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Electricricity Generation from Municipal Solid Wastes (MSW) in Kano Metropolis, through Different Waste to Energy Conversion Processes: A Comparative Study

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Abstract

The study intends to carry out a Comparative study of different Waste to Energy (WTE) conversion processes (Incineration, Anaerobic Digestion, and Landfill Gas to Energy) in terms of Electricity Generation from Municipal Solid Wastes (MSW) in Kano Metropolis, Nigeria in order to determine the most favourable process among them. The amount of landfill gas from the landfills sites (dumpsites) in Kano metropolis was estimated using Landfill Gas Emission Model (LandGEM) 3.02 software. The American Society for Testing and Materials (ASTM) methods (ASTM D5231) and (ASTM D2382-88), per capita waste generation and the population data obtained from national population commission (NPC), LandGEM 3.02 software, laboratory bomb calorimeter (Model 6100, Bomb Calorimeter, Parr Instrument Co., Moline, Illinois), were used as materials for the study. The results revealed that the amount of waste that could be used for landfill gas to energy Incineration, and Anaerobic Digestion were estimated as 9.004,560.61 tons/yr, 4,556,887.64 tons/yr and 4,447,672.97 tons/yr respectively. It was also known that, based on the amount of electricity that can be generated, the LFGTE presents the appropriate option of WTE process for Kano metropolis, Nigeria with electricity generation of 33,175,973.48KWh/yr. It is recommended that further study be carried out on the economic feasibility of the two processes.

Keywords: Waste to Energy; Environmental assessment; Anaerobic Digestion; landfill Gas-to-energy

INTRODUCTION

The government of British Columbia, 2015 (as cited in Soltani, 2016) defined Municipal Solid Waste (MSW) as "refuse that originates from residential, commercial, institutional, demolition, land clearing or construction sources".

Municipal Solid Waste is also referred to as all solid waste produced within a municipality's territory, independent on its physical and chemical nature and source of generation (Saleh and Koller 2019). Municipal waste may cover residential and commercial non-hazardous waste, and may also may include industrial and agricultural non-hazardous waste.

Energy from Waste – also known as waste to energy (WTE) – refers to the process of converting residual or non-recyclable waste into sources of energy including heat, fuel and electricity (Infrastructure Partnerships Australia 2020).

The world Bank, in 2017, reported that, the global municipal solid waste generation was estimated at about 2.01 billion tones, with projected increase to about 3.40 billion tonnes by the year 2050 (Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata 2018) Furthermore, the report found out that about 33% of the global solid waste generated is not properly managed, but instead, dumped in an open space. Such practices are leading to several public health and environmental problems (Jeevahan et al. 2021).

In most developing countries, the existing infrastructural facilities for waste management and energy supply are inadequate to keep pace with the rate of waste generation and energy demand. This has led to increased environmental degradation, loss of natural resources and energy poverty (Ayodele, Ogunjuyigbe, and Alao, 2017).

Rapid increase in population, industrialization and economic activities, living standard of people have greatly accelerated the MSW generation rate in developing as well as in developed nations. MSW is a renewable energy resource with the potentials of producing electrical energy via WTE plants.

According to the International Energy Agency (IEA), as cited by Melikoglu (2013), a tonne of municipal solid waste should have an energy potential between 8 and 12 MJ/kg for electricity generation. Globally, average energy potential of municipal solid waste is highly variable depending on the economy, cuisine, geographical location and removal of materials for recycling trends (Melikoglu 2013). Various processes that produce energy from wastes are anaerobic digestion, Incineration, landfill gas to energy, gasification etc. Abdallah et al. (2019) evaluated the waste-to-energy potential in middle income countries of Middle East and North Africa (MENA) by assessing multiple waste management options (incineration and anaerobic digestion), in which an energy potential of 597 kWh per ton of incinerated waste by total mass-burning was predicted. This was low compared to 5970 kWh per ton of MSW estimated by Moya et al. (2017).

Dastjerdi *et al.*, (2019) investigated the potential of the WTE technologies (Landfilling with Energy Recovery, Incineration and Anaerobic Digestion) for energy recovery and greenhouse gas (GHG) emission reduction in North South Wales, Australia. The authors classified MSW as combustible, non-combustible and food organic wastes. Findings from their research showed that by employing a combination of Incineration and Anaerobic for combustible and food parts of residual waste, about 4165 GWh of electricity could be generated annually, which is equivalent to about 5.9% of the total electricity generation in NSW. This result was supported by (Zhou et al. 2018).

In Nigeria, efforts have been made by some researchers in assessing the potentials of MSW in some part of the country: Somorin, Adesola, and Kolawole (2017) assessed the electricity generation potentials of MSW for the 36 states in Nigeria using incineration waste to energy conversion. Their results showed that the Nigeria’s annual electricity generation potential from MSW was estimated to be 26744 GWh/year, with 89% of the states having sufficient generation capacity at minimum regulatory electricity generation requirement of 50 MW. Similarly, Daura (2016), evaluated the Electricity generation potential of MSW from four dumpsites using Incineration in Kano Metropolis and found that 805,579.68 kWh/day of electricity can be generated by incineration.

Ayodele et al. (2017) in their LCA study, estimated the electrical energy potentials of MSW in North-Western (NW) Nigeria using landfill gas to energy (LFGTE), hybrid of incineration and anaerobic digestion (INC/AD) and hybrid of incineration and landfill gas to energy (INC/LFGTE).

The aim of this study is to carry out a Comparative study of different Waste to Energy (WTE) conversion processes (Incineration, Anaerobic Digestion, and Landfill Gas to Energy) in terms of Electricity Generation from Municipal Solid Wastes (MSW) in Kano Metropolis, Nigeria in order to determine the most favourable process among them.

