Biofuels from wastes in the Marmara Region, Turkey: Potentials and constraints

Semra Ocak (semra.ocak@boun.edu.tr)
Boğaziçi University https://orcid.org/0000-0001-6320-0585
Sevil Acar
Boğaziçi University

Research Article

Keywords: biofuels, bioenergy, biogas, biomass, renewable energy, sustainable energy

Posted Date: March 16th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-245086/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on July 29th, 2021. See the published version at https://doi.org/10.1007/s11356-021-15464-3.

Abstract

Turkey as an energy importing country, is heavily dependent on fossil fuels, which causes an increase in environmental problems and raises concerns on energy security. However, biowastes offer a significant potential, especially in the Marmara Region of the country. In this study, the waste potential of the region for energy production is analyzed. Within this context, agricultural and livestock wastes are examined in terms of their amounts, theoretical energy potentials and costs to generate electricity. To evaluate economic costs, collection and feedstock costs for animal and agricultural wastes are handled in three different scenarios based on FAO's assessment. Given the results for wastes and energy potentials, it has been deduced that biowastes can theoretically meet more than half of the electricity consumption of the region. The results of the cost analysis demonstrate that both direct combustion of agricultural wastes and conversion of animal wastes to biogas in CHP plants to produce electricity are economical according to several scenario options considering the LCOE and feed-in-tariff values.

1. Introduction

Biofuels have gained an increasing attention in recent years as part of the renewable energy discussions in terms of energy efficiency and climate change. Shifting energy production methods from scarce and environmentally or politically unsustainable resources such as petroleum, coal etc. towards biofuels provides solutions to these problems in theory as a low- or zero-carbon fuel alternative although there are debates on its sustainability (Solomon 2010). As a promising alternative to fossil fuels, biofuel applications have become prevalent worldwide to overcome issues related to energy security and independence (Lehrer 2010; Achinas et al. 2017), global climate change, rural development, and environmental conservation (Mol 2007; Solomon 2010; Jaeger and Egelkraut 2011; Guo et al. 2015). As most natural resources such as oil reserves are available in generally unstable parts of the world, biofuels (biogas and biomethane) can decrease dependence on external sources as they may replace conventional fuels (Achinas et al. 2017). In this regard, biofuel production has become an alternative as a new market; hence, governments in Brazil, the USA and the EU are subsidizing biofuel production (Mol 2007). According to the data in 2017, 4.7 billion liters of bioethanol production took place in Europe, while its amount was 74.3 billion liters in the USA (WGB 2019). Considering ethanol production which is produced from biomass via fermenting sugar within it, the USA is the biggest producer country with the amount of 15.8 billion gallons in total in 2019. Brazil is the second ethanol producer country with nearly 8.6 billion gallons (statista.com 2020). The USA and Brazil are the two leading countries in terms of biofuel production that together produced 69% of the total amount of biofuels in the world in 2018 (REN21 2019). It is assumed that total biofuel output will increase at a rate of 25% by the year of 2024 (IEA 2019).

It is estimated that electricity consumption will globally increase more than double in 15 years (World Energy Council 2016). Turkey, as an energy importing country, uses fossil fuels that account for 87% of its total energy supply (The World Bank 2015). With a growing population and GDP in Turkey, renewable energy has become a prominent option in order to alleviate the dependency on foreign energy sources (Acar and Yeldan 2016). The distribution of primary energy sources in power generation in Turkey is presented as 37% coal, 30% natural gas, 19.7% hydro, 6.5% wind, 2.6% solar, 2.4% geothermal and 1.2% renewable/waste as of 2018 according to the Turkish Electricity Transmission Company (TETC 2020). On the other hand, Turkey has renewable energy targets in line with the Renewable Energy Directive, with which renewable energy sources are aimed to contribute up to 20% of the total energy consumption and 30% of the electricity consumption (Rincon et al. 2019).

Turkey's energy consumption was 148 Mtoe, while China's and the USA's consumptions were 3164 Mtoe and 2258 Mtoe respectively in 2018 (yearbook.enerdata.net). Oil and natural gas are the major components of its energy consumption. Turkey's energy demand in 2030 is estimated to be nearly fivefold compared to 2000 (Dumanlı et al. 2007). In that sense, biomass is offered as an alternative source to meet energy demand and to become less dependent on foreign and conventional resources (Dumanlı et al. 2007). Rincon et al. (2019) [14] point out that Turkey is the 7th largest agricultural producer, which offers a high potential to produce biofuels. The Ministry of Energy and Natural Resources announced that the total installed capacity of the existing biomass power plants will be 719 MW in 2019 (Küçükkaya 2019). As such, considering that Turkey's installed capacity by the electricity utilities was 88550.8 MW in 2018, biomass potential may cover 0.8% of the total installed electricity power (TETC 2020). According to the Energy Market Regulatory Authority (EMRA) data, the produced and sold proportion of biodiesel increased by 40% in 2018 compared to the data of the last 4 years. At the same year, 30% waste vegetable oils and 70% vegetable oil seeds were used in the production of biodiesel in Turkey (Biyodizel Sanayi Derneği 2019). 28% of the total biodiesel produced in the European Union countries is covered by waste vegetable oils and animal fats, and 72% of it is generated from vegetable oil seed plants (Biyodizel Sanayi Derneği 2019).

Agricultural and livestock residues have substantial potential in bioenergy production. Besides, it is suitable since using crop residues left over in the field does not have a negative impact on biodiversity, food sovereignty, and ecosystems. The amount of theoretical energy equivalence derived from crop and livestock residues is approximately 12 million toe/year in Turkey according to the MENR (2019). It is estimated that the amount of biogas that can be obtained by digesting these wastes in an oxygen-free environment will be around 1.5 to 2 million toe (Yağlı and Koç 2019).

In this paper, we aim to investigate the biowaste potential of the Marmara Region, Turkey in terms of energy production. Since the utilization of wastes as an alternative feedstock may eliminate some concerns such as land and water requirements and environmental problems compared to non-renewable energy sources, biowaste potential rather than the option of producing oilseeds and crops for biofuel purposes is addressed here. To this end, we review the previous studies and analyze available data obtained from national institutions on biowaste potential and use in electricity production in Turkey at national and regional levels.

This paper is organized as follows: Section 2 summarizes the literature on biofuels and biowastes regarding the opportunities they cause in terms of sustainable energy production as well as their disadvantages. Section 3 presents the data and methodological approach in regards to biowastes and the potential of wastes that may offer to meet the energy demand in the Marmara Region. In this section, we focus on agricultural and livestock wastes as renewable energy sources in order to recover them in the process of energy production together with their potentials and constraints. In Section 4, costs of electricity production from wastes are calculated and compared to costs of other energy sources in different scenarios. Section 5 includes a discussion of the results and concludes.

2. Literature Review

Biomass is defined as a wide ranging source including wood, logging residues, agricultural crops, municipal and food processing wastes, animal wastes and algae (Demirbas 2009: 1573-1582). Ho et al. (2014) classify biomass as generations. Food crops (sugarcane, cereal, cassava, maize, grass, wheat, rye) are considered as the first generation biomass, whose sustainability is questioned because of the possibility of jeopardizing food sovereignty and the potential effects on climate and nature. To overcome this problem, second generation biomass is introduced, which comprises non-food lignocellulosic materials. Agricultural residues and wastes are also considered as second generation biomass sources. Municipal and industrial wastes are used for biofuel production transforming waste to energy in line with waste management practices. They also provide environmental benefits to reduce waste amount, GHG emissions, and landfill areas (Ho et al. 2014).

Alternatively, Özer (2017) defines biomass as a renewable energy source derived from organic wastes including animal manure, agricultural residues, municipal and industrial wastes. Primary agricultural residues can be collected after harvesting, whereas secondary residues are obtained during the processing phase. On the other hand, dedicated energy crops are grown for biomass purposes, such as miscanthus, poplar, willow (Bioenergy Europe 2019). Using (dedicated) energy crops instead of agricultural residues and wastes globally represents a small fraction with a ratio of 0.1% of the total biomass production (Camia et al. 2018). According to Bioenergy Europe (2019), it is estimated that 50 kha was cultivated with these crops to produce energy in 2017. Maize, rapeseed, sugarcane, corn, sugar beet, and sweet sorghum are used for energy production.

Yet, biofuel production has some limitations in terms of the availability of biomass, limited land, water and nutrient resources, required external energy inputs, and so on. Mol (2007) argues that the excessive increase in biofuel production in the world, especially in Brazil and the USA, has some potential sustainability-related risks for different regions and groups. Biofuels are criticized for whether they really offer a cost-effective carbon emission mitigation strategy or not. Besides, deforestation, loss of biodiversity, monocropping, soil degradation, water pollution etc. are put forward among other environmental problems associated with biofuel production (Mol 2007; Lora et al. 2011). Furthermore, Jaeger and Egelkraut (2011) argue that biofuel production may cause an increase in food prices and possible land use changes related to the large area requirements.

