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THE BIOGAS POTENTIAL OF ANIMAL MANURE AND ITS GHG REDUCTION EFFECT IN KONYA PROVINCE, TURKEY

Cengiz KARACA*

Department of Biosystems Engineering, Hatay Mustafa Kemal University, Hatay, Turkey

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Highlights

- Biogas is an important biofuel in terms of energy and environmental impacts.
- The biogas potential of the three most available animal manures was investigated.
- Konya is the largest province of Turkey in terms of livestock farming.
- The environmental effects of animal manure can be eliminated by using it in biogas production.

Abstract. This study aims to assess the amount of biogas and value of energy produced from animal manure in Konya province. Therefore, the potential of biogas was calculated by considering the number of cattle, broilers, and laying hens. It was calculated that a total of 5.63 million tonnes of animal manure comprising 5.25 million tonnes of cattle manure, 1.07 thousand tonnes of broiler manure, and 382.38 thousand tonnes of laying hen manure could be taken from these animals in the province. 105.67 Mm^3 biogas can be produced from the available amount of this manure. It was calculated that electric energy of approximately 266.53 GWh_{el} can be produced from this biogas. Furthermore, greenhouse gas (GHG) emission reduction was calculated to show the environmental benefits of biogas production from animal manure. Upon benefiting from the total of the calculated biogas potential, it was determined that CO_2 emission reduction ranging from 1.04–1.57 million tonnes could be provided.

Keywords: biogas, animal manure, GHG emission, Konya.

Introduction

Waste management or waste disposal includes the activities and actions required to manage waste from its inception to its final disposal. This includes the collection, transport, treatment, and disposal of waste, together with monitoring and regulation of the waste management process. Exploiting waste as a profitable resource would be a good way to resolve simultaneously several challenges and this inspires the aphorism that one's trash is another man's treasure. Waste management methods include landfilling, incineration or combustion, recovery and recycling, composting, plasma gasification, and waste to energy conversion. The aim of waste management is to reduce the dangerous effects of such waste on the environment and human health (Ebeid & Zakaria, 2021).

Nowadays, energy issues raise the concerns of environment and ecology more than ever. After the global enactment of energy efficiency and the rise of the renewables, we have to adopt eco-energy into our lives practically. Energy is a big issue for achieving ecological welfare and sustainability. Carbon energy sources that destruct the living standards of cities act against global ecology damaging health. However, the renewable energy sources are healthful, clean and cheap. Environment and cities where we live can only be protected with creative eco-energy. Nowadays, the future of global ecology is to create a world with zero-carbon cities. Turkey, as a developing country finally solved the energy problem and implemented policies to improve renewables and energy efficiency (Okay, 2016).

Energy has a major role around the world. Energy is a necessity for economic development, and there is a clear relationship between standards of living and energy use (Karaca, 2015). Although energy is a vital component of our lives, consuming fossil fuels in vast quantities gives rise to many serious problems (Dumanli et al., 2007).

The negative environmental impact of greenhouse gases (GHG) forming as a result of the continuous use of fossil

*Corresponding author. E-mail: *ckaraca@mku.edu.tr*

fuels led to research for the production of alternative fuels from biological sources (Achinas et al., 2017). An increase in energy demand and problems concerning the current nonrenewable energy sources have led researchers to research alternative energy sources in recent years (Isci & Demirer, 2007).

Biogas is a gas that is formed as a result of a biological process in which biodegradable materials degrade in an anaerobic environment. The process of biogas production is a complex procedure in which organic waste is processed by various bacteria. Biogas formation from organic materials occurs under the influence of anaerobic bacteria in three stages: hydrolysis, acetogenesis and methanogenesis (Baltrėnas et al., 2005). Biogas contains roughly 50–70% methane (CH_4), 30–40% carbon dioxide (CO_2) and trace amounts of other gases. Biogas can be produced from various wastes such as garbage material, animal manure, wastewater, and industrial, traditional, and commercial organic wastes. Anaerobic digestion provides economical, environmental, and climatic advantages by using biogas in the generation of energy such as heat and fuel. The natural deterioration of manure causes methane and carbon dioxide emissions to diffuse into the atmosphere during storage. It is necessary to take into account that the greenhouse effect of methane is more intense than carbon dioxide (Baltrėnas & Kvasauskas, 2008). Anaerobic deterioration of manure prevents methane emission arising from natural decomposition during storage and reduces GHG released into the atmosphere. Fossil fuels are substituted as a result of using biogas that is produced using manure in energy generation; thus, it contributes to reducing greenhouse gas and other pollutant emissions (Scarlat et al., 2018).

