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**Evaluation of Kaduna Municipal Solid Waste (MSW) as an Alternative Source of Energy**

**Abdulaziz Habibu<sup>1\*</sup>, Mary Samuel<sup>1</sup>, and Musa Tanko Zarmai<sup>2</sup>**

<sup>1</sup>Department of Mechanical Engineering, Nigerian Defence Academy (NDA) Kaduna, Nigeria

<sup>2</sup>Department of Mechanical Engineering, University of Abuja, Nigeria

\*Corresponding Author's e-mail [abdulaziz.habibu2022@nda.edu.ng](mailto:abdulaziz.habibu2022@nda.edu.ng)

**ABSTRACT**

Kaduna metropolis generates significant quantities of municipal solid waste (MSW), with an average Higher Heating Value (HHV) of 21.18 MJ/kg, indicating strong potential for energy recovery. This study evaluates the techno-economic feasibility of converting MSW into electricity, with emphasis on calorific value assessment and household energy supply potential. Laboratory analysis of waste samples collected from Goni Gora and Kakau dumpsites revealed HHV values of 23.24 MJ/kg and 19.11 MJ/kg, respectively. Waste generation was projected using a compound annual growth rate (CAGR) model based on a 2025 baseline population of 1.26 million and a per capita generation rate of 0.497 kg/person/day. The organic fraction (52%) was incorporated into the energy estimation model, and sensitivity analysis ( $\pm 10\%$  and  $\pm 20\%$ ) was performed to account for variability in waste generation. Results indicate that Kaduna MSW could generate up to 700 GWh/year of electrical energy under ideal conditions. However, this represents theoretical energy potential; assuming a typical conversion efficiency of about 30% for waste-to-energy systems, the net electrical output is significantly lower. The energy generated has the potential to supply electricity to about 73,000 to 175,000 households annually. The findings demonstrate that MSW represents a viable supplementary energy resource capable of contributing up to 16% to 20% of Kaduna's electricity demand while improving environmental sustainability.

**Keywords:** Municipal Solid Waste (MSW), Waste-to-energy (WtE), Higher Heating Value (HHV), Energy Recovery, Kaduna Metropolis, Household Electrification

**1.0 INTRODUCTION**

Solid waste refers to unwanted or discarded materials generated from residential, commercial, industrial, and agricultural activities (Adewumi *et al.*, 2005). With rapid population growth and increasing urbanization, global municipal solid waste (MSW) generation is projected to reach approximately 3.40 billion tonnes by 2050 (Lisbona *et al.*, 2023). In Nigeria, only about 41% of generated MSW is formally collected and disposed of at landfills or dumpsites, while the remaining fraction is indiscriminately discharged into the environment (Ddiba *et al.*, 2022).

In Kaduna metropolis, an estimated 1,500 tonnes of MSW are generated daily (Olukanni *et al.*, 2016; Ajaero *et al.*, 2023). The increasing volume of waste has become a major environmental concern, with visible accumulations along roadsides, waterways, and open spaces. This situation has contributed to serious health risks and environmental degradation due to inefficient waste management practices. The primary sources of solid waste in Kaduna include households, markets, schools, healthcare facilities, food outlets, construction activities, and abattoirs. Although institutions such as the Kaduna State Ministry of Environment, Kaduna Environmental Protection

Agency (KEPA), and some private operators are responsible for waste management, their performance has remained inadequate in addressing the growing challenge (Lind *et al.*, 2019).

Municipal solid waste can be utilized as a valuable resource for energy generation through various waste-to-energy (WtE) technologies, including direct combustion (mass burning), anaerobic digestion, pyrolysis, and thermal gasification (Adewumi *et al.*, 2005). The energy potential of MSW can be determined through compositional, proximate, ultimate, and calorimetric analyses. Given the substantial volume of waste generated in Kaduna, there is a strong need to explore its potential as a sustainable energy source. Harnessing this resource could simultaneously address waste management challenges and contribute to electricity generation within the city.

This study therefore evaluates Kaduna municipal solid waste as an alternative energy resource by assessing the quantity of waste generated annually, forecasting future waste generation from 2019 to 2030, and determining the aggregate energy content of the waste stream. In addition, the study estimates the potential electrical energy that can be produced and the number of households that could be supplied under a typical WtE system.

