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Research Article

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Potential for Electricity Generation of Landfill Gas Emission from Municipal Solid Waste in Kano Metropolis

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Abstract The potentials for generation of electricity from landfill gas emissions of four major municipal solid waste disposal sites in Kano metropolis from the years 2012 -2040 were determined. The methane generation potential of the dumpsites were determined using U.S. EPA LandGEM model. The result show that total average annual electricity generation potential of 6,762.159 MWh/yr from the four disposal sites. Based on average household electricity consumption of 4200 kWh/year for Kano metropolis as estimated by Kano electricity distribution company (KEDCO, 2015), the total potential electricity generation of 6,762.159 MWh/yr(18,526.46 kWh/day) would supply about 1,610 households with electricity.

Keywords Landfill gas, Methane, municipal solid waste, Incineration, Energy, electricity

Introduction

Municipal solid waste consists of organic and inorganic matter and anaerobic reaction within solid waste disposal sites generates various gases (landfill gas) mainly methane and carbon dioxide, in addition other non methane volatile organic compounds are also produced [1-2]. Anaerobic digestion is a three stage process in which bacteria converts organic compounds to soluble molecules, convert those molecules to organic acids and break down those acids to produce biogas [3]. The exact percentage distribution of gases in landfill varies, but typical constitution found in municipal solid waste disposal sites are methane 45 – 60%, carbon dioxide 40 - 60% [4]. Both of the two primary constituents of the landfill gas (methane and carbon dioxide) are considered green house gases, which contribute to global warming, but IPCC does not considers carbon dioxide present in raw landfill gas to be a green house gas (GHG) because it considers landfill gas carbon dioxide as biogenic and thus part of the carbon cycle, therefore only the methane content in landfill gas is considered as GHG. Methane is more potent green house gas than carbon dioxide, with global potential of over 21 times that of carbon dioxide [5]. The atmospheric concentration of methane has increased by 151% since 1750 and its concentration continues to increase [6]. Global efforts are being made to control green house gas emission from various sources, waste sector inclusive. Solid waste disposal sites comprise the principal sources of anthropogenic methane emissions, and are estimated to account for 5 – 20% of anthropogenic methane emissions globally [1]. Landfill gas can be piped to power plant to generate electricity. The gas is first treated and then compressed before being utilized for electricity generation. It has been estimated that Kano Metropolis generates about 156,676 tonnes of solid waste per month and with a population of about 3,248,700 the per capita solid waste generation is about 0.56 kg/capita day [7], this makes Kano city the second to Lagos in terms of waste generation in Nigeria. Most of the waste generated which consists of plastics, paper wood, glass, metal and food remnants are dumped in an open uncontrolled waste disposal sites scattered within the urban areas of the city which is typical of most developing countries where the dominant disposal method is open dumping compared to the wide use of sanitary landfills in western countries [8]. The waste disposal sites in Kano are characterized by odour and smoke coming from spontaneous fires (due to the presence of methane gas), which causes pollution problems to the environment and can lead to serious health hazards. According to Intergovernmental Panel on Climate Change (IPCC), gaseous emissions from solid waste disposal sites particularly methane can be a local hazard [1]. The aim of this paper is to determine the electrical energy generation potential of these emissions from four major municipal solid waste disposal sites in Kano metropolis.

Methodology

The four dumpsites namely, Court road, Maimalari, Hajj camp and Ubagama are located within Kano municipality.

Waste characterization/ physical composition

Characterization of waste at the disposal sites were carried out according to the American Society for Testing and Materials (ASTM D5231). The procedure involved random collection of waste from trucks loads in the amount of 15 to 20kg per unit. About 100 kg sample of solid waste was collected per day in each of the four dumpsites. At each dumpsite the collected sample waste was then spread on a polythene sheet and sorted into different categories of plastics, paper, textile material, glass, vegetable /Agricultural waste, metal and earth/ decayed matter. The categorized wastes were then weighted using a weighting scale and their percentage weight recorded. This procedure was conducted in the months of October, March and August (2012-2013) to cater for seasonal variations.

Dumpsites Capacity

The years of opening of the dumpsites (t) were obtained from Kano State Refuse management and sanitation Board (REMASAB). As the dumpsites have not reached their full capacity, the expected year of closure of the dumpsites are determined based on the capacity and rate of waste disposal at the dumpsites. The capacities of the waste dumps were determined based on waste dump area, average depth and density of the waste. The dumpsites areas were obtained using Google Map and Esri Arcgis software program (Google Map, 2013, ArcGIS, 2003). Satellite image of the dumpsites were obtained and the area determined using the program. Record of average depths of the dumpsites and estimated amount of waste in the dumpsites as of 2012 were obtained from REMASAB. The density of waste were determined by placing the samples of waste collected in a 250 ml beaker, shaking and slightly dropping and then weighting. The waste density is then calculated by dividing the weight of the waste by its volume [9].