The total electric generation of Türkiye will reach 305.4 TWh in 2020. 14.1% of this generation was provided by renewable sources. It was seen that the top generation was provided by biogases with a generation of 3,302 GWh upon ranking sources according to the amounts of the electricity generated from biofuels and waste. These sources are followed by primary solid biofuels (1,321 GWh), liquid biofuels (38 GWh), industrial waste (15 GWh), and urban renewable waste (14 GWh). Furthermore, heat generation sources from biofuels and waste are respectively biogases (3,900 TJ), industrial waste (1,523 TJ), and solid biofuels (1,141 TJ) (International Energy Agency, 2020).

Depending on the greenhouse gas inventory results of Türkiye, total greenhouse gas emission for 2020 was calculated as 523.9 Mt $CO_{2eqv.}$ upon rising 3.1% compared to the previous year. While total greenhouse gas emission per capita was calculated as 4 tonnes CO_{2eqv}. In 1990, it was calculated as 6.2 tonnes CO_{2eqv}. In 2019 and 6.3 tonnes CO_{2eqv}. In 2020. While in 2020, energy-based emissions received the biggest share with a share of 70.2% as $CO_{2eqv.}$, respectively it is followed by agriculture with a share of 14%, industrial operations and product use with a share of 12.7% and waste industry with a share of 3.1% (Turkish Statistical Institute [TURKSTAT], 2022).

The biggest share belongs to the agriculture industry, with a share of 61% in the generation of CH_4 emission in greenhouse gases. According to 2020 data concerning CH_4 emission generation arising from the agricultural activities shown in Figure 1, it is seen that enteric fermentation has the biggest share with a share of 88.74%. It was determined that the CH_4 emission generation from animal manure has a rate of 10.25% (TURKSTAT, 2022).

Konya is the biggest province of Türkiye in terms of the potential for breeding (Karaca, 2018). This study aims to determine biogas generation potential from animal manure (only dairy cattle, broiler, and laying hen) and to show the distribution of this potential to districts. To this end, the biogas and energy potential of animal manure was mapped using ArcMap, which is a GIS (Geographic Information System) software. The mapping process was performed to show the distance between sources and data difference between districts. The calculated data of Konya and its districts were processed in the database. Furthermore, GHG emission reduction was calculated to show the environmental benefits of biogas production from animal manure.

1. Material and method

Konya is a Turkish province located in the Central Anatolia. Konya is comprised of 31 districts including three central district municipalities (Figure 2).

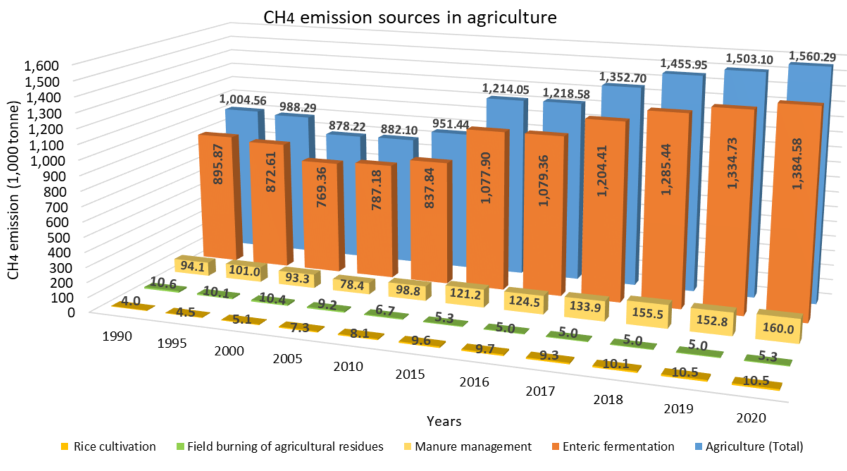

Figure 1. Agricultural activities-based CH_4 emission inventory in Türkiye (TURKSTAT, 2022)

