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ENVIRONMENTAL AND ECONOMIC BENEFITS OF ENERGY RECOVERY FROM LANDFILL GAS IN NORTH EAST NIGERIA

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ABSTRACT

The North-eastern Region of Nigeria is the region with least access to grid electricity in the country, this and poor solid waste management are some of the problems hindering the economic and general growth of the region. This research focuses on economic and environmental benefits of recovering energy from landfill gas (LFG). The study utilized secondary data obtained from literature covering a period of 24 years. It was observed that the cumulative quantity of solid waste generated in the region for the period studied reached 104,886,616 tonnes. Using IPCC's default model, it was determined that such quantity of MSW has the potential of emitting 3,199,142.95 tonnes of methane, and has the capacity of generating 9,066.96 ×106 kWh of electricity. It was estimated that the electricity recovered from the waste produced in the region has the potential for powering about 12% of the households in the region. Findings also suggested that the region could cumulatively earn US$ 2.25 billion from the sale of electricity and carbon trading within the studied time period. From an environmental perspective, it was discovered that the emission of 89,576,002.54 tonnes of carbon dioxide equivalent could be avoided by recovering energy from LFG rather than letting it dissipate into the atmosphere. Hence, this study concluded that the environmental and economic benefits of recovering energy from landfill gas are enormous, and it is suggested that the recovery potential can be further improved by having a more efficient waste collection system.

1. INTRODUCTION

The sight of solid waste littering roads, street corners, clogging waterways and drainages is almost a norm in most cities in the developing world. Factors like the general average economic growth, urbanization and high population growth coupled with a generally inefficient and poorly coordinated solid waste management system exacerbates the situation. In addition to the aesthetics problem caused by poor management of huge quantities of solid waste generated in developing countries, another problem is the impact it has on the environment. In most developing countries, the dumping of unsegregated solid waste in unsanitary landfills and dumpsites or burning of the waste openly are the most commonly practiced solid waste disposal technique [1]. These solid waste management (SWM) techniques are notorious for being unfriendly to the environment because of their high carbon footprint and causing air and groundwater pollution [2].
Experts have stated that climate change is one of the biggest problems facing humanity, and anthropogenic emission of greenhouse gases (GHGs) is considered as one of the key driving forces of climate change. The waste management sector is responsible for the emission of about 5% of the total amount of GHGs emitted into the atmosphere [3], and in developing countries where the waste management industry is less coordinated, and the predominant waste disposal method is open dumping, the contribution of the waste sector to the total anthropogenic GHGs emission is much higher [4]. This, however, is not entirely grim. This suggests that there is a need for improvement and reduction of emission of GHGs from the SWM sector in developing countries [5].
In Nigeria, SWM is the responsibility of the local (municipal) and state governments. These authorities usually have agencies that handle this responsibility, however, in few states, the responsibility is bequeathed to private waste collection agencies

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with the government playing a supervisory role [6]. In spite of this, waste collection by these agencies of government and private collectors cover limited areas, in most cases just urban areas. The solid waste disposal (SWD) method of open dumping being practiced all over the country and the northeast in particular, has been adjudged to be environmentally unsafe. This contributes greatly to the pollution of water bodies, groundwater, and climate change through the emission of methane [7].

In spite of the huge quantities of waste being generated in Nigeria [7-8] and the enormous potential for recovery of energy and generation of electricity, the problem of erratic power supply is one that has been a major problem in the country. It is a problem that is pervasive in most developing countries. It is reported that just about 50% of the population of Nigeria have access to grid electricity [9]. Of the six geopolitical regions in the country, the north-eastern region has the least access to electricity, just about 16% of its populace have access to grid electricity, this is in sharp contrast to the 82% and 75% access to grid electricity in the south-south and south-west regions respectively [10]. The double jeopardy scenario facing the region is that in addition to the low access to grid electricity, the few who are connected to the grid have an average daily electricity supply of 5 hours [11].

The challenges of poor SWM and inadequate electricity supply is one that is pervasive in the whole country, but more acute in the north-eastern region. This is a problem that can be tackled using a unified approach – an efficient SWD method in which methane from landfill gas (LFG) can be harnessed and used for the generation of electricity. Hence, this research was aimed at evaluating the economic and environmental benefits of such waste to energy scheme in north-eastern Nigeria.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The northeast geopolitical region of Nigeria comprises six states: Adamawa; Borno; Bauchi; Gombe; Taraba and Yobe. The region covers about 289,421.7 km^2 and lies within longitude 9.9992 and 13.1520 and latitude 11.8846 and 7.9867 [12–17]. The states in the northernmost part of the region have a warm desert climate, those at the middle are characterized by a warm semiarid climate while those at the southernmost part are characterized by a tropical savannah climate [18]. As at 2017, the region had an estimated population of 26,263,865 [19]. Fig. 1 shows the map of Nigeria with the north-eastern region highlighted.

