J. Int. Environmental Application & Science, Vol. 17(3): 115-122 (2022)
Research Paper

The Evolution of the Biogas Potential of the Lakes Region, Türkiye by Years: Comparison at Provincial Level

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Received September 17, 2022; Accepted October 19, 2022

Abstract: The energy shortage in Europe in 2022, especially the problems related to natural gas, has revealed how important energy is in today's world. For this reason, energy saving and renewable energy are considered to be the most important issues in the world. Biogas energy is a valuable and renewable energy source that is developing in use and production. Gases originating from organic matter, called biogas, can be obtained through many different sources. One of them is animal manure, which consists of organic matter. In this study, the theoretical biogas potential of the provinces of Antalya, Afyonkarahisar, Burdur, Denizli, Isparta, and Konya was determined. In the study, an average of 2092686 tons/year of manure has been generated for these provinces between 2016-2020. An average of 677.18x10^6 m^3/year biogas potential was determined from the waste. The average energy equivalent is 8.73 GJ.m^3/year. If electrical energy is obtained from animal manure, the electrical energy potential per capita for the years used in the study was determined as approximately 159 kWh/person/year. It has been understood that the average per capita electrical energy supply will have the biomethane potential to meet the parts of Isparta (3.9%), Antalya (0.7%), Burdur (7.8%), Afyonkarahisar (11.7%), Konya (4.4%)) for the provinces in the Lakes Region.

Keywords: *Biogas, Lakes Region, Methane, Electricity*

Introduction

Industrialization steps and social-economic development policies in countries increase the need for energy. Energy is needed in many areas such as heating, industry, and transportation in all areas of life. Fossil resources such as coal and oil are mainly used to meet the energy demand (Yenigün *et al.,* 2021; Seyitoğlu & Avcıoğlu, 2021). These resources have an important share in the world's energy supply. However, these resources are not sufficient to meet the demand and cause environmental problems such as air pollution, global warming, and acid rain. Today, while researchers are trying to develop new technologies for the efficient use of these resources, they are also working on the use and evaluation of renewable energy, which can be considered unlimited in terms of environmental resources. Renewable energy sources are alternative energy sources that reduce foreign dependency on energy and prevent the instability of prices. In this respect, alternative and renewable energy sources are very important (Abbas *et al.,* 2017). Global environmental and energy policies emphasize the need to increase the share of renewable resources and increase the efficiency of energy conversion facilities and aim to develop advanced solutions for the renewal of existing facilities and power generation (Baldinelli *et al.,* 2017). One of the renewable energy sources that have gained importance in recent years is biomass energy. Biomass energy makes important contributions to the prevention of environmental pollution and reducing the greenhouse effect. Biogas is a colorless, flammable, and high-heat fuel type that is formed as a result of the decomposition of organic materials in an airless environment (Kadam & Panwar, 2017; Polat Bulut & Topal Canbaz, 2019). With the production of biogas from food and animal waste, environmental pollution can be reduced and the residues after biogas production can be converted into a valuable organic fertilizer (Seyitoğlu & Avcıoğlu, 2021; Polat Bulut & Topal Canbaz, 2019). In Turkey, incentives are given within the scope of renewable energy systems and it is aimed to supply 30% of the total electrical energy needs from renewable energy sources by 2023. In line with this target, when it is desired to increase the rate of electric energy production and reach the target of zero-emission in 2053, the importance to be given to biogas production emerges (Atelge, 2021). Looking at the world in general, Türkiye is in an important position in the field of agriculture and animal husbandry. Biogas constitutes an important energy source potential due to the high agricultural lands, animal potential, and

