

Comparative Analysis of Waste to Energy (WTE) Conversion Processes for Electricity Generation from Municipal Solid Wastes (MSW) in Kano Metropolis, Nigeria

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Abstract

Selecting an appropriate waste-to-energy (WTE) process requires evaluating electricity generation potential, environmental impacts, and economic viability. This study compared landfill gas-to-energy, incineration, and anaerobic digestion for electricity generation from municipal solid waste (MSW) in Kano Metropolis, Nigeria. The methodology comprised determining waste quantities and composition available for each process, estimating electricity generation, assessing environmental impacts, and evaluating economic performance through life cycle cost analysis. The assessment used ASTM D5231 and ASTM D2382-88, per capita waste generation estimates, population data from the National Population Commission, LandGEM 3.02, a Parr 6100 bomb calorimeter, and GaBi Education version 9.2.1.68 for life cycle assessment. Landfill gas-to-energy provided the highest estimated electricity generation potential, at 33,175,973.48 kWh/year, making it the preferred option when electricity output was the primary criterion. Anaerobic digestion exhibited the lowest environmental impacts across all assessed impact categories and the most favorable economic performance, characterized by the lowest levelized cost of electricity, a life cycle cost of USD 260,700.19, and a payback period of 4.13 years. These findings demonstrate that the preferred conversion process depends on the evaluation criterion: landfill gas-to-energy offers the greatest electricity generation potential, whereas anaerobic digestion provides stronger

environmental and economic performance. The study provides comparative evidence to inform WTE technology selection and project planning in Kano Metropolis. Further research should evaluate alternative processes, including pyrolysis and gasification, and examine the development of a comprehensive legal framework and implementation roadmap for WTE projects in Nigeria.

Keywords: Municipal Solid Waste; Waste-to-Energy; Electricity Generation; Life Cycle Assessment; Life Cycle Cost Analysis

INTRODUCTION

(Dawar *et al.* 2025) defined Municipal Solid Waste (MSW) as a waste collected by municipalities or other local bodies. It mainly comprises waste generated at home, commercially, and institutionally by enterprises and organizations. These wastes are often solid or semi-solid. The world bank in 2022, reported that more than 2 billion tonnes of municipal solid waste (MSW), mostly due to the rapid urbanization of the increasing global population and the high consumption rate of food and commercial products (furniture, electronic equipment, etc) is generated annually, with a projected increase to about 3.4 billion tonnes by 2050 (Valavanidis-Athanasious 2023). Furthermore, the report found out that, while about 67% of the global solid waste generated could be well managed, only about 33% was found to be unmanaged, but instead, dumped in an open space. Such practices are leading to several public health and environmental problems (Jeevahan *et al.* 2021).

Presently, the quest of nations in trying to meet their energy demands has been conquered by burning fossil fuels. However, this practice has been found to be unsuitable regarding environmental issues and hence declared to be environmentally unfavourable (Akanni, Mohammed, and Raphael 2022).

The practice of burning municipal solid wastes (MSW) generated in an uncontrolled landfill or open dumpsite without concerns about the environmental consequences poses a dangerous threat to public health and also the emission of Green House gases (Powrie, Velis, and Cook 2021).

According to Hadidi and Omer (2016), effective management, utilization and conversion of MSW to useful energy have the potential to cut down carbon emission footprint and could be a means of providing a sustainable and environmentally friendly

solution to bridging the gap between energy and the environment. An estimate by the International Renewable Energy Agency, showed that the world has a potential of generating approximately 13 Giga Watt of energy from Waste to Energy (WTE) sector alone (Renewable and Agency 2016). The WTE technologies have been greatly modernised and prioritised in many countries especially in the developed nations with significant progress on their applications as waste management options and methods for producing cleaner energy. In 2012, the United States of America generates 14.5million MWh of electricity from 84 WTE facilities (Michaels, 2014).

However, the adoption of the WTE technologies in Nigeria, for effective utilization and conversion of MSW to useful energy is low. Waste-to-energy practice in Nigeria is limited to traditional biomass (wood fuel and charcoal) to complement district heating and cooking in the rural areas without taking cognizance of its environmental consequences.

Attempts have been made by some researchers to evaluate the potential of MSW for energy generation in some parts of the country. Akinshilo et al. (2019) and Ibikunle et al. (2019) assessed the potential of MSW for energy generation in some states in Nigeria.

Ayodele *et al.* (2017) reported that, while waste to energy technologies have been developed to a considerable extent in most countries around the world, Nigeria is yet to develop any meaningful technology to tap the potentials due to lack of concrete scientific information that could encourage the development of such technology.

Therefore, the focus of this research work is on the analysis and comparison of WTE conversion processes for electricity generation using municipal solid wastes generated within Kano metropolis. The methodology adopted for the study consists of life cycle assessment (LCA) based on ISO 14040 using Gabi software and cost benefit analysis.

