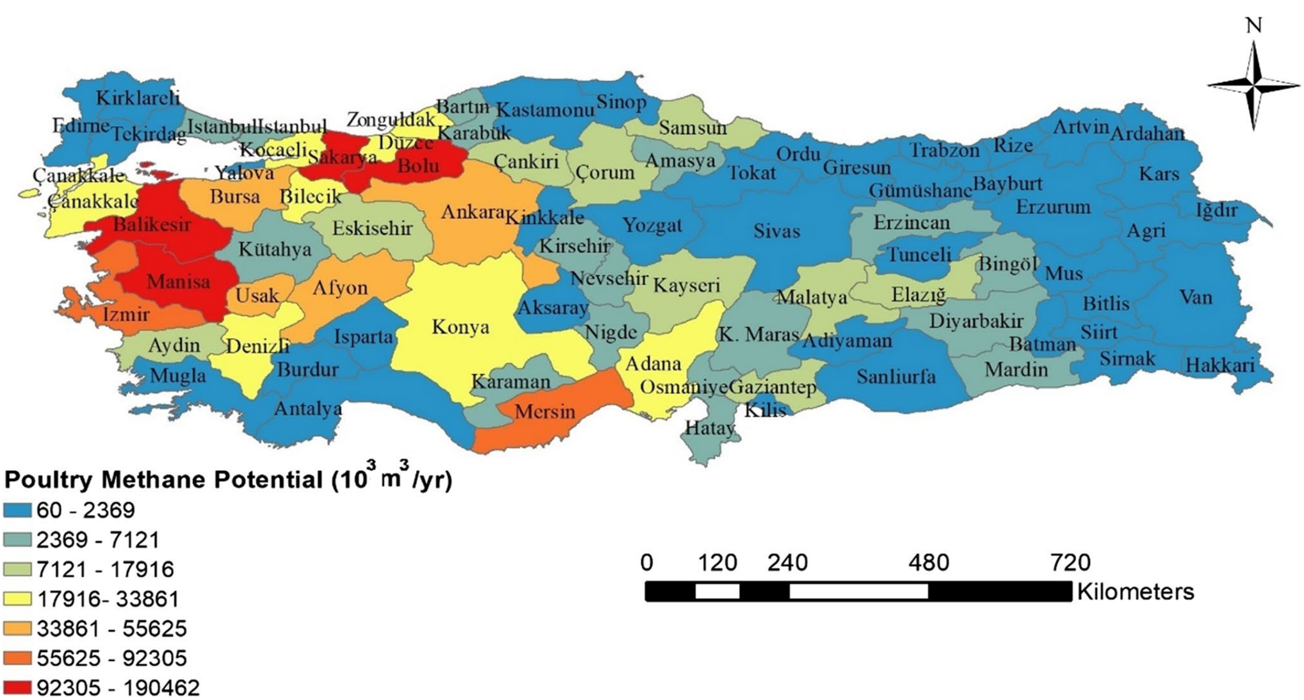


Fig. 6 Methane potential of cities from poultry manure

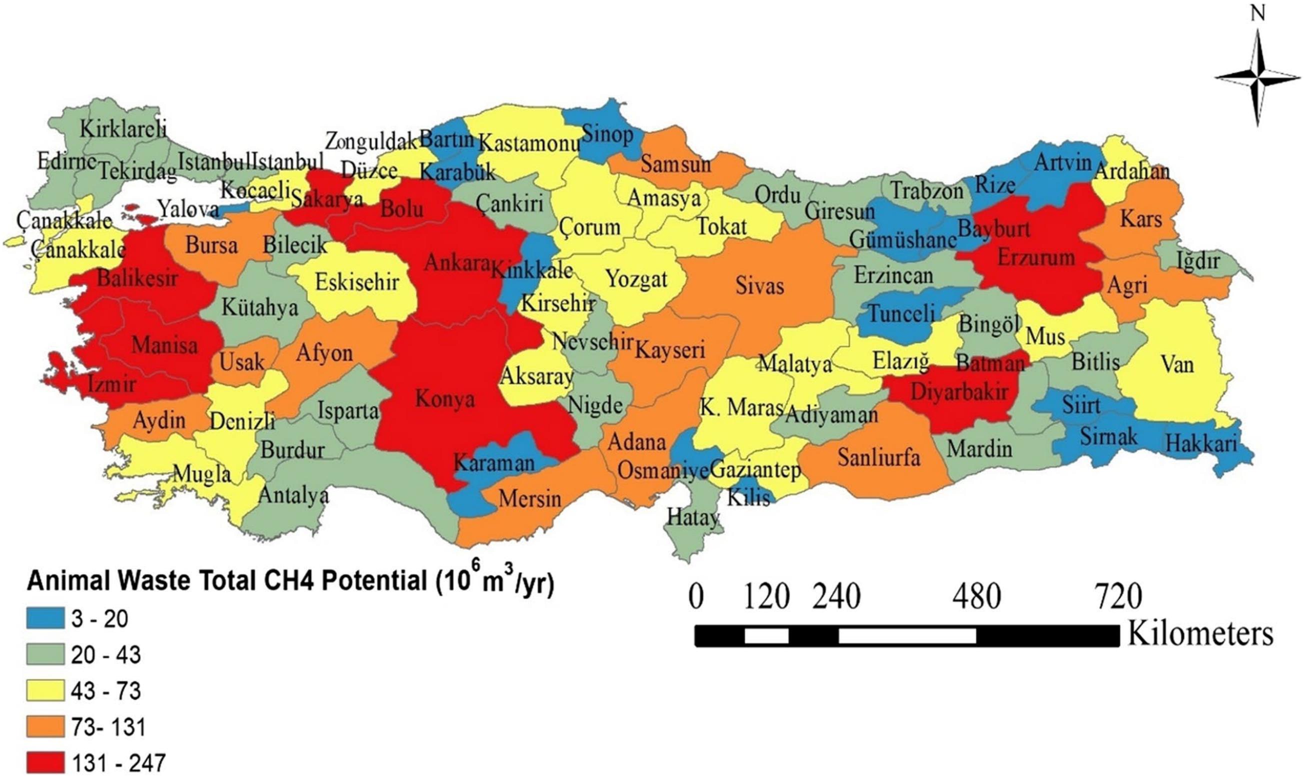


Fig. 7 Methane potential of cities from animal waste

The cities with the lowest potential are low-populated cities with inadequate animal presence. These are Osmaniye (Mediterranean) with 20.8 million m^3CH_4/year, Sinop (Western Black Sea) with 20.4 million m^3CH_4/year, Şırnak (Southeastern Anatolia) with 19.7 million m^3CH_4 /year, Karaman (Western Anatolia) with 19.4 million m^3CH_4/year, Bayburt (Northeastern Anatolia) with 19.3 million m^3CH_4/year, Karabük (Western Black Sea) with 19.1 million m^3CH_4/year, Gümüşhane (Eastern Black Sea) with 18.3 million m^3CH_4/year, Artvin (Eastern Black Sea) with 17 million m^3CH_4/year, Kırıkkale (Central Anatolia) with 16.7 million m^3CH_4/year, Bartın (Western Black Sea) with 15 million m^3CH_4/year, Siirt (Southeastern Anatolia) with 11.4 million m^3CH_4/year, Hakkari (Mid-Eastern Anatolia) with 10.8 million m^3CH_4/year, Tunceli (Mid-Eastern Anatolia) with 8.5 million m^3CH_4/year, Rize (Eastern Black Sea) with 4.6 million m^3CH_4/year, Kilis (Southeastern Anatolia) with 4.1 million m^3CH_4/year, respectively.

Avcioglu and Turker (2013) examined possible biogas values from manures in Turkey in a related study. And Bolu, Balıkesir, Izmir, Sakarya, Konya, Manisa, Erzurum, Afyon, Kars ve Ankara were the cities that have the potential of biogas over 1 PJ. Thus, it is seen that the data obtained in this study and given above are compatible with the literature [34].

Some regions may include cities with both poor and rich biomass potentials. Decrease in the number of labor in agriculture and animal husbandry, insufficient area for agriculture and animal husbandry, incentives, and supports for smaller cities development are some reasons for this situation.

When the potentials of animal-sourced methane are assessed based on regions, it is listed as follows; Aegean, with 922 million m^3CH_4/year, Eastern Marmara, with 609 million m^3CH_4/year, Northeastern Anatolia, with 561 million m^3CH_4/year, Western Black Sea, with 461 million m^3CH_4/year, Southeastern Anatolia, with 416 million m^3CH_4/year, Central Anatolia, with 413 million m^3CH_4/year, Western Anatolia, with 408 million m^3CH_4/year, Mediterranean, with 407 million m^3CH_4/year, Western Marmara, with 400 million m^3CH_4 /year, Mid-Eastern Anatolia, with 305 million m^3CH_4 /year, Eastern Black Sea, with 130 million m^3CH_4/year and Istanbul, with 27 million m^3CH_4/year.

Regarding data calculated, it can be expressed that almost all regions have a respectable biogas potential. Biogas can be purified and utilized to meet the local natural gas need or get electricity and heat energy by operating cogeneration systems. In addition, organic fertilizer remains at the end of biogas production can be used for agricultural activities in the region. Thus, the cost of fertilizers and the damages caused by artificial fertilizers in the soil can be reduced.

The amounts of animal waste that can be collected regionally are as follows; Aegean with 53 million tonnes/year, Northeastern Anatolia with 49 million tonnes/year, Southeastern Anatolia with 39 million tonnes/year, Central

