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Landfill Gas Generation and Utilisation (Case study: Chasinato Landfill. Ambato, Ecuador)

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Abstract. The landfill is a final disposal technique to confine solid waste, it has big potency as renewable energy source since it generates biogas from organic waste degradation process which can be used for cogeneration plants. The purposes are to quantify the gas production potential of landfilled refuse and to suggest alternatives to use energy from Landfill gas generated. In 2020, the volume of solid waste disposed to Chasinato Landfill reached 250.61 tons per day, with 41.03% of organic waste. Landfill gas (LFG) generated was evaluated using LandGEM and Ecuador LFG model, which was modified applying methane rates obtained with on site experimental measures. It was projected to obtain 365.40 cubic meters per hour in 2021, and 522.33 cubic meters per hour in 2029. The available power from recovered LFG reach: 820 kW in 2021 and 1,180 kW in 2029. Finally, the biogas generated reduces the impact related to global warming and would contribute cogeneration in low scale with electric energy and useful heat.

Key words. Energy, Landfill, Solid waste, Cogeneration.

1. Introduction

LFG could be used in some ways: direct use in furnaces, dryers and kilns; as electricity; as a boiler system for production of steam and hot water; as vehicle fuels; as natural gas network for domestic purposes and as leachate evaporation [1].

An important innovation in energy application around the world is Manggar landfill that produced in 2017 about 6.44×106 m3 CH4/year. The estimated methane was converted to electricity using gas engine and trigeneration methods. Using gas engine, methane from Manggar Landfill is predicted to produce electricity about 787 MWh/month. By the way, if trigeneration method applied (by keeping the same gas engine as before), it produces 41.8% of heat which convert to 29.3 kWh of cold **[2]**.

In South-Central Ecuador, it was estimated that in 2053 Pichacay landfill, the highest generation of biogas would be 76,982,177 (m^3/year) and Las Iguanas landfill would generate 693,975,228 (m^3/year) of biogas. In 2020 gas analysis in Pichacay landfill reach an average of 51.49% CH_4,40.35% CO_2, 1.75% O_2 and 17.8% H_2S, whereas Las Iguanas landfill had an average of 51.88% CH_4, 36.62% CO_2, 1.01% O_2 and 187.58 ppm H_2S **[3]**.

In Ecuador, an average of 13,372.47 tons of solid waste was collected daily in 2018. Currently, the Per Capita Production of solid waste (PCP) reaches between 0.22 to 1.8 kg/inhab/day, with an average of 0.597 kg/inhab/day. According to the National Institute of Statistics and Census (INEC) of Ecuador, Ambato is a city with metallurgical, automotive and fruits production, it has 378,523 inhabitants and a solid waste production of 234.68 tons per day **[4]**.

Ecuador has 221 Municipal Decentralized Autonomous Governments (GADM), 51% dispose of their waste in landfills and/or emergent cells, while 49% dispose of their waste in open-air dumps **[5]**, which is the worst form of disposal, with the disposal of all municipal waste directly on the ground, without any care or treatment **[6]**.

The GADM categorization and prioritization respond to the amount of urban solid waste generated. Being these of type: special greater than 500 t/day, large between 251 to 500 t/day, medium between 101 to 250 t/day, small 51 to 100 t/day and micro less than 50 t/day **[5]**. GADM Ambato corresponds to medium type, there are fifteen similar ones in this country (6.8% of total).

Cities in Ecuador with the greatest PCP are Guayaquil, Quito, Santo Domingo, Cuenca, Portoviejo, Ambato, Manta, Esmeraldas, Durán y Quevedo, they produce 70% of total solid waste generation. The PCP average in them reach 1.07 kg/inhab/day **[7]**.

The biggest CO_2 equivalent emissions in Quito and Guayaquil are 157 and 150 ktCO_2eq., respectively, followed by Cuenca (35 ktCO_2eq), with middle emissions: Ambato, Santo Domingo, Portoviejo, Machala, Ibarra, Riobamba y Loja (7.27 a 17 ktCO_2eq.) **[4]**.

The objective of this study is to estimate the amount of biogas produced in Chasinato Landfill, in order to determine the amount of electricity and heat generated from the total biogas. To accomplish this objective, were applied the mathematical models: "Landfill Gas Emissions Model" LandGEM and Ecuadorian model.