MATERIALS AND METHODS

The Study Area

The study domain is Kano Metropolis in Kano State, Nigeria, located between latitudes 11°55'N and 12°3'N and longitudes 8°27'E to 8°36'E with an elevation of 472m above sea level. Kano metropolis is a conurbation of eight Local Government Areas around the main city which includes; Dala, Fagge, Kano Municipal, Nassarawa, Tarauni, Kumbotso, Gwale and Ungogo. The city is the trade nerve centre of West Africa and a major industrial centre of Northern Nigeria (Isah, A.T. and Suleiman 2024). It is chosen due to its high population density and varying socio-economic structures. Figure. 3.1 below depicts the map of the study area showing the local government areas.

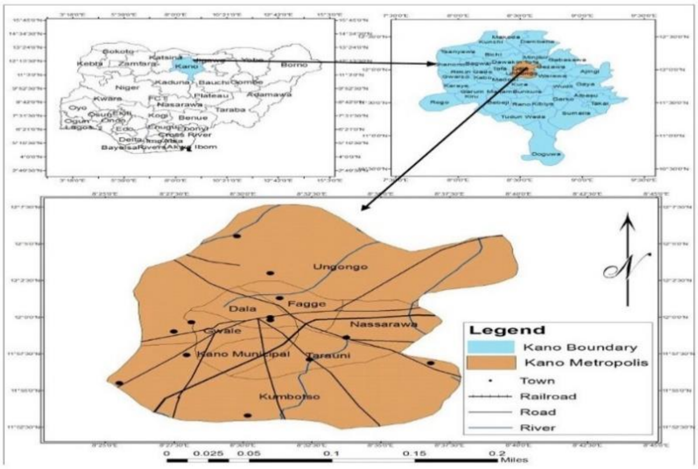


Figure. Map of the study area (Kano Metropolis, Nigeria)

Municipal Solid Waste Management in Kano

Solid waste management in Kano was handled centrally by a single agency of the state, the Refuse Management and Sanitation Board (REMASAB) which was established in 2003 and saddled with the responsibility of waste management in Kano metropolis. (Mshellia 2020). The law establishing the agency specifically enumerated the following functions: Refuse collection and disposal; management of refuse collection centres and dump sites; land reclamation; streets weeping and cleaning; control of street hawking and random refuse disposal; vector control (mosquito control) by means of fumigation and other mean of control; inspection and enlightenment programs on sanitation. With the metropolis generating several thousands of metric tonnes of waste on daily basis, on 21st May 2021, the Kano state government had entered into a Private Public Partnership with a Private Company (Capegate Investment Limited) to take over the handling of its wastes. The Public Private Partnership (PPP) was supposed to lead to generation of 10 Megawatts of electricity from waste in 2022 and 150 MW in the next five years. Data obtained officially from Capegate indicates that daily per capita municipal solid waste generation was 0.55kg/cap/day. The current authorized dumpsites and their locations within Kano Metropolis are as shown in table 3.1.

Formal Dumpsites in Kano Metropolis					
Dumpsite	**Latitude**	**Longitude**	**Eastings**	**Northings**	**Status**
Court Road	11.96779	8.54263	450204.7	1323033.1	In Use
Uba Gama	12.01217	8.50256	445850.9	1327948.3	Closed
Hajj Camp	12.02395	8.52269	448044.5	1329247.1	Closed
Maimalari	12.02380	8.57361	453587.2	1329221.4	In Use

Table 3.1. Authorized dumpsites and their locations within Kano Metropolis

Currently, waste has only been collected, transported, and finally disposed at the formal dumpsites as there is no treatment or management in place. However, Capegate have a plan for the treatment or management of waste which include the production of organic fertilizer, generation of 150MW.

Sampling Locations

Locations of waste disposal in the government designated dumpsites within the metropolis; namely Court Road and Maimalari are shown in (figures 3.1 and 3,6 respectively). The dumpsites contained waste from various collection centres mostly residential, industrial and service layouts from within the metropolis.

Sample Collection and Waste Characterization

Waste in this study was sampled using the quartering technique. This is a sampling method often used to sample heterogeneous materials such as municipal solid waste, often used when the sample is too large to be analysed in its entirety (Bassey et al. 2024). The entire sample is divided into four equal parts, and two opposing quarters are discarded while the remaining two quarters are combined and mixed. The process is then repeated until the desired sample size is achieved, which is usually a smaller, more manageable portion.

i. Data for waste dumpsites in Kano metropolis and other related documents were obtained from Capegate Investment Company.

ii. Random truck sampling methods was applied in this work to identify the waste characteristics. The method, published by the American Society for Testing and Materials (ASTM D5231) was used to identify the waste composition of incoming waste to landfill per day. The procedure is applicable for collecting the representative municipal solid waste in waste stream.

iii. Sampling and sorting team consisting of a skilled waste collector as well as two scavengers on-site were engaged in the sorting, weighing and categorization of the MSW at the dumpsites.

iv. Waste samples were collected randomly from the arriving trucks at the dumpsites using a hand truck (Figures 3.3, 3.4, and 3.5) immediately after it was unloaded, during each day of the sampling periods.

v. The collected waste sample was placed on a tarpaulin and manually divided by utilizing the coning and quartering method where, the entire sample was thoroughly mixed and spread into a cone. The cone was then divided into four parts using a metal square pipe and spade. Two quarters, diagonally placed, were extracted and the remaining two quarters were mixed and quartered again. This procedure was repeated six times until the desired and manageable sample size was acquired.

vi. As the desired sample size was obtained, the waste was moved to a nearby location for manual sorting and characterization (Figure. 3.7). The sorted samples were then categorised as organic (biodegradable and nonbiodegradable) and inorganic (recyclable) components and were weighed using an electronic weighing scale (Figure, 3.8). The organic fractions includes food waste, paper/cardboard, textiles, leather and wood, while the Inorganic waste fractions include glass, plastics, metals. Other wastes were categorised as sand, ceramic, etc. The readings were then recorded in a daily record book (Figure. 3.9).

vii. The MSW sampling/sorting process was carried out during the dry season in two months (December – January) with seven (7) days each in a month. Tables 3.1 - 4 show the daily samples as collected from the various waste areas.