Methane generation potential of the solid waste disposal sites

Landfill gas generation can be modeled using zero-order, first-order, and/or second-order generation models. Studies have shown that first-order models provide more reliable outcomes in comparison to the zero-order models and are not as complicated as the second-order or multi-phase models [10-11]. Methane generation from the solid waste dumpsites were estimated using the LandGEM model equation which is based on first order decay reaction and is consistent with the approach of Intergovernmental Panel on Climate change [1].

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

Where:

Q_{CH4} = Annual methane generation in the year of calculation (m^3 yr-1)

i = The yearly time increment

n = Difference : (year of the calculation) – (initial year of waste acceptance)

j = 0.1 year increment

L0 = Methane generation potential (m^3/Mg)

Mi= Mass of waste accepted in the ith year (Mg)

k = Methane generation rate (yr-1)

tij = Age of jth section of waste mass Mi accepted in the ith year.

The important parameters of the LandGEM equation for the generation of methane gas are Lo (methane generation potential) and k (methane generation rate)[11].

Methane generation potential (L_O)

The methane generation potential is determined from the equation [1];

$$L_O = DOC \times DOC_f \times F \times {}^{16}/_{12} \times MCF \quad (2)$$

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \quad (3)$$

Where:

DOC = degradable organic carbon

A= fraction of MSW that is paper and textiles wastes, B = fraction of MSW that is garden park waste, C= fraction of MSW that is food waste and D= fraction of MSW that is wood or straw.

DOCf = fraction of assimilated degradable organic carbon(DOC)is obtained from the IPCC default value of 0.77 (IPCC, 1996).

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MCF = Methane correction factor. This is based on the category of the solid waste disposal site (SWDS) management as presented by IPCC:
Managed sites MCF = 1.0
Unmanaged, deep sites (≥ 5m) MCF = 0.8 Unmanaged, shallow sites (< 5m) MCF = 0.4
Unspecified SWDS - default value: MCF = 0.6
F = fraction of methane in landfill gas (0.5 default)
16/12 = stoichiometric factor.
2.32 Methane generation rate constant
The methane generation rate constant or decay rate k, is determined based on US EPA (2005);

$$k = 3.2 \times 10^{-5}(x) + 0.01 \quad (4)$$

Where x is annual average precipitation.

Energy generation potential of methane gas

The power potential of the methane gas is computed using equation (5), also the annual electricity generation potential is computed using equation (6).

$$P = V \times E \times Ꝝ \times \frac{1}{H_r} \quad (5)$$

Where: *P* = Power (kW); V = Methane gas flow rate (m^3/day); E= Energy content (J/m^3); Ꝝ is the recovery rate with a value of 75% – 85% (US EPA, 2006), a value of 80% is used in this computation; H_r = Heat rate (J/kWh).
The annual electrical generation is expressed as:
Annual electricity (kWh) = generation potential (kW) x 24hr/day x 365 days/year (6)

Results and Discussions

Waste composition

The result of the composition analysis of the solid waste at the four dumpsites conducted in the months of October, March and August (2012-2013) are shown in table 1.

Table1: Average% of waste composition

Category	**Court road (%wt)**	**Maiamalari (%wt)**	**Hajj camp (%wt)**	**Ubagama (%wt)**
Plastics	27.88	28.34	29.14	29.22
Paper	7.60	4.70	12.68	8.31
Textiles	11.48	5.13	8.41	10.18
Glass	1.87	3.63	1.57	2.94
Agricultural	21.78	15.54	18.69	17.58
Earth/ garbage	21.65	34.27	28.20	30.97
Metals	0.19	0.06	0.00	0.12
Food waste	7.49	8.33	1.32	0.67

Dumpsites capacity

The capacities of the waste dumps were determined based on waste dump area, average depth and density of the waste. The dumpsites areas were obtained using Google Map and Esri Arcgis software program (Google Map, 2013, ArcGIS, 2003). Satellite image of the dumpsites were obtained and the area determined using the program. Table 2 shows the density of the solid waste in the dumpsites, average depth and areas of the dumpsites.