2. Methodology

Cities around the world use landfills like places to deposit solid waste. It is a way to degrade solid waste under the soil, but it generates two subproducts that have negatives environmental effects. First, leachate can pollute undergrounds waters where the landfill is located, and second, LFG contents an important gas greenhouse for climate changing. Methane (CH_4) is 21 times more polluter than carbon dioxide (CO_2). In this study, landfill gas was estimated using LandGEM v3.02 (LFG emissions model) and Ecuadorian model v1.0. Also, an experimental measurement in Chasinato LFG let to modify the Ecuadorian model with a real methane rate to contrast the results. These mathematical models were developed by USEPA (U.S. Environmental Protection Agency) in a way to reduce the climate changing.

A. Landfill gas emissions models

LandGEM models use some information about Chasinato landfill such as: opening year, closing year, amount of solid waste per year deposited in the landfill and two fundamental parameters k, L_0 that can be selected or calculated based on geographic location and features of the landfill [8]. LandGEM uses the following first order equation

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k \cdot L_0 \cdot \left(\frac{M_i}{10}\right) \cdot e^{-kt_{ij}} \quad (1)$$

Where:
Q_{CH_4} = the annual production of methane in the year of calculation (m^3/year),
i = time increment of 1 year,
n = the different between the year of calculation and the first year,
j = cutting the year in tenth,
k = the generation coefficient of methane ($year^{-1}$),
L_0 = the potential of CH_4 waste (m^3/Mg),
M_i = the mass of waste accepted in year i^{th} year (Mg),
t_{ij} = the age of the waste section j^{th} accepted the year i^{th} (decimal year).

Ecuadorian model is a modification of LandGEM adapted to geographic and climatologic conditions of Ecuador. Features and information of some Ecuadorian landfills: Las Iguanas in Guayaquil, Pichacay in Cuenca, Chabay in Azoguez, El Valle in Cuenca and Loja landfill were taken to adapt LandGEM for this country [9]. The Ecuadorian model uses this equation to estimate the biogas production

$$Q = \sum_{0}^{n} \frac{1}{\% \, vol} \, k \cdot M \cdot L_0 \cdot e^{-k(t-t_{lag})} \quad (2)$$

Where:
Q = total quantity of landfill gas generated (m^3/year),
n = total number of years modelled,
t = time in years since the waste was deposited,
t_{lag} = estimated lag time between deposition of waste and generation of methane,
$\% \, vol$ = estimated volumetric percentage of methane in LFG,
k = estimated rate of decay of organic waste ($year^{-1}$),
L_0 = estimated volume of methane generated per ton of solid waste (m^3/Mg),
M_i = the mass of waste accepted in year i^{th} year (Mg).

B. Characteristic data of Chasinato landfill

Chasinato landfill started its activities in 2004, but this study took information from 2010. In 2020, Chasinato landfill received approximately 250.61 tons of urban waste per day. This landfill accepts any kind of waste, but the principal residue to produce methane is the organic waste (in this case 41.03%) [3]. Ambato projects that in 2028 Chasinato landfill will use 100% of its capacity to dispose solid waste, so this would cause to stop its activities.

The rate of methane in LFG was determined using an LFG measure equipment, with 0,01 % of resolution and 0,1 m/s for gas flow rate. The LFG measures were carried out in 37 passive wells in two zones of Chasinato landfill. Results of LandGEM, Ecuadorian model and modified Ecuadorian model were mathematically averaged to approximate results to the real case.

3. Results and discussion

The case study was carried out in the landfill of the city of Ambato, located in Complejo Ambiental Chasinato, in the 10 km of Pillaro road. It's located in the following geographic coordinates: 2° 48' 17" S, 79° 25' 20" W (Lat: -1.1953 Lon: -78.5767).

A. Waste composition in Chasinato landfill

Several months after that urban waste is deposited in landfills, it starts to discompose in anaerobic conditions. LFG will be produced after some years, and this will continue until organics nutrients of waste disappear. Table I and II, show information of parameters involved in the estimation and waste generation in Chasinato landfill.

