



INVESTIGATING THE ENERGY POTENTIAL AND QUANTIFICATION OF BIDA WASTE LANDFILL: A CASE STUDY OF KUTUFANI DUMP SITE

¹A. L. Ndagiman, ²D. R. Suleiman* and ³I. Sulaiman*

^{1,2}Department of Chemical Engineering, The Federal Polytechnic Bida, Nigeria.

³Department of Mechanical Engineering, The Federal Polytechnic Bida, Nigeria

*Corresponding author's email address: skishk2009@gmail.com

ARTICLE INFORMATION

Submitted 5 Oct., 2023
Revised 2 February, 2024
Accepted 9 February, 2024

Keywords:

Characterization
energy generation
gasification process
greenhouse gases
incineration
waste-to-energy
conversion

ABSTRACT

Waste management has become a pressing global issue, with an increasing focus on sustainable solutions that not only mitigate environmental concerns but also harness valuable resources. Solid waste in various dump sites in Bida, Nigeria, present a significant environmental challenge, posing health risks to the community while emitting harmful greenhouse gases. Characterisation of Kutufani solid waste was carried out. The proximate and ultimate analysis of the waste samples were carried out. Results showed that 29.7 % of the waste to be composed of various types of plastic materials. Other categories of the waste is composed of paper, agricultural waste and textile materials. The proximate analysis of the waste was conducted and the highest moisture content of 6.36 % and volatile matter 43.16 % were obtained. The ultimate analysis results showed Nitrogen and Sulphur content to be within safe limits. The combined calorific values obtained were 25,771 kJ/kg (HHV) and 18,841 kJ/kg (LHV). The waste is suitable for conversion to energy with gasification or incineration process.

1.0 Introduction

Energy plays an important role in meeting the needs of residential, industrial, transport, agricultural and other sectors of economy. An estimated 93 percent of Africa's economically viable hydropower potential remains unexploited (Eberhard *et al.*, 2011). Much of that is located in the Democratic Republic of Congo, Ethiopia, Cameroon, Angola, Madagascar, Gabon, Mozambique, and Nigeria (Eberhard *et al.*, 2011). Many African nations have everyday electricity blackouts. According to data from the World Bank, only a small number of nations on the continent can claim to have 100% access to electricity, including Egypt and Tunisia, while a few others come close, including Mauritius, Cape Verde, and Gabon (Amauakwa-Mensah and Surry, 2022). Some of the larger economies, such as South Africa and Ghana, provide the vast majority of their people with power, but they are still not yet at 100% and power cuts remain a problem (Amauakwa-Mensah and Surry, 2022).

In addition to hydropower, fossil fuels have long been used as the primary source of energy. However, their use results in the production of acid rain-inducing pollutants like SO₂ and NO_x as well as greenhouse gases like CO₂. Globally, the supply of fossil fuels is running out while use is rising (Sarakikya and Kiplagat, 2015). According to Sarakikya and Kiplagat (2015), oil finds peaked around 1960 and have since considerably decreased. In fact, a moment will come when

production will begin to drop while extraction costs would rise. World energy consumption doubled between 1970 and 2000, and it is expected to double again between now and 2050. Global consumption of coal increased by 5.4% in 2011, to 3.72 billion tons of oil equivalent, while natural gas use grew by 2.2% to 2.91 billion tons of oil equivalent (Sarakikya and Kiplagat, 2015).

Due to the depletion of fossil fuels and environmental concerns, it is increasingly a priority to meet energy demands through the use of innovative alternatives and renewable energy sources. Municipal solid waste (MSW) is a byproduct of human activities that, if an effective management system is not implemented, may cause environmental damage and put human health in danger (Ibikunle *et al.*, 2019). However, the increase in MSW generations can be taken as an opportunity for power generation in domestic or industrial use, when the MSW is seen as a raw material. For instance, barely 20 to 30% of the 32 million tons of solid municipal waste produced in Nigeria each year by its 196 million residents is collected. In Lagos, Nigeria's commercial hub, 21 million people produce more than 10,000 tons of MSW per day at a rate of 0.5 kg/capita/day, while more than 730,412 people in Onitsha generate 370,706 tons annually (Ibikunle *et al.* 2019). Data currently available indicate a rise of MSW globally, which is undoubtedly attributable to population expansion, however managing MSW is very challenging (Alao *et al.*, 2022) Solid waste management has emerged as one of the greatest challenges facing state and local government environmental protection agencies in Nigeria. The volume of solid waste being generated continues to increase at a faster rate than the ability of the agencies to improve on the financial and technical resources needed to parallel this growth (Alao *et al.*, 2022).

Viewing MSW as a resource (rather than waste that needs to be managed) for energy generation in the waste-to-energy initiative will better aid the efficient management of the MSW generated across the country. Waste-to-Energy (WtE) includes processes such as incineration, gasification, and pyrolysis that thermally treat solid waste and directly recover energy in the form of electricity and/or heat (Alao *et al.*, 2022; Oyedepo, 2012). It also includes bio-chemical processes such as landfill gas recovery, anaerobic digestion that converts the chemical energy in solid waste to yield products of high energy value example methane (Aneni, 2018). A direct conversion of the waste to an energy source, which shortens the time of treatment, the ability to treat toxic materials, and the ability to control emissions from point sources make thermal treatment methods with energy recovery options very popular. The advantages include the potential to significantly reduce waste quantities, recover minerals and chemicals, and destroy contaminants. Their use is anticipated to improve quality of life because it can reduce harmful waste dumping, preventing environmental pollution and land degradation; reduce fossil fuel use and greenhouse gas emissions; offset methane that could be released from open landfills; prevent harmful health effects from exposed waste burning; and stop the spread of infectious diseases via parasitic agents (Aneni, 2018).

Certain studies have carried out a community-level assessment of the WtE potential that could be derived from MSW for selected localities and States in Nigeria. Daura *et al.* (2014) determined and analysed the characteristics and composition of municipal solid waste in Kano metropolis. Ibikunle *et al.* (2019) estimated the power generation capacity from municipal solid wastes in Ilorin metropolis, North-Central, Nigeria. The study determined the amount of MSW produced annually and the amount produced per person each day in the Nigerian Kwara State capital of Ilorin. The number of daily combustible waste fractions that could be employed for power generation as well as the fractions' proximate and final analyses were calculated. The

study was designed to determine the steam power plant's capacity to produce electricity from the available combustible waste fractions.

The University of Nigeria, Enugu's solid waste composition and treatment potential were estimated by Nwoke et al. (2022). Based on a student population of 36000 and a weekly generation of 4821.1kg, the study found that the estimated waste generation rate for the University campus was 0.019kg/capita/day from the four sources evaluated. Only a small part, or 7.16% of created garbage, which cannot be composted or recycled, will be transferred to landfill. Of the waste generated, 28.35% is biodegradable and 64.49% is recyclable (Nwoke et al., 2022). Olatunji et al. (2019) estimated the combustion enthalpy of MSW for the purpose of energy recovery. Abba et al. (2019) estimated the potential of MSW in Yola; the study estimated that 685.69 tons of methane was generated from MSW between a decade (2004-2014).

