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Energy Recovery and Greenhouse Gas Emission Reduction Potential of Bio-Waste in the Mediterranean Region of Turkey

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Abstract: Continuous demand for global power generation has increased the attention on renewable energy sources. Biogas is one of the viable options for conversion of organic waste materials into green power and valuable products. In this study, the impact of biogas production from agricultural residues (wheat straw, barley straw, corn stover, cotton residue, olive residue, banana peel, sugarcane bagasse, tomato residue) and municipal solid waste (MSW) on reduction of greenhouse gas (GHG) emissions in Mediterranean Region of Turkey (Antalya, Burdur, Isparta, Mersin, Adana, Hatay, Osmaniye and Kahramanmaraş) has estimated. The results revealed that the Region has 1942.6 million m^3/year biogas production potential corresponding to 11.11 TWh energy generating capacity. Biogas generation in the Region has annual 27 million tons of CO_2 emission reduction potential to contribute 7.4 % reduction in total GHG emissions in Turkey. Bio-waste is a favorable renewable substitute to energy production from fossil fuels.

Keywords : Bio-waste, Renewable energy, GHG emission, Biogas, Waste management, Turkey

Türkiye'nin Akdeniz Bölgesinde Biyo-Atıklardan Enerji Kazanımı ve Sera Gazı Emisyonlarının Azaltım Potansiyeli

Öz: Küresel enerji üretimine yönelik sürekli talep yenilenebilir enerji kaynaklarına olan ilgiyi artırmıştır. Biyogaz, organik içerikli atık malzemelerin yeşil enerji ve değerli ürünlere dönüştürülmesi için uygun seçeneklerden birisidir. Bu çalışmada, tarımsal artıklar (buğday samanı, arpa samanı, mısır bitkisi artığı, pamuk küspesi, pirina, muz kabuğu, şeker kamışı küspesi, domates artıkları) ve belediye katı atıklarından (MSW) biyogaz üretiminin, sera gazı emisyonu azaltımına etkisi Türkiye'nin Akdeniz Bölgesi (Antalya, Burdur, Isparta, Mersin, Adana, Hatay, Osmaniye ve Kahramanmaraş) için tespit edilmiştir. Sonuçlar Bölge'nin 11.11 TWh enerji üretme kapasitesine karşılık gelen 1942.6 milyon m^3/yıl biyogaz üretim potansiyeline sahip olduğunu ortaya koymaktadır. Bölge'deki biyogaz üretimi, Türkiye'deki toplam sera gazı emisyonunu % 7,4 oranında azalmaya katkıda bulunacak olan yıllık 27 milyon ton CO_2 emisyonu azaltım potansiyeline sahiptir. Biyo-atıklar, fosil yakıtlardan elde edilen enerji üretimi için uygun bir yenilenebilir ikame kaynaktır.

Anahtar kelimeler: Biyo-atık, yenilenebilir enerji, sera gazı emisyonu, atık yönetimi, Türkiye.

1. Introduction

Concerns on depletion of fossil fuel reserves, increased greenhouse gas emissions and climate change initiated s series of measures on the global level. Priority has given to utilization of renewable energy sources and promoting energy efficiency efforts to reduce the carbon footprint of the energy generation. As being a candidate for European Union Membership and an energy importing country, Turkey needs a shift from fossil fuels towards renewable sources to contribute the collective efforts to combat climate change in line with its national circumstances and capabilities, for fulfilling the

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greenhouse gas emission reduction amendments according to The European Directive 2009/28/EC, Turkey's Intended Nationally Determined Contribution, The Tenth Development Plan of Turkey (2014-2018) and Energy Efficiency Strategy Paper of Turkey (2012-2023).

Anaerobic digestion is a core waste treatment technology that can be used to reduce and stabilize organic matter of waste materials in an oxygen-free medium with different metabolic steps generated by a consortium of bacteria and archaea while simultaneously producing an energy carrier called biogas [1-3]. Products of anaerobic digestion process generated from different metabolic steps produce energy sources (methane, hydrogen) for boilers, internal combustion engines, fuel cells [4,5]. The digestate is used as soil additive or organic fertilizer for enhancing agricultural crop production [6]. Common sources for biogas production are agricultural residues, livestock manure, municipal solid waste, and organic waste and waste water from different industries.

