# GIS mapping of biogas potential from animal wastes in Bursa, Turkey

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**Abstract:** This paper introduces biogas potential of animal waste in Bursa, an important agricultural, industrial and tourism centre in northwest Turkey. This research has focused on Bursa's biogas potential from animal wastes. The potential quantity of electric energy, the potential amount of biogas as well as potential bio-electric energy per capita to be obtained from animal wastes were studied. If the evaluation of biogas potential is conducted thoroughly, 1.12% of the electricity consumption of Bursa can be met with the conversion of biogas from animal wastes into electricity. This study also revealed that the power for 95% of street lighting, approximately twofold of the electricity consumed in official apartments and all of the agricultural irrigation operations can be provided with electrical energy obtained from biogas obtained from animal wastes in Bursa. In addition, the research efficiency was improved by creating thematic maps in GIS, which enabled differences in data among the districts to be observed more clearly.

**Keywords:** animal waste, biogas, energy, Bursa, GIS mapping

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## 1 Introduction

Growth figures in Turkey's energy sector are quite high compared to developed countries. Turkey ranks first in Europe in terms of the growth rate of electricity and natural gas demand for the last 10 years[1,2]. On the other hand, Bursa has a considerable share regarding the increase in the country's energy demand in terms of both its strong industry (food, textile and automotive) and natural-gas-combined-cycle plants which in the region. Bursa is the fourth largest city of Turkey with regard to population density.

Turkey's primary energy supply is composed of coal, natural gas, oil, hydraulic and other energy sources (wood, geothermal, wind, solar, waste, biofuel) with the respective rates of 32.7%, 31.1%, 26.0%, 4.1% and 6.1%. Being a net importer of fossil energy sources, Turkey imported 73.4% of energy supply in 2012 including 92% oil, 99% natural gas and 95% coal[3]. Fossil fuel and hydroelectricity generation accounts for nearly all of Turkey's electricity. Total electricity generation has been met through natural gas, coal, hydraulic, wind, liquid fuels (fuel-oil, diesel, asphaltite), geothermal and other sources (waste and renewable) with the respective rates of 43.8%, 26.5%, 24.8%, 3.2%, 1.0%, 0.6% and 0.5% by the year 2013[4]. According to the International Energy Agency (IEA), energy use will continue to grow at an annual growth rate of around 4.5% from 2015 to 2030, approximately doubling over the next decade. The IEA expects electricity demand growth to increase at

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an even faster pace[5]. When more than 70% of electricity generation is thought to be produced from fossil fuels in Turkey, it is important to mention that the country has partly external dependency concerning electricity production. It is financially significant for developing countries such as Turkey to minimize external dependency and turn to domestic sources during energy production.

Furthermore, the continuous increase in the world's energy needs are resulted from the rapid growth of technology and population; however, such factors as the exhaustion of fossil fuels as finite source of energy in the near future, a rapid and unavoidable increase in oil prices as well as environmental pollution caused by oil-derived fuel emissions[6] have led to an increase in tendency to the clean energy recently[7,8]. The European Union is planning to increase its share of renewables in ultimate energy consumption in individual member states to 20% by the year 2020[9].

In this regard, biogas can also be a good alternative and biogas potential is an issue that should be investigated thoroughly especially for countries livestock potential of which is high. Being composed of methane (50%-60%), carbon dioxide (40%-50%), nitrogen ($N_2$; 5%), biogas is colourless, odourless gas and lighter than air[10-13]. The typical raw materials for agricultural biogas plants include animal manure[14]. The manure of all kinds of animals may be used to obtain biogas from animal wastes; however, as animal manure embodies microorganisms providing anaerobic fermentation within itself, this group of organic wastes has a significant place in biogas production[15]. Environmental pollution can be avoided to a great extent through enabling the control of wastes as well as supplying energy with the use of biomass energy the most common use of which is biogas. Biogas is an energy source which can be used by converting it into electrical energy by means of a generator; besides it can also be used as a fuel[16-18].

So far, new technologies such as geographic information systems (GIS) have not been used intensively in the presence of various studies conducted on biogas. However, visual maps revealing correlations between data and geography with GIS provides an opportunity for the scientists dealing with various branches of science, policy-makers and the mass public to better understand the issue and the relationship between data. Considering a single image makes much more sense than thousands of words, the visual power of GIS is also evident. GIS can also integrate the data obtained from different sources[19]. With advances in technology in recent years, the GIS technology presented to various sciences has been intensively used for this purpose and hence has a significant place in this context.