This study therefore presents a community-level assessment of the WtE potential in Nigeria. Studies have been reported on the effects of indiscriminate waste dumping, types of waste generated in Bida and even proposing mathematical model for optimal MSW disposal in the town (Yahaya and Yahaya, 2022). However, limited research has been done on the energy content of its MSW. This research further investigates the potential of MSW as an alternative source of energy and a possible waste management solution, taking landfill sites of *Kutufani Bida*, Niger state as study area. The findings of this study are anticipated to contribute significantly to the broader discourse on sustainable waste management and renewable energy generation. Moreover, it underscores the importance of recognizing landfills as not merely a problem but as a potential solution to the global challenges of waste disposal, energy generation, and environmental protection. As the world strives to achieve sustainable development goals, this research endeavours to exemplify how a holistic approach to waste management can lead to a brighter, cleaner, and more energy-abundant future for urban communities like Bida.

2 Materials and Methods

2.1 Study Area

Bida is located in the central part of Nigeria, within Niger State. It lies approximately 120 kilometres west of the State capital, Minna and approximately 200 kilometres west of Nigeria's capital city, Abuja. The geographical coordinates of Bida are approximately latitude 9.0707° N and longitude 6.0086° E (Mohammed et al., 2021). Figure 1 shows Niger State relative to Nigeria in a map and Bida relative to Niger State as given by Ajiboye et al. (2023). The terrain in and around Bida is relatively flat, with some undulating areas (Mohammed et al., 2021). Niger State, in general, is characterized by a mixture of savannah grasslands and wooded areas. The location experiences a tropical climate, typical of the West African region. It has a rainy season that usually occurs from May to September, with the highest rainfall occurring in July and August. The dry season extends from October to April. Temperatures in Bida are relatively high round the year, with the hottest months typically being March and April (Adedibu et al., 2022). It is not directly situated on a major river, but it is in close proximity to the Niger River, one of Nigeria's largest rivers, which flows to the south of the town. The vegetation in and around Bida is characterized by savannah grasslands, with scattered trees and shrubs. This type of vegetation is typical of the Nigerian interior (Mohammed et al., 2021).

In September 2021, the population of Bida was estimated to be around 190,000 people (Ajiboye et al., 2023). Overall, Bida, Niger State, is a region with a rich cultural heritage,

predominantly agricultural economy, and a unique blend of traditional and modern influences (Ajiboye et al., 2023). It is an essential part of Niger State's cultural and economic landscape.

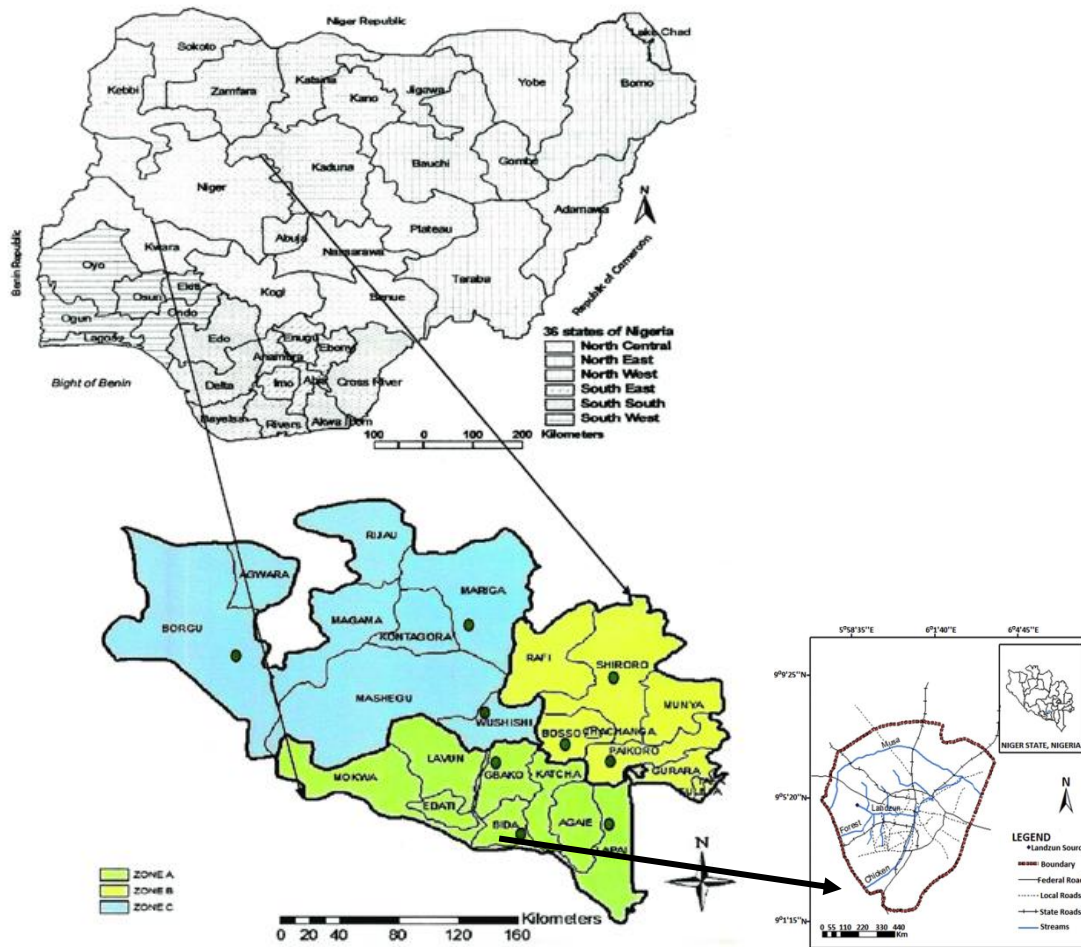


Figure 1: Map of Bida in the context of Niger State in the Nigerian map (Source: Ajiboye et al., 2023)

Kutufani is a district within Bida town. It can be accessed off *Banwuya* road and is situated west of the Old/Etswafura market. A dumpsite is located between about 25 houses as depicted in Figure 2.



Figure 2: a. Satellite view of *Kutufani* dump site (Source: Google maps), b. *Kutufani* Dump site (Source: Site survey)

The dumpsite had been evacuated before but has already accumulated to an enormous size. The volume of the waste dump was determined by sectioning the dump to basic shapes a

triangle of size 600 m by 420 by 400 m and apex of 400 m, and a rectangle of 200 by 100 m. The height was estimated to be 3 m using a tape measure on site. Hence, the volume of the waste study site is 312,000 m³.