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the population interested in agriculture and animal husbandry in the country. Biogas is among the important alternative energy sources originating from the anaerobic digestion of all kinds of organic matter. Biogas enables the production of energy and organic fertilizer from organic waste materials. Animal manure is one of the most widely used organic materials in biogas production (Kumaş & Akyüz, 2021). Türkiye is among the rich countries in terms of biogas potential and animal waste capacity. Although there is a significant amount of animal waste capacity, there is not enough benefit from this waste. The livestock sector in Türkiye has not yet reached the desired levels (Tınmaz Köse, 2017; Kumaş *et al*., 2019). Different measures are taken all over the world to reduce greenhouse emissions during fertilizer storage and processing. Techniques such as biogas energy, manure cooling, and ventilation are among these measures. Biogas production by anaerobic digestion is one of the important technologies in reducing greenhouse gas emissions from manure management (Kumaş & Akyüz, 2021). There are many studies in the literature on biogas production. Kalayci *et al.* (2019) evaluated biogas production from animal waste amounts in Kırklareli province. The biogas potential of animal waste amounts was determined based on districts of Kırklareli in 2018. It has been calculated that 2093331 tons of animal waste are generated annually in the region and that 81506.628 m^3 of biogas can be obtained (Kalayci *et al.,* 2019). Khalil *et al* (2019) examined the potential of biogas that can be produced from Indonesia's animal waste. It has been determined that approximately 9597.4 Mm^3/year of biogas energy can be produced depending on the waste and 1.7×10^6 kWh electricity can be produced annually if biogas energy is used (Khalil *et al.,* 2019). Çağlayan (2020) studied the biogas potential consisting of bovine and ovine animal waste in the Eastern Anatolia region. While calculating the biogas potential for each province separately, it was determined that the highest potential of 14 provinces was the province of Van with 539,167 kg m^3/day. The lowest was determined as Tunceli province with 78.135 kg m^3 /day (Çağlayan, 2020). Melikoğlu and Menekşe (2020) created a model for estimating the biomethane production potential from cattle and sheep waste. In the study, it was stated that cattle and sheep assets will reach 18.7 million and 39.2 million in 2026. Accordingly, they estimated that 1.99 billion m^3 and 0.15 billion m^3 of biomethane could be produced from cattle and sheep, respectively (Melikoğlu & Menekşe, 2020). Çalışkan and Tümen Özdil (2021) determined the biogas potential that can be obtained from animal waste by using the number of animals in different regions of Turkey for the years 2007-2019. It was stated in the study that the total available biogas for the relevant year range contained 76.448×10^6 m^3 methane and its heating value was 2339296×10^6 MJ (Çalışkan &Tümen Özdil, 2021). Aksüt et al., (2022), determined the biogas potential that can be obtained from the animal wastes of Tokat province. For 2021, the amount of waste due to animal presence was determined as 245988 tons of solid waste and the biogas potential was 49 million m^3. The energy equivalent of biogas has been calculated as 292.000 MWh (Aksüt *et al.,* 2022). Işık and Yavuz (2022) determined the biogas potential for the province of Bingöl by using different animal species for the years 2015-2020. In the study, it was determined that the biogas potential is 36.5 million m^3 in 2020 and that 171.4 GWh electrical energy and 171449 x 10^6 kcal /m^3 heat energy conversion can be obtained with this potential (Işık & Yavuz, 2022).

In this study, biogas energy potential was calculated by taking into account the different manure collectability rates for different animal species in the lakes region of Türkiye. In the study, the numbers of animals obtained from the Turkish Statistical Institute were used for different animal species for the years 2016-2020. Changes according to years and comparisons of provinces were made. In addition, the equivalent of obtainable biogas production was determined.

Materials and Method

Afyonkarahisar, Antalya, Burdur, Denizli, Isparta and Konya provinces are located in the Lakes Region of Türkiye. The main income source of the provinces in the region is based on agriculture and animal husbandry. Konya ranks first in Türkiye in terms of cattle, second in sheep and goats, third in laying hens and fourth in turkey. Approximately 75% of the population living in Konya is engaged in agriculture and animal husbandry. 40% of Burdur's economy consists of animal husbandry activities based on milk production and plant production that supports animal husbandry. Although agriculture is Denizli's primary source of income, the cattle breeding and poultry sector have also developed in the province. The main income source of Afyon is agriculture and animal husbandry. Animal husbandry has developed in Afyon due to its wide pastures. In terms of livestock, it comes after Konya, Ankara, Sivas, Kars, and Ağrı. Animal husbandry has developed in Afyon due to its wide pastures. In terms of