Fig. 1. Map of Nigeria Showing the North-eastern Region

An extensive review of literature was undertaken to extract data necessary for the research. It was found that all six states have a similar waste management approach – residents dispose wastes at designated points, the waste management agencies which are state owned evacuate the waste from the collection points to dumpsites and unsanitary landfills where the waste is occasionally burnt openly whenever the dumpsites are beginning to get filled up. It was also found that there is no sanitary landfill site in the entire region [1].

It was found in literature that the widely acceptable standard for characterisation of MSW (ASTM D 5231) [20] was used to determine the composition of MSW generated in each of the six states. This method involves taking samples from dumpsite at least 3 times a week for each season (to reflect seasonal variation) [21]. The next step is sorting of the samples manually into the specified categories and then measuring the weight of each category. The composition of MSW disposed of at dumpsites in each state of the region is presented in Table 1 [22–25].

Table 1: Average Weight Composition of MSW in The Six States

Category	Adamawa (%)	Bauchi (%)	Borno (%)	Gombe (%)	Taraba (%)	Yobe (%)
Food	6.0	5.4	6.2	9.0	5.0	6.0
Garden Waste	6.0	18.8	18.8	13.9	29.0	27.7
Plastics	24.0	25.0	32.6	11.4	15.0	38.2
Paper	18.0	15.0	6.7	8.2	0.0	3.6
Textiles	3.0	1.0	0.0	9.8	3.0	0.0
Leather/Rubber	32.0	0.0	0.0	8.3	35.0	16.6
Glass	3.0	4.9	5.6	8.9	1.0	4.2
Metal	3.0	7.8	2.9	8.3	10.0	3.6
Inert Materials	5.0	22.3	27.3	22.3	2.0	0.0
Total	**100**	**100**	**100**	**100**	**100**	**100**

Other data needed for the analysis which includes waste collection efficiency, per capita waste generation, population of the respective states and annual population growth rate were obtained from literature. Table 2 shows the per capita waste generation rate for each of the states in the region and their respective population as of 2016 [23, 25–29].

Table 2: Per Capita Waste Generation and Population of the region

State	Per Capita Waste Generation (kg)	Population
Adamawa	0.65	4,248,436
Bauchi	0.86	5,860,183
Borno	0.96	6,537,314
Gombe	0.68	3,265,962
Taraba	0.34	3,066,834
Yobe	0.3	3,294,137

2.2 Data Analyses

Following precedence in literature [7, 30], the per capita waste generation, waste collection efficiency and population for each of the states were used to estimate the annual quantity of waste (AQW) being disposed of at dumpsites for each of the states, see Eq. 1.

$$AQW = Per\ Capita\ Waste\ Generation\ \times \%\ Collection\ Efficiency\ \times Population\ \times 365 \quad (1)$$

Using the quantity and characteristics of MSW sampled in each of the six states, IPCC's default model formula for determining the potential amount of LFG that can be recovered from MSW was used. The default IPCC model is based on the theoretical gas yield (a mass balance equation), it does not reflect the time variation in solid waste disposal and the degradation process as it assumes that all potential methane is released the year the MSW is disposed of in the dumpsite [31-32].
The IPCC model is thus [33]:

$$Q = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times \frac{16}{12} - R) \times (1 - OX) \quad (2)$$

Where Q is total methane emissions in metric tonnes per year (MT/year), MSW_T is total solid waste generated (MT/year), MSW_F is fraction of solid waste disposed to landfill (40% for the region) [34], MCF is methane correction factor (fraction)

(0.6 for unmanaged sites) [32], DOC is Degradable organic carbon, fraction (tonnes C/tonnes waste), DOC_F is dissimilated organic fraction (i.e., fraction converted to LFG). Because the biodegradation of DOC is not total, the DOC_F default value is taken as 0.77 [35]. Also, F represents fraction of CH_4 in landfill gas = 0.5 [7, 36], R stands for recovered CH_4 (T/year) = 0 since no methane recovery takes place. $\frac{6}{12}$ ratio is the Stoichiometric ratio between methane and carbon. In Eq. 2, R can be taken as 0 and OX which represents the oxidation factor can also taken as 0 in the calculations.
DOC can be calculated by utilizing Eq. (3):

