Evaluation of energy potential for municipal solid waste in Turkey

İbrahim Halil Yılmaz[1,*], Aslı Abdulvahitoğlu[2], Mustafa Kılıç[2]

[1,*] Corresponding author, Department of Automotive Engineering, Adana Science and Technology University, Adana, Turkey
E-mail: iyilmaz@adanabtu.edu.tr; Tel.: +90 322 4550000; Fax: +90 322 4550009

[2]Department of Mechanical Engineering, Adana Science and Technology University, Adana, Turkey

Abstract
Energy recovery from municipal solid waste (MSW) can be performed in a variety of methods such as incineration, biochemical conversion or landfill gas (LFG). Some methods hold technical and economic challenges at the technological level and not proven at the commercial scale as well. In this study, the MSW generation in Turkey is projected from 2012 to 2023 based on the Malthusian theory of growth population, and MSW management is made for energy recovery as LFG collection. For this task, LandGEM tool is used, and the projections for the gas emissions are presented for each geographical region of Turkey. The results depict that about 1% of the energy deficit of the country would be met if all the MSW potential were put into practice by sanitary landfilling till 2023. The peak CO_2 emission is estimated to be 3.87 mtons while it corresponds to 355.5 mtons in the countrywide in 2012.

Keywords: energy recovery, landfill gas, LandGEM, municipal solid waste, Turkey

1. Purpose

Nowadays globally the world has come up with a serious waste problem; the reasons for this can be summarized as the rapid increase in the world population, the diversity of consumer goods and the change of consumption habits. In order to solve the waste problem effectively, the use of new technologies must be widespread all over the world. Since municipal solid wastes (MSWs) have significant economic value, wastes should be utilized as new energy sources.

The elimination of MSW, which is the final result of our vital activities, is an extremely important issue for sustainable development. MSW, known as garbage (including biomass materials such as paper, cardboard, food waste, metals, wood, etc), can be used to generate energy in waste to energy (WTE) plants and in landfills. The energy provided by MSWs has a great prospect especially in meeting the local energy needs. Incinerating the MSW to produce energy means that less waste is buried in a landfill. However, this will cause air pollution and release of chemicals and materials into the air. Some of these chemicals can be harmful to human health and environment. A good solid waste management is not only a takeaway model of solid wastes but also an economic resource to produce energy.

Today, different technologies are being developed for the evaluation of energy potentials while eliminating solid wastes, and efforts are being made to improve existing technologies. Landfills serve not only as waste repositories but also as significant sources of renewable energy. Landfills are the major source of CH_4 (methane) emissions, and implementing targeted waste management strategies, policies, and regulations can help to reduce CH_4 emissions from landfills or in capturing and using CH_4 for energy applications [1].

Turkey is an energy importing country. Since this import reaches up to 70% of its energy needs, Turkey obliges to evaluate new energy sources such as renewables. The current utilization rate of energy resources is very low in Turkey, which has a high potential of renewable energy sources such as biomass, hydraulics, wind, solar, geothermal etc. These renewable energies can cause to decrease the consumption of fossil fuels.

MSW activities in Turkey tend to be increasing trend. Nearly all the MSW is disposed of in dumpsites or landfills [2]. About one-third of the total MSW is still not being disposed of properly. The target is to increase the rate of the MSW facilities to be 100% landfill by the end of 2023 [3]. MSW is used in a variety of pathways for WTE production [4]. There are currently about 25 MSW plants in Turkey with an installed power capacity of 170 MW_e [5]. In most of the provinces of the country, there is a lack of MSW plant, but new facilities are in a phase of construction or planning. Hence projections on the energy production from MSW can be significant to determine the regional potentials.
The aim and distinctive of this study is to not only consider LFG production but also to quantify the energy production by using the MSW potential both in Turkey and its geographical regions. For this task, it is

considered the maximum technical potential of energy to be recovered from MSW as LFG. The Landfill Gas Emissions Model (LandGEM) was used for the estimation of LFG emission rates. Energy recovery through LFG is projected from 2012 to 2023 to analyze how many portions of the energy deficit of the country can be met by landfilling.

2. Methods

This study is based on the MSW data collected by Ministry of Environment and Urbanization of Turkey. Data on waste generation for 2012 were statistically made by the Turkish Statistical Institute (Turkstat) for each province of the country [2].

