THE EVALUATION OF ENERGY POTENTIAL OF MUNICIPAL SOLID WASTE IN BITLIS

Emre GONEL[1*], Faruk ORAL[1], Rasim BEHÇET[2]

[1] *Bitlis Eren University, Department of Mechanical Engineering, Bitlis, Turkey*
[2] *Inonu University, Department of Mechanical Engineering, Malatya, Turkey*

ABSTRACT

Increasing energy demand with population and limited fossil based energy sources have caused an increase in energy costs. Utilizing renewable and clean energy sources can reduce energy costs and contribute to a country's economy. There are many these sources such as wind, solar, hydroelectric plants, municipal solid waste, etc. Municipal solid waste has a great potential in Turkey, as the amount of municipal solid waste has increased dramatically in last 10 years with population and technological advances. Nowadays, one of the most discussed topics is how to produce energy from municipal solid wastes. There are many methods and technological advances for managing municipal solid wastes and producing energy. The aim of this study is to investigate energy potential of municipal solid waste of Bitlis municipality. The union of Bitlis Province, Bitlis Province Districts and Sub-Districts Solid Waste Disposal Facilities Construction and Operation (Bİ-KA) was established in Bitlis by the decision of council of ministers on June 21, 2006 to collect, carry and dispose of the municipal solid wastes in Bitlis and its districts and sub-districts. A sanitary landfill was built for that purpose in Belektepe, in Tahtalı village, Güroymak district, Bitlis province by Bİ-KA in 2012. Bİ-KA and its members reached an agreement in January 2016 to expand their facility to generate electricity. The results indicate that there is great potential to produce energy from municipal solid wastes. It has been found that the plant would recover its investment in 5 years and then would profit $544265,00 for the next 5 years, and it would save 37701,83 m^3 tons of greenhouse gas emissions for 8 years.

Keyword : *Bitlis, Municipal Solid Waste, Electric Generation, and Waste to Energy*

1. INTRODUCTION

The population of the world is increasing by 1.18 per cent per year today, it was 7.35 billion in 2015. The United Nations, Department of Economic and Social Affairs, Population Division estimates that the population of the world will reach 8.5 billion in 2030, 9.725 billion in 2050, and 11.213 billion in 2100 [1]. In the last 10 years, population of Turkey has increased as well [2]. Municipal solid waste can be described as a renewable energy source [3]. In the literature, there have been numerous studies about producing electricity from solid wastes [4-8].

In Turkey, municipalities collect the wastes and store them in either uncontrolled landfill or controlled landfill sites. Uncontrolled landfilling is an old method to handle wastes. Basically, the wastes are carried from cities and stored there without any precautions. The uncontrolled landfill areas are dangerous for the environment and people. For instance, leachate is a fluid from landfills, which is generated from liquids present in the waste and external water, e.g. rainwater, percolating through the waste. The leachate can mix with the ground water.

On the other hand, controlled landfilling is a technologically advanced method to handle wastes [9,10]. There are many plants built in Turkey, especially in big cities, for managing municipal solid wastes. A sanitary landfill was built in 2012 by the union of Bitlis Province, Bitlis Province Districts and Sub-Districts Solid Waste Disposal

Facilities Construction and Operation (Bİ-KA). In the facility, anaerobic decomposition will be utilized to generate electric.

In this study, the capacity of Bitlis's municipal solid wastes are investigated, and electricity and energy production analyses are evaluated.

2. METHODOLOGY

2.1 Waste to Energy Technologies

One of the technologies to manage MSW is Waste-to-Energy technologies. In this method, energy is produced from MSW by combustion or products of inflammable fuels in shapes of methane, hydrogen, and other synthetic combustibles. Combustion, incineration, pyrolysis and gasification are the thermal conversion methods to produce energy. Other methods are biochemical conversion and landfilling [11]. In this study, biochemical conversion, also called anaerobic decomposition, is used to estimate energy production from municipal solid wastes.

2.2 Sanitary Landfilling

Controlled landfill sites are used in developed and developing countries. In this site, having an engineering plant is necessary. Detailed plans and properties, specific construction and every precaution are needed. Wastes are collected from urban and rural areas, then they are transferred to the landfilling site. First, recycling parts are removed from wastes, and the rest of wastes are weighted, compressed by garbage compactors on the pier and stored in landfilling area.