Table 3.4. Sampling Data from Court Road Dumpsite

S/N	**Waste Fractions**	**Amount (Kg)**							
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	**Total (kg)**
1	Paper	0.45	0.48	2.51	1.19	1.03	1.25	0.25	**7.16**
2	Plastics	0.33	0.22	0.22	0.33	0.21	0.2	1.2	**2.71**
3	Textiles	6.15	1.4	1.6	2.18	1.36	2.24	2.1	**17.03**
4	Food Wastes	3.57	4.03	4	7.04	2.05	6.51	7.01	**34.21**
5	Metals	0.29	0.33	0.23	0.2	0	0.22	0.22	**1.49**
6	Rubber	0.71	0.25	0.22	0.41	0.37	2.39	2.44	**6.79**
7	Glass	0	0.24	0.33	0.33	0.31	0.61	0.74	**2.56**
8	Wood	0.65	0.28	0.37	0.6	0.71	0.64	0.64	**3.89**
9	Leather	3.29	2.9	4	5.21	2.62	5.03	3.82	**26.87**
10	Fines and Others	1.8	2.02	2.3	3.2	5.45	3.67	3.62	**22.06**
	Total	**17.24**	**12.15**	**15.78**	**20.69**	**14.11**	**22.76**	**22.04**	**124.77**

S/N	**Waste Fractions**	**Amount (Kg)**							
		Day 1	Day 2	Day 3	Day4	Day 5	Day 6	Day 7	**Total (kg)**
1	Paper	0.96	0.68	0.55	0.48	1.01	2.2	1.05	6.93
2	Plastics	0.33	1.79	0.63	1.69	0.43	0.22	0.43	5.52
3	Textiles	1.4	1.7	1.26	2.01	1.1	1.3	0.99	9.76
4	Food Wastes	2.29	2.12	4.38	2.62	2.49	4.5	2	20.4
5	Metals	0.16	0.3	0.19	0.8	0.25	0.15	0.25	2.1
6	Rubber	0.22	0.24	0	0.24	0.32	0.32	0.32	1.66
7	Glass	0.96	2.45	1.74	2.72	0.98	0.13	0.68	9.66
8	Wood	0.21	0.36	0.99	0.36	0.15	0.51	0.15	2.73
9	Leather	4.26	5.2	3.28	4.9	4.06	2.61	4.1	28.41
10	Fines and Others	2.18	4.11	1.52	4.02	2.21	3	2.21	19.25
11	**Total**	12.97	18.95	14.54	19.84	13	14.94	12.18	**106.42**

Table 3.5. Sampling Data from Maimalari Dumpsite

Table 3.6 Sampling Data for Kano Metropolis

Waste Components	**Court Road**	**Maimalari**	**Total (kg)**	**%**
Paper	7.16	6.93	14.09	**6.09**
Plastics	2.71	5.52	8.23	**3.56**
Textiles	17.03	9.76	26.79	**11.59**
Food Wastes	34.21	20.4	54.61	**23.62**
Metals	1.49	2.1	3.59	**1.55**
Rubber	6.79	1.66	8.45	**3.66**
Glass	2.56	9.66	12.22	**5.29**
Wood	3.89	2.73	6.62	**2.86**
Leather	26.87	28.41	55.28	**23.91**
Fines and Others	22.06	19.25	41.31	**17.87**
Total	124.77	106.42	**231.19**	**100**

For energy generation, different waste compositions will be required for different waste to energy conversion process. Therefore, Waste fractions of the possible waste composition (f) that could be used for waste-to-energy project using any of the three technologies was extracted and allocated (Tables 5 -7.). Food waste, paper, cardboard, textiles, and wood, were allocated to Landfill Gas to Energy (LFGTE); while Paper, cardboard, textiles, and wood to Incineration. (Gao et al. 2017) revealed that, based on the features of food waste, anaerobic digestion is a preferred choice to treat food waste, and therefore food waste only was allocated for Anaerobic Digestion.

Table 3.7. Percentage Composition of Waste *f*(.) allocated to LFGTE Process.

LFGTE Process	
Waste Components	%
Food wastes	23.62
Rubber	3.66
Textiles	11.59
Paper	6.09
Wood	2.86
Total	**47.82**

Table 3.8. Percentage Composition of Waste f(.) allocated to Incineration Process.

INCINERATION	
Rubber	3.66
Textiles	11.59
Paper	6.09
Wood	2.86
Leather	23.91
Total	**48.11**

Table 3.9. Percentage Composition of Waste f(.) allocated to Anaerobic Digestion Process.

ANAEROBIC DIGESTION	
Food wastes	**23.62**

The amount of waste composition that could be used for the WTE conversion processes considered (i.e. LFGTE, incineration, anaerobic digestion) to generate electricity in a waste-to-energy process was determined using the following equation (Ogunjuyigbe, Ayodele, and Alao 2017):

$$M_{F(i)} = M_F \times f(i) \quad \text{(tons/yr)} \qquad (3.4)$$

Where i is type of WTE conversion process (i.e. Landfill Gas to Energy, Anaerobic Digestion, or Incineration process), f is the fraction (organic) of the waste composition that will be fed into the specific process. It was assumed that plastic, metals and glass, and ceramics products are sorted out for recycling

The study did not cover the rate of waste collected by informal waste collectors.

Evaluation of Electricity Generation Potential by Landfill Gas to Energy Process:

The potential of landfill gas to generate electricity depends on its methane generation potential. The amount of landfill gas from the landfills sites (dumpsites) in Kano metropolis was estimated using Landfill Gas Emission Model (LandGEM) 3.02 software (EPA 2005). The model uses the following first-order decomposition rate equation to estimate annual quantity of emissions from decomposition of MSW deposited in the landfills:

$$\boldsymbol{Q_{CH_4} = \sum_{k=1}^{n} \sum_{j=0.1}^{1} KL_o \left(\frac{M_{LFGTE}}{10}\right) e^{-t_{kj}}} \qquad (3.5)$$

Where

$\boldsymbol{Q_{CH_4}}$= Annual methane generation in the year of the calculation (m^3/year)

t = 1-year time increment

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

j = 0.1-year time increment

k = methane generation rate ($year^{-1}$)

L_o = potential methane generation capacity (m3 /Mg)

$\boldsymbol{M_{LFGTE}}$ = Waste landfilled in a year (Mg/yr).