Turkey has 81 provinces under seven geographical regions with a population of about 76 million by the end of 2012. It is composed of seven geographical regions: Eastern Anatolia (EA), Southeastern Anatolia (SA), Black Sea (BS), Central Anatolia (CA), Mediterranean (MT), Aegean (A), and Marmara (M). The population density of the country and the regions are demonstrated in Fig. 1.

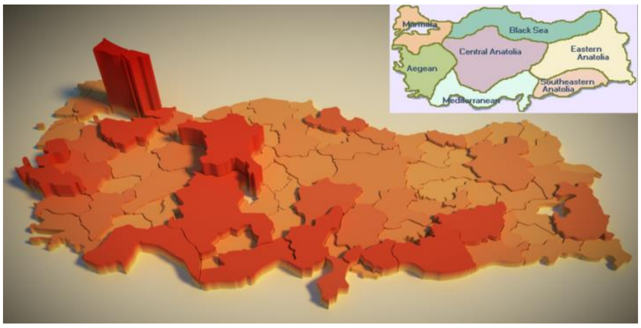

Fig 1 Population density in Turkey

2.1. MSW management in Turkey

In 2012, 25,642,290 tons of MSW (not including industrial waste) were collected in the country. Methods of disposal of this MSW are shown in Fig. 2. According to Turkstat 2012 data, waste generation per capita is calculated as 1.12 kg/day. In the last ten year, this amount stayed nearly constant. The number of landfill sites was increased about 4.5 times in 2012 relative to one decade ago but still, it is not sufficient. It is planned to renovate the residue of the disposal methods into sanitary landfilling until 2023.

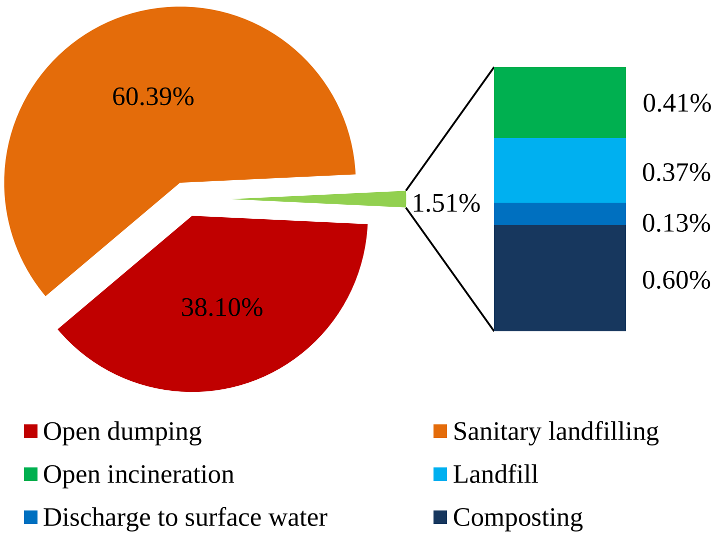

Fig. 2 MSW disposal methods in Turkey [2]

Waste characterization of Turkey was defined in the report of Solid Waste Master Plan [6]. Table 1 shows the waste composition of the country. According to the report, the trend of Turkey's historical waste characteristics indicates a slight increase in the ratio of paper and cardboard and a slight decrease in kitchen waste while the rest of the composition became nearly constant. It is evident that more than 50% of the MSW can be considered biodegradable.

Table 1 MSW characteristics of Turkey

Waste composition	Weight in %
Kitchen waste	34
Paper	11
Glass	6
Cardboard	5
Plastics	2
Metals	1
Other combustibles	22
Other non-combustibles	19

2.2. LFG emission model

The most reliable method for calculating the available LFG production is to open test wells and measure the LFG collected in these wells. The main weakness of this method is its cost. This method is very expensive, and also it can be applied only if there is enough waste in the storage area to produce LFG in large quantities. Although the test wells provide real data on the LFG production rates on the site at certain times, the mathematical model calculations reveal data on LFG production during storage on site and after shutdown. These models typically require data such as storage time, the amount of waste stored, and the characteristics of the waste. Many models have been developed for the determination of LFG in solid waste storage areas [7]. One such model is LandGEM developed by EPA [8]. The rate of formation of the CH_4 in the model is based on the first order deformation equation. The equation used in the model is as follows:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}} \tag{1}$$

where

Q_{CH_4} = annual methane generation in the year of the calculation (m^3/year)

i = 1 year time increment

n = (year of the calculation) − (initial year of waste acceptance)

j = 0.1 year time increment

k = methane generation rate ($year^{-1}$)

