

# DETERMINATION OF METHANE AND ENERGY GENERATING POTENTIALS FROM MUNICIPAL SOLID WASTE USING IPCC DEFAULT MODEL

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## ABSTRACT

*The gas generated from bio-degradation of municipal solid waste usually called landfill gas comprises mainly of methane a potent greenhouse gas and small fractions of other hazardous gasses. Therefore, there is need to harness this methane as usefull energy source biogas and an environment burden. The aim of the study is to characterise the MSW deposited at Doubeli and Limawa community dumpsites in Jimeta, Yola town and determine their methane and energy generation potential. The methodology involves measuring the temperature, area and volume of the existing waste at the sites, collecting, separating and weighing the bio-degradable and non-degradable components of the collected waste. Approximate volumetric analyses show that, the dumpsites were opened 2011, 2008, 2010 and 2007 for dumpsites A, B, C and D respectively. These dumpsites contained about 295.67 Mg, 1,311.94 Mg, 264.47 Mg and 1,059.74 Mg of bio-degradable waste and 443.50 Mg, 1,967.91 Mg, 396.71 Mg and 1,589.61 Mg of other types respectively. The yearly waste components for all the dumpsites are 263.66 Mg, 681.45 Mg, 1,797.20 Mg and 189.50 Mg for paper and textile, GPNFW (garden, park and non-food waste), food and kitchen waste, and wood and straw respectively. Using annual waste generation, approximate population and default factors, annual methane generation potential was determined to be 23,252.42 Mg for 2015 using IPCC default method. The result also shows that 28,403.76 Mg of CH<sub>4</sub> will be released in 2022 equivalent to 219.685 GJ and 65.905 GWh of heat and electricity respectively. From 2015 to 2022, the dumpsites emitted 3,684.926 Gg of methane equivalent to 8,550.179 GWh of electricity. These will generate gross revenue of ₦1,473.97b when use as fuel and ₦384.758b when used for electricity. The study reveals that utilising the dumpsites for harnessing LFG will reduce air, water and atmospheric pollution (environment), generate revenue to the authority (economic) and employment and clean environment to the populaces (social).*

**Keywords:** Anaerobic digestion, Energy, Landfill gas, Methane, Municipal solid waste, Potentials

## 1 INTRODUCTION

Municipal solid waste (MSW), also known as residual waste, is defined as “mixed waste from households and similar institutions with the exception of separately collected fractions”. However, miscellaneous organics (e.g. food and garden wastes), recyclables (e.g. plastics, glass and metals) and hazardous materials (e.g. batteries, cigarette butts and drugs) are also found in MSW [1, 2]. Generally, MSW constitute of organic degradable waste which include food, garden waste, paper, straw, vegetables, fruits, kitchen and cafeteria waste, etc. The other component is non-degradable waste such as metallic and plastics cans, tins, and bottles, metals rods, plate, buckets. Other non-degradable wastes include wires, sand, clothes and polythene bags etc. [2]. The organics have a considerable share in fresh residual waste, both in developed and developing countries [1, 2]. The major problem is effective disposal and management of MSW, because the biodegradable part of MSW leads to unrestrained emissions of greenhouse gas (GHG) when dumped untreated. However,

due to rapid urbanisation, landfill sites are becoming scarce and stringent legislations are in force, particularly restricting disposition of degradable waste in landfills [3]. Solid waste management is a basic service provided by the city municipal authorities to their residents. Factors influencing the quality of that service are finance, technology, and trained staff available to the individual city municipal administration for waste management. In low-income countries, municipal authorities are lacking the required funds, technical facilities, and trained manpower for municipal waste management. Moreover, due to the within-country migration of people from rural to urban areas, the burden on the municipal authorities in major cities has increased to sustainably handle the high amount of waste generated from different sectors. In Nigeria, there are deficiencies in the availability of funds, planning, technology, and trained workforce for proper and sustainable municipal solid waste management. Even in major cities like Kano, Kaduna, Lagos, Ibadan and Abuja, municipal authorities are striving for the allocation of required funds and other resources for proper municipal waste management. As a result, MSW is poorly managed and public health and environmental quality is highly compromised in the country [4, 5]. To reduce the greenhouse gas (GHG) emissions from the MSW sector, different waste treatment technologies have been developed, such as composting, incineration, anaerobic digesters, an-aerobic landfills with gas capturing facilities and refused derived fuels (RFD) [5]. Currently, there are several studies that consider generation of biogas such as methane or cooking gas from different types of waste around the world. Expecially, studies of [5, 6, 7] studied the potentials of generation usefull energy source from MSW. Other previous old and recend studies include generation of methane from food cafeteria or kitchen waste [8, 9, 10, 11]. Agricultural waste such as garden, animals and poultry waste as biodegradable waste also generate substantial quantity of biogas as reported in studies of [12, 13, 14, 15, 16]. Generally, it has been realised that, organic wastes are the most important part of the waste when generating biogas is of greeter concern [17, 18, 19]. Therefore evaluating the LFG potentials of MSW from various dumpsites in the country is a neccesity rather than previlage. The Inter governmental Panel on Climate Change (IPCC) Guidelines recommended two methods for estimation  $CH_4$  emissions from solid waste disposal. The IPCC default method is a simple mass balance calculation which estimates the amount of  $CH_4$  emitted from the SWDS assuming that all  $CH_4$  is released the same year the waste is disposed of. The other method is the First Order Decay (FOD) method which takes the time factors of the degradation process into account, and produces annual emission estimates that reflect this process. IPCC default method has merits e.g. in studies comparing the potential to reduce the  $CH_4$  emissions by alternative waste treatment methods. The use of all the recommended methods requires input such as annual SW disposal data including information on the composition of the waste and on the conditions at the dumpsites. The IPCC default method requires this data only for the inventory years, and contains default values for most of the data needed, whereas the guidance and default values needed in the use of the FOD method are insufficient [20, 21, 22]. The LFG produced from MSW are usually purified and used mainly for power generation. After pre-treatment, LFG can be converted to electricity by a number of techniques in terms of LFG energy content. Conversion efficiency is 25% - 30% for gas turbines, steam turbines and micro-turbines and 28% - 40% for reciprocating gas engines. Capacity factors for biomass energy systems range in 80% to 90% [23]. The use of LFG for generating electricity is a promising approach both in terms of conserving energy and also for reducing air pollution. Energy recovery from waste represents an important way to reduce the amount of electric energy to be produced using fossil fuels, that is, non-renewable sources of energy. In addition to conserving valuable alternative energy resources, direct LFG utilization results in reduced greenhouse gas emissions [24]. It is evident that, every million tons of MSW in a landfill is estimated to be able to produce approximately 300 cfm of LFG. Through various technologies, this amount of LFG could generate approximately 0.78 MW of power or provide 2.64 MW thermal energy [4]. Currently, the LFG or methane are either flared, converted to compressed natural gas (CNG), liquefied natural gas (LNG) and ordinary town gas for cooking and warming of buildings in well control dumpsites in the developed countries. Current study propose the use of gas generated from the studied landfills after proper treatment for either sell as gas for cooking heating and other industrial processes or used the gas to generated electricity for the immediate community as the power shortage is evidentially a problem [5]. A simple schematic diagram of converting the generated methane in to RNG or electric is shown in Figure 1.

