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Application of a Proposed Methodology for Estimating Natural Gas in a landfill. Case Study Landfill Juana, Bogota, Colombia

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Abstract

Since landfills are a source of the large amounts of biogas containing 50% methane of gas generated by anaerobic decomposition of organic matter, being a global problem because it is a greenhouse gas, this gas is generated in depending on the amount, type and age, moisture, temperature and pH of solid waste within a landfill.

In this context, and given the biogas contains large amounts of methane, it is necessary to estimate it through a series of methodologies such as the EPA, Mexican and IPCC, however, in some countries also use others such as Default, triangular, stoichiometric, to name a few.

This article describes some methods used to estimate the biogas and also a brief description of some studies found regarding the issue in question.

Keywords: Biogas, landfill, estimation methodology.

INTRODUCTION

Currently one of the alternatives for disposal of solid waste are landfills or dumps, which are facilities designed to operate so that the environmental impact is appropriate healthcare. However, more landfills that are operated in an appropriate manner generate

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emissions of biogas which is produced by the decomposition of organic matter produced by microorganisms under anaerobic conditions (Martin, 29). The generation of these emissions vary over time and different environmental conditions in which it carries out the degradation of organic matter and other compounds, leads to the generation of methane (CH4) as well as compounds such as carbon dioxide (CO_2), nitrous oxide (NOx) and other volatile compounds, where the methane gas corresponds to 40% - 50% (Fornieles, 16). Methane (CH4) produced in these areas contributes about 3 to 4 percent of the emissions of anthropogenic greenhouse gases a year globally. (IPCC, 18). This mixture of gases particularly methane, may in time to contribute to the concentration of greenhouse gases in the atmosphere and can also become a cause of explosions in landfills. In order to prevent this from occurring is required to estimate models that allow biogas to provide their behavior over time, however, the complexity of the processes that occur within a landfill such as physical, chemical and biological not allowed to perform a good estimate of biogas which has created some empirical models to carry out this estimation, such as those that are governed by the kinetics of first order decay of organic matter. (Meraz & Domin, 31).

The estimation of biogas especially the methane gas component can be done through a series of methodologies such as: Default method, the method applied in Mexico (López & Uribe, 28), the triangular method, the Gaussian model (Buitrago, 9), biogas volume model (Tchobanoglous, 53), green stick model, Sheldon-Arleta, Lee JJ, Jung YH, Lee WB and Kim J.O., the model of F.G. Pohland and B. Al-Yusfi, the model proposed by Jimenez and Christopher Scholl Canyon (Pineda, 41), the zero-order model or SWANA (Oonk & Boom, 38). It also has the model Modified First Order (SWANA) described by Van Zanten & Scheepers (55), the multiphase model (Scharff, et al, 44), the model Gassim, French EPER model (Gregory et al, 18), EPA model, the model IPCC, among others, the most used methodologies EPA, Mexican method and the method IPCC models do not take into consider variables such as those that influence the decomposition of waste as precipitation, internal temperature of solid waste, which makes these methods do not estimate the amount of methane gas that is actually being generated.

Therefore, this paper contains a methodological proposal which includes variables that have not been considered in the estimation models are available such as precipitation and internal temperature of solid waste. For the development of this work were analyzed to estimate three models currently used in EPA, Mexican and IPCC and compared with the proposed model, by estimating and comparing methane gas and see what the error is less. Furthermore, we have that the methodology developed in this research project is a study of quantitative descriptive case where the data were analyzed by the sum of squares and compared with EPA methods and Mexico.

MATERIALS AND METHODS

First stage: a literature review was conducted and the state of the art in regard to existing methodologies for estimating greenhouse gas, by consulting ScienceDirect database, Sage Journals Dialnet. This literature review led to the elaboration of theoretical and conceptual framework of the project. Likewise, analyzed and collected information about the emission of greenhouse gases generated in the degradation of solid waste in Bogotá. This process was carried out by the inquiry to the Special Administrative-Utility-UAESP, the biogas plant and the Ministry of Environment, Housing and Territorial Development and further visits were made to the landfill.

Second stage: For the estimation of methane gas to Mexican methodologies, EPA and IPCC, it was necessary to download software from the pages of the EPA and IPCC in order to enter the data that was supplied by the UAESP and biogas plant and to estimate this for the Doña Juana Landfill Area II Area 3.
Mexican model: To estimate the amount of methane gas, we used the software Mexico LFG Model, a model that is used in several countries and is applicable to landfill at depths greater than 5 meters. This model also estimates the degradation caused by solid wastes in landfills, which assumes that the composition of methane gas is about 50%, estimating the biogas in cubic meters per hour (m3 / h) or cubic meters per year (m3/year). On the other hand, the methane generated is calculated using the rates L0 = methane generation potential and k = Methane Generation Rate / year, brings the model parameters included and which can be seen in Tables 1 and 2.