Wastes are kept in an oxygen free environment, so they can be putrefied. After a period of time, the site releases some gasses which contains a variety of gasses. The gasses are collected with perforated pipes. Methane is one of these gases. Then, the gas is burned in internal combustion engines which produce mechanical energy. It is converted into electrical energy via the alternator. Generated electricity's voltage is increased by transformers then transferred to the national grid transmission. The whole process is called the methane to electricity process. Figure 1 shows the basic elements of sanitary landfilling [12].

2.2.1 Anaerobic Decomposition

The landfill gas (LFG) can be generated with anaerobic decomposition in landfill sites. The typical range of LFG composition from MSW landfills is shown in the table below. (Table -1)

The landfill gas will be produced during the active operation lifetime of the landfill and will last for a considerably long time after the closure. Therefore, the issue of handling the gas shall be considered.

Table -1: Range of LFG composition from MSW landfills

Parameter	Unit	Range of variation
Methane	CH_4, %	30-65
Carbon dioxide	CO_2, %	20-40
Nitrogen	N_2, %	5-40
Oxygen	O_2, %	0-5
Argon	Ar, %	0-0,4
Hydrogen sulphide	H_2S, %	0-0,01
Total sulphate	S, %	0-0,01
Total chloride	Cl, %	0,005

Nowadays, one of the biggest problems in the world is global warming. The greenhouse gasses have a very dangerous impact for the environment. LFG are consisted of some of the greenhouse gasses such as methane, etc.

One solution could be to collect gases from the landfills and burn them in engines with releasing carbon dioxide (being approximately 23 times less as harmful than methane as a greenhouse gas) and at the same time have the possibility to exploit the landfill gas for energy production [13].

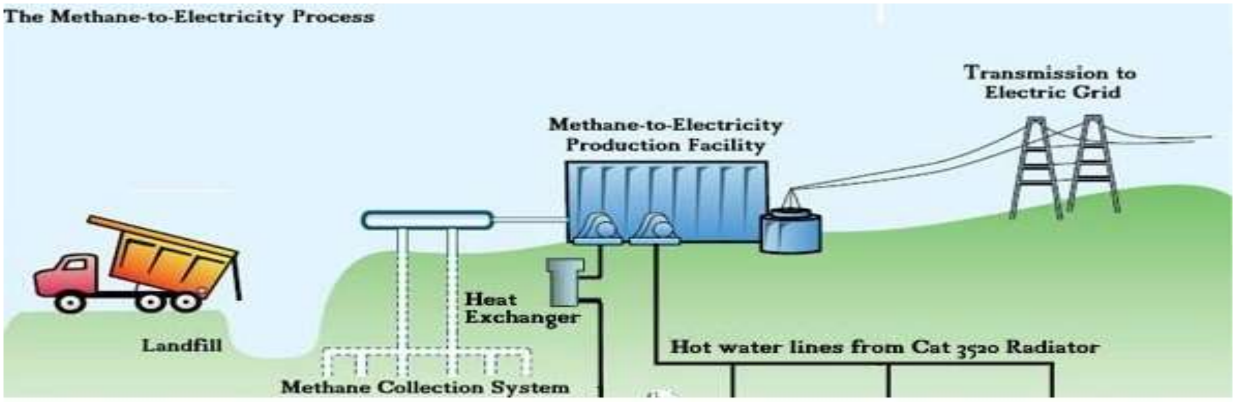

Fig -1: The Methane to Electricity Process [12]

3. RESULTS AND DISCUSSION

3.1 Municipal Solid Waste

Municipal solid waste (MSW) has a heterogeneous amount of wastes. The composition of wastes is very important for gas production. Bitlis's solid waste composition during winter season is 44,61 % food wastes, 9,69 % is plastic, 1,84 % is glass, 3,40 % is metal, 3,01% is paper and 30,43% is ash, and 10,43% is other incombustibles such as construction waste, etc.. The amount of ash is very high in winter season. Coil is consumed for heating in Bitlis from November to May. Amount of food and other recyclable wastes are expected to be higher in other months. However, there is not any survey available for the other months. According to the data obtained from Bİ-KA, the amount of municipal solid wastes which have been collected is shown in Table 2.

