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Reducing Emissions of Greenhouse Gases from Oradea Landfill by Generating Renewable Energy from Landfill Gas

Ion Vasile-Emilian[1], Laslo Eugen[2], Ionescu Vlad-Sebastian[3]

[1]*University of Oradea & Universtităţii str no.1, Oradea, Romania*
[2]*University of Oradea & Universtităţii str no.1, Oradea, Romania*
[3]*University of Oradea & Universtităţii str no.1, Oradea, Romania*

***Abstract*— Ecological municipal landfills should address several issues related to environmental protection related to protecting the environment against air pollution by greenhouse gases and against water pollution. Landfill gas contains about 50% CH4 and 50% CO2, gases with strong greenhouse effect, and is recommended to burn it with flares or use in turbines or internal combustion engines to produce electricity and heat. Leachate is a highly polluted landfilled waste product and must be treated before release into the environment. Accurate estimation of the amount of landfill gas generated and possibly to be recovered, allow the design of a modular power generation system which allow to add or remove modules at the optimum time, depending on the amount of landfill gas generated and recovered. Landfill gas emissions in the atmosphere can thus be calculated and reduced.**

***Keywords*— Renewable energy, landfill gas, greenhouse gases, municipal solid waste, landfilling.**

I. Introduction

Oradea's municipal landfill was opened in 2005 and has a volume V=3.782.184 m3, having the form of a pyramid trunk with a base area of S=227.000 m2 and an upper area of s=153.600 m2. This is projected to accommodate Bihor county's landfill needs until the year 2025. For this projection, the following factors were taken into account:

The population distribution by settlement type in the year 2005:

- densely populated urban settlements – 37,0 %,
- urban settlements – 15,5 %,
- rural settlements – 47,5 %;

Estimated waste quantities for the year 2005:

- 628 kg / person / year in densely populated urban areas,
- 488 kg / person / year in urban areas,
- 256 kg / person / year in rural areas;

And finally Bihor county's population in 2005: 575398.

TABLE I
WASTE QUANTITIES GOING TO LANDFILLDURING 2005-2025

Waste quantities going to landfills during 2005- 2025	Oradea landfill capacities
3.036.140,67 t	4.538.620,80 t
2.530.117,22 m^3	3.782.184,00 m^3

Having at least this data, we can obtain an estimate of the landfill gas emissions for the aforementioned monitoring period.

Most landfill gas emission prediction models are based on the general kinetic expression of the biodegradation process, known as the Monod equation:

$$\frac{dC}{dt} = \frac{KxC}{K_C+C} \quad (1)[1]$$

where C is the organic carbon concentration left over in the wastes at time t (the mass of carbon in the wastes / the total mass of the wastes), x is the concentration of microorganisms in the wastes (kg/m^3, K is the maximum decaying rate of wastes per kg of microorganisms. K_C is the concentration of wastes for which this rate is half of K.

II. LandGEM Model

The LandGEM software program was developed by the United States Environmental Protection Agency (USEPA) and uses a first order decay equation to predict the amount of gas generated over time:

$$Q_{CH_4} = \sum_{i=1}^{n} k * L_0 * M_i * e^{-k*t} \quad (2)[2]$$

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k * L_0 * \frac{M_i}{10} * e^{-k*t_{ij}} \quad (2')[2]$$

where Q_{CH4} is the amount of methane generated, k is the constant rate of first order decay, L_0 is the methane generation potential, M_i is the amount of existing landfill at time t. In the second improved form of the equation the mass of waste deposited in year i is divided in 10 fraction and t_{ij} is the age of waste fraction j from waste mass M_i accepted in year i. We can use implicit values for k and L_0, or specific values taken from on-site measurements.

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III. Oradea's Landfill Data

To estimate the quantity of landfill gas generated by the wastes deposited in Oradea landfill during 2005-2025 we used the amounts of wastes deposited in the period 2005-2013 and for the period 2014-2025 was used the average of amounts deposited in the years 2005-2013.