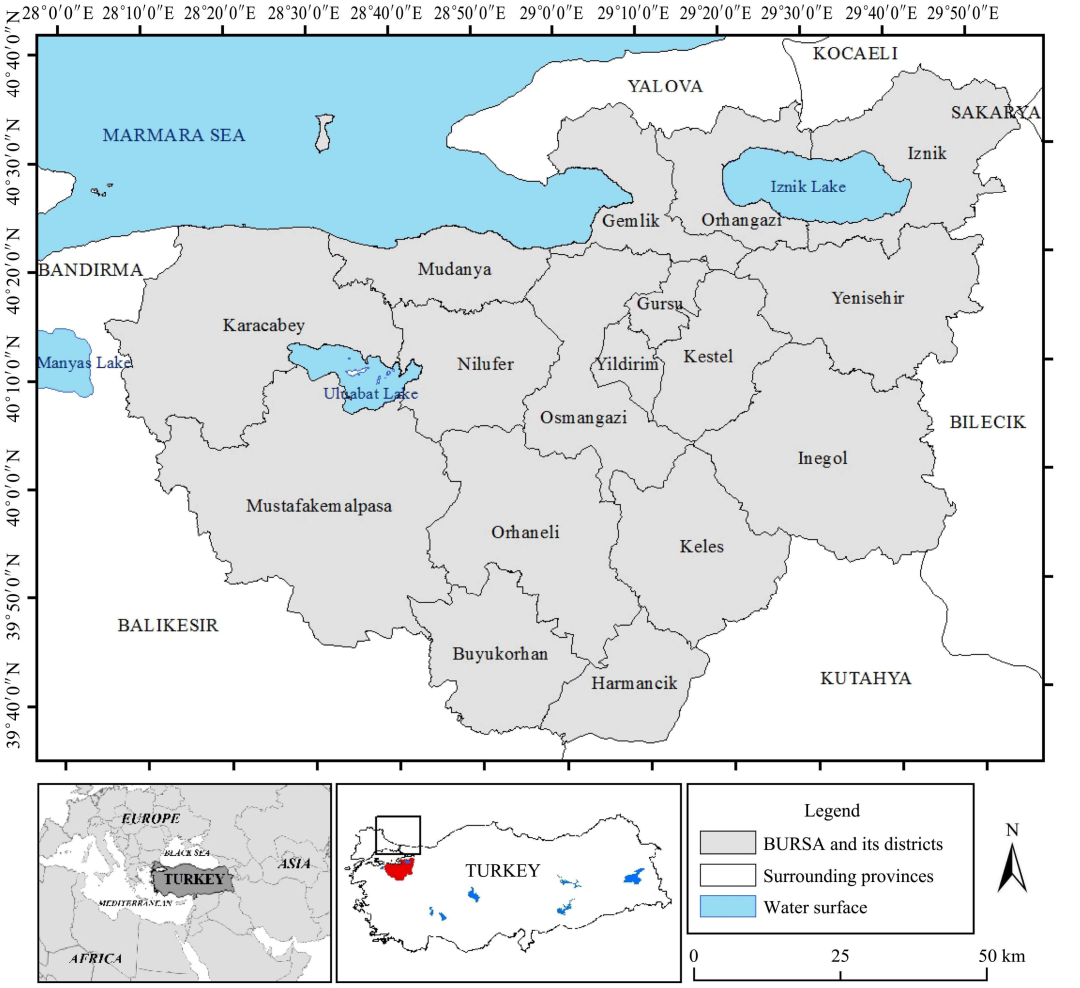
Throughout this study, a database was created within a GIS; the number of animals (large ruminants, small ruminants, poultry and equidae) available in Bursa for a long time (in the past 11 years) was entered into this database; for Bursa and its districts, comparison maps have been produced at county-level in GIS by calculating biogas potential from animal wastes; the amount of electricity and natural gas consumed in the region as well as the region's energy consumption which can be met by biogas potential were calculated; the necessity for the establishment of biogas plants in some districts was discussed in terms of the biogas potential of districts; all calculations, mapping and analyses were carried out in GIS and hence it is aimed to be a model for similar areas and other countries. Moreover, for Bursa province and its districts, biogas potential and the differences among districts were provided for policy-makers through scientific data and maps.

## 2 Materials and method

### 2.1 Study area

Bursa province is located between 39°35′-40°38′N latitudes and 28°5′-29°58′E longitudes and it covers 10 886 km$^2$ (Figure 1). Bursa province has 17 districts in total. These districts include Central districts (Nilufer, Osmangazi and Yildirim districts), Buyukorhan, Gemlik, Gursu, Harmancik, Inegol, Iznik, Karacabey, Keles, Kestel, Mudanya, Mustafakemalpasa, Orhaneli, Orhangazi and Yenisehir.

Being an agricultural, industrial and touristic city, Bursa is the fourth largest city of Turkey in terms of population density. The population is over 2.7 million[20] by the year 2013. Agricultural production is dominated by fruit growing (pears, cherries, peaches, apples), vegetable agriculture (tomatoes, peppers, onions, watermelon, melon) and grains (wheat, corn, sunflower). Bursa industry has focused on food industry, automotive and textile. Bursa has become an important tourist region for such reasons as it was the first capital city of Ottoman Empire and it has awesome natural beauties as well as healing hot spring sources; moreover, Uludag Mountain hosts the most fashionable skiing centre of the country.




Note: Bursa is bordered by the provinces of Balikesir in the west, Bilecik in the east, Kutahya in the south and the Marmara Sea, Yalova and Kocaeli from the north to the northeast.