1.1. Animal manure and biogas generation calculation method

2019 animal statistical data from the Turkish Statistical Institute is used for the calculations to be performed within the scope of this study (TURKSTAT, 2020). Only dairy cattle, broiler, and laying hen population data was used in the calculation of biogas manufacturing potential. Because the accessibility value of animal manure, which is determined based on the duration of staying in an animal house, reaches the highest values in dairy cattle breeding farms (65%) and broiler and laying hen farms (99%) (Başçetinçelik et al., 2005). The following equations were used to compute animal manure and biogas generation amount (Salminen & Rintala, 2002; Başçetinçelik et al., 2006; Ozsoy & Alibas, 2015; Karaca, 2018a).

$$FM = NA \times MPA / 1000, \quad (1)$$

where: FM – daily amount of fresh manure (t.day^{-1}); NA – number of animals; MPA – manure production per animal per day (kg.day^{-1}).

The MPA is 27.24 for cattle, 0.0476 for broiler and 0.08 for laying hens.

$$SM = FM \times SR, \quad (2)$$

where: SM – solid manure amount (t.day^{-1}); SR – the ratio of solid in manure (%).

$$ASM = SM \times AM \times GD, \quad (3)$$

where: ASM – available solid manure (t.year^{-1}); AM – manure accessibility (%); GD – growing duration (day.year^{-1}); GD – 365 (dairy cattle and laying hens); GD – 42 (broiler).

$$BA = ASM \times BCR_{SM}, \quad (4)$$

where: BA – biogas generate amount (m^3.year^{-1}); BCR_{SM} – biogas conversion ratio of solid manure (200 m^3.t^{-1}).

$$TCV = BA \times BCV, \quad (5)$$

where: TCV – total calorific value (MJ); BCV – unit biogas calorific value (22.7 MJ.m^{-3}).

Figure 2. Districts of Konya and its location in Türkiye

Electricity generation from biogas with a gas engine was calculated by the following equation:

$$EG = (TCV \times EPE_{Net}) / 3.6, \quad (6)$$

where: EG – electricity generation (MWh$_{el}$.year^{-1}); EPE_{Net} – electricity generation efficiency of a gas engine (40%) (Clarke Energy, 2016).

1.2. The calculation for GHG emission reduction of the biogas system

The greenhouse gas reducer effect of biogas generation depends on two factors, ERMM (emission reduction by manure management) and ERES (emission reduction by energy substitution).

ERMM (Emission reduction by manure management)

Decay of animal manure under anaerobic conditions (in the absence of oxygen) generates CH_4 during storage. The most important advantage of a biogas generation system is to prevent out of control methane emission. The following formulas were used to calculate CH_4 generation from outdoor lagoon storage systems (Intergovernmental Panel on Climate Change, 2006; Guo Guo, 2010). Greenhouse gases warm the earth by absorbing energy and decreasing the rate at which the energy escapes the atmosphere. These gases differ in their ability to absorb energy, that is, they have various radiative efficiencies. They also differ in their atmospheric residence times. Each gas has a specific global warming potential (GWP), which allows comparisons of the amount of energy the emissions of 1 ton of a gas will absorb over a given time period, usually a 100-year averaging time, compared with the emissions of 1 ton of CO_2 (Vallero, 2019).

The calculations were performed based on the annual average temperature.

$$ME_{MM} = EF_{(T)} \times NA_{(T)}, \quad (7)$$

where: ME_{MM} – methane emission amount (kg.CH_4.year^{-1}); $EF_{(T)}$ – emission factor for livestock group T (kg.CH_4.animal^{-1}.year^{-1}); NA – the number of animal; T – kinds/group.

$$EF_{(T)} = \left(VS_{(T)} \times 365\right) \times \left(MMG_{(T)} \times 0.67\right) \times \left(\frac{MCF_{S,k}}{100}\right), \quad (8)$$

where: $VS_{(T)}$ – volatile solid per day T (kg.drymatter.animal^{-1}.day^{-1}); $MMG_{(T)}$ – max. methane generation capacity (m^3.kg^{-1}); 0.67 – conversion factor from m^3 to kg for CH_4; $MCF_{S,k}$ – methane conversion parameters for manure management system S, by climate region k (%).

$$ERMM_{CO_2eqv.} = ME_{MM} \times 27.2, \quad (9)$$

where: $ERMM_{CO_2eqv.}$ – CO_2 equivalent emission reduction from manure management (kg.CO_2.year^{-1}); 27.2 – multiple of the CO_2 equivalent of CH_4 (ERC Evolution, 2023).