2.2 Population Assessment of Kutufani

About 60 compounds have close proximity to the waste dump site with no alternative dump site; hence it is assumed waste is generated by the residents. Saidu et al. (2022) estimated population of direct people generating refuse in the area to be 1,600. Equation 1 is used to predict the population of Kutufani over a 20 year period, from 2022 (Rominiyi and Adaramola, 2020).

$$P_{t+n} = P_t(1+r)^n \quad (1)$$

where: P_{t+n} is the projected population for a specified year, P_t is the population of the base year which is 2022 in the present situation, t is the base year in consideration, r is the growth rate used for the projection, and n is the time interval between projections. Saidu et al. (2022) studied the trend of waste generation in Bida and estimated a 0.46 kg/person/day as the average daily generation rate of solid waste. The future waste generation is determined using equation 2 as given by Suryati et al. (2021).

$$R_g = \frac{W_g}{n_g} \quad (2)$$

where: R_g is the rate of waste generated in %, W_g is the weight or volume of generated waste in kg and n_g is the number of waste producer. Saidu et al. (2022) gave the growth rate of Bida to be 3.87 %; this is adopted for Equation 1.

2.3 Sample Collection

According to suggestions by Adeboye et al. (2022), the dumpsite was separated into six sections and samples were collected from each section over a three-weeks period. As per recommendations from Gukop et al. (2021) that recurrent sample selection and analysis would best give a more accurate representative data, the recurrent waste samples were selected for further analysis. The sample was characterised using the ASTM D523 method for measuring the composition of unprocessed MSW garbage (ASTMD-5231-92, 2022). Over the course of three weeks, representative MSW samples were gathered and then homogenized. Each slice yielded a sample that could weigh up to 10 kg. The collected MSW samples were divided into four equal sections, two of which were rejected, and the process was repeated until only a sizable portion, weighing about 1 kg, was left.

All six of the sections of the dumpsite chosen locations underwent this process. The waste streams were divided into various waste fractions during the characterisation phase. Due to their regular occurrence in waste streams and combustibility, the most prevalent waste components among the various waste fractions defined were taken into account for energy content studies. Following that, the waste sample was manually sorted. The trash sample's organic component was then the topic of additional experimental research. The samples were weighed using a digital weighing scale with a capacity of 2 kg and a spring scale with a capacity of 25 kg.

The procedure for gathering and sorting the samples also involved the use of garbage bags, hand shovels, and bin bags.

2.4 Proximate Analysis

Proximate analysis can be defined as a technique to measure the chemical properties of a compound based on four particular elements: moisture content, volatile matter, ash content and fixed carbon (Nunes *et al.*, 2018; Soares *et al.*, 2019).

2.4.1 Determination of Moisture Content

The determination of moisture content is a crucial step in proximate analysis, which is commonly performed to assess the composition of a sample, typically in coal, biomass, and other organic materials. American Standard Testing Methods (ASTM) D3173 was employed for determining Municipal Solid Waste (MSW) sample (Adeboye *et al.*, 2022; Nwoke *et al.*, 2020; Rominiyi and Adaramola, 2020). The required sample to be analysed was pulverised in a THOMAS willey mill, model ED-5 milling machine to appropriate sizes and a representative sample of the material to be analysed was obtained. An empty moisture tin/container was weighed and its mass recorded.

2 g of the sample was placed into the moisture tin/container and the combined weight recorded. Subsequently the sample was placed in a drying oven set (SearchTech instruments: DHG-9101-2SA) at 105°C for 2 hours. After drying, the container was taken out from the oven and placed in a container in a desiccator to cool to room temperature. Equation 3 was used to determine the moisture of the sample (%) (Ibikunle *et al.*, 2022; Adeboye *et al.*, 2022).

$$\text{Moisture content (\%)} = \left(\frac{W_2 - W_3}{W_2 - W_1} \right) \times 100 \quad (3)$$

where: W_1 is the mass (g) of empty crucible, W_2 is the mass(g) of crucible + test-sample, W_3 is the mass (g) of empty crucible + test-sample after heating, $W_2 - W_3$ is the moisture content. For each sample, triplicate samples were analyzed for moisture content determination.

2.4.2 Determination of Volatile Matter Content

The volatile matter is the condition of the material at which when heated in the absence of air under prescribed condition, liberated as gases and vapours (Elehinafe *et al.*, 2019). The ASTM standard ASTM D3175-II, which outlines the procedure for determining the volatile matter content of solid fuels was used to determine the volatile matter content (Neto *et al.*, 2023; Ahmed *et al.*, 2017; Ndecky *et al.*, 2022). The sample was finely ground to a particle size of 0.212 mm (No. 70 sieve). The finely ground sample is dried to constant weight and anhydrous calcium chloride was prepared as the desiccant to be used.

A clean, dry crucible is weighed to the nearest 0.1 mg and 2 g of the dried finely ground sample is placed into the crucible. The weight of the crucible with the sample is taken Subsequently the crucible with the sample is placed in a Carbolite Sheffield muffle furnace preheated to 950 ± 25°C and kept in the furnace for a minimum of 7 minutes or until the sample stops visibly evolving volatile matter.

The volatile matter content (VM) is determined using Equation 4 (Alexio da Silva *et al.*, 2021; Ibikunle *et al.*, 2022; Durogbitan, 2019).

$$VM (\%) = \left(\frac{W_2 - W_3}{W_2 - W_1} \right) \times 100 - \text{Moisture content (\%)} \quad (4)$$

where: VM is the volatile matter content in percent, W_1 is the mass (g) of empty crucible, W_2 is the mass(g) of crucible + test-sample before heating and W_3 is the mass (g) of empty crucible + test-sample after heating.

2.4.3 Determination of Ash Content

Ash content is an essential parameter in proximate analysis to determine the amount of inorganic residue present in a sample after complete combustion. ASTM D3174 is used to determine the ash content in this study (Zakariya et al., 2020; Ondachi et al., 2023; Ibikunle et al., 2018).

A clean dry crucible is weighed and recorded and 2 g of sample is added to the crucible. The crucible with the sample is then placed in the muffle furnace preheated to 550 °C. The sample was ignited in the crucible at this temperature for at least 4 hours and a constant weight is obtained (when the weight of the crucible and ash no longer changed significantly). The furnace temperature was stable throughout the ignition process. The crucible was removed and allowed to cool in a desiccator to prevent moisture absorption. Once the crucible was at room temperature, it was weighed again and noted. The residue left after determining the volatile matter was used as the fresh sample for the ash content determination. The ash content was determined using Equation 5 (Ibikunle et al., 2022; Durogbitan, 2019; Ibikunle et al., 2018).

$$\text{Ash content (\%)} = \left(\frac{W_3 - W_1}{W_2 - W_1} \right) \times 100 \quad (5)$$

where: W_1 is the weight of the empty crucible (g), W_2 is the weight of the crucible + the test sample before heating (g) and W_3 is the weight of the empty crucible + the residue (g).