livestock, it comes after Konya, Ankara, Sivas, Kars, and Ağrı. Animal husbandry also has a very important place in Isparta and its region. Animal husbandry in the form of family businesses is quite common. Although animal husbandry is an economic activity that is not very common in Antalya, small ruminants breeding is common in the villages of the Central district. Poultry farming is a common economic activity (Anonim, 2022). In this study, the amount of waste and biogas potential of the Lakes Region, Türkiye for the years 2016-2020 were calculated depending on the number of cattle (dairy and beef cattle), small ruminants (sheep and goat), hoofed (horse, donkey, mule) and poultry (turkey, goose, duck, meat and laying hen). In addition, the amount of methane that can be produced from the biogas potential and the heat and electrical energy equivalents depending on this amount were calculated. Animal numbers for different animal species were obtained from the Turkish Statistical Institute. The number of animals for the relevant years is given in Table 1 (TUIK, 2022).

Table 1. Number of Animals

Year	Animal Type	Afyonkarahisar	Antalya	Burdur	Denizli	Isparta	Konya
2016	Cattle	320582	160946	198644	242389	147788	752533
	Small Ruminants	768078	1141951	437867	588517	466436	2088454
	Hoofed	5268	4206	1620	3409	2880	8705
	Poultry	17401182	511860	171558	4274741	421582	12494818
2017	Cattle	374417	174002	208936	264097	133654	868551
	Small Ruminants	895946	1131915	400272	616815	418653	2134897
	Hoofed	5452	3913	1562	2958	2633	8396
	Poultry	19111645	535509	201629	5026908	392773	15637818
2018	Cattle	391507	185833	222843	292086	145012	921572
	Small Ruminants	949973	1245651	410449	703754	491550	2252461
	Hoofed	5391	3753	1073	2678	2485	8232
	Poultry	19687110	530582	205813	5456579	445574	13470742
2019	Cattle	416500	192037	217165	293655	150959	927082
	Small Ruminants	1045000	1273635	410055	699302	537493	2459960
	Hoofed	5186	3445	926	2399	2531	7991
	Poultry	16456029	567134	238346	5603910	311884	13218994
2020	Cattle	437259	190687	213798	307093	149110	946144
	Small Ruminants	1235046	1312814	365044	740663	585259	2843229
	Hoofed	4922	2903	519	1617	2404	5496
	Poultry	16893961	558646	270392	5693485	226702	11234107

Table 2. Biogas Energy Parameters

Livestock Category	Mass	Manure Amount	Solid Matter Content in Manure		Volatile Solids Content in Manure		Biogas Efficiency	Manure Recovery Rates*
	kg head^{-1}	kg head^{-1} day^{-1}	%	kg head^{-1} day^{-1}	%	kg head^{-1} day^{-1}	m^3 kg^{-1}	%
Cattle (Dairy)	550	47.30	14.00	6.62	83	5.50	0.3	50
Cattle (Non-Dairy)	391	22.68	14.70	3.33	85	2.82	0.3	50
Buffalo	380	22.30	14.70	3.28	85	2.78	0.3	50
Sheep	48.5	1.94	27.50	0.53	84	0.45	0.2	13
Goat	38.5	1.58	31.70	0.50	73	0.37	0.2	13
Horse	377	19.23	31.70	6.10	67	4.07	0.3	29
Ass and Mule	130	6.63	31.70	2.10	67	1.40	0.3	29
Poultry (Broiler)	0.9	0.08	25.90	0.02	77	0.02	0.51	99
Poultry (Layer)	1.8	0.12	25.00	0.03	75	0.02	0.51	99
Turkey	6.8	0.32	25.50	0.08	76	0.06	0.51	26
Duck and Goose	2.7	0.30	28.20	0.08	61	0.05	0.51	22

