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ESTIMATION OF METHANE GENERATION AND ENERGY POTENTIAL OF NIGDE LANDFILL SITE USING FIRST ORDER MATHEMATICAL MODELLING APPROACHES

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Keywords
Energy potential,
Landfill gas,
Methane generation,
Methane modelling.

Abstract

Methane content of landfill gas is approximately 50%. Methane has a significant calorific and economic value, rather than its greenhouse effect. Therefore, it is essentially important to estimate future LFG and methane production in terms of usage and management policies. More than a few models have been used to computerize prospective methane trends based on deposited waste characters and climatic information. This study aims to calculate LFG and methane production using different models. The model inputs were adopted from field measurements, waste characterization, meteorological information, and technical papers prepared by Conestoga-Rovers & Associates (CRA), Intergovernmental Panel on Climate Change (IPCC), and United States Environmental Protection Agency (EPA). This study indicates that the first order models have different outcomes for Niğde Landfill Site and the increase in methane generation potential value causes higher generation volumes of LFGs for the future. The maximum total LFG production is estimated as 600 million m^3 with a methane potential of 126 m^3/ton and total methane yield for the same method was calculated as 312.5 million m^3. This study also estimates the maximum electricity generation from LFG. The maximum electricity generation was estimated 6.9 million kWh for 2042.

NİĞDE DÜZENLİ DEPOLAMA ALANININ METAN ÜRETİMİ VE ENERJİ POTANSİYELİNİN BİRİNCİ DERECEDEN MATEMATİKSEL MODELLEME YAKLAŞIMLARI İLE TAHMİNLENMESİ

Anahtar Kelimeler
Enerji potansiyeli,
Düzenli depolama gazı,
Metan oluşumu,
Metan modellemesi.

Öz

Düzenli depolama gazlarının (DDG) yaklaşık %50'sini metan gazı oluşturmaktadır. Metanın sera etkisinden başka önemli ölçüde kalorifik ve ekonomik değeri vardır. Bu nedenle, gelecekteki DDG ve metan üretiminin kullanım ve yönetim politikaları açısından tahmin edilmesi önemlidir. Gelecekteki metan salınımlarını katı atık karakteristiklerine ve iklim bilgilerine göre hesaplamak için birden fazla model kullanılmıştır. Bu çalışmada, farklı modeller kullanılarak DDG ve metan üretiminin hesaplanması amaçlanmıştır. Model girdileri saha ölçümlerinden, atık karakterizasyonundan, meteorolojik bilgilerinden ve Conestoga-Rovers & Associates (CRA), Hükümetler arası İklim Değişikliği Paneli (IPCC) ve Amerika Birleşik Devletleri Çevre Koruma Ajansı (EPA) tarafından hazırlanan teknik dokümanlardan elde edilmiştir. Bu çalışma, birinci derece modellerinin Niğde Depolama Sahası için farklı sonuçlara sahip olduğunu ve metan üretimi potansiyel değerindeki artışın, gelecek için daha yüksek DDG oluşumuna neden olduğunu göstermektedir. Toplam maksimum DDG üretimi, 126 m^3/ton metan potansiyeli ile 600 milyon m^3 olarak tahmin edilmiştir ve aynı yöntem için toplam metan verimi 312,5 milyon m^3 olarak hesaplanmıştır. Bu çalışma aynı zamanda DDG'den elde edilecek maksimum elektrik üretimini de tahmin etmektedir. 2042 yılı için maksimum elektrik üretimi 6,9 milyon kWh olarak hesaplanmıştır.

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1. Introduction

The handling of municipal solid waste (MSW) in an open field has environmental effects and health risks. Today, controlled proper landfilling techniques have been used to minimize environmental concerns of solid wastes in most of the municipalities in Turkey. In any controlled landfill site, air pollution control can be done with gas collection system and water pollution control can be evaluated with leakage collection system in sanitary landfills (Christensen 2011). The sanitary landfills can be considered as bioreactors (Machado et al., 2009) and after biochemical reactions of organic wastes, landfill gases and water could be produced. In this bioreactor, also anaerobic degradation processes can be occurred. In the first step, substrates disintegrate into their monomers by hydrolysis, then these monomers are reduced to organic acids by bacteria and then degraded to acetic acids. Finally, methanogenic bacteria produce methane from acetic acids (El-Fadel and Leckie, 1997). About 50-60% methane can produced in landfill after biodegradation (Kiriş and Saltabaş, 2011).