Table2: Dumpsites densities and areas

Dumpsite	**Density of solid waste (kg/m³)**	**Average depth (m)**	**Area (m²)**
Court Road	276.00	20.00	43,337.93
Hajj Camp	321.60	10.00	41,855.16
Maimalari	255.00	13.50	92,832.31
Ubagama	234.00	8.00	28,867.84

The density of the solid waste from the four dumpsites varies from 321.60 kg/m^3 – 234.00 kg/m^3, while average depth and area of the dumpsites ranges from 20.0m - 8.00m and 92,832.31 m^2 – 28,867.84m^2 respectively. Table 3 shows the estimated capacities of the four dumpsites.

Table 3: Estimated capacities of the dumpsites

Dumpsite	Estimated capacity (m^3)	Estimated capacity (tons)
Court Road	866,788.60	239,233.65
Hajj Camp	418,551.60	134,606.20
Maimalari	1,253,236.19	319,575.23
Ubagama	230,942.72	54,040.60

The amounts of waste in place as of year 2012 in the four dumpsites are shown in table 4.

Table 4: Waste in place as of year 2012.

Dumpsite	Initial year of waste disposal (year)	Waste in place as of 2012 (Mg)	Average annual waste disposal (Mg/year)
Court Road	1991	188,304.60	9415.23
Hajj Camp	2003	72,203.40	9025.43
Maimalari	2003	120,395.29	15049.41
Ubagama	1999	13,693.38	1,141.12

Methane generation

The parameters in the LandGEM equation (1), methane generation potential (L_o) and methane generation rate constant (k) were computed from equation (2) and (4) respectively.

The DOC values of the waste in the four dumpsites were computed using equation (3) and the waste compositions in table 1.

DOCf = fraction of assimilated degradable organic carbon(DOC)is obtained from the IPCC default value of 0.77 (IPCC, 1996). As all the four dumpsites fall within the category of unmanaged , deep dumpsites ($\geq$ 5m, from table 2) their MCF value is therefore 0.8. Default value of 0.5 (IPCC, 1996) for fraction of methane in the landfills is assigned.

The methane generation rate or decay rate k, was calculated using equation (4) where the annual average precipitation of Kano (x) was obtained based from Nigeria Meteorological Agency (NIMET) data in which the average annual precipitation from 1911 – 2010 was 883.47mm (Abaje et al., 2014).

Table 5: Parameters of LandGEM equation

Dumpsites	DOC (tonne /tonne)	DOC_f	MCF	k(yr^{-1})	L_O (m^3 /tonne)
Court Road	0.125	0.77	0.8	0.038	76.94
Maimalari	0.078	0.77	0.8	0.038	48.01
Hajj Camp	0.118	0.77	0.8	0.038	72.63
Ubagama	0.105	0.77	0.8	0.038	64.63

The annual methane generation potential power and annual electricity generation for the four dumpsites are shown in figures 1-3.