Anatolia with 35 million tonnes/year, Western Black Sea with 34 million tonnes/year, Western Anatolia with 31 million tonnes/year, Mediterranean with 29 million tonnes/year, Mid-Eastern Anatolia with 28 million tonnes/year, Eastern Marmara with 24 million tonnes/year, Western Marmara with 23 million tonnes/year, Eastern Black Sea with 11 million tonnes/year, Istanbul with 2 million tonnes/year.

3.2 Assessment of Turkey's agricultural waste and biogas potential

The total amount of agricultural waste that can be obtained varies according to the size of the cultivated area, the amount of agricultural waste generated per decare, and the collection ratio. The amount of biogas varies according to the total amount of collectible agricultural waste and the unit methane yield of the agricultural waste. These values are obtained from studies in the literature and are shown in Table 4 [16, 22–24].

In agricultural waste estimations, the fields where the top 5 most-produced agricultural crops harvested in each region are used. These statistics are taken from the data provided by the Turkish Statistical Institute for the year 2020 [33]. According to data obtained from the literature, the collection ratios of agricultural wastes are adopted as 40% for cereals such as wheat, rye, barley, oat, and 50% for sunflower, rapeseed, rice, and maize, regardless of location [23]. The issue that should be given priority in obtaining energy from agricultural wastes is that those wastes that can be used as animal fodder are not considered. Thus, agricultural products such as sainfoin, wild vetches, maize silage, beets for fodder, turnip (for fodder), wheat (green), barley (green), rye (green), pea (fodder) (green), cow vetches, clover, alfalfa, meadow grass, oats (green), sorghum (green), triticale (green), grass pea (green), Italian ryegrass are not held in the assessment. The harvested areas of agricultural crops held in the calculations and the amount of waste that can be obtained are given in Table 5.

Figure 8 shows the methane potential from agricultural residues by region in Turkey. As seen in Fig. 8, the Southeastern Anatolia region and the Western Anatolia region are the leaders in terms of agricultural waste potential. Here, factors such as the interest of the people in agriculture and the livelihood, the climatic conditions in cereal production, the access of water resources to the field, and soil productivity play an important role. The reason the Istanbul region has the lowest potential stems from the fact that it is a metropolis with a huge population. There are no adequate fields for agriculture and animal husbandry. Although the Northeast Anatolia region has high values in terms of animal husbandry, it has a low agricultural methane potential due to the climatic conditions and the fact that agricultural products used as animal fodder in this study are not considered in this study. The Eastern Black Sea region also has low values due to the adverse effects of its climate and geographic characteristics on cereal production and the widespread cultivation of products such as tea and hazelnut. These productions are excluded from the calculations.

