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THEORETICAL ESTIMATION OF CO_2eq MITIGATION, IMPLEMENTING A LANDFILL WITH CAPTURE OF BIOGAS APPLIED TO THE LERMA-CHAPALA REGION IN MICHOACAN, MEXICO

Iván Vera-Romero
Trayectory of energy engineering,
University of the Ciénega of Michoacan State,
Sahuayo, Michoacan, Mexico
ivanverar@gmail.com

Melitón Estrada Jaramillo
Trayectory of energy engineering,
University of the Ciénega of Michoacan State,
Sahuayo, Michoacan, Mexico

Agustina Ortiz Soriano
Trayectory of educational innovation,
University of the Ciénega of Michoacan State,
Sahuayo, Michoacan, Mexico

Conrado González Vera
CIIDIR-Jiquilpan, National Polytechnic Institute,
Jiquilpan, Michoacan, Mexico

José Martínez Reyes
Trayectory of energy engineering,
University of the Ciénega of Michoacan State,
Sahuayo, Michoacan, Mexico

ABSTRACT
The aim of this work was to evaluate the use of Municipal Solid Wastes (RSU) to mitigate the CO_2 equivalent (CO_2eq) through the proposal to implement a landfill to produce biogas and use it as a substitute fuel. This proposal is made for the Lerma-Chapala region in the Mexican state of Michoacan de Ocampo, which consists of 17 municipalities at the Norwest of the State. Biogas production was estimated with the Biogas Mexican Model version 2.0. The energy fuels that could be substituted are: alcohol, gasoline, gas oil, natural gas, coal, diesel, LP gas, wood, barrels of oil equivalent (BEP) and electric power. The estimation was for a 21 years period considering the useful life of the landfill. Five fuel energy sources were finally considered as substitutes: oil, diesel, LP gas, BEP and electric power, contrasting the gross saving with total costs of the landfill. The best output was when gasoline was substituted. On the other hand, 890,361 ton of de CO_2eq could be avoided by direct burning of biogas and 147,456 ton of CO_2 by not burning fossil fuels to generate electricity.

Keywords
Municipal Solid Waste, CO_2 mitigation, Fuel substitute, Biogas.

1. INTRODUCTION
Mexico is at the top ten Municipal Solid Waste (RSU) producers worldwide [1] and among the main methane (CH_4) producers [2], [3]. The Mexican state of Michoacan generated 1,100,000 ton of RSU in 2008 (www.inegi.org.mx), and only 60% of them were deposited in controlled landfills, while the rest were dumped without any control. The Lerma-Chapala region of Michoacán state has no control over its waste, contaminating water and creating a negative impact for the environment [4], [5], [6], [7], [8], [9], [10].

The Lerma-Chapala region (Fig. 1) comprises 17 municipalities (Briseñas, Chavinda, Ixtlán, Jacona, Jiquilpan, Marcos Castellanos, Pajacuarán, Purépero, Cojumatlán de Régules, Sahuayo, Tangamandapio, Tangancícuaro, Tlazazalca, Venustiano Carranza, Villamar, Vista Hermosa, Zamora) with Zamora-Jacona and Sahuayo-Jiquilpan as the main ones.

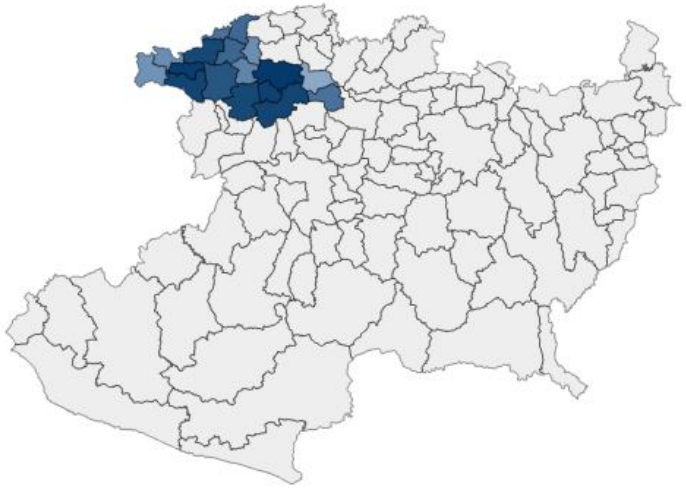

Figure 1. Lerma-Chapala region of Michoacan (www.inegi.org.mx).