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) \tag{3}$$

Here, A is the fraction of solid waste that is food, B is the fraction of solid waste that is garden waste and other plant debris, C is the fraction of solid waste that is paper, D is the fraction of solid waste that is wood and E is the fraction of solid waste that is textiles.
Using the data collected in Eqs. 1, 2 and 3, the methane generation potential for the region is estimated for the year 2016. Using the annual growth rate of 2.9%, 3.4%, 3.4%, 3.2%, 2.9% and 3.5% for Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe states respectively [19], the annual quantity of MSW and corresponding methane emissions for the region was estimated for a period of 24 years. Given that methane has a density of 0.667 kg/m^3 at 30°C and calorific value of 17 megajoules per cubic meter (MJ/m^3) [7], the potential amount of electrical energy that can be recovered from the MSW was estimated using conversion efficiency of thermal engines to be 40% [37].
The economic benefits from recovering electricity from LFG could be in the form of electricity sale and carbon trading [32], a tariff of 0.02USD/kWh [38] was used to estimate the gross income from sale of electricity. For the potential revenue to be generated from carbon trading, the carbon dioxide equivalent of the methane gas generated from the MSW was estimated by multiplying it (methane recovered from LFG) with methane's global warming factor of 28 [39], the carbon trading price of 23.05USD [40] per tonne of carbon dioxide equivalent (CO_2e) was then used to estimate the amount of money that can be earned. While making all the estimations, the following assumptions were made:

1. The composition of the MSW generated in the region does not change for the period being studied.
2. The waste collection efficiency remains at 40%.
3. The electricity tariff and carbon credits remain constant.
4. The population growth rate in each of the states remains constant.

3. RESULTS AND DISCUSSION

3.1 Municipal Solid Waste Disposed of in Dumpsites and Energy Recovery

It was estimated that a total of 2,665,237 tonnes of MSW was disposed of in the year 2016 at the various dumpsites and unsanitary landfill sites in the region. Over a period of 25 years, it is projected that 104,190,930.54 tonnes of MSW will be disposed of in the region. On a state-by-state level, it was estimated that for the period of 25 years, dumpsites in Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe will have 15,030,879.73 tonnes, 32,866,177.36 tonnes, 32,887,723.24 tonnes, 12,572,435.79 tonnes 5,666,342.73 tonnes and 5,167,371.70 tonnes of MSW disposed of in them respectively.

The 2,665,237 tonnes of MSW disposed of at dumpsites in the index inventory year has a potential of yielding 81,093.19 tonnes of methane whose calorific value is estimated to be 2,066.84×10^6 MJ and is capable of generating 574 ×10^6 kWh of electricity. These values steadily increase until they reach 172,399.48 tonnes of methane, calorific value of 4,393.99×10^6 MJ and electricity generation potential of 1,221.53×10^6 kWh. With the annual average household electricity consumption of 1,080 kwh [10], the electricity recovered from the waste produced in the region has the potential for powering about 12% of the households in the region, that is 531,481 households in the index year and up to 1,130,556 households by the end of the period being projected. Fig. 2 shows the quantity of MSW generated in each of the states in the region for the period being studied while Table 3 shows the potential quantity of methane, its corresponding calorific value and potential amount of energy that can be recovered from the MSW generated in the region for the period being studied.