2.4.4 Determination of Fixed Carbon

Fixed carbon represents the carbon content that remains after volatile matter has been driven off. This determination is typically performed using the ASTM D3172-13 standard method (Ibikunle et al., 2018). The experimental method depicted by the ASTM D3172-13 starts with the same procedures used to determine the moisture content, volatile matter and ash content respectively. The fixed amount of carbon left behind was then calculated by deducting the percentage amount of ash, moisture, and volatile matter from 100, as given in Equation 6 (Ibikunle et al., 2018; Ondachi et al., 2023).

$$\text{Fixed Carbon} = 100 - (\% \text{ MC} + \% \text{ VM} + \% \text{ Ash content}) \quad (6)$$

where, MC is the Moisture content and VM is the Volatile matter in %.

2.5 Ultimate Analysis

Ultimate analysis of municipal solid waste (MSW) involves determining the composition of the waste in terms of its major components, such as carbon, hydrogen, nitrogen, sulphur and oxygen. ASTM D5231-92(2016) standard test method for determination of the composition of unprocessed municipal solid waste was employed for the study.

A representative sample of *Kutufani* solid waste from the dump site was collected. The collected sample was well-mixed to capture the variability in waste composition. The large non-combustible items like metals, glass, and stones were taken out and homogenized by thoroughly mixing it to ensure a representative subsample can be taken. The composite sample was then dried in an oven at a temperature of 105 °C to 110 °C until it reached a constant weight. This step is crucial to remove moisture content. The procedure continued with sample combustion following the ASTM Standard: ASTM D3176-89(2017) - Standard Practice for Ultimate Analysis of Coal and Coke.

2.5.1 Carbon and Hydrogen Analysis

Standard test method for determination of Carbon, Hydrogen, and Nitrogen in analysis samples of coal (ASTM D5373-16) was used to analyse the carbon in the sample. For carbon and hydrogen analysis the representative sample of 10 mg was weighed and placed into a combustion furnace. The sample was heated to a high temperature (around 1000 °C) in the presence of oxygen for carbon analysis. The amount of carbon dioxide (CO₂) and water vapour (H₂O) produced during combustion was measured (Vasileiadou et al., 2023).

2.5.2 Sulphur Analysis

Using the standard test method ASTM Standard: ASTM D4239-19 the sample was weighed put into a crucible and loaded into the tube furnace combustion system. The sample was also heated to a high temperature (about 1000 °C) in the presence of oxygen. The sulphur in the sample is converted to sulphur dioxide (SO₂) during combustion. The generated SO₂ gas is collected and passed through a sulphur dioxide detector to quantify sulphur content (Vasileiadou et al., 2023; Ubuoh et al., 2021).

2.5.3 Nitrogen Analysis

Nitrogen content is estimated using Kjeldahl's method as outlined by Ondachi et al. (2023). Estimating nitrogen content in MSW using Kjeldahl's method involves a series of chemical reactions and titrations.

The MSW sample was weighed and accurately measured and recorded (W). The weighed sample is transferred into the digestion flask and concentrated sulfuric acid (H₂SO₄) was added to the sample in the digestion flask. The amount of acid used was ensured to be sufficient to digest all the organic matter. Ondachi et al. (2023) suggested 2 to 3 times the weight of the sample. A stopper is placed on the digestion flask while heat is applied using a cooking gas setup. The digestion flask is heated gently until the mixture turns clear or slightly brownish. This process is called digestion and can take several hours. No fume was allowed to escape from the flask.

After digestion, the flask was cooled for a few minutes and the contents of the digestion flask transferred into the distillation flask. The distillation apparatus was setup with the receiving flask in place. A few drops of a pH indicator (methyl red) were added to the contents of the distillation flask and heat was applied to the distillation flask, which caused ammonia (NH₃) to be released from the digested sample. This ammonia gas was collected by condensation in a known volume of hydrochloric acid (HCl) solution in the receiving flask. The acid was sufficient to ensure complete neutralization of ammonia.

Lastly titration of the collected ammonia solution in the receiving flask was done with a standardized solution of sodium hydroxide (NaOH). The NaOH solution was slowly added until the pH reached a stable endpoint as indicated by a colour change in the pH indicator. The volume (V) of the NaOH solution used for titration was recorded. The nitrogen content in the sample was calculated using the Equation 7 (Ondachi et al., 2023).

$$\text{Nitrogen content (g/kg)} = \frac{N \times V \times M}{W} \quad (7)$$

Where, N is the normality of the titrant (NaOH or HCl), V is the volume of titrant used (mL), M is the Molar mass of nitrogen (14.007 g/mol) and W is the weight of the sample (g).

2.5.4 Oxygen Analysis

The oxygen content is simply determined using Equation 8.

$$\text{Oxygen (\%)} = 100 - (\text{Carbon (\%)} + \text{Hydrogen (\%)} + \text{Nitrogen (\%)} + \text{Sulphur (\%)}) \quad (8)$$

2.6 Calorific Value Determination

The experiment used combustible MSW that was prepared in accordance with ASTM D2013 standards for sample preparation for calorific value estimation. After separating combustibles from non-combustibles, a 100 g sample was obtained. To calculate the moisture contents, they were baked for 24 hours at a temperature of 105 °C. In order to achieve complete combustion in the Bomb Calorimeter experiments, the dried samples were size decreased using a milling machine and sorted using a 1 mm sieve at the National Cereal Research Institute (NCRI), Badeggi, Niger State, Nigeria (Nwoke et al., 2020). The calorific values of the device were determined by testing two duplicates of each type of waste. The samples were burned in an enclosed space with only pure oxygen, and the energy released was measured as an increase in the temperature of the bomb and its surroundings (Adeleke et al., 2021; Nwoke et al., 2020).

The experiment employed an oxygen bomb calorimeter model AT8-OBCA. 1g of solid materials were compressed into pellets before being dropped into the bomb's metallic cup. The test material was fed through with a 10-cm-long fuse wire. The sample is heated more intensely by the fuse wire, which also served as a solid support to hold the sample in place while handling the bomb before it detonated (Adeleke et al., 2021; Nwoke et al., 2020).

Caloric value was calculated using Equation 9 (Adeleke et al., 2021; Nwoke et al., 2020).

$$Q = \frac{m_c \cdot \Delta T}{m_s} \quad (9)$$

Where, Q is the calorific value in joules or calories, m is the mass of the sample in g, c is the heat capacity of the calorimeter in J/°C, ΔT is the temperature change in °C and m_s is the mass of the ignition source in g.

3 Results and Discussion

3.1 Population Prediction

The data generated for the population and waste predictions for *Kutufani* is presented in Table I.

Table I: Population prediction of *Kutufani*

S/N	Year	Population of <i>Kutufani</i>	Waste generation rate	Total waste generated (Metric ton/day)
1.	2022	1,600	0.47	0.752
2.	2027	1,631	0.48	0.783
3.	2032	1,663	0.49	0.815
4.	2037	1,696	0.50	0.848
5.	2042	1,729	0.51	0.882
6.	2047	1,762	0.52	0.916
7.	2052	1,797	0.53	0.952

Figure 3 indicates that there is going to be a steady rise in the waste generation of the dump site with the rate of growth.

