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LANDFILLS

EFFICIENCY AND RELIABILITY OF THEORETICAL MODELS OF BIOGAS FOR LANDFILLS

EFICIENCIA Y CONFIABILIDAD DE MODELOS DE ESTIMACIÓN DE BIOGÁS EN RELLENOS SANITARIOS

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Resumen

Este artículo muestra un análisis comparativo de las emisiones de biogás generadas en un relleno sanitario al aplicar el modelo mexicano de biogás, el modelo de la Agencia de Protección Ambiental de los Estados Unidos de América (EPA) y comparar los resultados con datos obtenidos in-situ. Las estimaciones con los modelos teóricos y la medición en campo se realizaron en 36 pozos de venteo de un relleno sanitario ubicado en el Estado de México, México, con una recepción diaria de 3500 kilogramos de RSU. Los resultaron in-situ mostraron una generación de biogás (CH_4, CO_2 y O_2) con una frecuencia media de $35,44$ Hz (1/s) y emisiones de metano de $3355,99$ m^3/hr. En contraste los modelos teóricos estimaron valores para el año 2018 de $6270,57$ m^3/hr para el modelo de la EPA y $8379,52$ m^3/hr para el modelo mexicano de biogás. Los resultados mostraron variaciones significativas en las estimaciones de los modelos teóricos versus la medición in-situ. La información generada permite discutir la confiabilidad del uso de modelos teóricos para formular proyectos de aprovechamiento y valorización de RSU al considerar los altos montos de inversión que implican y que las proyecciones de generación de energía se basan en la frecuencia de generación del flujo de biogás estimado en el relleno.
Palabras clave: Biogás, metano, relleno sanitario, estimación teórica.

Abstract

This paper highlights a comparative analysis of biogas emissions produced in a Mexican landfill. The Mexican biogas model, the model of the Environmental Protection Agency of the United States of America (EPA) were applied in order to compare results with data obtained in-situ. The sanitary landfill located in the State of Mexico, Mexico, has 36 wells with a daily reception of 3500 kilograms of MSW. The results showed an in-situ generation of biogas (CH_4, CO_2 and O_2) with an average frequency of $35,44$ Hz (1/s) and methane emissions of $3355,99$ m^3/hr. The theoretical models estimated values for the year 2018 of $6270,57$ m^3/hr for the EPA model and $8379,52$ m^3/hr for the Mexican

biogas model. The results showed significant variations in the estimates of the theoretical models versus in-situ measurements. This result discusses the reliability of the use of theoretical models to formulate projects for the utilization and valorization of MSW, considering the high amounts of investment involved and that the projections of power generation are based on the frequency of generation of the estimated biogas flow in the landfill.
Keywords: Landfill gas, methane, landfill, theoretical estimation.

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1 Introduction

Biogas is a mixture of methane (CH_4) ($40\% - 70\%$), carbon dioxide (CO_2) and other gases (hydrogen, nitrogen, oxygen and hydrogen sulfide) generated by the fermentation of organic materials (Gautam et al., 2009). This gas is the result of the fermentation of methane from different materials, such as agricultural raw material, agricultural products, food waste and liquid or solid feces (Iglinski et al., 2012). The combustion of biogas allows energy recovery and has been widely used in thermal and electrical power plants, among other industrial applications (Tampio et al., 2014). Biogas can be used as a power source in combined heat and energy engines. It can also be used as a substitute for natural gas by eliminating CO_2 from CH_4. Therefore, biogas is a versatile fuel used for energy generation and the chemical industry (Scholz et al., 2013). Biogas is generated in large volumes, mainly in landfills. In landfills, organic matter decomposes in the absence of oxygen resulting in the emission of biogas into the atmosphere (Colling et al., 2016). Landfills of municipal solid waste (MSW) are the third source of methane emissions related to human activity worldwide, representing approximately 15,4% of these emissions (EPA, 2016). At the same time, methane emissions from landfills represent a lost opportunity to capture and use an energy-potential resource (Cabrera and Ortiz, 2011). The control and use of this gas must estimate, with reasonable certainty, the daily production and the accumulated production of methane (CH_4) in the long term. However, according to Calvo et al. (2005), regardless of the method selected for estimating, methodologies should consider that: 1) The diagnosis is only valid at the time of evaluation and its validity decreases over time if the Landfill is not monitored periodically; 2) The methodology can only be performed for MSW sanitary landfills independent of the reception scale; 3) The composition of landfill waste can be obtained from reported historical data, characterization data of average waste in a population or *in situ* characterization.