ERES (Emission reduction by energy substitution)

Solid fossil fuels and other biomass fuels can be substituted by biogas in rural areas due to their calorific value (22.7 $MJ.m^{-3}$). Therefore, the impact of the biogas generation system on CO_2 emission reduction depends on the amount of fossil fuel substitution. ERES is calculated as GHG emissions generated by biogas-substituted fuel consumption. In this section, CO_2 emission reduction was calculated separately for every fossil fuel that is substituted for the calculated biogas potential. Therefore, the following equations were used (Guo Guo, 2010).

$$ERES_{CO_2\ fuel} = FS \times CE_{fuel} \times EF_{CO_2\ fuel}, \quad (10)$$

where: $ERES_{CO_2\ fuel}$ – CO_2 emission reduction for substituted fuel ($kg.year^{-1}$); *FS* – fuel substitution value of biogas energy equivalent ($GJ.year^{-1}$); CE_{fuel} – combustion efficiency of fuels; $EF_{CO_2\ fuel}$ – CO_2 emission factors ($kg.GJ^{-1}$).

$$FS = TCV \times CE_{biogas}, \quad (11)$$

where: *TCV* – total calorific value of biogas potential ($GJ.year^{-1}$); CE_{biogas} – combustion efficiency of biogas 60%).

2. Result and discussion

2.1. Animal manure, biogas generation, and energy value potentials

The results of total animal manure potential depending on the number of dairy cattle, broiler, and laying hen of Konya province for 2019 are shown in Table 1.

The total available solid manure amount taken from dairy cattle, broiler, and laying hens in Konya province was 528.4 thousand tonnes in 2019. Dairy cattle manure has the biggest share with 82% in terms of the distribution of manure sources. This value is followed by laying hen manure with a share of 17.9%. The share of broiler manure is at a value as low as 0.1%.

Animal manure-based biogas generation potential of Konya was calculated as 105.64 Mm^3. Furthermore, the calorific value of the generated biogas was calculated as 2,398.77 TJ in total. It was determined that an annual 266.53 GWh_{el} of electric energy could be obtained by converting the complete biogas potential obtained from animal manure to electric energy through a gas engine (Table 2). This value corresponds to 4.45% of the annual electric energy consumption of Konya.

Karaca (2016, 2017, 2018b, 2019a, 2019b) determined the total biogas obtained from animal manure as 84.8, 14.5, 153.4, 26.3, and 40.3 Mm^3 respectively, as a result of the studies conducted for Afyonkarahisar, Hatay, Balıkesir, Adana and Ankara. Animal manure-based biogas generation potential of Samsun was determined as 53.6 Mm^3 in another study conducted by Karaca and Gurdil (2019). Compared to the studies conducted, it can be seen that Konya has a great biogas generation potential.

Upon examining Table 3, it can be seen that Meram and Ereğli districts have the biggest potential, with a biogas generation potential of 14.88 Mm^3 and 14.77 Mm^3.

Table 1. The number of animals and the total amount of animal manure

Animal	NA	FM ($t.d^{-1}$)	SR (%)	SM ($t.d^{-1}$)	AM (%)	ASM ($t.year^{-1}$)
Dairy cattle	527,669	5,246,402	12.7	666,293	65	433,090
Broiler	535,520	1,071	60.0	642	99	636
Laying hens	13,095,022	382,375	25.0	95,594	99	94,638
TOTAL		5,629,847		762,529		528,364

Table 2. Biogas and energy potential of Konya province

Animal	ASM ($t.year^{-1}$)	BA ($m^3.year^{-1}$)	TCV ($GJ.year^{-1}$)	EG ($MWh_{el}.year^{-1}$)
Dairy cattle	433,090	86,618,094	1,966,231	218,470
Broiler	636	127,189	2,887	321
Laying hens	94,638	18,927,545	429,655	47,739
TOTAL	528,364	105,672,827	2,398,773	266,530