Table -2: Municipal waste collection

Years	Amount (tons)
2016	38312
2015	37249
2014	36054
2013	32199
2012	29094

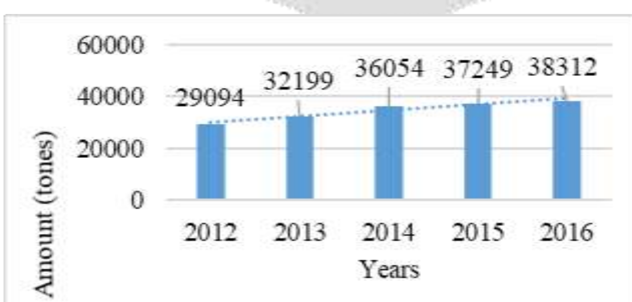

Chart-1. Municipal solid waste collection the years between 2012-2016

As it is seen in Chart-1, there is an increasing trend. According to the last five years' statistics, the next five years MSW amount can be estimated. There is a linear regression between years and amount of MSW collected in Bitlis. Using R, which is a statistic program, the estimated linear regression equation is shown in equation (1).

$$\text{Amount (year)} = -4695498{,}8 + 2348{,}6 \text{ x (year)} \quad (1)$$

R reports indicates that R^2 is 93,51 % and r (correlation coefficient) is 0,9134. The positive sign of r means the relationship is positive and the amount of wastes is increasing with each year. R^2 implies how close the data is fitted. Since R^2 is close to 100%, the relationship is strong.

Moreover, the next five years MSW amount is estimated with the regression equation. And, it is given on the table 3.

Table -3: Municipal solid waste estimation

Years	Amount (tons)
2021	51021,8
2020	48673,2
2019	46324,6
2018	43976,0
2017	41627,4

Food wastes are crucial for landfill gas production so food wastes are needed. The average percentage of food wastes might be higher during a year than 44,61 % but it is assumed to be 45% for the calculations. The food waste estimation is given in table 4.

Table -4: Estimation of food wastes

Years	Amount of food wastes (tons)
2021	22959,81
2020	21902,84
2019	20846,07
2018	19789,20
2017	18732,33
2016	17240
2015	16762
2014	16224
2013	14490
2012	13092

3.2 Gas production and electricity generation

3.2.1 Gas Production

Since the Bitlis sanitary site does not have an electric production system, useful gasses are released from the site. Therefore, an electric production system is needed. Wastes are collected from Bitlis province, Tatvan, Güroymak Mutki and Yolaçan districts and stored in the sanitary landfill site. Let's assume that food wastes have been stored in the sanitary landfilling area since 2012. From 2012 to 2016, the site approximately would have 77.808,6 tons of food wastes stored. In addition, from 2012 to 2021, the site would have 182.039,25 tons of food wastes. The table 5. shows the stored food wastes for 10 years.

Table -5. Food waste accumulation for 10 years

Years	Total amount of food wastes stored (tons)
2021	182038,25
2020	159078,44
2019	137175,6
2018	116329,53
2017	96540,33
2016	77808
2015	60568
2014	43806
2013	27582
2012	13092

Anaerobic decomposition is the key method to obtain methane gas from food wastes. The maximum amount of methane can be generated from the equation (2);

$$C_6H_{10}O_4 + 1.5H_2O \rightarrow 3.25CH_4 + 2.75CO_2 \quad (2)$$

In the equation (2), C6H10O4 is the molecular structure of the organic wastes, H_2O is water, CH_4 is methane, and CO_2 is carbon dioxide [14].

According to M. Melikoğlu, 94.0-123.0 m^3 of methane could be generated from the 1 ton waste in Turkey [15].

Approximate methane gas generation is shown in table 6.

Table -6: Methane gas generation (million m^3/year)

Years	Min	Max
2021	17,11	22,39
2020	14,953	19,57
2019	12,89	16,87
2018	10,93	14,3
2017	9,07	11,87
2016	7,31	9,57
2015	5,69	7,45
2014	4,11	5,39
2013	2,59	3,39
2012	1,23	1,61

In the first years, methane gas production would be low but with each year, it would increase. After wastes are landfilled, they can produce gas for up to 20-30 years [16].