As a means of environmental protection, landfill gases from sanitary landfills must be collected via gas collection systems. In sanitary landfills, produced landfill gases make a gas collection system obligatory for environmental protection. Methane can be considered as an environmental risk due to its greenhouse effect factor. According to the IPCC, the contribution of methane to the global climate change is 28 times higher than the contribution of carbon dioxide and from 1970 to 2009 the level of methane in atmosphere arises at a ratio of 25% (Thompson et al., 2009). According to the EPA 2002 data, 13% of total amount of global anthropogenic methane arises from landfill sites (Du et al., 2017). In 2010 the total value of methane is approximately 7 gigatons (Gt) and it is estimated that in 2020 the amount of methane will rise up to 8.6 Gt (Xin et al., 2016). Rather than its greenhouse effect potential, methane causes odor problems and also it is a flammable and explosive gas which causes management issues in a landfill site (Donovan et al., 2010). Another advantage of collecting gases from landfill sites is making use of the energy potential of methane. Methane from landfill has a high energy potential with the values between 1800-1900 kJ Nm^{-3} (Penteado et al., 2012). In order to decrease environmental impacts of methane from landfills, some methodologies have been used in Europe. With the Directive of EU in 1996, the member states have to decrease the organic contents of their MSWs before landfilling, therefore some members prefer to use mechanical biological treatment of solid waste before landfilling (Donovan et al., 2010). In many provinces in Turkey, electric energy generation from landfill gases is preferred as a technique for reducing the greenhouse effect of landfill gases and obtaining economic benefits.

As a result of its economic benefits and energy source, it is important to estimate the future amount of methane production from a landfill site. According to Ishii & Furuichi, (2013), there are two techniques of modelling landfill gases which are generated from landfill. The first modelling technique depends on direct measurement and remote sensing procedures. Second methane modelling technique from a landfill site is indirect modelling. According to this model type, the mathematical calculations are done based on biological reaction kinetics and reaction parameters in order to project methane production. The models in this category are classified among the reaction degrees chosen. In zero order models, the estimations are done irrespective of the age of the stored solid waste (Rajaram et al., 2011). Since zero order models do not reflect the real-life situations these models are not preferred due to high error rates. The first order model, which is the simplest mathematical model of organic decomposition, is recommended by IPCC and is also the central point of the USEPA estimations of the amount of methane productions (Bo-Feng et al., 2014). The second order models for methane production are another option, but they are not practical and their results are approximately similar with 1st order models and also they have exhausive workloads (Amini et al., 2012).

The study aims to estimate the total amount of methane that will be produced in the landfill site in the city of Niğde, Turkey. Indirect modelling techniques were applied in order to make a presentable estimation. TNO, Tabasarran and Rettenberger, Multiphase Model (Afvalzorg Model), and US EPA LandGEM first order models have been used for calculating future methane potential. Furthermore, the study aims to estimate the gross and net energy potentials of methane to be generated in the future.

2. Material and Methods

2.1. Study Area

The province of Niğde is located in the south-east of Central Anatolia Region and in the Cappadocia Region. Figure 1. shows the location of the city. The average annual precipitation of Niğde is 341.1 mm and the average annual temperature value is 11.2 °C (Turkish State Meteorological Service, 2017). The population distribution based on districts of Niğde can be seen in Table 1. (Turkish Statistical Institute, 2017).

Table 1. Population distribution of Niğde in 2016

District	Population
Merkez	216.695
Bor	61.178
Çiftlik	27.589
Altunhisar	13.350
Çamardı	12.773
Ulukışla	9.883

The Niğde Landfill site is located in the Hıdırlık district of the city. Before the construction of the landfill site, 850.000 m^2 area in Hıdırlık district was expropriated. The landfill site is 1500 m above the sea level. Niğde Solid Waste Association was established by local municipalities for collection and disposal of regional MSW. The landfill site started operating in 2014 and three lot areas were planned for three stages with a total lifetime of 28 years. Hereby, only one lot area is actively accepting MSW with the area of 25.000 m^2 and a lifetime of 8 years. The second lot area will start operating in 2022 for a period of 9 years. Thereafter, third stage will start in 2031 for an operation period of 11 years. Along with the MSW; medical wastes, sludge from wastewater treatment facilities, and slaughterhouse wastes are accepted. So far, a biogas generator has been used with a capacity of 800 kW. Also, a 1200 kW generator is planned to be used in second and third stages. Solid waste characterizations acquired from the municipality were analyzed based on seasonal variations of solid wastes (Table 2) Seasonal changes were accepted as 5 months for the summer period and 7 months for the winter period. The waste characterization was determined based on 4 measurements in summer and 4 measurements in winter during 2015-2016. The three of the measurements were analyzed from the samples that were collected from accepted MSW from places where the level of incomes were low, medium, and high. The last sample was taken from MSW collected from downtown. The daily load of the landfill site was accepted as 170 tons/day. As it can be seen in Table 2, the percentages of waste types were different according to seasonal conditions. For example, the percentage of ash increased in winter.

According to the data from Niğde Municipality, in 2014, the expected amount of annual solid waste was approximately 42.250 tons. Furthermore, the total amount of MSW was 102,848 metric tons (Turkish Statistical Institute, 2017) and 41% of them were stored in the landfill. Besides, National Waste Management and Action Plan 2023 implies that the amount of MSW will be increase with a rate of 23% between 2014 and 2023. Thus, there will be an increase in MSW for the following years. The data sets that include waste characterization and the amount of the MSW that accepted to landfill site obtained from the municipality were used for the estimations. There was a dramatic fall at the closing year because according to information obtained from municipality, the 3 lot will have a total capacity between 1.000.000 tons and 1.250.000 tons of solid waste. For the 3. lot a total capacity of 1.150.000 tons were preferred and therefore closing year had an annual estimated amount of 70.000 tons. In this set of materials, the expected minimum daily load was 150 tons and the maximum daily load was 300 tons (Table 3).