Given the advantages and constraints of biofuels, wastes stand out as a more economical option to produce biofuels for ensuring sustainability and considering potential environmental problems that biofuels may cause. Although using logging residues and municipal solid wastes (MSW) create some externalities on nature as forests need logging residues for soil retention and wildlife habitat and also MSW is used in composting and combustion of energy, they are still preferred as they help not to increase further feedstock production (Jones et al. 2007)[1]. The most common wastes that are used for biofuel production are agricultural and municipal wastes, sewage sludge, animal manure, agriculture-related industries' wastes, food waste, and/or collected municipal waste from households (Achinas et al. 2017). Agricultural residues, which include straws, fruit seeds, and molasses, are commonly used as potential renewable sources (Bhatia et al. 2018). In this sense, Meyer et al. (2018) investigate biogas energy potential of sustainable agricultural residues, animal manure, permanent grasslands and meadows for future projections for the EU28 for the year 2030. Based on three scenarios which correspond to high, moderate and low availability, they find that maize is suitable to contribute to the biogas sector in all members of the EU28 (Meyer et al. 2018).

Agricultural wastes as well as livestock wastes are used as sources for renewable energy, GHG emissions reduction and carbon sequestration (Sarmah 2009). According to the US Environmental Protection Agency Report (2000), there are 376000 livestock operations, which generate 58.1 million tons of manure each year (EPA 2000). As Guber et al. (2007) point out, animal feces may be deposited on lands and livestock wastes contain pathogenic bacteria which may be released into the environment and create water pollution and public health risks (EPA 2000; Guber et al. 2007). Sarmah (2009) states that cow manure, as an appropriate biogas source, produces biogas proportionally; for 1 cubic foot biogas, 1 pound of cow manure is required. Manure can be converted into methane equivalent to 200 liters of gasoline. In Canada, nearly 7500 cattle produce 1 megawatt of electricity. It is estimated that New Zealand has more than 5 million cattle, which offer an enormous amount of waste and hence biogas production potential. Developing countries have also high potential in terms of animal wastes and thus biogas production (Sarmah 2009).

Agricultural residues, which can be classified as crop residues and agricultural industrial by-products, can be converted into biofuel based on their constituents. The global use of wood is nearly 4 billion cubic meters annually, 55% of which is used as fuel wood by direct combustion and 45% of which is used as industrial raw material. 40% of this 45% part ends up as residues which are used as raw material for second generation biofuel production (FAO 2009). Silayo et al. (2008) state that bioconversion of agricultural wastes such as sugarcane bagasse and sisal waste for bioethanol production has gained more attention in recent years than incineration of them considering possible pollution problems (Silayo et al. 2008).

Renewable energy sources have gained increased attention in Turkey as well with current and future energy generation projections. Despite the limited share of renewable sources in energy production, renewable energy markets have been promoted since 1984 via the Electricity Market License Regulation (Erdoğdu 2008). According to TETC (2020), distribution of Turkey's gross electricity generation by primary energy resources in 2019 is as follows: 175078.1 thermal, 66224.1 GWh hard coal/imported coal, 46893.7 GWh lignite, 40287.2 GWh geothermal/wind/solar and renewable/wastes 4523.7 GWh. In the last 5 years, 16.3 billion dollars of investment was made for a total of 16653 MW of renewable installed power (ntv 2019). However, the renewable energy market is still considerably dominated by hydropower. Despite the fact that biofuel production from wastes is relatively new and involves some uncertainties, such practices have been occurring in different regions of Turkey.

Animal manure provides another biowaste potential in Turkey. Doruk and Bozdeveci (2017) examine biogas potential of animal manure in Denizli province, which is located in the southeast of the Aegean Region. They calculated the potential as 70.16 m^3/year of biogas from 4370129 animals which produce 4578889 kg/day of manure. Energy equivalent is calculated as 46.30 million liters of diesel and 329 million kW/h electricity (Doruk and Bozdeveci 2017). Similarly, animal manure use for biogas production in Düzce, which is located in the Western Black Sea Region, is analyzed in the paper of Yürük and Erdoğmuş (2015). They argue that poultry wastes have considerable biogas potential in the city center with the amount of 5553849 m^3/year and in Akçakoca district with the amount of 5587289 m^3/year (Yürük and Erdoğmuş 2015). The Thrace Region's potential with cattle, sheep and poultry population is calculated as 2427.81 TJ/year. Methane production amounts and energy potentials of methane derived from animal wastes are calculated using the Turkish Statistical Institute (TurkStat) data. As a result of this calculation, the potential energy value to be obtained from animal manure in the Thrace Region corresponds to 1.17% of the total energy value which is derived from petroleum in Turkey (Köse 2017).

Gümüşçü and Uyanık (2010) examine cattle manure based on the data on the number of cattle and waste production in the Southeastern Anatolia Region. According to the findings, 1700 m^3/day and 612000 m^3/year of biogas and 2880000 kW/year of energy can be obtained from 1500 cattle. They recommend facilities that should be installed with a capacity of 500 or more animals in the region. In facilities with 1000 or more animal capacity, the first investment return periods are around 5 years. In another paper, the Marmara Region's animal waste potential is examined for biogas production from cattle manure from 2005 to 2014. It is calculated that biogas potential of the region increased by 15% in 2014 with 1242.17 Mm^3 of biogas compared to 2005 despite the fluctuations in hen production (Ayhan 2016). Şenol et al. (2017a) evaluate biogas production from animal wastes, kitchen wastes, wastewater treatment plant wastes and agricultural wastes. In a landfill facility in Mamak district of Ankara city, urban solid wastes are utilized to produce 38.6 MW/hour of electricity, corresponding to 7% of the electricity need of Ankara (Şenol et al. 2017a).

Salihoğlu et al. (2019) examine the biogas potential to be obtained from animal (cattle and sheep) waste of Balıkesir province, which is located in the Marmara Region. They find that 82815600 m^3 biogas and 1879914120 MJ energy can be produced potentially per year in Balıkesir from 5955318 tons of animal waste. As a result of the study, they claim that biogas potential can be taken into consideration to meet the energy demand of the region and transform the fertilizers into usable forms as an end product. Similarly, Yağlı and Koç (2019) investigate biogas production from animal manure and its energy equivalent in Adana province based on daily animal manure, wet manure per unit animal (kg/day-animal), solid matter ratio, volatile solids ratio, the proportion of volatile solids in the solid matter and finally the ratio of methane ratio. Using these data, the amount of methane that can be produced and the corresponding energy value are calculated. As a result, it is calculated that 88367417 m^3 of methane can be produced from a total of 3062992 animals per year, and the energy equivalent of the total methane gas corresponds to 3181.227 GJ/year and 75979 toe/year. When methane gas is burnt in a combined heat and power engine (CHP) with an average electric efficiency of 35%, 309.286 MWhe per year electricity production will be possible. Considering that 1 kWh electricity saving corresponds to approximately 0.58 kg CO_2 emissions, the study shows that 179.4 tons of CO_2 emissions annually can be reduced by producing biogas from animal wastes.

Biogas production from animal wastes have been frequently studied in the literature, there are also studies on biogas production from agricultural wastes. Sözer and Yaldız (2011) determine the amount of biogas to be obtained from mixed banana greenhouse wastes and cattle manure. They carry out experiments in a laboratory type biogas generator with a net 15 liter fermentation volume and use supplies from the plastic covered banana greenhouse located in Akdeniz University Faculty of Agriculture Application Research Farm. They find that the highest biogas production is obtained from a mixture of 70% cattle manure and 30% banana greenhouse waste. The amount of biogas was 12.044 L per day and the methane ratio of biogas was determined as 51.1%. Görgülü (2019) investigates the biogas potential that can be obtained from animal and agricultural wastes in Burdur province by using 2018 TurkStat data and calculates their energy equivalents. According to the research, biogas production of Burdur province and its districts can be obtained 87% from cattle, 11% from sheep and the remaining 2% from poultry. Considering the total biomass potential of the selected field crops across the province, it can be stated that corn production has the highest energy value whereas cabbage and potato have the lowest energy value in term of biogas production.

Although there is a broad literature on biogas production in the world, more detailed studies on agricultural wastes and MSWs for biogas production are required to analyze the case of Turkey. Considering agricultural production, animal husbandry and urbanization, Turkey has significant potential for biogas production. On the other hand, the Marmara Region embodies both agricultural areas and big cities, which offer a potential in terms of from crop and livestock wastes as well as MSWs. Previous literature on biogas production is summarized above in order to shed light on further analysis of biogas potential of the Marmara Region leading to comparative analysis between costs of biogas production from agricultural products and their wastes.

[1] The use of biowaste in biofuel production may also create problems related to waste management due to disposal issues or other problems. For instance, municipal solid waste has some potential risks due to its metal and salt concentration, which adversely affect soil structure (Demirbas 2009).

3. Data And Methodology For Calculating The Marmara Region's Biogas Production Potential

In this study, the amount of biowastes, their energy potentials and their costs to produce electricity are aimed to be calculated. We focus on crop residues (agricultural waste) and livestock residues (animal waste) produced in the Marmara Region and make cost assessments based on three scenarios adapted from FAO's "BEFS Assessment for Turkey" Report (Maltsoglou et al. 2016). The waste amounts that can be used in biofuel production in the Marmara Region at provincial level are taken from the publicly available data on MENR General Directorate of Energy Affairs website. Data on animal and agricultural production and their wastes were checked against the TurkStat 2019 data for verification purposes. Along with animal manure and agricultural production wastes, urban wastes have been shown and how much energy they can theoretically generate has been calculated. A projection is made taking into account the animal numbers, agricultural production, waste amounts and theoretical energy potentials. Calorific values of the wastes are not taken into account in this analysis as they are elaborately analyzed in FAO's assessment.