L_o = potential methane generation capacity (m^3/ton)

M_i = mass of waste accepted in the i^{th} year (ton)

t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

The production of CO_2 is calculated from CH_4 production using the equation,

$$Q_{CO_2} = Q_{CH_4} \left[\frac{1}{CH_4\,\%/100} - 1 \right] \tag{2}$$

LandGEM requires several model parameters; k, L_o, NMOC concentration, and CH_4 content, to predict landfill emissions. Table 2 indicates those former two parameters used for the regions. Other latter parameters were chosen using default options. LFG is assumed to include 50% CH_4 and 50% CO_2 with an additional constituent of NMOC. LandGEM considers the landfill type whether it is conventional or else arid area that receives less than 25 inches of rainfall per year. The weather conditions of landfill located areas were determined considering the conditions of the regions [9]. On the other hand, the values of k and L_o parameters were selected considering the primary factors affecting the CH_4 generation listed in [10].

Table 2 Operating parameters used in the simulation

Region	Landfill type	k year^{-1}	L_0 m^3/ton
EA	Arid area	0.02	100
SA	Arid area	0.02	100
BS	Conventional	0.04	100
CA	Arid area	0.02	100
MT	Conventional	0.04	100
A	Conventional	0.04	100
M	Conventional	0.04	100

2.3. Demography and MSW generation

In this study it is assumed to be the MSW acceptance of the landfill site between 2012 open year and 2023 closure year. The amounts of MSW accepted for each year depending upon the population growth. It should be noted that there is a direct relationship between MSW generation/energy consumption and population growth [11]. It is significant to estimate the population growth and the corresponding MSW generation in order to make a better projection for the targeted year of 2023. Fig. 3 shows the population projections for the country based on three different scenarios. The population change in the country is monitored by TurkStat, which uses the Malthusian theory of growth population for the projections.

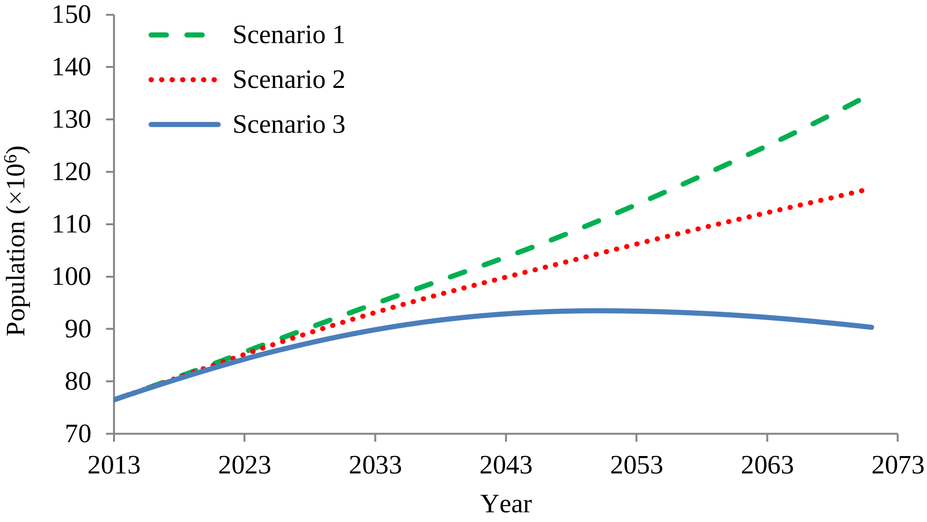

Fig. 3 Total population of Turkey by scenarios

Here, in Scenario 1, it is assumed that the total fertility rate increases to 3.0 in 2050, and then remains stable to 2075. In Scenario 2, it is assumed that the total fertility rate increases to 2.11 in 2020 and to 2.50 in 2050 gradually, and then remains stable between the years 2050 and 2075. In Scenario 3, it is assumed that the total fertility rate decreases in its natural flow and reached to its lowest value 1.65 in 2050, and then increases after this year and reached the value 1.85 in 2075. These three scenarios yield close projections until 2023. Scenario 3 is the basic scenario which was taken into consideration for the population projections in the analyses. The factor lying under the selection of this scenario is that the increment in the average age of Turkey's young population will result in reducing fertility rate at oncoming years.