Table 3. Manure, biogas, calorific, and electric generation potentials based on the districts of Konya

Districts	Manure (t $year^{-1}$)	Biogas (m^3 $year^{-1}$)	Heating Value (GJ $year^{-1}$)	Electricity production (MWh)	Share in Total (%)
Ahırlı	46,062	763,377	17,329	1,925	0.7
Akören	42,636	731,849	16,613	1,846	0.7
Akşehir	210,413	3,736,647	84,822	9,425	3.5
Altınekin	87,457	1,670,288	37,916	4,213	1.6
Beyşehir	217,807	3,612,844	82,012	9,112	3.4
Bozkır	66,852	1,106,619	25,120	2,791	1.0
Çeltik	15,974	267,191	6,065	674	0.3

End of Table 3

Districts	Manure (t year^{-1})	Biogas (m^3 year^{-1})	Heating Value (GJ year^{-1})	Electricity production (MWh)	Share in Total (%)
Cihanbeyli	239,343	3,978,630	90,315	10,035	3.8
Çumra	586,740	11,655,677	264,584	29,398	11.0
Derbent	27,460	456,248	10,357	1,151	0.4
Derebucak	16,138	269,081	6,108	679	0.3
Doğanhisar	52,341	869,835	19,745	2,194	0.8
Emirgazi	175,140	2,896,183	65,743	7,305	2.7
Ereğli	871,092	14,764,907	335,163	37,240	14.0
Güneysınır	58,232	1,009,580	22,917	2,546	1.0
Hadim	15,066	251,155	5,701	633	0.2
Halkapınar	42,762	707,925	16,070	1,786	0.7
Hüyük	50,936	847,498	19,238	2,138	0.8
Ilgın	279,337	4,650,864	105,575	11,731	4.4
Kadınhanı	191,408	3,174,699	72,066	8,007	3.0
Karapınar	433,093	7,164,914	162,644	18,072	6.8
Karatay	512,457	11,167,564	253,504	28,167	10.6
Kulu	107,737	2,298,925	52,186	5,798	2.2
Meram	609,961	14,862,706	337,383	37,487	14.1
Sarayönü	212,214	4,298,381	97,573	10,841	4.1
Selçuklu	103,224	2,519,310	57,188	6,354	2.4
Seydişehir	204,867	3,393,814	77,040	8,560	3.2
Taşkent	5,230	87,006	1,975	219	0.1
Tuzlukçu	61,256	1,019,525	23,143	2,571	1.0
Yalıhüyük	4,031	69,630	1,581	176	0.1
Yunak	82,582	1,369,959	31,098	3,455	1.3
TOTAL	5,629,847	105,672,827	2,398,773	266,530	100

These districts are followed by Çumra (11.66 Mm^3), Karatay (11.17 Mm^3) and Karapınar (7.17 Mm^3) provinces, respectively.

The amount of manure and biogas was calculated and mapped separately for each district. The animal manure and biogas generation potential distribution maps of 31 districts of Konya province are shown in Figures 3 and 4. It is seen that dairy cattle manure has the biggest potential in all districts. Furthermore, it is seen that also laying hen manure has a potential that can be deemed important in Meram and Selçuklu districts.

These maps show that biogas potential is intensive in an area extending from Meram to the east, Ereğli. And this means that biogas generation plants can be built in these districts (Meram, Çumra, Karatay, Karapınar, and Ereğli) intensively. This provides an advantage to biogas generation plants in terms of raw material procurement.