MATERIALS AND METHODS

Determination of MSW Composition for WTE Conversion Processes

The dumpsites designated by the Kano State Government within Kano metropolis (Court Road and Maimalari Dumpsites) were identified from the relevant Waste management authorities. Sampling method, using quartering technique was used during the dry season in two months (December – January) with seven (7) days each in a month to sample heterogeneous materials such as municipal solid waste. 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 sorted samples were then categorized as organic (biodegradable and nonbiodegradable) and inorganic (recyclable) components and were weighed using an electronic weighing scale.

Determination of Municipal Solid Waste (MSW) Generation for WTE Conversion Processes

The quantity of waste generated in Kano metropolis per year was determined using the most recent population data from the National Population Commission (NPC) and interpolated to year 2020 based on population growth rate and the per capita waste generation. It is assumed that not all the waste generated is disposed-off in the dumpsites. According to Adewumi *et al*, (2005), only 74% of total municipal waste generated in Nigeria is taken to the dumpsites. Bakare, (2022) reported that Nigeria generates more than 32 million tons of solid waste annually, out of which only 20-30% is collected, while the rest was taken to dumpsites.

Therefore, to determine the quantity of waste taken to dumpsite (M_F), the following were first calculated:

- (i) the amount of Municipal Solid Waste generated (MSW_{Gen}) in tons/year,
- (ii) amount of waste collected (tons/year),
- (iii) quantity of recyclables in the waste fractions or waste diverted.

The quantity of waste taken to dumpsite (M_F), thus, is

$$M_F = \text{Waste Collected} - \text{Waste Diverted}$$

Hence, the total mass of MSW generated per year (tons/yr) can be estimated using equation 1 (Ogunjuyigbe, Ayodele, and Alao 2017)

$$MSW_{T(Gen)} = P \times w_c \times 365 \quad (1)$$

Where P is the extrapolated population of the study area based on the population growth rate, w_c is the per capita waste generation per day (kg/cap/day). The extrapolated population, P, was determined using the Geometric increase method of population forecast (Gawatre, Kandgule, and Kharat 2016):

$$P = P_0 (1 + r)^n \quad (2)$$

Where P_0 = Base Population of the study area using the 2006 Census,

n = number of years, r = Population growth rate taken as 3.18% (NPC, 2006)

The quantity or amount of waste collected was estimated using equation 3.2 (Ayodele, Alao, and Ogunjuyigbe 2018)

$$MSW_{Collected} = MSW_{Gen} \times C_R \text{ tons/yr} \quad (3)$$

Where C_R is the collection rate taken as 0.74 (74%)

$$MSW_{Gen} = \text{Waste generated (tons/year)}$$

The quantity of recyclables in the waste streams was determined using equation 4

$$Q_{(i)recycled} = MSW_{Collected} \times Q_{i(fractions)} \times Q_{(i)rate} \quad (4)$$

Where:

$$MSW_{Collected} = \text{the quantity of waste collected.}$$

$Q_{(i)fraction}$ = Percentage composition of recyclable materials or components in the waste stream (expressed in fraction). Plastics, metals, glass, are considered for this study and determined as

$$\text{Plastics} = 3.56\% = \mathbf{0.0356}$$

$$\text{Metals} = 1.55\% = \mathbf{0.0155}$$

$$\text{Glass} = 5.29\% = \mathbf{0.0529}$$

$$Q_{(i)rate} = \text{Recycling rate (assumed 10\%)}$$

Municipal Solid Waste (MSW) Composition for WTE Conversion Processes

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 from table 1 and allocated accordingly (Tables 2 - 4); where Food waste, rubber, paper, textiles, and wood, were allocated to Landfill Gas to Energy (LFGTE); while rubber, paper, textiles, leather and wood to Incineration (Ogunjuyigbe et al. 2017).

Table 1. Sampling Data for Kano Metropolis

Waste Components	Court Road	Maimalari	Total (kg)	%
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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

Table 2. Percentage Composition of Waste $f(.)$ allocated to LFGTE Process.

LFGTE Process		
S/N	Waste Components	%
1	Food wastes	23.62
2	Rubber	3.66
3	Textiles	11.59
4	Paper	6.09
5	Wood	2.86
Total		47.82

Table 3. Percentage Composition of Waste $f(.)$ allocated to Incineration Process.

INCINERATION		
S/N	Waste Components	%
1	Rubber	3.66
2	Textiles	11.59
3	Paper	6.09
4	Wood	2.86
5	Leather	23.91
Total		48.11

Table 4. Percentage Composition of Waste $f(.)$ allocated to Anaerobic Digestion Process.

ANAEROBIC DIGESTION		
S/N	Waste Components	%
1	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 therefore, determined using the following equation (Ogunjuyigbe et al. 2017):

$$M_{F(i)} = M_F \times f(i) \quad (\text{tons/yr}) \quad (5)$$

Where i = type of WTE conversion process (i.e. Landfill Gas to Energy, Anaerobic Digestion, or Incineration process);

f = 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.

