Agronomy Research **14**(3), 650–660, 2016

Biogas potential from animal waste of Marmara Region-Turkey

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Abstract. The purpose of this study was to determine the biogas production capacity from animal wastes in Marmara region of Turkey for the years 2005–2014. The wastes from the cattle and hen in the region were considered the resource for biogas production taking the number of animals and the collectability of the wastes into the account. Three scenarios were evaluated to estimate the biogas capacity by assuming that 100% (theoretical potential), 50%, and 25% of the total animal waste could be used for biogas production in the region. For theoretical biogas production from cattle wastes, the greatest potential in the year 2014 was calculated for Balıkesir province with 145.53 Mm^3, followed by Çanakkale, Bursa, Sakarya, and other seven provinces. Balıkesir had the highest biogas potential in 2014 from the poultry waste, too, followed by Sakarya, Kocaeli, Bursa, and other seven provinces. Biogas potential (100%) of Marmara region increased by 15% from 2005 to 2014 with 1,242.17 Mm^3 in 2014. The heat and electrical energy equivalents of the biogas were found to be 7,453.02 GWh and 2,608.56 GWh_e, respectively. In the other two scenarios, depending on the utilization rate of theoretical biogas potential: biogas amount, heat and electric power values were determined proportionally.

Key words: Renewable energy, biogas, animal waste, Marmara region.

INTRODUCTION

According to International Energy Agency (2013), energy supply of the country was provided mainly by natural gas, coal, oil, hydro, biofuels/waste and geothermal/solar/wind with 32.4%, 28%, 27.3%, 4.4%, 4.2% and 3.6%, respectively (IEA, 2015a).

Total energy consumption of Turkey in 2015 was 83,633 ktoe (kilo ton of oil equivalent) and natural gas was responsible for 56% of the total energy used in the country, followed by electrical energy with 27%, and diesel fuel with 17% (Republic of Turkey ministry of energy and natural resources, 2015a, 2015b). The total electrical energy production was 259,690.3 GWh while the consumption was 264,136.8 GWh in 2015 (TETC, 2016). Clearly, Turkey has an energy market that is dependent on fossil energy sources. The instability of the costs of these sources and their environmental effects make renewable energy sources more preferable.

The fossil fuels received subsidies/incentives about 550 billion USD in 2013, four times greater than renewable energy incentives (IEA, 2015a). Despite the slow progress in Turkey, the interest and the investments in renewable energy keeps increasing. In the last decade, biogas, liquid biofuels, geothermal, solar, thermal, and wind energy production increased in Turkey. The greatest rises occurred in wind energy production with 7,557 GWh and biogas energy production with 8,511 TJ, respectively (IEA, 2015b).

Cooperatives and the agricultural industry show particular interest in biogas utilization in Turkey since storage and discharge of animal waste is one of the most important problems of agricultural enterprises (Dena, 2015). Another reason of interest to biogas is that agricultural industry is faced with high energy costs.

Biogas is renewable energy resource generated by digestion under anaerobic conditions as a result of conversion of organic wastes by the use of microorganisms, and primarily composed of methane and carbon dioxide. It is mostly used to generate electricity and heat both for urban and rural areas (Alfa et al., 2014; Li et al., 2014; Oleszek et al., 2014; Yingjian et al., 2014; Igliński et al., 2015). The animal wastes are deposited and energy costs are reduced by producing biogas in the agricultural enterprises.

A research project was undertaken to determine the biogas potential of Turkey in 2011 (DBZF, 2011). Studies were also conducted focusing on specific regions and provinces for different feedstocks to be used for biogas production in Turkey (Ediger & Kentel, 1999; Evrendilek & Ertekin, 2003; Demirel et al., 2010; Ergür & Okumuş, 2010; Ulusoy et al., 2009; DBZF, 2011; Altıkat & Çelik, 2012; Coskun et al., 2012; Onurbaş Avcıoğlu & Türker, 2012; Koçer & Kurt, 2013; Aktaş et al., 2015; Eryılmaz et al., 2015). Previous studies showed that the most appropriate feedstock are animal wastes for biogas production for Turkey in terms of costs and management aspects.