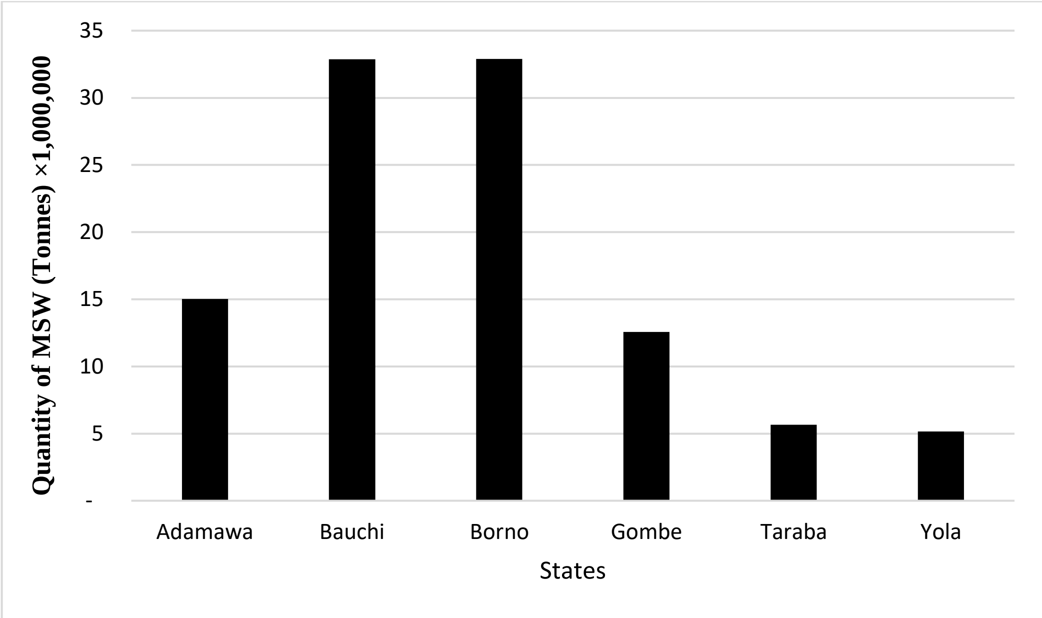

Fig 2. Projected Cumulative Waste Generated in Each of the States in the Region

Table 3: Methane and Energy Generation Potentials of LFG in North-Eastern Nigeria

Year	Quantity of MSW (Tonnes)	Methane (Tonnes/Year)	Calorific Value ($\times 10^6$ MJ)	Electricity ($\times 10^6$ Kwh)
2016	2,665,237	81,093.19	2,066.84	229.83
2017	2,845,789	86,615.79	2,207.60	245.48
2018	2,940,620	89,517.12	2,281.55	253.71
2019	3,038,624	92,516.03	2,357.98	262.21
2020	3,139,908	95,615.80	2,436.98	270.99
2021	3,244,580	98,819.84	2,518.65	280.07
2022	3,352,757	102,131.67	2,603.06	289.46
2023	3,464,554	105,554.92	2,690.31	299.16
2024	3,580,094	109,093.37	2,780.49	309.19
2025	3,699,503	112,750.90	2,873.71	319.56
2026	3,822,910	116,531.54	2,970.07	330.27
2027	3,950,450	120,439.43	3,069.67	341.35
2028	4,082,262	124,478.89	3,172.63	352.80
2029	4,218,490	128,654.35	3,279.05	364.63
2030	4,359,281	132,970.42	3,389.05	376.86
2031	4,504,789	137,431.83	3,502.76	389.51
2032	4,655,174	142,043.51	3,620.30	402.58
2033	4,810,598	146,810.53	3,741.80	416.09
2034	4,971,232	151,738.15	3,867.39	430.05
2035	5,137,250	156,831.79	3,997.21	444.49
2036	5,308,835	162,097.06	4,131.41	459.41
2037	5,329,299	156,621.13	3,991.84	474.84
2038	5,501,483	161,474.72	4,115.55	490.78
2039	5,679,418	166,490.44	4,243.38	507.27
2040	5,887,793	172,399.48	4,393.99	526.36

3.2 Economic and Environmental Benefits of Energy Recovery from Landfill Gas

Methane which forms 50% of LFG [41] is a huge potential energy reserve. However, allowing it to be naturally dissipated into the atmosphere from landfills have huge consequences on the environment and the wellbeing of the surrounding inhabitants. Chief among the environmental effects of emission of methane from landfills according to [1], is the contribution to the amount of GHGs in the atmosphere and consequently global warming. Its contribution to the depletion of the ozone layer is another of its negative effects on the environment. Yusuf *et al.* [7] buttressed the environmental benefits of capturing methane from LFG by stating: “when LFG energy projects are executed, cleaner air and reductions of smog, odor, and greenhouse gas emissions are assured. Project partners and host communities will benefit from using LFG, as the projects will ensure proper management of local landfills”.

In the light of these facts, the capture and utilization of methane from LFG is not just a venture that puts money into the pockets of the entity involved but a venture which is also environmentally beneficial. It was estimated that in the index year of the study, if the MSW generated in the region is landfilled and the methane produced from its anaerobic decomposition is collected, the emission of 81,093.19 tonnes of methane into the atmosphere will be avoided, this is equivalent to 2,270,609.45 tonnes of carbon dioxide equivalent (tCO_2e), this is about four times the annual GHGs emission from all activities in Africa’s smallest country – Seychelles [42]. This study shows that by the end of year 2040, the recovery of energy from MSW generated in the north-eastern part of Nigeria has the capacity to serve as a carbon sink for approximately 1,221,410.96 tCO_2e on an annual basis, this is almost equivalent to the annual GHGs emission from the use of diesel fuel in the entire country [43]. The numbers aside, other environmental benefits of recovering energy from LFG that the region stands to benefit include reduction in the risk of explosion and fire at landfill sites; reduction in the emission of toxic substances from the combustion of other fuels (used in the generation of electricity) which the LFG substitutes since it’s a relatively cleaner fuel; reduction in the damage to the ozone layer, flora, and fauna caused by the emission of toxic substances from the combustion of fossil fuels.