The methane potential of cities from agricultural waste is demonstrated in Fig. 9. Regarding the methane potentials of agricultural residues given in Fig. 9, it is seen that Konya (Western Anatolia) with 478 million m^3 CH_4/year, Şanlıurfa with 358 million m^3 CH_4/year, Adana (Mediterranean) with 221 million m^3 CH_4/year, Ankara (Western Anatolia) with 220 million m^3 CH_4/year, Diyarbakır (Southeastern

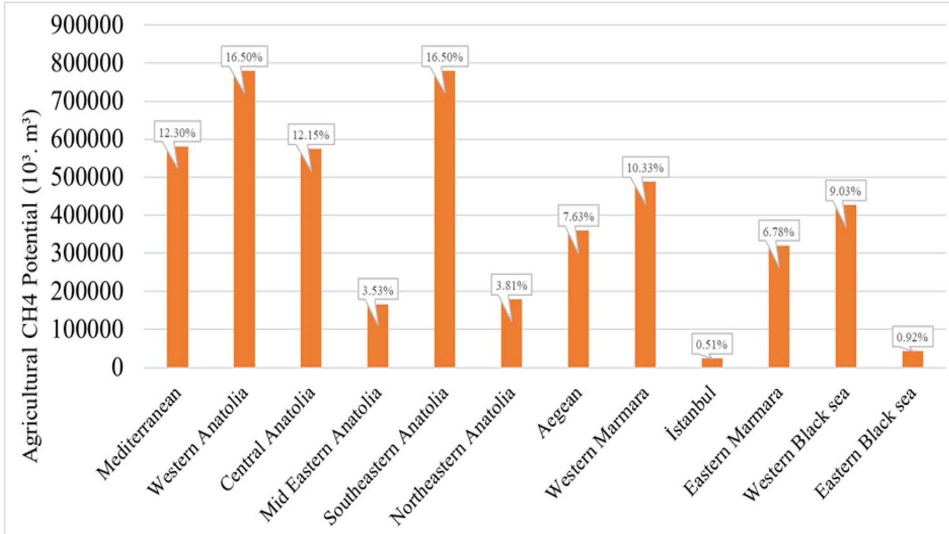
Table 4 Agro-waste characteristics for methane production

Cereal type	Wheat	Barley	Maize	Rice	Oat	Rye	Sunflower	Ref
Residue (tonnes/da)	0.325	0.20	1.48	0.60	0.434	0.450	0.6	[22, 24]
Collection ratio (%)	40	40	50	50	40	40	50	[23]
Unit CH_4 (m^3/tonnes)	295.2	351.9	250.9	260.5	156	273.6	154	[16, 24]

Table 5 Total agro-waste potential of Turkey

Type of crop	Harvested area (da)	Collectible waste (tonnes)	Total methane potential (m^3 CH_4)
Wheat	56,574,622	7,354,700	2,171,107,693
Maize	6,699,454	4,951,953	1,242,445,123
Barley	29,005,975	2,320,478	816,576,208
Sunflower	7,283,680	2,185,104	336,506,016
Rice	1,202,705	359,941.50	93,764,760.75
Oat	1,062,648	184,475.69	28,778,208.08
Rye	615,799	111,829.10	30,596,441.32
Total	102,444,883	17,468,482.61	4,719,774,451.34

Fig. 8 Methane potential from agricultural residues by region in Turkey



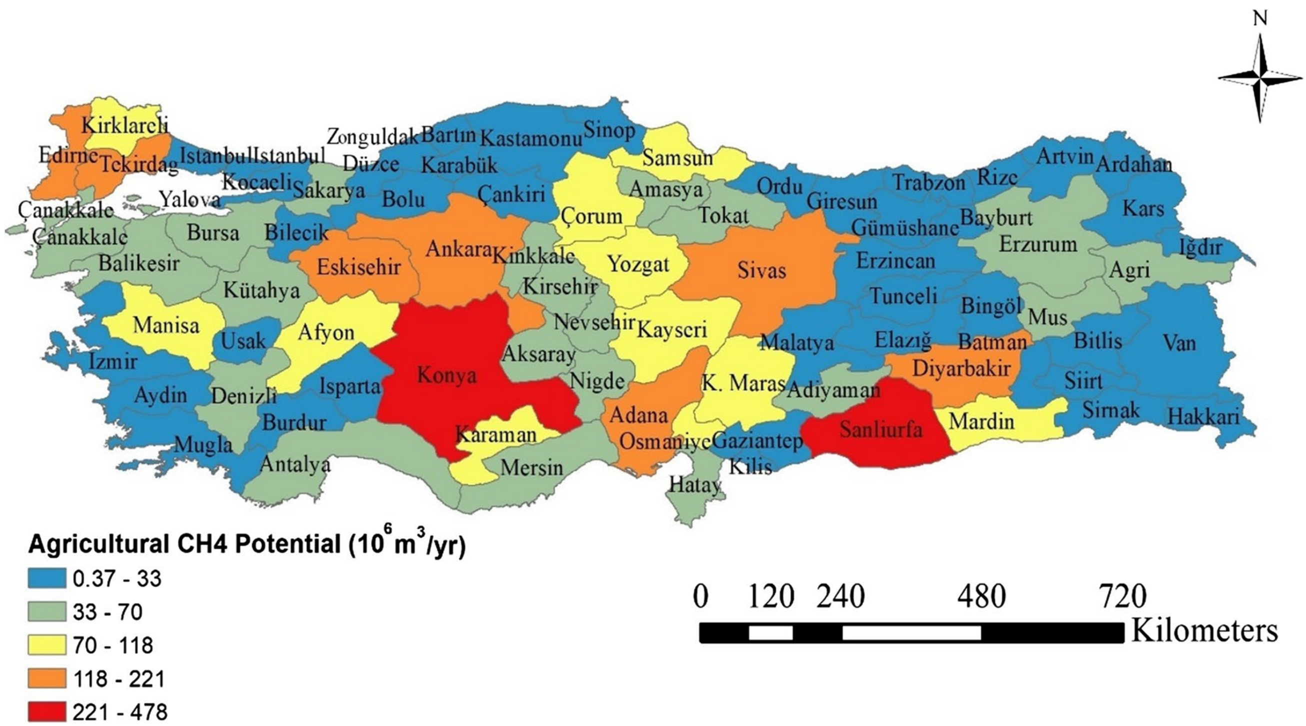


Fig. 9 Methane potential of cities from agricultural waste

Anatolia) with 162 million m^3 CH_4/year, Eskişehir (Eastern Marmara) with 143 million m^3 CH_4/year, Edirne (Western Marmara) with 133 million m^3 CH_4 /year, Mardin (Southeastern Anatolia) with 118 million m^3 CH_4/year, have a great volume, respectively.

When the methane potentials deriving from agricultural wastes are classified based on regions, the ranking is as follows; Southeastern Anatolia with 779.16 million m^3 CH_4/year, Western Anatolia with 779.12 million m^3 CH_4/year, Mediterranean with 581 million/year, Central Anatolia with 573 million m^3 CH_4/year, Western Marmara with 487 million m^3 CH_4/year, Western Black Sea with 426 million m^3 CH_4/year, Aegean with 360 million m^3 CH_4/year, Eastern Marmara with 320 million m^3 CH_4/year, Northeastern Anatolia with 180 million m^3 CH_4/year, Mid-Eastern Anatolia with 166 million m^3 CH_4/year, Eastern Black Sea with 43 million m^3 CH_4/year, Istanbul with 24 million m^3 CH_4/year.