The methane generation potential (Lo): This was determined through the Intergovernmental Panel on Climate Change (IPCC) methodology using the following equation (Johari et al. 2012):

$$L_o = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \qquad (3.6)$$

Where, MCF is the methane correction factor assumed to be 0,6 for unmanaged dumpsites or landfills and F is the fraction of methane in LFG, taken as 0.5 (Johari et al. 2012). Table 3.8 summarizes the data for estimating methane generation.

Table 3.10. Data for estimating methane Generation

Methane Correction Factor, MCF	0.6
F is the fraction of methane in LFG	0.5
% MSW that is Putrescible (food waste)	23.62
% MSW that is Wood	2.86
% MSW that is Paper	6.09
% MSW that is Textiles	11.59
Average temperature at landfill site, T (°C)	28
DOC	0.092
DOC_f	0.67

The methane generation potential **(Lo)** was thus, obtained as;

$$Lo = 0.6 \times 0.092 \times 0.67 \times 0.5 \times {}^{16}/_{12}$$
$$= 0.02466 \text{ Mg/yr}$$

But LandGEM requires that Lo to be in units of m3/Mg, and therefore taking the density of methane as 0.714kg/m3 (Coskuner et al. 2020),

The volume of methane per mass (methane generation potential) was calculated as,

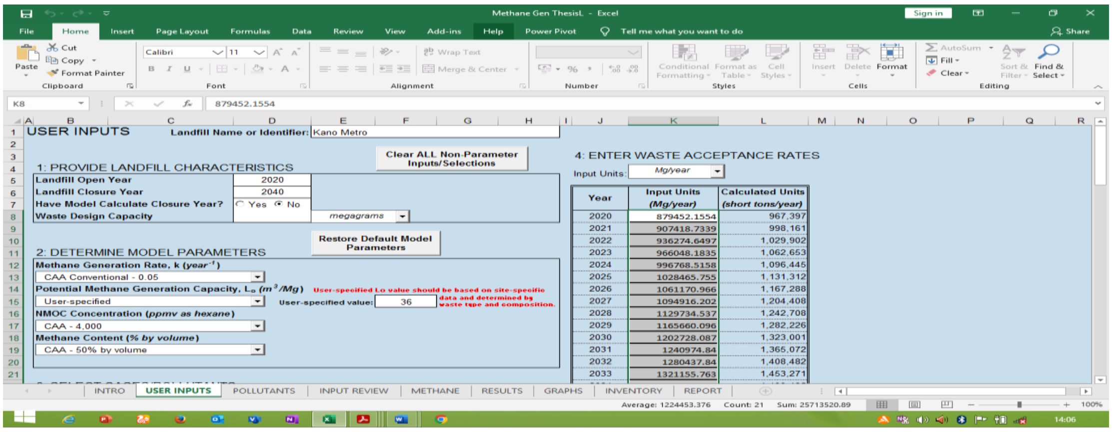
$$Lo = \frac{0.02466}{0.714} \times 1000 \approx 35\text{m3/Mg}$$

Methane generation constant, k: The most important parameter to estimate the value of k is precipitation and hence, the methane generation constant (k) will be determined based on precipitation rates using the following equation (Park et al. 2018):

k = (3.2×10-5 ×annual precipitation in mm) + 0.01 (3.7)

Annual precipitation rate for Kano will be taken as 864.35mm (World Bank Group, 2021).

The annual methane generation (Q_{CH_4}) in the year of the calculation (m3/year) was estimated based on required inputs such as the design capacity of the landfill site, the annual acceptance rate, the methane generation constant k, the methane generation potential Lo and the years of waste acceptance (Figure. 3.10).



K8 879452.1554

USER INPUTS Landfill Name or Identifier: Kano Metro

1: PROVIDE LANDFILL CHARACTERISTICS

Landfill Open Year: 2020

Landfill Closure Year: 2040

Have Model Calculate Closure Year? ○ Yes ● No

Waste Design Capacity: megagrams

2: DETERMINE MODEL PARAMETERS

Methane Generation Rate, k (year^{-1}): CAA Conventional - 0.05

Potential Methane Generation Capacity, L_o (m^3/Mg): User-specified; User-specified value: 36

User-specified Lo value should be based on site-specific data and determined by waste type and composition.

NMOC Concentration (ppmv as hexane): CAA - 4,000

Methane Content (% by volume): CAA - 50% by volume

4: ENTER WASTE ACCEPTANCE RATES

Input Units: Mg/year

Year	Input Units (Mg/year)	Calculated Units (short tons/year)
2020	879452.1554	967,397
2021	907418.7339	998,161
2022	936274.6497	1,029,902
2023	966048.1835	1,062,653
2024	996768.5158	1,096,445
2025	1028465.755	1,131,312
2026	1061170.966	1,167,288
2027	1094916.202	1,204,408
2028	1129734.537	1,242,708
2029	1165660.096	1,282,226
2030	1202728.087	1,323,001
2031	1240974.84	1,365,072
2032	1280437.84	1,408,482
2033	1321155.763	1,453,271

Average: 1224453.376 Count: 21 Sum: 25713520.89

Figure. 3.10. Screenshot of the User Inputs to LandGEM Software.

The Electricity generation potential for the Landfill Gas to Energy process (LFGE) that could be obtained from the methane content of the landfill gas collected was evaluated using eq. 8. (Oukili, Mouloudi, and Chhiba 2022):

$$E_{gp(LFGE)} = \frac{0.9 \times Q_{CH_4} \times LCV_{CH_4} \times \eta \times \lambda}{3.6} \quad (3.8)$$

Where $\mathrm{LCV}_{\mathrm{CH}_4}$ the lower heating value of methane, taken as 37.2MJ/m3 (Zubizarreta and Rodrigues 2010) and (Amoo and Fagbenle 2013).