Currently, there are 7 biogas plant investments in the province with a total installed capacity of 33.6 MW (3 in Karatay, 2 in Çumra, 1 in Meram and Sarayönü). The building of a part of these investments is ongoing, and a part was reported to be about to commence (Biyogazder, 2021). According to these calculations, the electricity generation potential of the biogas obtained from dairy cattle, broiler and laying hens manures is 38 MW. It is seen that

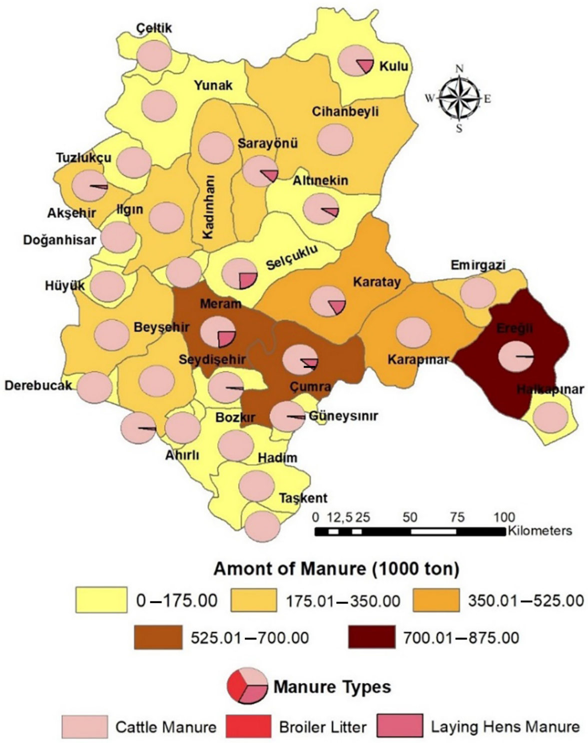

Figure 3. The animal manure potential map of Konya

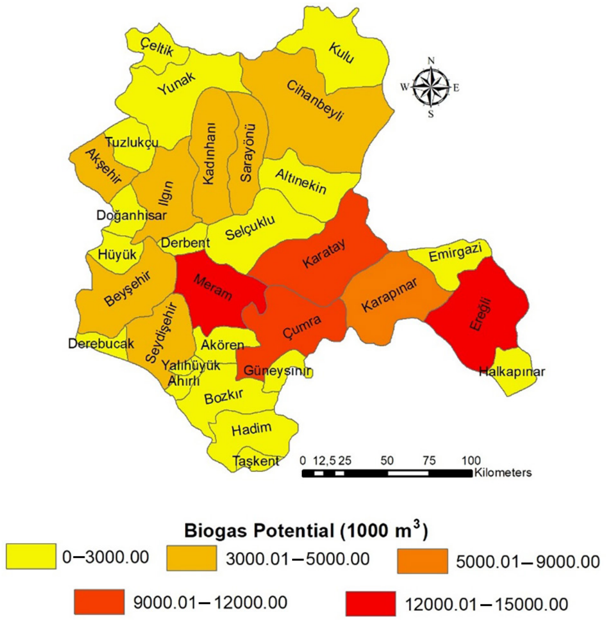

Figure 4. The biogas production potential map of Konya

the capacity will be able to be used almost fully (88%) upon the complete commencement of the plants that are built. This shows that the biogas potential use ratio in Konya is quite high in comparison with other provinces of Türkiye.

2.2. GHG emission reduction of the biogas system

The calculation results of emission reduction by manure management (ERMM) are shown in Table 4.

The amount of CH_4 to be emitted by three manure sources to the environment of Konya is calculated as approximately 36.08 tonnes. CO_2 equivalent of this value is approximately 981.37 thousand tonnes. It was determined that dairy cattle manure as an emission source was almost all of the total emission amount at a ratio of 99%.

The CO_2 emission reduction calculation results of the animal manure-based biogas to be used as a fuel substitute in Konya are shown in Table 5.

It was determined that the biggest emission reduction (671.66 thousand tonnes) could be formed as a result of using the generated biogas as a fuel as a substitution for wood.

Upon summing up the emission reduction arising from the animal manure management system and emission reductions forming as a result of using biogas generated from animal manure in the substitution of other fuels, it was determined that CO_2 emission reduction up to 1.65 million tonnes as a result of evaluating the complete potential of biogas obtained from three types of animal manure in Konya province (Table 6).

Biogas technology takes part in the global struggle against the greenhouse effect. It reduces the release of CO_2 from burning fossil fuels in two ways. First, biogas is a direct substitute for gas or coal for cooking, heating, electricity generation and lighting. Additionally, the reduction in the consumption of artificial fertilizer avoids carbon dioxide emissions that would otherwise come from the fertilizer producing industries. By helping to counter deforestation and degradation caused by overusing ecosystems as sources of firewood and by melioration of soil conditions biogas technology reduces CO_2 releases from these processes and sustains the capability of forests and woodlands to act as a carbon sink (ISAT/GTZ, 1999).