The significance of this research lies in its potential to improve environmental health by reducing open dumping practices and minimizing the hazards associated with unmanaged waste. Furthermore, converting waste into energy could contribute to reducing dependence on the national grid while promoting a cleaner and more sustainable urban environment.

Despite several studies on waste management in Nigeria, there remains limited information on long-term MSW projections for Kaduna and their implications for energy recovery. In particular, there is a lack of detailed analysis linking projected waste quantities to electricity generation potential and household energy supply capacity. This study addresses these gaps by providing forecast-based MSW data and evaluating its corresponding energy generation potential, thereby supporting future planning and policy development in waste-to-energy systems.

### **1.1 Basic Theory**

Municipal solid waste management remains a significant environmental challenge for urban authorities worldwide. In Kaduna metropolis, approximately 1,500 tons/day of municipal solid waste (MSW) are generated, posing serious health problem and management difficulties due to inadequate handling techniques (Olukanni *et al.*, 2016). The Kaduna State Environmental Protection Agency (KEPA), which is responsible for waste management within the state, has continued to face operational inefficiencies in addressing this growing problem (Lind *et al.*, 2019). Studies have shown that waste disposal practices among residents in Kaduna are largely informal and inefficient. Scarlet *et al.*, 2018 reported that about 33% of waste is collected by informal wheelbarrow operators, while 26% is disposed of through open dumping. Government and private sector collection account for 16% and 12%, respectively, whereas smaller proportions are managed through burning (6%), disposal in open drains (5%), and burying (2%). These practices contribute significantly to environmental pollution and public health concerns.

Several challenges have been identified as barriers to effective waste management in Kaduna. Aliyu *et al.*, 2020, based on a survey of 200 households, highlighted key constraints including the high cost of waste collection services (32%), long distances to dumping sites (26.5%), absence of

designated disposal sites (13%), irregular waste collection (12.5%), lack of waste management services (8.5%), and inadequate provision of waste bins (4%). These factors collectively hinder the implementation of sustainable waste management systems.

Waste characterization plays a critical role in determining the suitability of MSW for energy recovery. Studies by (Tomohiro, 2013; Batagarawa *et al.*, 2024) indicate that organic waste constitutes a dominant fraction of the waste stream in Kaduna, accounting for approximately 53.5%, while recyclable materials represent about 26%. This composition suggests a strong potential for resource recovery and energy generation.

Various waste-to-energy (WtE) conversion technologies have been developed to harness the energy potential of MSW. Incineration involves the controlled combustion of waste in specially designed facilities, primarily to reduce waste volume and generate energy without the need for auxiliary fuel under auto-thermal conditions (Dolgen *et al.*, 2005). Anaerobic digestion utilizes microorganisms to decompose organic waste in the absence of oxygen, producing biogas rich in methane and carbon dioxide, which can be used for energy generation while yielding nutrient-rich digestate. Pyrolysis involves thermal decomposition of biomass in the absence of oxygen to produce pyrolysis oil, which can serve as a fuel or chemical feedstock (Durogbitan *et al.*, 2005). Gasification converts biomass into a combustible gas mixture through partial oxidation, which can be used in gas turbines for electricity generation. Similarly, landfill gas recovery systems capture methane produced during the natural decomposition of organic waste in dumpsites, which can then be utilized for heat and power generation (Dieter *et al.*, 2017).

Laboratory analysis is essential for evaluating the energy potential of MSW and determining its suitability for different WtE technologies. Proximate analysis provides information on moisture content, volatile matter, fixed carbon, and ash composition, which are critical parameters for assessing combustion characteristics of a fuel (Abate *et al.*, 2021). Ultimate analysis determines the elemental composition of waste, including carbon, hydrogen, oxygen, nitrogen, and sulfur, and is particularly useful for mass and energy balance calculations in thermal processes. In addition, the calorific value of MSW, typically measured using a bomb calorimeter, represents the total energy content of the waste and is a key factor in evaluating its potential for energy recovery (Asnani *et al.*, 2007).