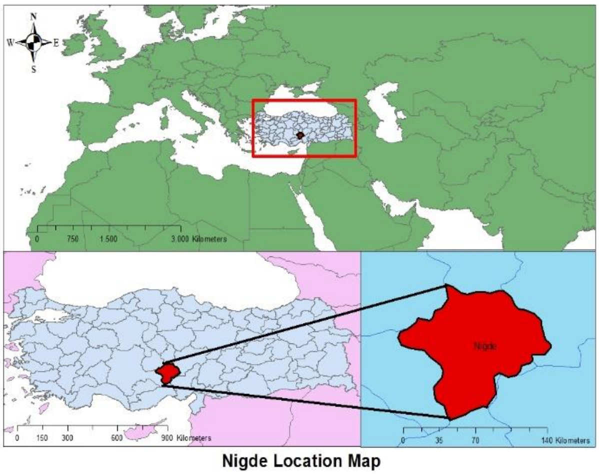

Figure 1. Location of Niğde city

Table 2. Solid Waste Composition in Niğde Landfill Site

Waste Type	Summer (%) (5 months)	Winter (%) (7 months)	Annual Average (%)
Organic Waste	78,18	43,32	60,75
Garden Waste	2,92	1,92	2,42
Paper	5,44	15,40	10,42
Plastic	5,24	9,42	7,33
Glass	2,09	5,41	3,75
Metal	0,00	4,66	2,33
Combustible	5,20	8,30	6,75
Ash	0,00	10,50	5,25
Other	0,97	1,03	1,00

Table 3. Predicted amount of waste in Niğde Landfill Site

Amount of Waste	
Year	Amount (ton/year)
2014	42.250
2015	62.000
2016	69.200
2017-2022	72.000
2023-2031	90.000
2031-2041	108.000
2042	70.000

2.2. Description of the LFG Models

TNO model was ideated by Oonk and Boom in 1995 (Oonk, 2010). This model estimates methane production based on first order biochemical decomposition of organic carbon in solid waste. It assumes that landfill gases occur exponentially by microbial degradation. The mathematical formula of TNO model is (Das et al., 2016) Eq. 1;

$$\alpha_t = \varsigma c A C_0 k_1 e^{-k_1 t} \quad (1)$$

For the landfills that have basic and optimal conditions, Tabasaran & Rettenberg first order model is useful in order to assess methane generation. Eq. 2. shows the mathematical description of this model (Işın, 2012):

$$G_t = c\, C_{org}(0.014T + 0.28)(1 - 10^{-kt})M_t \quad (2)$$

The Afvalzorg-model (Multi-phase model) was created by NV Afvalzorg Holding in the Netherlands. The distinguished part of this model is that it combines both literature obtained from IPCC and side specific data obtained from landfill sides at Nauerna, Braambergen and Wieringermeer (Afvalzorg Holding, 2015). Furthermore, the typical degradation rates (fast, moderate, and slow degradations) of wastes can be considered in this mathematical model (Scharff and Jacobs, 2006) Eq. 3:

$$\alpha_t = \varsigma \sum_{i=1}^{3} c\, AC_{0,i} k_{1,i} e^{-k_{1,i} t} \quad (3)$$

LandGEM model, which is also a first order model, was developed by USEPA and used for projecting methane generation in a specific landfill. Rather than other models explained above, this model uses the methane generation potential of solid waste instead of organic carbon in solid waste (Das et al. 2016). Mathematical formulation of LandGEM can be seen in Eq. 4 (USEPA, 2017)

$$Q_{Methane} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k\, L_o \left(\frac{M_i}{10}\right)\left(e_{ij}^{-kt}\right) \quad (4)$$

2.3. Estimation of Model Inputs

Three different methodologies were studied to determine the methane generation potential. First, LFG generation assessment guidelines prepared by CRA for British Colombia Ministry of environment was followed. According to this set of material, L_0 value of MSW was estimated through waste characterization and decomposability of the waste fractions. According to Conestoga-Rovers & Associates, (2009), methane generation potentials for decomposable, moderately decomposable, and inert MSW are respectively 160, 120, and 20 m^3 methane per ton MSW. The weighted averages of waste compositions were calculated so as to identify the waste category and possible methane generation potential of MSW (CRA method). The methodology adopted from Sarptaş, (2016) and estimations showed in Table 4. According to the estimation the CRA ID category of the waste was 2,43 which was showed that the MSW is highly decomposiable. A k value of 0,049 was estimated for three models except Multi-Phase model based on the methodology from Sarptaş (2016) and CRA.

Second methodology was adapted from IPCC, (2006). According to this default method (IPCC method), the methane generation capacity was calculated based on the decomposable degradable organic carbon values and moisture the contents of the waste compositions. The data for water content and DOC proposed values and were obtained from IPCC, (2006). Methane correction factor was selected as 0.6. This value was suggested by IPCC guidelines for uncategorized landfills. Eq. 7 shows the calculation of DOC_f value and this calculation was adapted from Tabasaran & Rettenberg model. Temperature was selected as 25 °C based on field measurements. According to the field measurements the methane volume of LFG was approximately 52%.