Figure 1 Study area

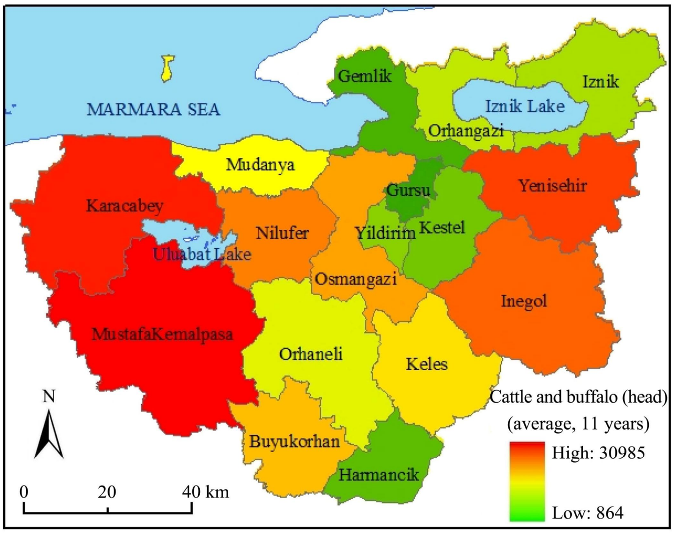
## 2.2 Multi-year animal population of Bursa

In the present study, animal populations of Bursa province were examined on the basis of districts. The number of large ruminants (cattle and buffaloes), small ruminants (sheep and goats), equidae (donkey, horse and mules) and poultry animals (meat and egg hens, turkeys, ducks, goose) belonging to each of the districts was compiled from TUIK (Turkish Statistical Institute) data[21]. Animal population data which are available between the years of 2003-2013 have been entered into the GIS one by one and multi-year (11 years) averages were calculated. In Table 1, the number of animals is presented by years in Bursa province.

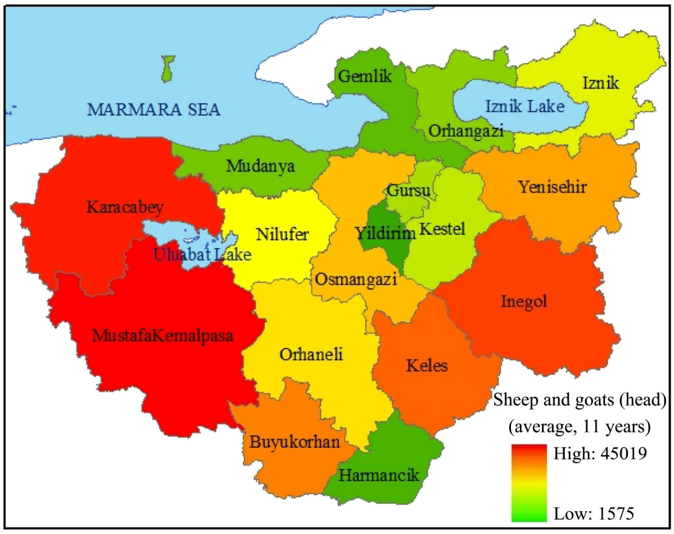
**Table 1 Animal population by years in Bursa province[21]**

| Year | Animal type (total number-head) | | | | TOTAL |
|---|---|---|---|---|---|
| | Cattle and buffaloes | Sheep and goats | Poultry | Equidae | |
| 2003 | 126 232 | 280 326 | 4 058 353 | 9 032 | 4 473 943 |
| 2004 | 124 266 | 263 769 | 6 239 634 | 7 203 | 6 634 872 |
| 2005 | 133 427 | 293 599 | 4 857 952 | 7 657 | 5 292 635 |
| 2006 | 117 578 | 303 794 | 6 001 832 | 8 005 | 6 431 209 |
| 2007 | 148 707 | 310 692 | 6 615 965 | 6 284 | 7 081 648 |
| 2008 | 134 248 | 270 227 | 6 270 609 | 5 904 | 6 680 988 |
| 2009 | 149 329 | 293 814 | 5 872 113 | 5 646 | 6 320 902 |
| 2010 | 151 232 | 329 837 | 5 586 221 | 5 069 | 6 072 359 |
| 2011 | 164 723 | 376 531 | 7 951 241 | 4 568 | 8 497 063 |
| 2012 | 189 774 | 423 968 | 8 686 389 | 4 404 | 9 304 535 |
| 2013 | 198 067 | 423 032 | 8 481 411 | 4 263 | 9 106 773 |
| Average | 148 872 | 324 509 | 6 420 157 | 6 185 | |

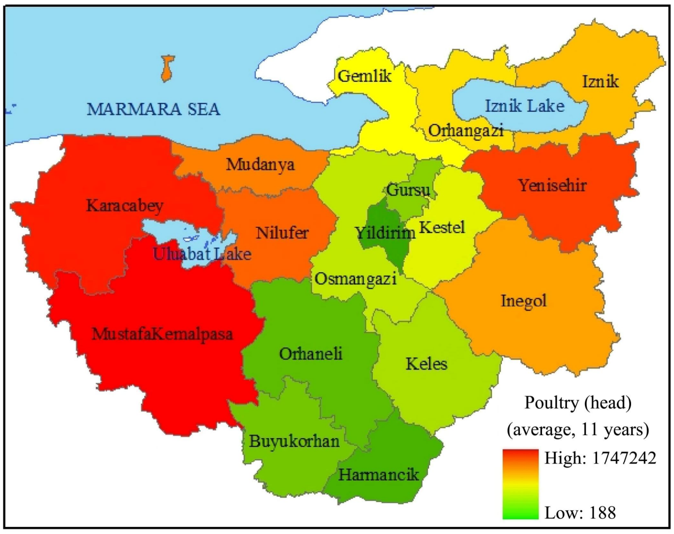
Moreover, presented in Figure 2, the map produced by the GIS illustrates multi-year (11 years) average numbers of animal population in the districts of Bursa. The differences among the districts can be observed clearly in terms of animal population.



