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Energy Recovery from a Municipal Solid Waste (MSW) Landfill Gas: A Tunisian Case Study

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Abstract

The purpose of this paper is to estimate the amount of landfill gas (LFG) generation from Jebel Chakir landfill which is the first largest landfill in Tunisia. To achieve that LandGEM model was used in predicting the amount of LFG generation. It was found that the LFG generation reaches its peak value of 2.61×10^7 m^3/year by the year 2011, one year after the landfill closure. Furthermore, the power that can be obtained from the landfill in case of LFG recovery was estimated to be 35.5 GWh, providing a significant power generation opportunity at Jebel Chakir landfill. Utilizing the biogas will not only generate a green energy, but also will create a source of revenue through selling the certified emission reduction regulated by Clean Development Mechanism of Kyoto protocol.

Keywords: Landfill gas; Energy recovery; Power energy; Land GEM

Introduction

Municipal solid waste (MSW), when landfilled, causes several environmental problems such as leachate, the presence of vectors (e.g., insects, rodents, and birds), public health hazard explosion and combustion, asphyxiation, vegetation damage, and greenhouse gas (GHG) emissions [1].

Landfill gas are produced from the decomposition of the organic fraction of municipal solid waste and they include mainly methane (CH_4) and carbon dioxide (CO_2) but also ammonia (NH_3), carbon monoxide (CO), hydrogen (H_2) and oxygen (O_2) [2]. Non-methane organic compounds (NMOCs) usually make up less than 1% of landfill Gas [3]. LFG can contribute to malodour and present health and safety hazards if it is not well controlled. Many landfill sites have installed LFG recovery and utilization systems or landfill gas to energy systems to recover the energy value of LFG and to minimize its pollutant effects.

The rate and volume of landfill gas produced depend on the age and composition of landfilled refuse, its moisture content, the geology of the site, the leachate level, the temperature distribution within the landfill, the presence of oxygen, and the effectiveness of capping of the site [4]. Methane is regarded as one of the most important GHG because its global warming potential has been estimated to be more than 25 times of that of carbon dioxide and is an explosive gas in concentrations between 5 and 15% in air [3].

In this study the possibility of reducing GHG emission during landfill life is analysed with reference to innovative possibilities of energy recovery from LFG.

Materials and Methods

The landfill site

The examined landfill of Jebel Chakir is located 10 km from the southwest of Tunis City; it has a capacity of about 7 million tons of Municipal Solid Wastes and a global area of 31.32 ha. The filling started in 1999 and stopped in 2010; Table 1 shows the yearly quantities of disposed wastes in the period 1999–2010.

The waste in the landfill is composed from organic fraction (composed mainly of food waste) (65%), papers-cardboard (12%), fines (8%), plastics, leather and rubber (7%), metals (4%), textiles (3%) and glass and ceramic (1%) [5].

Biogas extraction plant has worked since 2008, and Table 2 gives the measured biogas flow rate.

The climate in Tunis City is of Mediterranean type with a precipitation average of 450 mm/year. The summer (from June to August) is the dry season, while winter (from December to February) is the wet one. The annual average temperature is 19°C (minimum in January with 12°C and maximum in August with 27°C), and the average evaporation rate is 129 mm/month.

Landfill gas generation modeling

To estimate the amount of LFG generated from the landfill of Jebel Chakir, the LandGEM model was used. This model is selected since it is the most reliable model for the quantification of LFG emission rates and provides the most conservative and proximate estimates [6].

Year	Quantity (tons)
1999	400 000
2000	349 759
2001	622 270
2002	604 296
2003	628 662
2004	690 370
2005	672 004
2006	658 580
2007	657 395
2008	654 377
2009	654 156
2010	685 230

Table 1: Yearly disposed quantities of MSW in Jebel Chakir landfill.

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Year	LFG (m^3/h)
2008	1012
2009	1050
2010	1024
2011	867

Table 2: Extracted biogas flow rates.

The LandGEM is developed by the United States Environmental Protection Agency. It determines the mass of methane generated using the methane generation capacity and the mass of waste deposited. The LandGEM emission methodology can be described mathematically by [7]:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0,1}^{1} k L_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}}$$

Where

Q_{CH4} = annual methane generation in the year of the calculation (m^3/year)

i = 1-year time increment

n = (year of the calculation) - (initial year of waste acceptance)

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (1/year)

L_o = potential methane generation capacity (m^3/ton)

M_i = mass of waste accepted in the i^{th} year (ton)

t_{ij} = age of the jth section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

The required inputs for estimating the amount of generated landfill gas are the design capacity of the landfill, the annual acceptance rate, the landfill gas generation constant k, the landfill gas generation potential L_0 and the number of year of waste acceptance. In this study, AP-42 default values (arid region) have been taken under consideration as follows: k=0.02 /year; L_0=100 m^3/ton; NMOC concentration=600 ppmV; Methane volume content=50 %;

Results and Discussions

Landfill gas generation from Jebel Chakir landfill

The annual LFG productions predicted by the LandGEM model and the collected LFG during 38 months (end 2008 to 2011) are depicted in Figure 1. The peak LFG generation will take place one year after the landfill closure (2011) with a rate estimated to be 2.61×10^7 m^3/year. The LFG generation rate will decrease exponentially after the landfill closure parallel to the decrease of the amount of decomposable matter in the landfill [8,9].