η is the electrical conversion efficiency for the internal combustion engine taken as 33% (Ogunjuyigbe et al. 2017).

λ is the collection efficiency (75%) of methane from landfills (Ibikunle, R. A., Titiladunayo, I.F., Uguru-Okorie, D. C., Osueke, C.O. 2019). $\mathrm{Q}_{\mathrm{CH}_4}$ is the amount of methane gas emitted in the year of calculation from the landfill in a year (m^3 /year) which is presented in table 4.6, 0.9 is the empirical coefficient. 3.6 is the conversion factor from MJ to kWh.

The input data for the LandGEM model, used to estimate the annual methane generation ($\boldsymbol{Q_{CH_4}}$) in the year of the calculation (m3/year) is summarized in table 3.9.

Table 3.11. Input Data for Estimation of Annual Methane generation (m3 /year)

Landfill Open Year	2020
Landfill Closure year	2040
Methane Generation Rate, k	0.5 yr-1
Methane generation potential	35.0 m^3/Mg
Non-Methane Organic Concentration (NMOC)	4,000 ppmv as hexane
Methane Content	50% by Volume

Evaluation of Electricity Generation Potential by Incineration Process

The electricity generation potential by an incineration process, $E_{gp(Inc)}$(kWh/yr) was determined using the equation 3.9 (R. A Ibikunle et al. 2019):

$$E_{gp(Inc)} = \frac{HV_{msw} \times W_{msw} \times \eta}{3.6} \qquad (3.9)$$

Where, HV_{msw} = Heating value of MSW (MJ/kg), determined using laboratory bomb calorimeter.

η = Conversion efficiency estimated to be 35.8%

Wmsw = Average annual mass of MSW incinerated (tons/yr) which was estimated as follows:

$$W_{msw} = \frac{\sum_{t=1}^{n} M_{F_{INC}}}{n} \qquad (3.10)$$

$M_{F_{INC}}$ is the amount of waste composition that could be utilized for incineration process over a project life time, n (20years for this study) and was obtained from Eq.(4).

Determination of the heating value (HV) of waste: The determination of the HV was carried out experimentally at the Research Laboratory, Chemical Engineering Department, Ahmadu Bello University, Zaria using a laboratory bomb calorimeter (Model 6100, Bomb Calorimeter, Parr Instrument Co., Moline, Illinois) according to a standard procedure, ASTM D2382-88.

The result was then red at the display unit in (MJ/kg) or (Cal/g) depend on which unit the user selected. The procedure was repeated for four times for each fraction and average was taken. The data obtained is presented in table 3.10.

Table**3.**12. Experimental Data for Heating Value of Waste Fractions

Waste Fractions	**HV (MJ/kg)**				**Average Value**
	1	**2**	**3**	**4**	
Food wastes	33.3568	26.3399	32.6791	33.2009	31.3942
Wood	17.2436	15,7349	16.7960	17.1374	16.7280
Paper	18.9311	18.7439	14.2475	17.8515	17.4435
Plastic	59.1644	56.4726	53.4749	50.3182	54.8575
Textiles	24.7357	27.0566	29.7803	26.2176	26.9476

The data used for the estimation of Electricity generation potential by Incineration process is summarized and presented in table 3.13.

Table 3.13. Data for Evaluation of Electricity generation potential by Incineration process

M_F (tons/Year)	9,057,284.93
Average HV_{msw} (MJ/kg)	29.4742
Electrical Conversion Efficiency η (%)	35.8
W_{msw} (tons/Year)	452,864.25

Evaluation of Electricity Generation potential by Anaerobic Digestion process

Anaerobic digestion (AD) is the natural process that breaks down organic matter in the absence of oxygen to release a gas known as biogas (a mixture of methane, carbon dioxide and water which can be used to produce electricity and heat or used as a natural gas substitute), and digestate (a nutrient rich by-product of AD and can be used as a fertilizer and soil improver) (GMI 2016). The electricity generation potential (Ep(AD)) by an Anaerobic Digestion process (Biogas powered plant) was evaluated using an equation proposed by (Ogunjuyigbe et al. 2017):

$$E_{p(AD)} = \frac{0.85 \times \eta \times LHV_{CH_4} \times M_{F(AD)}}{3.6} \qquad (3.11)$$

$$M_{F(AD)} = \frac{\sum_{t=1}^{n} M_{FAD(t)}}{n} \qquad (3.12),$$

$M_{F(AD)}$(t) was obtained from Eq. (4) as $4{,}447{,}672.97\ tons/yr$

Where $\mathrm{LHV}_{\mathrm{CH_4}}$ is the lower heating value of methane (37.2MJ/m3). η is the electrical efficiency of the biogas powered generator, taken as 0.26 or 26% (Amoo and Fagbenle 2013). $M_{F(AD)}$ (tons/yr) is the average mass of feedstock fed into the digester and was obtained from Eq. (3.12) as 223,720.74 tons/year. 3.6 is the conversion factor from MJ to kWh.

RESULTS OF THE STUDY

Characterization and Percentage Composition of Waste Fractions in Kano Metropolis:

Characterization of the municipal solid waste was carried out for Kano metropolis in order to provide a preliminary indication of the composition of individual components or fractions of the waste. After manual sorting out of the collected materials, classification of solid waste was done, fractions for the individual WTE processes were allocated, and the results were presented in tables 4.1 and 4.2.

Table 4.1. Results from a waste characterization for Kano Metropolis

Waste Components	**kg**	**%**
Paper	14.09	**6.09**
Plastics	8.23	**3.56**
Textiles	26.79	**11.59**
Food Wastes	54.61	**23.62**
Metals	3.59	**1.55**
Rubber	8.45	**3.66**
Glass	12.22	**5.29**
Wood	6.62	**2.86**
Leather	55.28	**23.91**
Fines and Others	41.31	**17.87**
Total	**231.19**	**100**

Table 4.2. Waste composition allocated to various WTE processes

S/N	**Waste Fractions (%)**	**LFGTE**	**Anaerobic Digestion**	**Incineration**
1	Food wastes	23.62	23.62	-
2	Rubber	3.66	-	3.66
3	Textiles	11.59	-	11.59
4	Paper	6.09	-	6.09
5	Wood	2.86	-	2.86
	TOTAL	**47.82**	**23.62**	**24.2**

Amount of Waste Composition (tons/yr) Allocated for each WTE Process

The amount of waste that could be used for the different WTE conversion processes is shown in table 4.5.