The initial step of the study is to determine the amount of crop residues and animal manure in the Marmara Region and to calculate their theoretical energy equivalents in terms of megawatt-hours (MWh). Subsequently, costs are calculated and a cost comparison of energy production from biowastes and other sources is made using some parts of the techno-economic analysis in Maltsoglou et al. (2016) as a basis. FAO's BEFS analysis consists of assessment of natural resources and biomass potentials at both economic and technical levels for the different provinces of Turkey. In this study, agricultural and animal wastes in the Marmara Region are defined as biomass potential, and the costs of potential energy to be produced from these wastes per MWh are determined in three scenarios by using FAO's data. Consequently, a comparison of unit costs of energy production from other energy sources and the results of the three scenarios is made. Collection and feedstock costs in FAO's assessment are used in the case of biomass.

Energy production methods considered here consist of direct combustion from crop residues and biogas production from animal manure. As an energy production method, we aim to address electricity generation in combined heat and power (CHP) or cogeneration systems from direct combustion or from biogas. We assume that the entire content of crop residues and animal manure that are being produced in the Marmara Region are available for energy production. Therefore, it is theoretically assumed that all agricultural and animal wastes can be used in energy production. We calculate the energy equivalents and costs of these wastes and assert that bioenergy would be a preferable energy generation method compared to other energy production methods to meet the energy demand of the region.

The share of renewable energy sources (including hydro) in electricity generation was 29.6% in 2017 and 32.4% in 2018 (TurkStat 2019) (see Figure 1). Renewable energy is mostly derived from hydraulic energy respectively in Turkey. Biomass use is limited to conventional methods such as combusting wood, animal and vegetable waste for heating purposes covering half of the renewable energy sources (5.4 Mtoe) and there is an untapped potential in agricultural practices. According to EMRA Electricity Market - 2018 Market Development Report, the share of biomass in electricity production was 0.66% with 1939.72 GWh in 2018, whereas it slightly increased and reached 0.82% with 2410 GWh (EMRA 2019) in 2019[1]. On the other hand, organic wastes cover 65% of the total wastes in Turkey, which indicates a significant potential for energy production. In addition, 62 Mton agricultural waste (such as barley, wheat, tobacco, paddy, cotton, etc.) is produced annually in Turkey (Şenol et al. 2017b; MENR 2019).

Considering Turkey's animal husbandry and agricultural production sectors, biowastes receive attention as an alternative energy production method. Although there is a decreasing tendency over the years, around 25% of Turkey's population relies on agriculture, livestock and forestry (The World Bank 2018). According to the MENR (2019) General Directorate of Energy Affairs data, wastes and their energy equivalents in Turkey are as follows: theoretical energy equivalence of animal wastes amounts up to 4385371 toe/year, that of agricultural wastes makes 6009049 toe/year, and that of forestry wastes makes 859899 toe/year, total energy equivalence summing up to 11254319 toe/year.

The Marmara Region, located in the north-west of Turkey, has 67000 km^2 surface area, hosts more than 24 million population (Ministry of Interior 2019) and embodies industry, tourism, trade and agriculture sectors. The region consists of 11 cities, which are Istanbul, Edirne, Kırklareli, Tekirdağ, Çanakkale, Kocaeli, Yalova, Sakarya, Bilecik, Bursa, and Balıkesir. Together with Istanbul, which is the most densely populated city, Bursa and Kocaeli are the main industrial cities in the region. Other cities have substantial agricultural and livestock potentials. Agricultural and animal wastes of the provinces of the region and their biofuel potentials are displayed in Table 1.

Table 1 Animal and agricultural production/waste and their energy equivalents in cities

City	The Number of Livestock and Poultry	Animal Waste Amount (ton)	Energy Equivalence (toe/year)	Agricultural Production (ton)	The Amount of Agricultural Waste (ton)	Energy Equivalence (toe/year)	Total Energy Equivalence* (toe/year)
Balıkesir	34966167	6885871.04	310493.87	2626993	1096113.83	430335.64	740829.51
Bilecik	4548622	614734.68	33670.18	436912	205588.10	77983.62	111653.81
Bursa	11799447	3004653.29	134611.63	4028435	1512406.29	580621.47	715233.10
Çanakkale	6360705	2569039.77	54296.92	2342790	865126.53	345600.97	399897.89
Edirne	837417	1714313.90	15135.58	1411103	1755665.87	694012.86	709148.44
İstanbul	2019613	1005106.56	25649.69	345496	345642.47	142177.69	167827.38
Kırklareli	1099149	1710213.94	19037.72	920803	1067270.30	444566.17	463603.89
Kocaeli	6262386	1133270.57	50156.31	329913	149094.91	60402.10	110558.41
Sakarya	30153276	2230372.77	224389.41	1002572	643708.91	271689.68	496079.09
Tekirdağ	1188989	1688142.18	21242.59	1394785	1706775.31	704945.56	726188.15
Yalova	120916	140575.46	1874.58	91039	28166.39	10760.92	12635.50
TOTAL	99356687	22696294.16	890558.48	14930841	9375558.91	3763096.69	4653655.17

Source: Ministry of Energy and Natural Resources General Directorate of Energy Affairs 2019.
*Total energy equivalence is equal to the sum of energy equivalences of animal waste and agricultural waste in each city.

Livestock and agricultural production reported in Table 1 includes the following: Horse, camel, donkey, cattle, goat, sheep, goose, duck, laying hens, and safflower, barley, wheat, sunflower, tare, rye, rice, bean, beet, canola, lentil, corn, chickpea, potato, sorghum, cotton, oat, pear, quince, almond, walnut, strawberry, berry, apple, plum, apricot, hazelnut, fig, cherry, peach, grape, olive (MENR 2019 Turkey Biomass Energy Potential Atlas).

According to Table 1, the amount of the region's agricultural wastes (crop residues) reaches up to 9375558.91 tons. The theoretical energy equivalents of animal and agricultural wastes in the Marmara Region are 890558.48 toe/year and 3763096.69 toe/year respectively, which makes a total of 4653655.17 toe/year. Considering that Turkey's total energy equivalent of animal and agricultural wastes is 10394420 toe/year (MENR 2019), the Marmara Region has substantial share (45%) in the total theoretical energy amount.

The amount of residues of both crop and livestock can vary depending on the type of crop or animal breed (Maltsoglou et al. 2016). Table 1 demonstrates that Balıkesir and Sakarya provinces have more density in terms of animal population and theoretical energy equivalent. Considering agricultural production, Balıkesir and Bursa are the prominent provinces, yet Tekirdağ and Edirne have higher waste production capacity due to the type of products. Since corn and sunflower generate more residues than other products (Başçetinçelik et al. 2003), waste amounts are higher in Tekirdağ and Edirne, where these products are widely produced.

Although the waste amount of animal manure is more than agricultural wastes, Table 1 exhibits that the equivalent energy values of the animal wastes are quite low compared to agricultural wastes. This difference might stem from the amount of the organic dry matter, which is comparably low for animal manure (2-10%), and also due to the digestion of energy-rich substances that has already been carried out by the animals (Weiland 2003). Dry manure ratios (in percentages) for cows, sheep and poultry are considered as 12.7%, 25% and 25% respectively (Başçetinçelik et al. 2003).

Figure 2 illustrates the number of animals, animal wastes and their energy equivalents in the region. Balıkesir and Sakarya provinces have the highest numbers of animals with 34966167 and 30153276 respectively, and the largest amount of animal manure with 6885871.04 and 2230372.7 respectively. However, in spite of the fact that the number of animals in Bursa is less than that of Sakarya, Bursa province has more animal manure than Sakarya. Animal manure generation is dependent on the type of animal. Cattle and sheep produce a high amount of waste, while poultry produces a lower amount (Başçetinçelik et al. 2003; MENR Energy Potential Atlas 2019), which also affects the amount of energy equivalent.

The amounts of agricultural production and wastes are presented in Figure 3. While agricultural production takes place predominantly in Bursa and Balıkesir, the waste amount of agricultural production is higher in Edirne and Tekirdağ. Edirne and Tekirdağ are the provinces where sunflower and canola production is more common compared to other cities. According to the MENR data, sunflower, canola, rice and chickpea generate more waste than their own production amount. A vast scale of canola production is taken place in Tekirdağ. As noted above, it might be considered that this gap between amount of production and wastes stems from the types of the products.

Table 1 also demonstrates energy equivalence of animal and agricultural wastes and the total amount of them. Total (animal and crop wastes) energy equivalent is given as 4653655.17 toe/year (MENR Energy Potential Atlas 2019). Considering that 1 toe is equal to 11.63 megawatt-hours (MWh) (IEA, 2020), theoretical energy potential of the Marmara Region could be calculated as follows:

4653655.17 x 11.63 = 54122009.63 MWh = 54122 GWh

According to the Energy Market Regulatory Authority, the total licensed electricity generation in 2018 was 295442.15 GWh, while licensed electricity production from biomass was 2410 GWh (EMRA 2019). That is to say, the share of biomass in electricity generation corresponds to 0.82%. On the other hand, our assessment covering theoretical energy production from biowastes demonstrates that it is possible to obtain 54122 GWh from wastes in the Marmara Region, corresponding to 18.32% of the total electricity generation.