3.2.2 Electricity generation

Electricity can be generated with using landfill gas in gas engines. The methane gas's calorific value is 10 kWh/m3. Electricity generation potential can be calculated with 25% capture rate, and 45% electric efficiency. The mathematical results are shown in table 7 and 8.

Table -7: Electricity generation potential (GWh)

Years	Min (GWh)	Max (GWh)
2021	19,25	25,19
2020	16,82	22,01
2019	14,51	18,98
2018	12,30	16,10

2017	10,21	13,36
2016	8,23	10,77
2015	6,41	8,38
2014	4,63	6,06
2013	2,92	3,82
2012	1,38	1,81

Table -8: Electricity capacity potential (kW)

Years	Min (GWh)	Max (GWh)
2021	2197,55	2875,52
2020	1920,38	2512,84
2019	1655,97	2166,86
2018	1404,32	1837,57
2017	1165,43	1524,97
2016	939,29	1229,07
2015	731,17	956,75
2014	528,82	691,97
2013	332,97	435,69
2012	158,05	206,80

3.3 Environmental Effects

According to the Intergovernmental Panel on Climate Change (IPCC), releasing 1 kg methane (CH_4) is equivalent to releasing 25 kg CO_2. And, it means that 1 kg methane equals to 25 kg CO_2 in terms of 100-year global warming potential [17].

Collecting methane gas can contribute to the economy and the environment.

With the environment aspect, methane gas would be collected and used in gas engines. In equation (3), using methane gas in gas engine would deplete the effect of methane gas on the environment.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (3)$$

Instead of releasing methane gas to the environment, burning it in gas engines releases CO_2 and water. With current technology, only 25% of the methane gas can be collected. Greenhouse gas emissions are calculated with the density of methane and CO_2 and the equation. The density of methane and CO_2 are 0,668 kg/m^3 and 1.842 kg/m^3. Table 9 shows approximate greenhouse gas emission savings for the next 10 years. Equation (4) shows how to calculate Greenhouse gas saving.

Greenhouse gas saving= (m^3 methane) x (0,25) x (density of methane)x (44 gr CO_2 / 16 gr CH_4) x (1 metric ton/1000) (4)

Table 9. Greenhouse gas emission savings (metric tons)

Years	Min	Max
2021	7858,50	10282,93
2020	6867,34	8985,98
2019	5921,80	7748,74
2018	5021,89	6571,19
2017	4167,60	5453,35
2016	3358,93	4395,20
2015	2614,69	3421,35

2014	1891,08	2474,50
2013	1190,70	1558,04
2012	565,18	739,54

3.4 Feasibility Calculations

In this study, I only consider the first 10 years for the feasibility studies. YEKDEM is the Republic of Turkey Energy Market Regulatory. The prices of electricity to be applied to the facilities in the list of YEKDEM are determined by the YEK Act and are 7,3 US cents / kWh for production plants based on hydroelectric and wind energy, 10,5 US cents / kWh for production facilities based on geothermal energy, and production facilities based on biomass and solar energy 13,3 US cent / kWh. Gas engine costs are the main installment in the study as well as the electricity selling prices.

3.4.1 Gas Engine

After the landfill gas is stored, a gas engine is needed to produce electricity from the gas. General Electric Jenbacher type gas engine is very useful for the landfill plants. This engine's capacity is 615 kW, and its life time is 60 000 hours. The maintenance period of this engine is every 2000 hours [18]. The second engine is the same and will be installed 2 years after the first one.

Table 8 shows that there wouldn't be enough gas in the end of 2013 to produce electricity. For that reason, the electricity production would start in 2014. It is also assumed that the plant will operate in full capacity with 8 hours per day in 2014 and 2015, and in 2016 the capacity will increase to 1030 kW. And, the capacity won't change until the end of 2021. The cost of the engine is $ 350 000,00, and the maintenance cost is 7 euros per hour of working time.

In Table 10., investment cost income and outcome are summarized. A loan of $350000,00 is with %1,19 of interest rate. It would be paid in 5 years. And the same loan would be gotten in 2016. The maintenance cost would be 21000,00 euros per year (equals to $25300,00).

The income for the plant will be electricity. The plan will operate 8 hours per day during a year. It will be expected to income $ 238841.40 per year for selling the electric.