In commercial animal holdings, animals are usually kept in a closed environment. For this reason, all fertilizers produced in enterprises operating in this way can be collected. However, it is not always possible to keep animals raised on small-scale farms or in rural areas in a closed environment. In animal husbandry carried out in such environments, animals generally spend their time in open areas such as

pasture areas. For this reason, most of the fertilizers are stored in the field and it is difficult to collect them. Collectible fertilizer rates were used in many academic studies for Turkey; 50% for bovine animals, 13% for ovine animals, and 99% for poultry. In the study, the values given in Table 2 were used for the theoretical biogas calculation (IPCC, 2006). In addition, the CH_4 content in 1 m^3 biogas is 60%, the CH_4 heating value in 1 m^3 biogas is 21.48 MJ/m^3, and the electrical potential of 1m^3 biomethane is accepted as 2.09 kWh(Ersoy & Uğurlu, 2020).

Results and Discussion

According to the animal numbers data obtained from TUIK, there are cattle (1822882), small ruminants (5491303), hoofed (26088), and poultry (35275741) animals in the region in 2016. Considering the change in the number and type of animals in 2020 compared to 2016, there was an increase in cattle and small ruminants, while there was a decrease in hoofed and poultry. The calculated amount of manure for the years 2016-2020 depending on the number of animals is given in Figure 1. According to Figure 1, it is seen that the amount of manure has increased over the years. While the amount of manure was 1846x10^6 kg in 2016, this amount increased to 2213 x10^6 kg in 2020. Considering the total amount of available manure on a provincial basis, Konya has the highest value with 4294x10^6 kg, while Antalya has the lowest value with 850x10^6 kg.

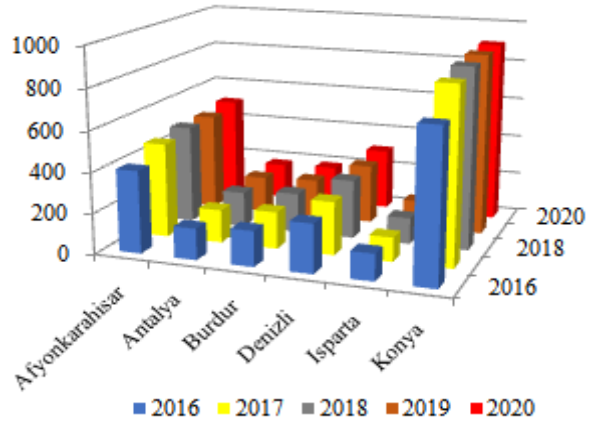

Figure 1. ManureAmount (10^6 kg.year^{-1})

Depending on the amount of available manure, the theoretically calculated biogas production potential covering the years 2016-2020 on a provincial basis is given in Figure 2. When the total biogas production potential for the years 2016-2020 is evaluated, the highest contribution was made in dairy cattle, while the least contribution was made in buffalo species. Dairy cattle are followed by laying hens. The highest contribution to the total biogas production on a provincial basis was obtained from Konya (1375x$10^6$$m^3$), while the least contribution was made from the province of Isparta (192x$10^6$$m^3$). The reason for the high potential of Konya province can be shown as the excess number of animals. Being the largest province in Turkey in terms of the area directly affects the number of animals and thus the potential for biogas energy. Konya province is followed by Afyonkarahisar (846x$10^6$$m^3$), Denizli (447x$10^6$ m^3), Burdur (277x$10^6$$m^3$), Antalya (248x$10^6$$m^3$), and Isparta(192x$10^6$$m^3$), respectively. The biomethane potential distribution for the years 2016-2020 depending on the amount of biogas is given in Figure 3. The biomethane potential, which was (360x10^6 m^3) in 2016, increased by 17.6% and reached (424x10^6 m^3) in 2020. Compared to 2016, there was an increase of 12.14 percent in 2017, 17.10% in 2018, and 16.52 percent in 2019. The order of the biogas potential based on provinces, from most to least, is Konya, Afyonkarahisar, Denizli, Burdur, Antalya, and Isparta.