TABLE II
Municipal Solid Waste Quantities Deposited In Oradea landfill

Year	Input Units *(tons/year)*
2005	22,070
2006	125,578
2007	129,843
2008	198,518
2009	141,001
2010	171,687
2011	252,467
2012	147,898.57
2013	128,931
2014-2025	146,444 average of 2005-2013 period

For wastes deposited at the landfill from Oradea were established the values for the rate constant of biodegradation k∈ [0.03;0.04] and for the methane generation potential L_0 ∈ [50,65] m3 / ton. The efficiency of landfill gas recovery system of Oradea landfill is currently at 40% because the deposited wastes are temporarily covered with a layer of soil of 50cm. If the stored wastes will be covered according to the project with a HDPE liner, the efficiency of the recovery system coul be over 80%. The percentage of methane is 54% in landfill gas recovered from Oradea landfill.

To calculate the amount of landfill gas generated we used a slightly modified LandGEM model formula, because in most cases described in the literature revealed that it overestimate the amount of landfill gas generated especially if landfill do not allow leachate recirculation.

We wrote a software for calculation that uses a modifiable time division year/j for waste section M_j mass, and we found that best value is year/6 or j=1/6. Values resulting from modeling were multiplied by coefficient of the efficiency of the recovery system and compared with the values measured in the field from the meter of the vacuum pump.

TABLE III
Landfill Gas Recovery Rates

Year	Landfill gas recovered
2011	100 m^3/h
2012	118 m^3/h
2013	130 m^3/h
2014	150 m^3/h

IV. Results

Because until the year 2025 Oradea landfill will accept wastes, the amount of generated landfill gas will increase, and after that the amount of landfill gas will begin to decrease.

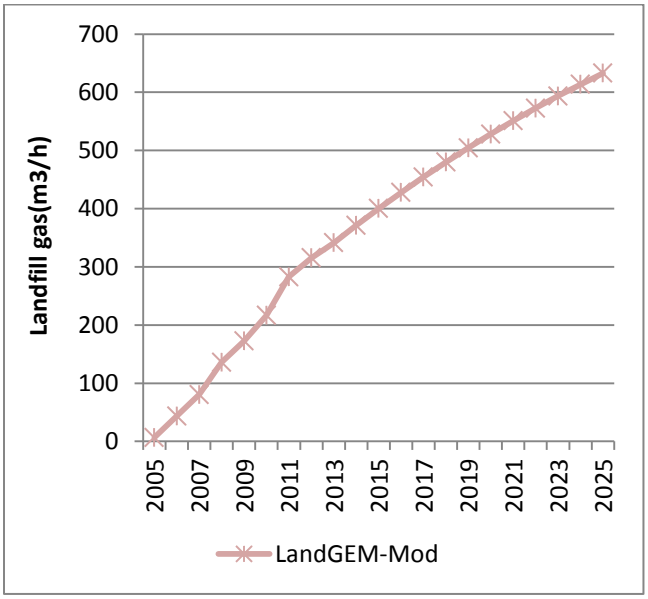

Figure 1 Modeling landfill gas generation for Oradea landfill with LandGEM modified equation for 2005-2025 period

Knowing the amount of landfill gas generated by the wastes from Oradea nonhazardous landfill and considering the collection efficiency of landfill gas and landfill gas calorific value of 6.2 kWh/m^3[3], we can calculate the amount of energy released by landfill gas burning.

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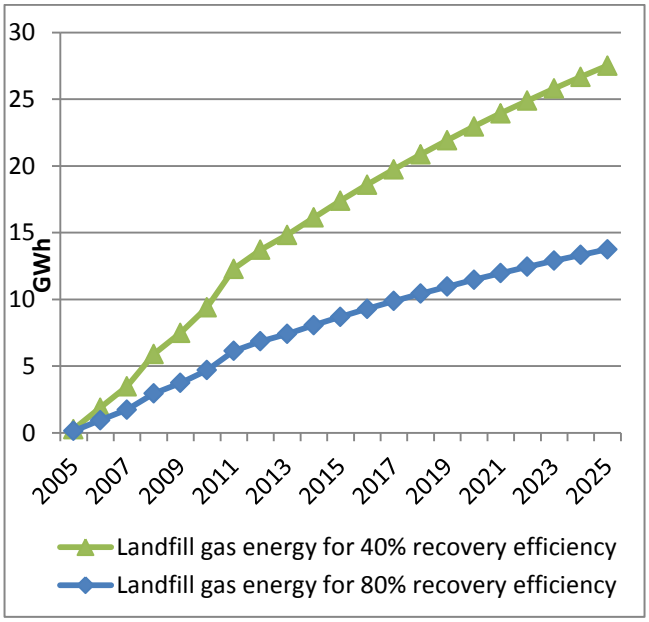

Figure 2 Energy content of landfill gas for different recovery efficiencies

In figure 3 are calculated amounts of electricity that can be produced in 2005-2025 period according to below equation:

$$E_{el} = m_{LFG} * LHV_{LFG} * R * \eta_{el} \quad (3)[4]$$

where: E_{el} is electric energy in kWh, m_{LFG} is the amount of generated landfill gas in m^3, LHV_{LFG} is calorific value of landfill gas(kW/m^3), R is recovery efficiency and η_{el} is electric efficiency of the power generation system(38%)[3].