Biogas is a colorless and odorless gas that contains high percentage of methane (35–75%), carbon dioxide (25–65%), hydrogen (1–5%) with minor quantities of water vapor, ammonia, hydrogen sulfide and halides [7,8]. Biogas is one of the most favorable renewable energy options. It is a common bioenergy production route due to its robust design configurations serving for multiple purposes [9]. Among the renewable energy generation technologies such as hydro, solar and wind, biogas production from anaerobic digestion of biomass has the lowest unit production cost [10]. Furthermore, biomass is an abundant and readily available indigenous resource in Turkey and hence it is not subjected to uncertainties such as energy price fluctuations worldwide.

Biogas technology has great potential to reduce greenhouse gas emission and carbon footprint by mitigating carbon dioxide and methane release to the environment. The improper disposal of waste releases methane into the atmosphere which triggers global warming. According to standards developed by the Intergovernmental Panel on Climate Change (IPCC), methane has 21 times the global warming potential of carbon dioxide, and nitrous oxide has 310 times the warming potential of carbon dioxide over 100-year period [11]. Landfilling of waste is one of the highest methane emission sources [12]. Anaerobic digestion is advantageous over other waste disposal methods or direct burning of the bio-wastes in terms of emissions. Replacement of fossil fuels by biomass have shown additional reduction impact on greenhouse gas emissions [13]. Considerable amount of artificial fertilizer and irrigation water could be saved with the utilization of the digested biomass [14,15].

Estimation of biogas potential is of significant contribution for developing national energy policy actions for energy recovery from waste materials. In Turkey, agricultural activities and livestock farming have high contribution to economy. Turkey is one of the world's leading countries in agricultural production representing 6.1% of GDP in 2016. Rapid population growth and developments in agricultural sector generate large quantities of agro-industrial residues which are generally destined to landfill or remain in the fields after harvesting operations. Managing bio-waste is of great importance due its impact on pollution of air and underground water resources [16].

Proper waste to energy strategies could provide simultaneous benefits such as sustainable development of the sectors, protection of public and environmental health and generation of bioenergy [17-19]. Co-digestion technology is increasingly being applied for simultaneous treatment of various organic wastes [20].

In the view of all above mentioned advantages, lignocellulosic agro-residues and domestic waste which contain significant amount of organic matter should not be discarded but should be valorized as efficient substrates for biogas operations. Therefore, this study aims to determine the total yield of biogas from agricultural residues and MSW in the Mediterranean Region of Turkey to be used for renewable energy generation, greenhouse gas emission reduction and waste management. The results of this study could give insight to policy makers when implementing energy policy instruments considering biogas production from animal biomass as well as the companies interested in biogas investments in the region.

2. Materials and Methods

The region under consideration occupies the southern coast of Turkey, including Antalya, Burdur, Isparta, Mersin, Adana, Hatay, Osmaniye and Kahramanmaraş provinces. Antalya is the sixth largest city of Turkey in terms of land area. It located in the south-west coast of Turkey by the Mediterranean Sea. Antalya has significant contribution to the economy in terms of agricultural production and greenhouse activities due to its fertile lands and warm climate. Agricultural and livestock farming has high economic value in Burdur and Mersin provinces. Turkey is one of the important cotton producers in the world. Cotton production prevails especially in Adana and Hatay provinces. In Isparta, Kahramanmaraş and Osmaniye, agricultural activities and livestock farming have also considerable contribution to regional development. Availability of various feed stocks in the Region offers great potential for renewable energy production. Agricultural production rates in the Region are shown in Table 1. The data has collected from Turkish Statistical Institute [21].

Stability and biogas yield of anaerobic digestion process are influenced by many factors such as the type of feedstock, total solids ratio (TS), volatile solids ratio (VTS), the availability ratio and operating conditions. In Table 2, typical waste characteristics of the agro-residues are presented.