In a similar study, Aybek et al. (2015) investigated Turkey's biogas potential from agricultural waste and determined the wealthiest region as Southeastern Anatolia Region and the poorest region as the Eastern Black Sea region [56]. In another study on the subject, Çakal and Çelik (2021) calculated the cities with the highest potential as Konya, Adana, and Urfa, and the cities with the lowest potential as Rize Yalova Ardahan [57]. The data given in the figure seem to comport with these studies.

3.3 Electricity generation potential from biogas obtained from animal and agricultural waste

Figure 10 and Table 6 show the biogas potential according to the regions and the corresponding electricity generation amounts. The estimation of electricity production from biogas is found according to Eqs. (5)–(6). Accordingly, while an annual electricity generation potential of 4754 GWh is in the Southeastern Anatolia region, 205 GWh is in the Istanbul region.

Figure 11 shows the map of the rate of meeting the electric energy demand of the cities with electricity produced from biogas. Accordingly, 6 cities, which are seen in red, can meet more of their annual electricity demands with electricity produced from biogas obtained from animal and agricultural waste. The number of cities that can meet 75.03–100% of the annual electricity demand is three, and they are located in Central Anatolia. Among the yellow-colored cities that can meet 39.55–75.03% of their electricity need from biogas, big cities such as Konya with a population of 2,250,000 and Diyarbakır with a population of 1,783,000. It is seen from Fig. 11 that the electricity needs of cities can be met from biogas by agriculture and animal husbandry. On the other hand, blue-colored cities can produce 18.15% of their electricity demand from biogas. The main reasons for this are that their population is high or that agriculture and animal husbandry are not vital together.

Table 6 Electricity production potential of regions from total biogas

Regions	Methane production (m^3)	Total electricity production (kWh/yr)
Mediterranean	988,348,149	3,929,672,242
Western Anatolia	1,187,220,258	4,720,387,747
Central Anatolia	987,591,905	3,926,665,417
Mid-Eastern Anatolia	471,834,812	1,876,015,216
Southeastern Anatolia	1,195,729,945	4,754,222,264
Northeastern Anatolia	740,840,393	2,945,581,403
Aegean	1,282,227,558	5,098,136,770
Western Marmara	888,259,879	3,531,721,279
İstanbul	51,692,775	205,530,474
Eastern Marmara	929,646,736	3,696,275,425
Western Black Sea	888,339,944	3,532,039,620
Eastern Black Sea	174,261,923	692,865,408
Turkey (Total)	9,785,994,283	38,909,113,270