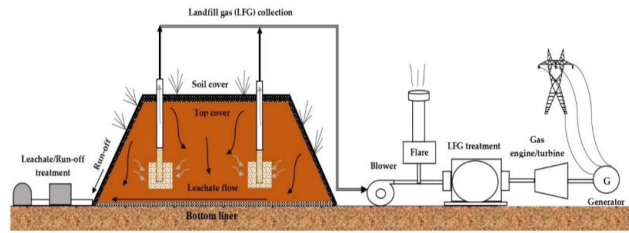


Figure 1. Schematic diagram of landfill gas engines for generating electricity [5]

Although gas composition varies from one site to another, LFG typically contains around 45–50% methane ( $\text{CH}_4$ ), 35–40% carbon dioxide ( $\text{CO}_2$ ), and 10–15% nitrogen ( $\text{N}_2$ ). The LFG also contain smaller amounts of hydrogen ( $\text{H}_2$ ), oxygen ( $\text{O}_2$ ), hydrogen sulphide ( $\text{H}_2\text{S}$ ), and ammonia ( $\text{NH}_3$ ). The gas is usually saturated with water vapour. In the presence of water, halogenated compounds (e.g., carbon tetrachloride, chloro-benzene, chloroform) that produce corrosive combustion products, and organic silicon compounds (e.g., siloxanes) that form siliceous deposits in downstream applications like internal combustion (IC) engines. Thus, an initial clean-up or pre-purification step is needed before LFG can be used in any application especially involving combustion in IC engines [25, 26]. Therefore, internal combustion engine technology was considered for power generation with the average electrical efficiency of ( $\eta_e$ ) of 30%. An accurate estimation of LFG, mainly methane, is important for conduction of life cycle assessment (LCA) for waste to energy pathways of landfills [5]. The importance of reducing the greenhouse gas (GHG) release to the atmosphere from decomposition of different type of waste had occupy most of the gathering throughout the world. Therefore, there is a need for exploring various methods of converting this MSW in to useful energy source such as methane. The current study aim at determining the potential of generating methane from MSW generated in Jimeta, Yola town (Yola North LGA) in Adamawa state Nigeria.

## 2 METHODOLOGY

### 2.1 Features of the Study Area

The study area is located in Jimeta, Yola North Local Government Area (LGA) Yola town Adamawa state Nigeria which is on Latitude  $9010^{\circ}\text{N}$  to  $9015^{\circ}\text{N}$  and Longitude  $120.11^{\circ}\text{E}$  to  $120.17^{\circ}\text{E}$ . The of the metropolis and the stusy area can be seen in Figure 2. The waste is mainly generated from the following communities: Anguwan Tana, Zango and Shunko communities of Limawa, Doubeli community and some part of the town. The dump site is located along Jimeta bypass between doubeli junction and the famous Jimeta bridge on the river bank side of the road. According to National Population Commission [27] Yola office, the population of Jimeta is around 167,426.28 as of 2015 while dumpsites neighbouring communities have average population of in the 25,719 as of 2015 with population growth rate of 1.029. The ban in the use of non official dumpsites by Yola North Government Authority in the town increases the volume of waste generated in the considered dumpsites. Thus, almost 50% of MSW from the city are taken to these sites and the remaining are found in drainages, smaller official and non-official dumpsites in the town and others taken to farm as manure [28].

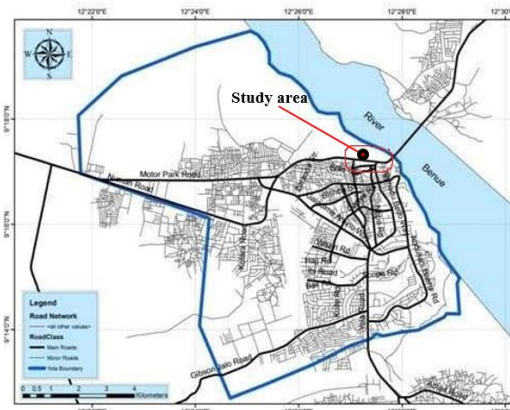


Figure 2. Map of Yola North local government area showing the study area

## 2.2 Materials And Equipment

The equipment used were simple weighing devices such as analog and digital weighing balance and containers such as small and big drums, buckets. Others are ropes, hand shovel, forks and poly bags. General safety gadgets such as boots, hand gloves, dust and fumes masks, etc. Carriages such as wheel barrow (single and double wheels), measuring devices such as tapes.

## 2.3 Waste Type And Characteristics

The dumpsites are characterised by an appropriate waste disposal planning, no personnel on site to exercise authority, no access or control over the type of waste entering the site, and scavenging by the rag pickers. Hence water logging and leaching during monsoon adversely cause water pollution. They are also open dumpsites characterised by offensive odour, open defecation, uncontrolled burning of waste and blowing of light materials and fumes by wind. There are four dumpsites in the study area which were tagged dumpsite A, B, C and D respectively. The types of wastes in the study area composed of commercial waste, street waste, market waste and domestic waste which were brought in wheel barrow, plastic buckets, polythene bags, pickup, vans, etc. by children and drivers from the respective communities.

## 2.4 Data Collection

The study starts with measuring the area and the volume of the dumpsites. Cylindrical drum was used to measure the quantity of the waste brought to each dumpsite daily for seven days. The experiment was conducted for seven days on each dumpsite. Total average of 7, 17, 6, and 13 drums was collected daily for dumpsites A, B, C and D respectively. Drum of 0.2271 m<sup>3</sup> volume was used for daily waste collection. The MSW were separated in to five components which are (a) paper and textile, (b) garden, park and non-food organic waste (GPNFW) (c) food waste, (d) wood and straw. Other major components of the waste were (e) others which include plastics, polythene bags, metals, sand, small stones, cans etc. These compositions were measured in kilogram. For non-organised and controlled dumpsite biodegradable components covers up to 40% while for controlled and well organised dumpsites it reaches up to 70% as reported in [1, 2, 29, 30, 31].

## 2.5 Model Equations

The volume of the cylindrical drum ( $V_D$ ) and that of the dumpsites ( $V_S$ ) were calculated using equation 1 and 2 respectively,

$$V_D = \pi r^2 h \quad (1)$$

$$V_S = L * B * H \quad (2)$$

Where:  $r$  is the radius of the drum;  $h$  is the height of the drum;  $L$  is the length of each dumpsite along the road;  $B$  is the width of the dumpsite perpendicular to the road;  $H$  is the height of the dumpsite from the datum level of river bank;  $S$  is the dumpsite. The number of drums per each dumpsites ( $D_n$ ) and years spend by each dumpsite ( $S_T$ ) can be calculated using equation 3 and 4.

$$D_n = \frac{V_s}{V_D} \quad (3)$$

$$S_T = \frac{D_n}{N} \quad (4)$$

Where  $N$  is average number of drums brought to each dumpsite every day. The mass in kg for each waste component was weight using weighing balance at the dumpsites. The daily biodegradable waste disposal for each of the dumpsites ( $B_w$ ) was calculated using equation 5.

$$B_w = \sum_{i=1}^n m_i N_i \quad (5)$$

Where  $m_i$  is the mass of the biodegradable components in the drum;  $N_i$  is the number of drums brought to each of the dumpsites and  $i$  is the number composition of biodegradable waste. The

average daily waste dispersal for each dumpsites *A* to *D* (*ADD*) was calculated by taking the mean of the waste dumped in seven days using equation 6. This are added up to get the total waste for each component per day and the average yearly waste dispersal (*AYD*) was calculated using equation 7.

$$ADD = \frac{\sum_{i=1}^7 DWD}{7} \quad (6)$$

$$AYD = \frac{ADD * 365}{1000} (Gg / Year) \quad (7)$$

Where *DWD* is the daily waste dispersal. Therefore, the approximate total waste disposed at the dumpsites *MSW<sub>D</sub>* to the time of study *Gg/year* can be calculated using equation 8.

$$MSW_D = \sum_{i=1}^n AYD * S_T \quad (8)$$

The fraction of waste that reaches the dumpsites (*MSW<sub>F</sub>*) was calculated using equation 9 [21].

$$MSW_F = \frac{MSW_D}{MSW_T} \quad (9)$$

Where *MSW<sub>T</sub>* is the total waste generated from the supply population in *Gg/year* which can be obtained using equation 10 and *i* is the number of dumpsites from *A* to *D*.

$$MSW_T = P * AWG \quad (10)$$

Therefore, the *AWG* is given by

$$AWG = \frac{MSW_{SY}}{P_{SY}} \quad (11)$$

Where *P* is the study area total population; *AWG* is the annual waste generation rate and *SY* represent a comprehensive data of the study year. The percentage waste composition (*PWC*) of each waste components can be calculated using equation 12.

$$PWC = \frac{WC_m}{MSW_D} \text{ or } \frac{WC_m}{MSW_T} \quad (12)$$

Where *WC<sub>m</sub>* is the weight of the waste component and *MSW<sub>m</sub>* is the total waste disposed at the dumpsite.