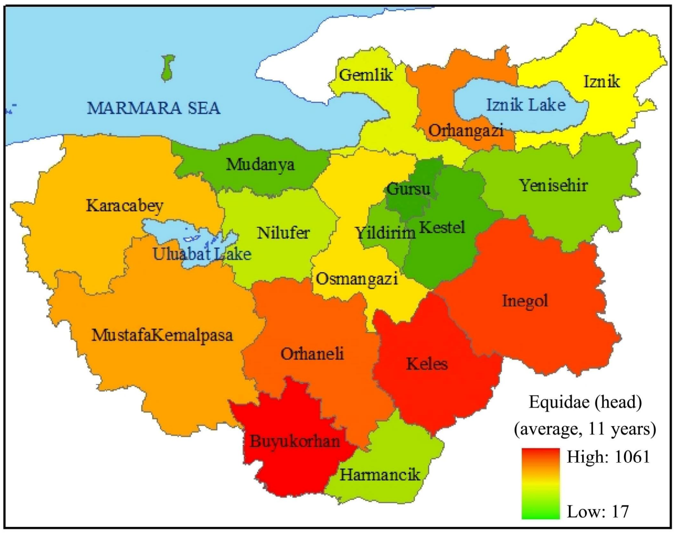

a. Cattle and buffaloes




b. Sheep and goats




c. Poultry (meat and egg hens, turkeys, ducks and goose)




d. Equidae (donkey, horse and mules)

Figure 2 Multi-year (11 years) animal population averages in the districts of Bursa

### 2.3 Geographic information system (GIS) and database creation

A database was created in GIS for all compiled data and data organization; besides, data relating to the number of animals were entered into the system one by one. Linear boundary map of Bursa province and its districts was utilized as base-maps on the basis of village boundaries. Map lines were converted into polygon format and attribute table was associated with data tables available in database. The obtained results were also entered as a separate column into the data table and they were associated with the boundary maps. In order to understand the data and the obtained results as well as to present differences among the districts more clearly, colourful distribution maps were created and easiness in interpretation was provided. Thus, ArcGIS 9.1 (ESRI©) GIS software was utilized for these purposes.

The aims of utilizing GIS in this study can be summarized as follows: to create an accurate database regarding the obtained data; to provide reliable scientific data for similar studies which are to be conducted in the future and also for policy-makers; moreover, to provide for updating and modifying the data in GIS database as well as enabling new input data; to reach more users by enabling them to quickly grasp the subject through converting the study results into visual maps; to show that

GIS may be used in these studies; to ensure coordination in GIS with past and future studies.

**2.4 Organic animal manure calculation methods**

$$DMP_{(SM)}=SM\times FM$$

Where; $DMP_{(SM)}$ is daily manure production as a solid matter ($kg_{(SM)}$/d·AU); $SM$ is solid matter content (%) and $FM$ is fresh manure production (kg/d·AU).

$$TOSM=\gamma\times DMP_{(SM)}$$

Where, $TOSM$ is total obtainable solid matter amount ($kg_{(SM)}$/d·AU), and $\gamma$ is staying time in the barn (%).

$$AU=(AP\times AAW)/LR_{AW}$$

Where, $AU$ is animal unit (kg); $AP$ is animal population; $AAW$ is average animal weight (kg) and $LR_{AW}$ is average weight of large ruminants (454 kg).

$$DAWP_{(SM)}=\frac{AU\times TOSM}{1000}$$

$$AAWP_{(SM)}=DAWP_{(SM)}\times 365$$

Where, $DAWP_{(SM)}$ is daily animal waste potential as a solid matter ($t_{(SM)}$/d) and $AAWP_{(SM)}$ is annual animal waste potential as a solid matter ($t_{(SM)}$/a).

$$ABA=AAWP_{(SM)}\times BA_{a-sm}$$

Where, $ABA$ is the annual amount of biogas ($m^3$/a); $BA_{a\text{-}sm}$ is the amount of availability of biogas ($m^3$/t).

$$E_t=(ABA\times I)/3.6$$

Where, $E_t$ is annual theoretical electricity amount from animal wastes (kW·h/a) and $I$ is the heating value ($MJ/m^3$).

$$E=E_t\times\eta$$

Where, $E$ is annual effective electricity amount from animal wastes (kW·h/a) and $\eta$ is the average yield of electrical engines (25%).

## 3 Results and discussion

Total organic waste potential of Bursa between the years of 2003-2013 as a solid matter depending on the number of large ruminants, small ruminants, poultry and equidae is presented in Table 2. Besides, the amount of biogas which can be obtained from the total organic waste as a solid matter along with the electrical energy gained from this biogas is given in Table 3. According to Table 2, animal organic wastes as a solid matter are obtained from large ruminants (cattle and buffaloes), poultry animals (meat and egg hens, turkeys, ducks, goose), small ruminants (sheep and goats) and equidae (donkey, horse and mule) at respective rates of 67.03%, 28.56%, 3.12% and 1.28%. According to Table 3, total biogas potential of Bursa was found to be 51.93 $Mm^3$/a. The biogas potential of Bursa was determined to be obtained from large ruminants, poultry animals, small ruminants and equidae at respective rates of 58.17%, 36.17%, 3.37% and 1.65%. In the study, it was determined that 100.10 GW·h/a energy can be obtained with the conversion of all the biogas potential from animal wastes into electric energy by means of a thermal engine. Large ruminants provided 56.57% of electrical energy obtained from biogas, which is followed by poultry animals, small ruminants and equidae with the rates of 38.32%, 3.40% and 1.72%, respectively.