Electricity consumption in the Marmara Region has been calculated as 93324352 MWh (93324.35 GWh) (TurkStat 2018), of which 57.99% could be theoretically covered by generating electricity from biowastes of the region. These numbers represent theoretical energy potentials, which might be a helpful tool to reshape regional energy policies. The Ministry of Energy and Natural Resources Energy announces that renewable energy installed capacity is expected to increase to 4533 GWh by 2023 (Maltsoglou et al. 2016). In line with this target, theoretical energy potential of biowastes of the Marmara Region would offer a solution in terms of meeting the goal via obtaining energy from biomass.

[1] The total capacity of biomass power plants in the world in 2018 was 130 gigawatts (GW), 16.2 GW of which was in the USA, 17.8 GW of which was in China and 10.2 GW of which was in India (REN21 2019).

4. Cost Calculation And Comparison Of Costs For Different Scenarios

As a further step of the study, costs of producing energy from agricultural residues and animal manure are calculated based on FAO's assessment (Maltsoglou et al. 2016). To calculate costs to produce electricity from agricultural and animal wastes in combined heat and power (CHP) or cogeneration systems, we use potential energy equivalents in terms of MWh and collection and feedstock costs based on the costs of the three scenarios determined by FAO. As a 4th scenario, we assume that feedstock costs are zero. Furthermore, we assume that all agricultural residues and animal manures are available for utilization and can be mobilized for energy production. Electricity generation of crop and livestock residues are defined in two ways, which are as follows (Rincon et al. 2019):

- CHP from direct combustion of biomass and
- CHP from biogas (residues first need to be converted into biogas and fed into the system)

Accordingly, the selected energy pathways are as follows: Crop wastes are used in direct combustion, whereas livestock wastes are used for biogas production in CHP systems.

On the other hand, accessibility to all wastes to be utilized as feedstock depends on the locations, which requires collection of agricultural and livestock residues and it can be challenging. In this study, collection and feedstock costs are used to determine proxies for the biomass price. Collection can be required if residues are dispersed in the field leading to a collection cost. If there is no need to collect residues, collection cost is taken as zero (Rincon et al. 2019). In line with this, we assign three costs based on FAO's assessment in terms of dollars denominated for agricultural and livestock residues. Given FAO's cost assessments, feedstock costs are determined based on collection costs ranging from 0 to 300 USD/t (transport excluded) for agricultural wastes (Table 2).

Table 2 Collection costs for cogeneration for agricultural wastes at province level in the Marmara Region.

City	Amount of Agricultural Waste (ton)	DIRECT COMBUSTION COLLECTION COST Scenario 1 – 0 USD/t	Scenario 2 – 150 USD/t	Scenario 3 – 300 USD/t
Balıkesir	1096113.83	0	164417075	328834149
Bilecik	205588.10	0	30838215	61676430
Bursa	1512406.29	0	226860944	453721887
Çanakkale	865126.53	0	129768980	259537959
Edirne	1755665.87	0	263349881	526699761
İstanbul	345642.47	0	51846371	103692741
Kırklareli	1067270.30	0	160090545	320181090
Kocaeli	149094.91	0	22364237	44728473
Sakarya	643708.91	0	96556337	193112673
Tekirdağ	1706775.31	0	256016297	512032593
Yalova	28166.39	0	4224959	8449917
TOTAL	9375558.91	0 USD	1406333837 USD	2812667673 USD
1 ton = 1.162 megawatt-hour >>	10894399.45 MWh	0	129.087 USD/MWh	258.176 USD/MWh
		0	0.129 USD/kWh	0.258 USD/kWh

Source: Maltsoglou et al. 2016; MENR 2019.
*Note: The exchange rate used was 1 USD = 2.47 TL.

Collection costs of crop wastes for three alternative prices at province level based on the quantity of agricultural waste are summarized in Table 2. Collection costs are then calculated per kWh using unit converter. Given the results for the three scenarios, the costs are found between 0 USD/kWh and 0.258 USD/kWh. This values are used together with feedstock costs (see Table 3) to calculate total costs for agricultural wastes (see Table 4). Transport costs are not taken into consideration here. Availability and accessibility of wastes are dependent on several variables such as location of the field, crop residue type and their yield amount, etc. (Maltsoglou et al. 2016). In scenario 1, the minimum collection distance value is chosen as 0 km, thus collection cost is equal to 0. In scenario 2 and 3, 150 USD/t and 300 USD/t are selected in regards to different collection distances. However, other indicators are not taken into account and it is assumed that all feedstock residues are available for energy production although crop and animal residues could alternatively be used for soil amendment, as animal feed and as fertilizers (Rincon et al. 2019).

Table 3 Feedstock costs per kWh for agricultural wastes in provinces.

City	Amount of Agricultural Waste (ton)	DIRECT COMBUSTION MAX-FEEDSTOCK COST Scenario 1-19 USD/t	Scenario 2-65.5 USD/t	Scenario 3-112 USD/t
Balıkesir	1096113.83	20826162.77	71795455.87	122764748.96
Bilecik	205588.10	3906173.90	13466020.55	23025867.20
Bursa	1512406.29	28735719.51	99062612.00	169389504.48
Çanakkale	865126.53	16437404.07	56665787.72	96894171.36
Edirne	1755665.87	33357651.53	114996114.49	196634577.44
İstanbul	345642.47	6567206.93	22639581.79	38711956.64
Kırklareli	1067270.30	20278135.70	69906204.65	119534273.60
Kocaeli	149094.91	2832803.29	9765716.61	16698629.92
Sakarya	643708.91	12230469.29	42162933.61	72095397.92
Tekirdağ	1706775.31	32428730.89	111793782.81	191158834.72
Yalova	28166.39	535161.41	1844898.55	3154635.68
TOTAL	9375558.91	178135619.29	614099108.61	1050062597.92
1 ton 1.162 megawatt-hour >>	10894399.45 MWh	16.351 USD/MWh 0.016 USD/kWh	56.368 USD/MWh 0.056 USD/kWh	96.386 USD/MWh 0.096 USD/kWh

Source: Maltsoglou et al. 2016; MENR 2019.

Feedstock costs are evaluated in four alternative scenarios. Three different costs for feedstock are displayed in Table 3. In addition to these three, we have calculated the total cost where the feedstock cost is equal to zero, as a fourth scenario. Feedstock costs are determined as 19 USD/t, 65.5 USD/t and 112 USD/t referring to the FAO's assessment. Feedstock costs are calculated based on their weights as in the collection cost calculation. The wide range of feedstock costs stems from technology differences that are used in CHP facilities and energy potentials of feedstock. Therefore, some feedstock is considered more valuable, while some have lower prices. In this analysis, technology, energy potential (MJ/kg) and efficiencies are not calculated, yet feedstock costs are adapted from FAO's report, which present low, middle and high prices. The results are shown in Table 3, which helps us infer that feedstock costs are more affordable compared to collection costs in scenarios 2 and 3.

In the case of zero-cost feedstock, collection costs are the main expenditures for bioenergy production, which are 0 USD/kWh, 0.129 USD/kWh and 0.258 USD/kWh based on the three scenarios. Accordingly, scenario 4, where feedstock cost is zero, is the most profitable option. The set of the results for total costs including collection and feedstock cost is summarized in Table 4. The total costs for agricultural wastes are calculated as 0.016 USD/kWh, 0.186 USD/kWh and 0.355 USD/kWh for the three scenarios respectively. Apparently, scenario 1 can be considered as the preferable option compared to other scenarios. Scenario 4, on the other hand, where both collection cost and feedstock cost are zero, is evidently the most profitable option.

Table 4 Estimated total costs per kWh for agricultural wastes in provinces.

		DIRECT COMBUSTION		
		TOTAL COST FOR COGENERATION (CHP)		
City	Amount of Agricultural Waste (ton)	Scenario 1 - 0 USD/t + Scenario 1 - 19 USD/t	Scenario 2 - 150 USD/t + Scenario 1 – 65.5 USD/t	Scenario 3 - 300 USD/t + Scenario 3 - 112 USD/t
Balıkesir	1096113.83	20826162.77	236212530.37	451598897.96
Bilecik	205588.10	3906173.90	44304235.55	84702297.20
Bursa	1512406.29	28735719.51	325923555.50	623111391.48
Çanakkale	865126.53	16437404.07	186434767.22	356432130.36
Edirne	1755665.87	33357651.53	378345994.99	723334338.44
İstanbul	345642.47	6567206.93	74485952.29	142404697.64
Kırklareli	1067270.30	20278135.70	229996749.65	439715363.60
Kocaeli	149094.91	2832803.29	32129953.11	61427102.92
Sakarya	643708.91	12230469.29	138719270.11	265208070.92
Tekirdağ	1706775.31	32428730.89	367810079.31	703191427.72
Yalova	28166.39	535161.41	6069857.05	11604552.68
TOTAL	9375558.91	178135619.29	2020432945.11	1050062597.92
1 ton 1.162 megawatt-hour >>	10894399.45 MWh	16.351 USD/MWh	185.456 USD/MWh	354.562 USD/MWh
		0.016 USD/kWh	0.186 USD/kWh	0.355 USD/kWh

Source: Maltsoglou et al. 2016; MENR 2019.