Table -10: Feasibility calculation

Year	**Income**	**Outcome**		**Total**
		Bank	**Maintenance**	
2012	-	-104688,00	-	-104688,00
2013	-	-104688,00	-	-104688,00
2014	238841,40	-104688,00	-25300	108853,00
2015	238841,40	-104688,00	-25300	108853,00
2016	477682,80	-209376,00	-50600	217706,80
2017	477682,80	-104688,00	-50600	322394,80
2018	477682,80	-104688,00	-50600	322394,80
2019	477682,80	-104688,00	-50600	322394,80
2020	477682,80	-104688,00	-50600	322394,80
2021	477682,80	-	-50600	427082,80

4. CONCLUSIONS

One of the biggest problems for big cities is the increasing amount of solid wastes. This causes very serious environmental problems. For that reason, municipalities have very important responsibilities. To solve this problem, solid waste would need to be collected, stored and disposed of very carefully in sanitary landfilling sites. The results show that it is very feasible to install gas engines to produce energy. The plant can recover itself in 5 years after the installment. After the recovery, the plant from only one gas engine would profit $544265,00 for the next 5 years. It is estimated that it would be very economic to produce electricity. In addition, using this approach as specified in the landfill directive, the general emission of greenhouse gasses to the atmosphere is reduced. Furthermore, the surroundings are secured against the risk of fires and explosions. 37701,83 m^3 tons of greenhouse gas emissions would be saved for 8 years from 2014 to 2021.

5. REFERENCES

[1]. United Nations, Department of Economic and Social Affairs, Population Division, 2015. World Population Prospects: the 2015 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.241.

[2]. Turkish Statistical Institute. (2014)

[3]. U.S. EPA (U.S. Environmental Protection Agency). 2015b. Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures. Accessed July 2015.

[4]. Bidart C., Fröhling M., Schultmann, F. (2013). Municipal solid waste and production of substitute natural gas and electricity as energy alternatives, Applied Thermal Engineering 51 1107e1115

[5]. Behçet R., Gönel E., Oral F., (2016) Economic Contribution of Energy Potential from Municipal Solid Waste in Elazığ, UEMK 2016 Conference Proceedings, 2016:33-41.

[6]. Mustafa S. S., Mustafa S. S., Mutlag A. H. (2013). Kirkuk municipal waste to electrical energy, Electrical Power and Energy Systems 44, 506–513 RenewableandSustainableEnergyReviews 54. 809–815

[7]. Tozlu A., Özahi E., Abuşoğlu A. (2016). Waste to energy technologies for municipal solid waste management in Gaziantep

[8]. Scarlat N., Motola v., Dallemand J. F., Monforti-Ferrario F., Mofor L. (2015) Evaluation of energy potential of Municipal Solid Waste from African urban areas, Renewable and Sustainable Energy Reviews50. 1269–1286

[9]. Behçet R, İkılıç C., Oral F., (2014) Malatya İlinde Oluşan Evsel Katı Atıklardaki Enerji Potansiyeli, 2nd international symposium on environment and morality(ISEM 2014), Adıyaman University , Turkey

[10]. Aydoğan Ö, Vrank G, Bilgili M. S. (2011) Gaziantep il merkezi kentsel katı atık yönetimi, Mühendislik ve Fen Bilimleri Dergisi. pp.268-275.

[11]. Cheng, H., Hu, Y. (2010). Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China. Bioresource Technology 101, pp. 3816-1824.

[12]. The Northern Tier Solid Waste Authority, 2013 (http://www.ntswa.org/ntgAbout.php)

[13]. Themelis, N. J., & Ulloa, P. A. (2007). Methane generation in landfills. Renewable Energy, 32(7), 1243-1257.

[14]. Johari, A., Ahmed, S. I., Hashim, H., Alkali, H., & Ramli, M. (2012). Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. Renewable and Sustainable Energy Reviews, 16(5), 2907-2912.

[15]. Melikoglu, M. (2013). Vision 2023: assessing the feasibility of electricity and biogas production from municipal solid waste in Turkey. Renewable and Sustainable Energy Reviews, 19, 52-63.

[16]. U.S. EPA (U.S. Environmental Protection Agency). 2017. LFG Energy Project Development. Accessed July 2017.

[17]. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., Miller, H. L., Parry, M. (2007). Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, 2007. Climate change.

[18]. Topkapi Endustri Malları, 2017. Accessed July 2017.