MSW generation can vary based on different factors such as demography and socioeconomy. The accurate prediction of the MSW generation is challenging in developing countries [11]. In our study, a linear relationship is designated between the MSW generation and the population growth. Since the waste generation per capita has stayed nearly fixed in recent years as it is mentioned before. The mass of waste accepted in the i^{th} year is projected according to Eq. (2),

$$M_i = M_{i-1}\frac{P_i}{P_{i-1}} \tag{3}$$

where P_i is the estimated population at an i^{th} year, P_{i-1} is the population at the previous year.

Fig. 4 shows the variation of waste acceptance amounts and the trend of projections being obtained for each region. The projections are the results of the Malthusian based linear growth model.

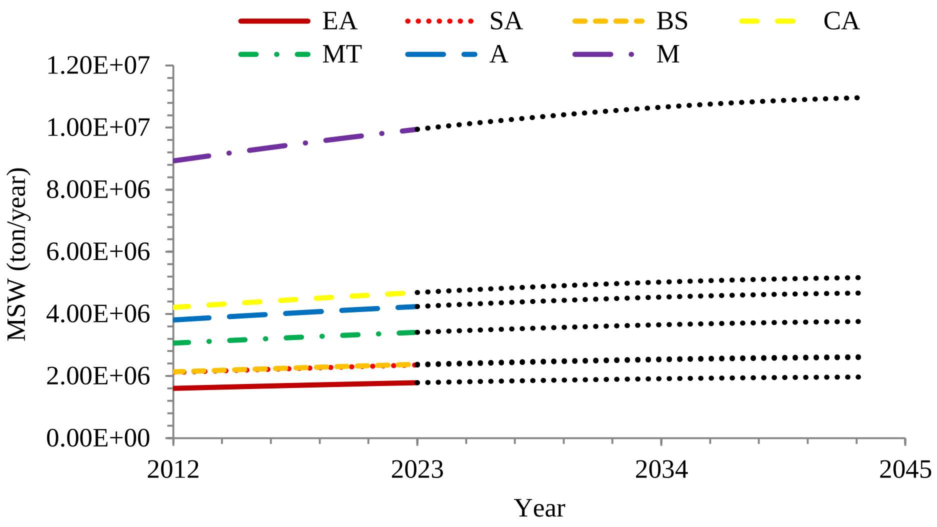

Fig. 4 MSW projections in the regions of Turkey

2.4. Energy recovery from LFG

The technical potential of the energy recovery can be estimated by burning CH_4 produced. The electricity from this potential can be produced using a WTE plant [12].

$$\text{Power} = Q_{CH_4} LHV_{CH_4} \eta_e \tag{4}$$

where LHV_{CH_4} is the lower heating value of CH_4 being equal to 50 MJ/kg, and η_e is the conversion efficiency of WTE plant that is considered to be 30% [13].

3. Results

Assessing the energy potential of landfilling is important at the country level. Emission estimates are presented in Fig. 5 to evaluate the technical potential of the entire country by landfilling. The question is that as the whole MSW is converted by landfilling into LFG how many portions of the energy deficit of the country can be met. The LFG can be used in a variety of way such as electricity production. The annual electricity consumption of Turkey in 2012 was around 205,632 GWh and forecasted to be 534,317 GWh in 2023 [11]. It is estimated that about 0.3% of the electricity consumption can be compensated by LFG collection at the end of 2013. This ratio increases to 1.02% according the electricity consumption of 2023 projection. It is seen from Fig. 5 that the peak value of CO_2 emission reaches to 3.87 mtons which correspond to a small part of the total CO_2 emission (355.5 mtons in 2012) of Turkey [2].