In figure 4 are calculated amounts of heat that can be produced in 2005-2025 period according to below equation:

$$E_{th} = m_{LFG} * LHV_{LFG} * R * \eta_{th} \quad (4)[4]$$

where: E_{th} is heat energy in kWh, m_{LFG} is the amount of generated landfill gas in m^3, LHV_{LFG} is calorific value of landfill gas(kW/m^3), R is recovery efficiency and η_{th} is thermic efficiency of the power generation system(45,4%)[3].

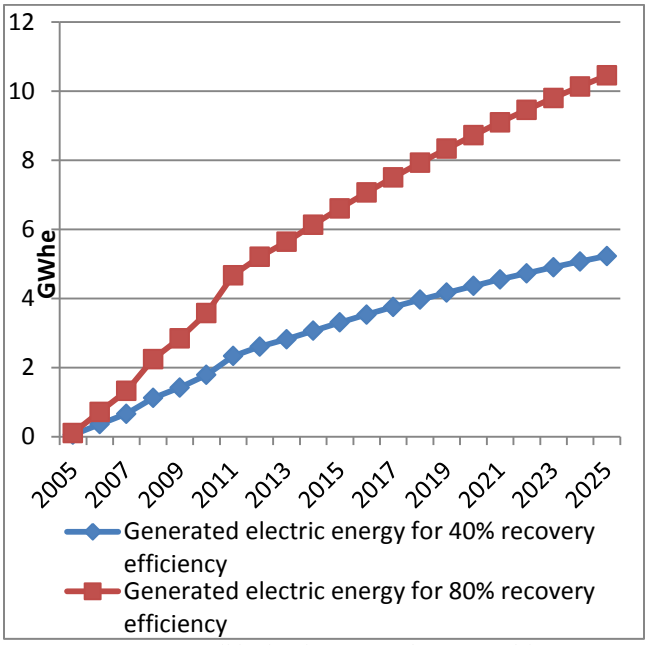

Figure 3 Possible electric energy to be generated for different recovery efficiencies

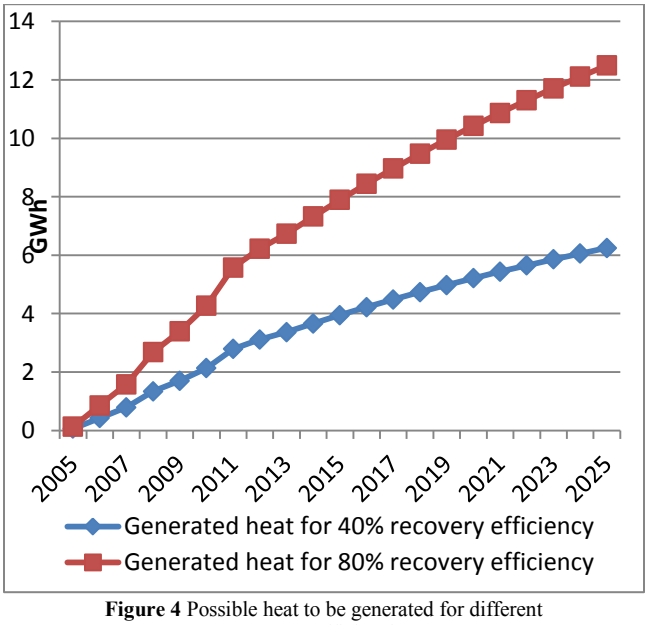

Figure 4 Possible heat to be generated for different recovery efficiencies

For the period 2005-2025 a forecast of the time periods in which it is appropriate to add additional power generation units of 250kW NRG250-GV8DTI is shown in figure 5(this generation units require $100m^3/h$ landfill gas flow [3]).