As earlier stated, revenue can be earned from a waste to energy project via two means: sale of electricity generated and carbon trading. In the index year of the study, a gross sum of 4,596,658.93 United States Dollars (USD) can be earned from the sale of electricity, while also earning 52,337,547.90 USD from carbon trading. By the year 2030, it was projected that the annual earnings will rise to 18.8 million and 85.8 million USD. It was also projected that these earnings from carbon trading and sales of electricity will rise by 88% reaching 7.54 million USD and 93.36 million USD respectively by the year 2030. At the end of the period studied, the annual revenue from the sale of electricity and carbon trading is expected to have increased to 10.53 and 119.86 million USD respectively. These figures are just a fraction of the economic benefits that a waste to energy project can bring to the region. Although they do not capture things like the direct and indirect employment opportunities, it can ensure improvements in the standard of living of residents through improved power supply.

Table 4 shows the estimated avoided carbon emission (carbon sink) and the potential earnings from the recovery of energy from LFG in north-eastern Nigeria for the period being studied.

Table 4: Projected carbon sink and earnings from energy recovery from LFG

Year	Avoided CO_2 Emission ($tCO_2e\times10^3$)	Earnings from Carbon Trading (USD $\times10^6$)	Gross Earnings from Electricity Sales (USD $\times10^6$)	Total Gross Earnings (USD $\times10^6$)
2016	2,270.61	52.34	4.60	56.93
2017	2,425.24	55.90	4.91	60.81
2018	2,506.48	57.77	5.07	62.85
2019	2,590.45	59.71	5.24	64.95
2020	2,677.24	61.71	5.42	67.13
2021	2,766.96	63.78	5.60	69.38
2022	2,859.69	65.92	5.79	71.70
2023	2,955.54	68.13	5.98	74.11
2024	3,054.61	70.41	6.18	76.59
2025	3,157.03	72.77	6.39	79.16
2026	3,262.88	75.21	6.61	81.81
2027	3,372.30	77.73	6.83	84.56
2028	3,485.41	80.34	7.06	87.39
2029	3,602.32	83.03	7.29	90.33
2030	3,723.17	85.82	7.54	93.36
2031	3,848.09	88.70	7.79	96.49
2032	3,977.22	91.67	8.05	99.73

2033	4,110.69	94.75	8.32	103.07
2034	4,248.67	97.93	8.60	106.53
2035	4,391.29	101.22	8.89	110.11
2036	4,538.72	104.62	9.19	113.81
2037	4,385.39	108.13	9.50	117.63
2038	4,521.29	111.76	9.82	121.58
2039	4,661.73	115.51	10.15	125.66
2040	4,827.19	119.86	10.53	130.39

4. CONCLUSIONS

Solid waste has been a nuisance to authorities, especially in developing countries with large populations and poor solid waste management facilities. Some of the problems it poses to authorities in these countries are the clogging of drainages, littering of streets, defacing of aesthetic valuable real estate, and causing diseases and illnesses from inappropriate disposal. Having noted these negative effects of waste generation and disposal, the picture is not entirely gloomy when waste is managed appropriately.

This study explored the environmental and economic benefits of recovering energy from LFG. It was found that for the period being studied (2016-2040), 104,190,930.54 tonnes of MSW would be generated in the region. This quantity of waste would cumulatively generate 3,150,721.90 tonnes of methane when it anaerobically decomposes. It was also estimated that in the index year, 229.83×106 kWh of electricity could be recovered from the waste generated that year. This study proposed that this figure will steadily increase to 330.27×106 kWh by the year 2026 and 459.41×106 kWh by the year 2036 and finally 526.36×106 kWh by the year 2040. From the economic point of view, it was found that earnings from sale of electricity and carbon trading will attract a total gross income of 2.24 billion USD to the region for the period being projected. This is a potentially huge boost to the economy of the northeast whose collective annual GDP is just a fraction of this amount. The recovery of energy from solid waste is a viable alternative to the conventional unsustainable fossil fuel used for the generation of electricity. This study has shown that the quantity and composition of solid waste generated in the north-eastern region of Nigeria has the potential to generate electricity to meet the needs of the populace while also benefitting the environment and improving the earnings of the region. The energy recovery potential from LFG in the region can be further improved by having a more efficient waste collection system.

NOMENCLATURE

IPCC – Intergovernmental Panel on Climate Change
kWh – Kilowatts hour
MJ – Megajoules
MSW – Municipal Solid Waste
tCO2e – Tonnes of carbon dioxide equivalent
USD – United States Dollars

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