In terms of biogas use to produce electricity, similar calculations are made. We account for livestock wastes that are suitable for conversion into biogas and use in cogeneration facilities instead of direct combustion. Since some biomass is not appropriate for direct combustion due to its water content or ash producing potential, it needs to be modified. Therefore, animal manure is a convenient biomass to be converted into biogas generating electrical energy in a CHP plant. The amount of livestock waste may vary in regards to several factors such as animal type, age and productivity, etc. (Maltsoglou et al. 2016). However, these indicators are not used for calculation of animal manure since these values are not provided in the database of MENR covering the Marmara Region.

As in the case of crop waste costs, livestock manure costs are calculated in two stages which are collection costs (Table 5) and feedstock costs (Table 6). For the two stages, initially costs per kWh for collection and feedstock costs are calculated and then they are summed up to find the total cost (Table 7). Again, as in the case of agricultural waste calculations, costs are solely calculated based on the weights of wastes in the provinces since the other indicators (machinery, labor, capital investment, etc.) are excluded from our assessment. Thus, the provinces producing more animal wastes have higher collection and feedstock costs. According to the three scenarios, collection costs are chosen as 14 USD, 35 USD and 55 USD per ton and calculated as 0.012 USD/kWh, 0.030 USD/kWh and 0.047 USD/kWh, respectively (Table 5).

Table 5 Estimated collection costs per kWh for animal wastes.

		BIOGAS TO ELECTRICITY		
		COLLECTION COST		
City	Animal Waste Amount (ton)	Scenario 1-14 USD/t	Scenario 2-35 USD/t	Scenario 3-55 USD/t
Balıkesir	6885871.04	96402195	241005486	378722907
Bilecik	614734.68	8606286	21515714	33810407
Bursa	3004653.29	42065146	105162865	165255931
Çanakkale	2569039.77	35966557	89916392	141297187
Edirne	1714313.90	24000395	60000987	94287265
İstanbul	1005106.56	14071492	35178730	55280861
Kırklareli	1710213.94	23942995	59857488	94061767
Kocaeli	1133270.57	15865788	39664470	62329881
Sakarya	2230372.77	31225219	78063047	122670502
Tekirdağ	1688142.18	23633991	59084976	92847820
Yalova	140575.46	1968056	4920141	7731650
TOTAL	22696294	317748118 USD	794370295 USD	1248296178 USD
	26373093.63 MWh	12.048 USD/MWh	30.121 USD/MWh	47.332 USD/MWh
		0.012 USD/kWh	0.030 USD/kWh	0.047 USD/kWh

Source: Maltsoglou et al., 2016; MENR, 2019.

In terms of feedstock costs for animal manure, a similar calculation is made for 3 USD, 6.5 USD and 10 USD per ton for the low, medium, and high scenarios respectively, adapted from FAO's assessment (Maltsoglou et al. 2016). When animal feedstock costs based on scenario 1, 2, and

3 are compared to those of crop wastes, animal waste option appears to be more profitable, which reveals 0.003 USD/t, 0.006 USD/t, and 0.008 USD/t costs respectively (Table 6). Animal feedstock type also affects biogas yield. Cows, sheep and poultry manures that we use for our analysis have different available dry manure ratios, which are 65, 13 and 99% and thus have different calorific values (Başçetinçelik et al. 2003) leading to feedstock cost differences.

Table 6 Max-feedstock costs in three scenarios for animal wastes.

		BIOGAS TO ELECTRICITY		
		MAX-FEEDSTOCK COST (for different KWe)		
City	Animal Waste Amount (ton)	Scenario 1–3 USD/t	Scenario 2-6.5 USD/t	Scenario 3-10 USD/t
Balıkesir	6885871.04	20657613	44758162	68858710
Bilecik	614734.68	1844204	3995775	6147347
Bursa	3004653.29	9013960	19530246	30046533
Çanakkale	2569039.77	7707119	16698759	25690398
Edirne	1714313.90	5142942	11143040	17143139
İstanbul	1005106.56	3015320	6533193	10051066
Kırklareli	1710213.94	5130642	11116391	17102139
Kocaeli	1133270.57	3399812	7366259	11332706
Sakarya	2230372.77	6691118	14497423	22303728
Tekirdağ	1688142.18	5064427	10972924	16881422
Yalova	140575.46	421726	913740	1405755
TOTAL	22696294	68088882	147525912	226962942
	26373093.63 MWh	2.582 USD/MWh	5.594 USD/MWh	8.606 USD/MWh
		0.003 USD/kWh	0.006 USD/kWh	0.008 USD/kWh

Source: Maltsoglou et al., 2016; MENR, 2019.

Finally, the collection and feedstock costs for the three scenarios are summed up to arrive at total costs, which are 0.015 USD/t, 0.036 USD/t and 0.055 USD/t respectively (Table 7). Compared to agricultural wastes, animal wastes are slightly less costly according to the scenario 1. However, scenario 2 and 3 indicate a considerable difference between the total costs when feedstock costs are not equal to zero.

On the other hand, as we do for the case of crop waste cost calculation, zero feedstock costs for animal manure are also taken into account as a fourth scenario. In this case, the total costs of producing biogas from animal wastes are calculated as 0.012 USD/kWh, 0.030 USD/kWh and 0.047 USD/kWh respectively. (The corresponding costs for crop wastes are calculated above as 0 USD/kWh, 0.129 USD/kWh and 0.258 USD/kWh.) When feedstock costs are equal to zero, the results reveal that electricity generation is more economical when it is produced from crop wastes according to scenario 1. Scenarios 2 and 3 exhibit that animal wastes should be preferred on condition that feedstock cost is equal to zero.

Table 7 Total costs for biogas production from animal wastes.

		BIOGAS TO ELECTRICITY		
		TOTAL COST FOR COGENERATION (CHP)		
City	Animal Waste Amount (ton)	Scenario 1 - 14 USD/t + Scenario 1 - 3 USD/t	Scenario 2 - 35 USD/t + Scenario 2 – 6.5 USD/t	Scenario 3 - 55 USD/t + Scenario 3 - 10 USD/t
Balıkesir	6885871.04	117059808	285763648	447581618
Bilecik	614734.68	10450490	25511489	39957754
Bursa	3004653.29	51079106	124693112	195302464
Çanakkale	2569039.77	43673676	106615150	166987585
Edirne	1714313.90	29143336	71144027	111430404
İstanbul	1005106.56	17086812	41711922	65331926
Kırklareli	1710213.94	29073637	70973879	111163906
Kocaeli	1133270.57	19265600	47030729	73662587
Sakarya	2230372.77	37916337	92560470	144974230
Tekirdağ	1688142.18	28698417	70057900	109729242
Yalova	140575.46	2389783	5833882	9137405
TOTAL	22696294.16	385837001	941896208	1475259120
	26373093.63 MWh	14.630 USD/MWh	35.715 USD/MWh	55.938 USD/MWh
		0.015 USD/kWh	0.036 USD/kWh	0.055 USD/kWh

Source: Maltsoglou et al. 2016; MENR 2019;

Given the overall results of the total costs above, electricity production by obtaining biogas from animal wastes can be considered as the most economical option. However, if feedstock costs are equal to zero, energy production from crop wastes based on scenario 1 is the most preferable option mainly due to the zero collection cost in this scenario. In Scenarios 2 and 3, energy production from animal wastes appears to be less costly mainly due to the higher collection costs for crop wastes, when feedstock costs are equal to zero. When feedstock costs are taken into consideration (Table 3 and Table 6), it can be concluded that energy production from animal wastes are the most profitable option for all scenarios. Energy production via direct combustion of crop wastes in CHP systems, due to the challenges of collecting dispersed material, may seem to be least preferable option (Table 2). While crop residues can be used for soil amendment and animal feeding, animal manure is primarily considered as fertilizer. Remaining parts of crop residues are left in the field, which could then be used for energy production (Başçetinçelik et al. 2003; Rincon et al. 2019). This mostly leads to the differences between collection costs.

The set of results reveal that energy production from wastes is a preferable option considering also incentives to biomass powered electricity generation in Turkey, which is introduced by the Renewable Energy Law No. 6094. The law defines a price called feed-in-tariff, which is a fixed cash-per-kWh payment determined by the administrative body and generally available for eligible renewable energy producers. Feed-in-tariff for electricity generation from biomass-based production facilities (including landfill gas) is 13.3 USD cent/kWh. Furthermore, in the case of domestic equipment use, this price reaches up to 18.9 USD cent/kWh (see Appendix. Incentive prices for renewable energy sources). The results of the analysis demonstrate that the feed-in-tariff would be profitable for some of our options to produce electricity whether direct combustion or conversion to biogas in CHP plants is chosen. When feedstock costs are not equal to zero, for crop wastes, scenarios 1 and 2; and for animal wastes, scenarios 1, 2 and 3 appear less expensive compared to feed-in-tariffs. In case feedstock costs are not taken into consideration, for crop wastes, scenarios 1 and 2; and for animal wastes, all scenarios can be applied in CHP plants.