This region has a great demand of energy compared to the rest of the State, therefore biogas from a landfill is presented as an alternative for energy. The energy fuels that could be substituted

are: alcohol, gasoline, gas oil, natural gas, coal, diesel, LP gas, wood, dried cow dung, crop residues, barrels of oil equivalent (BEP) and electric power; evaluating a reduction of CO_2 that an electric station could stop producing and the CO_2eq that will not go to the atmosphere by the CH_4 burned from the captured biogas.

2. METHOD

To estimate the production and capture of biogas [11], the Mexican model for biogas version 2 was used [12], which is based on the following equation:

$$Q_{LFG} = \sum_{i=0}^{n} \sum_{j=0.1}^{1} 2kl_0 \left[\frac{M_i}{10}\right] \left(e^{-kt_{ij}}\right) (MCF)(F)$$

Where Q_{LFG} = maximum expected biogas flow in m^3 $year^{-1}$, i = 1 year time increment, n = year of the estimation minus the initial year of the waste dumping, j = time increment in 0.1 years, M_i = mass of the waste in year i, t_{ij} = age of j from M_i in year i, MCF = Methane correction factor (this value depends on the deepness and type of landfill, F = fire adjustment factor. This model assumes that the biogas has 50% CH_4 and 50% CO_2 with less than 1% of other elements, k = Methane generation index and its value depends on humidity content, nutrients availability, pH and the temperature of the landfill, L_0 = Methane potential generation. This model assigns values to a, k and L_0 depending on the climate zone of the site and the waste degradation speed [13] using predetermined data for the characterization of the RSU (Table 1).

Table 1. Characterization of RSU.

Waste category	Michoacan
Food	34.5%
Cardboard and paper	8.1%
Gardening waste	10.6%
Wood	4.6%
Natural gum, leather, bones and hay	2.3%
Textiles	2.3%
Other organics	10.5%
Metals	27.0%

The amount of RSU introduced to the model was obtained from the production index of RSU per capita (0.6926 kg $person^{-1}$ day^{-1}) which resulted from dividing RSU in Michoacan by its population (www.inegi.org.mx), and then by the population of each municipality (Table 2) with a 21 years period.

Table 2. RSU production in the Lerma-Chapala region.

Municipalities	Population	RSU		
	2010	kg day^{-1}	ton $year^{-1}$	ton (11 years)
Briseñas	10,653	7,379	2,693	56,558
Chavinda	9,975	6,909	2,522	52,958
Ixtlán	13,584	9,409	3,434	72,119
Jacona	64,011	44,337	16,183	339,839
Jiquilpan	34,199	23,688	8,646	181,565
Marcos Castellanos	13,031	9,026	3,294	69,183
Pajacuarán	19,450	13,472	4,917	103,262
Purépero	15,306	10,602	3,870	81,261
Cojumatlán de Régules	9,980	6,913	2,523	52,985
Sahuayo	72,841	50,453	18,415	386,719
Tangamandapio	27,822	19,271	7,034	147,709
Tangancícuaro	32,677	22,633	8,261	173,485
Tlazazalca	6,890	4,772	1,742	36,580
Venustiano Carranza	23,457	16,247	5,930	124,535
Villamar	16,991	11,769	4,296	90,207
Vista Hermosa	18,995	13,157	4,802	100,846
Zamora	186,102	128,902	47,049	988,030
TOTAL	575,964	398,935	145,611	3,057,838

The parameters considered for the model are shown in table 3.

Table 3. Data for the estimation.

Concept	Value
Year of opening the site:	2017
Year of dumping the waste:	2017
Year of closure of the site:	2027
Estimated annual increment of the wastes:	2.0%
Average depth of the landfill(m):	12
Design and management of the landfill:	2
It has been any fire in the landfill?	No
Initial year of the capture system (actual/estimated):	2018
Percentage of the area of site with wastes with capture system:	85%
Percentage of the area of the site with wastes with final cover:	20%
Percentage of the area of the site with wastes with medium cover:	40%
Percentage of the area of the site with wastes with daily cover:	40%
Percentage of the area of the site with wastes without cover:	0%
Percentage of the area of the site with wastes with an internal layer of lime/geomembrane:	100%
Are the wastes compacted regularly?	Yes
Dumping is made in a specific area?	Yes
Is there any lixiviate at the surface of the landfill?	No

The calculation of the equivalent for the fuel was done with data from table 4, for a 21 year period.