**Table 2 Total animal waste amount and animal waste potential as a solid matter in Bursa province between the years of 2003-2013**

| Animal type | FM | SM | $DMP_{(SM)}$ | $\gamma$ | TOSM | AP | AAW | AU | AAWP |
|---|---|---|---|---|---|---|---|---|---|
| Equidae | 37.710 | 21 | 7.919 | 29 | 2.297 | 6 185.00 | 250 | 3 405.84 | 2 854.90 |
| Large ruminants | 33.331 | 12.7 | 4.233 | 65 | 2.751 | 148 871.18 | 454 | 148 871.18 | 149 509.55 |
| Poultry | 25.292 | 25 | 6.323 | 99 | 6.260 | 6 329 238.18 | 2 | 27 882.11 | 63 705.48 |
| Small ruminants | 16.440 | 25 | 4.110 | 13 | 0.534 | 324 508.09 | 50 | 35 738.78 | 6 969.76 |
| Total | | | | | | 6 808 802.45 | | | 223 039.69 |

**Table 3 Electrical energy gained from biogas which can be obtained from animal waste potential of Bursa province.**

| Animal type | $AAWP_{(SM)}$ | $BA_{a-sm}$ | ABA | I | $E_t$ GW·h·a$^{-1}$ | E GW·h·a$^{-1}$ |
|---|---|---|---|---|---|---|
| Equidae | 2 854.90 | 300 | 856 469.31 | 28.9 | 6.88 | 1.72 |
| Large ruminants | 149 509.55 | 202 | 30 200 928.22 | 27 | 226.51 | 56.63 |
| Poultry | 63 705.48 | 300 | 19 111 645.35 | 28.9 | 153.42 | 38.36 |
| Small ruminants | 6 969.76 | 251 | 1 749 409.34 | 28 | 13.61 | 3.40 |
| Total | 223 039.69 | | 51 918 452.22 | | 400.41 | 100.10 |

Considering 17 districts of Bursa province between the years of 2003 and 2013, animal organic waste potential as solid matter, biogas which can be obtained from this potential, the quantity of electric energy gained from this potential and the amount of biogas from animal wastes as well as bio-electric energy per capita were presented in Table 4. A map is presented in Figure 3A referring to the distribution of biogas potential from animal wastes by districts in Bursa. It was revealed that among the districts having over 5 $Mm^3/a$ biogas potential from animal wastes, Mustafakemalpasa has the highest potential with 11.87 $Mm^3/a$ value and 22.87% rate. This is followed by Karacabey, Yenisehir and Nilufer district with the respective values and rates of 8.97 $Mm^3/a$ and 17.28%, 6.38 $Mm^3/a$ and 12.29%, 5.44 $Mm^3/a$ and 10.48%. The biogas potential from animal wastes in Inegol was determined to follow the ranking above with 4.55 $Mm^3/a$ and 8.77%. Having 2.87 $Mm^3/a$ value, biogas potential of Mudanya obtained from animal wastes was found to constitute 5.53% of the overall potential. Besides, it was found that biogas potentials of Osmangazi, Buyukorhan, Keles, Orhaneli, Iznik and Orhangazi are in the range of 1-2 $Mm^3/a$ while those of Kestel, Gemlik, Yildirim, Harmancik and Gursu are below the value of 1 $Mm^3/a$.

**Table 4 The quantity of electric energy that could be gained from biogas potential of Bursa province between the years of 2003 and 2013 by districts**

| Town | $AAWP_{(SM)}$ | ABA | $EGW\cdot h\cdot a^{-1}$ | Human population[20] | ABA per capita* | E per capita** |
|---|---|---|---|---|---|---|
| Nilufer | 22 500.08 | 5 443 164.57 | 10.57 | 358 265 | 15.19 | 29.50 |
| Osmangazi | 8 455.52 | 1 786 406.04 | 3.38 | 802 620 | 2.23 | 4.21 |
| Yildirim | 3 112.34 | 635 174.72 | 1.19 | 637 888 | 1.00 | 1.87 |
| Buyukorhan | 7 534.81 | 1 600 112.70 | 3.03 | 11 913 | 134.32 | 254.39 |
| Gemlik | 3 024.72 | 713 358.58 | 1.38 | 101 389 | 7.04 | 13.60 |
| Gursu | 1 170.58 | 255 916.71 | 0.49 | 68 872 | 3.72 | 7.07 |
| Harmancik | 2 176.92 | 455 378.33 | 0.86 | 7 091 | 64.22 | 121.26 |
| Inegol | 20 638.73 | 4 553 180.78 | 8.69 | 236 168 | 19.28 | 36.80 |
| Iznik | 5 657.36 | 1 386 057.78 | 2.70 | 43 287 | 32.02 | 62.30 |
| Karacabey | 37 075.43 | 8 969 151.88 | 17.41 | 80 527 | 111.38 | 216.23 |
| Keles | 7 490.82 | 1 601 450.72 | 3.04 | 13 639 | 117.42 | 222.67 |
| Kestel | 3 487.97 | 775 164.64 | 1.48 | 51 872 | 14.94 | 28.56 |
| Mudanya | 11 564.12 | 2 870 936.29 | 5.60 | 77 461 | 37.06 | 72.28 |
| Mustafakemalpasa | 49 894.06 | 11 871 288.98 | 22.98 | 99 999 | 118.71 | 229.81 |
| Orhaneli | 6 628.55 | 1 393 660.58 | 2.63 | 22 175 | 62.85 | 118.79 |
| Orhangazi | 5 196.21 | 1 225 424.51 | 2.37 | 75 672 | 16.19 | 31.30 |
| Yenisehir | 27 431.47 | 6 382 624.42 | 12.31 | 52 132 | 122.43 | 236.06 |
| Bursa (totally) | 223 039.69 | 51 918 452.22 | 100.10 | 2740970 | 18.94 | 36.52 |

Note: *Annual biogas amount per capita ($m^3\cdot a^{-1}$ per capita); **Electricity per capita ($kW\cdot h\cdot a^{-1}$ per capita).