Table 4. Model inputs based on CRA method

Waste Type	Annual Mean	CRA Category	Lo (m3/ton)	Lo	Weighted Sum of CRA Category
Organic Waste	60,75%	3	160	97,2	1,8225
Garden Waste	2,42%	3	160	3,872	0,0726
Paper	10,42%	2	120	12,504	0,2084
Plastic	7,33%	1	20	1,466	0,0733
Glass	3,75%	1	20	0,75	0,0375
Metal	2,33%	1	20	0,466	0,0233
Combustible	6,75%	2	120	8,1	0,135
Ash	5,25%	1	20	1,05	0,0525
Other	1,00%	1	20	0,2	0,01
			Total	125,608	2,4351

$$DDOC_m = DOC.DOC_f.MCF \quad (5)$$

$$DDOC_m = MCF.\sum_{i=1}^{n} DOC_i\,.FR_i.DOC_{fi} \quad (6)$$

$$DOC_f = 0.014.T°C + 0.28 \quad (7)$$
$$L_o = \frac{DDOC_m.F_{CH_4}.16/12}{qCH4.(1+w)} \quad (8)$$

For the purpose of estimating L_0, the final method was applied from Machado et al. (2009) (EPA method). In this method, L_0 is estimated from stoichiometric calculations that are obtained from biodegradable fraction of waste composition. The biodegradable fraction and the methane yield potentials for each waste categories (C_m times BF as methane yield (Machado et al., 2009) are collected from Staley and Barlaz, (2009), for this method. The water content (w) data was used for both EPA method and IPCC method and was obtained from IPCC, (2006).

$$BF_w = \sum_{i=1}^{n} BF_i \ . FR_i \quad (9)$$
$$C_m = \frac{\sum_{i=1}^{n} BF_i .FR_i \ .C_{mi}}{BF_w} \quad (10)$$
$$L_0 = \frac{BF_w \ .C_m}{1+w} \quad (11)$$
$$L_0 = C_{org} \text{ x } 0.93 \quad (12)$$

The conjectural organic carbon amount in solid waste can be estimated according to the methane generation potential as indicated by Scharff and Jacobs, (2006), and shown in Eq. 12. The LFG generation rate constant of Niğde landfill site was estimated based on waste fractions and the climatic characteristics of the city as proposed in IPCC, (2006). For TNO, Tabasaran & Rettenberg, and LandGem models, the LFG generation rate constant was estimated as 0.049 year^{-1}. For Multi-phase model, the rate constant values for fast, moderate and slow degradation were selected as 0.07, 0.05, and 0.03 year^{-1} respectively. Table 5 summarizes the model inputs for each model and test runs. Reaction rate constant value can range from 0.005 to 0.4 year^{-1} based on IPCC, (2006). According to Amini et al. (2012), the minimum L_o is13 m^{3}CH$_4$ ton^{-1} MSW and the maximum L_o is 170 m^{3}CH$_4$ ton^{-1} MSW. For estimating the average annual electricity production from collected LFG is shown in Eq. 13 (Broun and Sattler, 2016). In this formulation the catalytic value of carbon dioxide is not taken into account. The LHV value of LFG was adopted from Rajaram et al. (2011), as 18.52 MJ m^{-3}. The HR value ranged from 9.5 to 12.5 kwh MJ^{-1} and was selected as 9.5 kwh MJ^{-1}. The PL value and AF values were suggested as 0.06 and 0.9 (Broun and Sattler, 2016).

$$AE = CLB \ x \ LHV \ x \ 1/HR \ x(1 - PL)x \ AF \quad (13)$$

Table 5. Parameters for Each Model

Model	Input	EPA Method	IPCC Method	CRA Method
TNO and Tabasaran Rettenberg	k	0,049	0,049	0,049
	Co	73	29	135
	ς	0,58	0,58	0,58
	c	1,87	1,87	1,87
	T	25	25	25
Multi-Phase (Alfvarzorg)	k_{slow}/	0,03	0,03	0,03
	$k_{moderate}$	0,05	0,05	0,05
	k_{fast}	0,07	0,07	0,07
	Co	73	29	135
	ς (-)	0,58	0,58	0,58
	c	1,87	1,87	1,87
	T	25	25	25
LandGEM	k	0,049	0,049	0,049
	Lo	68	27	126
	T	25	25	25

3. Results

3.1. LFG Estimations

There were huge differences of methane generation potential values among three different methodologies. The basis of the CRA method was characterized by impact factors according to the organic and inorganic contents of the MSW. For example, food and garden wastes had an impact factor of 3 because their potential of producing methane was greater than other solid waste type. On the other hand, inorganic wastes such as ash and metal had an impact factor of 1. The moderate level of decomposition was identified by an impact factor of 2. The organic content of Niğde MSW is high so that the highest $L_o(C_o)$ values were calculated in this method. The main advantage of this method was that the model parameters were specified for waste composition rates along with diverse precipitation and climatic characteristics (Conestoga-Rovers & Associates, 2011).