Table I projects population growth and waste generation in *Kutufani* from 2022 to 2052, showing a gradual population increase from 1,600 to 1,797 individuals and a corresponding rise in the waste generation rate per person per day from 0.47 to 0.53 metric tons. Consequently,

the total daily waste output is expected to grow from 0.752 to 0.952 metric tons as depicted in Figure 3.

This data highlights the need for significant enhancements in waste management strategies and infrastructure to accommodate the increasing waste output as the population expands. The projections suggest that *Kutufani* will face heightened demand for efficient waste collection, recycling, and disposal services. As waste volumes grow, the environmental impacts are likely to intensify, necessitating the adoption of sustainable practices such as improved waste minimization and energy recovery techniques. Local authorities will need to consider these trends carefully to ensure that infrastructure and policy developments are adequately planned to meet the escalating needs for waste management, aiming to mitigate environmental consequences and support sustainable growth.

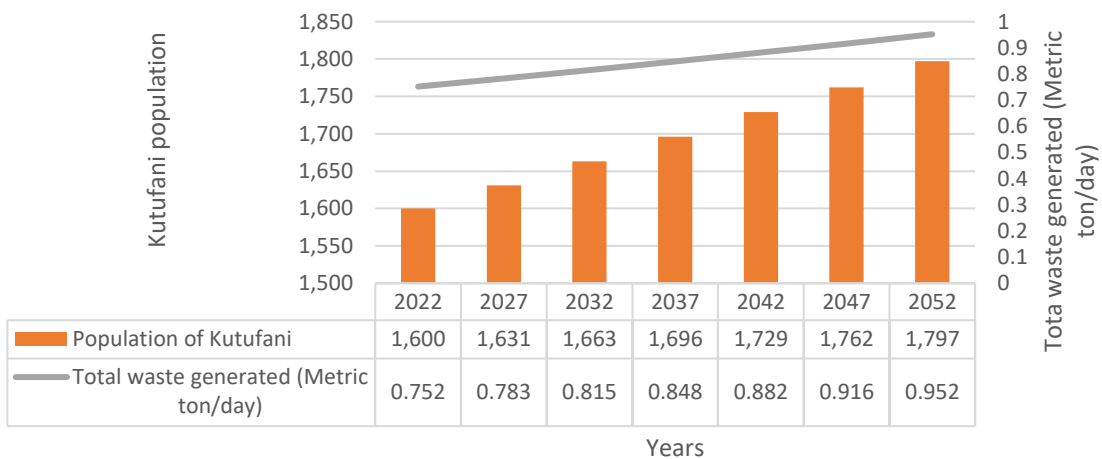


Figure 3: Waste generation prediction for *Kutufani* waste dump site

3.2 Solid Waste Composition

The composition of municipal solid waste at the dumpsite is shown in Table 2. The detailed analysis of waste categories over the three-week study highlights significant variations and trends crucial for developing effective waste management strategies. Nylon exhibited the most dramatic fluctuations, increasing from 6.42% to 16.45%, suggesting potential seasonal influences or variable consumer behaviour that could be targeted in waste reduction initiatives. In contrast, agric waste and textile materials demonstrated relatively stable but significant contributions to the waste stream, indicating their suitability for consistent recycling or composting programs. Lower, yet consistent contributors like bones and wood, although less impactful overall, still offer opportunities for specialized recycling efforts, such as bone meal production or wood chipping for biofuel. Plastics, despite slight variations, remained a high-volume category throughout the study, underscoring the ongoing need for robust plastic waste management and recycling measures. This analysis suggests that understanding both the variability and the average impact of each waste category can guide tailored and effective strategies for waste reduction and recycling, ultimately enhancing sustainability in waste management practices.

Table 2: Waste Characterisation for Kutufani dumpsite

S/N	Waste category	Weight (%) in the time of study in week			Average (%)
		1	2	3	
1.	Textile materials	10.22	11.85	10.95	11.01
2.	Nylon	6.42	12.1	16.45	11.66
3.	Paper	13.41	10.31	10.88	11.53
4.	Agric waste	15.41	14.25	13.54	14.4
5.	Rubbers	6.19	6.32	5.04	5.85
6.	Toiletries	9.21	10.54	8.69	9.48
7.	Plastics	20.5	16.51	17.1	18.04
8.	Bones	5.01	4.22	4.69	4.64
9.	Wood	5.49	3.45	5.42	4.79
10.	Glass and Ceramics	8.14	10.45	7.24	8.61

Ahmed (2019) stated that there is a mild significant difference between fresh waste collected and waste that has aged in the dump site.

One of the differences are often the absence of food waste which is evident in the results of the physical characterisation in Table 2. Results presented by the study conducted by Ahmed (2019) also show the absence of food, this is because of natural deterioration. An earlier study carried out by Saidu et al. (2022) analysing fresh waste collected from houses in the area shows above 40 % food waste. Figure 4 shows the graphical representation for the waste sample characterised from the dumpsite.

Physical Waste Characterisation

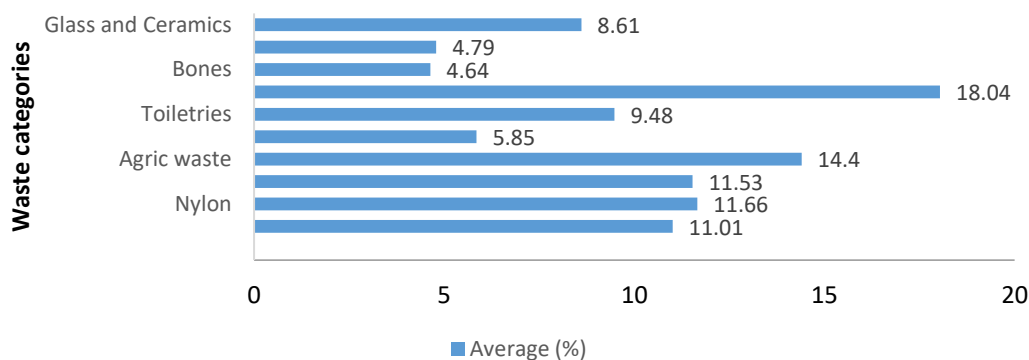


Figure 4: Waste characterisation

From Figure 4, Plastic has the highest percentage while agricultural waste was the second highest. The percentage of agricultural waste shows that residents of the area are farmers as inferred by Mohammed et al. (2021). The large proportion of waste items, including plastic, paper, and other recyclable materials, is a sign that material reuse and recycling are not well-practiced in the area, however, the absence of metal waste is an indication of some form of recycling being practised (Adeboye et al., 2022). Currently, the area recycles only metallic materials. The low to no percentage composition of metals in the research region is due to scavengers moving with large magnets collecting metallic debris for recycling before reaching the dumpsite and even within the site.