The aim of this study was to determine the biogas potential from animal wastes of Marmara region, Turkey by analysing the relevant data from 2005 to 2014. The cattle and hen wastes were considered the resource for biogas production taking the number of animals and the collectability of the wastes into the account.

MATERIALS AND METHODS

Marmara Region is situated on the North West part of Turkey with a surface areas of 67,000 km², corresponding to 8.5% of the total land. The industry, commerce, tourism, and agriculture are strong in the region. About 30% of the land is arable and 11.5% is forestry. The region consists of 11 provinces (Balıkesir, Bilecik, Bursa, Çanakkale, Edirne, İstanbul, Kırklareli, Kocaeli, Sakarya, Tekirdağ, Yalova) and is the leading region in energy consumption in the country (Wikipedia, 2015).

The numbers of cattle and hens in Marmara region of Turkey in the period of 2005–2014 were obtained from Turkish Statistical Institute (TSI, 2015). Amount of daily produced manure varies according to animal species. Furthermore, length of stay in the shelter affects amount of collectable manure. While the manure can be almost completely collected in poultry depending on the length of stay in the shelter, amount of collectible manure is lower in feeder cattle, sheep and goats. In this study, the cattle were classified as calf and mature animal, according to the TSI data, and the corresponding manure weights were determined based on this age classification. Length of stay in the shelter for cattle was taken as 100% as the relatively larger enterprises are concentrated in western part of Turkey and the animals are kept in shelters rather than grazing in pastures. Length of stay in the shelter of some animals and solid matter contents of manures are presented in Table 1. In calculations, mean live weights were taken as 500 kg for cattle and 2 kg for hens (Alçiçek & Demiruluş, 1994; Alibaş, 1996; Karaman, 2006; Koçer et al., 2006; Eliçin et al., 2014).

Table 1. Time spent ratio in the shelter and solid matter content of the organic waste from various animals (Alibaş, 1996; Ekinci et al., 2010; DBZF, 2011; Kaya & Öztürk, 2012; Eliçin et al., 2014; Aktaş et al., 2015)

Animal type	Time spent in the shelter (%)	Solid matter content (%)
Mature cattle	100.00	15.00
Calf	100.00	15.00
Meat hen	99.00	40.00
Egg hen	99.00	40.00
Turkey	68.00	25.00
Sheep, Goat	13.00	25.00
Horse	29.00	20.00

The following equations were used to calculate the amount of biogas and its energy value. The total amount of manure that can be produced by the animals per day was determined by equation 1.

$$M_{Dw} = M_w \times T_S \text{s} \quad (1)$$

where M_{Dw} is obtainable daily total manure per head (kg (day head)$^{-1}$), M_w is wet based daily total manure per head (kg (day head)$^{-1}$), and T_S is the length of stay in the shelter of animals (%). The amount of biogas that can be produced from the manure was obtained using equation 2.

$$B_A = M_{Dw} \times P_L \times C_b \times 0.365 \quad (2)$$

where B_A is annual amount of biogas (m^3 a^{-1}), P_L is livestock population (number), and C_b is biogas coefficient which was determined by animal type and biogas amount in m^3 t^{-1}. Dry matter contents for cattle and hen manures were assumed to be ≤ 15% and ≤ 40%, respectively. Manure of hen has significantly higher biogas potential than cattle manure due to better feedstock qualities such as dry matter and protein content (Akbulut & Dikici, 2004; Kaya et al., 2009; FNR, 2010; Kaya & Öztürk, 2012). Equation 3 was used to calculate the calorific energy value of biogas.

$$B_T = C_c \times B_A \quad (3)$$

where B_T is equivalent calorific energy value of biogas (MJ) and C_c is calorific coefficient which was determined by the rate of methane in the biogas (MJ m^{-3}). Although calorific value of biogas varies according to its methane content, it is approximately 20–27 MJ m^{-3} (Alibaş, 1996; Banks, 2009; Eryaşar & Koçar,2009; Gümüşçü & Uyanık, 2010; Frost & Gilkinson, 2010; Kaya & Öztürk, 2012; FM Bioenergy, 2013).