Table 4. Equivalent for a 1m^3 of biogas [14], [15].

Fuel	Value	Unit
Alcohol	1.1	L
Gasoline	0.8	L
Gas-oil	0.65	L
Natural gas	0.76	m^3
Coal	1.5	Kg
Diesel	0.55	L
LP gas	0.488	Kg
LP gas	0.884	L
Wood	1.3	Kg
Dried cow dung	1.2	Kg
Crops residues	1.3	Kg
Barrels of oil equivalent (BEP)	0.0033	BEP
Electric power	1.25	kWh
Saving of CO_2	0.675	kg of CO_2

Five out of 13 possible fuel substitutes were analyzed in terms of finacial benefits: gasoline, diesel, LP gas, BEP and electric power, contrasting the savings by sustitution of the fuels with the cost of a landfill *ad hoc*.

3. RESULTS

The quantities of fuel equivalents by municipality are shown in tables 5a and 5b. The costs used for the analysis (Table 6) were not affected by an annual increment according to the tendency in the markets (www.hacienda.gob.mx; www.inegi.org.mx; www.cfe.gob.mx), therefore the savings shown in tables 7a and 7b are conservative.

Table 5a. Energetic equivalent amounts at 21 years of the project.

Source	Briseñas	Chavinda	Ixtlán	Jacona	Jiquilpan	Marcos Castellanos	Pajacuarán	Purépero	Cojumatlán de Régules
	(x 10^6)								
Biogas [m^3]	3.449	3.232	4.210	19.285	10.377	4.101	5.841	4.754	3.232
Alcohol [L]	3.794	3.555	4.631	21.214	11.415	4.512	6.425	5.229	3.555
Gasoline [L]	2.759	2.585	3.368	15.428	8.301	3.281	4.673	3.803	2.585
Gas-Oil [L]	2.242	2.101	2.737	12.535	6.745	2.666	3.796	3.090	2.101
Natural gas [m^3]	2.621	2.456	3.200	14.657	7.886	3.117	4.439	3.613	2.456
Coal [kg]	5.174	4.848	6.315	28.928	15.565	6.152	8.761	7.130	4.848
Diesel [L]	1.897	1.777	2.316	10.607	5.707	2.256	3.212	2.614	1.777
LP gas [kg]	1.683	1.577	2.055	9.411	5.064	2.001	2.850	2.320	1.577
LP gas [L]	3.049	2.857	3.722	17.048	9.173	3.626	5.163	4.202	2.857
Wood [kg]	4.484	4.201	5.473	25.071	13.490	5.332	7.593	6.180	4.201
Dried cow dung [kg]	4.139	3.878	5.052	23.142	12.452	4.922	7.009	5.704	3.878
Crops residues [kg]	4.484	4.201	5.473	25.071	13.490	5.332	7.593	6.180	4.201
BEP	0.011	0.011	0.014	0.063	0.034	0.013	0.019	0.016	0.011
Electric power [kWh]	4.311	4.040	5.263	24.106	12.971	5.127	7.301	5.942	4.040
CO_2 [kg]	2.910	2.727	3.552	16.272	8.755	3.461	4.928	4.011	2.727

Table 5b. Energetic equivalent amounts at 21 years of the project (continuation).