Numerous investigations have been carried out showing that biogas in landfills are produced over long periods of time, even after the disposal of waste (Pillai, 2018; Lombardi and Carnevale, 2016; Dace et al., 2015; Xiaoli et al., 2011). However, the accumulation of dioxins, furans and other toxic gas emissions in landfills creates severe environmental and public health risks in the surrounding populations (Gomez et al., 2018; Kret et al., 2018; Hirata et al., 1995; Bramryd, 1997; Meadows et al., 1997). Therefore, biogas must be monitored to ensure proper control of these emissions. This treatment usually involves the capture and use of biogas for energy production purposes.

The economic viability of the projects to build and operate technologies for the use and capture of biogas requires accurate information on the gas composition and especially on the estimated generation projections (Chakrabarty et al., 2013). The quantity of biogas produced at the final disposal sites varies depending on the quantity of waste, the type of waste, the humidity content, the temperature and the handling practices; thus, it is necessary to make an estimation of the gases present for quantifying the emissions (Knox, 2005). The estimation of the methane generated by the MSW can be carried out using methodologies such as the EPA model and the Mexican biogas model, that are empirical models based on a first order equation for the degradation of organic matter. These methodologies assume that the generation of biogas reaches its maximum after a period of time prior to the generation of methane; this period is one year after the placement of solid waste for the generation of biogas. After a year of disposing of MSW, the generation of biogas decreases exponentially while consuming the organic fraction of waste (Urrego and Rodríguez, 2016).

Because of the latter, this research considers the application of two theoretical models (EPA model and Mexican model) for the estimation of biogas in a MSW sanitary landfill. The results are compared with precise measurements obtained *in situ*. This allows to identify the degree of reliability and efficiency of the theoretical models versus the real *in situ* measurement by comparing variations and analyzing parameters and aspects that may cause possible inconsistencies.

2 Materials and methods

The research was carried out using different methodologies to estimate the biogas generated in a landfill in the state of Mexico, Mexico. These figures were compared with current measurements obtained with a gas analyzer (GA5000) to identify the effectiveness in theoretical models.

2.1 In situ measurements

The sampling site was a sanitary landfill located at a latitude of 19.320539 and a length of 98.808288, with an extension of 255.619 m2 and located at 2260 masl with an average temperature of $16,51°C$ and $19,50°C$ and an average yearly rainfall from 600 to 800 millimeters. The landfill receives a daily average of 3500 tons of waste from Mexico City and some municipalities in Mexico State.

The filling has 36 vent wells, of which 20 refer to wells

Table 1. Feeding information to theoretical models.

Parameter	Value
Year of opening	2010
Closing year	2037
Beginning of the capture system	2017
Average annual quantity of waste reception	1'105,427
Waste estimation in the landfill in the closing year	29'846,539
Depth of the landfill	65m
Surface in acres	36 (1 per pit)
Methane content in biogas	50.00%
Capture efficiency	85.00%
Size of the Project	Minimum
% of the area with residues with capture system	80

Source: Surveys in the landfill .

with burning system, while 16 are only used to release biogas to the atmosphere. The measurements included data from the 36 wells currently in full operation. The average height of each well was estimated at 3 m with a total length of 65 m. The wells are composed of columns with a 6-inch diameter perforated polyethylene tube. The tubes are arranged at a distance of 25 meters from each other, and each has 4 perimeter slots set along the length of the tube at a distance of 25 cm between them.