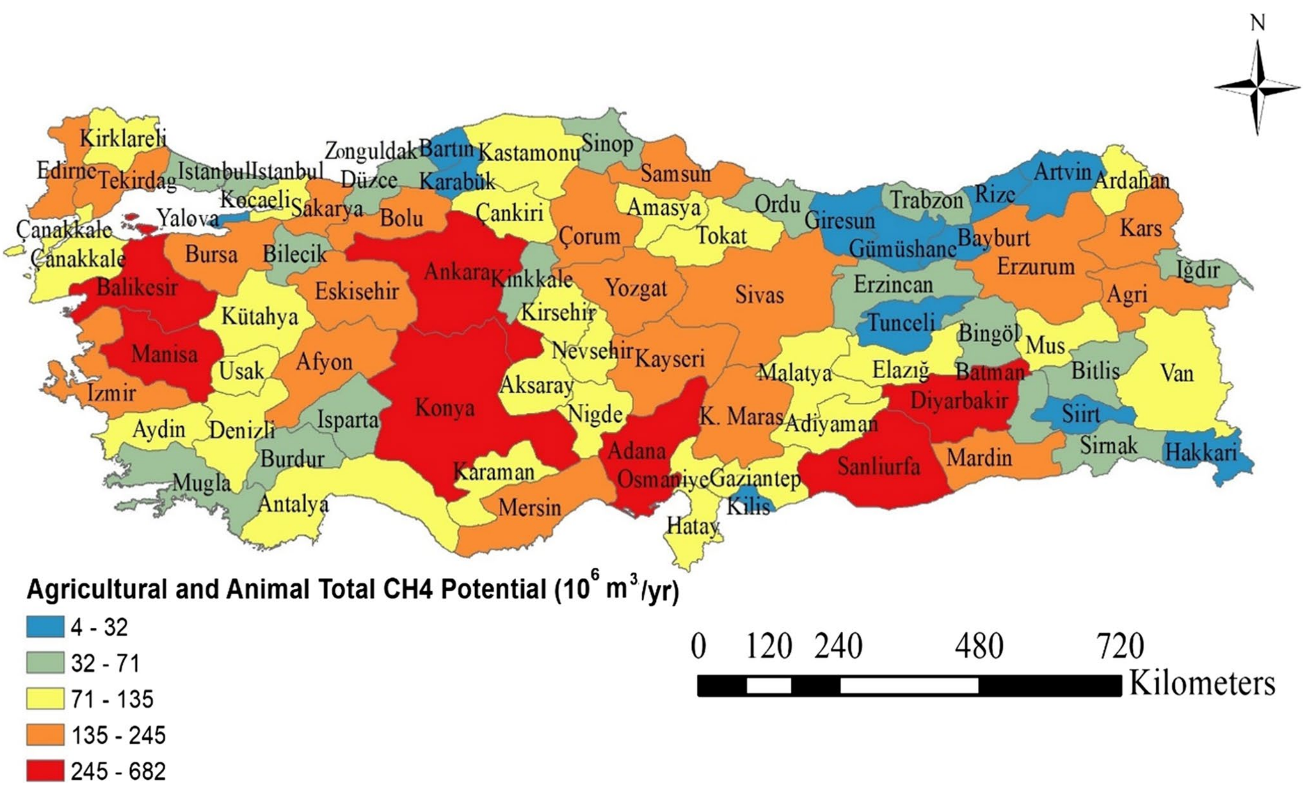


Fig. 10 Total methane potential of cities

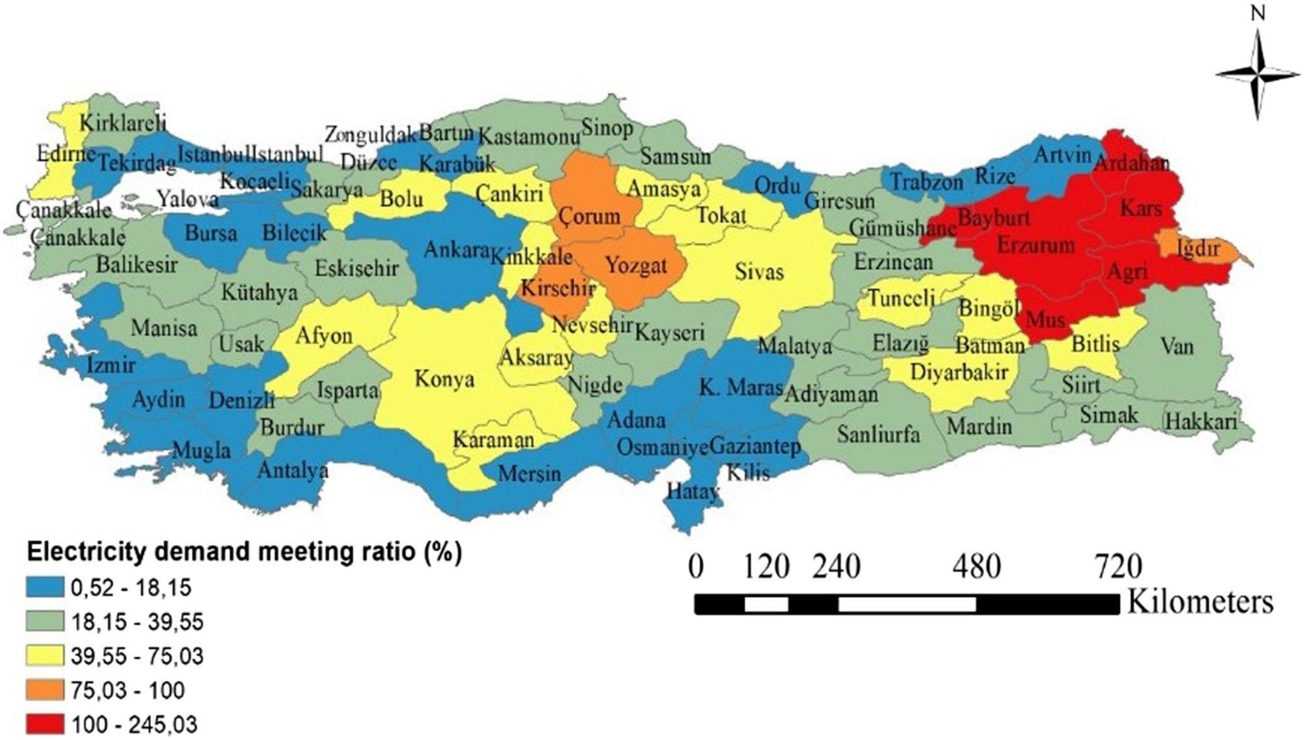


Fig. 11 Electricity demand meeting ratio potential of cities from total biogas

3.4 *CO_2 reduction by biogas process*

Biogas is a gas obtained from anaerobic fermentation, which is used to generate electricity and heat energy consisting of 40–70% Methane and 30–60% carbon dioxide and trace amounts of nitrogen, hydrogen, ammonia, and hydrogen sulfide. Anaerobic fermentation ensures the reduction of unpleasant odor, air pollution, and water pollution caused by biomass material, and greenhouse gas emissions can also be lowered by reducing fossil fuel-based energy production [22, 25, 49].

The global warming potential of 1 kg methane relative to 1 kg CO_2 depends on the time that the heating effects of these gases are compared. According to the latest IPCC assessment report, the global warming potential of methane in the standard 100-year period is 28 to 34 times CO_2. For a 20-year period, this value is between 84 and 86 times CO_2 [58, 59].

If biomass material is not used or left in the field, the emission of biogas to be emitted into the atmosphere has been determined as 9.2 kg CO_2/m^3. The emission value that will arise with burning biogas will be 1.96 kg CO_2/m^3 biogas, and if it is applied in electricity generation, it will be 0.734 kg CO_2/kWh [27]. The largest CO_2 emitter, which accounts for 30% of carbon dioxide emissions related to energy consumption, is generated from coal-fired power plants. Fossil fuel consumption continues to increase as the growing energy demand which is not entirely met by renewable facilities [60]. According to the Institute of Statistics of Turkey 2018 data, 37.2% of the 304,802 GWh of electricity is produced from coal-based energy production plants. Providing the energy demand from biomass-sourced wastes will also reduce emissions [61].

Table 7 shows the total CO_2 emission reduction amount by region in Turkey. Equations (8)–(11) are used for calculations. According to Table 7, Turkey's possible total CO_2 emission reduction is 174×10^9 kg CO_2 by biomass utilization. Additionally, as seen in Table 7, the highest CO_2 emission reduction is observed in the Aegean region with 21.2×10^9 kg CO_2, while the lowest CO_2 emission reduction is realized in Istanbul with 0.9×10^9 kg CO_2. Since CO_2 reduction is directly related to biogas production and electricity production, the data are shown in the table together.

3.5 Cost calculation of biogas plants in Turkey by region

The World Biogas Association (2019) data indicate that there are 132,000 small, medium, and large-scale anaerobic digesters and 700 biogas treatment plants serving around the world. In Asia, biogas plants are mostly family-sized and produce biogas for home usage, while in European countries and America, most biogas plants are large-scale plants [62]. Large-scale commercial biogas plants first meet their

Table 7 Total CO_2 emission reductions of regions

Regions	Biogas production m^3 (55% CH_4)	Emission reduction (kg CO_2)
Mediterranean	1,796,996,635	17,577,661,858
Western Anatolia	2,158,582,287	21,114,580,181
Central Anatolia	1,795,621,646	17,564,212,144
Mid-Eastern Anatolia	857,881,477	8,391,529,635
Southeastern Anatolia	2,174,054,446	21,265,924,025
Northeastern Anatolia	1,346,982,533	13,175,763,957
Aegean	2,331,322,832	22,804,274,435
Western Marmara	1,615,017,962	15,797,603,110
İstanbul	93,986,864	919,350,254
Eastern Marmara	1,690,266,793	16,533,663,758
Western Black Sea	1,615,163,535	15,799,027,061
Eastern Black Sea	316,839,861	3,099,228,919
Turkey (Total)	17,792,716,871	174,042,819,343

internal energy needs. They aim to profit by trading heat and electricity to national grids, improved biogas to the natural gas grid and vehicle refueling stations, post-fermentation products such as organic fertilizers and soil stabilizers [63].

Table 8 presents the cost analysis results for installing biogas plants in high potential cities for each region, which are obtained as a result of the calculations. It is assumed that a cogeneration system with a power of 5 MW is used in each facility established in the selected cities with 1150 $/kW (960.5 €/kW) installation cost and that 10 staff are employed for each 5 MW facility. And the higher coefficients are taken from the data given in Table 1 and the facility cost and payback period are determined. Consequently, the cogeneration unit maintenance and repair expenses are adopted as 1.1 €, insurance and tax expenses 10%, raw material procurement, and transportation expenses 6 €.