The LFG collection system efficiency defined as ratio of the collected LFG quantity relative to the LandGEM estimated LFG production was around 33%.

The LFG collection at the landfill of Jebel Chakir decreased by about 15% from the year 2008 to 2011. According to the field inspection at the Jebel Chakir landfill, MSW are directly exposed to the atmospheric air due to the poor daily covering of waste. The final cover layer revealed also the presence of runoff erosion, cracks and leachate springs on the slopes of the site. Also a seasonal variation in the LFG collection was recorded with the highest value (9.7×10^4 m^3) depicted in summer and the lowest (8.6×10^4 m^3) in winter. This fact may be related to the role of temperature in the organic compounds degradation as. This last was enhanced by summer high temperature and inhibited by lower winter one.

LFG energy potential

The goal of this analysis is to determine the amount of electric energy potentially available in the landfill of Jebel Chakir assuming the actual and the projected LFG collection efficiency as 33% of LFG production. Furthermore, a CH4 calorific value of 4475 kcal/m^3 was presupposed. The energy potential of recuperated LFG (GWh/y) is reported in Figure 2. During the year 2011, the LFG is estimated to be sufficient to generate 47 GWh. If considering a plant began operation in 2011, it would be 15 years old by the end of 2025. That is, it would be near the end of a typical useful economic life of engines and other equipment used in a landfill. In the year 2025, the recovered landfill biogas will be sufficient to generate 35.5 GWh, providing a significant power generation opportunity at Jebel Chakir landfill.

Greenhouse gas emission reductions

Landfill biogas recovery projects can decrease emissions of greenhouse gases. One ton of methane is estimated to have a global warming potential (GWP) equivalent to 25 tons of carbon dioxide. It is recommended to best exploit the methane as a renewable source of energy and hence reducing the environmental problems resulting

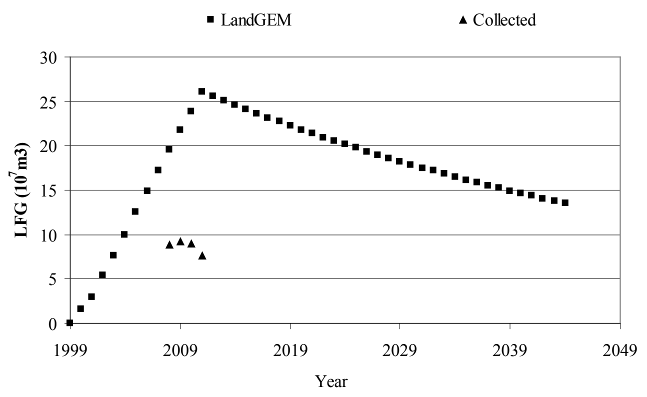

Figure 1: Annual LFG production provided by LandGEM and collected (2008-2011) in Jebel Chakir landfill.

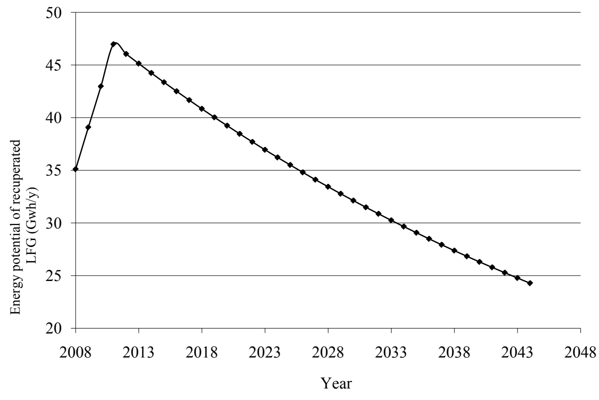

Figure 2: LFG Energy potential (GWh) in the landfill of Jebel Chakir.

from its emission to the atmosphere. In Jebel Chakir landfill, the total Emission reductions achievable from the LFG recovery during the 15-year period, 2011 through 2025, are 8.14×10^7 tons of CO2eq. This suggests the possibility of making use from the Clean Development Mechanism of Kyoto Protocol, by selling the certified emission reduction. Assuming a cost of 12 US $ for each ton of CO_2, the income from the carbon credit will be about 976,800,000 US $ in the year 2011.

Conclusion

Landfills are source of greenhouse emissions. If biogas recovered from the landfill, adverse environmental impacts will be minimized. In addition, clean energy will be produced that will offset the polluting fossil fuel. In this study, LFG generation from Jebel Chakir landfill was estimated using LandGEM model. It was estimated that the amount of landfill gas generated in the year 2011 is set to 2.61×10^7 m^3/year, while the power that can be obtained from the landfill in case of gas recovery will be 35.5 GWh, providing a significant power generation opportunity at Jebel Chakir landfill. In addition, the amount of greenhouse gas emission reduction will be about 8.14×10^7 tons of CO_2 eq in that year. It is recommended to carry out a field study by conducting a pump test, so as to verify the results of landfill gas modelling process.

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