3.3 Proximate Analysis

The proximate analysis yielded the results presented in Table 3. Agricultural waste was discovered to contain the highest moisture content of the solid waste sample analysed; it was found to be 6.36 %. The moisture content indicates the amount of water present in the waste. A high moisture content can affect the waste's calorific value and its suitability for incineration. But even though this is the case, it does not mean the sample with lowest moisture content automatically becomes valuable during incineration, like Glass and ceramics (0.12 in Table 3) in the case of samples studied here.

The sample with highest volatile matter content of the waste sample was toiletries with a value of 43.16 %. Volatile matter consists of organic compounds that can be released as gases during combustion. This parameter is crucial for assessing the waste's potential for energy recovery through incineration. Adeboye *et al.* (2022) explained that the volatile matter content influences the rate at which a solid fuel burnout and a high percentage of volatile matter indicates that a solid fuel contains large amount of useful gases such as methane which can be released easily when such material is subjected to a heating regime. The volatile matter for *Kutufani* samples has generally high volatile matter values which is promising for the energy recovery potential of the dump site.

Table 3: Proximate analysis results for *Kutufani* dump site

S/N	Sample Description	Moisture Content (%)	Ash content (%)	Volatile Matter Content (%)	Fixed Carbon (%)
1.	Textile materials	5.40	1.50	36.06	57.04
2.	Nylon	4.02	0.06	36.01	59.04
3.	Paper	5.62	0.04	34.06	60.28
4.	Agric waste	6.36	0.92	36.14	56.58
5.	Rubbers	3.72	0.16	36.02	60.10
6.	Toiletries	2.01	0.13	43.16	54.70
7.	Plastics	3.84	0.43	38.41	57.32
8.	Bones	2.11	1.50	33.19	63.20
9.	Wood	4.32	1.52	33.10	61.06
10.	Glass and Ceramics	0.12	0.04	32.51	67.33
11.	Combined samples	4.46	1.66	29.57	64.31

The fixed carbon content was determined to be at a range of 67.33 to 54.7 %, which is a good indication of the wastes sample's combustibility. Fixed carbon represents the non-volatile, solid components of the waste, primarily composed of carbon and minerals. It is an essential parameter for assessing the waste's combustibility (Adeboye *et al.*, 2022; Ibikunle *et al.*, 2022). Ash consists of the inorganic materials that remain after combustion. It is an indicator of the waste's mineral content and plays a role in determining its disposal method. The highest ash content of the samples studied was determined to be 1.52 % (wood) which is relatively low and is within the range 0.49–12.58 %, which is said to indicate lower quantity of salt, heavy metal and chlorine and other organic pollutants thereby making the management of the MSW easier and also advantageous to the environment (Adeboye *et al.*, 2022; Anshar *et al.*, 2014).

The moisture content can reduce the energy potential of the waste and make it less suitable for incineration. Proper moisture management may be required to improve its combustibility. The relatively low results obtained for the moisture content of the samples is as a result of taking samples during the dry seasons. Although there are indications that high moisture content in samples can aid in the production of methane in case of organic waste management (Adeboye et al., 2022). The remaining parameters studied like the volatile Matter, fixed carbon and ash content all indicate the suitability of *Kutufani* solid waste to have potential as a fuel source for energy recovery through incineration or gasification, have excellent combustibility and suitability for landfilling.

3.4 Ultimate Analysis

The ultimate analysis of solid waste involves determining the elemental composition, which typically includes carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O). This analysis was conducted using a combination of analytical techniques, such as elemental analysis and bomb calorimetry. The results of the ultimate analysis are given in Table 4.

The carbon content in solid waste is a crucial parameter for estimating energy content, as it is the primary source of energy during combustion. The percentage of carbon in solid waste typically ranges from 20 to 50%. A higher carbon content indicates a higher energy potential for waste-to-energy conversion processes (Jabeen et al., 2022).

Table 4: Ultimate analysis results for *Kutufani* dump site

S/N	Sample Description	Carbon (%)	Hydrogen (%)	Sulphur (%)	Nitrogen (%)	Oxygen (%)
1.	Textile materials	62.00	5.60	0.00	0.39	32.01
2.	Nylon	56.10	6.10	0.01	0.15	37.64
3.	Paper	56.30	6.00	0.01	0.20	37.09
4.	Agric waste	53.78	4.90	1.20	0.28	39.84
5.	Rubbers	55.24	6.00	0.01	0.13	38.46
6.	Toiletries	40.68	5.70	0.06	0.26	34.66
7.	Plastics	37.77	6.10	0.22	0.12	31.33
8.	Bones	41.91	6.40	1.32	0.13	34.06
9.	Wood	44.90	5.40	1.00	0.08	38.42
10.	Glass and Ceramics	28.33	4.17	0.00	0.04	32.46
11.	Combined samples	59.12	5.30	1.08	0.28	34.22

The results indicate Glass and ceramics with lowest carbon value 28.33 %. Hydrogen is another important element that contributes to the energy content of solid waste. It combines with oxygen during combustion to produce water vapor (H₂O), releasing additional heat. The hydrogen content in solid waste is usually in the range of 2 to 10% (Abdel-Shafy and Mansour, 2018; Jabeen et al., 2022).

The highest value of hydrogen from Table 4 is determined to be 6.40 and the lowest 4.17 % within the range that will increase heat during energy recovery. Nitrogen and Sulphur contents were determined to be 0.39% and 1.32% respectively which are both within acceptable limits indicating that the effect of air pollution as a result of the emission of oxides of these elements

will be reduced. Nitrogen content in solid waste is significant because it can lead to the formation of nitrogen oxides during combustion, which are harmful pollutants. Nitrogen content in solid waste typically varies between 1 and 5% (Abdel-Shafy and Mansour, 2018; Jabeen et al., 2022).

Sulphur on the other hand is a potentially problematic element in solid waste, as it can lead to the formation of Sulphur dioxide (SO₂) during combustion, contributing to air pollution. Sulphur content in solid waste is typically low, ranging from 0.1% to 2%. Oxygen (O) Content: Oxygen content is an essential parameter to consider when estimating energy content, as it affects the stoichiometry of combustion reactions. Oxygen content varies widely but is usually between 20 and 40% (Abdel-Shafy and Mansour, 2018; Jabeen et al., 2022). The highest oxygen content was determined to be 39.84 %.

3.5 Solid Waste Calorific Value

The calorific value analysis of solid waste is essential for estimating its energy content, which plays a crucial role in waste-to-energy conversion processes such as incineration and gasification (Adeboye et al., 2022). The results obtained from the calorific value analysis of a representative sample of *Kutufani* solid waste is given in Table 5.