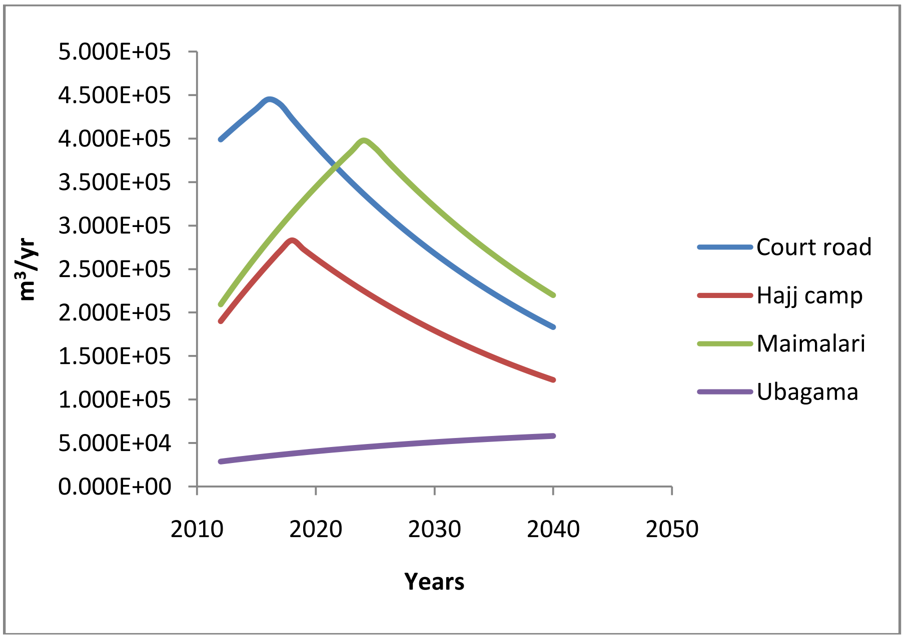

Figure 1: Methane generation of the four dumpsites

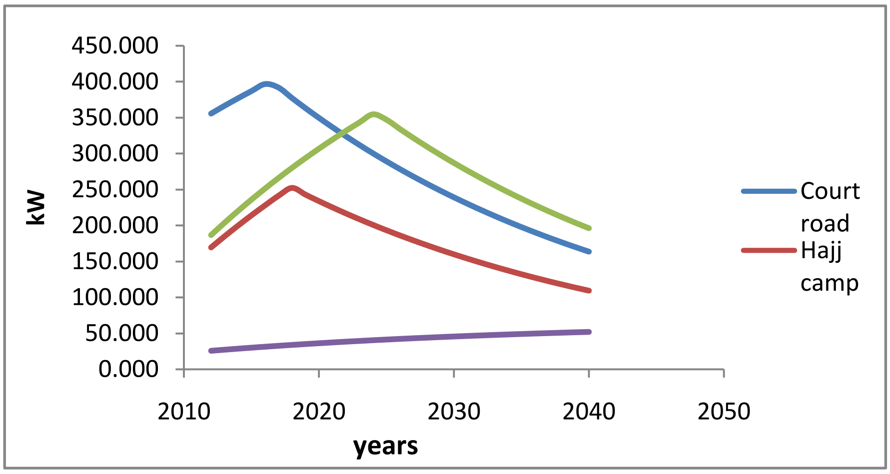

Figure 2: Potential power generation of the four dumpsite

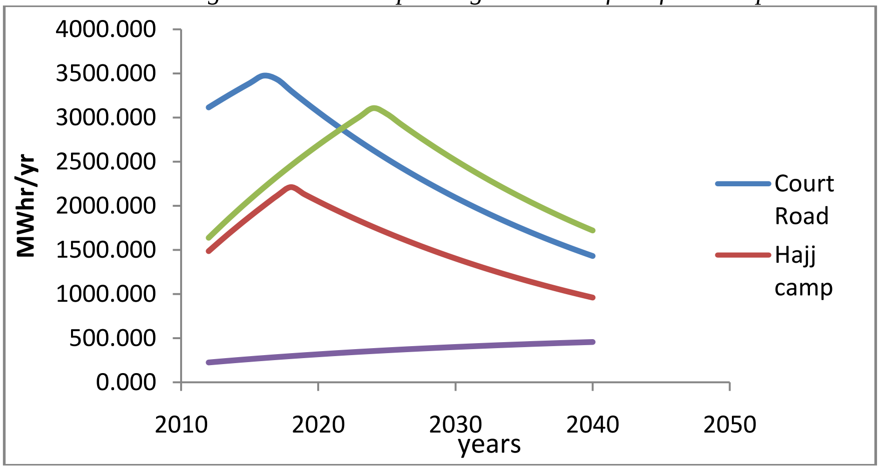

Figure 3: Annual electricity generation of the four dumpsites

The maximum annual potential electricity generation from court road dumpsite is 3,476.150 MWh/yr by the year 2016 which would decline to 1,432.530 MWh/yr by the year 2040, while for Hajj camp dumpsite the maximum is 2,211.993 MWh/yr by the year 2018 which would decline to 958.763 MWh/yr by the year 2040. The maximum potential for Maimalari dumpsite is 3,108.009 MWh/yr by the year 2024 which would decline to 1,720.142 MWh/yr by the year 2040 while for Ubagama dumpsite generation would rise from 262.855 MWh/yr in 2015 to 455.501 MWh/yr. The average total annual electricity generation potential of 6,762.159 MWh/yr can be generated from the four solid waste disposal sites. Based on average household electricity consumption of 4200 kWh/year for Kano metropolis as estimated by Kano electricity distribution company (KEDCO, 2015), the total potential electricity generation of 6,762.159 MWh/yr(18,526.46 kWh/day) would supply about 1,610 households with electricity.

Conclusion/Recommendation

Landfill gas emissions from waste disposal sites are considered green house gases which contribute to global warming due to presence of methane gas. Therefore utilization of landfill gas for electricity generation would reduce the green house gas emission from waste disposal sites. The results show that substantial electricity can be generated which can provide electricity to about 1,610 households. It is therefore recommended that the authority concern should consider the possibility of electricity generation from methane emissions in these waste disposal sites as this would augment the increasing demand of electricity supply in Kano.

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