Source	Sahuayo	Tangamandapio	Tangancícuaro	Tlazazalca	Venustiano Carranza	Villamar	Vista Hermosa	Zamora	TOTAL [21 years]
	(x 10^6)								
Biogas [m^3]	22.058	8.256	10.051	1.848	6.928	5.188	5.732	56.222	174.76
Alcohol [L]	24.264	9.082	11.056	2.033	7.620	5.707	6.305	61.844	192.24
Gasoline [L]	17.646	6.605	8.041	1.478	5.542	4.151	4.586	44.978	139.81
Gas-Oil [L]	14.338	5.366	6.533	1.201	4.503	3.372	3.726	36.544	113.59
Natural gas [m^3]	16.764	6.275	7.639	1.404	5.265	3.943	4.356	42.729	132.82
Coal [kg]	33.087	12.38	15.076	2.772	10.39	7.783	8.598	84.333	262.14
Diesel [L]	12.132	4.541	5.528	1.016	3.810	2.854	3.153	30.922	96.120
LP gas [kg]	10.764	4.029	4.905	0.902	3.381	2.532	2.797	27.436	85.284
LP gas [L]	19.499	7.298	8.885	1.634	6.124	4.587	5.067	49.700	154.49
Wood [kg]	28.676	10.73	13.066	2.402	9.006	6.745	7.452	73.089	227.19
Dried cow dung [kg]	26.470	9.907	12.061	2.218	8.313	6.226	6.878	67.466	209.71
Crops residues [kg]	28.676	10.73	13.066	2.402	9.006	6.745	7.452	73.089	227.19
BEP	0.072	0.027	0.033	0.006	0.023	0.017	0.019	0.184	0.571

Electric power [kWh]	27.573	10.32	12.563	2.310	8.660	6.486	7.165	70.277	218.45
CO_2 [kg]	18.612	6.966	8.480	1.559	5.845	4.378	4.836	47.437	147.45

Table 6. Costs of fuels and electric power (@17.25 Mexican pesos USD^{-1}; www.banxico.org.mx).

Fuel	Value	Unit ($=Mexican pesos)
Gasoline	13.16	\$ L^{-1}
Diesel	13.77	\$ L^{-1}
LP gas	14.84	\$ kg^{-1}
BEP	24.48	USD MME^{-1}
	422.28	\$ MME^{-1}
Electric power	1.697	\$ kWh^{-1}

Note: Petroleum Mexican Export Mix (MME).

Table 7a. Financial benefits by the substitution of fuels (Mexican pesos x 10^6).

Source	Briseñas	Chavinda	Ixtlán	Jacona	Jiquilpan	Marcos Castellanos	Pajacuarán	Purépero	Cojumatlan de Régules
Gasoline [L]	36.31	34.02	44.32	203.03	109.25	43.18	61.49	50.05	34.02
Diesel [L]	26.12	24.48	31.89	146.06	78.59	31.06	44.23	36.00	24.48
LP gas [kg]	24.98	23.40	30.49	139.66	75.15	29.70	42.30	34.43	23.40
BEP	4.76	4.46	5.81	26.63	14.33	5.66	8.07	6.56	4.46
Electric power [kWh]	7.32	6.86	8.93	40.92	22.02	8.70	12.39	10.09	6.86

Table 7b. Financial benefits by the substitution of fuels (Mexican pesos x 10^6), (continuation).

Source	Sahuayo	Tangamandapio	Tangancícuaro	Tlazazalca	Venustiano Carranza	Villamar	Vista Hermosa	Zamora	TOTAL [21 years]
Gasoline [L]	232.23	86.92	105.81	19.46	72.93	54.62	60.35	591.9	1,839.91
Diesel [L]	167.06	62.53	76.12	14.00	52.47	39.29	43.41	425.8	1,323.57
LP gas [kg]	159.74	59.79	72.79	13.38	50.17	37.57	41.51	407.1	1,265.62
BEP	30.46	11.40	13.88	2.55	9.57	7.16	7.92	77.64	241.33
Electric power [kWh]	46.80	17.52	21.33	3.92	14.70	11.01	12.16	119.2	370.82

The results were compared to the costs of a new landfill, which included fixed and operating costs as well as the costs of closing the site (8.89 USD ton^{-1}) [16]; and the benefits were obtained only for the substitution of gasoline, diesel and LP gas, whilst for the BEP and electric power the results were negative (Table 8); however, the negative results can be reversible and attractive, since oil could increase in price in the short and medium term, and electric power could be applied for higher rates.

Table 8. Benefits for substitution of fuels at the end of the project (21 years).

Fuel substitute	Gross Benefit [Mexican pesos t^{-1}]	Gross Benefit [USD t^{-1}]	Net Benefit [Mexican pesos t^{-1}]	Net Benefit [USD t^{-1}]
Gasoline	\$601.70	34.88	\$448.35	25.99
Diesel	\$432.84	25.09	\$279.49	16.20
LP gas	\$413.89	23.99	\$260.54	15.10
BEP	\$78.92	4.58	-\$74.43	-4.31
Electric power	\$121.27	7.03	-\$32.09	-1.86

Burning biogas directly will avoid 890,361 ton of CO_2eq, whilst 147,456 ton of CO_2 would be avoided by using it to generate electric power instead of fossil fuels (CO_2eq obtained by burning biogas is included in the natural cycle of carbon).