Evaluation of Electricity Generation Potentials of the WTE Conversion Processes

The methods and procedure for determining the electrical energy potential of a WTE conversion process differ, and therefore, was based on the specific process (LFGE, Incineration, and Anaerobic Digestion).

Procedure for 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:

$$Q_{CH_4} = \sum_{k=1}^n \sum_{j=0.1}^1 KL_o \left(\frac{M_{LFGTE}}{10} \right) e^{-t_{kj}} \quad (6)$$

Where, 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 (m^3/Mg), M_{LFGTE} = Waste landfilled in a year (Mg/yr).

Hence, 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. 7. (Oukili, Mouloudi, and Chhiba 2022):

$$E_{gp(LFGE)} = \frac{0.9 \times Q_{CH_4} \times LCV_{CH_4} \times \eta \times \lambda}{3.6} \quad (7)$$

Where LCV_{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), Q_{CH_4} is the amount of methane gas emitted in the year of calculation from the landfill in a year (m³ /year) which is, presented in table 4.6, 0.9 is the empirical coefficient, 3.6 is the conversion factor from MJ to kWh.

Procedure for 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 below (R. A Ibikunle *et al.* 2019):

$$E_{gp(Inc)} = \frac{HV_{msw} \times W_{msw} \times \eta}{3.6} \quad (8)$$

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

η = Conversion efficiency estimated to be 35.8%

W_{msw} = Average annual mass of MSW incinerated (tons/yr) which was estimated as follows:

$$W_{msw} = \frac{\sum_{t=1}^n M_{F_{INC}}}{n} \quad (9)$$

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

Procedure for Evaluation of Electricity Generation potential by Anaerobic Digestion process

The electricity generation potential ($E_p(AD)$) by an Anaerobic Digestion process (Biogas powered plant) was evaluated using an equation proposed by (Ogunjuyigbe et al. 2017):

$$E_{p(AD)} = \frac{0.85 \times \eta \times LHV_{CH_4} \times M_{F(AD)}}{3.6} \quad (10)$$

$$M_{F(AD)} = \frac{\sum_{i=1}^n M_{FAD(i)}}{n} \quad (11),$$

Where LHV_{CH_4} is the lower heating value of methane (37.2 MJ/m^3), 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. (11) as 223,720.74 tons/year, 3.6 is the conversion factor from MJ to kWh.

Determination of Environmental Impacts of the WTE Conversion Processes

Goal and Scope of the LCA:

The goal of this study is to develop an LCA model and compare three different WTE Processes (i.e. Landfill gas to energy, Incineration, and Anaerobic) that may be implemented in Kano metropolis. The study will be carried out by GaBi Education software, life cycle impact assessment will also be conducted base on CML 2 baseline (2000) method.

System Boundaries:

The respective tonnages of the waste components of MSW were considered as the input materials, while slag or solid residue, emission to the air and electricity generation are considered as the output of the LCA models. For comparison of the WTE conversion processes, process start up energy and one tonne of municipal solid waste were considered as the input of the comparative LCA model. The produced energy, heat, emissions to the air, and the final residue from the systems were considered as the output of the systems. Figure 3.11 presents the system boundary for the WTE Conversion processes.

Assumptions Used in the LCA Model

The following assumptions were made in carrying out the LCA model:

- All environmental impacts generated from the production of a product prior to becoming a waste were neglected, therefore the life cycle of the MSW begin after it has been discarded. This is called Zero Burden assumption.
- The waste collection and transportation will be the same and therefore omitted from the LCA.
- All the WTE plants are located at the outskirts of Kano city at an equal distance from the transfer station. Hence, emission as a result of waste transportation for each process will be the same and therefore neglected. (Zaman 2010).
- Energy and emission during construction of the waste to energy handling facilities was neglected.
- The environmental impact analyses for all the waste to energy processes was carried out over a period of 20 years (2020–2040).

Lifecycle Inventory Analysis:

The Life cycle inventory of the LCA model has been made primarily based on field waste characterization, GaBi database, literature, report and publications (Table 5.).

Table 5. Life Cycle Inventory (LCI) Data for the WTE processes

Life Cycle Inventory (LCI) Data			
	Incineration	Anaerobic	LFGTE
Input/Output Flows			
Diesel (kg)	2.5 (*)	-	2.5 (*)
Electricity (MJ)	3.6 (¥)	3.6 (¥)	3.6 (¥)
Natural gas ((kg)	0.09 (β)	-	-
Textiles ((kg)	1.9 (α)	-	1.9kg (α)
Paper ((kg)	1.0 (α)	-	1.0kg (α)
Wood ((kg)	0.5 (α)	-	0.5kg (α)
Rubber ((kg)	0.6 (α)	-	0.6kg (α)
Food Wastes ((kg)	-	3.9 (α)	3.9kg (α)
Air Emissions			
Carbon dioxide, fossil ((kg)	4.00 (β)	0.2 (β)	30.00 (β)
Nitrogen oxides ((kg)	3.67 (β)	0.57 (β)	15.00 (β)
Sulphur dioxide ((kg)	20.83 (β)	0.009 (β)	-
Sulphur oxides ((kg)	1.00 (¥)	-	-
Dioxins ((kg)	1.00 (β)	-	-
Other emissions to air ((kg)	4.00 (β)	-	-