Equivalent electrical energy varies according to methane content of biogas and electrical conversion efficiency (Banks, 2009; Astals & Mata, 2011; DBZF, 2011; Kaya & Öztürk, 2012; SGC, 2012). In this study, methane content and electrical conversion efficiency values were assumed to be 60% and 35%, respectively. The equivalent electrical energy value of biogas was determined using equation 4.

$$B_E = C_e \times B_A \quad (4)$$

where B_E is equivalent electrical energy value of biogas (kWh_e) and C_e is electrical coefficient determined by the rate of methane in the biogas and conversion efficiency to electricity ($kWh_e\ m^{-3}$).

Usually, the theoretical potential is reported in biogas potential determination studies. However, it is unlikely to use all of the theoretical potential in practice due to other uses of the animal waste in agricultural production, handling and logistics problems of the wastes, cultural preferences, etc. It might be more realistic to assume that the theoretical biogas potential can be utilized only partially. Therefore, in this study, three different scenarios were considered for biogas utilization in the evaluations: 100% (theoretical potential), 50%, and 25% use of theoretical potential of animal waste.

RESULTS AND DISCUSSION

According to TSI data, number of mature cattle, calves and egg hens in Marmara region increased 39%, 98%, and 46%, respectively in 2014 compared to 2005. The changes in the animal populations in the region are given in Figs 1 and 2. Based on Fig. 1, both the mature cattle and calf populations kept increasing steadily from 2005 to 2013 with some reduction in 2014.

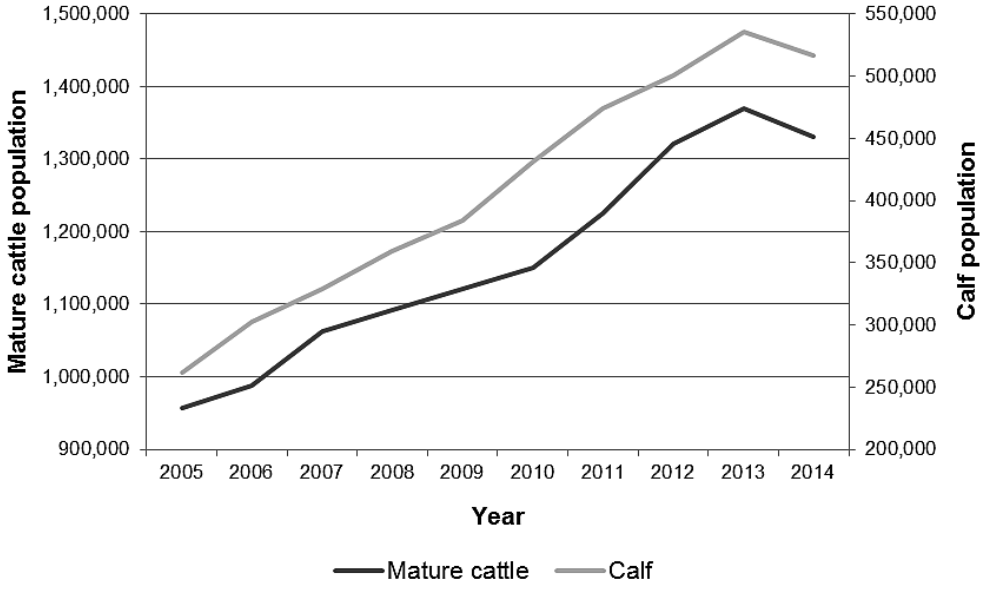

Figure 1. The change in cattle population in Marmara Region from 2005 to 2014.

Although the number of meat hens look similar in 2005 and 2014, there were extreme variations in the number of meat hens from 2005 to 2007, and then 2007 to 2009. Therefore, yearly variations in hen production should have serious implications in terms of accessibility to the manure when the number of hens decreases sharply as shown in Fig. 2. The production reduced further for meat hens until 2011, followed by small recovery since then. Egg hen production, on the other hand, has been increasing at a fast rate since 2010.