Table 1. Indices of Methane Potential Generation Lo. Mexican model.

Annual Rainfall (mm / yy)	LO (M 3 /Tons)
0-249	60
250-499	80
≥500	84

Source*: Stege, G. (46). User: Mexican model biogas.*

Table 2. Methane Generation Rate (K). Mexican model

Precipitación anual (mm/año)	K (por año)
0-249	0.040
250-499	0.050
500-999	0.065
>1000	0.080

Source*: Stege, G. (47). User: Mexican model biogas.*

Was has entered the software the amounts of solid waste disposed in the zone II area 3 of the sanitary landfill for the year 2008 been entered a total of 249,862.913 tons and for 2009 was entered a total of 273,812.6717 tons. Assumes 60% capture efficiency, we use the average annual precipitation mm / year. K (Methane Generation Rate): for a precipitation per year of 553.47 mm which corresponds a value of 0.065 1/year; L0 (Methane Generation Potential) for the same precipitation is 84 m3/ton.

EPA model. To bring out the estimation of methane gas by the EPA model, took into account the cumulative amount of waste disposed of in 2008 and 2009 with a total of 523,675.584 tons, the parameters of Lo (Generation Rate Potential methane) and K (methane Generation Indices), which are dependent on the available organic fraction, temperature and moisture content of waste, where it is assumed that the composition of methane is 50%. This model predicts the generation of methane gas in cubic meters per hour (m3 / h), cubic meters per minute (m3/min) or cubic meters per year (m3/year). On the other hand, the values of I and K can be seen in Table 3.

Table 3. Parameters for I and K for conventional fillers. EPA model.

Model parameters	Value (amount, valor)
K	0.050 por año
Lo	170 m3/ton.

Source: *EPA. (1). Landfill Gas Emissions Model.*

IPCC model. To bring out the estimation of methane by the IPCC model, took into account the cumulative amount of waste disposed of in a year, this model assumes that the generation of methane increases for decades and then begin its phase of decline. The main entrance of this model is the amount of degradable organic matter (docm) contained in the waste and the different types of this. Furthermore this model also admitted index values of methane generation (K), a value that the model assumes for Bogota a tropical dry climate with temperatures above 20 º C and rainfall below 1000 mm / year (see Table 4) ; degradable organic carbon-DOC-, degradable organic carbon fraction that decomposes (DOCf), which has a default value recommended by the model 0.5, a value that is assumed hypothetically to anaerobic environments in landfills, oxidation factor for the case of RSDJ the IPCC assumes a value of 0 for being a waste disposal site of solid-SEDS-managed, and the delay time that the model considered a default of six months, equivalent to the time where it is carried out the reaction for generation of methane at 1 January of the year in which they were deposited solid waste.

Table 4. Methane Generation Rate (K). IPCC model

Kind of Waste	**Methane Generation Rate (K)**		**Values**
		Rank	**Default**
Moderate degradation	Food waste, garden	0.05-0.08	0,65
slow degradation	Paper and textile	0.04-0.06	0,045
	Wood and straw	0.02-0.04	0,025
rapid degradation	Food waste and sewage sludge boiled	0,07-0,1	0,085

Source*: Intergovernmental Panel on Climate Change. (19). IPCC Guidelines, 2006 for national inventories of greenhouse gases.*

Furthermore, each of the models was performed for statistical analysis with a confidence level of 95% for this, we took into account the average, which indicates the average methane gas that is generated every year. In addition, we analyzed the standard deviation indicates the spread of data that exists in each of the models and also examined the minimum and maximum value that indicates the amount of methane gas emissions minimum and maximum expected for the period 2080-2030. It should be noted that the three models are exponential, which means that model the growth of a given population during or period of time, and then show a decay which is due to methane gas production is slower compared to the first two years.

Third stage: For the proposed methodology took into account the variable amount of waste, precipitation and temperature of solid waste. This mathematical expression was used to estimate the amount of methane gas generated at the Doña Juana Landfill Area II Area 3. To raise the mathematical expression it was necessary: Complete database of precipitation: Because there are days in which information is available, this absence would create bias in the final estimate, so it was necessary to impute values for to this day. The temperature variables of waste, precipitation, and amount of solid waste are not related to time, ie it can be assumed that all days are the "values," it was determined by linear regression. Complete the information for months: The first and last months have incomplete information, for example, waste started to be observed from the September 8, 2008, losing information from the first 7 days of the month, therefore we can´t assume the total waste during this month is the sum of the observations in the database provided by the UAESP, because it would underestimate the total.

Information was completed based on data provided by the Special Administrative Unit of Public Service-UAESP-assuming that each month had 30 days and every day the same amount of generated waste.