The lowest $L_o(C_o)$ were estimated from IPCC method. DOC_f value was related to the anaerobic conditions therefore this parameter was sensitive to the ambient conditions such as pH, temperature, and moisture. Also, this parameter was similar to the BF parameter used in EPA method based on sensibility(Machado et al. 2009). According to Machado et al. (2009), the values of $L_o(C_o)$, were significantly different between the estimations of $L_o(C_o)$ done by adopted parameters and the estimations of $L_o(C_o)$ done by measured parameters from laboratory results for both EPA and IPCC methods. Furthermore, a similar study was done by Işın (2012) for İzmir Harmandalı Landfill Site. The $L_o(C_o)$ values were estimated from literature adaptations. L_o values were estimated 57 m^3 ton^{-1}and 32 m^3 ton^{-1} for EPA and IPCC methods respectively. If laboratory and analytical methods are not used, the CRA method can be proposed for saving time instead of literature acceptance according to the other two methods. When analytical methods cannot be used, the CRA method could be preferred for saving time instead of reviewing of literature.

Figure 2 shows the methane generation with the highest adopted L_o that was advised by CRA. It can also be considered as a good case scenario. According to this method lowest methane volume was calculated with the TNO model. The highest values for methane volume were obtained from Tabasaran & Rettenberg model until the closure year. After that year, LandGem model methane volume results are much more than other model types after closure year. Table 6 also shows the results of mathematical models with different L_o values. According to CRA method results, the total LFG potential is 601 million m^3 as estimated from LandGEM model. The peak methane generation year was estimated as 2042 for all models except Tabasaran & Rettenberg model. The Multi-Phase model which calculates the degradation of organic matter based on decomposition rates, had moderate results.

Figure 3 shows the results when EPA method's L_o value is calculated from chemical reaction of decomposition of organic matter. The figure shows a similar pattern with Figure 2. but the methane volume values are lower than the first method. The lowest L_o value was adopted from IPCC, (2006), guidelines and all of four models have the lowest outcomes in this methodology and this situation can be accepted as the worst case scenario. A similar study was done by Işın, (2012) for another landfill site in İzmir, Turkey. According to this study, the maximum methane production for İzmir landfill site was 30 million m^3 based on LandGem models. Nigde landfill site may have 8.93 million m^3 methane gas in 2041 according to Tabasaran & Rettenberg model for L_o equial to 68 m^3 ton^{-1}. When the results of İzmir and Niğde were compared, the value of Lo was higher in Niğde than in İzmir. The main reason was the organic load of Niğde MSW is higher than İzmir's due to the fact that the socioeconomic gap between two cities. The reason for the higher production of landfill gas in İzmir could be the amount of landfilled waste in İzmir is higher than the amount of landfilled waste in Niğde.

A similar study was accomplished by Amini et al. (2012) and according to their study, approximately three landfill sites had the highest methane volume that was estimated as approximately 33 million m^3.