On the other hand, construction costs for the biogas and biofertilizer production system from animal wastes are the main expenses of a facility (Gümüşçü and Uyanık 2010). Energy potential of feedstock and heat amount to convert into electricity are the main requirements in CHP systems, which affect electricity output and capacity. Thus, it is possible to produce the maximum electricity with the maximum feedstock, advanced technology and the highest energy potential. If heat surplus is converted into electricity, high investment amounts are required although potential profit is also high (Maltsoglou et al. 2016). Within this context, comparison of capital investments is carried out in FAO's BEFS assessment for different production scenarios based on different plant capacities (kWe). However, capital investment expenditures are not taken into account in the current analysis.

Additionally, as an indicator to evaluate cost-efficiency of energy generation methods "levelized cost of electricity (LCOE)" is used, which represents "the average revenue per unit of electricity generated" to recover the building and operational costs during a financial life (EIA 2020). To calculate the LCOE value, variables such as investment expenditures, operation and maintenance and fuel costs, discount rate and lifetime of the facility are taken into consideration (IRENA 2019; EIA 2020). Considering renewable energy technologies, the capital cost has significant importance on the LCOE, since they are require high capital costs. However, as technology becomes more advanced, this cost has a tendency to decrease leading to an advantage to renewable energy sources over fossil-fuel-based energy sources (Acar et al. 2015).

According to EIA (2020), it is estimated that the total LCOE value will be 94.83 USD/MWh (0.0948 USD/kWh) (based on 2019 dollars level) for biomass in the world entering service in 2025. The LCOE of bioenergy-fired power generation projects varies in different regions due to the different installed costs, feedstock and technologies. While this value was 0.06 USD/kWh in China and India between 2000-2018, Europe and North America had higher values (0.08 USD/kWh and 0.09 USD/kWh respectively). Total installed costs depend on feedstock types and technology that are deployed; thus they may vary in different regions and countries. While bioenergy plants that use rice husks and bagasse have lower installation costs, those using landfill gas, agricultural waste and MSWs have slightly higher installation costs. Therefore, bioenergy plants using rice husks and bagasse have lower LCOEs (IRENA 2019).

In Turkey, the LCOE values for 2014 are estimated as 120 USD/MWh (0.12 USD/kWh) for onshore wind projects. It is expected to decline to the 60-80 USD/MWh range (0.06-0.08 USD/kWh range) for similar projects, whereas the LCOE for coal is between 73-116 USD/MWh (0.073-0.116 USD/kWh). Similarly, the LCOE values are estimated as 85-120 USD/MWh for a ground-mounted solar project, which was calculated as 150 USD/MWh in 2014 (WWF 2014). Due to the lack of data on the LCOE for biomass in Turkey, an approximation can be made using the LCOE value in Europe (0.08 USD/kWh). Once we consider this value, scenario 1 for crop residues and all scenarios for animal wastes in our analysis appear to be economical. When feedstock costs are equal to zero, the same result prevails.

On the other hand, there has been a decreasing tendency in the cost of renewable energy in 2018 compared to 2017 values. This amount is 26% in concentrating solar power (CSP), followed by bioenergy with the rate of 14% (IRENA 2019). As feedstock (agricultural, forestry) and technology costs decrease, energy production from biomass can compete with other energy sources. Global weighted average LCOE from biomass was 0.062 USD/kWh in 2018, while it was 0.071 USD/kWh in 2017. The same trend can be observed between 2010 and 2015, where LCOE values were 0.056 and 0.055 respectively (IRENA, 2019). Additionally, the total installed costs of bioenergy projects have decreased from 2850 USD/kW to 2100 USD/kW between 2017 and 2018. This value was 0.072 USD/kWh for geothermal, 0.047 USD/kWh for hydro, 0.085 for solar photovoltaics, 0.185 concentrating solar power, 0.127 for offshore wind and 0.056 for onshore wind (IRENA 2019).

Overall, considering the results of this study, biowastes for energy production would be profitable in certain technologies and scenarios. In our analysis, biowaste for electricity generation is considered a promising method when also compared to LCOE values.

5. Discussion And Conclusion

Energy production methods may vary depending on a country's energy policies, technological development level and agricultural and livestock potential. Animal manure and agricultural wastes have become promising feedstocks that can compete with other conventional energy sources. Animal and agricultural wastes are traditionally burnt or left as fertilizer in the field. However, wastes offer a significant potential for energy production either via direct combustion or biogas techniques. In this study, it has been suggested that animal and agricultural wastes in the Marmara Region can be considered as a profitable option for generating electrical energy. The amounts of agricultural and animal wastes and their energy equivalents in the Marmara Region have been evaluated using MENR's data. Then, costs of producing electricity in CHP plants using wastes have been calculated based on FAO's assessment. It is concluded that agricultural and animal wastes show a substantial potential. Cultivating energy crops or other conventional energy production methods are not suggested in this study due to environmental and energy security concerns.

The Marmara Region has both urban and rural cities, which provide agricultural and animal wastes and municipal wastes. Municipal wastes are not included in our calculations, even though Istanbul has importance in terms of municipal solid wastes. Nevertheless, all cities in the region have substantial waste potential compared to the amounts of wastes that are being produced in other parts of Turkey. This energy potential of wastes is considered to be tapped either via direct combustion in CHP or conversion to biogas in CHP systems. Using three different scenarios, total costs per kWh are calculated here. The assessment is adapted from FAO's BEFS assessment. In line with FAO's analysis, it is assumed that agricultural wastes are more suitable for direct combustion for CHP, and animal wastes are considered as a more preferable option for CHP from biogas.

As a result of calculations for energy equivalents and costs at provincial level in the Marmara Region, biowastes can theoretically provide more than half of the electricity consumption of the region. Besides, it appears that costs of energy generation of wastes indicate an economical option considering several scenario selections. On the other hand, using agricultural and livestock wastes have some challenges in terms of logistic costs including collection and transportation from the fields. Energy-related agricultural production is another problem which leads to increase in food prices, thus jeopardizes food sovereignty. It may also lead to environmental problems such as loss of biodiversity, monocropping, soil degradation, water pollution etc. Within this context, getting benefit from wastes is emphasized in this study instead of producing crops for energy in arable lands. Additionally, considering the incentives to renewable energy, a strategy could be developed for energy generation techniques for the use of wastes that contribute to the acceleration of the renewable energy market. Besides, environmental and climate concerns can be resolved through biowaste-based energy generation systems.

Declarations

Ethical Approval:

Not applicable

Consent to Participate:

Not applicable

Consent to Publish:

Not applicable

Authors Contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Semra Ocak and Sevil Acar. The first draft of the manuscript was written by Semra Ocak and Sevil Acar and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests:

The authors declare that they have no conflict of interest.

Availability of data and materials:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

ORCID:

Semra Ocak https://orcid.org/0000-0001-6320-0585

Sevil Acar https://orcid.org/0000-0001-5535-8673

References

Acar S, Kitson L, and Bridle R (2015) Subsidies to coal and renewable energy in Turkey. Manitoba, Canada: International Institute for Sustainable Development

Acar S, Yeldan AE (2016) Environmental impacts of coal subsidies in Turkey: A general equilibrium analysis. Energy Policy, 90, 1-15. doi: 10.1016/j.enpol.2015.12.003

Achinas S, Achinas V, Euverink GJW (2017) A technological overview of biogas production from biowaste. Engineering, 3(3), 299-307. doi: 10.1016/J.ENG.2017.03.002

Ayhan A (2016) Biogas potential from animal waste of Marmara Region-Turkey. Agronomy Research, 14(3), 650-660

Azbar N (2013) Kentsel Katı Atıkların Biyoenerji ve Gübre Üretimi ile Çevre Dostu Kullanım Seçenekleri [Bioenergy and Fertilizer Production and Environmentally Friendly Usage Options of Urban Solid Wastes], TMMOB 2. İzmir Kent Sempozyumu, İzmir, Turkey, November 28-30

Başçetinçelik A, Öztürk HH, Karaca C, Kaçıra M, Ekinci K, Kaya D, Baban A, Güneş K, Komitti N, Barnes I. et al. (2003) A guide on exploitation of agricultural residues in Turkey. Life, 3

Bhatia SK, Joo HS, Yang YH (2018) Biowaste-to-bioenergy using biological methods–A mini-review. Energy Conversion and Management, 177, 640-660. doi: 10.1016/j.enconman.2018.09.090

Bioenergy Europe (2019) Biomass for Energy: Agricultural Residues & Energy Crops, Bioenergy Explained 5. Brussels. https://bioenergyeurope.org/article/204-bioenergy-explained-biomass-for-energy-agricultural-residues-energy-crops.html Accessed 20 April 2020

Bilgen S, Keleş S, Kaygusuz A, Sarı A, Kaygusuz K (2008) Global warming and renewable energy sources for sustainable development: a case study in Turkey. Renewable and Sustainable Energy Reviews, 12(2), 372-396. doi: 10.1016/j.rser.2006.07.016

Biyodizel Sanayi Derneği (2019) Biyodizel Endüstri Raporu 1 [Biodiesel Industry Report 1]. http://www.biyodizel.org.tr/asset/pdf/biyodizel.pdf Accessed 4 April 2020

Camia A, Robert N, Jonsson R, Pilli R, García-Condado S, López-Lozano R, van der Velde M, Ronzon T, Gurría P, M'Barek R et al. 2018. Biomass production, supply, uses and flows in the European Union