Life Cycle Inventory (LCI) Data			
Methane (VOC) ((kg)	-	-	5.00 (β)
Carbon dioxide (Land use change) ((kg)	-	-	20.00 (β)
Carbon monoxide ((kg)	-	-	277.79(β)
Carbon monoxide, from soil or biomass stock ((kg)	-	-	92.60 (β)

Note: [¥]Estimated; ^{*}Literature; ^aMeasured; ^βCalculated

Life Cycle Impact Assessment (LCIA):

The impact categories for this study were selected from CML 2001 which encompassed of Global Warming Potential (GWP), Acidification Potential (AP), Abiotic Depletion Potential (ADP), Photochemical Oxidation Potential (PCOP), Human Toxicity Potential (HTP) and odour potential. These categories were be chosen base on the fact that many related studies have discussed them, as they had significant effects on the environment and humans (Wulandari et al 2021).

Evaluation of the Economics of the WTE Conversion Processes.

Thus, for Landfill Gas to Energy (LFGTE) process:

The investment cost for a LFGTE according to (Cudjoe *et al.*, 2020), can be estimated as

the sum of the following costs as indicated in Equation (12)

$$C_{inv(LFGTE)} = C_v + C_w + C_{kout} + C_{eng} + C_{ICE} \quad (12)$$

Where,

C_v = Installed capital cost of vertical extraction Wells, given as

$$C_v = (Z - 10)\text{ft} \times \text{USD}85 \times W$$

Where, W is No. of Wells taken as 50

C_w = Cost of Installing Wellheads and pipes gathering, given as

$$C_w = \text{USD}17,000 \times W$$

C_{kout} = Cost of Installing knockout, blower and flare, expressed as

$$C_{kout} = V^{0.6} \times \text{USD}4600$$

Where, V is methane flow rate (m^3/year)

C_{eng} = Cost of engineering, permitting and surveying systems, expressed as

$$C_{eng} = \text{USD}700 \times W$$

C_{ICE} = Cost of Installation of Reciprocating Internal Combustion Engine (ICE), expressed as,

$$C_{ICE} = \text{USD}1300 \times P_{s(LFGTE)} + \text{SD}1,100,000$$

$P_{s(LFGTE)}$ = Electrical Energy generated (kWh) by the proposed ICE /Annual Operating hours.

In terms of the operation and maintenance of cost of the LFGTE system TE ($C_{o \& m(LFGTE)}$), it can be obtained as shown in Equation (13):

$$C_{o \& m(LFGTE)} = C_{o \& m} (LF) + C_{o \& m} (ICE) \quad (13)$$

Where,

$C_{o \& m} (LF)$ is the Operation and Maintenance Cost of Landfill site, expressed as,

$$C_{o \& m} (LF) = (\text{USD}2600 \times W) + \text{USD}5100$$

$C_{o \& m} (ICE)$ is the Operation and Maintenance cost of Internal Combustion Engine, expressed as, $C_{o \& m} (ICE) = \text{USD}0.025 \times E_{p(LFGTE)}$

$E_{p(LFGTE)}$ = Annual Electrical Energy (kWh) Produced by the Internal Combustion Engine (ICE).

For Incineration Process:

The model for investment cost ($C_{inv(inc)}$) and the Operation and Maintenance Costs ($C_{inv(inc)}$) for Incineration according to (Nubi et al. 2022b) was estimating using equations 14 and 15:

$$C_{inv(Inc)} = \text{UDS}16,587 \times [P_{s(Inc)}]^{0.82} \quad (14)$$

$$C_{o \& m} (Inc) = 0.04 \times [C_{inv(Inc)}] \quad (15)$$

For Anaerobic Digestion Process:

The investment and operation and maintenance costs were determined according to (Hadidi and Omer 2016) using equations 16 and 17:

$$C_{inv(AD)} = C_{p(AD)} \times P_{s(AD)} \quad (16)$$

$$C_{o \& m} (Inc) = 0.03C_{inv(AD)} + 0.05E_{p(AD)} \quad (17)$$

Where,

$C_{p(AD)}$ is the plant specific cost of AD plants taken as USD4339/kW;

$0.03C_{inv(AD)}$ is the fixed operating and maintenance costs (USD), which is expressed as 3% of capital cost.

$0.05E_{p(AD)}$ = variable operating and maintenance costs (USD), which is related to the plant output.

$P_{s(AD)}$ is kWh plant capacity.