Formulating the Model: functional formula of the proposed model was obtained in analogy to the shape of the models compared (EPA and Mexican) by adding the information about temperature and precipitation. In addition, we used the annual non-monthly information, in order to avoid the enormous loss of information obtained when using the information added annually. On the other hand, for the formula it was necessary to obtain four (4) b constant calls according to the characteristics of the sanitary landfill which were estimated by applying Microsoft Excel solver (see Figure 1), which implements iterative numerical methods to determine the parameter values that minimize a criterion of efficiency by the Mean Square Error-ECM-ie initial values are sought that minimize the Mean Square Error.

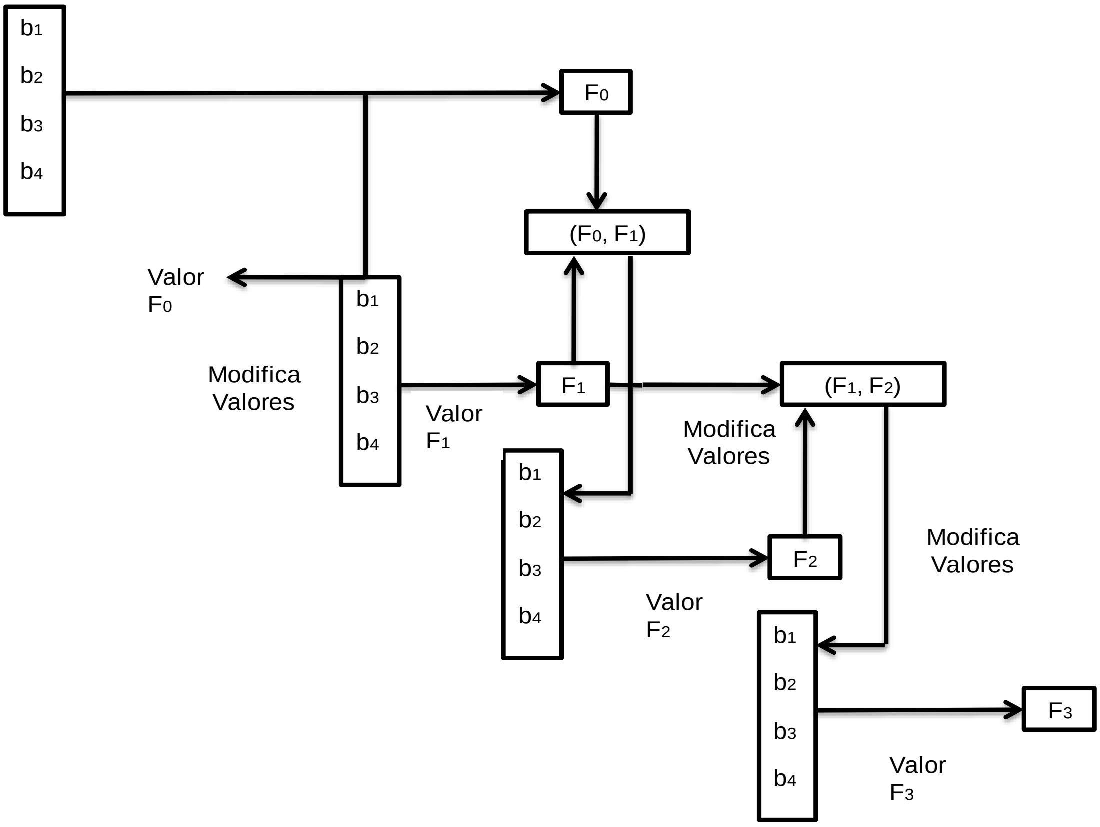

Figure 1. Flowchart Method Excel Solver. Authors. 2011

Fourth stage: A comparison between the EPA models, Mexican, and the proposed amount of methane gas currently observed in the Doña Juana Landfill to make sure that this model is closer to reality compared to the others. For this, an estimate was made between the periods between October 2009 and September 2010 with actual observations in the area, using as criteria for determining which of the three models had a better fit with the Mean Square Error (MSE).

RESULTS AND DISCUSSION

Amount of waste generated in the Doña Juana Landfill (RSDJ).

The amount of solid waste entering the landfill Joanna shows daily behavior, where the recorded data and daily fluctuations have almost the same intensity, indicating that variation in the amount of waste that entered the zone II area 3 is minimal. Furthermore, the graphs shows the monthly performance of solid waste entering the landfill and methane biogas, where it notes that the months in which most residues were entered in October, November, December 2008 and January 2009, maintaining a steady trend, while in the months of September 2008, February, March, April and May 2009 were the months in the least amount of waste entered. According to data released by the silver of Biogas, methane gas captured monthly exhibits behavior.