Chester M, Martin E (2009) Cellulosic ethanol from municipal solid waste: a case study of the economic, energy, and greenhouse gas impacts in California. Environ. Sci. Technol. 2009, 43, 14, 5183–5189. doi: 10.1021/es802788z

Demirbas A (2009) Biofuels from agricultural biomass. Energy Sources, Part A, 31(17), 1573-1582. doi: 10.1080/15567030802094011

Doruk İ, Bozdeveci A (2017) Denizli ilinin kırsal kesimlerinde hayvansal kaynaklı atıklardan biyogaz potansiyelinin belirlenmesi [Determination of biogas potential from animal wastes in rural areas of Denizli province]. Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 7(3), 181-186

Dumanli AG, Gulyurtlu I, Yürüm Y (2007) Fuel supply chain analysis of Turkey. Renewable and Sustainable Energy Reviews, 11(9), 2058-2082. doi: 10.1016/j.rser.2006.03.011

Energy Market Regulatory Authority (EMRA) (2019) Electricity Market - 2018 Market Development Report, Ankara, 2019. https://www.epdk.org.tr/Detay/Icerik/3-0-24/elektrikyillik-sektor-raporu Accessed 4 May 2020

Erdogdu, E (2008) An expose of bioenergy and its potential and utilization in Turkey. Energy Policy, 36(6), 2182-2190. doi: 10.1016/j.enpol.2008.02.041

FAO (2009) Planted Forests and Second-Generation Biofuels. Linda Rosengren. Planted Forests and Trees Working Paper 42E. Forest Resources Development Service. FAO. Rome, Italy. www.fao.org/forestry/site/10368/en Accessed 7April 2020

Farmanbordar S, Karimi K, Amiri H (2018) Municipal solid waste as a suitable substrate for butanol production as an advanced biofuel. Energy conversion and management, 157, 396-408. doi: 10.1016/j.enconman.2017.12.020

Global Energy Statistical Yearbook, Total energy consumption (2018). https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html Accessed 7 April 2020

Görgülü S (2019) Burdur İlinin Hayvansal ve Bazı Tarımsal Atık Kaynaklı Biyogaz Potansiyelinin Belirlenmesi [Determination of Biogas Potential of Animal and Some Agricultural Waste in Burdur Province]. El-Cezeri Journal of Science and Engineering, 6(3), 543-557

Guber AK, Pachepsky YA, Shelton DR, Yu O (2007) Effect of bovine manure on fecal coliform attachment to soil and soil particles of different sizes. Appl. Environ. Microbiol., 73(10), 3363-3370. doi: 10.1128/AEM.02434-06

Guo M, Song W, Buhain J (2015) Bioenergy and biofuels: History, status, and perspective. Renewable and Sustainable Energy Reviews, 42, 712-725. doi: 10.1016/j.rser.2014.10.013

Gümüşçü M, Uyanık S (2010) Güneydoğu Anadolu Bölgesi Hayvansal Atıklarından Biyogaz ve Biyogübre Eldesi [Obtaining biogas and biofertilizer from animal wastes in Southeastern Anatolia Region]. Tesisat Mühendisliği (MMO), 16(118), 59-65

International Energy Agency (IEA) (2020) https://www.iea.org/reports/unit-converter-and-glossary#unit-converter Accessed 22 March 2020

IEA (2019) Renewables. https://www.iea.org/reports/renewables-2019 Accessed 12 April 2020

IEEFA-Institute for Energy Economics and Financial Analysis (2016) Turkey at a crossroads: Invest in the old energy economy or the new? http://ieefa.org/wp-content/uploads/2016/09/Turkey-Crossroads-Invest-in-the-Old-Energy-Economy-or-the-New_June-2016-v2.pdf Accessed 20 March 2020

IRENA, LCOE 2010-2015. http://resourceirena.irena.org/gateway/dashboard/?topic=3&subTopic=33 Accessed 12 May 2020

IRENA (2019) Renewable Power Generation Costs in 2018. Report, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf Accessed 20 March 2020

Jaeger WK, Egelkraut TM (2011) Biofuel economics in a setting of multiple objectives and unintended consequences. Renewable and Sustainable Energy Reviews, 15(9), 4320-4333. doi: 10.1016/j.rser.2011.07.118

Jones A, O'Hare M, Farrell A (2007) Biofuel boundaries: Estimating the medium-term supply potential of domestic biofuels. UC Berkeley: Transportation Sustainability Research Center.

Koç E, Şenel MC (2013) Dünyada ve Türkiye'de enerji durumu-genel değerlendirme [Energy situation in the world and Turkey – General assessment]. Mühendis ve Makina, 54(639), 32-44

Köse ET (2017) Trakya bölgesinde hayvan gübrelerinin biyogaz enerji potansiyelinin belirlenmesi ve sayısal haritaların oluşturulması [Determining the biogas energy potential of animal manure in the Thrace region and creating digital maps]. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 23(6), 762-772

Küçükkaya E (2019) Türkiye'nin Biyokütle Enerjisi Santrali Kurulu Gücü 719 MW Olacak! [Turkey's Biomass Energy Power Plant to Be Installed Capacity 719 MW!]. April 2, 2019. https://www.enerjiportali.com/turkiyenin-biyokutle-enerjisi-santrali-kurulu-gucu-719-mw-olacak/ Accessed 25 March 2020

Lehrer N (2010) (Bio) fueling farm policy: the biofuels boom and the 2008 farm bill. Agriculture and Human Values, 27(4), 427-444

Lora EES, Palacio JCE, Rocha MH, Renó MLG, Venturini OJ, Del Olmo OA (2011) Issues to consider, existing tools and constraints in biofuels sustainability assessments. Energy, 36(4), 2097-2110. doi: 10.1016/j.energy.2010.06.012

Maltsoglou I, Rincon L, Kojakovic A, Puri M (2016) BEFS assessment for Turkey. Environment and Natural Resources Management. FAO Working Paper eng no. 64. Accessed March 20, 2020. http://www.fao.org/3/a-i6480e.pdf

Meyer AKP, Ehimen EA, Holm-Nielsen JB (2018) Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. Biomass and Bioenergy, 111, 154-164. doi: 10.1016/j.biombioe.2017.05.013

Ministry of Environment and Urbanization Directorate General of Environmental Management. https://cevreselgostergeler.csb.gov.tr/yenilenebilir-kaynaklardan-uretilen-elektrik-orani-i-85810 Accessed 20 March 2020

Ministry of Energy and Natural Resources General Directorate of Energy Affairs (MENR) (2019) https://bepa.enerji.gov.tr/. Accessed 15 March 2020

Ministry of Interior General Directorate of Civil Registration and Citizenship (2019) https://www.icisleri.gov.tr/turkiyenin-nufus-haritasi. Accessed 15 April 2020

Mol AP (2007) Boundless biofuels? Between environmental sustainability and vulnerability. Sociologia ruralis, 47(4), 297-315. doi: 10.1111/j.1467-9523.2007.00446.x

ntv.com.tr (2019) Yenilenebilir enerjiye 5 yılda 16 milyar dolar [16 billion dollars for renewable energy in 5 years], October 9, 2019. https://www.ntv.com.tr/ekonomi/yenilenebilir-enerjiye-5-yilda-16-milyar-dolar,W8JPFeqO_U-xiuz9hAYmkg. Accessed 17 April 2020

Özer B (2017) Biogas energy opportunity of Ardahan city of Turkey. Energy, 139, 1144-1152. doi: 10.1016/j.energy.2017.07.052

REN21 (2019) Renewables 2019 Global Status Report. https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf. Accessed 15 April 2020

Republic of Turkey Ministry of Energy and Natural Resources (2019) https://www.enerji.gov.tr/tr-TR/Sayfalar/Biyokutle. Accessed 15 March 2020

Rincon L, Puri M, Kojakovic A, Maltsoglou I (2019) The contribution of sustainable bioenergy to renewable electricity generation in Turkey: Evidence based policy from an integrated energy and agriculture approach. Energy Policy, 130, 69-88. doi: 10.1016/j.enpol.2019.03.024

Salihoğlu NK, Teksoy A, Altan K (2019) Büyükbaş ve küçükbaş hayvan atıklarından biyogaz üretim potansiyelinin belirlenmesi: Balikesir ili örneği [Determination of biogas production potential from catlle and sheep waste: Balikesir province example]. Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 8(1), 31-47

Sarmah AK (2009) Potential risk and environmental benefits of waste derived from animal agriculture. In Agriculture Issues and Policies Series-Agricultural Wastes, ed. G. S. Ashworth and P. Azevedo, Nova Science Pub Inc

Silayo DA, Katani JZ, Maliondo SMS, Tarimo MCT (2008) Forest plantation for biofuels to serve natural forest resources. Research and development for sustainable management of semiarid Miombo woodlands in East Africa. Working Papers of the Finnish Forest Research Institute, 98, 115-124

Solomon BD (2010) Biofuels and sustainability. Annals of the New York Academy of Sciences, 1185(1), 119-134. doi: 10.1111/j.1749-6632.2009.05279.x