## 2.0 MATERIALS AND METHOD

This study adopted a quantitative, analytical, and projection-based research approach, integrating historical municipal solid waste (MSW) data, population growth modelling, and energy potential estimation for Kaduna metropolis. The methodology follows established approaches used in municipal waste forecasting and waste-to-energy feasibility studies in developing urban centres (Dodo *et al.*, 2022; Etim *et al.*, 2025).

Laboratory analyses were conducted using standardized methods:

- i. Proximate analysis (ASTM D3172)
- ii. Ultimate analysis (ASTM D5373)
- iii. Calorific value (ASTM D5865)

A mass–energy balance approach was adopted to estimate energy potential. The system boundary includes waste collection, energy conversion, and electricity generation, excluding transmission and distribution losses (Dodo *et al.*, 2022).

Energy conversion efficiencies of 20%, 30%, and 100% were used to represent pessimistic, realistic, and ideal scenarios, respectively, consistent with typical WtE systems (Singh & Nizami, 2020). Sensitivity analysis ( $\pm 10\%$  and  $\pm 20\%$ ) was incorporated to account for variability in waste generation.

### 2.1 Data Sources

The study utilized both primary laboratory data and validated secondary datasets. Laboratory-derived data include the Higher Heating Values (HHV) obtained from municipal waste samples collected from Kakau and Goni Gora communities (Appendix C). In addition, MSW collection records for the period 2019–2023 were obtained from the Kaduna Environmental Protection Agency (KEPA) (Appendix A), while the organic waste fraction (52%) was adopted from the KEPA and Federal Ministry of Environment (FMEnv) Urban Waste Composition Study (2022), (Appendix B). Secondary data include a baseline population of 1.26 million for Kaduna metropolis in 2025, obtained from the National Population Commission (NPC) and National Bureau of Statistics (NBS) report (2023). Electricity demand benchmarks for Kaduna were sourced from relevant literature.

### 2.2 Population Projection Model

Population projection was carried out from the 2025 baseline both retrospectively (2019) and prospectively (2030) using the Compound Annual Growth Rate (CAGR) model, which is widely applied in demographic-based waste forecasting (Etim *et al.*, 2025; Ilorin MSW Study, 2022), Equation (1);

$$P_t = P_0 (1 + r)^t \quad (1)$$

Where:  $P_t$  = projected population,  $P_0$  = base population,  $r$  = annual growth rate and  $t$  = number of years before and after baseline.

Historical MSW data from KEPA (2019–2023) were used to establish baseline waste generation trends. To account for uncertainties in waste generation and collection efficiency, a scenario-based sensitivity analysis was performed using four cases: pessimistic ( $-10\%$ ), realistic (baseline data), optimistic ( $+10\%$ ), and highly optimistic ( $+20\%$ ). Similar approaches have been applied in MSW forecasting under uncertain conditions (Dodo *et al.*, 2022).

### 2.3 Per Capita Waste Generation Rate

The per capita waste generation rate (PCWG) was estimated using a compound growth-based approach that integrates both population and waste generation data, including sensitivity adjustments. The relationship is expressed in Equation (2);

$$PCWG \text{ (kg/person/day)} = \frac{MSW \text{ (tons/year)} \times 1000}{Population \times 360} \quad (2)$$

This approach is consistent with international waste modelling practices and Nigerian case studies (Ilorin MSW Study, 2022).

An organic fraction of 52% was applied uniformly across the study period based on KEPA and FMEnv 2022 Urban solid waste study in Kaduna State. This assumption is consistent with findings reported by the World Bank, 2019, which indicate that the organic component of MSW in African

cities typically ranges between 50% and 60%. Meanwhile, (Batagarawa *et al.*, 2024) reported 48% to 62% organic fraction range for Kaduna metropolis.