## 2.6 Methane Recovery Methodology

The IPCC Default Methodology (IPM) is used worldwide for determining the LFG recovery potential from MSW which is based on the theoretical gas yield (a mass balance equation) as reported in [5, 32, 33, 34, 35, 36, 37]. The method assumes that all the potential CH<sub>4</sub> emissions are released during the same year the waste is disposed of. The method is simple and emission calculations require only input of a limited set of parameters as can be seen in equation 13. The IPCC Guidelines provide default values, where country-specific quantities and data are not available [22].

$$CH_4(Gg / yr) = (MSW_T * MSW_F * MCF * DOC * DOC_F * F * \frac{16}{12} - R) * (1 - OX) \quad (13)$$

Where *MSW<sub>T</sub>*: total MSW generated (Gg/yr.), *MSW<sub>F</sub>*: fraction of MSW disposed to solid waste disposal sites equation 9, *MCF*: methane correction factor (fraction), *DOC*: degradable organic carbon (fraction) (kgC/kg SW), *DOC<sub>F</sub>*: fraction DOC dissimilated, *F*: fraction of CH<sub>4</sub> in landfill gas (IPCC default is 0.5), 16/12: conversion of C to CH<sub>4</sub>, *R*: recovered CH<sub>4</sub> (Gg/yr.) (default 5% for landfill less than 2million m<sup>3</sup>), *OX*: oxidation factor (fraction – IPCC default is 0).

Default values for some parameters in the considered model according to [22] are

- a. *MCF*: Methane Correction Factor (fraction), which lies between 0.4 for unmanaged site to 1.0 for managed site with 0.6 general default values.

- b. DOC: Degradable Organic Carbon (fraction). It can be estimated using equation 14 below.

$$\%DOC = 0.4 * A + 0.17 * B + 0.15 * C + 0.03 * D \quad (14)$$

Where A = %MSW that is paper and textile, B = %MSW that is GPNFW waste, C = %MSW that is food and kitchen waste and D = % MSW that is wood or straws.

- c.  $DOC_F$ : Fraction of DOC that is converted to methane and was estimated using equation 15.

$$DOC_F = 0.014T + 0.28 \quad (15)$$

Where  $T$  is the average temperature of the dumpsite and default value of  $DOC_F$  ranges from 0.5 to 0.77.

## 2.7 Energy Recovery from LFG

There are several facilities using landfill gas for power production that are in operation worldwide utilizing gas engines, gas turbines and steam turbines. The gas engine had an advantage over the other facilities in the sense that it produced less waste heat, therefore, increasing its efficiency [24]. Among the gas engines, internal combustion engines occupy the market due to their low cost and high electrical efficiency ( $\eta_e = 30 - 40\%$ ). Gross or thermal energy potential can be calculated based on the volume or mass of  $CH_4$  collected per year using equation 16 [5, 23, 24] and the net energy potential or electrical energy potential can be calculated using equation 17 [5, 24].

$$EP_{th} = \eta_{gc} \times EC \times G_t \quad (16)$$

$$EP_{el} = EP_{th} (kWh) \times \eta_{el} \quad (17)$$

Where  $EP_{th}$ : Thermal energy potential ( $kWh$  or  $kJ$ ),  $\eta_{gc}$ : Gas collection or recovery efficiency,  $EC$ : Energy content (i.e. LHV) ( $kJ/m^3$  or  $kJ/kg$ ),  $G_t$ : The volume or mass of  $CH_4$  identified by LFG modelling ( $kg$  or  $m^3$ ),  $\eta_{el}$ : electrical efficiency and  $EP_{el}$ : Electrical energy potential.

## 3 RESULTS AND DISCUSION

### 3.1 Dumpsites Characteristics and Raw Results

Average study area dumpsites characteristics were shown in Table 1. Variation of average daily waste disposal in kg for seven days at each dumpsite A to D are shown in Figure 3.

Table 1. Study area dumpsites approximate volumetric characteristics

Parameters	Dumpsite (A)	Dumpsite (B)	Dumpsite (C)	Dumpsite (D)
Length (m)	52	136	36	132
Height (m)	3.3	3.2	5.1	3.9
Breadth (m)	13.3	21	11.4	15.5
Area covered by dumpsites ( $m^2$ ) (along and perpendicular to the road)	691.6	2856	410.4	2046
Volume of each dumpsite ( $m^3$ )	2282.28	9139.20	2093.04	7979.40
Volume of drum ( $m^3$ )	0.2271	0.2271	0.2271	0.2271
No of drums per dumpsites (units)	10,049.67	40,243.06	9,216.38	35,136.06
No of drums per day (units)	7	17	6	13
Average dumpsite time (yrs.)	3.9	6.5	4.2	7.4
Average yearly weight of waste (kg)	188,084.50	505,369.88	157,050.38	358,019.38
Average density of the waste ( $kg/m^3$ )	82.41	55.30	75.03	44.87
Approximate dumpsite opening date	2011	2008	2010	2007
Analyses starting date	2015	2015	2015	2015
Assumed dumpsite closing date	2065	2065	2065	2065
Assumed period of closing the dumpsites	43yrs	43yrs	43yrs	43yrs
Methane extraction period (from 2022)	100yrs	100yrs	100yrs	100yrs
Methane project closing date	2122	2122	2122	2122