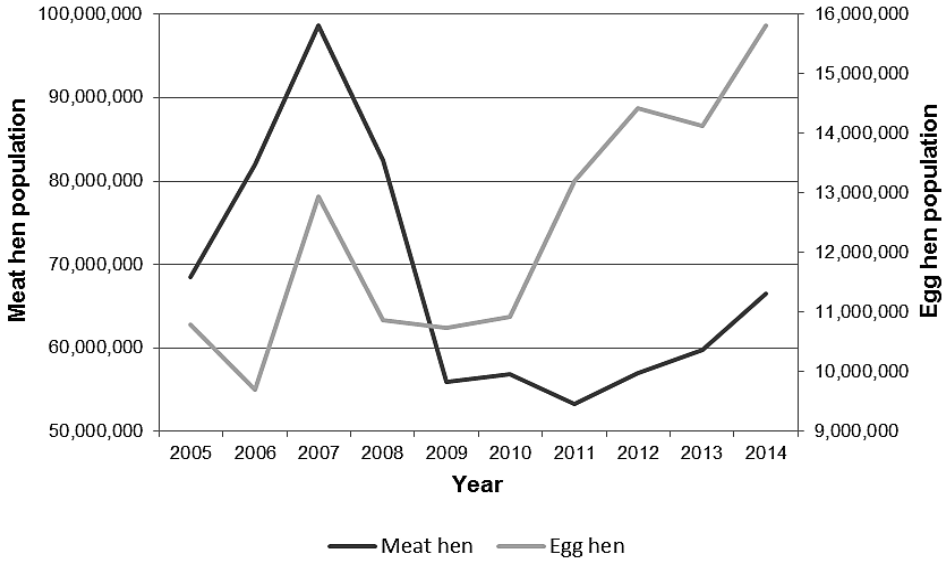

Figure 2. The change in hen population in Marmara Region between 2005 and 2014.

Balıkesir, Edirne, and Bursa were the first three provinces in cattle production in 2005, producing 35% of the total mature cattle in the region. The three provinces with the lowest mature cattle population were Yalova, Bursa and Kocaeli. Total number was about 81,000 cattle in these three provinces which was less than that of Bursa province. The three provinces with the highest number of animals in 2014 were Balıkesir, Çanakkale and Bursa, respectively. While the two provinces with the lowest animal numbers were the same as 2005, the third ranking province was replaced by İstanbul in 2014.

Balıkesir has the highest calf population in 2005 and 2014. Bursa and Çanakkale were the other provinces for the highest calf population in 2005 and 2014. These three provinces produced more than half of the calf population in the region in 2014 with Balıkesir 31%, Bursa 12%, and Çanakkale 10%. Yalova, Bilecik and İstanbul had the lowest calf population between 2005 and 2014.

According to TSI data, meat hen population in the Marmara region decreased about 2 million in 2014 compared to 2005. However the highest first three provinces (Kocaeli, Sakarya and Balıkesir) increased approximately 3 million in 2014 compared to 2005. The lowest provinces were Yalova, Kırklareli and Edirne in 2005. Tekirdağ had the least number of hens in 2014, followed by Yalova and Kırklareli.

In egg hen production, the greatest share belonged to Balıkesir, Bursa, and Sakarya in both 2005 and 2014 while Yalova, Bilecik and Edirne had the smallest share. In general, number of egg hens in Marmara region increased by five million during the ten years' time from 2005 to 2014.

The obtainable manure calculated based on Eq. 1 and numbers of mature cattle, calf, and egg and meat hen were given in Table 2. Although the number of animals increased 4%, the manure production increased 31.7% from 2005 to 2014. This rise resulted from greater number of cattle and egg hens in this period. As a result, manure production was more than 25 Mt in the region in 2014, 72% of which was produced from

manure cattle, 18%, 7% and 3% from meat hen manure, calf manure, and egg hen manure, respectively.