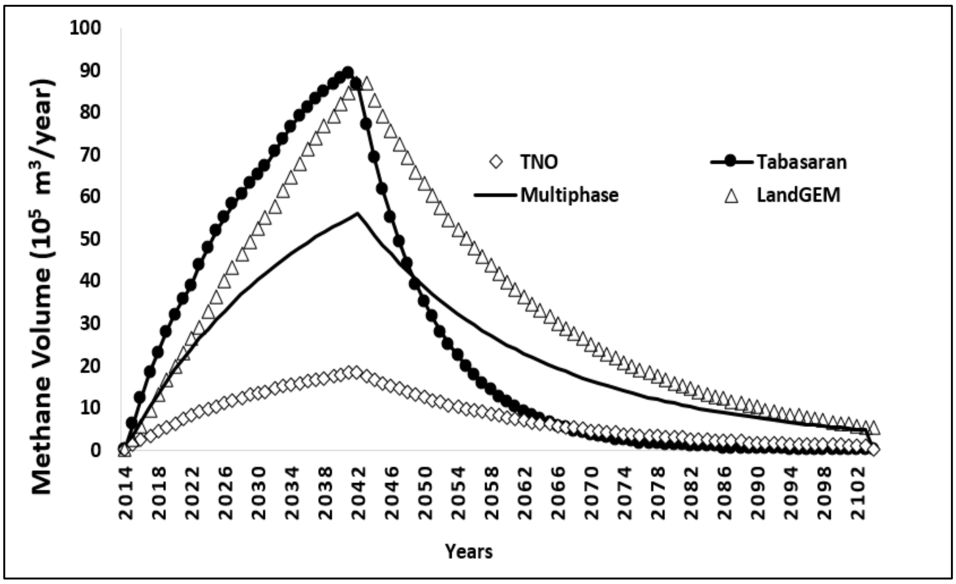

Figure 2. Methane Generation Obtained by CRA Method

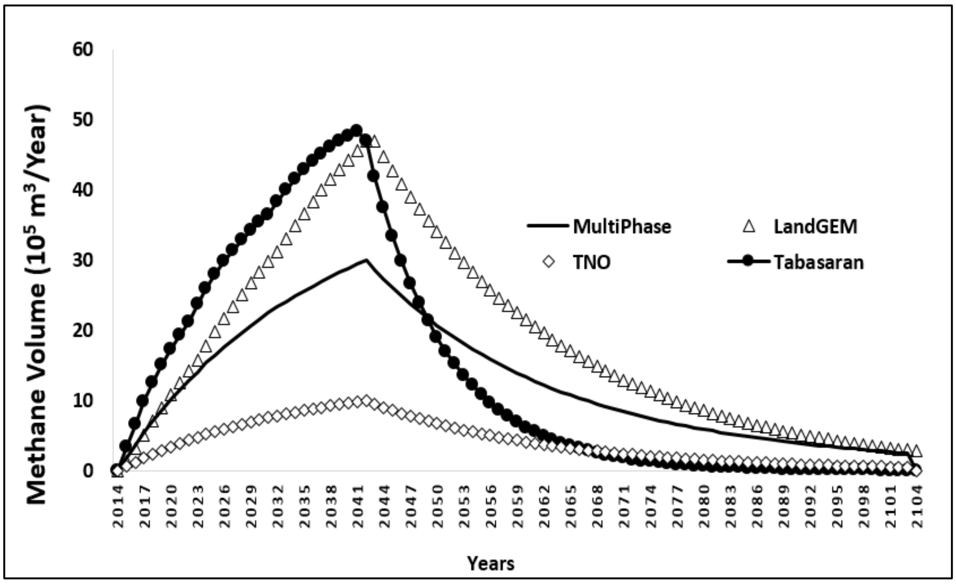

Figure 3. Methane generation obtained by EPA method

Table 6 shows the methane reserve after the year 2042. It is important to note that there will be a methane potential between 31% to 60% after depositing municipal wastes. A study for İzmir Landfill site was concluded remaining methane potential as 74 % after closure of the site (Sarptaş, 2016). Figure 4. shows the results based on IPCC method. According to this method, the maximum methane production will be seen between 2041 and 2044. Figure 5 shows the methane production for each of the used and planned lot areas. The maximum methane volume will be available during and after the operation of the third lot. When all lots were inspected separately, Tabasaran & Rettenberg model showed higher gas volume results than other estimations.