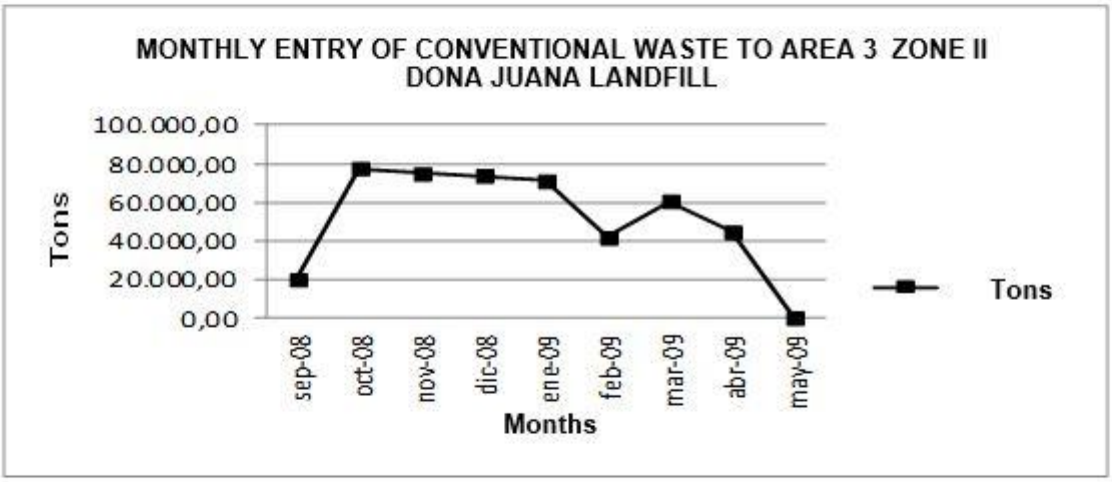

Figure 1. Monthly Performance of Waste as Provided in the Area 3 Zone II Doña Juana Landfill.
***Source**: Unidad Administrativa Especial de Servicios Públicos -UAESP-. 2010*

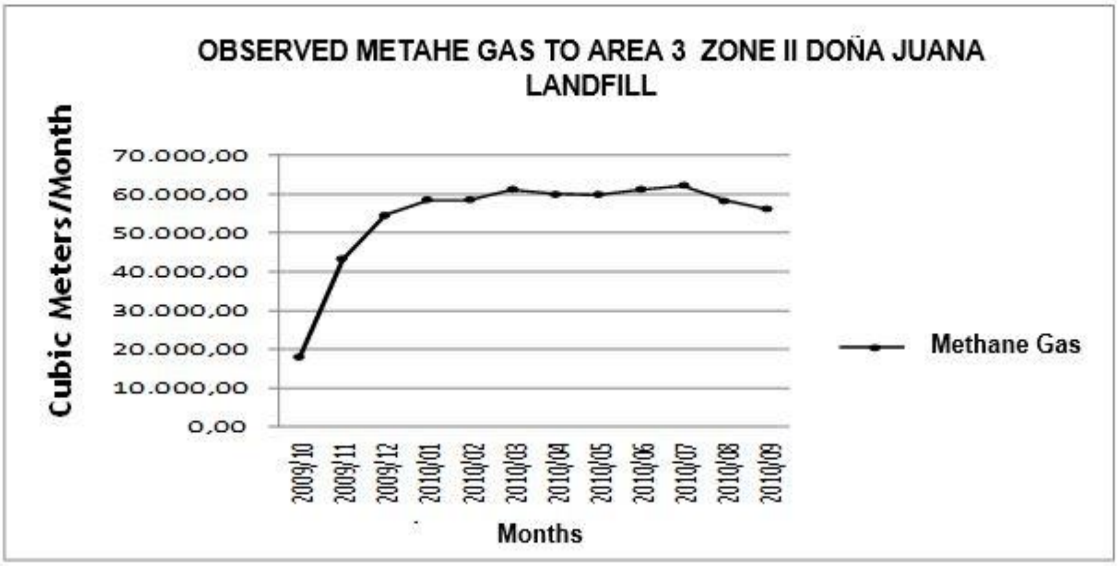

Figure 2.. Observed Methane. Doña Juana Landfill Area 3 Zone II.
***Source**: Unidad Administrativa Especial de Servicios Públicos -UAESP-. 2010*

The graph shows that the production of methane gas which had a sharp increase from October 2009 until December 2009. During the remaining observation period, the production level remained relatively stable.

Mexican Model. This is followed by statistical analysis to the results of the Mexican model

Table 5: Mexican Model Descriptive Statistics

Mexican Model	
Media	2,48E+05
standard deviation	1,16E+05
Mínimum	0,00E+00
Máximum	4,46E+05
Confidence Level (95.0%)	5,02E+04

Source: *Authors. 2011*

The average of methane gas for the years 2008-2030 corresponds to 2.48E +05 m3/year, with a standard deviation equal 1.16+05 m3/year. The minimum value corresponds to 0 emissions for the year 2008 began operation of the Zone II area 3 the maximum emission value during the time period between the years 2008-2030 amounts to 4.46E+05 m3/year.