Table 2. Total manure production levels in Marmara region between 2005 and 2014

	Total Manure Production (t)			
Year	Mature cattle	Calf	Meat hen	Egg hen
2005	13,098,485.81	897,607.93	4,698,148.65	504,527.13
2006	13,526,165.44	1,036,844.77	5,630,867.45	453,526.32
2007	14,541,271.50	1,128,627.45	6,767,244.43	604,413.04
2008	14,954,250.75	1,234,271.37	5,662,799.62	507,397.61
2009	15,350,011.13	1,316,769.77	3,842,423.42	501,415.63
2010	15,755,544,38	1,480,256.92	3,899,226.85	510,389.28
2011	16,767,173.81	1,625,985.21	3,658,991.80	616,432.79
2012	18,073,262.44	1,718,316.85	3,912,185.88	673,491.74
2013	18,759,485.25	1,838,659.18	4,098,879.28	660,175.09
2014	18,207,961.13	1,772,372.26	4,565,818.42	738,912.21

Calculated theoretical biogas potential of each province for the animal types studied was given for 2005 and 2014 in Table 3. As expected from animal manure potentials, Balıkesir had the highest biogas potential both in 2005 and 2014. Kocaeli and Sakarya were the other provinces for high biogas potentials in 2005. In 2014, Bursa was the third large potential after Balıkesir and Sakarya.

Table 3. Theoretical biogas potential of the eleven provinces in 2005 and 2014

	Theoretical Biogas Potential (Mm^3)			
	2005		2014	
Province	Cattle	Hen	Cattle	Hen
Balıkesir	84.82	166.65	145.53	288.36
Bilecik	10.11	18.82	10.68	11.40
Bursa	40.01	40.91	52.68	73.86
Çanakkale	35.91	110.76	56.99	48.20
Edirne	41.30	1.86	44.53	1.95
İstanbul	18.71	7.85	20.91	12.42
Kırklareli	26.32	2.23	42.49	2.22
Kocaeli	17.44	207.24	31.71	75.67
Sakarya	36.47	168.14	50.33	223.49
Tekirdağ	36.34	3.29	40.52	4.78
Yalova	2.48	0.64	3.13	0.31
Total	349.90	728.37	499.51	742.66

The greatest increase in biogas production from 2005 to 2014 took place in Balıkesir province with 182.42 Mm^3 due to high level of increases in both cattle and hen manure. Balikesir itself could provide almost one third of the biogas potential of Marmara Region in 2014. The increases in the biogas potential were high also in Kırklareli and Bursa with 56.61% and 56.38%, respectively. Serious reduction could be seen in biogas production in Kocaeli (Table 3). Çanakkale and Bilecik also experienced decreases in this period. All provinces, except three of them, increased the biogas potential from 2005 to 2014.

While Balıkesir lead the biogas production both in cattle and hens, Sakarya province also had high biogas potential coming from hen production. Balıkesir was followed by Çanakkale despite the reduction seen in this province.

Farm structure, storage capabilities for the animal wastes, and transportation might affect the utilization ratio from animal waste for biogas production. Biogas potential, calorific energy and electrical energy values of Marmara region between 2005 and 2014 were shown in Table 4.

Table 4. Biogas, calorific energy and electrical energy potential of Marmara region between 2005–2014 based on 100, 50, and 25% use of the total manure

	Biogas Potential (Mm^3)			Calorific Energy of Biogas (GWh)			Electrical Energy of Biogas (GWh_e)		
Year	100%	50%	25%	100%	50%	25%	100%	50%	25%
2005	1,078.28	539.14	269.57	6,469.66	3,234.83	1,617.42	2,264.38	1,132.19	566.10
2006	1,215.89	607.95	303.97	7295.34	3,647.67	1,823.84	2,553.37	1,276.68	638.34
2007	1,423.78	711.89	355.94	8542.68	4,271.34	2,135.67	2,989.94	1,494.97	747.48
2008	1,268.54	634.27	317.14	7611.24	3,805.62	1,902.81	2,663.94	1,331.97	665.98
2009	1,024.81	512.40	256.20	6,148.84	3,074.42	1,537.21	2,152.09	1,076.05	538.02
2010	1,048.24	524.12	262.06	6,289.45	3,144.72	1,572.36	2,201.31	1,100.65	550.33
2011	1,058.39	529.19	264.60	6,350.33	3,175.17	1,587.58	2,222.62	1,111.31	555.65
2012	1,136.78	568.39	284.20	6,820.71	3,410.35	1,705.18	2,387.25	1,193.62	596.81
2013	1,181.22	590.61	295.31	7,087.33	3,543.66	1,771.83	2,480.56	1,240.28	620.14
2014	1,242.17	621.09	310.54	7,453.02	3,726.51	1,863.26	2,608.56	1,304.28	652,14