Table I.- Chasinato landfill Information [10], [11]

Open/Closure year	2010 / 2028
Rainfall average annual	1402 mm/year
Area	12 Ha
Composition of waste	%
Organics	36.55
No identified	11.52
Textile	10.98
Toilet paper	10.08
Paper	5.96
Plastics	4.69
Garden organics	4.48
Paperboard	3.26

Table II. Waste disposed in Chasinato landfill [11]

Year	Waste Generation (t/year)
2010	85,348
2011	87,070
2012	88,792
2013	90,514
2014	92,243
2015	97,087
2016	92,444
2017	92,976
2018	103,638
2019	102,372
2020	101,062
2021	104,292

B. Estimation of LFG production using models

Ambato is considered an agro-industrial city, with 41.03% of organic waste. These features of its solid waste and the rainfalls are advantage to generate landfill gas that mainly content methane (CH_4) and carbon dioxide (CO_2). Estimation models predicted a production of landfill gas from 2021 to closure year. However, Chasinato landfill will produce LFG several years ahead after of its operatives closing (Table III).

Table III. LFG generated by LandGEM, Ecuadorian model and modified Ecuadorian model

Year	Waste disposed	LFG generated, LandGEM	
	(t/year)	*(t/year)*	*(m^3/hour)*
2021	104,293	10,220.32	934.24
2022	106,015	10,721.16	980.02
2023	107,737	11,186.31	1,022.54
2024	109,459	11,620.50	1,062.23
2025	111,182	12,027.82	1,099.47
2026	112,904	12,411.84	1,134.57
2027	114,626	12,775.63	1,167.82
2028	116,219	13,121.88	1,199.47
2029	0	13,450.60	1,229.52
2030	0	11,670.03	1,066.76
2031	0	10,125.17	925.54

Year	LFG generated, Ecuadorian model		LFG generated, modified Ecuadorian model	
	(m^3/year)	*(m^3/hour)*	*(m^3/year)*	*(m^3/hour)*
2021	9,747,502.48	1,112.73	14,077,848.76	1,607.06
2022	10,399,197.76	1,187.12	15,019,060.89	1,714.50
2023	11,023,925.74	1,258.44	15,921,325.45	1,817.50
2024	11,623,759.79	1,326.91	16,787,636.90	1,916.40
2025	12,200,613.70	1,392.76	17,620,759.24	2,011.50
2026	12,756,254.39	1,456.19	18,423,244.36	2,103.11
2027	13,292,312.70	1,517.39	19,197,447.57	2,191.49
2028	13,810,294.31	1,576.52	19,945,543.48	2,276.89
2029	14,309,851.41	1,633.54	20,667,029.77	2,359.25
2030	13,209,657.75	1,507.95	19,078,073.01	2,177.86
2031	12,194,051.00	1,392.01	17,611,281.05	2,010.42

C. Comparative analysis of LFG models

The maximum LFG generated in 2029 would correspond to: LandGEM with 1,229.52 m^3/hour and Ecuadorian model with 1,633.54 m^3/hour. The estimated LFG by LandGEM is less than Ecuadorian model, because LandGEM works with information of USA, instead Ecuadorian model estimates LFG with specific information about Ecuador like geographic location, temperature, climatological conditions, and waste composition (Fig. 1 y 2).

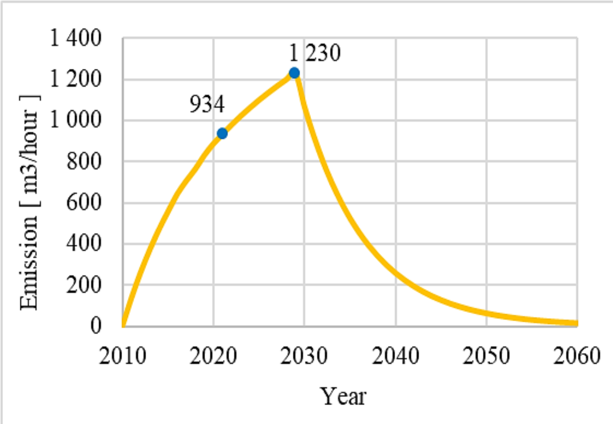

Fig. 1. Biogas emissions in Chasinato landfill, LandGEM model v3.02 (m^3/hour).

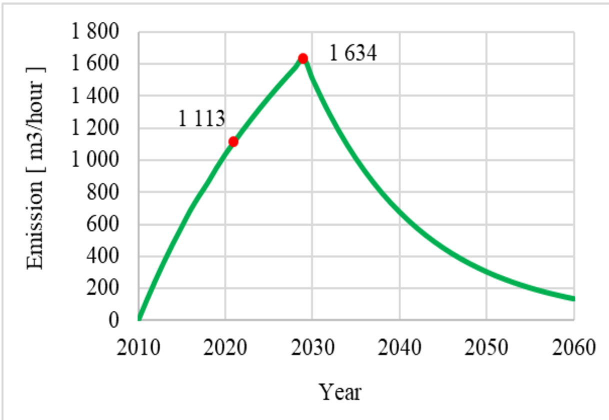

Fig.2. Biogas emissions in Chasinato landfill, Ecuadorian model v1.0 (m^3/hour).