The measurement was carried out in the period from 12 to 18 May, 2018. Triple replications were carried out in hours of 9:00 hrs, 14:00 hrs, 18:00 hrs. in order to consider different environmental temperatures. A portable Biogas analyzer model GA5000 was used. Initially, barometric pressure and relative pressure measurements were taken, and CH_4 and CO_2 were subsequently monitored for 45-second intervals. The data were analyzed using the Gas Analyzer Manager Software (GAM).

For the estimations with the theoretical models, the data from Table 1 were used to feed the algorithms of the biogas model of Mexico and the model of the Environmental Protection Agency (EPA). Para las estimaciones con los modelos teóricos se utilizaron los datos de la Tabla 1 para alimentar los algoritmos del Modelo de México de Biogas y el modelo de la Environmental Protection Agency (EPA).

2.2 EPA model

EPA model required data related to the average annual rate of eliminated waste, the number of years the landfill has been opened, the projected closing year, the eliminated waste potential to generate methane and the methane rate. The following first order equation was applied for subsequent estimations:

$$LFG = 2 \times L_0 \times R \times \left(e^{-k \times C} e^{-k \times T}\right) \tag{1}$$

Where LFG is the total amount of biogas generated in the current year or in consideration (ft^3); L_0 is the total methane generation potential of waste (ft^3/lb); R is the annual average of residues arranged during the life of the filling (lbs); k is the annual rate of methane generation (1/year); T is number of years of filling operation (years); C is the time elapsed since the closure of the landfill (years) (EPA, 2017). The value of L_0 and k were estimated based on the Table 2.

Table 2. Parameters for Lo and K for conventional sanitary landfills.

Parameters of the model	Value
K	0,050 per year
L_0	$170 m^3/ton$

Source: (EPA, 2016).

Table 3. Methane generation Potential Index (Lo).

Annual rain precipitation (mm/**year**)	Lo (m^3/Ton)
$0-249$	60
$250-499$	80
>500	84

Source: Adapted from Stege and J. (2009).

Table 4. TMethane generation rate (K).

Annual rain precipitation (mm/**year**)	Lo (m^3/Ton)
$0-249$	0.040
$250-499$	0.050
$500-999$	0.065
>1000	0.080

Source: Adapted from Stege and J. (2009).

2.3 Mexican model

The model used the following information to estimate the generation and recovery of biogas: 1) The amount of waste deposited annually in the landfill, 2) the year of opening and closing of the site, 3) The generation rate of the methane (k), 4) Potential methane generation (Lo), 5) The methane correction factor (MCF), 6) The fire adjustment factor (F), 7) The recovery efficiency of the capture system. The first-degree degradation equation was used to estimate the rate of biogas generation for each year:

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0,1}^{1} 2kLo \left[\frac{Mi}{10}\right] \left(e^{-kt_{ij}}\right) (MCF)(F) \qquad (2)$$

Where: Q_{LFG} = maximum expected flow of biogas (m^3); i = 1-year time increase; n = (year of calculation) -(initial year of waste disposal); j = increase in time in 0,1 years; k = methane generation (1/year); Lo = potential methane generation (m^3/Mg); Mi = mass of waste arranged in year i (Mg); t_{ij} = age of the j section of the mass waste; Mi arranged in year i (decimal years); MCF = methane correction factor; F = fire adjustment factor.

The equation above estimated the generation of biogas using the quantities of waste eliminated and accumulated for one year. The projections for several years are developed varying the annual projection, and then iterating the equation. The total generation of biogas is equal to double the generation of calculated methane. The biogas composition assumed in the model was 50% (CH_4) and 50%, including carbon dioxide (CO_2) and other compounds. The exponential degradation function assumes that the generation of biogas is at its maximum a period before the generation of methane. The model assumed a six-month period between the waste filling and the generation of biogas. For each waste unit, after six months, it was assumed that the generation of biogas decreases exponentially as the organic fraction of the waste is consumed. The maximum year of generation usually occurs in the closing year or the following year (depending on the disposition rate in the final years).
The following parameters were used to calculate the methane generation rate and the methane potential index (Tables 3 and 4).

