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Estimation of gas emission and derived electrical power generation from landfills. Trinidad and Tobago as study case

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ABSTRACT

In Trinidad and Tobago, it is a common practice to dispose of generated solid waste in open areas without any prior treatment. The average person generates approximately 4 lbs of waste per day This amounts to approximately 1000 tonnes of waste that reaches the landfill sites per day. Actually, the country is facing a shortage in natural gas for power generation; hence, the purpose of this article is to illustrate the environmental benefits and feasibility of utilizing landfill gas as alternative source energy. The methane generation model used for this study is the Landfill Gas Emissions Model (LandGEM). The methane generation rate constant, k and the potential methane generation capacity, L_0 were determined using theoretical methods. The LandGEM model assumed 50% methane and 50% carbon dioxide landfill gas composition by volume. Using a k value of 0.119/year and a L_0 value of 159 m^3 methane/year the model estimated a methane generation flowrate of 30,367,038 m^3/year (20,259 Mg/year) and a total landfill gas flowrate of 60,734,076 m^3/year (75,846 Mg/year). This project has an IRR of 3% and is capable of generating 8.3 MW of electricity.

Introduction

A municipal solid waste landfill is a discrete area of land or an excavation that receives household waste. Landfills can also receive commercial solid waste, non-hazardous sludge and industrial solid waste. Landfill waste typically includes organic material that decomposes in the landfill. The practice of compacting and covering the waste creates suitable conditions during decomposition which produces landfill gas. Landfill gas typically consists of methane and carbon, in the literature, the landfill gas production is wide reported offering several methods for to mitigate the emissions [1–3]. Emissions associated with landfilling waste need to be estimated for the counterfactual scenario. One way to estimate emissions is to directly measure the flowrate from landfills. However, in practice, emissions from a mixture of waste streams are usually measured together at a certain point in time. The methane generation model that will be used for this study is the Landfill Gas Emissions Model (LandGEM) which was developed by the U.S. Environmental Protection Agency (EPA) [5,6] based on the estimated waste acceptance data, preliminary waste characterization and estimated methane generation constants. The economics of viable utilization options for the landfill gas at will be assessed. The environmental benefits of utilizing the landfill gas and the impact of flaring the landfill gas will also be evaluated for the Landfill.

Methodology

LandGEM uses the following first-order decomposition rate equation to estimate annual emissions over a specified time period. The equation used is defined below:

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_i}{10}\right)\left(e^{-kt_{ij}}\right) \tag{1}$$

The following user inputs are required to estimate annual emission in LandGEM:

- Landfill Open Year – This is the first year that the landfill accepted waste
- Landfill Closure Year – This is the year the landfill stopped or is expected to stop accepting waste. This is required if the waste design capacity of the landfill is not known.
- Waste Design Capacity – This is the total amount of waste that can be disposed in the landfill. This input is required if the landfill closure year is not known. Either landfill closure year or waste design capacity is required to be entered, not both.

The following model parameters are required to estimate annual emissions in LandGEM:

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Nomenclature

Ar	ratio of paper and fabric in total waste
Br	ratio of organic waste such as garden and park waste, in total waste
Cr	ratio of food wastes in total waste
CHP	combined heat and power
DOC	degradable organic carbon (fraction)
DOC_F	degradable organic carbon by microorganisms (fraction)
Dr	ratio of wood and straw in total waste
F	ratio of methane gas in landfill gas.
i	1-year time increment
j	0.1-year time increment
k	methane generation rate (1/year)
L_o	potential methane generation capacity (m^3 per megagram [Mg] or cubic feet per ton)
LandGEM	Landfill Gas Emissions Model
MCF	methane correction factor. If aerobic, MCF = 0, and, if anaerobic, MCF = 1. A general default value of 0.6 is recommended
M_i	mass of solid waste disposed in the *i*th year (Mg or ton)
N	(year of the calculation) – (initial year of waste acceptance)
Q_{CH4}	estimated methane generation flow rate (in cubic meters [m^3] per year or average cubic feet per minute [cfm])
t_{ij}	age of the *j*th section of waste mass disposed in the *i*th year (decimal years)
T	temperature in the landfill Trinidad and Tobago Solid Waste Management Company Limited (SWMCOL)

- Methane generation rate (k)
- Potential methane generation capacity (L_0)
- NMOC concentration
- Methane content

Suitable values of the methane generation rate (k) and the potential methane generation capacity (L_0) will be determined based on the characteristics of the Landfill. The default value for NMOC concentration will be used since this is not within the scope of this study. A methane content of 50% by volume will be used.

Annual methane emissions.

The landfill opened at the end of 1970 as an uncontrolled dump site [5]. Since the waste design capacity is not available, it is assumed the maximum waste acceptance of the landfill is 80 years from 1971 to 2050. The waste acceptance data from 1970 to 2004 has been extracted from a study conducted by the Trinidad and Tobago Solid Waste Management Company Limited, however, they can't provide the data prior to 1990 and after 2005. But LandGEM model requires the annual waste acceptance date since the landfill is open. Therefore, the total waste acceptance rate from 1971 to 1989 (1,381,132 Mg) was assumed equally distributed over that time period. Besides, the approach to waste estimation for the period of 2005–2050 would be based on population and population growth data for Trinidad and Tobago coupled with expected waste generated per capita. However, there are several factors which should be considered in estimating the waste acceptance rates for the landfill. The waste acceptance data for the landfill from 1990 to 2004 is summarized in the Table 1, which will be used to for the inputs and parameters in the project.

Waste characterization

The waste characterization data for the Landfill was extracted from [6]. The data is summarized in the Table 2.

Waste characterization has been grouped into three major categories:

- Relatively Inert – Paper, textiles, fabric, wood, straw
- Moderately decomposable – organics
- Decomposable – Food

The Table 3 has been developed to group the waste types [6] into the above categories. Note that plastics, glass, metals, rubber, leather and other were grouped as relatively inert [8].

Methane generation rate constant k estimation

The literature review presented four sources that utilize different characteristics of the landfill to determine the methane generation rate constant, k [5–7,9,10]. The sources used annual precipitation, average temperature, and waste characterization to determine appropriate values of k which can be used in the methane generation model (LandGEM). Average Annual Rainfall: 1670 mm (averaged from 1990 to 2012)

The Table 4 presents the methane generation rate constant derived from the fours sources:

As seen in the Table 4, there is a wide range of values that can be used for the methane generation rate constant, k. However, is the only source that utilizes the widest range of landfill characteristics (annual precipitation, average temperature and waste type) to determine the k value to be used. Therefore, a methane generation rate constant of 0.119ft^3/year will be used in this study [9]. This value is wide used in the literature

Potential methane generation capacity L_0 estimation

The Landfill Gas Generation Assessment Procedure Guidelines and a study conducted on landfills in Ghana give recommended values for L_0 based on the rate of decomposition of the waste [10]. The potential methane generation capacity, L_0 can also be estimated directly from the carbon contents of organic waste [9] using the equation used is given

Table 1
Estimated/Recorded Waste Generation at the Landfill Disposal Site.

Year	Annual Filled (tonnes) [Mg/year]
Prior to 1990$^+$	1,381,132
1990	185,860
1991	180,935
1992	183,687
1993	185,715
1994	187,164
1995	186,440
1996	187,888
1997	189,337
1998	186,150
1999	187,309
2000	170,360
2001	188,323
2002	188,945
2003	189,570
2004	190,196
Total	4,169,012

$^+$ For brevity, the sum of values for these earlier years of site operation is shown.