According to Table 8, the lowest payback period is the Adana city of the Mediterranean Region with 5.14 years. The highest payback period is 7.55 years for Erzurum in the Northeastern Anatolia region. Since the highest coefficients are applied while considering the facility costs, the payback period has also had the maximum value. One of the significant aspects of biogas plant investments is the facility payback period, and the maximum values obtained here will guide investors.

Since the unit manure production of the animals and the volume of biogas to be obtained vary, the income that can be reached from the organic fertilizer can vary. For this reason, the payback period differs in cities with similar installed capacities.

4 Conclusion

Animal manure needs to be treated since it causes serious environmental problems such as increased greenhouse gas emissions, soil infertility, and water pollution. Besides preventing environmental pollution, proper waste management provides energy production and organic fertilizer income. In this research, where cattle, goats, sheep, broiler chickens, and laying hen manure are assessed in collectible manure, Turkey has a manure potential of 176 million tonnes/year. Among the 12 regions, the highest manure-based biogas potential is in the Aegean region, with 922 million m^3 CH_4/year.

Table 8 Cost analysis of biogas plants for selected cities

Region	City	Built in capacity (MW)	Installation cost (Euro)	Expenses annual (Euro)	Revenues annual (Euro)	Profit annual (Euro)	Pay back (years)
Mediterranean	Adana	149.120	596,480,000	100,140,070	216,058,759	115,918,688	5.14
Western Anatolia	Konya	339.345	1,357,380,000	235,521,300	467,907,755	232,386,455	5.84
Central Anatolia	Sivas	105.535	422,142,974	79,408,501	146,845,719	67,437,218	6.26
Mid-Eastern Anatolia	Muş	60.887	243,550,255	52,462,752	88,348,641	35,885,888	6.79
Southeastern Anatolia	Şanlıurfa	221.813	887,252,145	148,888,682	307,070,947	158,182,265	5.61
Northeastern Anatolia	Erzurum	118.761	475,045,511	110,685,005	173,575,687	62,890,681	7.55
Aegean	Manisa	158.634	634,537,783	114,134,468	215,749,095	101,614,627	6.24
Western Marmara	Balıkesir	156.059	624,239,343	122,491,036	227,039,579	104,548,542	5.97
İstanbul	İstanbul	25.691	102,765,237	20,483,622	38,259,574	17,775,951	5.78
Eastern Marmara	Sakarya	109.060	436,243,172	80,221,414	156,751,015	76,529,601	5.70
Western Black Sea	Samsun	87.633	350,532,597	69,271,974	128,917,002	59,645,027	5.88
Eastern Black Sea	Trabzon	23.056	92,227,688	20,853,899	35,048,107	14,194,207	6.50

In agricultural waste, wheat, barley, maize, rice, oat, rye, and sunflower crops are evaluated, and 17 million tons of collectible agricultural waste potential are obtained. The regions with the highest potential of biogas from agricultural waste are Southeastern Anatolia with 779.16 million m^3CH_4/year and Western Anatolia with 779.12 million m^3 CH_4/year. The total biogas potential that can be obtained from both animal manure and agricultural waste is 17.8 billion m^3. Among the 12 regions, the highest biogas potential is in the Aegean region, with 2.33 billion m^3.

The electrical energy that can be obtained from biogas is 38.909 GWh/yr. There are 6 cities in Northeastern Anatolia and the Mid-eastern Anatolia regions, where the ratio of meeting electricity consumption is greater than 100%. In other words, if these 6 cities use their biogas potential, they will be able to produce more than their electricity demands. If Turkey converts its biogas potential to electrical energy, the reduced carbon emission will be 174 million tons CO_2/yr. Among all regions, the Aegean region has the highest value with 22 million tons of CO_2/yr.

In the case of establishing a biogas plant under the conditions where the highest coefficients are taken in this research, the region with the lowest payback period on investment is the Mediterranean Region with 5.14 years, while the region with the highest is the Northeastern Anatolia Region with 7.55 years. The payback periods are calculated for the cases with the highest economic data in the literature that may be lower if evaluated under better conditions.