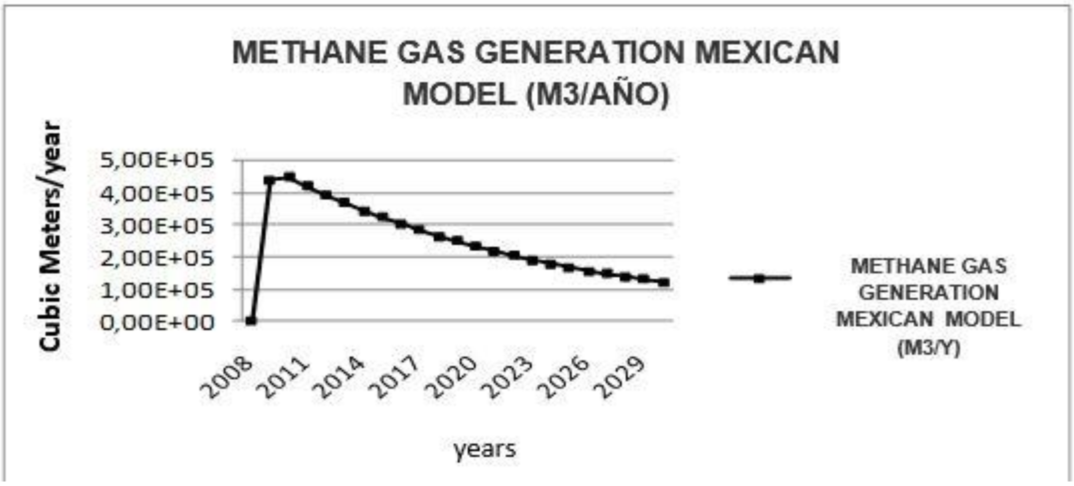

Figure 2: Methane Gas Generation. Mexican model, Doña Juana Landfill Area 3 Zone II.
Source*: Authors. 2011*

According to the Mexican model, the peak methane production begins in 2010 at a rate of 4.46E+05 m3/year decay phase starting in 2011 and whose estimate for 2030 is 1.22E+05 m3/year. Mexican model. The following is a statistical analysis to the results obtained in the Mexican model.

EPA Model. This is followed by statistical analysis to the results of the EPA model

Table 6. EPA Model Descriptive Statistics

EPA MODEL (m^3/years)	
Media	2,14E+05
standard deviation	8,29E+04
Mínimum	0,00E+00
Máximum	3,45E+05
Confidence Level (95.0%)	3,58E+04

Source: *Authors. 2011*

The average of methane gas for the years 2008-2030 corresponds to 2.14E +05 m3/year, with a standard deviation equal to 8.29E+04 m3/year. The minimum value corresponds to 0 because emissions by the year 2008 began operation of the Zone II area 3 and the maximum emissions during the period of time between the years 2008-2030 amounts to 3.45E+04 m3/year.

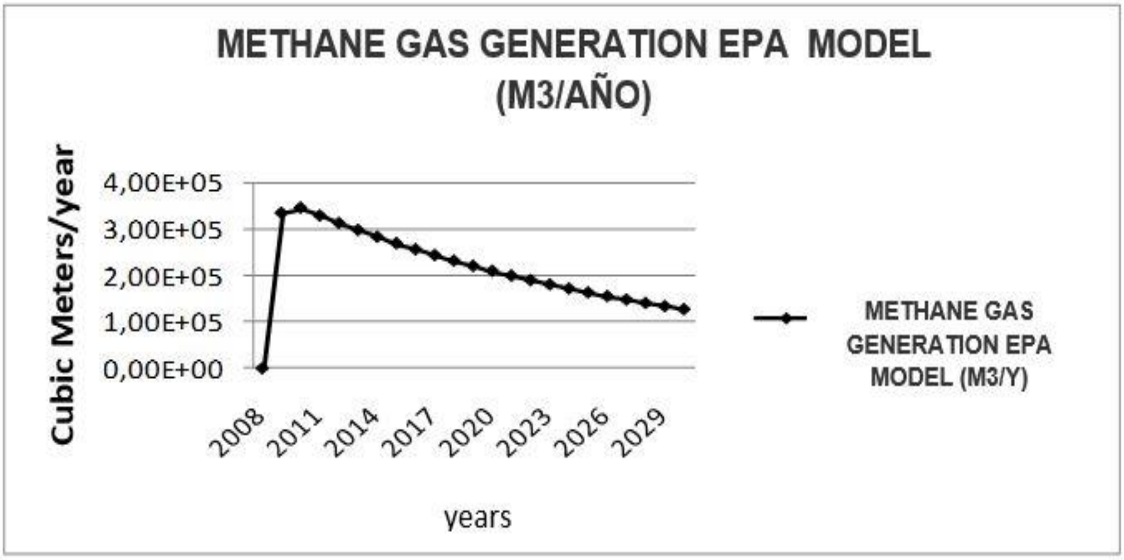

Figure 3. Methane Gas Generation. EPA model, Doña Juana Landfill Area 3 Zone II.
Source: *Authors. 2011*

According to the EPA model, the peak methane production begins in 2010 at a rate of 3.45E+05 m3/year decay phase starting in 2011 to finally reach the year 2030 with a rate of 1.27E+05 m3/year. This model has a decay pattern similar to Mexico.