Table 1. Agricultural production in the region (2017) Production (ton/year) [21]

Province	Wheat	Barley	Corn	Cotton	Tomato	Sugar cane	Olive	Banana
Adana	690,411	12,025	1,265,097	329,841	111,091	11,898	31,055	1213
Antalya	239,971	180,733	268,325	53,801	2,530,129	138,461	74,135	109,668
Burdur	135,661	70,435	369,643	-	1,449,623	186,801	271	-
Hatay	256,607	5,511	186,458	520,737	84,883	-	147,194	3,900
Isparta	96,696	98875	96,015	-	29,414	124,550	79	-
Kahramanmaraş	423,729	58,159	541,513	62,943	6,070	431,448	11,338	-
Mersin	236,069	10,242	292,808	41,647	20,104	-	142,869	253,728
Osmaniye	162,730	12,487	469,043	1,340	35,835	-	64,564	-
Total	2,241,874	448,467	3,488,902	1,010,309	4,267,149	893158	471,505	368,509

Table 2. Characteristics of different waste materials available in Mediterranean Region.

Waste Type	pH	TS %	VTS %	TN %	C/N	Ref.
Wheat Straw	5.9	90.0	94.4	1.11	49	[22]
Barley Straw	7.87	90.5	94.3	0.99	NA	[23]
Corn Stover	7.22	91.8	78.9	1.0	40.8	[24]
Cotton Stalk	NA	91.1	88.1	1.02	45.1	[25]
Sugarcane Bagasse	NA	75.2	73.6	0.5	88.7	[26]
Olive Residue	5.9	53.7	95.3	1.4	44.7	[27]
Banana Peel	4.4	17.7	88.1	1.7	23.1	[28]
Tomato Residue	6.3	17.4	81.9	3.5	15.3	[29]
MSW	NA	29.4	20.9	0.82	59	[30]

TS: Total Solids, VTS: Total Volatile Solids, TN: Total Nitrogen,

3. Results and Discussion

3.1 Impact of Waste Characteristics

Anaerobic digestion is one of the complex processes to generate bioenergy from organic wastes. Biogas yield of anaerobic digestion process is influenced by the operating conditions as well as the waste characteristics. The optimized feedstock C/N ratio for anaerobic digestion is introduced as 20–30 [31]. As seen from Table 2, C/N ratio of agro residues are over the optimized range which implies the need for adjustment of nitrogen content to provide preferred C/N ratio during anaerobic digestion [32]. Carbon rich agro-residues can be used to compensate the carbon poverty in waste stock such as livestock manure which are hardly used as a single substrate in anaerobic digestion process due to their low rate of biodegradability [33]. pH value is another major parameter for efficient anaerobic digestion that optimum value is changing between 6.8 and 7.2 [34]. Nutrient content (nitrogen, phosphorus, sulfur, carbon, magnesium, sodium, manganese, cobalt, iron, zinc) of the feedstock is also significant for providing high microbial activity in the digestor [35]. From all mentioned above, co-digestion can be an effective route to form a synergy between livestock manure, agro-residues and MSW to enhance the efficiency of anaerobic digestion process and hence to increase the bio-methane yield.

3.2 Waste Potential

The potential of biogas from agricultural residues and MSW was calculated for all provinces of Mediterranean Region of Turkey. The amount of wet waste production from different waste materials in the region according to the data recorded in 2017 is shown in Table 3. The agricultural waste in the region occupies 34 % of the total waste potential from livestock manure, agro residues and MSW. However, high biodegradability and biogas conversion rate of agro-residues makes them favorable alternatives for biogas production. The agro-residues accumulates in Adana, Hatay, Antalya and Kahramanmaraş provinces due to high economic potential of agricultural activities.

Table 3. Annual waste production potential in Mediterranean Region [21].

Province	Agricultural Residue (ton/year)	Municipal Solid Waste (ton/year)
Adana	1,848,653.0	57,787.6
Antalya	1,019,671.1	65,019.1
Burdur	688,653.2	5,410.0
Hatay	886,340.7	39,082.0
Isparta	256,838.3	8,844.0
Kahramanmaraş	976,845.8	49,530.4
Mersin	641,128.1	10,806.7
Osmaniye	548,681.7	27,960.8
Total	6,866,811.9	264,440.5

3.3. Biogas potential

Each type of biomass has different properties and specific methane production capacity. Biogas generation potential from waste is calculated as follows:

$$B_P = M \times TS \times VTS \times A \times EB_{VTS} \quad (1)$$

where B_p denotes the theoretical potential of biogas (m^3/year),

M is the total amount of the manure produced for each city (kg/year)
TS, VTS represents the ratio of the total solids and volatile total solids of the animal manure, respectively, %,
A denotes the availability, %
EB_{VTS} is the quantity of estimated biogas produced per kg of the volatile total solids (m^3/kg VTS).