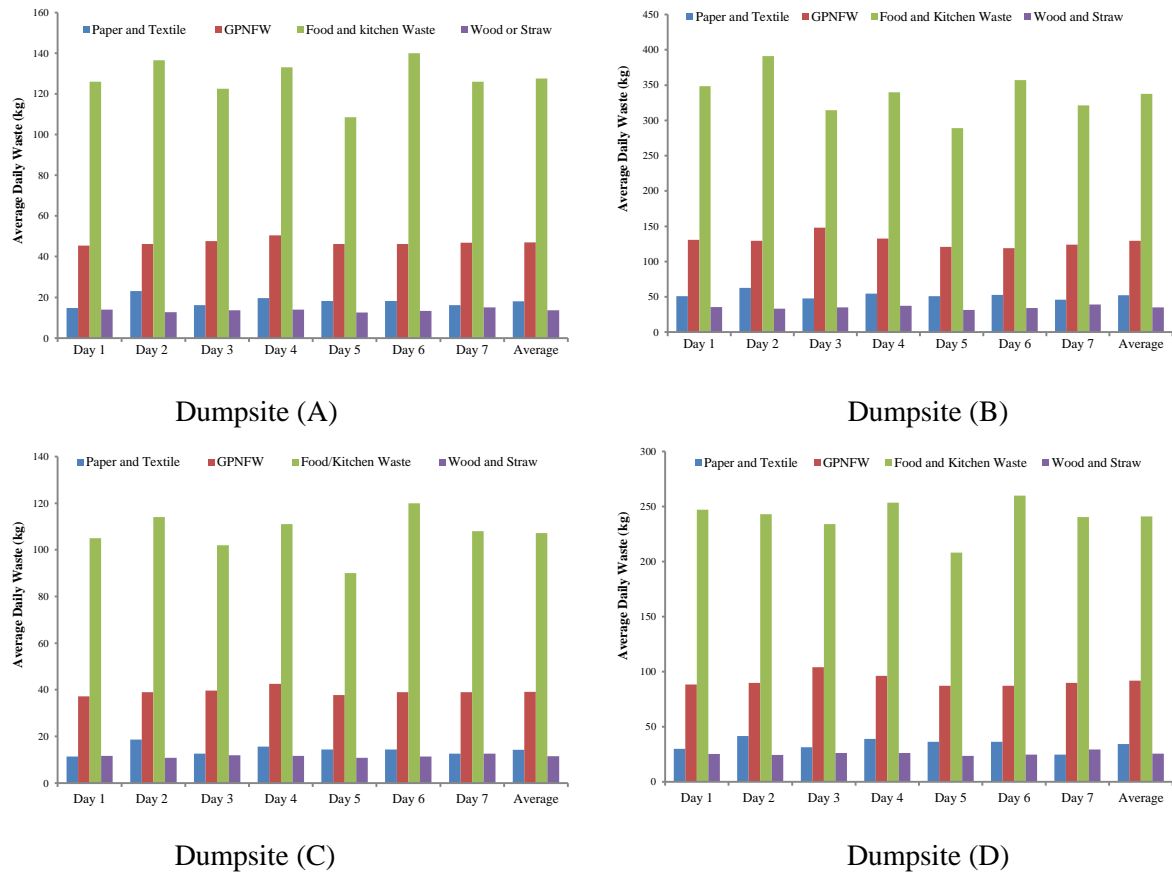


Figure 3. Average daily degradable waste disposed at the dumpsites A to D in kg

The environmental office in yola was not able to provide actual record when these dumpsites were opened. Therefore, the volumetric analyses predicted that, the disposal of waste donnot start at the same time as each dumpsites has its own starting time as can be seen from Table 1. This analyses show that the dumpsites A, B, C and D spend 3.9 yrs, 6.5ysr, 4.2yrs and 7.4yrs respectively. Dumpsite A being closed to the river have the lowest volume size and waste disposal as it is at the starting point of the supply community. While dumpsites B and D being at the center and the end of the study area heve the highest waste volume size and waste disposal as they recieve the highest percentage of the waste due to their strategic location. Dumpsite D being at the doubeli jounction recieves most of its waste from other parts of Jimeta community as it is reported that after closing un-official dumpsites in the town most of the waste were brought to this dumpsite. From the collected waste at all the dumpsites, it can be seen that food and kitchen waste constitute the highest percentage in the bio-degradable components of the waste. Also, the biodegradable waste constitute of up to  $\geq 40\%$  of the total waste deposited in the dumpsites yearly. This shows that the dumpsites have high potentials of extracting methane for use either as energy source in households, powering vehicles or generating electricity using state of art technologies. The summary of the average daily and yearly composition of waste disposed at all the dumpsites and their percentage deposition were shown in Table 2.

Table 2. Summary of total waste composition from the dumpsites

Composition	Dumpsite A (Mg)	Dumpsite B (Mg)	Dumpsite C (Mg)	Dumpsite D (Mg)	Total Yearl (Mg)	Percentage (%)
Paper and Textile	25.82	123.68	21.87	92.29	263.66	8.96
GPNFW	67.42	306.06	60.19	247.79	681.45	23.19
Food and kitchen Waste	182.89	799.08	164.64	650.59	1,797.20	61.37
Wood and Straw	19.54	83.12	17.78	69.06	189.50	6.48
Total degradable waste	295.67	1,311.94	264.47	1,059.74	2,931.82	40.00
Other waste types	443.50	1,967.91	396.71	1,589.61	4,397.73	60.00
Total disposed waste	739.17	3,279.85	661.18	2,649.34	7,329.55	100.00

### 3.2 Methane Generation Potential

The values of the various factors and initial data listed for the landfills analyses and methane recovery computation for total MSW from dumpsites using IPCC default model are given in Table 3. The methane recovery analyses assume that, the emissions start at the time of the experiment which is 2015 (i.e. it neglects emissions from dumpsites opening to 2015). The assumption also involves the dumpsites being closed after 43 years from 2022 further which the methane and LFG generation will reduce to less than 1,000Mg. The summary of IPCC default model analyses is shown in Table 4. The variations of methane recovered from MSW in the study area for the period of 140 years (i.e. 2015 to 2155) are shown in Figure 4.

Table 3. Factors and data used in estimating methane generation potential using IPCC default model

Parameters	Dumpsite A	Dumpsite B	Dumpsite C	Dumpsite D	Total Value
Waste generation rate $Mg.capita^{-1}year^{-1}$	0.128	0.128	0.128	0.128	0.128
Population to be served by landfill	11,827	52,293	10,542	42,241	116,903
Total waste generation $MSW_T$ (Mg)	1,513.86	6,693.50	1,349.38	5,406.85	14,963.58
Waste disposed in landfill $MSW_D$ (Mg)	739.17	3,279.85	661.18	2,649.34	7,329.55
Fraction of waste reaching landfill $MSW_F$	0.49	0.49	0.49	0.49	0.49
Methane Correction Factor $MCF$	0.4	0.4	0.4	0.4	0.4
A = % MSW that is paper and textiles	8.73	9.43	8.27	8.71	8.96
B = % MSW that is GPNFW	22.80	23.33	22.76	23.38	23.19
C = % MSW that is kitchen/food waste	61.86	60.91	62.25	61.39	61.37
D = % MSW that is wood or straw	6.61	6.34	6.72	6.52	6.48
Degradable organic carbon $DOC$	16.85	17.06	16.72	16.86	16.93
Average temperature at Landfill $T$ (°C)	35	35	35	35	35
Fraction of $DOC$ $DOC_F$	0.73	0.73	0.73	0.73	0.73
Fraction of methane in the landfill gas $F$	0.5	0.5	0.5	0.5	0.5
Recovered methane $R$ (Gg/yr.)	0.05	0.05	0.05	0.05	0.05
16/12-R ( $L_a$ )	1.283	1.283	1.283	1.283	1.283
Oxidation factor $OX$	0	0	0	0	0
CH <sub>4</sub> generation potential (Mg/yr) (2015)	2,341.93	10,483.85	2,071.38	8,369.32	23,258.46

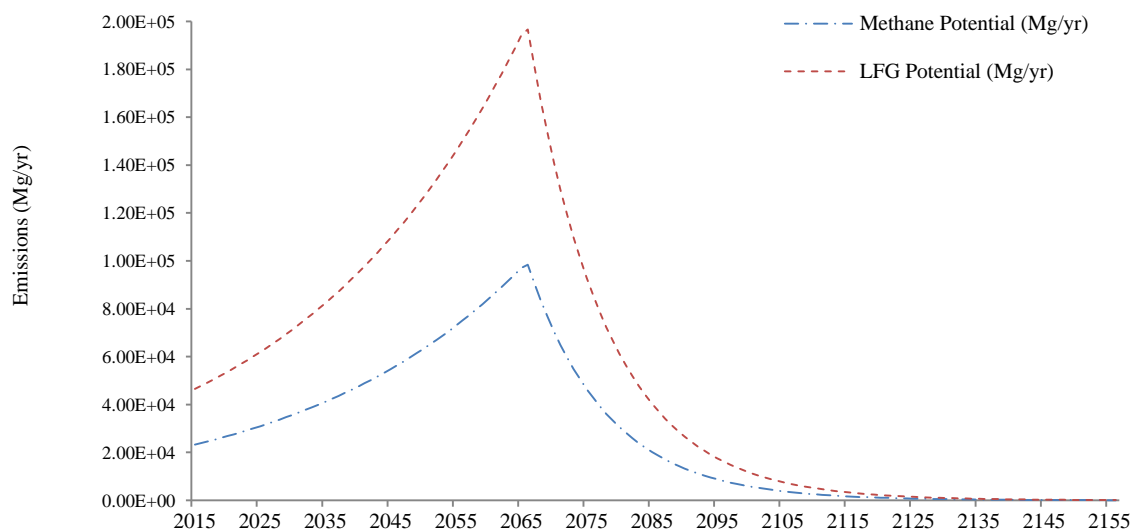


Figure 4. Variation of yearly recovery potential from MSW using IPCC default model