IPCC Model. This is followed by statistical analysis to the results of the IPCC model

Table 7. IPCC Model Descriptive Statistics

IPCC MODEL (m^3/years)	
Media	6,71E+09
standard deviation	2,71E+09
Mínimum	0,00E+00
Máximum	9,37E+09
Confidence Level (95.0%)	1,17E+09

Source: *Authors. 2011*

The average of methane gas for the years 2008-2030 corresponds to 6.71E +09 m3/year, with a standard deviation equal to 2.71E+09 m3/year. The minimum value corresponds to 0 because emissions by the year 2008 began operation of the Zone II area 3 and the maximum emissions during the period of time between the years 2008-2030 amounts to 9.37E+09 m3/year. Estimated observations are displayed in the chart below.

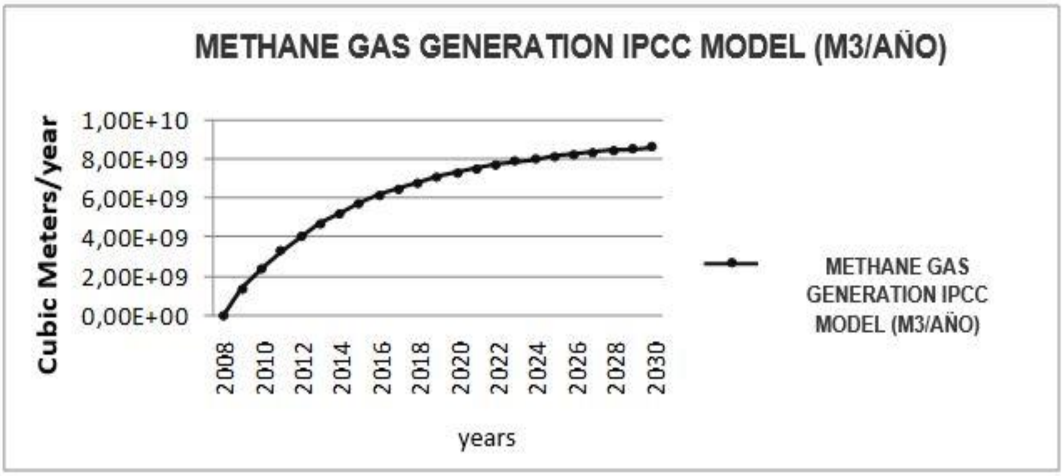

Figure No. 4. Methane Gas Generation. IPCC model. Doña Juana Landfill Area 3 Zone II.

Source: *Authors. 2011*

According to the IPCC model, the generation of methane gas in 2009 begins with a flow rate of 1.41 E +09 m3/year, which has grown exponentially, reaching the year 2030 at a rate 9.37 E +09 m3/year without observing decay because this model predicts that after a few decades begins the decay of methane gas, in our case the decay starts from the second decade is, for the year 2033.

It should be noted that although this study sought to compare the Mexican models, EPA and the proposed IPCC, the IPCC is discarded because it presents an atypical behavior compared to other models, since this only begins its decay phase after a few decades into the production of methane gas, in our case is in the second decade is about the year 2031.

Proposed Model. To estimate the amount of methane gas through the proposed model, we used the monthly solid waste, where, for the year 2008 was admitted a total of 249,862.913 tons by the year 2009 a total of 273.812.6717 tons . In addition, four coefficients were obtained ranging b called according to each of the specific conditions of Doña Juana Landfill, ie that these ratios vary depending on the location of the landfill, its precipitation and temperature of the waste and and its composition (see table 8).

Table 8. Coefficients for the model proposed

Coefficients	
b1	0,03
b2	0,015
b3	0,06
b4	0,01

Source: *Authors. 2011*

Once this is done, we proceeded to formulate the model which was as follows:

$$QI = \sum_{i=1}^{I} b1Mi * b2Pi * b3Ti\, e^{-(I-i)b4}$$

Where:

Mi = monthly solid waste
Ti =Monthly temperature
Pi = monthly precipitation
b = coefficient
I = Length of time to estimate
i = Increase in 1 years time

According to the proposed formula yielded the following statistical results:

Table 9. Descriptive statistics for the proposed model.

Proposed Model (m^3/years)	
Media	2,50E+05
standard deviation	1,93E+05
Mínimum	0,00E+00
Máximum	6,59E+05
Confidence Level (95.0%)	8,35E+04

Source*: Authors. 2011*

The average methane gas for the years 2008-2030 corresponds to 2.50E+05 m3/year, with a standard deviation equal to 1.93E+05 m3/year. The minimum value corresponds to 0 emissions for the year 2008 began operation of the Zone II area 3 and the maximum value of missions in that period of time equal to 6.59E+05 m3/year. Estimated observations are displayed in the chart below.