The annual biogas production potential from agro-residues and MSW in the region is 1,942.6 million m^3. Distribution of the total theoretical biogas potential among the provinces is presented in Figure 1. As seen from the figure, Adana province is obtained to have the highest biogas production potential followed by Kahramanmaraş, Antalya, Hatay, Burdur and Mersin. The biogas potential of the region mainly depends on agro-residues. This is due to both higher production amount and methane conversion yield of agro-residues with respect to MSW. MSW has highly variable composition which can significantly influence the biogas yield. Biogas potential of domestic waste inventory is obtained to be highest in Antalya due to its large land area and high human population.

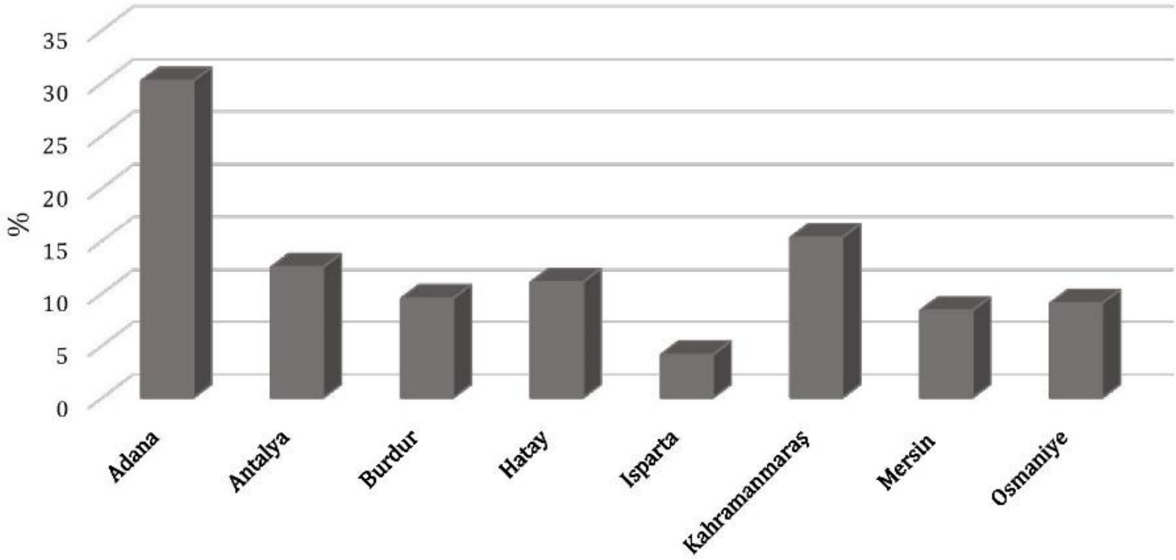

Figure 1. Distribution of biogas potential from agro residues and MSW in Mediterranean Region

3.3 Biogas Energy Potential

One of the main targets of the national energy policies in Turkey is to reduce the imported energy and to maximize utilization of renewable energy and energy efficiency improvements. In this respect, waste to energy conversion efforts is of great potential to contribute national goals. Biogas produced from different feedstock can be converted into electricity and heat through combined heat and power system, and connected to the electricity distribution system and district heating network.

The amount of energy produced from bio-methane (kWh) is calculated based on Equation 2;

$$E_M = B_p * M_p * E_{CH_4} \quad (2)$$

M_P represents the methane production ratio of biogas %

E_{CH4} is the energy content of methane (36 MJ/m^3 CH_4)

The results have revealed that the estimated annual energy potential from anaerobic digestion of biomass resources in the Mediterranean Region of Turkey is 11.11 TW_h. The share of bio-energy potential from livestock manure [17], agricultural residues and municipal solid waste is about 9.9 %, 89.0 %, and 1.1 %, respectively. The distribution of the energy potential among the provinces in the region is presented in Figure 2. As depicted from the figure, Adana province has shown the highest energy potential corresponding to 3.37 TW_h/year.