Table 4. Summary of methane recovery potential analyses using IPCC default model

Years	AWG ( $Mg/C/yr$ )	Population ( $P$ )	$MSW_T$ ( $AWG*P$ ) ( $Mg$ )	$L_{01}$ ( $MSW_T*MSW_F*DOC*DOC_F$ )	$L_{02}$ ( $F*L_a*L_b$ )	Methane Potential ( $L_{01} * L_{02}$ )	Methane Potential ( $10^6$ )
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				(Mg)	(Mg)	(Mg/yr.)	(m <sup>3</sup> /yr.)
2015	0.128	116,903	14,963.58	36,246.95	0.64	23,252.42	32.430
2016	0.128	120,293	15,397.53	37,298.12	0.64	23,926.74	33.371
2017	0.128	123,782	15,844.06	38,379.76	0.64	24,620.62	34.338
2018	0.128	127,371	16,303.53	39,492.77	0.64	25,334.61	35.334
2019	0.128	131,065	16,776.34	40,638.06	0.64	26,069.32	36.359
2020	0.128	134,866	17,262.85	41,816.57	0.64	26,825.33	37.413
2021	0.128	138,777	17,763.47	43,029.25	0.64	27,603.26	38.498
2022	0.128	142,802	18,278.61	44,277.10	0.64	28,403.76	39.615
2023	0.128	146,943	18,808.69	45,561.13	0.64	29,227.47	40.764
2024	0.128	151,204	19,354.15	46,882.41	0.64	30,075.06	41.946
2025	0.128	155,589	19,915.42	48,242.00	0.64	30,947.24	43.162
2026	0.128	160,101	20,492.96	49,641.01	0.64	31,844.71	44.414
2027	0.128	164,744	21,087.26	51,080.60	0.64	32,768.21	45.702
2028	0.128	169,522	21,698.79	52,561.94	0.64	33,718.48	47.027
2029	0.128	174,438	22,328.05	54,086.24	0.64	34,696.32	48.391
2030	0.128	179,497	22,975.57	55,654.74	0.64	35,702.51	49.794
2031	0.128	184,702	23,641.86	57,268.72	0.64	36,737.89	51.238
2032	0.128	190,058	24,327.47	58,929.52	0.64	37,803.29	52.724
2033	0.128	195,570	25,032.97	60,638.47	0.64	38,899.58	54.253
2034	0.128	201,242	25,758.93	62,396.99	0.64	40,027.67	55.827
2035	0.128	207,078	26,505.93	64,206.50	0.64	41,188.47	57.446
2036	0.128	213,083	27,274.61	66,068.49	0.64	42,382.94	59.111
2037	0.128	219,262	28,065.57	67,984.48	0.64	43,612.04	60.826
2038	0.128	225,621	28,879.47	69,956.03	0.64	44,876.79	62.590
2039	0.128	232,164	29,716.98	71,984.75	0.64	46,178.22	64.405
2040	0.128	238,897	30,578.77	74,072.31	0.64	47,517.39	66.273
2041	0.128	245,825	31,465.55	76,220.41	0.64	48,895.39	68.194
2042	0.128	252,954	32,378.05	78,430.80	0.64	50,313.36	70.172
2043	0.128	260,289	33,317.02	80,705.29	0.64	51,772.44	72.207
2044	0.128	267,838	34,283.21	83,045.74	0.64	53,273.85	74.301
2045	0.128	275,605	35,277.42	85,454.07	0.64	54,818.79	76.456
2046	0.128	283,597	36,300.47	87,932.24	0.64	56,408.53	78.673
2047	0.128	291,822	37,353.18	90,482.27	0.64	58,044.38	80.955
2048	0.128	300,285	38,436.43	93,106.26	0.64	59,727.67	83.302
2049	0.128	308,993	39,551.08	95,806.34	0.64	61,459.77	85.718
2050	0.128	317,954	40,698.06	98,584.73	0.64	63,242.10	88.204
2051	0.128	327,174	41,878.31	101,443.68	0.64	65,076.12	90.762
2052	0.128	336,662	43,092.78	104,385.55	0.64	66,963.33	93.394
2053	0.128	346,426	44,342.47	107,412.73	0.64	68,905.27	96.102
2054	0.128	356,472	45,628.40	110,527.70	0.64	70,903.52	98.889
2055	0.128	366,810	46,951.62	113,733.00	0.64	72,959.72	101.757
2056	0.128	377,447	48,313.22	117,031.26	0.64	75,075.55	104.708
2057	0.128	388,393	49,714.30	120,425.17	0.64	77,252.74	107.744
2058	0.128	399,656	51,156.02	123,917.50	0.64	79,493.07	110.869
2059	0.128	411,246	52,639.54	127,511.10	0.64	81,798.37	114.084
2060	0.128	423,173	54,166.09	131,208.93	0.64	84,170.53	117.393
2061	0.128	435,445	55,736.91	135,013.98	0.64	86,611.47	120.797
2062	0.128	448,072	57,353.28	138,929.39	0.64	89,123.20	124.300
2063	0.128	461,067	59,016.52	142,958.34	0.64	91,707.78	127.905
2064	0.128	474,438	60,728.00	147,104.13	0.64	94,367.30	131.614
2065	0.128	488,196	62,489.11	151,370.15	0.64	97,103.95	135.431
2066	0.128	502,354	62,489.11	151,370.15	0.64	98,356.59	137.178
2067	0.128	516,922	62,489.11	151,370.15	0.64	90,488.07	126.204
2068	0.128	531,913	68,084.85	164,924.96	0.64	83,249.02	116.107
2069	0.128	547,338	70,059.31	169,707.78	0.64	76,589.10	106.819
2070	0.128	563,211	72,091.03	174,629.31	0.64	70,461.97	98.273
2080	0.128	749,592	95,947.79	232,418.60	0.64	30,607.87	42.689
2090	0.128	997,651	127,699.36	309,331.84	0.64	13,295.70	18.544
2100	0.128	1,327,800	169,958.34	411,697.63	0.64	5,775.50	8.055
2110	0.128	1,767,202	226,201.89	547,938.88	0.64	2,508.81	3.499
2120	0.128	2,352,015	301,057.86	729,265.83	0.64	1,089.80	1.520
2130	0.128	3,130,356	400,685.59	970,598.49	0.64	473.40	0.660

Figure 4 show that large quantity of methane as highest fraction in the LFG will be generated from the dumpsites if the landfill is controlled and the gases are extracted and treated. The magnitude of the methane as well as LFG generated increases exponentially from 23,252.42 Mg in 2015 to

28,403.76 Mg in 2022 which will further rise up to 98,356.59 Mg in 2066 one year immediately after closing year of 2065. After 2066, Figure 4 shows methane generation reducing gradually to 473.40 Mg in 2130. The remaining LFG and methane potentials was calculated based on gas mass between the years 2015 to 2130 and plotted as shown in Figure 4 and Table 4. This indicates that remaining LFG/methane capacity of the site from the peak period is nearly more than 50%. Thus it can be concluded that energy recovery can be an option for the site for current potentials. In this study, it's assumed that the landfill site closed in 2065 and the modelling estimated for a longer period of time (i.e.  $\geq 100$  years) from 2022 to 2122 in order to assess the total LFG and methane potential. But as seen in Figure 4, the economic feasible lifespan of LFG energy recovery project was ended at almost 2122 when the methane generation is less than 1000Mg. So, remaining methane potential for the site was assessed for the period of 2123 – 2155 which yielded about 9,984.78 Mg of methane.