The evolution of the amount of heat that can be obtained from methane over years is given in Figure 4 and the amount of electrical energy is given in Figure 5. The total electricity potential from animal manure, covering the years 2016-2020, has been determined as approximately 4.3 billion kWh per year. While the total amount of electrical energy for 2016 was 0.76 billion kWh, this amount was calculated as 0.89 billion kWh for 2020. While Konya's total electrical energy amount is 1.7 billion kWh, this amount is followed by Afyonkarahisar with 1.06 billion kWh. The least amount of electrical energy was Isparta with 0.24 billion kWh. The total amount of heat energy for the years 2016-2020 has been

calculated as 43.64 GJ. The order of the total heat amount by provinces is Konya(17.72 GJ), Afyonkarahisar (10.90 GJ), Denizli (5.75 GJ), Burdur (3.57 GJ), Antalya (3.19 GJ) and Isparta (2.48 GJ).

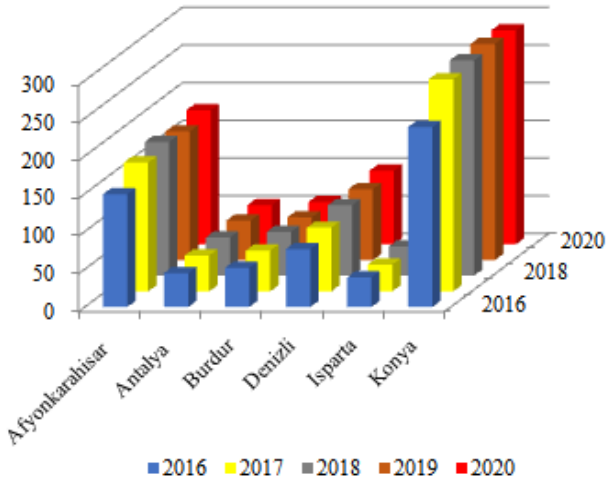

Figure 2. Biogas Amount ($10^6 m^3.year^{-1}$)

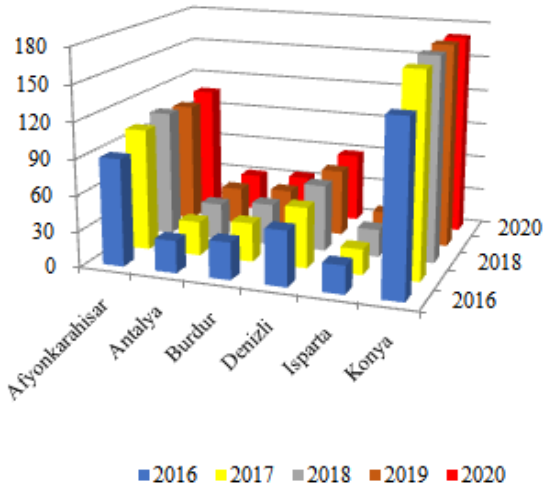

Figure 3. Amount of Methane ($10^6 m^3.year^{-1}$)

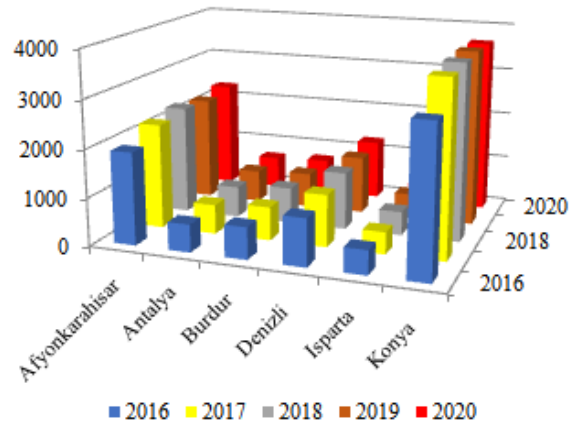

Figure 4. Energy value of methane ($10^6 MJ.(m^3)^{-1}.year^{-1}$)