Table 4.5. Waste composition (tons/yr) that could be used for each WTE process.

	LFGTE	**INCINERATION**	**ANAEROBIC DIGESTION**
$M_{F(i)}$	9,004,560.61	4,556,887.64	4,447,672.97

Projection of Annual Methane generation (Q_{CH_4})

The generation rate for total methane, is projected using LandGEM 3.02 software. The quantities of CH4 methane produced by the decomposition of the organic fraction of municipal solid waste buried in the dumpsites over the period 2020-2040 are presented in Table 4.6.

Table 4.6. Annual methane generation (QCH_4) in m3/year

Methane Generation		
Year	**(Mg/year)**	**(m3/year)**
2020	0	0
2021	1022.674337	1533000
2022	2027.993301	3040000
2023	3017.837494	4523000
2024	3994.028685	5987000
2025	4958.333727	7432000
2026	5912.468314	8862000
2027	6858.10059	10280000
2028	7796.854613	11690000

2029	8730.313697	13090000
2030	9660.02362	14480000
2031	10587.49571	15870000
2032	11514.20984	17260000
2033	12441.61729	18650000
2034	13371.14354	20040000
2035	14304.19095	21440000
2036	15242.14137	22850000
2037	16186.35866	24260000
2038	17138.19115	25690000
2039	18098.97399	27130000
2040	19070.03148	28580000
	Average	**14,413,369.6**

Electricity Generation Potential of Each of the WTE Processes

The electricity energy generation potential of MSW in Kano metropolis was evaluated using the three WTE processes selected (LFGTE, Incineration and Anaerobic Digestion) and the results are presented in Table 4.7.

Table 4.7. Electricity Generation Potential (kWh/yr)

Electricity Generation Potential (kWh/yr)		
Incineration	**Anaerobic Digestion**	**LFGTE**
1,327,365.69	507,850.13	33,175,973.48

DISCUSSION OF RESULTS

Waste Composition

Waste composition is important for determination of the energy content for incineration and the methane generation potential for landfilling. These parameters determine the amount of energy that can be recovered from both waste management methods. The changes in waste composition are presented in Figure 4.1. The result shows that food waste and leather have the highest percentage composition with about 24% each; while metals have the lowest with 1%.

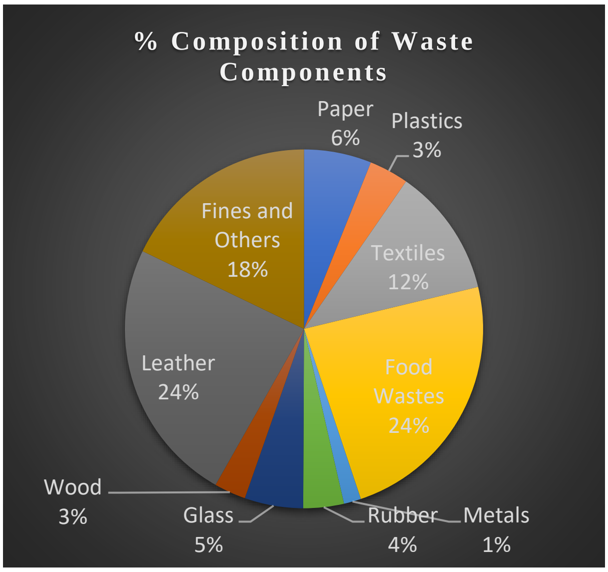


Figure 4.1. Average percentage composition of MSW fractions in Kano Metropolis

Municipal Solid Waste (MSW) Generation Rate

From table 4.4 and Figure 4.2, the total mass of waste generated and the quantity of waste taken to dumpsites continue to increase on yearly basis. This may due to increase in population data for the respective years.

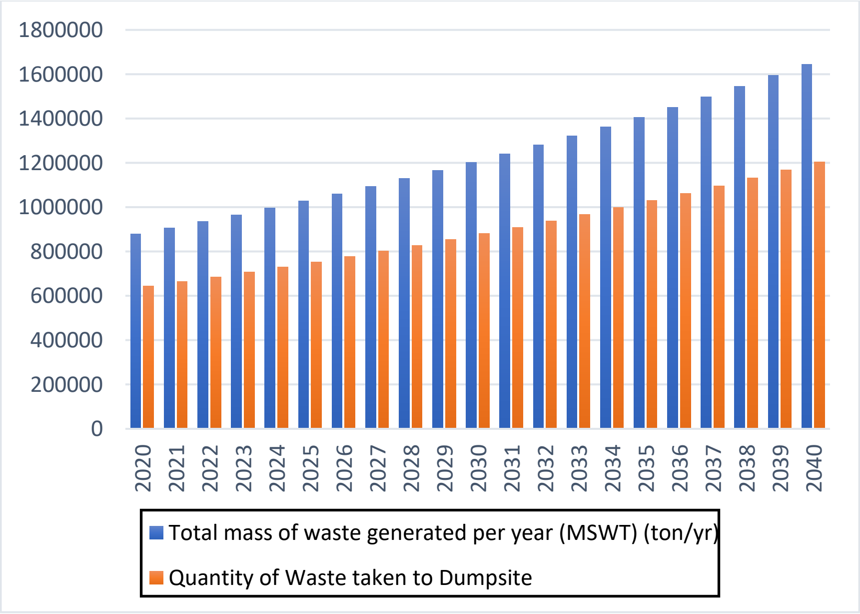


Figure 4.2. Projected annual waste generation and waste taken to dumpsites.