A map and the differences among the districts are presented in Figure 3B showing the distribution of biogas potential from animal wastes per capita in 17 districts of Bursa. This map has been created with the proportion of the biogas potential from animal wastes to the population living in respective districts. Analysing the data in Figure 3B and Table 4, it can be understood that of all districts in Bursa, Buyukorhan had the highest per capita biogas potential (134.32 $m^3/a$. per capita). It was followed by Yenisehir, Mustafakemalpasa, Keles, Karacabey, Harmancik and Orhaneli at respective values of 122.43, 118.71, 117.42, 111.38, 64.22 and 62.85 $m^3/a$ per capita. Per capita biogas potentials of the other 10 districts were found to be below 50 $m^3/a$ per capita. In addition, it was determined that per capita biogas potential of Bursa is 18.94 $m^3/a$ per capita. Accordingly, per capita biogas potential from animal wastes in Nilufer, Osmangazi, Yildirim, Gemlik, Gursu, Kestel and Orhangazi districts were found to be below the value of 18.94 $m^3/a$ per capita which is the average amount of Bursa. However, it was found out that total biogas potential from animal wastes of Nilufer, Osmangazi and Yildirim which are the central districts of Bursa and also Gursu being very close to these districts is 22.13 $m^3/a$ per capita, which is above the overall average of Bursa.

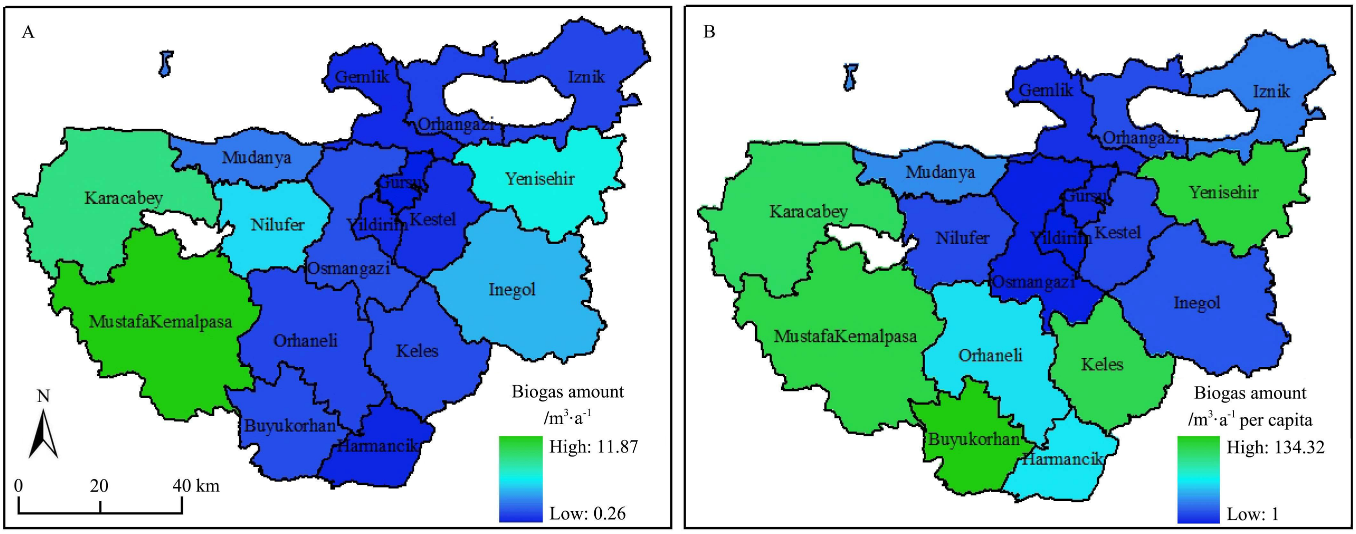



Figure 3 A: The distribution map of biogas potential from animal wastes in Bursa by districts ($m^3 \cdot a^{-1}$).
B: The distribution map of per capita biogas potential from animal wastes in Bursa by districts ($m^3 \cdot a^{-1}$ per capita)

The distribution of energy potential resulting from the conversion of the entire biogas potential from animal wastes into electrical energy by districts and the differences among the districts are presented in Figure 4A. Hence, it was determined that of all the districts, Mustafakemalpasa has the highest potential of 22.98 GW·h/a value and 22.96% coverage ratio which is followed by Karacabey with 17.41 GW·h/a and 17.39% share, Yenisehir with the value of 12.31 GW·h/a and 12.29% share, Nilufer with 10.57 GW·h/a and 10.56%, Inegol with 8.69 GW·h/a and 8.68%, Mudanya with 5.60 GW·h/a and 5.59% share, respectively. In addition, the biogas potential of the other 11 districts in which livestock is relatively made less compared to other districts was found to be below the value of 5 GW·h/a (Table 4). The proportioning of population to the electrical energy which can be obtained from biogas from animal wastes on the basis of districts along with per capita amount of this production were also calculated and given in Table 4. A map and the differences among the districts are presented in Figure 4B showing the distribution of per capita electric energy on the basis of districts.