Ecuadorian model was modified with a rate of methane obtained by experimental measurement on site. Biogas of Chasinato landfill contents 34.62% of methane (CH_4), 25.71% of carbon dioxide (CO_2) and 8.08% of oxygen. A variation of methane rate in the Ecuadorian model causes a high estimation of landfill gas than last twice. In 2029 the highest estimation will be 2,359 m^3/hour. These values are less than those corresponding Pichacay 51.49% CH_4 and Las Iguanas landfills 51.88% CH_4 [3] (Figure 3).

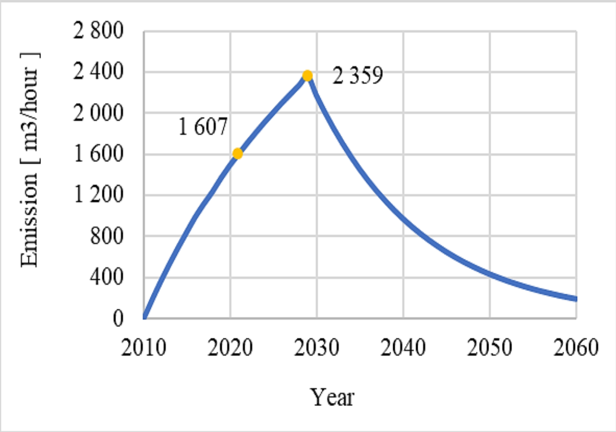

Fig. 3. Biogas emissions in Chasinato landfill, modified Ecuadorian model (m^3/hour).

The estimated LFG emissions by LandGEM are less than Ecuadorian and modified Ecuadorian models in the period 2010 to 2060. A graphic comparison between emissions (m^3/hour) in three LFG models is represented in Figure 4.

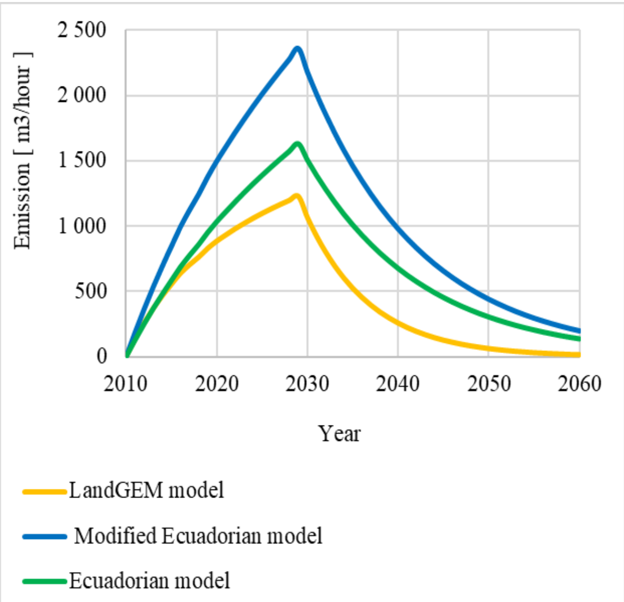

Fig. 4. Biogas emissions in Chasinato landfill, comparison between three LFG models (m^3/hour).

A descriptive statistics analysis that provides information about the central tendency and variability of biogas emissions in Chasinato landfill for three LFG applied models is showed in Table IV.

Table IV. Statistics analysis of three LFG models

Descriptive statistics	LandGEM	Ecuadorian model	Modified Ecuadorian model
Mean	459.18	717.18	1,035.79
Standard Error	57.38	66.13	95.51
Median	342.54	625.47	903.34
Standard Deviation	409.76	472.26	682.06
Sample Variance	167,904.76	223,027.81	465,205.57
Skewness	0.51	0.40	0.40
Range	1,229.52	1,633.54	2,359.25
Maximum	1,229.52	1,633.54	2,359.25
Sum	23,417.97	36,576.17	52,825.21
Confidence Level (95.0%)	115.25	132.82	191.83

D. Conversion of methane gas to electricity

Although Chasinato landfill produces less quantity of biogas according Pichacay and Las Iguanas landfills. This LFG would generate renewable energy to be applied in the same landfill. With an efficiency of 30% in the extraction system the averaged biogas recovered and estimated by LFG models for 2021 was 365.40 m^3/hour. This biogas recovered could produce 820 kW of energy to feed any type of generator, before biogas must be treated.