3 Results and discusion

3.1 In situ measurement results

Table 12 shows the results obtained after sampling 36 wells in the landfill. The concentration of methane, carbon dioxide, oxygen, as well as the generation frequency showed similar values for each well. The average values for the landfill are shown in Table 5.

Table 5. Average values obtained *in-situ* in the landfill.

CH_4 (%)	CO_2 (%)	O_2 (%)	Hz (1/s)	CH_4 per hour
50.29	46.88	1.01	35.44	3355.99

3.2 Results of the Mexican biogas model

The estimation was made by applying the first-order degradation equation [1]. The data used to feed the model can be seen in Table 1. The model provided values for the methane generation index (k) and the potential methane generation (Lo), which were verified by the values proposed by Aguilar et al. (2011). These values were developed using climatic data, characterization of waste and preloaded elimination practices in theoretical models. Table 6 shows the parameters used for the modeling.

Table 6. Parameters for the modeling (Mexican model of biogas).

Methane content in the biogas: 50 %				
Correction factor of methane (MCF): 1.0				
Characterization of the waste	Fast degradation	Partly fast degradation	Partly slow degradation	Slow degradation
CH_4 (k) generation index:	0.16	0.075	0.032	0.016
CH_4 (Lo) generation potential (m^3/Mg):	69	138	214	202

Table 7 presents the values obtained after the modeling. It should be noted that the theoretical models (EPA and Mexican model) estimate the generation according to the pre-established characterization. The model also estimates the accumulation of waste by increasing the amount of waste prepared per year. Although Table 7 presents data up to 2025, the model resulted in values up to 2037, year projected for the closure of the landfill.

Table 7. Biogas generation and recovery projections in the Mexican model.

Year	Waste (Mg/year)	Accumulated waste (Mg)	Biogas generation			Stimated recovery of the biogas		
			(m^3/hr)	(ft^3/min)	(mm Btu/hr)	(m^3/hr)	(ft^3/min)	(mm Btu/hr)
2010	981600	981600	0	0	0	0	0	0
2011	1001200	1982800	1424	838	25.4	0	0	0
2012	1021200	3004000	2706	1593	48.4	0	0	0
2013	1041600	4045600	3866	2275	69.1	0	0	0
2014	1062400	5108000	4922	2897	88	0	0	0
2015	1083600	6191600	5889	3466	105.2	0	0	0
2016	1105427	7297027	6781	3991	121.2	0	0	0
2017	1127500	8424527	7608	4478	135.9	4032	2373	72
2018	1150100	9574627	8380	4932	149.7	4441	2614	79.4
2019	1173100	10747727	9105	5359	162.7	4825	2840	86.2
2020	1196600	11944327	9790	5762	174.9	5189	3054	92.7
2021	1220500	13164827	10442	6146	186.6	5534	3257	98.9
2022	1244900	14409727	11065	6513	197.7	5865	3452	104.8
2023	1269800	15679527	11665	6866	208.4	6182	3639	110.5
2024	1295200	16974727	12244	7207	218.8	6489	3819	116
2025	1321100	18295827	12807	7538	228.8	6788	3995	121.3

3.3 Results of the EPA model

The EPA model uses a tool developed for the Landfill Methane Outreach Program (LMOP) to estimate emissions and costs in biogas capture and biogas use (Table 8). The main values obtained in the EPA model are shown in Table 9.

Table 8. Generation, collection and use of biogas.