#### 2.4 Energy Potential Estimation

The energy potential of MSW was estimated based on its calorific value (HHV) obtained from laboratory analysis. The conversion from thermal energy (MJ) to electrical energy (kWh) is expressed in Equation (3 & 4);

$$E_{MJ} = \text{Organic MSW (kg)} \times \text{HHV (MJ/kg)}, \quad (3)$$

$$E_{kWh} = \frac{E_{MJ}}{3.6} \quad (4)$$

Where:  $E_{kWh}$  = energy in kWh, and  $E_{MJ}$  = energy in mega-joule (MJ), HHV is the heating value obtained from laboratory analysis of the waste in MJ/kg.

The number of households that can be supplied with electricity was estimated based on the total energy generated and average household electricity consumption. According to (Olukanni *et al.*, 2016) this relationship can be expressed in Equation (5);

$$\text{No. of Homes} = \frac{\text{Energy from Organic MSW (kWh)}}{\text{Average household electricity consumption (kWh/year)}} \quad (5)$$

The Nigerian Electricity Regulatory Commission (NERC, 2025); (Olaniyan *et al.*, 2013) reported that the average annual household electricity consumption for most Nigerian urban cities ranges between 1,080 to 2,400 kWh/annum for at least five individuals. Kaduna electricity demand ranges between 3,500-4,200 GWh/year, reported by (KADIPA, 2023; Kaduna electric, 2024).

To reflect real operational conditions, three conversion efficiency scenarios were considered: optimistic (100%), realistic (30%), and pessimistic (20%). These assumptions are consistent with energy recovery estimates reported in MSW-to-energy feasibility studies in Nigeria (Dodo *et al.*, 2022).

#### 2.5 Analysis and Instrumentation

Laboratory analyses were conducted using standard equipment to determine the thermal and compositional properties of the MSW samples. Proximate and thermal stability analyses were performed using a PerkinElmer TGA 4000 and a muffle furnace/drying oven in accordance with (ASTM E871; ASTM E872) standard. Ultimate analysis was carried out using a CHNS/O elemental analyzer in line with (ASTM D5373) standard, while the calorific value was determined using an oxygen bomb calorimeter consistent with (ASTM D5865).

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Result

The estimated population of Kaduna metropolis was approximately 1.26 million in 2025 and 1.113 million in 2020, corresponding to an annual growth rate of 3.2%.

**Table 1: MSW Collection Rate from 2019-2023 by KEPA**

Year	Waste Collected (Mt/y)	MSW Recycled (Mt/y)
2019	191,114.0	23,889.25
2020	196,917.5	24,614.69
2021	202,903.5	25,362.94
2022	209,072.0	26,134.00
2023	215,423.0	26,927.88

Table 1 presents the MSW collection data obtained from KEPA for the period 2019–2023. The results indicate a steady increase in waste collection over time, reflecting the influence of population growth and urban expansion.

**Table 2: MSW per Capita Waste Generation Rate Variation**

Year	Population	MSW (t/yr)	PCWG (kg/p/day)	PCWG avg (2019– 23)	PCWG opt (+20%)	PCWG pes (- 20%)
2019	1,085,726	191,114.0	0.4823	0.4898	0.5877	0.3918
2020	1,113,000	196,917.5	0.4847	0.4898	0.5877	0.3918
2021	1,140,960	202,903.5	0.4872	0.4898	0.5877	0.3918
2022	1,169,621	209,072.0	0.4897	0.4898	0.5877	0.3918
2023	1,199,003	215,423.0	0.4922	0.4898	0.5877	0.3918

**Table 3: MSW Collection under Variable Generation Probabilities**

Year	Population	MSW collected (t/yr)	PCWG (kg/p/day)	MSW -10% (t/yr)	MSW +10% (t/yr)	MSW +20% (t/yr)	Organic (52%) (t/yr)
2019	1,085,720	191,114	0.483	172,002.6	210,225.4	229,336.8	99,379
2020	1,113,000	196,917.5	0.485	177,225.8	216,609.3	236,301.0	102,216
2021	1,140,832	202,903.5	0.488	182,613.2	223,193.9	243,484.2	105,510
2022	1,169,372	209,072	0.490	188,164.8	229,979.2	250,886.4	108,765
2023	1,198,643	215,423	0.493	193,880.7	236,965.3	258,507.6	112,020

The per capita waste generation rate (PCWG) presented in Table 2 shows a gradual increase from 0.4823 kg/person/day in 2019 to 0.4922 kg/person/day in 2023, with an average value of approximately 0.4898 kg/person/day. Sensitivity analysis shows that this value could vary between 0.3918 kg/person/day (pessimistic) and 0.5877 kg/person/day (optimistic), highlighting the uncertainty associated with waste generation dynamics.