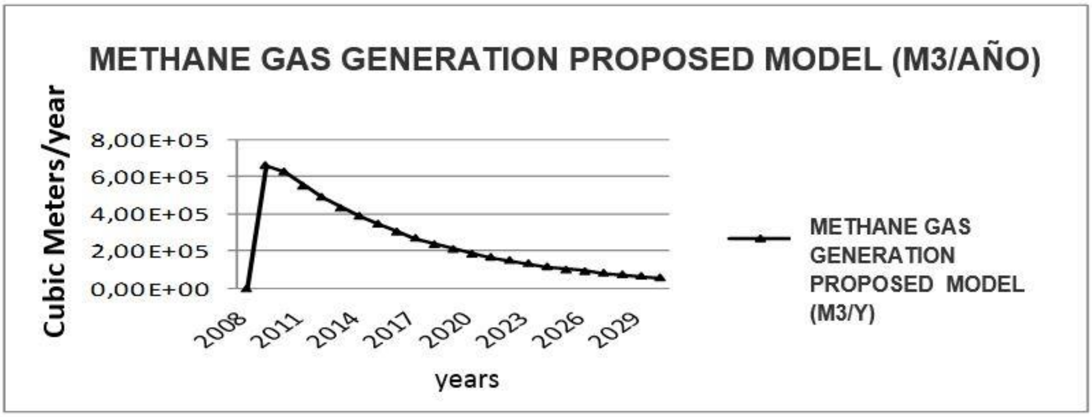

Figure No. 5. Methane Gas Generation. Proposed Model. Doña Juana Landfill Area 3 Zone II.
***Source**: Authors. 2011*

According to the proposed model, the peak methane production begins in 2009 at a rate of 6.59 E +05 m3/year decay phase starting in 2010 to finally reach the year 2030 with a flow rate of 5.67e +04 m3/year. This indicates that the estimate of methane gas is better with this model This model features a similar decline in Mexican and EPA models. The models were compared with the amount of methane observed, ie the amount that is being generated now in the Doña Juana Landfill, in order to know which one comes closest to reality, for this was taken into account monthly periods since making an annual analysis information was lost, besides, there was a statistical analysis of EPA models, Mexican and proposals in methane observed. Statistical analysis to compare the three models was done by the mean square error (MSE) in the periods between October 2009 and September 2010, which was calculated for each of the models with the observed methane gas, the ECM can be seen in table 10.

Table 10. Square Error (MSE) EPA models, Mexican and Proposed.

MODELO	ECM
EPA	787.129.824
Mexican	428.668.804
Proposed	174.287.219

***Source:** Authors. 2011*

This indicates that the model has less error is proposed and this can be corroborated in the Figure 6, where an estimate is made of methane gas from 2008 to 2030, there are three models compared with the observed methane . In making this comparison shows that the model with the lowest distance from the methane observed is the proposed model. The graph 6 presents the estimates of methane emissions for each of the three models (EPA, Mexican and proposed) from 2008 to 2030, also presents the observed values of methane gas for the years 2009 2010. As noted in the chart, the proposed model yields estimates closer to actual observations than the other two models, on the other hand, the functional form of the three models is similar: initially have a rising trend, reaching a maximum of emission around of 2009 and from this point begins a decrease exponentially.

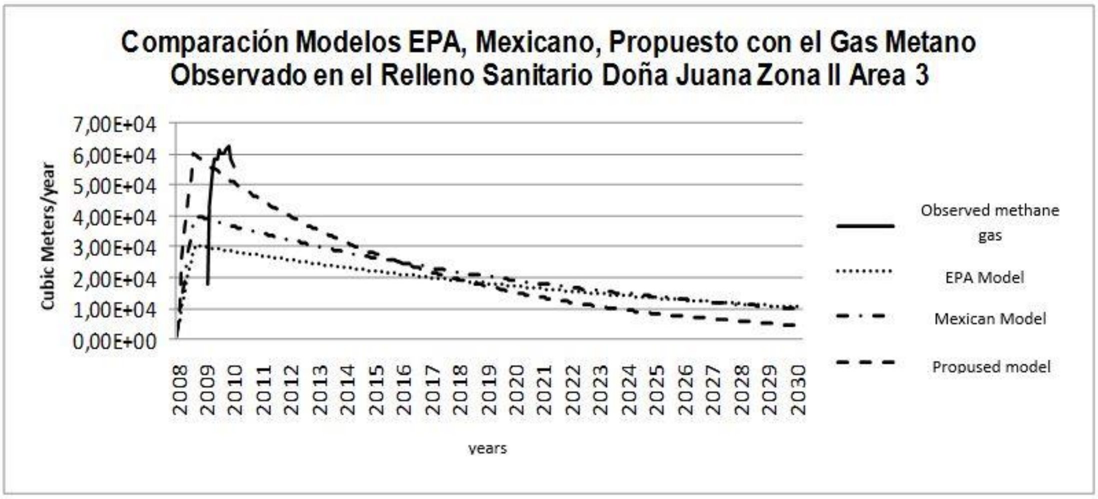

Figure 6. Comparison of methane gas. EPA models, Mexican, and Proposed Model Number observed in the Doña Juana Landfill Area 3 Area II.
***Source**: Authors. 2011*