Table 5: Calorific value results for *Kutufani* solid waste materials

S/N	Sample Description	LHV (kJ/kg)	HHV (kJ/kg)
1.	Textile materials	13,362	17,476
2.	Nylon	17,820	18,566
3.	Paper	12,782	14,085
4.	Agric waste	11,338	15,668
5.	Rubbers	18,163	22,197
6.	Toiletries	12,752	14,085
7.	Plastics	23,708	33,712
8.	Bones	12,970	14,770
9.	Wood	14,600	16,580
10.	Glass and Ceramics	14,210	14,353
11.	Combined samples	18,841	25,771

Due to the larger percentage of moisture, organic, and mineral components in the trash, the calorific values of MSW waste fractions are typically lower for developing nations like Nigeria than for industrialized countries (Adeboye et al., 2022). MSW's heating value depends on its elemental composition and nearby analyses. For the plastic samples that were examined, the highest values for higher heating value (HHV) and lower heating value (LHV) were found to be 33,712 kJ/kg and 23,708 kJ/kg, respectively. The combined sample calorific values are 25,771 kJ/kg (HHV) and 18,841 kJ/kg (LHV) which is in accordance with literature (Durogbitan, 2019).

According to Adeboye et al. (2022), solid wastes must have a calorific value of 7.5 to 17 MJ/kg in order to qualify as a fuel source. This is encouraging because even the lowest values discovered for the samples are greater than expected, making *Kutufani* solid waste a potential candidate for energy recovery and a good source of fuel. Nevertheless, it has a lower calorific value than coal, which ranges between 37 and 40 MJ/k (Benedict et al., 2022). Practically speaking, this means that a kilogram of coal produces around twice as much energy as the

same amount of MSW's organic fraction. Although this fraction has a lower heating value than coal, which means it produces less power per unit mass, it is nevertheless used and is considered a renewable energy source because it is cost-free and has the added benefit of utilizing waste.

4. Conclusion

In the pursuit of effective and sustainable waste management strategies, the comprehensive Municipal Solid Waste (MSW) assessment study for *Kutufani* dump site has undertaken a multidimensional approach.

the study has successfully predicted population growth for *Kutufani* over a 30-year period along with waste generation rate for the predicted period. This prediction serves as a critical reference point for estimating future waste generation rates. Proximate Analysis reveal solid waste maximum moisture content of about 6.36 % and volatile matter of 43.16 % making it suitable for energy recovery through incineration or gasification. The harmful pollutant released during the ultimate analysis are within safe levels for Nitrogen at 0.39 % and Sulphur at 1.32 %. The plastic samples examined, recorded 33,712 kJ/kg as the higher heating value (HHV) and 23,708 kJ/kg as lower heating value (LHV). These values are within limits for *Kutufani* solid waste to be considered as fuel. The combined sample calorific values are 25,771 kJ/kg (HHV) and 18,841 kJ/kg (LHV) which is in accordance with literature.

In conclusion, our MSW assessment study has not only provided a comprehensive understanding of waste generation but has also laid the groundwork for informed decision-making in waste management and renewable energy utilization.

Acknowledgements

The authors especially are extremely grateful to Tertiary Education Trust Fund (TETFUND), Nigeria. This work has been possible with the financial support of Tertiary Education Trust Fund (TETFUND) under the Institution-Based Research (IBR) Intervention (TETF/DR&D/POLY/BIDA/IBR/2022/VOL.II/3).

References

- Abba, AH., Babagana, UM., Atiku, AA. and Burmamu, BR. 2019. Evaluation of energy potentials from municipal solid waste: a case study of Yola, Nigeria. *FUTY Journal of the Environment*, 13(1): 36-46.
- Abdel-Shafy, H. and Mansour, MSM. 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, 27(2): 1275-1290.
- Adeboye, BS., Idris, MO., Adedeji, WO., Adefajo, AA., Oyewusi, TF. and Adekun, A. 2022. Characterization and energy potential of municipal solid waste in Osogbo metropolis. *Cleaner Waste Systems*, 2(20): 1-6.
- Adedibu, PA., Opeyemi, AA., Lawrence, AJ., Paul, JI. and Oguntoye, E. 2022. Savanna biomes in Nigeria: indicator species and plant adaptation strategies. *ScienceOpen*, 12(4): 1-23.
- Adeleke, OA., Akinlabi, SA., Jen, TC. and Dunmade. I. 2021. Evaluation and prediction of energy content of municipal solid waste: a review. *IOP Conference Series: Materials Science and Engineering*, 11(07): 1-19.
- Ahmed, MI., Rizman, ZI., Rasat, MSM., Alauddin, ZAZ., Soid, SNM., Aziz, MSA., Mohamed, M., Amini, MHM. and Amin, MFM. 2017. The effect of torrefaction on oil palm empty fruit bunch

properties using microwave irradiation. *Journal of Fundamental and Applied Sciences*, 9(3): 924-940.

Ahmed, R. 2019. Evaluation and prediction of energy potential of landfill mined solid waste. Texas: The University of Texas Press, 1-24.

Ajiboye, AO., Owoeye, AS., Zarumi, GM., Oni, BG. and Abubakar, ID. 2023. Assessment of compliance level of automobile drivers to traffic rules and regulations in Bida, Niger State. *Centre for Human Settlements and Urban Development Journal*, 9(1): 39-55.

Alao, MA., Popoola, OM. and Ayodele, TR. 2022. Waste -to -energy nexus: An overview of technologies and implementation for sustainable development. *Cleaner Energy Systems*, 3(22): 1-14.

Alexio da Silva, D., Hansted, ALS., Nakashima, GT., Padilla, ERD., Pareira, JC. and Yamaji, FM. 2021. Volatile matter values change according to the standard utilized? *Research, Society and Development*, 10(12): 1-8.

Amauakwa-Mensah, S. and Surry, Y. 2022. Association between rural electrification and agricultural output: Evidence from Sub-Saharan Africa. *World Development Perspectives*, 25(5): 1-17.

Aneni, MO. 2018. Waste to energy solution in antiquity and Ibadan. *Ogirisi: a New Journal of African Studies*, 14(18): 127-142.

Anshar, M., Ani, FN. and Kader, AS. 2014. The energy potential of municipal solid waste for power generation in Indonesia. *Jurnal Mekanikal*, 37(7): 42-54.

ASTMD-5231-92. 2022. Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste. West Conshohocken, Pennsylvania Retrieved from American Society Group: www.ipcc.ch/publications_and_data/ar4/wgl/encontents.html

Benedict, JN., Nasir, MM., Ndikilar, CE., Moses, GW., Gaima, DKA. and Dankawu, MU. 2022. Characterization of some Nigerian coal for effective power generation and industrial utility. *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, 8(1): 117-126.

Daura, LA., Enaburekhan, J. and Rufai, AI. 014). Characteristics and Composition Analysis of municipal solid waste in Kano, Nigeria. *International Journal of Scientific & Engineering Research*, 5(9): 1-6.