Analysis of biogas production potential from animal waste in Marmara region showed that despite the fluctuations in hen production, the total manure production in Marmara region increased from 2005 to 2015. Biogas potential increased in the region significantly in 2006 and 2007. In 2007, theoretical biogas potential increased 32% compared to 2005 with 1,423.78 Mm^3. Then the biogas capacity reduced as a result of sharp drop in the number of hens in 2008 and 2009. However, the number of cattle was not adversely affected. A trend with gradual increase was observed in the number of hens and cattle since 2010. Biogas potential in 2014 increased 15% compared to 2005 with 1,242.17 Mm^3. Biogas potentials in 2014 were 621.09 Mm^3 and 310.54 Mm^3 if 50% and 25% of the theoretical potential could be used, respectively.

Calorific energy value in 2005 was 6,469.66 GWh and increased to 7,453.02 GWh in 2014. Proportional to the increase in calorific energy value, electrical energy potential of 2005 (2,264.38 GWh_e) increased (2,608.56 GWh_e) in 2014 (Table 4). In the other two scenarios, i.e. for 50% and 25% use of the theoretical biogas potential, heat and electric power values were determined proportionally.

The electrical energy produced from biogas is subsidized the Renewable Energy Law in Turkey. The Law was put into practice in 2005 for the companies that have license to produce biogas according to the subsidy policy from 2005 to 2015. The policy imposes that any company conforming to the subsidy mechanism would sell electricity at 0.133 USD kWh for ten years from the date of obtaining the license to produce biogas. According to the calculations, the theoretical biogas potential of Marmara Region is equivalent to 347 million USD in terms of electrical energy.

Although both cattle and hen rearing are developed in Marmara region, very small portion of the biogas potential is currently used. Animal waste potential of Marmara region is remarkable and farmers and investors can make benefits from biogas technologies if properly guided and supported by policy makers.

Although the exact number of biogas facilities in Turkey is not known, based on the project titled 'Source Efficiency Of Animal Wastes Through Biogas And Its Climate Friendly Usage Project' the number of active biogas facilities was 36 in 2011 and the projected biogas facilities were 49 (DBZF, 2011). Even though more investments are made in Marmara region compared to the rest of the country, limited investments were made to benefit from biogas in the region (Fig 3). The main reason for this was related to the lack of appropriate incentives for biogas production. Since the theoretical biogas potential cannot be put into production, some realistic proportions of the theoretical potential should be targeted. As shown in Table 4, significant amount of electrical energy could be produced even with the 25% of the theoretical biogas potential.

Figure 3. Number of biogas plants in the provinces of Turkey.

The amount of manure, and hence the potential for biogas and electricity production may increase further given the trend in manure production from 2005 and 2014. Within this scope, the biogas production should be considered one of the most important means of utilizing the manure in the region. Furthermore, production and utilization of biogas is an environmentally-friendly method and is a strong candidate in meeting the rural energy need. Awareness of public institutions and private sector should be raised and investments should be further promoted to benefit from the biogas potential.

CONCLUSIONS

In this study, biogas potential from animal wastes of Marmara region of Turkey was determined and calorific and electrical energy values of the theoretical biogas potential were calculated. It was found that manure production increased from 2005 to 2014 and will probably increase further in the near future. Although the amount of hen wastes reduced sharply in some of the provinces, the total manure production did not reduce in the region. The farmers and entrepreneurs invested in cattle production from

2005 to 2015, resulting in gradual increase in cattle population whereas significant drops were observed in the number of hens from 2007 to 2011. In recent years, the hen production has a tendency of increasing.

The animal waste produced in 2014 was about 25 Mt corresponding to a theoretical biogas volume of 1,242.17 Mm^3. Theoretical biogas can generate 7,453.02 GWh of calorific energy and 2,608.56 GWh_e of electrical energy. Putting a small segment of the theoretical biogas production, such as 25%, into energy production would be important to meet some of the energy requirements in rural areas.

In Turkey, the number biogas plants tends to increase, but anaerobic fermentation is yet to be used efficiently. More incentives and financial support is needed for investors to take advantage of the existing biogas technology.

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