Methane Generation Potential

The methane generation rate (QCH4) from the selected landfill sites (Dumpsites) in Kano metropolis from the initial year of waste deposition (2020) to closure (2040) is shown in Figure 4.3. It was discovered that the methane generation rate is zero in 2020 (Landfill open year); it then increased exponentially from 1,533,000 m3/year in 2021 until it reaches 28,580,000 m3/year in 2040 (when the landfill was closed year) respectively; and then declines rapidly afterwards.

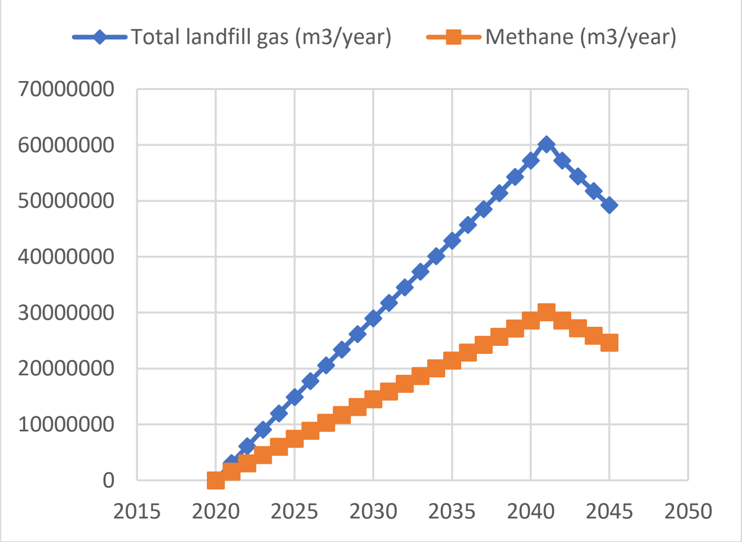


Figure 4.3. Estimated rates of landfill gas and methane emissions

Electricity Generation Potential

From the perspective of electrical energy generation (Figure 4.4), LFGTE is the most appropriate option among the processes for the study area, with the electrical energy potential of about 33,175,973.48 kwh per annum. This is in line with the findings of (Daura 2016). Following LFGTE process is Incineration process with electrical energy potential of 1,327,365.69 kwh per annum. Anaerobic Digestion (AD) presents the least electricity generation capacity with 507,850.13 kWh per annum for Kano metropolis. This is in line with the findings of (Ogunjuyigbe et al. 2017) which states that LFGTE is the most preferred WTE technology in North Western Cities of Nigeria, for instance in Dutse (14.7 GWh per annum) and Katsina (29.0 GWh per annum); and that Anaerobic Digestion (AD) technology is not always a viable technology in the Northern part of Nigeria.

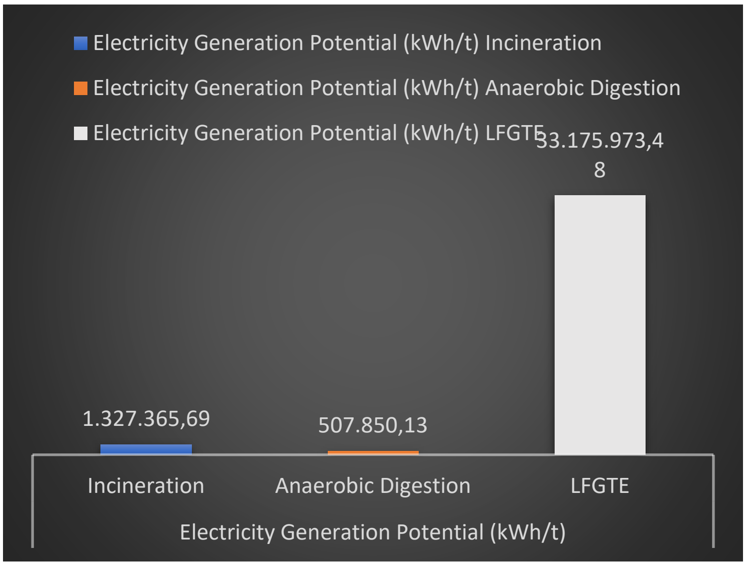


Figure 4.4. Electricity generation potential (kW h/yr) by different WTE Processes.

CONCLUSION

The following conclusion was deduced from the study.

i. From the waste composition study, food waste and leather have the highest percentage composition with about 24% each; while metals have the lowest with 1%.

ii. It was found that LFGTE presents the appropriate option of WTE process for Kano metropolis, Nigeria based on the amount of electricity that can be generated, followed by Incineration process. It is therefore recommended that:

i. Base on this study, only three WTE conversion processes (Incineration, Anaerobic Digestion, and Landfill Gas to Energy) were considered. It is therefore recommended that the viability of other systems of such as pyrolysis, gasification etc should be considered for the study area.

ii. Due to non-regulatory framework regarding emission control of WTE plants as it affects their usage and installation, it is recommended that researchers from within and outside the academia to carry out a study on a comprehensive legal framework and roadmap on WTE project for Kano, Nigeria.

REFERENCES

Abdallah, Mohamed, Abdallah Shanableh, Mohamed Arab, and Ahmad Shabib. 2019. "Waste to Energy Potential in Middle Income Countries of MENA Region Based on Multi-Scenario Analysis for Kafr El-Sheikh Governorate , Egypt." *Journal of Environmental Management* 232(May 2018):58–65. doi: 10.1016/j.jenvman.2018.11.029.

Amoo, Olaleye M., and Richard Layi Fagbenle. 2013. "Renewable Municipal Solid Waste Pathways for Energy Generation and Sustainable Development in the Nigerian Context." *International Journal of Energy Environmental Engineering* 4(42):1–17.

Ayodele, T. R., A. S. O. Ogunjuyigbe, and M. A. Alao. 2017. "Life Cycle Assessment of Waste-to-Energy (WtE) Technologies for Electricity Generation Using Municipal Solid Waste in Nigeria." *Applied Energy* 201:200–218. doi: 10.1016/j.apenergy.2017.05.097.