4. CONCLUSIONS

Using biogas as a substitute fuel is highly attractive, especially for internal combustions motors that use gasoline and diesel. On the other hand, biogas could be used for domestic uses and industries that use LP gas. Avoiding the emissions of CO_2eq to the atmosphere, stops the high environmental damage that otherwise is created. This study shows that the generation of biogas by RSU could be a fuel alternative that helps to reduce the energy costs and the mitigation of CO_2eq production.

REFERENCES

[1] Rawat, M. and Ramanathan, A.L. 2011. Assessment of methane flux from municipal solid waste (MSW) landfill areas of Delhi, India. *Journal of Environmental Protection*, 2, 399-407.

[2] US-EPA. 2005. Global anthropogenic Non-CO2 greenhouse gas emissions:1990-2020. U.S. EPA, Washington DC.

[3] Johari, A., Ahmed, S.I., Hashim, H., Alkali, H., and Ramli, M. 2012. Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. *Renewable and Sustainable Energy Reviews*, 16, 2907-2912.

[4] Kumar, S., Gaikwad, S.A., Shekdar A.V., Kshirsagar, P.S., and Singh R.N. 2004. Estimation method for National Methane Emission from solid waste landfill. *Atmospheric Environment*, 38, 3481-3487.

[5] Laurila, T., Tuovinen, J.P., Lohila, A., Hatakka, J., Aurela, M., Thum, T., Pihlatie, M., Rinne, J., and Vesala, T. 2005. Measuring methane emissions from a landfill using a cost-effective micrometeorological method. *Geophysical*

Research Letters, 32, [on line]. DOI: http://dx.doi.org/10.1029/2005GL023462

[6] Aguilar-Virgen, Q., Armijo-De Vega, C., and Taboada-González, P. 2009. El potencial energético de los residuos sólidos municipales. *Ingeniería Revista Académica*, 13, 59-62.

[7] Ayomoh, M.K.O., Oke, S.A., Adedji, W.O., and Charles-Owaba O.E. 2008. Anapproach to tackling the environmental and health impacts of municipal solid waste disposal in developing countries. *Journal of Environmental Management*, 88, 108-114.

[8] Moy, P., Krishnan, N., Ulloa, P., Cohen, S., and Brandtl-Raul, P.W. 2008. Options for management of municipal solid waste in New York City: A preliminary comparison of health risks and policy implications. *Journal of Environmental Management*, 87, 73-79.

[9] Gillett J.W. 1992. Issues in risk assessment of compost from municipal solid waste: occupational health and safety, public health, and environmental concerns. *Biogas and Bioenergy*, 3, 145-162.

[10] Karak, T., Bhattacharyya, P., and Das, T. 2013. Non-segregated municipal solid waste in an open dumping ground: A potential contaminant in relation to environmental health. *International Journal of Environmental Science and Technology*, 10, 503-518.

[11] Temelis, N.J., and Ulloa, P.A. 2007. Methane generation in landfills. *Renewable Energy*, 32, 1243-1257.

[12] Aguilar-Virgen, Q., Armijo-de Vega, C., and Taboada-González, P., 2011. Modelo mexicano para la estimación de la generación de biogás. *Ingeniería Revista Académica*, 15, 37-45.

[13] Stege, G.A., and Davila, J.L. 2009. Manual del usuario modelo mexicano de biogás versión 2.0. Washington DC.

[14] Vera, R.I. 2014. Análisis de la viabilidad para un proyecto de microgeneración. Cogeneración integral a pequeña escala. Editorial Académica Española. Ed. España.

[15] Martínez, L.M. 2015. Producción potencial de biogás empleando excretas de ganado porcino en el estado de Guanajuato. *Nova Scientia*. 96-115.

[16] Chong, T.L., Matsufuji, Y., and Hassan, M.N. 2005. Implementation of the semi-aerobic landfill system (Fukuoka method) in Developing Countries: A Malaysia Costo Analysis. *Waste Management*, 25: 702-711.