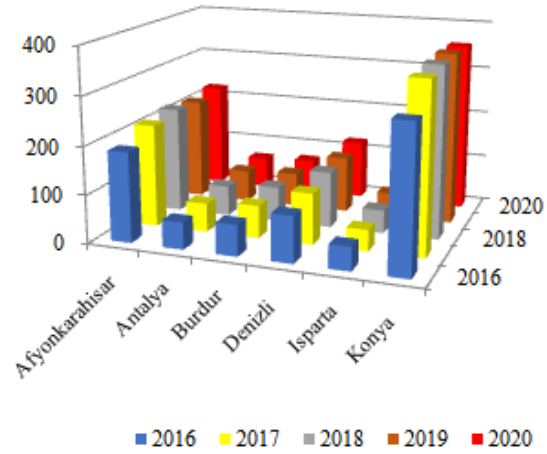

Figure 5. Electrical energy equivalent ($10^6.kWh.(m^3)^{-1}.year^{-1}$

The electrical energy potential per capita that can be obtained by the conversion of methane to electrical energy in the provinces used in the study is given in Figures 6 and 7. The total electricity consumption per capita is given in Figure 8 and the ratio of the total electricity produced per capita to the total consumption is given in Figure 9. The total population between 2016 and 2020 is 38.45 million people. In the case of obtaining electrical energy from animal manure, the electrical energy potential per capita was determined as approximately 159 $kWh.person^{-1}.year^{-1}$. The capacity to meet the per capita electrical energy need from biomethane is Afyonkarahisar, Burdur, Konya, Isparta, Denizli, and Antalya, respectively. While Antalya has the highest population among the provinces, this province is followed by Konya, Denizli, Afyonkarahisar, Isparta, and Burdur, respectively. The electrical energy potential of Afyonkarahisar that can be obtained from biomethane for 2020 is calculated as 223 million $kWh.year^{-1}$ and the amount of energy that can be produced per capita is calculated as 302 $kWh.person^{-1}.year^{-1}$. It has been determined that approximately 11.49% of the per capita electrical energy need of Afyonkarahisar province in 2020 can be obtained from animal manure. While the highest consumption

coverage rate by years was seen in Afyonkarahisar in 2018, the least consumption coverage was in Antalya in 2019.

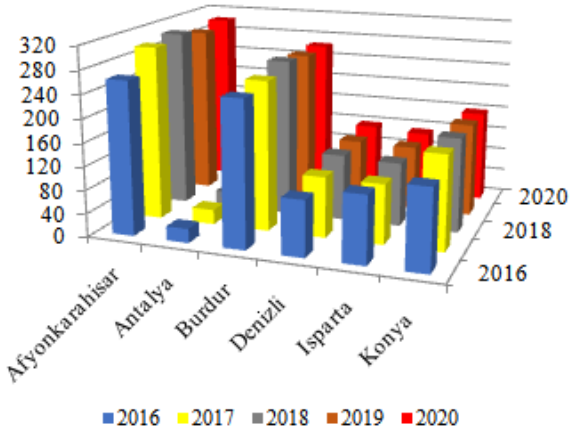

Figure 6. Electric potential per capita (kWh.person^{-1}.year^{-1})

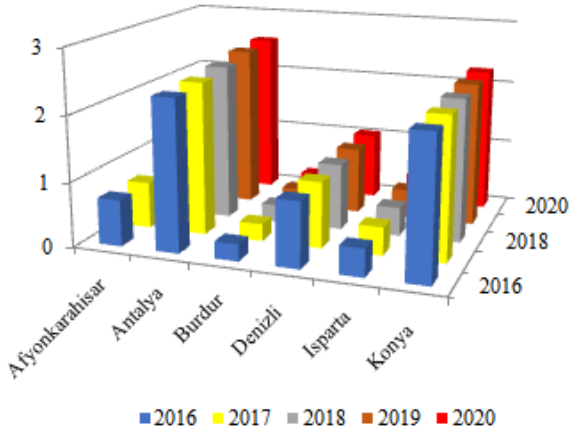

Figure 7. Population distribution by years (10^6 people)