### 3.3 Energy Generating Potentials

According to [23], energy content of LFG varies depending on the gas quality which generate from 16 - 20 MJ/m<sup>3</sup> for low and medium-quality LFG. Whereas, high quality LFG produced by effective pre-treatment can have up to 30 MJ/m<sup>3</sup>. Using relations and default values in Table 5 obtained from [5, 23, 24, 38], the thermal and electrical energy potentials from internal combustion engine using the generated methane/purified or cleaned LFG can be calculated using equations 15 and 16.

Table 5. Default values for thermal and electrical energy potential analyses

Symbol	Description	Values
$\eta_{gc}$	Gas collection efficiency	75%
$EC$	Energy content of methane (LHV) in (kJ/m <sup>3</sup> ) and (kJ/kg)	26.885*10 <sup>3</sup> kJ/m <sup>3</sup> 37.500*10 <sup>3</sup> kJ/kg
$\rho$	Density of methane	0.717 kg/m <sup>3</sup>
$G_t$	The volume or mass of CH <sub>4</sub> identified (kg or m <sup>3</sup> )	From result
$\eta_{ec}$	Electricity conversion efficiency	30%
$EP_{th}$	Gross thermal energy potential (kWh) or (kJ)	?
$EP_{el}$	Electrical energy potential (kWh)	?

Variation of thermal and electrical energy generated from the methane potential in the study area for 2015 to 2155 are shown in Figure 5.

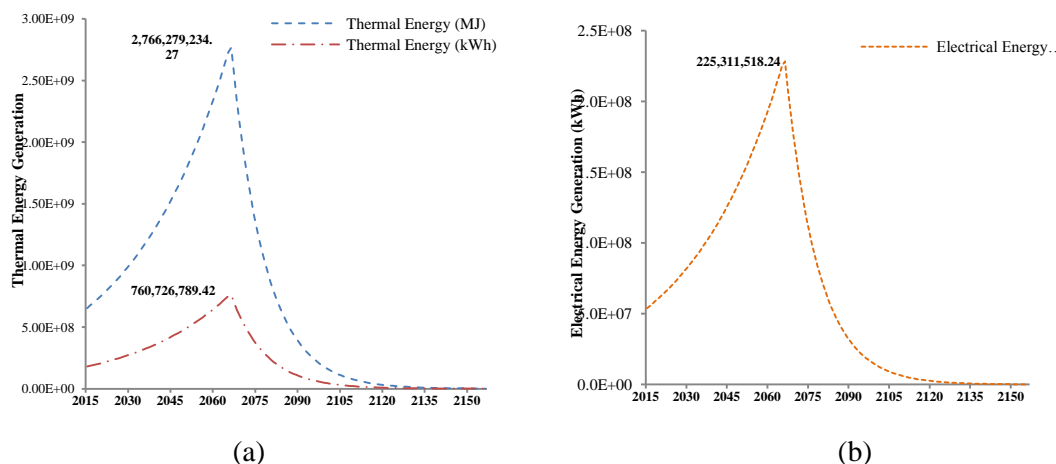


Figure 5. Variation of monthly (a) thermal energy and (b) electrical energy potential of the generated methane

The goal of this analysis is to determine the amount of electric energy that is potentially available in the Doubeli – Limawa communities’ dumpsites. Methane generation for dumpsites A to D in 2015 was found to be 2,341.93 Mg, 10,483.85 Mg, 2,071.38 Mg and 8,369.32 Mg respectively which added up to 23,258.46 Mg. These quantity of methane will generate thermal and electrical energy of 798.85TJ and 65.91 GWh respectively in 2015. These quantity of methane potential increase to 28,403.76 Mg in 2022 which will generate up to 798.856 TJ and 65.906 GWh of thermal

and electrical energy respectively. This is sufficient to subsidise the supply of gas and electricity to the immediate community daily activities and reduce pollution, provide job opportunity and reduce the quantity of GHG emitted to the atmosphere. If this amount of CH<sub>4</sub> produced from waste disposal sites would be collected, treated and utilized for electrical energy generation, a total of about 8,550.18 GWh of electric power would be generated at a 75% methane recovery rate from the dumpsites. Possible revenue generation from the methane and energy generation potential of the dumpsites are described in the following Table 6.

Table 6. Revenue recovery potential of the dumpsites in the study area

Periods	Methane Potential (Mg)	Methane Potential (Mm <sup>3</sup> )	Use as Fuel ₦400/kg	Price in US \$ \$1 = ₦430	Use for Electricity Generation		Price in US \$ \$1 = ₦430
					MWh	₦45/kWh	
2015	23,252.42	32.43	₦9.301b	\$21.63m	53,952.88	₦2.428b	\$5.646m
2022	28,403.76	39.61	₦11.362b	\$26.42m	65,905.59	₦2.966b	\$6.897m
2015-2022	206,036.06	287.36	₦82.414b	\$191.65m	478,068.05	₦21.513b	\$50.030m
2022-2122	3,684,926.01	5,139.37	₦1.474tr	\$3.42b	8,550,179.89	₦384.758b	\$894.786m
2123-2155	9,984.78	13.926	₦3.994b	\$9.28m	23,167.81	₦1.042b	\$2.425m

From Table 6, it can be seen that the gas generated can either be used as fuel for households, vehicles and other industrial applications from the immediate communities or can be used for electricity generation. Either ways, the potentials provide the communities and government enough revenue that will sustained itself and solve other societal problems. From Table 6, the gas potential for 2015 to 2022 can generate up to ₦82b equivalent to \$191.65m if the gas is sold for domestics, vehicle and industrial application and about ₦21b equivalent to \$50m as gross revenue. These show that the community and the government are losing huge amount of money and sustainable environmental condition from these dumpsites. If the dumpsites are properly managed and the generated gas was properly collected and utilised for economic purpose from 2023 to 2122, it will have generated gross revenue of ₦1.47tr and ₦384.76b when used as fuel and electricity which are equivalent to \$3.42b and \$894.79m respectively. Further activities in the dumpsites will also yield reasonable revenue to the government even though there may be no net revenue. The quantities of GHG and air contaminant emitted to the immediate environment are shown in Table 7. LFG is a threat to human health and global warming, and flaring or utilizing it for energy greatly reduces its climate change impact. Burning LFG also serves to mitigate its public health impact by destroying the majority of hazardous air pollutants in landfill gas through the combustion process.

Table 7. Amount of greenhouse gas emitted to the atmosphere during period of dumpsite life

Periods	Landfill Gas Potential (Mg)	Landfill Gas Potential (M.m <sup>3</sup> )
	2015	46,504.84
2022	56,807.52	79.229
2015-2022	412,072.12	574.717
2022-2122	7,369,852.03	10,278.734
2123-2155	19,969.56	27.852

From the quantity of LFG released to the immediate environment as can be seen from Table 7, it worth noting that the environment is highly polluted and there must be serious health issues in the community. Subsequently, reasonable quantities of GHG are released to the atmosphere thereby contributing to global warming.