The study is expected to draw the attention of both researchers and investors to the biomass potential of Turkey.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Tabak A, Kayabasi E, Guneser MT, Ozkaymak M (2019) “Grey wolf optimization for optimum sizing and controlling of a PV/WT/BM hybrid energy system considering TNPC, LPSP, and LCOE concepts”, *Energy Sources*. Part A Recover Util Environ Eff. https://doi.org/10.1080/15567036.2019.1668880
2. Canan A, Calhan R, Ozkaymak M (2021) Investigation of the effects of different slags as accelerant on anaerobic digestion and methane yield. Biomass Convers Biorefinery 1–12. https://doi.org/10.1007/s13399-021-01340-0
3. Turkish Presidency Strategy and Budget Office (2019) 11th development plan (2019–2023). https://www.sbb.gov.tr/wp-content/uploads/2019/11/ON_BIRINCI_KALKINMA-PLANI_2019-2023.pdf. Accessed 10 May 2021
4. Sarteshnizi FR, Seifdavati J, Abdi-benemar H, Salem AZM, Sharifi RS, Mlambo V (2018) The potential of rumen fluid waste from slaughterhouses as an environmentally friendly source of enzyme additives for ruminant feedstuffs. J Clean Prod 195:1026–1031. https://doi.org/10.1016/j.jclepro.2018.05.268
5. Roopnarain A, Adeleke R (2017) Current status, hurdles and future prospects of biogas digestion technology in Africa. Renew Sustain Energy Rev 67:1162–1179. https://doi.org/10.1016/j.rser.2016.09.087
6. Lofthouse J, Simmons R, Yonk R (2015) Reliability of renewable energy: solar. Utah State Univ 87(403):1–55
7. Republic of Turkey Ministry of Environment and Urbanization (2015) Paris agreement - climate change. Available: https://iklim.csb.gov.tr/paris-anlasmasi-i-98587. Accessed 10 May 2021
8. Canan A, Calhan R, Ozkaymak M (2021) Investigation of the effects of blast furnace slag ratio, total solid, and pH on anaerobic digestion: modeling and optimization by using response surface methodology. Biomass Convers. Biorefinery 2021 115 11(5):2219–2232. https://doi.org/10.1007/S13399-021-01865-4
9. Kaltschmitt M (2019) Utilization of biomass in the German energy sector. In Strategies and technologies for greenhouse gas mitigation: an Indo-German contribution to global efforts, pp 151–170
10. Kaskun S, Çalhan R, Akinay Y (2021) Enhancement of biogas production using SnO2 nanoparticle-doped mica catalyst. Biomass Convers Biorefinery. https://doi.org/10.1007/S13399-021-01983-Z
11. Ali MM, Ndongo M, Bilal B, Yetilmezsoy K, Youm I, Bahramian M (2020) Mapping of biogas production potential from livestock manures and slaughterhouse waste: a case study for African countries. J Clean Prod 256:120499. https://doi.org/10.1016/j.jclepro.2020.120499
12. Silva Neto JV, Gallo WLR (2021) Potential impacts of vinasse biogas replacing fossil oil for power generation, natural gas, and increasing sugarcane energy in Brazil. Renew Sustain Energy Rev 135:110281. https://doi.org/10.1016/j.rser.2020.110281
13. Yan B, Yan J, Li Y, Qin Y, Yang L (2021) Spatial distribution of biogas potential, utilization ratio and development potential of biogas from agricultural waste in China. J Clean Prod 292:126077. https://doi.org/10.1016/j.jclepro.2021.126077
14. KhoshgoftarManesh MH, Rezazadeh A, Kabiri S (2020) A feasibility study on the potential, economic, and environmental advantages of biogas production from poultry manure in Iran. Renew Energy 159:87–106. https://doi.org/10.1016/j.renene.2020.05.173
15. Abusoglu A, Tozlu A, Anvari-Moghaddam A (2021) District heating and electricity production based on biogas produced from municipal WWTPs in Turkey: a comprehensive case study. Energy 223:119904. https://doi.org/10.1016/j.energy.2021.119904
16. Özer B (2017) Biogas energy opportunity of Ardahan city of Turkey. Energy 139:1144–1152. https://doi.org/10.1016/j.energy.2017.07.052
17. Caliskan M, Tumen Ozdil NF (2020) Potential of biogas and electricity production from animal waste in Turkey. Bioenergy Res. https://doi.org/10.1007/s12155-020-10193-w
18. Akyürek Z, Coşkun S (2019) Determination of biogas energy potential of Aegean region based on animal waste. Celal Bayar Üniversitesi Fen Bilim. Derg 15(2):171–174. https://doi.org/10.18466/cbayarfbe.492880
19. Kizilaslan N, Kizilaslan H (2007) Turkey’s biogas energy potential, Energy Sources. Part B Econ Plan Policy 2(3):277–286. https://doi.org/10.1080/15567240600629377
20. Gunduz U, Kaya T (2015) Regıonal employment generatıon potentıal of the turkısh labor market: an ınter-sectoral perspectıve. Technol Econ Dev Econ 23(5):726–741. https://doi.org/10.3846/20294913.2015.1015110
21. Akyürek Z (2018) Potential of biogas energy from animal waste in the Mediterranean Region of TurkeyP. J Energy Syst 2(4):160–167. https://doi.org/10.30521/jes.455325