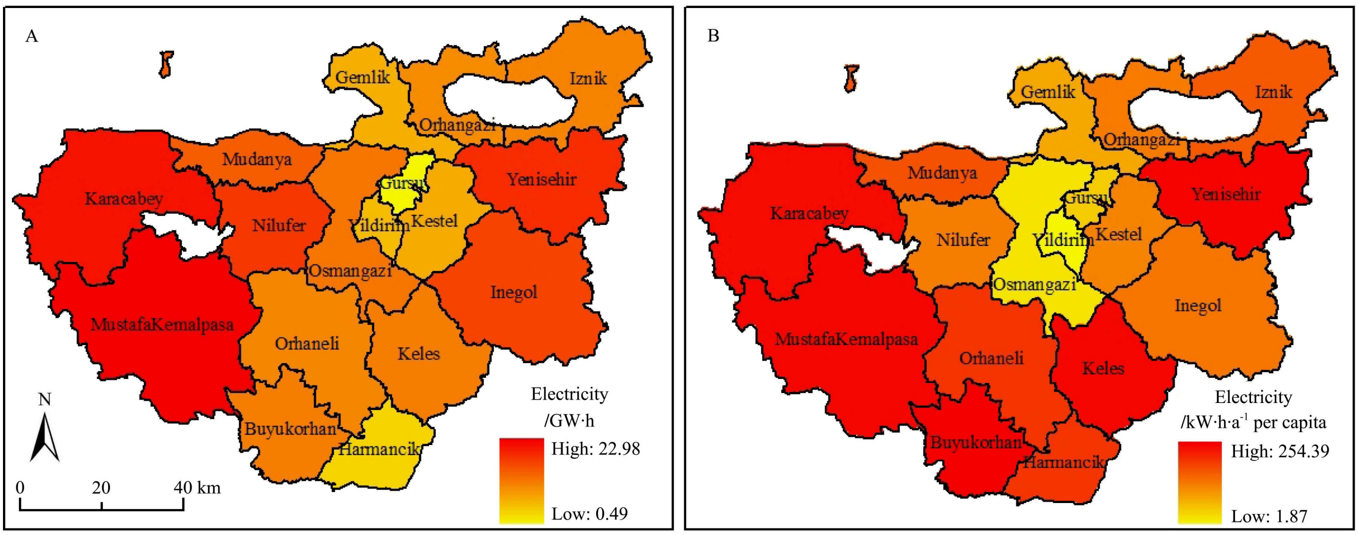



Figure 4 A: The distribution map of electrical energy that can be generated by biogas potential from animal wastes by districts in Bursa.
B: The distribution map of per capita electrical energy that can be generated by biogas potential from animal wastes by districts in Bursa

Accordingly, in case of utilizing the obtained biogas by converting it directly into electricity, Buyukorhan is identified as the district which has the maximum bio-electric potential from animal wastes with the value of 254.39 kW·h/a per capita. It is evident that per capita bio-electric potential of Yenisehir, Mustafakemalpasa, Keles and Karacabey is above the value of 200 kW·h/a per capita while Keles and Orhaneli has the potential which is above 100 kW·h/a per capita. Electricity consumption of Bursa in 2013 is 8 975.143 GW·h and per capita electricity consumption is 3 274.44 kW·h/a per capita[22]. It was found that residential consumed 20.2% of the electricity in Bursa in 2013. Per capita residential electricity consumption in Bursa is 661.38 kW·h/a per capita annually. Accordingly, it was reported through this study that the electricity consumed in a 3-person family in Buyukorhan, Yenisehir, Mustafakemalpasa, Keles and Karacabey can be provided by bio-electricity from animal wastes. On the other hand, the electricity consumption of a 3-person family in Orhaneli and Harmancik was determined to be obtained from bio-electricity from animal wastes with respective rates of 55% and 53.85%. According to BOTAS (Petroleum Pipeline Company, Turkey) the total natural gas consumption of Bursa in 2013 is 3 650.35 $Mm^3/a$ [23].

Bursa is a large industrial city and the fourth largest city of Turkey. Therefore, natural gas consumption of Bursa constitutes about 8% of total natural gas consumption of Turkey. Even though Bursa has 17 districts, gas distribution can only be made to the central district including city centre (Nilufer, Osmangazi and Yildirim), Gemlik, Inegol, Karacabey, Mustafakemalpasa, Orhangazi and Yenisehir districts. Natural gas consumption in Central Districts (Nilufer, Osmangazi and Yildirim) forms 79.99% of the total consumption of Bursa province with the value of 2 919.84 $Mm^3/a$ while Gemlik, Yenisehir, Inegol, Orhangazi, Mustafakemalpasa and Karacabey constitute 7.19%, 5.22%, 3.10%, 1.91%, 1.37%, and 1.22%, respectively with the values of 262.56, 190.59, 113.28, 69.85, 49.87 and 44.37 $Mm^3/a$[23].