### 3.4 General Discussion

Currently, there are three global concerns raised with regard to MSW and LFG. The first concern raised is about the health impacts of the water and air pollution and the exhaust from burning MSW and LFG. Second concern raised is on substantial environmental and public health damage caused by land filling and landfills. These called into question the sustainability of landfills themselves and thus landfill gas. The third concerns are on the provision of subsidies on proper

utilisation of MSW and LFG which suggested that these subsidies are just another stone on the scale of promoting land filling over recycling. Methane is a potent GHG with global warming potential (GWP) of 25 as reported by [29]. It is almost 28 to 36 times more effective than carbon dioxide at trapping heat in the atmosphere over a 100-year period as reported in [4]. Raw LFG contains many hazardous air pollutants, many of which are carcinogenic as reported in [25, 26]. The destruction of the vast majority of these air pollutants from burning the LFG more than makes up for the formation of minute amounts of dioxins. The analysis of the inhalation cancer-risk factor of the burn LFG suggests that the overall toxicity of LFG combustion is 23 times less than that of raw LFG [39]. Even though flaring emits CO<sub>2</sub> and purifying the LFG and converting it into CNG or LNG for vehicle fuel still emits CO<sub>2</sub>. However, the CO<sub>2</sub> would have been emitted anyway (hence, there is no net additional positive effect). Moreover, the CO<sub>2</sub> from LFG displaces a near equivalent amount of CO<sub>2</sub> from fossil fuels (natural or petroleum gas) that would have been emitted if the vehicles operating on LFG-derived CNG/LNG had not been converted from their original fossil fuel. In either case, the purified gas can be used in fuelling vehicles, generating electricity from on-site or off site generators or can be transported via pipes or tank truck to further various industrial processes [5, 25, 26]. Given the similar amount of waste disposed in landfills, emissions in Nigeria are still very low, compared with the developed countries (like China, US and Europe) landfill emission level. The CH<sub>4</sub> emission abatement in landfills should be a high priority for the decision makers. Co-management of pollution and CH<sub>4</sub> reduction is essential and feasible in all the uncontrolled landfill in Nigeria. The degradable organic carbon is the key to the generation of pollutants and CH<sub>4</sub>. The technology and policy for co-management should be implemented according to the specific conditions. The IC engines are the most commonly used conversion technology in LFG applications because of its relatively low cost, high efficiency and engine sizes that complement the gas output of many landfills. IC engines have generally been used at landfills where gas quantity is capable of producing 800 kWh to 3 MWh, or where sustainable LFG flow rates to the engines are approximately 300 to 1,100 cfm at 50% methane. Multiple engines can be combined together for projects larger than 3 MW [4]. IC engines are efficient at converting LFG into electricity, achieving electrical efficiencies in the range of 30 to 40 percent. Even greater efficiencies are achieved in combined heat and power (CHP) applications where waste heat is recovered from the engine cooling system to make hot water, or from the engine exhaust to make low-pressure steam.

#### **4 CONCLUSIONS**

This article provides feasibility of utilisation MSW from dumpsites located in some Jimeta communities in Yola Adamawa state Nigeria. From the analyses provided in this study, the following conclusions were made.

- a. The studied MSW contains large amounts of biodegradable wastes of about 2,931.82 Mg/year and release methane gases of about 23,252.42 Mg/year with high calorific values that can be utilized for town gas and energy generation.
- b. The dumpsites studied contain 7,329.55 Mg MSW and a potential of receiving 14,963.58 Mg enough for generation large quantity of methane and subsequently energy.
- c. The magnitude of the methane as well as LFG generated increases exponentially from 23,252.42 Mg in 2015 to 28,403.76 Mg in 2022 which will further rise up to 98,356.59 Mg in 2066 one year immediately after closing year of 2065.
- d. Total of 206,036.06 Mg of methane was released to atmosphere between 2015 to 2022 which is enough to generate 478,068.05 MWh of electricity. These is already a waste of resources and contributor to air pollution and climate change.
- e. The waste potential from the supply community population can be up to 412,072.12 Mg of which the remaining end up in water ways and streets sites which cause serious health and environmental problems.
- f. The use of LFG for generating gas and electricity is a promising approach both in terms of conserving potential energy resources and also for reducing air pollution.
- g. The gas and energy will be sufficient to provide jobs with reasonable loaded earning, revenue to landfill owner and government and cleaner environment. Hence further utilisation of the

dumpsites is beneficial to immediate community, local and national government and global environment.

- h. Further proper management of the dumpsites (2023 onward) will generate up to 3,684,926.01 Mg of methane. These quantities of methane can generate up to ₦1.474tr when sold as RNG and 8,550,179.89MWh of electricity and gross revenue of ₦384.758b.
- i. Proper utilisation of the generated gas can also offset the use of non-renewable resources (fossil fuel), help improve local air quality, provide revenue for landfill owners, reduce energy costs for users of LFG energy and create jobs and promote investment in local businesses.
- j. It can also be concluded that LFG energy and gas projects can offset release of about 7,369,852.03 Mg of methane from 2023 onward from the waste supply population. These will reduce air and water pollution and hence improve public health of the immediate community.

## REFERENCES

1. Marotta Alfaia, R.G.S., Costa, A.M. and Campos, J.C. (2017). Municipal solid waste in Brazil: A review. *Waste Management and Research: The Journal for a Sustainable Circular Economy*, vol. 35, no. 12, pp. 1195-1209.
2. Precci Lopes, A.C., Ebner, C., Gerke, F., Wehner, M., Robra, S., HupFauf, S. and Bockreis, A. (2022). Residual municipal solid waste as co-substrate at wastewater treatment plants: An assessment of methane yield, dewatering potential and microbial diversity. *Science of the Total Environment*, vol. 804, pp. 1-15.
3. Mustafa, M.Y., Calay, R.J. and Roman, E. (2016). Biogas from Organic Waste - A Case Study. *Procedia Engineering*, vol. 146, pp. 310-317.
4. Environmental Protection Agency (2021). Landfill Gas Energy Project Development Handbook. *Landfill Methane Outreach Program, Washington*, 143p.
5. Sohoo, I., Ritzkowski, M., Heerenklage, J. and Kutcha, K. (2021). Biochemical methane potential assessment of municipal solid waste generated in Asian cities: A case study of Karachi, Pakistan. *Renewable and Sustainable Energy Reviews*, vol. 135, pp. 1-17.
6. Pearce, L.F., Hettiarachi, J.P.A. and Da Costa, D. (2020). A new biochemical methane potential assay for landfilled waste using the organic fraction of municipal solid waste. *Bioresource Technology Reports*, vol. 12, pp. 1-9.
7. Pant, A. and Rai, J.P.N. (2021). Application of Biochar on methane production through organic solid waste and ammonia inhibition. *Environmental Challenges*, vol. 5, pp. 1-8.
8. Islam, M.N., Park, K.J. and Yoon, H.S. (2012). Methane Production Potential of Food Waste and Food Waste Mixture with Swine Manure in Anaerobic Digestion. *Journal of Biosystems Engineering*, vol. 37, no. 2, pp. 100-105.
9. Maskhoot Al Saadi, A.J. and Nageswara Rao, L. (2016). Design and Production of Methane Gas from Food Waste using Anaerobic Digestion. *GRD Journals- Global Research and Development Journal for Engineering*, vol. 1, no. 8, pp. 77-82.
10. Suhartini, S., Lestari, Y.P. and Nurika, I. (2019). Estimation of methane and electricity potential from canteen food waste. *International Conference on Green Agro-industry and Bioeconomy. An IOP Conference Series: Earth and Environmental Science*, vol. 230, pp. 1-6.
11. Qin, Y., Yang, J., Wu, Y., Wang, D., Liu, X., Du, M., He, D. and Yi, N. (2021). The degradation of allyl isothiocyanate and its impact on methane production from anaerobic co-digestion of kitchen waste and waste activated sludge. *Bioresource Technology*, vol. 50, pp. 1-14.
12. Santos, L.A., Valenca, R.B., Santos da Silva, L.C., Holanda, S.H.B., Viana da Silva, A.F., Thomé Jucá, J.F. and Sales Santos, A.F.M. (2020). Methane generation potential through anaerobic digestion of fruit waste. *Journal of Cleaner Production*, vol. 256, pp. 1-18.