22. Braun R (2007) Anaerobic digestion: a multi-faceted process for energy, environmental management and rural development. In Improvement of Crop Plants for Industrial End Uses. Springer Netherlands, Dordrecht, pp 335–416
23. Monforti F, Lugato E, Motola V, Bodis K, Scarlat N, Dallemand JF (2015) Optimal energy use of agricultural crop residues preserving soil organic carbon stocks in Europe. Renew Sustain Energy Rev 44(Elsevier Ltd):519–529. https://doi.org/10.1016/j.rser.2014.12.033
24. DBFZ (2011) Türkiye'de Biyogaz Yatırımları İçin Geçerli Koşulların ve Potansiyelin Değerlendirilmesi. T.C. Çevre ve Şehircilik Bakanlığı; Ankara. [Online]. Available: http://www.biyogaz.web.tr/files/docs/dbfz_turkiye_biyogaz_potansiyel_raporu.pdf.
25. Ekinci K, Kulcu R, Kaya D, Yaldiz O, Ertekin C, Ozturk H (2010) The prospective of potential biogas plants that can utilize animal manure in Turkey. Energy Explor Exploit 28(3):187–206. https://doi.org/10.1260/0144-5987.28.3.187
26. Hakawati R, Smyth BM, McCullough G, De Rosa F, Rooney D (2017) What is the most energy efficient route for biogas utilization: heat, electricity or transport? Appl Energy 206:1076–1087. https://doi.org/10.1016/j.apenergy.2017.08.068
27. Murphy JD, McKeogh E, Kiely G (2004) Technical/economic/environmental analysis of biogas utilisation. Appl Energy 77(4):407–427. https://doi.org/10.1016/j.apenergy.2003.07.005
28. Atilgan B, Azapagic A (2016) An integrated life cycle sustainability assessment of electricity generation in Turkey. Energy Policy 93:168–186. https://doi.org/10.1016/J.ENPOL.2016.02.055
29. Kaya D, Çağman S, Eyidoğan M, Aydoner C, Çoban V, Tırıs M (2009) Türkiyenin Hayvansal Atık Kaynaklı Biyogaz Potansiyeli veEkonomisi. Atık Teknol Derg 1
30. Balussou D, Kleyböcker A, McKenna R, Möst D, Fichtner W (2012) An economic analysis of three operational co-digestion biogas plants in Germany. Waste and Biomass Valorization 3(1):23–41. https://doi.org/10.1007/s12649-011-9094-2
31. Topic D, Sljivac D, Jozsa L, Nikolovski D, Vukobratovic M (2017) Cost–benefit analysis of biogas CHP combined heat and power) Plant. *Sci Pract 2010, 28th Int. Conf.*, no. January 2017, 2010, https://doi.org/10.13140/2.1.4026.0168
32. Christoph Kost TS, Shammugam S, Fluri V, Peper D, Davoodi Memar A (2021) Study: levelized cost of electricity- renewable energy technologies. *Fraunhofer ISE*, no. June, 2021. Available: www.ise.fraunhofer.de. Accessed 31 Oct 2021
33. Turkish Statistical Institute (2020) Agriculture statistics. https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr. Accessed 26 Apr 2021
34. Avcioğlu AO, Türker U (2012) Status and potential of biogas energy from animal wastes in Turkey. Renew Sustain Energy Rev 16(3):1557–1561. https://doi.org/10.1016/j.rser.2011.11.006
35. Melikoglu M Menekse ZK (2020) Forecasting Turkey's cattle and sheep manure based biomethane potentials till 2026. Biomass and Bioenergy 132. https://doi.org/10.1016/j.biombioe.2019.105440
36. Gitz V, Meybeck A, Lipper L, Young C, Braatz S 2016 Climate change and food security: risks and responses
37. Erdal H, Erdal G (2020) Panel FMOLS model analysis of the effects of livestock support policies on sustainable animal presence in Turkey. Sustain 12(8):3444. https://doi.org/10.3390/SU12083444
38. Esbah Tuncay M, Hayriye, Akyol, Meliz, Steindl (2014) Urban agriculture: ımplications on istanbul cultural heritage. J Environ Prot Ecol 15:1793–1800. [Online]. Available: https://www.researchgate.net/publication/290857458_Urban_agriculture_Implications_on_istanbul_cultural_heritage. Accessed 20 Jan 2022
39. Yalçın BC (1986) Sheep and goats in Turkey, p. 168
40. Yenilmez F, Uruk E (2014) Organic Poultry in Turkey Poultry Industry a. Turkish J Agric Nat Sci Spec (1). Available: www.turkjans.com. Accessed 20 Jan 2022
41. Somuncu M, Akpınar N, Kaya NÇ, Kurum E, Tanyel, Eceral Ö (2011) Land-use change in Yaylas of the eastern Black Sea mountains. Turkey, vol. 4
42. Çağlayan GH (2020) Doğu Anadolu Bölgesindeki Büyükbaş Ve Küçükbaş Hayvan Atıklarının Biyogaz Potansiyelinin İncelenmesi. Türk Tarım ve Doğa Bilim Derg 7(3):672–681. https://doi.org/10.30910/turkjans.699879
43. Lule F (2019) Güneydoğu Anadolu Bölgesinin Hayvansal Atıklardan Elde Edilebilecek Enerji Potansiyeli. ÇOMÜ Ziraat Fakültesi Derg 7(1):145–150. https://doi.org/10.33202/comuagri.435371
44. Karaca C (2018) Determination of biogas production potential from animal manure and GHG emission abatement in Turkey. Int J Agric Biol Eng 11(3):205–210. https://doi.org/10.25165/IJABE.V11I3.3445
45. YılmazİH Saka K (2017) Exploitable biomass status and potential of the Southeastern Anatolia Region. Turkey 13(1):46–52. https://doi.org/10.1080/15567249.2017.1403498
46. Mata-Alvarez J, Dosta J, Romero-Güiza MS, Fonoll X, Peces M, Astals S (2014) A critical review on anaerobic co-digestion achievements between 2010 and 2013. Renew Sustain Energy Rev 36:412–427. https://doi.org/10.1016/j.rser.2014.04.039
47. Lehtomäki A, Huttunen S, Rintala JA (2007) Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: effect of crop to manure ratio. Resour Conserv Recycl 51(3):591–609. https://doi.org/10.1016/j.resconrec.2006.11.004
48. Aksay MV, Ozkaymak M, Calhan R (2018) Co-digestion of cattle manure and tea waste for biogas production. Int J Renew Energy Res 8(3):1346–1353
49. Braun R, Holm-nielsen JB, Seadi TaL (2002) Potential of co-digestion. IEA Bioenergy 16. https://doi.org/10.1007/s11356-015-4998-1
50. Avcioglu AO, Colak A, Turker U (2013) Turkey's Chicken waste biogas potential. J Tekirdag Agric Fac 10(1): 21–28. [Online]. Available: http://acikerisim.nku.edu.tr/xmlui/handle/20.500.11776/1733. Accessed 16 Feb 2022
51. Verstraete W, Morgan-Sagastume F, Aiyuk S, Waweru M, Rabaey K, Lissens G (2005) Anaerobic digestion as a core technology in sustainable management of organic matter. Water Sci Technol 52(1–2):59–66. https://doi.org/10.2166/wst.2005.0498
52. Miah MR, Rahman AKML, Akanda MR, Pulak A, Rouf MA (2016) Production of biogas from poultry litter mixed with the co-substrate cow dung. J Taibah Univ Sci 10(4):497–504. https://doi.org/10.1016/j.jtusci.2015.07.007
53. Zhang T, Yang Y, Liu L, Han Y, Ren G, Yang G (2014) Improved biogas production from chicken manure anaerobic digestion using cereal residues as co-substrates. Energy Fuels 28(4):2490–2495. https://doi.org/10.1021/ef500262m
54. Zhu J, Wu S, Shen J (2019) Anaerobic co-digestion of poultry litter and wheat straw affected by solids composition, free ammonia and carbon/nitrogen ratio. J Environ Sci Heal - Part A Toxic/Hazardous Subst Environ Eng 54(3):231–237. https://doi.org/10.1080/10934529.2018.1546494
55. Rahman MA, Møller HB, Saha CK, Alam MM, Wahid R, Feng L (2017) Optimal ratio for anaerobic co-digestion of poultry droppings and lignocellulosic-rich substrates for enhanced biogas production. Energy Sustain Dev 39:59–66. https://doi.org/10.1016/j.esd.2017.04.004
56. Aybek A, Ucok S, Bilgili M, İspir M (2015) Digital mapping and determination of biogas energy potential of usable animal manure and cereal straw wastes in Turkey view project view project Serdar üçok. JOTAF 109–120. [Online]. Available: https://www.researchgate.net/publication/301285082. Accessed 16 Feb 2022
57. Çakal S, Celik S (2022) Türkiye Genelinde En Çok Yetiştirilen Tarımsal Ürünlerin Atıklarının Biyogaz Potansiyelinin

Belirlenmesi. El-Cezeri 9(1):1–11. https://doi.org/10.31202/ECJSE.872565
58. International Gas Union (IGU) (2017) Methane's impact on clımate change
59. Havrysh V, Kalinichenko A, Mentel G, Olejarz T (2020) Commercial biogas plants: lessons for Ukraine. Energies 13(10):2668. https://doi.org/10.3390/en13102668
60. Cannone SF, Lanzini A, Santarelli M (2021) A review on CO2 capture technologies with focus on CO2-enhanced methane recovery from hydrates. Energies 14(2):387. https://doi.org/10.3390/en14020387
61. Turkish Statistical Institute (2018) Turkish electricity generation statistics. https://data.tuik.gov.tr/Kategori/GetKategori?p=cevre-ve-enerji-103&dil=1. Accessed 10 May 2021
62. Bakkaloglu S et al (2021) Quantification of methane emissions from UK biogas plants. Waste Manag 124:82–93. https://doi.org/10.1016/j.wasman.2021.01.011
63. Mittal S, Ahlgren EO, Shukla PR (2018) Barriers to biogas dissemination in India: a review. Energy Policy 112:361–370. https://doi.org/10.1016/j.enpol.2017.10.027