Is noted in Chapter 10, the estimation of methane gas models with EPA, Mexican and IPCC are the result of the calculation of mathematical assumptions that were made with the kinetic theory of first-order decay, ie the speed decomposition of solid waste, where there is always an exponential decay of the concentration of methane gas generated during which time zero and no production of methane gas because the generation of this is given to the following six months or years after the waste disposed, moreover, in all first-order reaction exists a linear relationship with respect to the amount of time waste and disposal of these.

With respect to EPA and Mexican models, use two constants such as K and I, which were set according to weather patterns and solid waste from the United States and Mexico. As for the humidity of the waste, the temperature of the waste and the cellulose content containing residues of these countries are very different from the characteristics that have residues that are produced in other countries in our case Bogotá, Colombia, Like the average annual rainfall, making these models have a significant error not only

in our country if not in others when making the estimate of methane gas. This indicates that these parameters should be selected with prior knowledge of the specific conditions of the landfill, the type of waste entering the disposal site and geographic location.
Furthermore, the model IPCC, is a model that has four climatic zones such as the boreal and temperate (dry and wet) with temperatures below 20 ° C and the tropical with temperatures above 20 ° C where, you have a dry climate with rainfall below 1000 mm / year, wet and dry precipitation above 1000 mm / year, these climate zones do not possess all countries, so this model also has a considerable error in estimating the time of methane gas. In addition, this model has an exponential growth during a certain period of time, in our case is about 20 years after the completion of two decades, begins its decay phase, presenting a totally different behavior to the EPA and Mexican models.
Moreover, the proposed model is the result of the observed data in the Doña Juana landfill, which is more accurate because all mathematical models according to authors like Ogor & Guerboi not always come to reality, because it has a margin of error that varies between 10% and 20%.
The error in the models EPA and IPCC Mexico, was confirmed at the time of the estimate of methane gas RSDJ data, which can be seen in Figure 6 where the EPA has an error model approximately 51% compared to the observed methane gas also has to be the error between the Mexican model and the observed methane gas is about 35%, confirming what says the Agency for Environmental Protection, USEPA -, with respect to Mexican model which has a higher estimate compared to the previous one.
With respect to the proposed model, it has an error of 3%, which is that the model was formulated with data such as precipitation, temperature of the waste as independent variables but not as constant as do the other models; also used monthly and annual information because when you use each year, information is lost causing the error in the estimation of methane is much greater.
The proposed model builds on the fact Juana landfill in that the production time of the gas starts to two months after having disposed the waste, this is due to how to operate the fill and shape as compacted waste, once closed cell residues have a much more rapid degradation by the type of coverage they used.
Furthermore, the precipitation is an important factor because the greater this, the higher the humidity of the waste and therefore lower production of methane gas, ie the moisture content within a landfill is very important because it affects the generation of methane gas because moisture is a means of transport of nutrients and bacteria. However, in the landfill Juana precipitation is not a factor because they are very low and because the coverage used (clay) is quite waterproofing which prevents moisture from the waste and thus increase there is adequate generation of methane gas.

CONCLUSIONS

It is very remarkable that the EPA models, Mexican and IPCC were made with the characteristics of other countries like the U.S. and Mexico, where the waste composition and climate are very different to that of Colombia. In regard to the Mexican model found what he says about the theory that this has less error than the EPA model, because the Mexican model takes into account the characteristics of different regions of Mexico, however, is not the most suitable for our country because we still have characteristics of other countries. Furthermore, the IPCC model, handles are constant according to different types of climatic zones which account for a certain temperature, which may make this model becomes more accurate, but the climate zone in which Bogota is located and the temperature assigned to the model, it does not own this city, causing considerable error exists in the estimation of methane gas. The values of the constants K and I for the three models in a way have a degree of uncertainty due to geographical conditions were formulated and the site of final disposal of countries like the U.S. and Mexico. Furthermore, these values vary according to rainfall of the place, which influences the decomposition of solid waste. It is clear that these models have been developed from mathematical assumptions and annual reporting, which makes them look very limited in regard to the actual processes of gas generation. For the proposed model using monthly data Juana landfill, causing no loss of information and therefore can more accurately calculate the estimate of methane gas.

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