Bassey, Uduak, Abasi Tom, Udemeobong Okono, Mbetobong John, Maja Sinn, Ayoge Bassey, Uduak Luke, and Satyanarayana Narra. 2024. "Characteristics and Management of Municipal Solid Waste in Uyo , Akwa Ibom State , Nigeria." *Scientific Reports* 1–14. doi: 10.1038/s41598-024-61108-0.

Coskuner, Gulnur, Majeed S. Jassim, Nauman Nazeer, and Galbokka H. Damindra. 2020. "Quantification of Landfill Gas Generation and Renewable Energy Potential in Arid Countries : Case Study of Bahrain." doi: 10.1177/0734242X20933338.

Daura, Lawal Abdu. 2016. "Electricity Generation Potential of Municipal Solid Waste in Kano Metropolis." 3(4):157–61.

EPA, US. 2005. *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide.*

Gao, Anqi, Zhenyu Tian, Ziyi Wang, Ronald Wennersten, and Qie Sun. 2017. "Comparison between the Technologies for Food Waste Treatment." *Energy Procedia* 105:3915–21. doi: 10.1016/j.egypro.2017.03.811.

Ibikunle, R. A., Titiladunayo, I.F., Uguru-Okorie, D. C., Osueke, C.O., Olayanju. 2019. "Predicting the Quantity of Municipal Solid Waste Required for Power Generation Using Power Plant Design Parameters Predicting the Quantity of Municipal Solid Waste Required for Power Generation Using Power Plant Design Parameters." *Journal of Physics: Conference Series* 1378 03209. doi: 10.1088/1742-6596/1378/3/032090.

Infrastructure Partnerships Australia. 2020. *Putting Waste to Work: Developing a Role for Energy from Waste.*

Initiative, Global Methane. 2016. "Overview of Anaerobic Digestion for Municipal Solid Waste." Pp. 1–98 in.

Isah, A.T. and Suleiman, Y. M. 2024. "Confluence Journal of Environmental Studies Vol. 18 (Issue 3),2024." 18(3):1–15.

Jeevahan, Jeya, A. Anderson, V. Sriram, R. B. Durairaj, G. Britto Joseph, and G. Mageshwaran. 2021. "Waste into Energy Conversion Technologies and Conversion of Food Wastes into the Potential Products: A Review." *International Journal of Ambient Energy* 42(9):1083–1101. doi: 10.1080/01430750.2018.1537939.

Johari, Anwar, Saeed Isa Ahmed, Haslenda Hashim, Habib Alkali, and Mat Ramli. 2012. "Economic and Environmental Benefits of Landfill Gas from Municipal Solid Waste in Malaysia." *Renewable and Sustainable Energy Reviews* 16(5):2907–12. doi:

10.1016/j.rser.2012.02.005.

Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. *What a Waste 2.0 Introduction -"Snapshot of Solid Waste Management to 2050." Overview Booklet.*

Melikoglu, Mehmet. 2013. "Vision 2023: Assessing the Feasibility of Electricity and Biogas Production from Municipal Solid Waste in Turkey." *Renewable and Sustainable Energy Reviews* 19:52–63. doi: 10.1016/j.rser.2012.11.017.

Moya, Diego, Clay Aldás, Germánico López, and Prasad Kaparaju. 2017. "Municipal Solid Waste as a Valuable Renewable Energy Resource: A Worldwide Opportunity of Energy Recovery by Using Waste-To-Energy Technologies." *Energy Procedia* 134:286–95. doi: 10.1016/j.egypro.2017.09.618.

Ogunjuyigbe, A. S. O., T. R. Ayodele, and M. A. Alao. 2017. "Electricity Generation from Municipal Solid Waste in Some Selected Cities of Nigeria : An Assessment of Feasibility , Potential and Technologies." *Renewable and Sustainable Energy Reviews* 80(May 2016):149–62. doi: 10.1016/j.rser.2017.05.177.

Oukili, Ahlam Idrissi, Meriyem Mouloudi, and Mostafa Chhiba. 2022. "LandGEM Biogas Estimation , Energy Potential and Carbon Footprint Assessments of a Controlled Landfill Site . Case of the Controlled Landfill of Mohammedia-Benslimane , Morocco." 23(3):116–29.

Park, Jin Kyu, Yong Gil Chong, Kazuo Tameda, and Nam Hoon Lee. 2018. "Methods for Determining the Methane Generation Potential and Methane Generation Rate Constant for the FOD Model: A Review." *Waste Management and Research* 36(3):200–220. doi: 10.1177/0734242X17753532.

Saleh, Hosam M., and Martin Koller. 2019. "Introductory Chapter : Municipal Solid Waste." Pp. 1–8 in *Municipal Solid Waste Management*. Intechopen.

Soltani, Atousa, Rehan Sadiq, and Kasun Hewage. 2016. "Selecting Sustainable Waste-to-Energy Technologies for Municipal Solid Waste Treatment: A Game Theory Approach for Group Decision-Making." *Journal of Cleaner Production* 113:388–99. doi: 10.1016/j.jclepro.2015.12.041.

Somorin, Tosin Onabanjo, Sola Adesola, and Aisha Kolawole. 2017. "State-Level Assessment of the Waste-to-Energy Potential (via Incineration) of Municipal Solid Wastes in Nigeria." *Journal of Cleaner Production* 164(October):804–15. doi: 10.1016/j.jclepro.2017.06.228.

World bank group. 2021. *Climate Change Knowledge Portal.*

Zhou, Zhaozhi, Yuanjun Tang, Jun Dong, Yong Chi, Mingjiang Ni, Nan Li, and Yongfang Zhang. 2018. "Environmental Performance Evolution of Municipal Solid Waste Management by Life Cycle Assessment in Hangzhou , China." *Journal of Environmental Management* 227(July):23–33. doi: 10.1016/j.jenvman.2018.08.083.

Zubizarreta, Javier, and Marcos Rodrigues. 2010. "Potential and Cost of Electricity Generation from Human and Animal Waste in Spain." 35:498–505. doi: 10.1016/j.renene.2009.07.027.