In the present study, biogas potential from animal wastes in Bursa between the years of 2003 and 2013 is estimated to be 51.93 $Mm^3/a$. Hence, Bursa has the potential to meet 1.42% of the annual gas consumption from biogas from animal wastes. When this potential is examined in terms of districts, it was found that Mustafakemalpasa, Karacabey, Inegol, Yenisehir, Orhangazi and Central District (Nilufer, Osmangazi and Yildirim) had provided 23.80%, 20.22%, 4.02%, 3.35%, 1.75% and 0.67% of natural gas consumption from biogas potential of animal wastes, respectively. When it comes to the other eight districts, it can be expressed that fuels such as wood and coal are consumed for heating, which leads to the reduction of forests and environmental pollution as well as global warming. In Buyukorhan, Keles, Harmancik and Orhaneli to which natural gas distribution is not made, per capita biogas potential from animal wastes is very high. Therefore, in addition to Mustafakemalpasa, Karacabey, Yenisehir, Nilufer and Inegol whose overall potential is high, biogas potential of Buyukorhan, Keles, Harmancik and Orhaneli also must be evaluated.

Total electricity consumption of Bursa in 2011 was 8 975.14 GW·h[22]. The total electricity consumption of 5 595.97 GW·h has been used in industrial enterprises, which is followed by 1 812.82 GW·h in dwellings, 1 232.71 GW·h in commerce, 105.43 GW·h in street lighting, 93.15 GW·h in agricultural irrigation, 50.48 GW·h in state offices and 84.59 GW·h in other works[22]. In this study, the amount of electrical energy that can be obtained from biogas potential from animal wastes in Bursa was found to be 100.10 GW·h. Accordingly, 1.12% of the electricity consumption of Bursa can be met with the conversion of biogas potential from animal wastes into electricity by evaluating it thoroughly. In addition, this study reveals that 95% of street lighting, approximately twofold of the electricity consumed in the official apartments and all of the agricultural irrigation operations can be met in Bursa with electrical energy obtained from biogas potential from animal wastes. It was determined that the biogas potential from animal wastes and bio-electric potential of Mustafakemalpasa, Karacabey, Yenisehir, Nilufer and Inegol, and per capita biogas potential from animal wastes and bio-electric potential of Buyukorhan, Keles, Harmancik and Orhaneli were potentially high enough to be assessed. Moreover, this study demonstrates the necessity for building pioneer pilot biogas plants to the districts of Mustafakemalpasa, Karacabey and Yenisehir depending upon both their general and per capita biogas potential from animal wastes.

***The advantages of GIS used in the study***

In this study, the differences in data among districts were observed more clearly by means of the produced thematic maps.

GIS-generated maps have briefly provided the following advantages:

1) Biogas potential from animal wastes is presented by geographic location. Thus, biogas potential which was calculated for each district and its differences with the other districts is visually put forth in a more striking manner.

2) Data which are entered into the database created for this study can be corrected or updated if desired; besides, different queries can be produced (eg. the calculation of biogas potential only for cattle or hens; the potential increase or decrease in animal wastes in future years can be easily updated in this database and new maps can be produced).

3) The data obtained in this study are comparable to different data belonging to the same geographical location (eg. District-based comparison of the amount of biogas from vegetative wastes with the biogas potential from animal wastes).

4) That all of the data are presented with map images has provided a better understanding of issues for the people who do not know much about the subject, and especially for policy-makers, thus wide awareness of the issues can be raised.

5) GIS applications and maps are further enriched in this type of studies.

6) As seen in the corresponding maps, in areas where livestock is intensely made, there is a greater amount of animal waste and biogas potential. However, great differences between the districts are shown when this is associated with the population, per capita biogas and the amount of electricity to be converted from biogas. GIS and map images have provided great ease for uncovering these differences. In districts with lower biogas potential and smaller population, per capita electricity amount was calculated to be higher than those with higher biogas potential and bigger population. Presenting these comparisons through maps in GIS offers more understandable data for policy-makers.

## 4 Conclusions

In the present study, it was identified that Bursa's biogas potential from animal wastes is 51.93 $Mm^3/a$ depending on the number of the animals between the years 2003 and 2013; 22.87% of this potential was enabled by Mustafakemalpasa while 17.28%, 12.29%, 10.48%, 8.77%, and 5.53% of it are supplied by Karacabey, Yenisehir, Nilufer, Inegol and Mudanya, respectively. Biogas potential of the remaining 11 districts was determined to constitute 22.78% of the total potential. Electricity 100.10 GW·h was determined to be achieved through biogas potential from animal wastes; besides, it was also identified that 22.96% of the electricity was supplied by Mustafakemalpasa, which is followed by Karacabey, Yenisehir, Nilufer, Inegol and Mudanya at the respective rates of 17.39%, 12.29%, 10.56%, 8.68% and 5.59%.

Consequently, it was put forward that biogas potential from animal wastes of Karacabey, Yenisehir, Niluferand Inegol is high; furthermore, it has been demonstrated that considering the population of the districts, Buyukorhan, Keles, Harmancik and Orhaneli have a great potential in terms of per capita biogas from animal wastes. That it is appropriate to primarily build pilot biogas plants in Mustafakemalpasa, Karacabey and Yenisehir in terms of municipalities and as secondary, it is necessary to establish biogas plants in Nilufer, Inegol, Buyukorhan, Keles, Harmancik and Orhaneli. Besides, with this study, producing thematic maps in GIS increased the efficiency of research results and differences in data among the districts were observed more clearly. GIS can be used with success in this type of studies and it can also raise public awareness of the subject. In addition, a database in the GIS and a large quantity of data about the region were also produced for policy-makers' reference.

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