Enteric methane from the microbial fermentation of plant material by ruminant animals, primarily cattle, contributes 30% of methane released into the atmosphere, which is more than any other single source. Enteric methane is the largest contributor (40%) to global greenhouse gas emissions from livestock supply chains, contributing 6% of total anthropogenic greenhouse gas emissions.

Table 5. CO_2 emission reduction arising from energy substitution in Konya

Fuels	FS (GJ.year^{-1})	$EF_{CO_2\ fuel}$ (kg.GJ^{-1})	CE_{fuel}	$ERES_{CO_2\ fuel}$ (kg.year^{-1})
Firewood	1,439,264	112	0.24	671,656,489
Coal	1,439,264	94.6	0.4	340,385,914
Biogas	1,439,264	0	0.6	0
Natural gas	1,439,264	56.1	0.57	141,653,869

Table 6. Reduction of CO_2 emission reduction of animal manure biogas system in Konya

$ERMM_{CO_2eqv.}$ (t·year^{-1})	Fuels	$ERES_{CO_2\ fuel}$ (t·year^{-1})	Total CO_2 emission abatement (t·year^{-1})
981,369,9	Firewood	671,656.5	1,653,026.4
	Coal	340,385.9	1,321,755.8
	Natural gas	141,653.9	1,123,023.8

Table 4. Reduction of CH_4 emission of manure management system in Konya

T	NA	VS (kg.(animal.d)$^{-1}$)	MMG (m^3.kg^{-1})	MCF (%)	EF (kg.CH_4.year^{-1})	ME_{MM} (kg.year^{-1})	$ERMM_{CO_2eqv.}$ (kg.year^{-1})
Dairy cattle	527,669	2.8	0.13	76	67.6523	35,698,028	970,986,357
Broiler	535,520	0.01	0.36	1.5	0.0132	7,072	192,356
Laying hens	13,095,022	0.02	0.39	1.5	0.0286	374,679	10,19,278
TOTAL						36,079,779	981,369,991

Ruminants also produce a substantial amount of carbon dioxide (CO_2), with a CH_4:CO_2 ratio of approximately 4:1, making a total contribution of ruminants to anthropogenic greenhouse emissions of 8% (Black et al., 2021).

This study was conducted to estimate only the energy and environmental benefits of biogas production from animal manure. Of course, there will be different parameters such as the content of manure, the structural and technical condition of the biogas plant, the efficiency of the combustion systems, etc. that will affect these data obtained as a result of the realization of these projects. Considering the effects of such parameters, different studies can be carried out in the future.

Conclusions

In this study, it was determined that the biogas potential obtained from dairy cattle, broiler, and laying hen manures was 105.67 Mm^3 in 2019, depending on the number of animals.

The districts of Meram and Ereğli were determined as the districts with the biggest biogas potential. Çumra, Karatay and Karapınar districts follow these districts. If the complete biogas potential obtained from animal manure is converted to electric energy through a gas engine, an annual 266.53 GWh_{el} electric energy can be obtained (Table 2). It was determined that this potential of Konya was highly evaluated through the biogas plant which was built and of which construction is ongoing.

It was determined to visualize the differences and distribution of the potentials of the districts by the maps that are formed in this study.

Due to the environmental benefits provided by biogas, more emphasis should be placed on using as an alternative and sustainable fuel to fossil fuels. Evaluation of the biogas production potential of such wastes can contribute to increasing the energy supply security of countries. In addition, it can also provide a great environmental benefit by reducing GHG emissions. The method of preventing the emission of gases formed as a result of anaerobic fermentation in the open to the atmosphere and using this gas as a substitute fuel for fossil fuels is an effective application that will contribute to the reduction of greenhouse gas emissions. Therefore, biogas plants to be built in Konya will be a significant contribution to terms of the environment through their contribution to the reduction of greenhouse gas emissions besides being a alternative energy source. Environmental contributions besides energy should be considered to evaluate such investments to be made across the country. This study was conducted to point out such matters.

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