Durogbitan, AA. 2019. Evaluation of Impact of Solid Wastes and Its Potential as A Source of Renewable Energy. A Case Study from Minna and his Environs, Nigeria. *ACTA Scientific Agriculture*, 3(5): 145-152.

Eberhard, A., Rosnes, O., Shkaratan, M. and Vennemo, H. 2011. Africa's Power Infrastructure; Investment, Intergration, Efficiency. Washington DC: The World Bank, 1-5.

Elehinafe, FB., Okedere, OB., Odunlami, OA., Mamudu, AO. and Bamidele, SF. 2019. Proximate analysis of the properties of some southwestern Nigeria sawdust of different wood species. *International Journal of Civil Engineering and Technology (IJCIET)*, 10(3): 51-59.

Ibikunle, RA., Lukman, AF., Titiladunayo, IF. and Haadi, A. 2022. Modeling energy content of municipal solid waste based on proximate analysis: R-k class estimator approach. *Cogent Engineering*, 9: 1-21.

Ibikunle, RA., Titiladunayo, IF., Akinnuli, BO., Dahunsi, SO. and Olayanju, TMA. 2019. Estimation of power generation from municipal solid wastes: A case Study of Ilorin metropolis, Nigeria. *Energy Reports*, 5(19): 126-135.

Ibikunle, RA., Titiladunayo, IF., Akinnuli, BO., Lukman, AF., Ikubanni, PP. and Agboola, OO. 2018. Modelling the energy content of municipal solid waste and determination of its physicochemical correlation, using multiple regression analysis. *International Journal of Mechanical Engineering and Technology (IJMET)*, 9(11): 220-232.

Jabeen, F., Adrees, M., Ibrahim, M., Mahmood, A., Khalid, S., Sipra, HFK., Bokhari, A., Mubashir, M., Khoo, KS. and Show, PL. 2022. Trash to energy: a measure for the energy potential of combustible content of domestic solid waste generated from an industrialized city of Pakistan. *Journal of the Taiwan Institute of Chemical Engineers*, 137: 1-15.

Kamran, A., Chaudhry, MN. and Batool, SA. 2015. Effects of socio-economic status and seasonal variation on municipal solid waste composition: a baseline study for future planning and development. *Environmental Sciences Europe*, 27(16): 1-8.

Mohammed, YM., Arimoro, FO., Ayanwale, AV., Adamu, KM., Keke, UN., Abubakar, MD. and Achebe, AC. 2021. The current state of water quality and benthic invertebrate fauna in Chikke Stream (North-Central Nigeria). *Ukrainian Journal of Ecology*, 11(3): 26-34.

Ndecky, A., Tavares, PW., Senghor, A., Kane, M., Ndiath, H. and Youm, I. 2022. Proximate Analysis of Alternatives Cooking Solides Fuels in Sub Saharan by Using ASTM Standards. *International Journal of Clean Coal and Energy*, 11: 1-12.

Neto, FS., Neta, MN., Sousa, A., Damsceno, L., Sousa, B., Medeiros, S., Melo, R., Lopes, A., Santos, J. and Rios, M. 2023. Analysis of the Fuel Properties of the Seed Shell of the Neem Plant (*Azadirachta indica*). *Processes*, 11(24): 1-17.

Nunes, LJR., Matias, JC. and Catalão, JP. 2018. *Torrefaction of Biomass for Energy Applications: From Fundamentals to Industrial Scale*. Amsterdam: Elsevier, 89-124.

Nwoke, OA., Ime, C., Solueke, MM. Ogwo, V. Chukwuma, EC. Obuladike, CE. and Ugwu, SN. 2022. Analysis of solid waste composition and its treatment potentials in University of Nigeria Enugu State. Nigeria. *Nigerian Journal of Technology (NIJOTECH)*, 4(4): 817-826.

Nwoke, OA., Okonkwo, WI., Echiegu, EA., Okechukwu, CH. and Ugwuishiwu, BO. 2020. Determination of the calorific value of municipal solid waste in Enugu, Nigeria and its potential for electricity generation. *Agricultural Engineering International CIGR Journal*, 22(2): 86-97.

Olatunji, O., Akinlabi, S., Madushele, N. and Adedeji, P. A. (2019). Estimation of Municipal Solid Waste (MSW) combustion enthalpy for energy recovery. *EAI Endorsed Transactions on Energy Web*, 6(23): 1-9.

Ondachi, PA., Ozigis, II. and Zarmai, MT. 2023. Physicochemical Characterisation of Abuja's Municipal Solid Wastes as a Renewable Energy Resource. *ABUAD Journal of Engineering Research and Development (AJERD)*, 6(1): 38-43.

Oyedepo, SO. 2012. Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, 2(15): 1-17.

Rominyi, OL. and Adaramola, BA. 2020. Proximate and ultimate analysis of municipal solid waste for energy generation. *ABUAD Journal of Engineering Research and Development (AJERD)*, 3(1): 103-111.

Saidu, MB., Musa, HD. and Akanbi, MO. 2022. Waste generation and trend among households in Bida town. *Nigerian Journal of oil and Gas Technology*, 4(1): 1-10.

Sarakikya, H. and Kiplagat, J. 2015. Combustion characteristics and energy potential of municipal solid waste in Arusha city, Tanzania. *American Journal of Energy Engineering*, 3(5): 71-77.

Soares, RB., Martins, MF. and Goncalves, RF. 2019. A conceptual scenario for the use of microalgae biomass for microgeneration in wastewater treatment plants. *Journal of Environmental Management*, 252(19): 1-19.

Suryati, I., Khair, H., Siregar, RL., Sibagariang, H. and Utami, R. 2021. Study on solid waste generation in Lake Toba area. In *IOP Conference Series: Materials Science and Engineering*, 1041(1): 1-7.

Ubuoh, EA., Ogbonna, PC., Eze, WU. and Emeka, CC. 2021. Characterization of municipal solid wastes for resources recovery in Owerri, Southeast Nigeria. *The Nigerian Journal of Energy & Environmental Economics*, 12(1): 27-40.

Vasileiadou, A. Zoras, S. and Dimoudi, A. 2023. A comprehensive experimental study of municipal solid waste (MSW) as solid biofuel and as composite solid fuel in blends with lignite: quality characteristics, environmental impact, modeling, and energy cover. *Energy, Ecology and Environment*, 8(3): 211–240.

Yahaya, AA. and Yahaya, TA. 2022. Mathematical model for optimal solid waste management and disposal in Bida Metropolis, Niger State, Nigeria. *The Review of Contemporary Scientific and Academic Studies*, 2(7): 1-5.

Zakariya, IA., Fazhil, NA., Izhar, TNT., Zaaba, SK. and Jamaluddin, NF. 2020. Municipal solid waste characterisation and quantification as a measure towards effective solid waste management in Universiti Malaysia Perlis. *IOP Conference Series: Earth and Environmental Science*, 616 (20): 1-6.