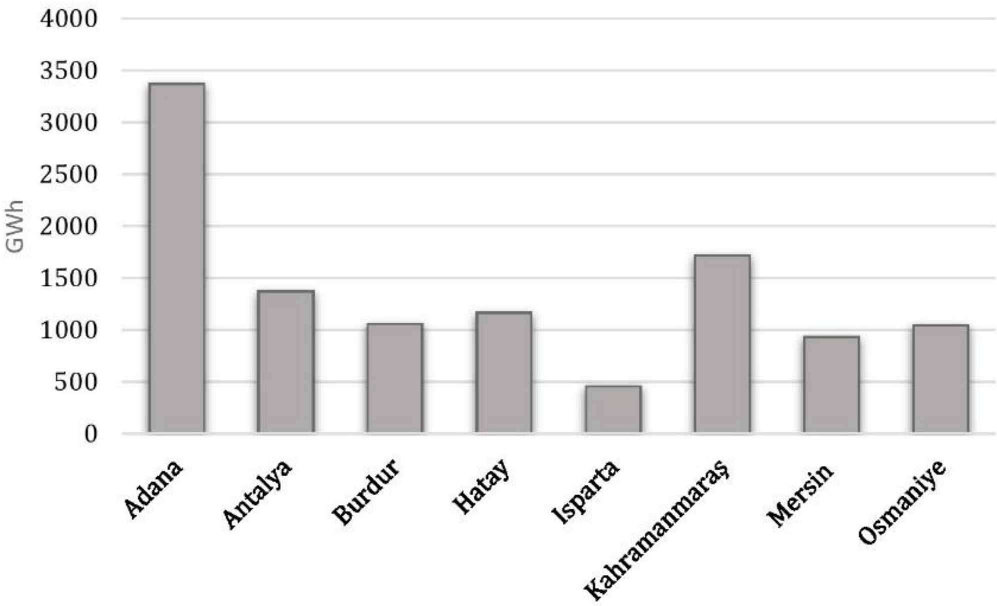

Figure 2. Energy Potential of Agro-residues and MSW in Mediterranean Region (GW_h).

3.4 Carbon Dioxide Gas Emission Reduction Potential

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), in order to keep global warming below 2°C, the maximum amount of greenhouse gases that can be emitted since the industrial revolution, in other words the carbon budget of the world is 2900 $GtCO_2$ and 65 % of this budget had already released until 2011 [36]. In 2013, Turkey's CO_2 emissions has reached to 363 $MtCO_2$ and it is projected to rise 659 $MtCO_2$ by 2030 under realistic growth scenario [37]. Hence, to ensure significant emission reductions, utilization of renewable sources is of great importance.

Potential savings of carbon dioxide emissions are estimated by considering the biogas production from anaerobic digestion process, biogas production and coal displacement. Total savings of greenhouse gas (GHG) emission from electricity generation from biogas on behalf of coal is obtained from the following equation [38];

$$GHG\ Savings = B_{CO2} + C_{e,CO2} - B_{e,CO2} \tag{3}$$

where B_{CO2} denotes the potential savings from direct CO_2 emission release by unprocessed bio-waste;
$C_{e,CO2}$ is the CO_2 emission savings from coal replacement with bio-waste;
$B_{e,CO2}$ represents the potential CO_2 emissions of biogas plant processing.

The results of this study revealed that carbon dioxide reduction potential of the region corresponds to 27 million tons of CO_2/year. The agricultural residue and MSW potential in Mediterranean Region can contribute to 7.4 % reduction in total GHG emissions in Turkey. The results of this study signify the huge impact of valorization of readily available bio-waste through anaerobic digestion process on climate change combat**.**

4. Conclusion

Anaerobic digestion of agricultural residues and municipal solid waste offer a promising route for efficient biogas production in line with environmentally friendly energy generation. This study has estimated a total of about 1,942.6 Mtons of biogas production corresponding to 11.11 TW_h per year of recoverable bio-energy potential in Mediterranean Region of Turkey. Small scale decentralized biogas production plants in the region will create potential to contribute waste management and energy production and also to create employment. Exploitation of this energy will also address climate change problem by reducing GHG emissions by 27 $MtCO_2$/year. The results of this study emphasize that Mediterranean Region of Turkey has considerable unexplored potential of biogas to be used for renewable power generation. Therefore, bioenergy sector should be fostered in the region.

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