Table 3 illustrates MSW generation under different probability scenarios. The results show that total waste generation and its organic fraction increase proportionally with population growth. The organic component, which constitutes approximately 52% of the total waste, represents the most significant fraction for energy recovery applications.

**Table 4: Number of Households Powered Under Different Efficiencies**

Year	Organic MSW (t/y)	Energy Realistic HHV (MJ/y)	Energy Realistic HHV (kWh/y)	HH Optimistic (100%)	HH Realistic (30%)	HH Pessimistic (20%)
2019	99,378	2,104,913,000	584,142,500	534,451	486,785	97,357
2020	102,357	2,169,001,000	602,500,250	551,282	502,083	100,416
2021	105,490	2,237,393,000	621,498,000	569,147	517,915	103,583
2022	108,726	2,306,393,000	640,109,000	585,494	532,591	106,518
2023	111,981	2,375,216,000	659,788,000	602,895	549,823	109,965

The estimated number of households that can be supplied with electricity is presented in Table 4. The results demonstrate a strong dependence on conversion efficiency, with significantly higher household coverage under optimistic conditions compared to realistic and pessimistic scenarios.

Population and MSW projections from 2019 to 2030 based on the compound annual growth rate (CAGR) model are provided in Appendix D, serving as a basis for long-term waste-to-energy (WtE) planning.

### 3.1.1 Laboratory Analysis of Kaduna MSW

#### Thermal Stability

**Table 5: TGA Information of Organic Waste Samples**

Sample	Onset 150)°c	T.(30- Endothermic Peak T (200-450)°c	Degradation Range (450-700)°c
Kakau	16.73%	58.32%	17.22%
Goni Gora	14.71%	57.68%	18.52%

The thermo-gravimetric curve is depicted on Figure 1, showing the waste behaviors under varying temperature.

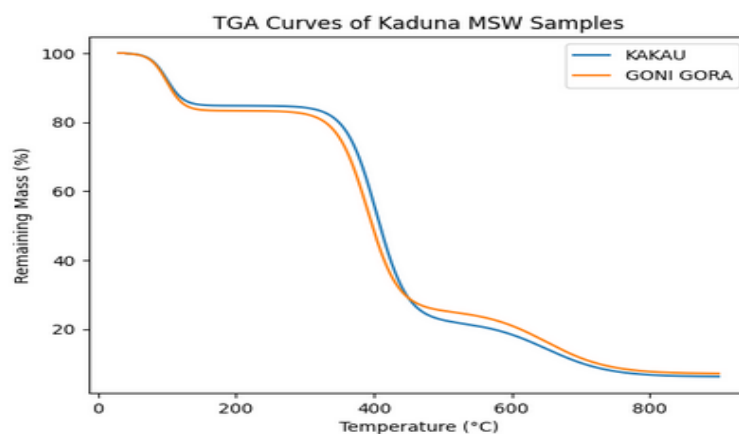


Figure 1. TGA curves of Goni Gora and Kakau at 10 °C/min

Thermogravimetric analysis (TGA) of MSW samples from Goni Gora and Kakau reveals a typical three-stage degradation pattern. The initial stage (30–150 °C) corresponds to moisture evaporation, followed by a major devolatilization phase (200–450 °C), and finally a degradation stage (450–700 °C) associated with char oxidation. These results confirm the suitability of the waste for thermochemical conversion processes.

#### Proximate Analysis

**Table 6: Proximate Analysis Data of Kaduna MSW Samples**

Sample ID	Moisture Content (%)	Volatile Content (%)	Fixed Carbon Content (%)	Ash Content (%)
KAKAU	15.23 ± 0.2	62.32 ± 0.4	16.22 ± 0.4	6.22 ± 0.2
GONI GORA	16.71 ± 0.2	57.68 ± 0.4	18.52 ± 0.4	7.08 ± 0.2

Heating rate Average: 15 °C min<sup>-1</sup>, Temperature Average: 550 °C, Residence Time: 2 Hours.