Net Present Value (NPV):

This is the difference between all costs incurred and the revenue earned by a system over its lifetime, obtained from the following model, proposed by (Boongaling, Samala, and Ordonia 2020):

$$NPV_k = \frac{\sum B_k - \sum C_k}{(1 + \delta)^t} - I_k \quad (18)$$

Where k is the respective WTE technology, B is the Revenue for WTE, C is the costs of WTE (Operation and Maintenance Costs), t is the life time of the WTE technology, δ is the discount rate and I is the Cost of Investment for the WTE technology.

Levelized Cost of Electricity (LCOE):

The LCOE refers to the minimum cost at which electricity is generated for a system when it breaks even (Ogunjuyigbe *et al.* 2017). It allows comparison of the WTE conversion technologies with different power capacity against one another base on the unit cost of electricity (kWh). The LCOE was determined for each of the WTE conversion processes using equation:

$$LCOE = \frac{LCC}{E_p} \quad (19)$$

where LCC (USD) is the life cycle cost of the WTE project.

Pay Back Period (PBP):

PBP is the time (in years) after which the revenue (income) has paid back the initial investment costs of a project. In other words, it is the time to recover the amount invested in a project and was determined through the following equation: (Cudjoe, DanCudjoe, Dan and Han 2020).

$$PBP = \frac{C_{inv}}{Rev - C_{o\&m}} \quad (20)$$

Where C_{inv} is the initial investment cost, $C_{o\&m}$ is the operation and maintenance cost; and Rev is the revenue generated from each WTE conversion process.

RESULTS AND DISCUSSIONS

Amount of MSW Generation and Quantity of Waste taken to Dumpsites, projected for a 20-year period (2020-2040).

The MSW generation potential of the Kano metropolis was calculated based on projected population and the waste generated per capital. The results for the projected population, estimated waste generation and the quantity of waste taken to dumpsites over 20 years (landfill site opened in 2020 and closes in 2040) are presented in fig. 1. 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.

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 figure 2. From the perspective of electrical energy generation (Figure 2), 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 (Ogunjuyigbe et al. 2017) which states that LFGTE is the most preferred WTE technology in North Western Cities of Nigeria

LCA Model for Environmental Impact Categories of the WTE Processes

The results for the selected impact categories for incineration, anaerobic digestion and LFGTE conversion processes as obtained from the LCA software (GaBi Education 9.2.1.68) are presented in Figure 3. reveals that the Anaerobic Digestion has the least Acidification Potential which signifies its environmental benefit compared to other Waste to Energy process considered. This is in agreement with the findings of (Ayodele et al. 2017). It can also be observed that Global Warming Potentials due to LFGTE process is higher for area studied (Kano metropolis). This could be due to the waste stream containing a large percentage of food wastes which when degraded produce a high content of methane.

Economic Analysis/Viability of the waste-to-energy processes.

The economic analysis was carried out and evaluated based on life cycle cost (LCC), Levelized Cost of Electricity (LCOE), Payback Period (PBP) and the Net Present Value (NPV) for each of the three WTE processes. The analysis is presented in Figures. 4 and 5., respectively. In general, the results indicate Anaerobic Digestion process to be the most economically sustainable process for Kano metropolis, having the lowest LCOE, LCC and PBP.

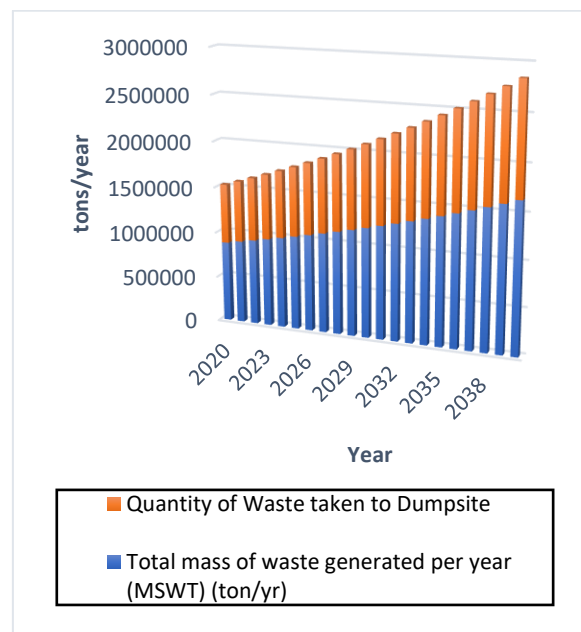


Figure 1. Projected annual waste generation and waste taken to dumpsites.