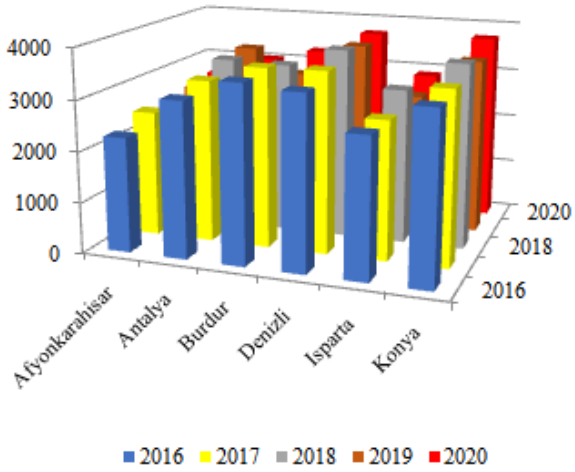

Figure 8. Total electricity amount per capita (kWh.year^{-1})

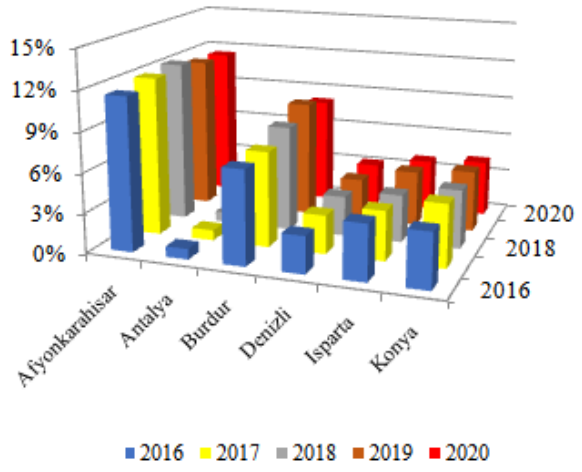

Figure 9. The ratio of electricity generation per capita to meet the total consumption (kWh.year^{-1})

Conclusion

Here is a more detailed and expanded version of the study, which was presented in the TFD 38 congress (İnan et al., 2022). In this study, the biogas energy potential was calculated by taking into account the different manure collectability rates for different animal breeds/species of Antalya, Afyonkarahisar, Burdur, Denizli, Isparta, and Konya provinces in Turkey's lakes region. In addition, the amount of methane from the biogas production available was determined. Depending on the amount of methane, the ratio of the amount of thermal and electrical energy and the amount of electrical energy per capita to meet the total consumption were determined . According to this;

- The provinces with the highest biogas potential originating from animal manure were determined as Konya, Afyonkarahisar, Denizli, Burdur, Antalya, and Isparta, respectively.
- Biogas potential was calculated as 3.39 billion m^3/year in total between 2016 and 2020, and biomethane potential as 2.03 billion m^3/year. While the total biomethane potential was 0.36 billion m^3/year in 2016, this value is 0.43 billion m^3/year for 2020.
- For the years 2016-2020, the total amount of thermal energy has been calculated as 43.64 GJ, and the total electric potential has been calculated as approximately 4.3 billion kWh.
- The total population between 2016 and 2020 was 38.45 million people. The provinces with the highest population were respectively Antalya, Konya, Denizli, Afyonkarahisar, Isparta, and

Burdur. The average per capita electricity consumption for the five years of relevant years is approximately 3173 kWh.

- In the case of obtaining electrical energy from animal manure, the per capita electrical energy potential has been determined as approximately 159 kWh.person^{-1}.year^{-1} for the years 2016-2020. It has been understood that the average per capita electrical energy supply will have the biomethane potential to meet the parts of Isparta (3.9%), Antalya (0.7%), Burdur (7.8%), Afyonkarahisar (11.7%), Konya (4.4%) for the provinces in the Lakes Region.

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