The proximate analysis results indicate that the moisture content of the samples ranges between 15% and 17%, suggesting a moderately wet waste stream. Although higher than the ideal range for direct combustion, this moisture level remains manageable for most WtE technologies. The volatile

matter content (58–62%) is relatively high, indicating strong potential for pyrolysis and gasification processes due to enhanced gas yield. Fixed carbon values (16–18%) suggest moderate char formation, while ash content (6–7%) remains within acceptable limits for thermal conversion systems.

### Ultimate Analysis

**Table 7: Ultimate Analysis Data of Kaduna MSW Samples**

Sample ID	C (%)	H (%)	N (%)	O (%)	S (%)
KAKAU	42.31 ± 0.3	5.88 ± 0.2	0.82 ± 0.2	50.54 ± 0.3	0.45
GONI GORA	46.45 ± 0.3	5.37 ± 0.2	0.96 ± 0.2	46.81 ± 0.3	0.41

Heating rate Average: 15 °C min<sup>-1</sup>, Temperature Average: 550 °C, Residence Time: 2 Hours.

The ultimate analysis shows that carbon content ranges from 42% to 46%, while hydrogen content is between 5% and 6%, indicating good combustibility characteristics. The higher carbon content observed in the Goni Gora sample corresponds to its relatively higher heating value. Oxygen content (47–51%) tends to reduce the overall calorific value; however, the combined carbon and hydrogen composition still supports effective energy recovery. Nitrogen (0.8–1.0%) and sulfur (~0.4%) contents are relatively low, which is advantageous as it minimizes the formation of harmful nitrogen and sulfur oxides during thermal conversion.

### Calorific Value

**Table 8: Calorific Values of Kaduna's Organic Waste Samples**

Sample ID	HHV (MJ/kg)
GONI GORA	23.2418
KAKAU	19.1134
AGGREGATE	21.1776

The calorific value analysis indicates that the Higher Heating Values (HHV) of the MSW samples are 23.24 MJ/kg (Goni Gora) and 19.11 MJ/kg (Kakau), with an average value of 21.18 MJ/kg. This value falls within the acceptable range for mixed municipal waste and confirms its suitability as a feedstock for energy generation.

### 3.2 Discussion

**Table 9: Important Parameters for Kaduna WtE Analysis**

ITEM	QUANTITY
Average Per capita waste generation rate	0.497 kg/day/man
Population (2025)	1,260,000.00
Total MSW collected	228,580 tons/annum
Organic fractions	52%
MSW Organic	118,862 tons/annum
Aggregate HHV	21.20 MJ/Kg
Net Energy from organic fractions per annum	699,305,000 kWh/annum

### 3.2.1 Energy Potential of Kaduna MSW

Projection of MSW generation from 2019 to 2030 using the CAGR model (Appendix D), indicates that approximately 228,580 tons/year of waste were collected in 2025, meanwhile the total MSW generation of the city is estimated at about 547,500 tons/year (Olukanni *et al.*, 2016; Ajaero *et al.*, 2023). This discrepancy highlights the relatively low waste collection efficiency in Kaduna.

The average per capita waste generation rate of 0.4898 kg/person/day obtained in this study is very close to (0.35–0.44) kg/person/day reported by (Batagarawa *et al.*, 2024), but slightly lower than 0.58 kg/person/day reported by (Ogwueleka, 2013).

The average per capita waste generation rate was estimated at 0.4898 kg/person/day, consistent with the national average of 0.5 kg/person/day reported by (World Bank, 2019). This value also aligns with the 0.35–0.44 kg/person/day range reported by (Batagarawa *et al.*, 2024), but is slightly lower than 0.58 kg/person/day reported by (Ogwueleka, 2013).

The organic fraction (52%) agrees closely with 53.3% national average reported by (World Bank, 2024), and falls within the (48–62) % range typical of northern Nigeria (Batagarawa *et al.*, 2024). This confirms that Kaduna's waste stream is highly suitable for biological energy recovery processes.