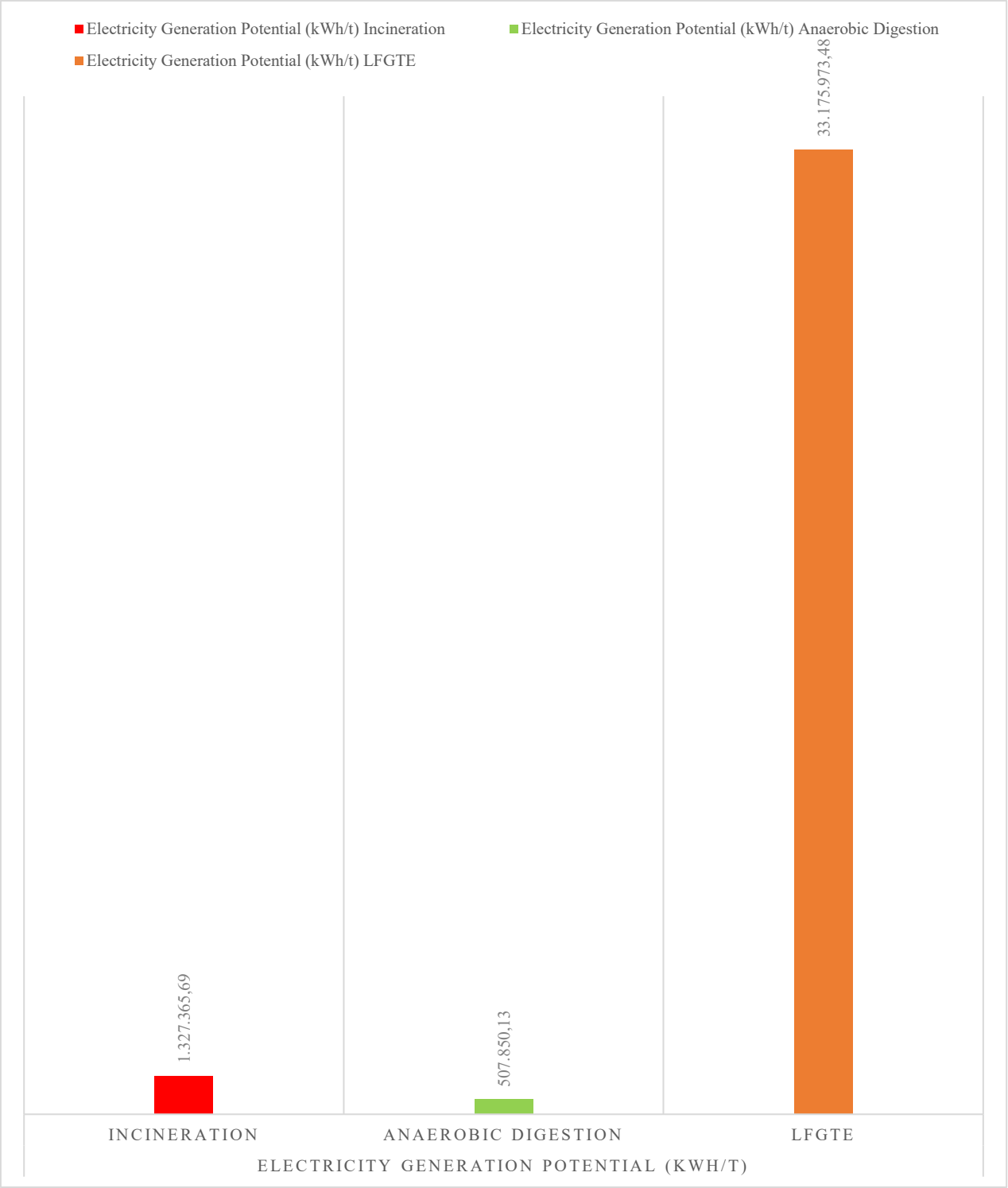


Figure 2. Electricity generation potential (kW h/yr) by different WTE Processes.