Parameters for modeling :	
Generation rate of methane, k (1/year):	0.04
Generation capacity of methane, LO (ft^3/ton):	3204
Methane Content of LFG:	50.00 %
Stimated waste during the filling (ft^3/min LFG):	
Mínimum:	3291
Annual average	5663
Maximum	7659
Recovery during filling (ft^3/min LFG):	
Minimum:	2798
Annual average:	4814
Maximum:	6510
Size of the project:	Mínimo
Generation rate (ft^3/min LFG):	2798
Used for the project: (ft^3/min LFG):	
Annual average	2601.8
Recovery efficiency of biogas:	85.00 %

4 Discusión

The values obtained showed significant differences in the biogas levels. The theoretical models (EPA and Mexican model) estimated values that result from the modeling data in first-order degradation equations. The results are shown in Figure 1:

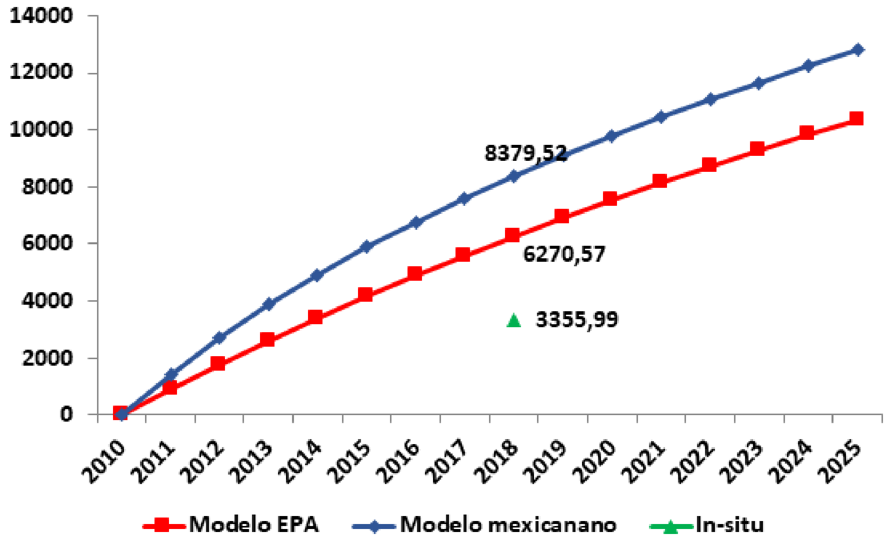

Figure 1. Estimated generation of methane(m^3/hr).

Figure 1 shows the methane emissions in cubic meters per hour. It is possible to see that the theoretical models estimated values in 2018 of 8379.52 m^3/hr (Mexican model) and 6270.57 m^3/hr (EPA model). These values contrast significantly with the real *in situ* value, which shows that in the year 2018 the generation is 3355.99 m^3/hr. The variations in the results obey to different elements, firstly, the assumptions of the theoretical models.

Table 9. Projections of methane generation (m^3/hr) in EPA model. Values obtained in modeling.

Year	m^3/hr
2010	0
2011	897.83
2012	1760.46
2013	2589.27
2014	3385.57
2015	4150.66
2016	4885.74
2017	5592
2018	6270.57
2019	6922.53
2020	7548.93
2021	8150.76
2022	8729
2023	9284.56
2024	9818.34
2025	10331.19

In the EPA model, the estimated biogas generation (LFG) produced is multiplied by the harvesting efficiency to estimate the methane and volume that can be recovered. However, projections are calculated based on reasonable capture efficiency estimates for landfills that meet the standards set forth in title 40, part 258 of the Code of Federal regulations in the United States of America. The collection efficiencies reported in these sanitary landfills range from 50 to 95 % of efficiency, so the model assumes 75 % capture efficiency. Additionally, the EPA model assumes facilities with a comprehensive collection and treatment system that will increase its efficiency and projected years. Consequently, the variation of the real value *in situ* with the estimates of the EPA model is understandable since landfills in Mexico lack of integral systems that guarantee an efficiency in the capture of biogas, and above all, most health landfills in Mexico base their operation on rudimentary methods and obsolete technologies (Escamilla et al., 2016).

The results obtained in the Mexican model of biogas, present an even higher variation than the data of the EPA model. The difference of the m^3 per hour of methane generated in 2018 among the real *in situ* measurement and the EPA model was 2914.58 m^3/hr, while the difference with the Mexican biogas model was 5023.53 m^3/hr. This implies a difference 2.5 times greater than the current emission. The Mexican model automatically assigns the k values according to the values in Table 10.