There are engines designed to operate with LFG, in this case, the best option was a cogeneration equipment with 499 kW of maximum electrical power, 37.1% of electrical efficiency and 46% of thermal efficiency. The production of electrical and thermal energy by cogeneration for 2021 and 2029 is showed in Table V.

Table V. Analysis of electrical and thermal energy production

In 2021	
Electric power produced at 61% of max load	304 kW
Total recovered in heat water at 61% of max load	372 kW
Operation daily hours	12
Energy production per month	109,440 kWh
In 2029	
Electric power produced at 88% of max load	438 kW
Total recovered in heat water at 88% of max load	536.8 kW
Operation daily hours	12
Energy production per month	157,680 kWh

Electrical and thermal energy produced in the cogeneration system could be used in landfill illumination, and the heat water recovered could be employed in containers cleaning and garbage trucks washing. The energy cogeneration exploitation of Chasinato landfill in 2021 and 2029 is showed in Figures 5 and 6.

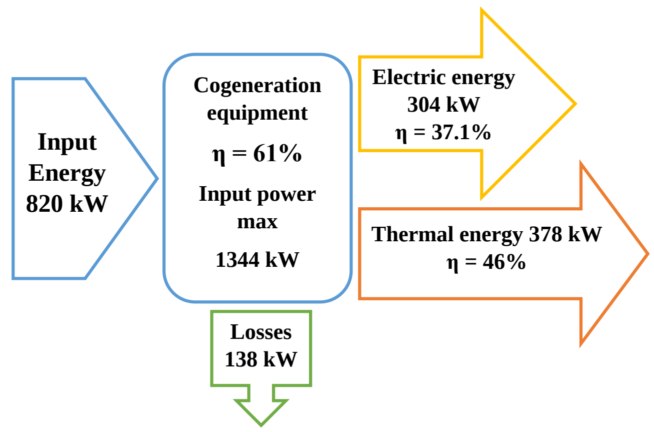

Fig. 5. Sankey diagram of energy exploitation, 2021

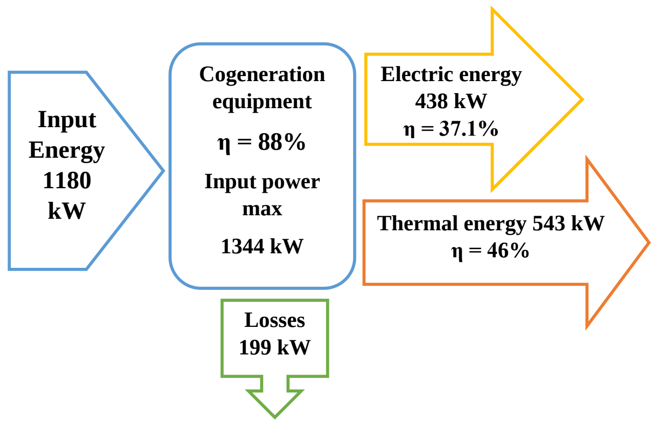

Fig. 6. Sankey diagram of energy exploitation, 2029

By the way, applying this cogeneration method, Chasinato landfill would produces 46% of heat, in comparison with 41.8% of heat in Manggar landfill trigeneration method.

4. Conclusion

In Ecuador 51% of GADM dispose of their waste in landfills and/or emergent cells, while 49% dispose of their waste in open-air dumps. GADM Ambato corresponds a medium type landfill with a solid waste production of 234.68 tons per day. It would project that in 2028 Chasinato landfill would use 100% of its capacity to dispose solid waste. It was estimated the generation of biogas in Chasinato Landfill in 2021, among three LFG models applied, the highest estimation corresponds to modified Ecuadorian model with 1,607.06 m^3/hour and an average content of 34.62% methane, 25.71% CO_2 and 8.08% O_2. Electrical and thermal energy produced in the cogeneration system could be used in landfill illumination, and the heat water recovered could be employed in containers cleaning and garbage trucks washing.

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