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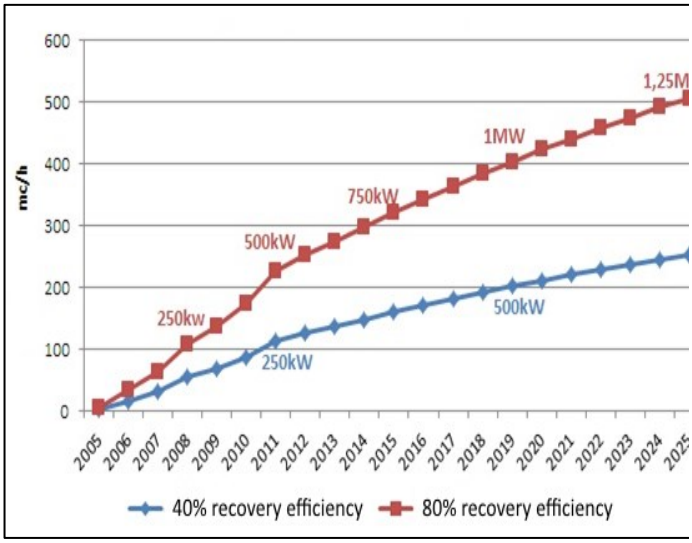

Figure 5 Time periods when is necessary to install additional CHP units of 250kW power

The amount of landfill gas that is not recovered reaches the surface of the landfill and is emitted into the atmosphere. The amount of landfill gas emitted is calculated by the following formulas:

$$Q_{LFGe} = Q_{LFGg} - Q_{LFGr} \quad (5)$$

$$Q_{eqCO_2} = Q_{LFGe} * F_{CH_4} * 0.6802 * 21 + Q_{LFGe} * F_{CO_2} * 1.797 \quad (6)[5]$$

where:

- Q_{LFGe} is the amount of emitted landfill gas,
- Q_{LFGg} is the amount of generated landfill gas,
- Q_{LFGr} is the amount of recovered landfill gas,
- Q_{eqCO2} is amount of emitted landfill gas in CO_2 equivalent,
- F_{CH4} is methane fraction in landfill gas,
- F_{CO2} is carbon dioxide fraction in landfill gas,
- 0,6802 is weight in kg. of one m^3 of methane at standard temperature and pressure,
- 1,797 is weight in kg. of one m^3 of carbon dioxide at standard temperature and pressure,
- 21 is global warming potential of methane compared to carbon dioxide.

In figure 6 are calculated landfill gas emissions in CO2 equivalent depending on efficiency of landfill gas recovery system.

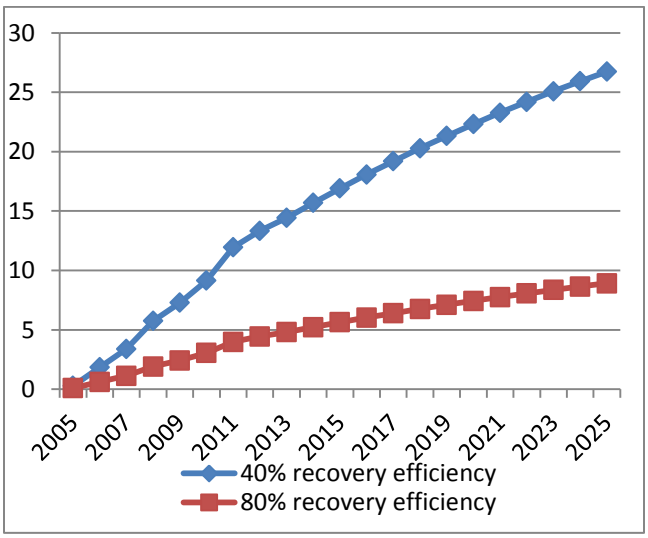

Figure 6 Landfill gas emissions in thousand tons of CO_2 equivalent for different recovery efficiencies

V. Conclusions

The recovery and use of landfill gas in a cogeneration system at the Oradea landfill during 2005-2025 could produce electricity between 50,6GWh and 101,2GWh and thermal energy between 76,2GWh and 152,4GWh (depending on landfill gas recovery efficiency 40% current and 80% possible) using NRG250-GV8DTI generating units of 250kW.

Knowing how the amount of gas generated increase and decrease it is possible to add (or remove) power generating units of 250kW at optimal time according to figure 5 to avoid landfill gas (energy) loss.

If a HDPE liner will be installed landfill gas recovery efficiency would increase to 80% and emissions would decrease as shown in figure 6.

References

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