Sözer S, Yaldız O (2011) Muz serası atıkları ve sığır gübresi karışımlarından mezofilik fermantasyon sonucu üretilebilecek biyogaz miktarının belirlenmesi üzerine bir araştırma [A research on determining the amount of biogas that can be produced by mesophilic fermentation from banana greenhouse waste and cattle manure mixtures]. Akdeniz Üniversitesi Ziraat Fakültesi Dergisi, 24(2), 75-78

Statista.com (2020). Fuel ethanol production worldwide in 2019, by country (in million gallons). https://www.statista.com/statistics/281606/ethanol-production-in-selected-countries/. Accessed 12 April 2020

Şenol H, Elibol EA, Açikel Ü, Şenol M. (2017a) Biyogaz üretimi için Ankara’nın başlıca organik atık kaynakları [Ankara's main organic waste sources for biogas production]. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 6(2), 15-28

Şenol H, Elibol EA, Açıkel Ü, M. Şenol (2017b) Türkiye’de biyogaz üretimi için başlıca biyokütle kaynakları [The main sources of biomass for biogas production in Turkey]. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 6(2), 81-92

The World Bank (2015) Fossil fuel energy consumption (% of total) – Turkey https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS?locations=TR. Accessed 15 March 2020

The World Bank (2018) Rural population (% of total population) – Turkey. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?display=graph--%3E&end=2018&locations=TR&start=1960. Accessed 18 April 2020

Turkish Statistical Institute (TurkStat) http://www.tuik.gov.tr/UstMenu.do?metod=temelist. Accessed 15 March 2020

Turkish Electricity Transmission Company (TETC) (2020) Türkiye Elektrik Üretim-Tüketim istatistikleri [Electricity Production-Consumption Statistics for Turkey]. https://www.teias.gov.tr/tr-TR/turkiye-elektrik-uretim-iletim-istatistikleri. Accessed 15 May 2020

U.S. Energy Information Administration (EIA) (2020) Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020. Last modified February 2020. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf. Accessed 4 April 2020

U.S. Environmental Protection Agency (EPA) (2000) Proposed regulations to address water pollution from concentrated animal feeding operations. https://www3.epa.gov/npdes/pubs/CAFO-brochure3.pdf. Accessed 14 March 2020

Weiland P (2003) Production and energetic use of biogas from energy crops and wastes in Germany. Applied biochemistry and biotechnology, 109(1-3), 263-274. doi: 10.1385/ABAB:109:1-3:263

World Bioenergy Association (2018) WBA Global Bioenergy Statistics. World Bioenergy Association: Stockholm, Sweden. https://worldbioenergy.org/uploads/201210%20WBA%20GBS%202020.pdf. Accessed 2 April 2020

World Energy Council (2016) 23rd World Energy Congress, Turkish Energy Market Outlook Achievements, Overview and Opportunities, October, 2016, İstanbul. https://www.dunyaenerji.org.tr/wp-content/uploads/2017/10/turkish-energy-market-outlook.pdf. Accessed 9 April 2020

World Global Bioenergy (2019) Statistics. World Bioenergy Association: Stockholm. https://worldbioenergy.org/uploads/191129%20WBA%20GBS%202019_HQ.pdf. Accessed 15 March 2020

WWF (2014) Turkey's renewable power: Alternative power supply scenarios for Turkey. http://awsassets.wwftr.panda.org/downloads/wwf_turkey___bnef___turkey_s_renewable_power___alternative_power_supply_scenarios_until_.pdf Accessed 20 April 2020

Yağlı H, Koç K (2019) Hayvan Gübresinden Biyogaz Üretim Potansiyelinin Belirlenmesi: Adana İli Örnek Hesaplama [Determination of Biogas Production Potential from Animal Manure: Sample Calculation for Adana Province]. Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 34(3), 35-48

Yürük F, Erdoğmuş P (2015) Düzce ilinin hayvansal atıklardan üretilebilecek biyogaz potansiyeli ve k-means kümeleme ile optimum tesis konumunun belirlenmesi [Determination of the biogas potential of Düzce province that can be produced from animal wastes and the optimum facility location with k-means clustering]. İleri Teknoloji Bilimleri Dergisi, 4(1), 47-56

Zhang Z, O'Hara IM, Mundree S, Gao B, Ball AS, Zhu N, Bai Z, Jin B (2016) Biofuels from food processing wastes. Current opinion in biotechnology, 38, 97-105

Appendix

Appendix A.

Table A1. Incentive prices for renewable energy sources.

Generation Plant Type Based on Renewable Energy Source	Prices to be applied (US Dollars cent/kWh)
Hydroelectric generation facility	7.3
Wind energy generation facility	7.3
Geothermal energy generation facility	10.5
Biomass based generation facility (landfill gas included)	13.3
Solar power based generation facility	13.3

Source: Law on the Use of Renewable Energy Sources for Electricity Generation Purpose
https://www.resmigazete.gov.tr/eskiler/2011/01/20110108-3.htm

Figures

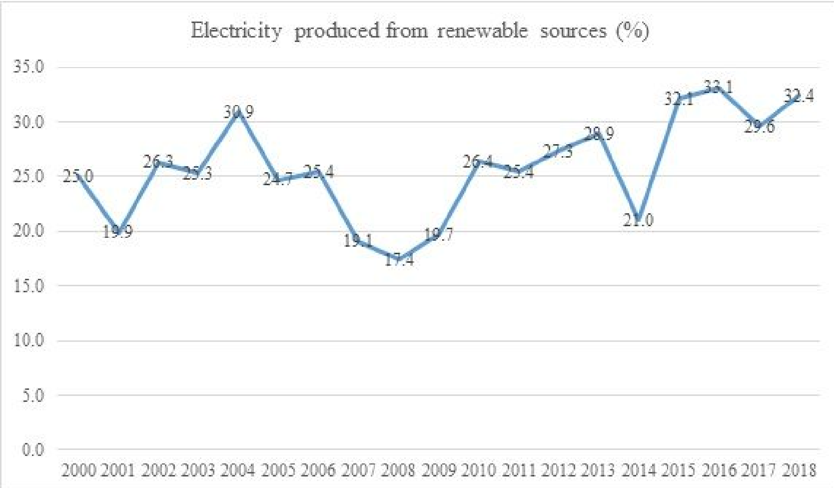

Figure 1

Electricity produced from renewable sources including hydropower, 2018 (%) Source: TurkStat.

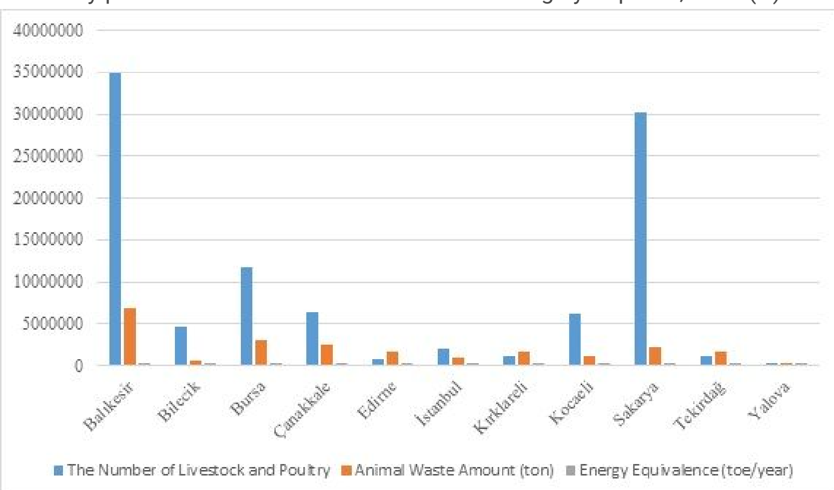

Figure 2

Animal wastes as biofuel sources and energy equivalents of cities in the region. Source: Ministry of Energy and Natural Resources General Directorate of Energy Affairs.

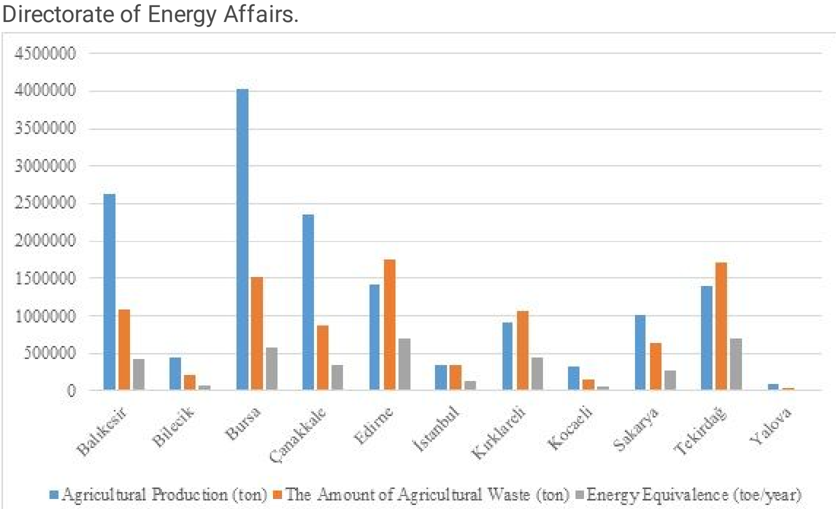

Figure 3

Agricultural wastes as biofuel sources and energy equivalents of cities in the region. Source: Ministry of Energy and Natural Resources General Directorate of Energy Affairs.