

Biogas Estimation as a Basis for the Implementation of an Intermunicipal Landfill: Michoacan, Mexico

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Abstract

Municipal solid waste (MSW) generated in the municipalities of Sahuayo, Jiquilpan and Venustiano Carranza in Michoacan, is deposited in open dumps becoming hot spots for health and the environment. The total population in the three municipalities is 130,497 habitants, with a per capita waste production estimated in 0.718 kg·hab⁻¹·day⁻¹ (34,203 t·yr⁻¹). The aim of this study was to estimate the formation of biogas for power generation from the decomposition of waste. The model used was the mexican model of biogas (version 2.0), assuming a useful life of 21 years of the landfill at a cost of 0.19 USD per kWh, the average CFE rate for municipal public lighting. Four possible scenarios were evaluated: one optimal recovering 68% of the biogas (10,095 tonnes of methane in 20 years), having a savings concept in electricity of 8,015,252 USD; in the second case (optimistic intermediate), it is assumed that it obtains 61% of biogas (9046 tonnes of methane) with benefits in power generation for 7,159,679 USD; the third case (pessimistic intermediate) estimating 48% of biogas recovered, being captured 7118 tonnes of methane with profits of 5,633,846 USD into electrical energy, the latter case (pessimistic), assuming 40% of biogas recovered, transforming 4672 tonnes of methane resultant in an economic benefit of 3,697,324 USD for electricity generation. The results justify the investment of the landfill and it is a measure to mitigate climate change and disease prevention.

Keywords

Municipal Street Lighting, Alternative Energy, Public Health

1. Introduction

Mexico is among the main countries producing methane derived from landfills [1] [2] and is on top 10 countries of MSW generation [3]. The deposit of municipal solid waste in Jiquilpan, Sahuayo and Venustiano Carranza, in the state of Michoacan, Mexico (Figure 1), is performed in open dumps (Table 1), causing adverse effects on the environment [4] [5], landscape and human health [6]-[8]. The gases inhalation, contact with waste, leachate infiltration into the bodies of deepwater and contact with pathogens are vectors that can affect the human health; causing simple nausea, irritation of eyes and contact with highly carcinogenic compounds [9] [10].

An alternative solution is the implementation of an intermunicipal landfill, where the biogas generated by the decomposition of organic matter in the MSW is captured [6] [11]. This paper presents four alternative scenarios in which the landfill could generate biogas and be transformed into energy with economic benefits generated for each scenario [12]-[14].

The main reactions that are generated on a garbage dump are the anaerobic type, except for the layers in contact with air, therefore, the main reactions are: fermentative bacterial hydrolysis followed from acetogenesis-acidogenesis and to finally form methane (methanogenesis), having a final composition in the gas mixture of 50% methane, 45% carbon dioxide, and <5% of other gases [15].

Biogas (methane) generated in a landfill is potentially usable as a source of renewable energy, capturing and converting it into energy or heat. Reducing the amount of methane into the atmosphere mitigates global warming, reducing climate change. Converting methane to carbon dioxide equivalent [16], methane has a global warming potential 21 times greater than CO₂ [6] [17]. The Mexican biogas model version 2.0 was used in order to simulate biogas generation. The objective of this work is to provide projections of generation and recovery more accurate and conservative of biogas according to the conditions of the country, to serve to the landfill owners and operators in Mexico as a tool for evaluating the feasibility and potential benefits of capturing and using biogas generated [18] [19].

2. Materials and Methods

In order to model the four scenarios was necessary change some characteristics between them. Besides estimating the generation and recovery of biogas, the model provides an estimate of methane (CH₄) and equivalent emissions of carbon dioxide (CO₂), taking the density of CH₄ as 0.0007168 t·m⁻³ [18] and with a predefined concentration of waste (Table 2).

Biogas production was estimated with the mexican biogas model version 2.0, developed by SCS Engineers under agreement with LMOP program (Landfill Methane Outreach) of the Environmental Protection Agency of the United States (U.S. EPA). The model generates projections of production and recovery of biogas for different scenarios depending on the management of the landfill and serves as a tool to landfill owners and operators in Mexico to evaluate the feasibility, performance and potential benefits of capturing and using biogas generated as an energy source.

To calculate the MSW generation in the municipalities (Jiquilpan, Sahuayo and Venustiano Carranza) the database of the National Institute of Statistics and Geography was used [20]. To obtain the amount of waste that is generated in the municipalities considered in this work, the value of per capita generation in the state of



Figure 1. (a) Mexican Republic, (b) Municipalities of Michoacan (www.inegi.org.mx).

Table 1. Population in the three municipalities.

Municipalities	Population	Waste Generated*
	habitants	t·y ⁻¹
Sahuayo	72,841	19,091
Jiquilpan	34,199	8963
Venustiano Carranza	23,457	6148
TOTAL	130,497	34,203

*No official information on waste recycling, incineration, composting or inert landfill.

Table 2. Characterization of municipal solid waste.