Table 10. Values of the Methane Generation Index (k) and of the Potential Generation of Methane (Lo) in Mexican biogas model by region.

Category of the waste	Region 1		Region 2		Region3		Region 4		Region 5	
	Southeast		West		Centre/ Interior*		Northeast		Northeast & North Interior	
	k	Lo	k	Lo	k	Lo	k	Lo	k	Lo
1	0.3	69	0.22	69	0.16	69	0.15	69	0.1	69
2	0.13	115	0.1	126	0.075	138	0.07	138	0.05	149
3	0.05	214	0.04	214	0.032	214	0.03	214	0.02	214
4	0.025	202	0.02	202	0.016	202	0.015	202	0.01	202

Source: Adapted from (Stege and J., 2009).

As can be observed in Table 10, the rate of methane generation used in the estimation is allocated depending on the location of the landfill to be evaluated. The model establishes five geographical regions. Each region first identifies rainfall and the area's average temperature. Subsequently, the category of waste refers to 1) area without management; 2) area with handling; 3) Semi-aerobic area and 4) unknown condition. If there is no precise information on the characterization of the waste, the model assumes characterization values for each zone.

Considering the fact that the Mexican model estimates the values based on particular information from Mexico, it should provide greater reliability in the results. These results would have to be at levels with an acceptable variation in relation to the current *in situ* measurement data. However, as evidenced, estimations showed significant variability. The EPA model reported values even closer to the current *in situ* data. This is an important situation because it is shown that the Mexican model, which given its characteristics would have to estimate values close to reality, showed the opposite by reporting the values furthest from the current measurement.

The main weakness of the Mexican model that might explain the wide variation in estimates is the information on the characterization of waste, particularly organic fractions. Statistical information related to the characterization of residues in Mexico is scarce and presents low levels of reliability. In a comprehensive MSW management system the characterization of waste is essential not only to establish estimates of methane in the organic fraction but to establish strategies for migrating to zero residue systems (Ayeleru et al., 2018; Adeniran et al., 2017).

The waste flow in a landfill and its characterization varies according to factors in each region such as: Economic activities, climate, culture, energy, sources of generation, among others. Developing countries tend to generate a significant proportion of organic waste, while developed countries have higher proportions in the inorganic fraction (Chang et al., 2011). Table 11 illustrates the different average composition values according to the type of economy.

Table 11. Waste composition by economic level*. Elaborated from **?** data.

Type of income	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Others (%)
Low income	64	5	8	3	3	17
Partly low income	59	9	12	3	2	15
Partly high income	54	14	11	5	3	13
High income	28	31	11	7	6	17

*Note: The table was created with information from the World Bank, which includes data from 105 countries classified by income and with MSW generation rates in the period 2006 to 2012. The generation rate included urban areas only and in some countries the composition values were of a single city.

Table 11 shows that low-income countries have an organic fraction of 64 % compared to 28 % in high-income countries. This shows that as a country increases its levels of economic development, it has an impact on the MSW flow and the organic fraction decreases. Consequently, the estimates of the Mexican biogas model present a low accuracy due to the characterization data of waste used as a base. The model assumes a high concentration of organic fraction while the current data show that this component is lower than the estimated. The values reported by the theoretical models in this research have a similar behavior due to the mathematical model applied and to the exponential degradation of the estimated residue. The significant variability between the data of the theoretical models and the *in situ* measurements reported in this article are aligned with the results reported by Urrego and Rodríguez (2016) who found atypical variations among the theoretical models and a model of the Intergovernmental Group of Experts on Climate Change (IPCC).

However, this research was carried out in Mexico and it was expected that the Mexican model would provide approximate but reliable information of methane generation. Research has shown the negative impact that improper quantification of biogas in a landfill can have on energy generation projects (Judy et al., 2018; Blanco et al., 2018; Li et al., 2018). As a result, theoretical models, particularly the Mexican biogas model, proved being unreliable in generating preliminary information on methane emissions.