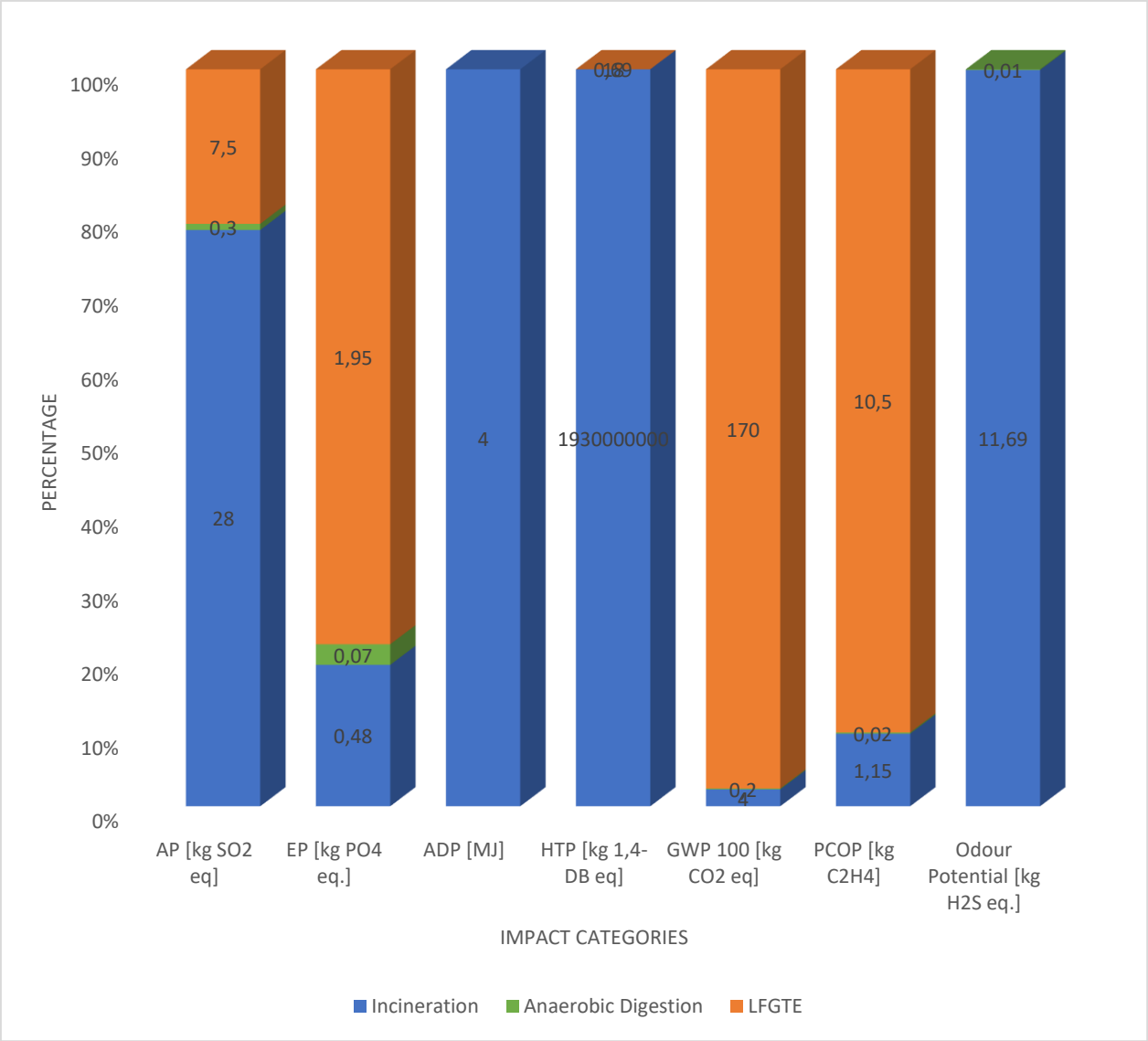


Figure 3. The characterization graph for the comparative LCA model for the three WTE Processes.