The 21.18 MJ/kg aggregate heating value obtained falls within the reported typical range for partially dried MSW (18–22 MJ/kg), but lower than values reported for highly dried waste streams (>30 MJ/kg) (Baze *et al.*, 2023; Baba *et al.*, 2025; Ondachi *et al.*, 2024).

Kaduna's electricity demand is estimated at approximately 3,500–4,200 GWh/year (KADIPA, 2023; Kaduna Electric reports, 2025). Capitalizing on the year 2025; the total theoretical energy potential is estimated at approximately 700 GWh/year. Assuming a boiler efficiency of 80% and turbine-generator efficiency of 30%, the estimated net electrical output is significantly lower but remains substantial for urban energy supply (Singh & Nizami, 2020). This will be able to relieve about 16% to 20% of Kaduna's electricity demand. The energy output could supply electricity to approximately 73,000 to 175,000 households annually, depending on the conversion efficiency of the selected WtE technology, (Appendix D).

### 3.2.2 Laboratory analysis of Kaduna MSW samples

The TGA results indicate a three-stage degradation process consistent with findings reported by Ondachi *et al.*, 2024. Moisture removal occurs at low temperatures, followed by significant volatilization and subsequent char oxidation at higher temperatures. This behaviour confirms that Kaduna MSW is capable to produce high thermal energy for incineration WtE system and also efficient for thermochemical conversion processes such as anaerobic digestion, pyrolysis and gasification.

The proximate analysis results demonstrate that Kaduna MSW possesses favourable characteristics for energy recovery. The relatively high volatile matter enhances fuel reactivity, while moderate fixed carbon content supports sustained combustion. Although the moisture content is slightly elevated, it remains within manageable limits for most WtE systems. The low

ash content further improves the efficiency of thermal conversion processes. However, moisture content (15–17%) may reduce combustion efficiency and necessitate pre-drying, which can introduce parasitic energy losses and reduce net output (Dieter *et al.*, 2017).

The elemental composition of the waste confirms its suitability for energy applications. High carbon and hydrogen contents contribute positively to energy generation, while relatively low nitrogen and sulfur contents reduce the environmental impact associated with gaseous emissions. Emissions such as NO<sub>x</sub>, SO<sub>x</sub>, and dioxins require mitigation through flue gas treatment systems, including scrubbers and baghouse filters, to meet regulatory standards (UNEP, 2019). These characteristics are consistent with typical MSW compositions reported in similar studies.

#### 4.0 CONCLUSION

This study evaluated the techno-economic feasibility of converting Kaduna municipal solid waste (MSW) into electrical energy. The findings indicate that Kaduna generates a substantial volume of MSW capable of supporting sustainable electricity production. The high organic fraction (52%) suggests strong suitability for biological conversion processes, particularly anaerobic digestion, although thermochemical options also remain viable based on the waste characteristics. The estimated per capita waste generation rate aligns with values reported in similar studies for Kaduna and other Nigerian cities. Furthermore, the calorific value and thermal stability results demonstrate that the waste stream possesses adequate energy potential for efficient waste-to-energy (WtE) conversion. The proximate and ultimate analyses also indicate favourable fuel properties, including high volatile content, moderate fixed carbon, and low sulfur and nitrogen content, which are desirable for energy recovery systems. The analysis shows that the energy recoverable from Kaduna MSW can supply electricity to a significant number of households annually, depending on the efficiency of the selected WtE technology. This highlights the potential of MSW as a complementary energy source capable of reducing dependence on conventional electricity supply while addressing environmental challenges associated with waste disposal.

In addition, this study contributes to existing knowledge by providing a comprehensive estimation of MSW generation trends for Kaduna from 2019 to 2030, supported by population-based forecasting. It also presents laboratory-based characterization of local MSW and quantifies its energy generation potential in terms of electricity output and household supply capacity. However, further studies are recommended to incorporate real operational efficiencies of WtE systems, as well as detailed design and simulation for performance evaluation, economic and life cycle assessments, in order to support large-scale implementation and investment decisions for sustainable waste-to-energy development in Kaduna metropolis.

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