Category of waste	Site specific data
	%
Food	34.5%
Paper and Cardboard	8.1%
Pruning (gardens)	10.6%
Wood	4.6%
Rubber, Skin, Bones and Straw	2.3%
Textiles	2.3%
Other Organic	10.5%
Metals	27.0%

Michoacan was determined by Equation (1),

$$IGH = \frac{\left(\frac{GRA}{DA} \right)}{HM} \quad (1)$$

where IGH is the value of per capita waste generation in the Michoacan State, GRA is the annual state waste generation (2008) given in kg, DA days of the year, HM is the number of inhabitants of the Michoacan State.

The value obtained ($0.718 \text{ kg} \cdot \text{hab}^{-1}$) was applied to the number of residents of the three municipalities resulting an overall product of 34202.827 t of waste per year.

The Mexican biogas model uses the equation of first order decay, expressed in Equation (2):

$$Q_{LFG} = \sum_{i=0}^n \sum_{j=0.1}^1 2kL_0 \left[\frac{M_i}{10} \right] \left(e^{-kt_{ij}} \right) (MCF)(F) \quad (2)$$

where Q_{LFG} is the maximum expected biogas flow, i is the annual increment, n is the year of the calculation less the year of waste initial disposal, j is the time increment at 0.1 years old, M_i is the mass of waste disposed in the year i , t_{ij} is the age of the section j of the mass M_i arranged in year i , MCF is the methane correction factor, value dependent on the depth and type of landfill, F is the adjustment factor for fire. The model assumes a value of 0.5 because the biogas consists of 50% methane and 50% CO_2 with less than 1% of other species, k is the rate of generation of methane and its value depends on the moisture content, nutrient availability, pH and temperature in the landfill, L_0 is the methane generation potential, the L_0 and k values depend on the climate zone where the site is located and speed of degradation of the waste [18].

To perform modeling four possible scenarios were established, variations are shown in **Table 3**.

Other considerations used in the model of biogas are: landfill receives waste for 11 years [21], Having a growth in 2% per year, landfill is a type fill trench with a depth of 12 m with a biogas capture system covering 85% of the area used for waste disposal.

To calculate the amount of electricity that can be generated, Equation (3) was used, based on the results concerning the capacity of the power plant that the model provides (MW) and assuming that operates 90% of the time, also that the total biogas recovered is burned.

$$EO = CPI \times DA \times HR \times PO \times 1000 \quad (3)$$

where EO is the energy obtained given in kWh; CPI is the ability of the plant to install, DA are the days of the year, HR the hours of day and PO is the percentage of operation of generation plant.

To estimate savings that would be obtained for electric power generation, it was considered an average rate 5-A from low to medium voltage of CFE (www.cfe.gob.mx), yielding a value of 0.19 USD per every kWh substituted.

3. Results and Discussion

The simulated period of recovery of biogas is 20 years ranging from 2013 to 2032 with benefits in different areas: environmentally, to reduce emissions of greenhouse gases released directly into the atmosphere, and the resources produced using biogas captured at the landfill to generate electricity and/or exchange of carbon emissions certificates. In **Figure 2**, the results of the four cases of study are shown.

Each CO₂ eq tonnes reduced can be exchanged as a emission reduction certificate (CER's), with a price of 4 euros (5.62 USD), depending on the exchange rate (www.tfsgreen.com), meaning additional benefits to the production of electrical energy generated using the total of CH₄ recovered at the landfill. Both resultant benefits are presented in **Figure 3**.

The overall 20-year results are presented in tabular form in **Table 4**.

At the end of landfill would be deposited 376,231 t of waste, in **Table 5** are shown unit profit per ton of garbage, corresponding only to the use of biogas in electricity generation excluding CER's.

Unit costs are an indicator for detecting the feasibility of such studies. A study carried out in Malaysian involves three important aspects to determine the cost: cost of investment, operation and maintenance and, closure; with a unit total cost of 8.89 USD·t⁻¹ [22]. According to the results obtained in this study, only the first three

Table 3. Features of the proposed scenarios.

Scenarios	Management Site	Fire	Control on the cover of waste	Adequate compaction	Adequate disposal of waste	Leachate outcrop	
						Rainy season	Any Season of year
Optimistic	Yes	No	Yes	Yes	Yes	No	No
Intermediate Optimistic	Yes	No	Yes	Yes	Yes	Yes	No
Intermediate Pesimistic	Yes	No	Yes	Yes	Yes	Yes	Yes
Pesimistic	No	Yes	No	No	No	Yes	Yes