In Mexico the provision of information on the characterization of waste is unreliable. It shows that while theoretical models can be a tool for practical use, the results cannot be used to define strategies and action plans especially in investment projects for energy generation. The efficiency and profitability of a MSW recovery plant for generation is based on the appropriate frequency and levels of constant emission of methane per hour. It is important that the Mexican biogas model be updated in terms of characterization of waste to avoid variability in estimates.

5 Conclusions

The *in situ* measurements showed methane emissions significantly lower than the values estimated by the theoretical models (*in situ* = 3355.99 m^3/hr, EPA model = 6270.57 m^3/hr, Mexican model = 8379.52 m^3/hr). The variations in the values obtained are due to the parameters that each model assumes and that differ widely from the real characteristics of the sanitary landfills in Mexico. The EPA model and the Mexican model do not have a wide variation between them because of the mathematical method applied (equation of first order).

The *in situ* measurement showed that the complexity of the elements necessary for the estimation of the biogas generated can have a significant impact on the results. Theoretical models provide projections that can be used as preliminary information. However, it is shown that they are not reliable and it is essential to make the measurement with specialized equipment *in situ* to obtain useful information for the decision making.

A theoretical model can underestimate or overestimate the generation of projected biogas. This is critical if such information is the basis for the implementation of biogas-based energy generation projects. If the interested parties are not able to carry out an *in situ* measurement, special attention must be paid to the theoretical model chosen for the projections to ensure the accurate provision of information on the characterization of waste in the landfill, since it is these data that can cause the variability of the final results.

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Table 12. Values obtained *in situ* by venting well.

Well	Methane (CH_4) (%)	Carbon Dioxide (CO_2)(%)	Oxygen (O_2) (%)	Frecuency Hz ($1/s$)	Hour emission of methane
1	48.8	51	0.2	5.42	53.1005715
2	50	50	0	5.06	1310.77465
3	49.5	50.5	0	77.57	19893.2849
4	49.7	50.3	0	113.77	1135.1787
5	51.7	48.3	0	90.1	24133.6408
6	49.8	50.2	0	0.3	77.4030562
7	38.5	59.2	2.3	0.3	59.8397121
8	51.3	48.6	0	76.57	20350.8955
9	50.4	49.2	0.4	96.93	25310.2398
10	50.4	49.6	0	79.6	20785.052
11	51.4	48.2	0.4	3.48	35.9105825
12	51.9	48.1	0	2.58	142.729123
13	50.7	48.9	0.3	164.1	1670.30825
14	51.3	48.7	0	4.02	41.4022082
15	50.5	49.4	0.1	130.97	1327.83249
16	50.6	48.5	0.8	2.32	23.5677753
17	51.4	48.6	0	165.1	1703.68884
18	52	48	0	72.13	753.007605
19	50.8	49.1	0.1	20.4	208.052992
20	50.2	49.7	0.1	0.87	8.76805078
21	50.7	49.1	0.2	0.3	3.05357999
22	49.9	50.1	0	22.79	228.310012
23	53.3	46.4	0.3	0.57	6.09933028
24	52.6	46.6	0.8	0.3	81.7550352
25	44.6	32.9	5.3	0.3	2.68618673
26	54.1	45.6	0.3	4.88	53.0025999
27	55.4	40.5	2.3	0.3	3.33665348
28	52.7	38.3	3.1	0.3	3.17403679
29	54.3	44.9	0.8	4.68	51.0182749
30	26	18.3	12.5	0.3	1.56593845
31	56.4	40.2	1.8	0.3	3.39688188
32	52.9	47.1	0	62.2	660.581099
33	49.8	50.2	0.1	15.38	153.767929
34	52.8	47.2	0.1	17.3	183.383439
35	52.6	47.4	3.9	5.29	55.862646
36	51.4	48.6	0	29.07	299.977193

Elaborated from *in situ* measurements.