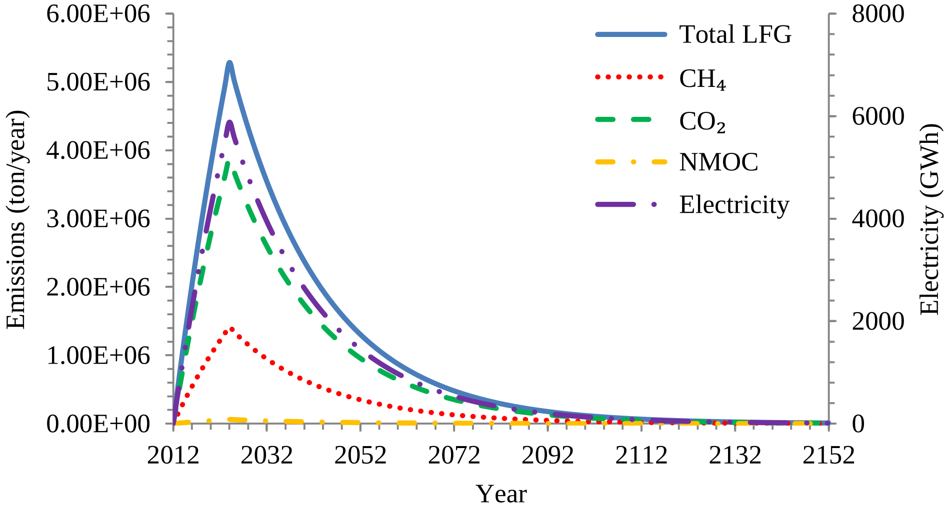

Fig. 5 LFG emissions per year

Fig. 6 illustrates the variation of regional electricity production. As it is expected, the Marmara region has the highest potential due to its population density. 30% of the population lives there where is the most industrialized region of Turkey. A great number of people in Turkey are living in the provinces where the industry is developed. For this reason, the MSW generated in these provinces is higher than those of others where there are no landfills. Currently there exist MSW landfills in 17 provinces. The Marmara region has currently a total installed capacity of around 63-MW. Its capacity can be increased up to 230 MW till 2023 according to the projections. The EA, SA, BS and especially the A region should have priority in landfilling construction since the technical potential of Turkey could reach 560 MW in 2023. 38.1% of this potential is used as open dumping by 2012 therefore renovations of new sanitary landfills are needed emergently.

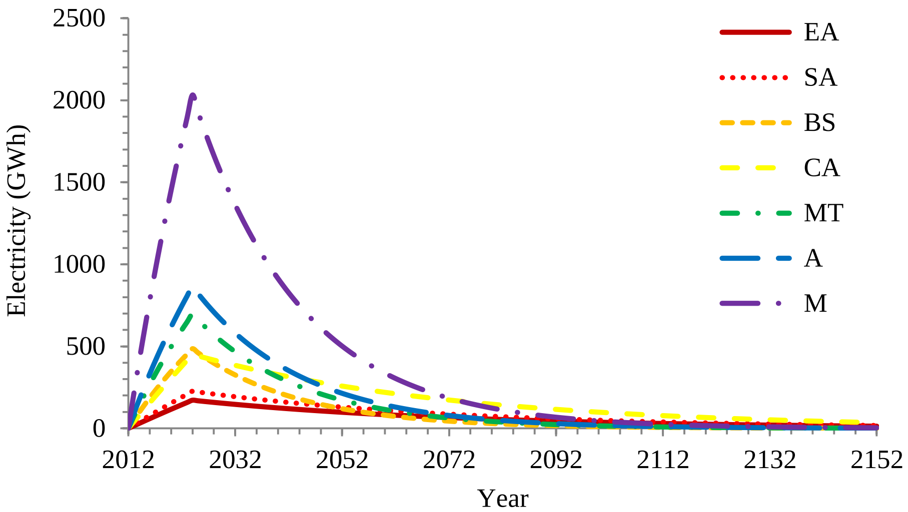

Fig. 6 Regional methane production per year

4. Conclusions

This study provides the MSW distribution in Turkey's geographical regions based on the 2012 data. Analyses of LFG potential have been made by using LandGEM tool. The methodology presented can provide guidance to decision makers in evaluating the potential energy production from MSW and the plants to be installed based on the projections.

Establishment of biogas plants from MSWs in countries like Turkey where the potential of the biodegradable matter is huge can provide a considerable amount of energy recovery. Providing sufficient incentives by the government for the energy, which is gained from renewable sources, will create new facilities to reduce energy deficit and create job opportunities for people. According to the projections, it is figured out that landfills would much serve as waste repositories rather than meeting the energy deficit of the country. However the number of landfills can be increased especially the provinces where the population growth is high and the industry is developing.

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