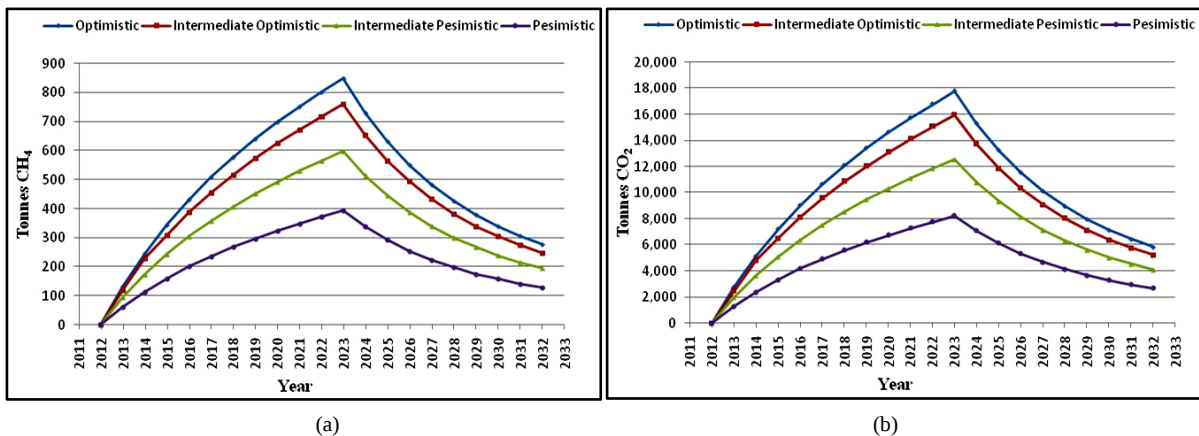


Figure 2. Reduction of emissions of CH₄ annually (a) and the equivalent in CO₂ (b).

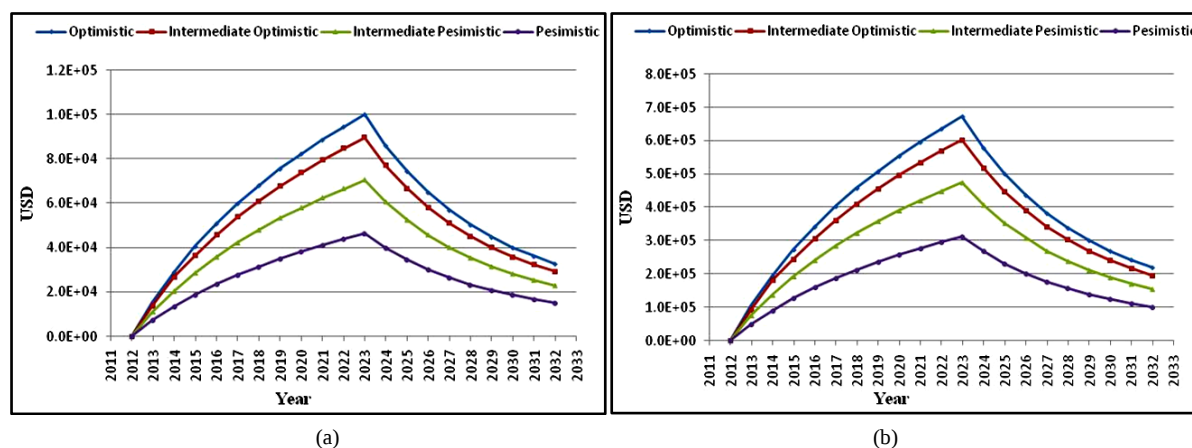


Figure 3. Gains on exchange of CER's (a) and power generation (b).

Table 4. Landfill total benefits.

Scenarios	Emission Reduction of CO ₂ eq (t)	Emission Reduction of CH ₄ (t)	Benefit carbon certificates (USD)	Earnings per energy (USD)	Total Revenue (USD)
Optimistic	211,999	10,095	1,190,607	8,015,252	9,205,860
Intermediate Optimistic	189,969	9046	1,066,882	7,159,679	8,226,561
Intermediate Pesimistic	149,484	7118	839,514	5,633,846	6,473,360
Pesimistic	98,102	4672	550,948	3,697,324	4,248,272

Table 5. Benefit per ton of waste.

Scenarios	Energy savings (USD·t ⁻¹)
Optimistic	19.26
Intermediate Optimistic	17.20
Intermediate Pesimistic	13.54
Pesimistic	8.88

cases are acceptable. The results observed were calculated with economic values at the time the study was conducted, however, it is important to note that the economic projections are subject to change depending on the trends in the price of carbon, combustibles for electrical energy production and costs of electricity. Despite the benefits seen to implement a project of this nature, it is necessary to supplement with a technical-economic financial analysis for a complete study. And the timely characterization of waste in landfills of the municipalities involved, among others.

4. Conclusion

The use of biogas model provides information necessary to make an analysis of situations that could arise during the lifetime of a project of this nature, it can be displayed which are the most important components in the selection of design features or the operation of the disposal site. According to the results obtained in the simulation, just the first three cases are viable for possible implementation in the municipalities of Jiquilpan, Sahuayo and Venustiano Carranza. Moreover, the amount of recoverable methane and transformed in energy represents a significant amount ($>339 \text{ t CH}_4 \text{ yr}^{-1}$), in the worst case, so it is an alternative for mitigating climate change.

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