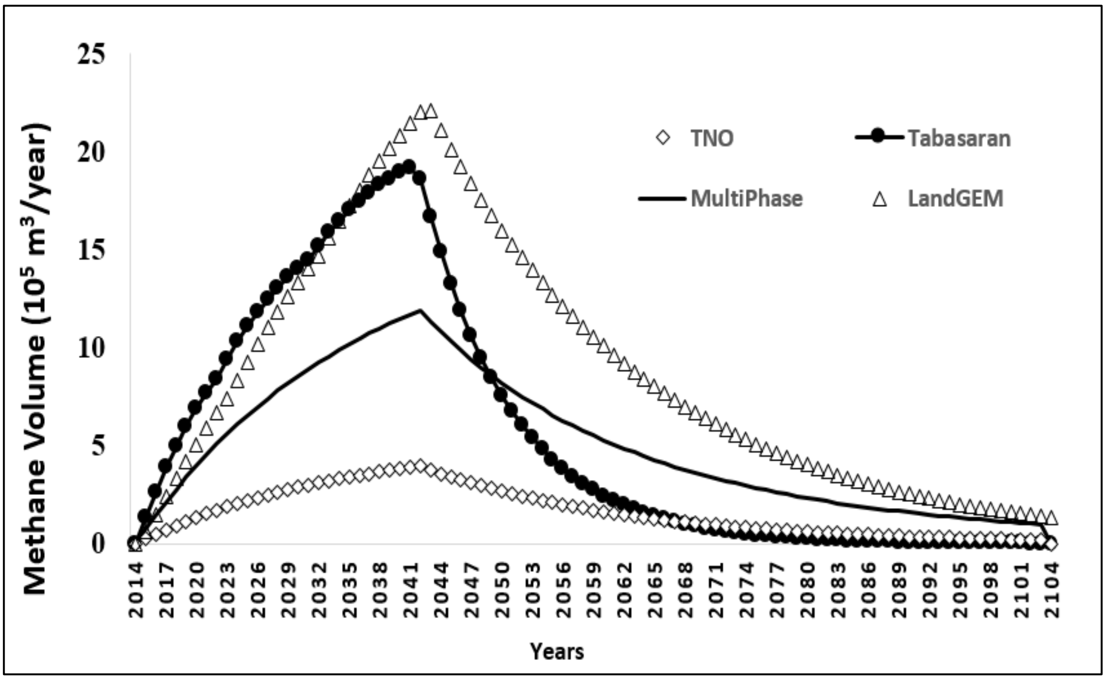

Figure 4. Methane generation obtained by IPCC method

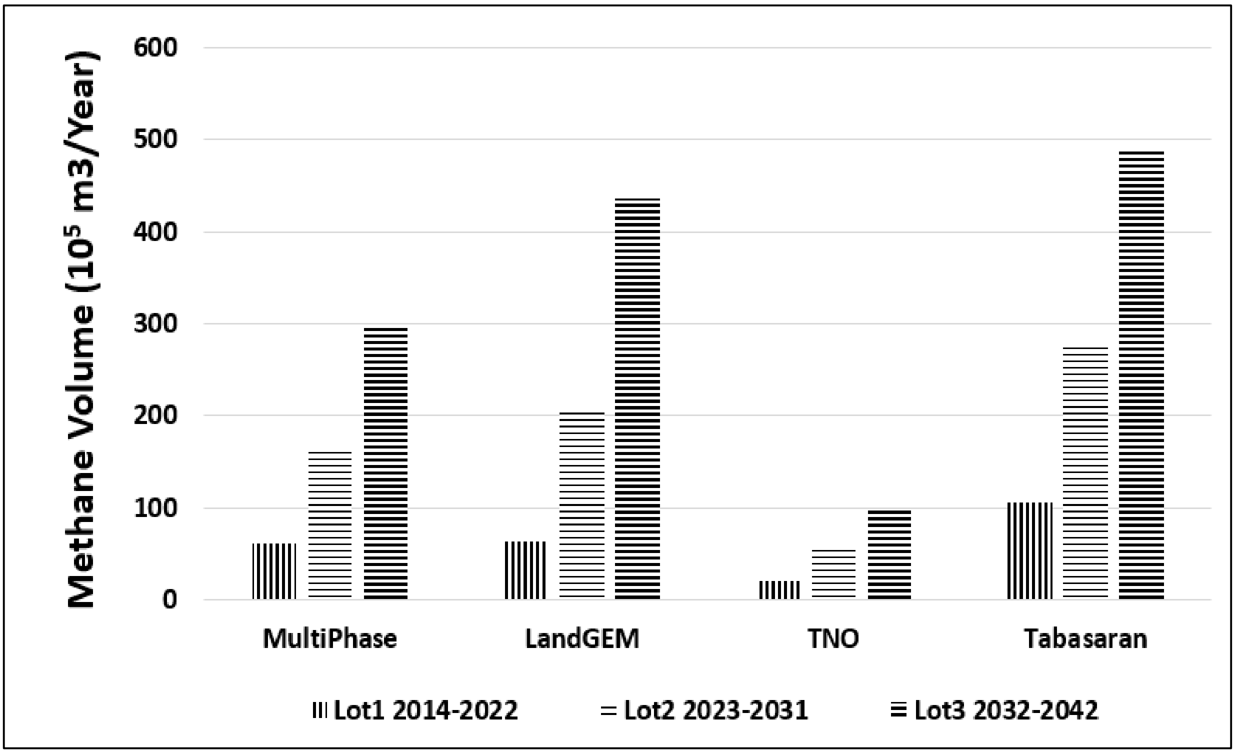

Figure 5. Methane production by lots obtained by EPA method

Table 6. Results of Models with different L_o values

First Order Model (TNO)					
Method	Methane Generation Potential(m^3 ton^{-1})	Total LFG Yield(million m^3)	Total Methane Yield (million m^3)	Maximum Methane Generation (million m^3)	Methane Reserve After Closure Year
CRA	126	129.25	67.21	184.1 (in 2042)	51.78%
EPA	68	69.90	36.35	1.00 (in 2042)	
IPCC	27	27.77	14.44	0.4 (in 2042)	
Tabasaran & Rettenberg Model					
Method	Methane Generation Potential (m^3 ton^{-1})	Total LFG Yield (million m^3)	Total Methane Yield (million m^3)	Maximum Methane Generation (million m^3)	Methane Reserve After Closure Year
CRA	126	467.83	243.27	8.93 (in 2041)	31.08%
EPA	68	242.58	126.14	4.83 (2041)	
IPCC	27	96.37	50.11	1.92 (in 2041)	
Multi-Phase (Afvalzorg) Model					
Method	Methane Generation Potential (m^3 ton^{-1})	Total LFG Yield (million m^3)	Total Methane Yield (million m^3)	Maximum Methane Generation (million m^3)	Methane Reserve After Closure Year
CRA	126	412.31	214.4	5.59 (in 2042)	54.45%
EPA	68	220.65	114.74	2.99 (2042)	
IPCC	27	87.65	45.58	1.189 (in 2042)	
LandGEM Model					
Method	Methane Generation Potential (m^3 ton^{-1})	Total LFG Yield (million m^3)	Total Methane Yield (million m^3)	Maximum Methane Generation (million m^3)	Methane Reserve After Closure Year
CRA	126	600.92	312.48	8.68 (in 2042)	58.18%
EPA	68	324.67	168.83	4.68 (2042)	
IPCC	27	152.79	79.45	2.21 (in 2042)	

3.2. Electricity Generation Estimations

The electricity generation results were estimated based on Multiphase Model with the parameters estimated from CRA method. The gas collection efficiency was suggested 75% (Sarptaş, 2016). The maximum electricity generation was in 2042 with an annual production of 6.9 million kWh. According to the estimations done by Sarptaş, (2016) The maximum energy generation for İzmir Harmandalı Landfill Site was estimated 223 million kWh. It was suggested that the energy production will continue for 30 years Uisung et al., (2017) and Figure 6 shows the annual energy generation for the years between 2042-2072.