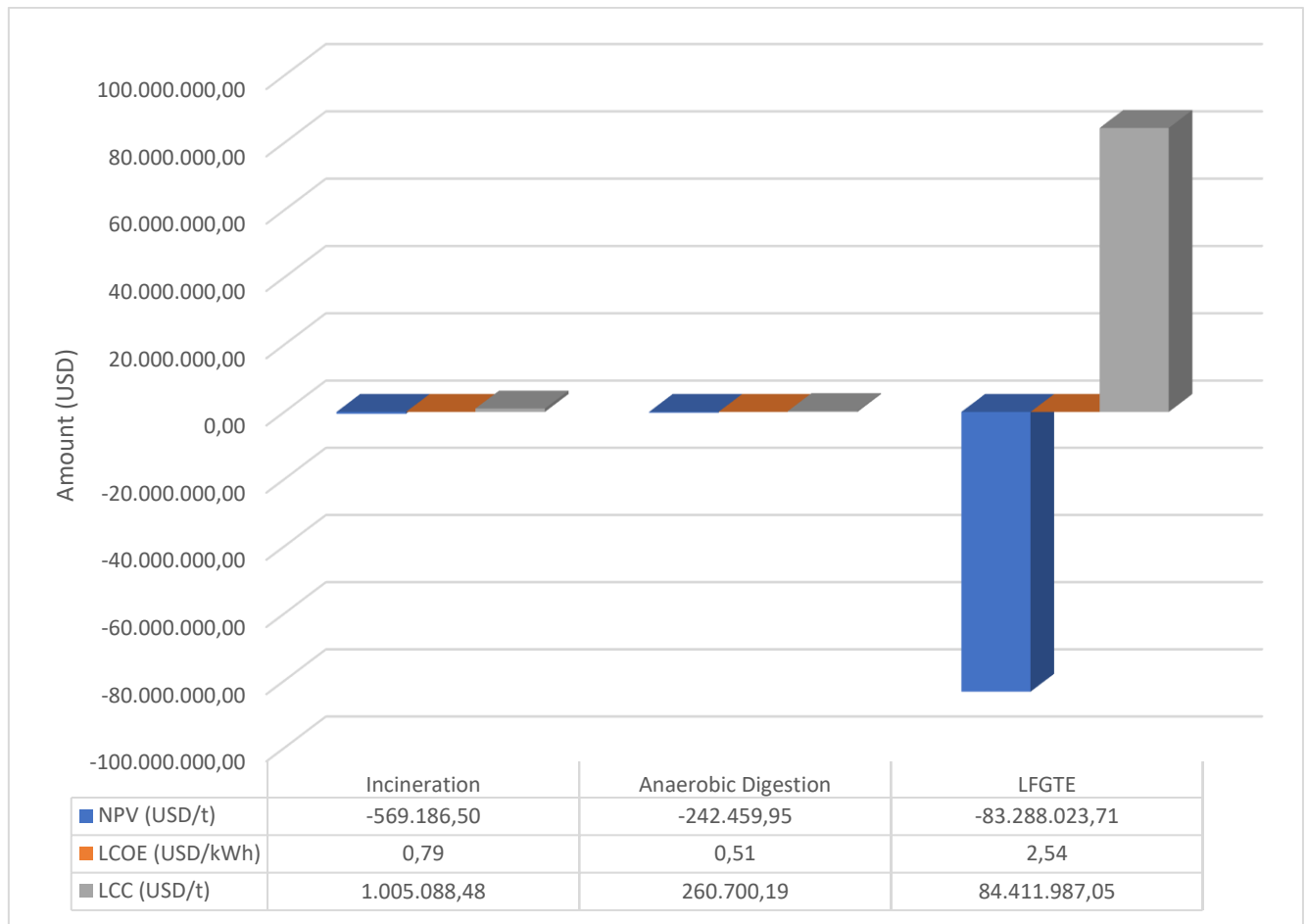


Figure 4. Economic analysis of the WTE Processes.in terms of Net Present Value (NPV), Levelized Cost of Electricity (LCOE) and Life Cycle Cost (LCC).

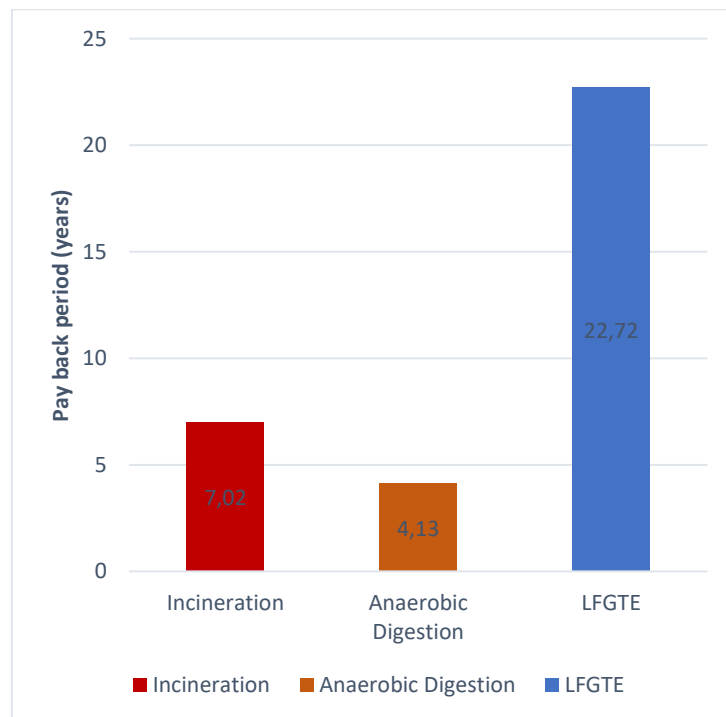


Figure 5. Economic analysis in terms of Pay Back Period (PBP) for the WTE processes.

CONCLUSION

A comparative analysis of various waste-to-energy process (Incineration, Anaerobic Digestion and Landfill Gas to Energy) for electricity generation in Kano metropolis, Nigeria have been carried out. 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, with a generating capacity of 33,175,973.48KWh/yr followed by Incineration process with an electricity generation capacity of 1,327,365.69 kWh per annum.
- iii. Anaerobic Digestion (AD) has the least environmental impact amongst the three WTE processes for Kano metropolis based on all the impact categories selected, with acidic potentials of 0.3 kg SO₂ eq., Eutrophication potential (0.07 EP kg PO₄ eq.), Human toxicity (0.69 HTP kg 1,4-DB eq), Global warming potential (0.2 GWP 100 kg CO₂ eq), Photochemical oxidation potential (0.02 PCOP kg C₂H₄), and Odour Potential 0.01 kg H₂S eq.).
- iv. In terms of economic viability, LFGTE process is uneconomical with highest LCOE, LCC, PBP and NPV values, while Anaerobic Digestion process was considered to be the most favourable due to the low LCOE (0.51), LCC (USD260,700.19 or ₦403,430,937.023) and PBP (4.13years), followed by Incineration.

Recommendations

- 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 further study on a comprehensive legal framework and roadmap on WTE project for Kano, Nigeria.

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