13. Lucio Silva, T. H., Santos, L. A., Oliveira, C. R. D. and Porto, S. T., Thomé Jucá, J. F. and Sales Santos, A. F. M., (2021). Determination of methane generation potential and evaluation of kinetic models in poultry wastes. *Biocatalysis and Agricultural Biotechnology*, vol. 32, pp. 1-12.
14. Ozarlan, S., Abut, S., Atelge, M.R., Kaya, M. and Unalan, S. (2021). Modeling and simulation of co-digestion performance with artificial neural network for prediction of methane production from tea factory waste with co-substrate of spent tea waste. *Fuel*, vol. 306, pp. 1-16.
15. Fernández, L.M.G., Estévez, E.P., Navarrete, B. and Falcón, R.G. (2022). Estimation of methane production through the anaerobic digestion of greenhouse horticultural waste: A real case study for the Almeria region, *Science of The Total Environment*, vol. 807, no. 3, pp. 1-15.
16. Borth, P.L.B., Perin, J.K.H., Torrecilhas, A.R., Lopes, D.D., Santos, S.C., Kuroda, E.K. and Fernandes, F. (2022). Pilot-scale anaerobic co-digestion of food and garden waste: Methane potential, performance and microbial analysis. *Biomass and Bioenergy*, vol. 157, pp. 1-10.
17. Environmental and Energy Study Institute (EESI) (2017). Fact Sheet| Biogas: Converting Waste to Energy. *Environmental and Energy Study Institute (EESI), Washington*, 9p.
18. Huang, J., Bekiaris, G., Fitamo, T., Scheutz, C. and Bruun, S. (2021). Prediction of biochemical methane potential of urban organic waste using Fourier transform mid-infrared photoacoustic spectroscopy and multivariate analysis. *Science of the Total Environment*, vol. 790, pp. 1-14.
19. Jin, H.U., He, Z.W., Ren, Y.X., Yang, W.J., Tang, C.C., Chen, F., Zhou, A.J., Liu, W., Liang, B. and Wang, A. (2022). Role and significance of water and acid washing on biochar forregulating methane production from waste activated sludge. *Science of the Total Environment*, vol. 817, pp. 1-12.
20. Inter governmental Panel on Climate Change (2006). Solid Waste Disposal, Volume 5; Chapter 3:, in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, kanagawa.. *Intergovernmental Panel for Climate Change*, pp. 3.1-3.4.
21. Center for People and Environment (2010). Landfill Recovery and Use in Nigeria (Pre-Feasibility Studies of Using LFGE). *Center for People and Environment, Ibadan*, 57p.
22. Inter governmental Panel on Climate Change (2015). CH<sub>4</sub> Emissions from Solid Waste Disposal (A Background Paper), in Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. *Intergovernmental Panel on Climate Change*, pp. 419-439.
23. Sarptas, H. (2016). Assessment of Landfill Gas (LFG) Energy Potential Based on Estimates of LFG Models. *Fen ve Mühendislik Dergisi*, vol. 54, no. 3, pp. 491-501.
24. Surroop, D. and Mohee, R. (2011). Power Generation From Landfill Gas, in 2011 2nd International Conference on Environmental Engineering and Applications (IPCBEE), Singapore.
25. Mintz, M., Han, J., Wang, M. and Saricks, C. (2010). Well-to-Wheels Analysis of Landfill Gas-Based Pathways and Their Addition to the GREET Model. *Argonne National Laboratory (U.S. Department of Energy), Illinois, Chicago*, 65p.
26. Fallahizadeh, S., Rahmatinia, M., Mohammadi. Z., Vaezzadeh, M., Tajamiri, A. and Soleimani, H. (2019). Estimation of methane gas by LandGEM model from Yasuj municipal solid waste landfill, Iran. *MethodsX*, vol. 6, p. 391-398.
27. National Population Commission (2015). The Population of Jimeta - Yola North Local Government Area, National Population Commission, Yola.

28. Orisakwa, K.U. and Bakari, G. (2013). Development of Cadastral Information System for Part of Kofare Government Residential Area of Jimeta - Yola in Adamawa State of Nigeria. *Environmental Sustainability, Abuja*, 43p.
29. Inter governmental Panel on Climate Change (2006). Waste Generation, Composition and Management Data, Volume 5; Chapter 2, in IPCC Guidelines For National Greenhouse Emission Inventories (IGES), Kanagawa. *Intergovernmental Panel on Climate Change*, pp. 21-23.
30. Cai, B.F., Liu, J.G., Gao, Q.X., Nie, X.Q., Cao, D., Zhou, Y. and Zhang, Z.S. (2014). Estimation of Methane Emissions from Municipal Solid Waste Landfills in China Based on Point Emission Sources. *Advances in Climate Change Research*, vol. 5, no. 2, pp. 81-91.
31. Kummer, S., Röhreich, M., Langholz, C., Hennwald, K., Krause, S., Hermann, T. (2020). Analyzes of waste separation in households (Analysen zur abfalltrennung in haushalten). *Mull and Abfall*, pp. 492-498.
32. Kumar, S., Gaikwad, S.A., Shedkar, A.V., Kshirsagar, P.S. and Sing, R.N. (2004). Estimation method for national methane emission from solid waste landfills. *Atmospheric Environment*, vol. 38, p. 3481-3487.
33. Jigar, E., Bairu, A. and Gesessew, A. (2014). Application of IPCC model for estimation of methane from municipal solid waste landfill. *Journal of Environmental Science and Water Resources*, vol. 3, no. 4, pp. 52-58.
34. Mboowa, D., Banadda, N., Kiggundu, N., Kebenge, I. and Komakech, A.J. (2015). Estimation of methane generation based on anaerobic digestion and mass balance at Kiteezi Landfill, Kampala, Uganda. *African Journal of Environmental Science and Technology*, vol. 9, no. 9, pp. 741-746.
35. Singh, C.K., Kumar, K. and Roy, S.S. (2018). Quantitative analysis of the methane gas emissions from municipal solid waste in India. *Scientific Reports*, vol. 8, pp. 1-8.
36. Townsend, T.G., Chickering, G.W. and Krause, M.J. (2018). Determination of As-Discarded Methane Potential in Residential and Commercial Municipal Solid Waste. *U.S. Environmental Protection Agency, Gainesville, Florida*, 122p.
37. Dimiskovska, B. and Berisha, A. (2021). Calculation of Methane Emissions from Municipal Solid Waste Landfill Germova Using IPCC Method. *Geo-Information*, vol. 26, pp. 26-36.
38. Zuberi, M.J.S. and Ali, S.F. (2015). Greenhouse effect reduction by recovering energy from waste landfills in Pakistan. *Renewable and Sustainable Energy Review*, vol. 44, pp. 117-131.
39. Chen, C. and Greene, N. (2003). Is Landfill Gas Green Energy. *Natural Resources Defence Council (NRDC), New York and California*, 82p.