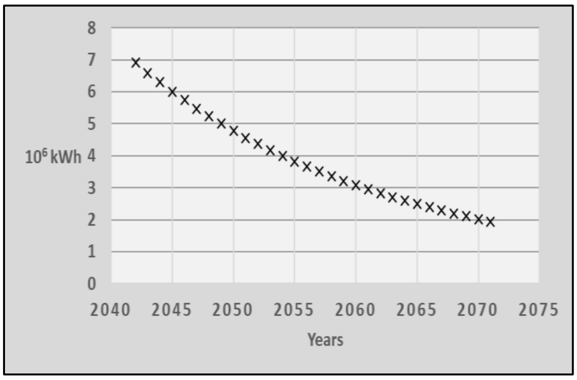

Figure 6. Annual Energy Generations for 30 Years After Closure Year

4. Conclusion

Among other LFGs, methane gas is the most important greenhouse gas and one of the main sources of municipal waste decomposition. In order to compute future patterns of LFG and methane, there are several methods also available in literature. In case of deficiency of technical equipment and information, mathematical models for projecting LFG volumes are technical options to assist gas control management. Also with the results of any mathematical model, relevant individuals can calculate energy potential of biogases produced in a landfill site so as to convert any waste into energy and thus, the carbon footprint will be lowered. This study provides LFG and methane estimations for Niğde Landfill Site. The estimations were evaluated by mathematical models. There were four different first order models used with three different methane generation potential values. The reaction rate constants for models were adopted from climatic information and solid waste characterization data for the landfill site and the other parameters were obtained from technical studies and guidelines to implement models. The energy potentials were adopted from the results of the models to compute gross and net electricity generation as MW.

This study intends that Niğde Landfill site has a potential to produce methane emissions and the results can be used by any stakeholders for the future policy and management strategies. According to our results, the highest LFG generation will be between 2041 and 2042. The total LFG production was estimated as 60 million m^3 in accordance with maximum methane generation according to the good case scenario the production of methane gas has a significant relationship with the organic portion of the deposited waste. Furthermore, the landfill site could be used for a methane reserve for generating energy even after accomplishing depositing of MSW. Currently, Bor Municipality has not attended the Niğde Solid Waste Association and also Bor is the second largest district in the area. When Bor district joins the association, in the good case scenario, the waste composition ratios will alter and L_o values will change. The increase in the amount of solid waste will cause an increase in methane volume. Therefore, the stakeholders of solid waste management in Niğde should consider new strategies and policies to decrease the environmental impact of methane and other LFGs. In an economic point of view, the stakeholders could consider to increase LFG collection efficiently or to use new pre-treatment techniques for LFG to treat H_2S before combustion. For further studies, the former produced LFG or methane volumes from landfill sites could be used for adopting model parameters and more reliable site information could be obtained from remote sensing techniques and methodologies.

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Nomenclature

α_t	LFG production at a certain time [m^3 gas/year]
ς	dissimilation factor [-]
c	unit conservation factor [m^3 LFG.kg /$d_{egraded}$]
A	The quantity of the waste that stored in landfill [ton]
C_o	The amount of organic carbon in solid waste [kg organic carbon/ ton waste]
t	time since depositing in landfill [year]
k_1	biodegradation rate constant [1/year]
G_t	Landfill gas generation at a given time [m^3]
c	unit conservation factor [m^3 LFG.kg /degraded C]
T	The temperature [°C]
C_{org}	Organic carbon in waste [kg organic carbon/ ton waste]
k	reaction rate constant [1/year]
M_t	Waste in place in a given time
i	waste fraction with a specific degradation speed
$k_{1,i}$	biodegradation rate constant for specific degradation speed [1/year]
Q_{CH4}	Flow rate of methane generation [m^3 /year]
i	time increment
n	the subtraction between calculated year and first year of waste
j	0.1-year time increment
k	reaction rate constant [1/year]
L_0	Methane generation capacity [m^3/ton]
M_i	the amount of the waste disposed in a specific year (i) [ton]
t_{ij}	waste age in the j^{th} section of waste mass disposed in the i^{th} year [decimal years]
$DDOC_m$	Decomposable organic carbon
MCF	Methane correction factor
DOC	Degradable organic carbon
FR	Component fraction in the waste composition, dry basis
DOC_{fi}	Fraction of DOC that decomposes under anaerobic conditions
F_{CH4}	Methane volume in LFG; q_{CH4}: Methane density
BF	Biodegradable fraction
BF_w	Biodegradable fraction of waste as a whole
BMP	Biochemical methane potential
C_m	MSW organic matter methane generation potential
FR	Component fraction in the composition, dry basis
w	Water content (dry basis)
AE	Annual electricity generation [kWh]
CLB	Collected landfill biogas [m^3/year]
LHV	Lower heating value of methane [MJ/m^3]
HR	Heat Rate [kwh/MJ]
PL	Parasitic load
AF	Engine availability factor

Conflict of Interest

No conflict of interest was declared by the authors.

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