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Feasibility Studies of Waste-to-Energy System Using Municipal Solid Waste in Kaduna State

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Abstract*—Municipal solid waste management has become a serious environmental challenge in many rapidly growing cities in developing countries, including Nigeria. Kaduna Metropolis experiences increasing waste generation due to population growth, urbanization, and expanding commercial activities. Inefficient waste collection, poor disposal practices, and lack of waste segregation have contributed to environmental pollution and public health risks. This study examines the composition of municipal solid waste in Kaduna Metropolis with emphasis on the proportions of organic and inorganic fractions and their implications for sustainable waste management and waste-to-energy development. The study adopted a secondary data review approach using published literature and existing waste characterization reports. Findings indicate that organic waste constitutes approximately 63.75% of the total municipal solid waste generated in Kaduna Metropolis, while inorganic and mixed waste account for about 36.25%. The dominant organic components include food residues and biodegradable household waste, whereas plastics, metals, glass, paper, and textiles make up the major inorganic fractions. The high percentage of biodegradable waste suggests strong potential for anaerobic digestion, composting, and biogas-based electricity generation. The recyclable inorganic fraction also presents opportunities for resource recovery and reduction of landfill pressure. The study concludes that Kaduna Metropolis possesses favorable waste characteristics for integrated waste management systems combining recycling and waste-to-energy technologies. It is recommended that government agencies promote source segregation, improve waste collection efficiency, encourage private sector investment, and establish pilot biogas facilities to enhance environmental sustainability and renewable energy generation.*

Keywords— *Municipal solid waste, Kaduna Metropolis, Organic waste, Inorganic waste, Waste-to-energy, Recycling.*

I. INTRODUCTION

Municipal solid waste (MSW) management is a growing environmental and public health concern in rapidly urbanizing regions of the world, particularly in developing countries. Increasing population, urban expansion, and changing consumption patterns have led to a significant rise in the quantity and complexity of waste generated in cities. In many African countries, including Nigeria, ineffective waste collection systems, open dumping, and uncontrolled burning remain common practices, contributing to environmental pollution, greenhouse gas emissions, and health risks (World Bank, 2018).

Nigeria faces persistent challenges in managing municipal solid waste due to inadequate infrastructure, weak institutional frameworks, and limited public awareness of proper waste handling practices. Urban centers such as Kaduna Metropolis generate large volumes of waste daily from households, markets, commercial activities, and institutions. However, the absence of efficient waste segregation and recycling systems has resulted in the accumulation of mixed waste in dumpsites and drainage systems (Ogwueleka, 2009). These challenges necessitate the exploration of sustainable waste management approaches that not only address environmental concerns but also recover value from waste.

One promising approach is waste-to-energy (WtE), which involves converting municipal solid waste into useful forms of energy such as electricity, heat, or fuel. WtE technologies, including anaerobic digestion, incineration, and refuse-derived fuel (RDF) systems, offer the dual benefits of reducing waste volume and generating renewable energy. The suitability of these technologies largely depends on the composition of the waste stream, particularly the proportion of organic and inorganic materials (Tchobanoglous & Kreith, 2002).

Waste characterization studies in Nigeria have consistently shown that municipal solid waste streams are dominated by biodegradable organic materials. In Kaduna Metropolis, for instance, organic waste constitutes approximately 63.75% of total waste generated, while inorganic and mixed materials account for the remaining 36.25% (Nwude et al., 2009). This high organic fraction suggests strong potential for biological treatment technologies such as anaerobic digestion and composting, which can produce biogas and organic fertilizers. Additionally, the inorganic fraction, including plastics, metals, and glass, presents opportunities for recycling and material recovery.

Given Nigeria's ongoing energy deficit and increasing demand for electricity, the conversion of municipal solid waste into energy presents a viable and sustainable solution. Harnessing the energy potential of waste in Kaduna Metropolis could contribute to improved waste management, reduced environmental pollution, and enhanced energy supply. However, successful implementation requires accurate data on waste generation and composition, as well as supportive policies, infrastructure, and public participation.

This study aims to analyze the composition of municipal solid waste in Kaduna Metropolis with a focus on organic and inorganic fractions and to evaluate their implications for waste-to-energy development. By providing data-driven insights, the study contributes to the growing body of knowledge on sustainable waste management and renewable energy solutions in Nigeria.

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II. Literature Review

Municipal solid waste (MSW) management has become one of the most pressing environmental challenges in rapidly urbanizing cities, particularly in developing countries. Population growth, urban expansion, industrialization, and changing consumption patterns have significantly increased the volume and complexity of waste generated in urban centers. Poor waste handling practices such as open dumping, uncontrolled burning, and inadequate collection systems have contributed to land degradation, greenhouse gas emissions, flooding, and public health concerns (World Bank, 2018).

In Nigeria, municipal solid waste management remains a major challenge due to weak institutional capacity, insufficient funding, lack of infrastructure, and low public participation in waste segregation. Most cities rely heavily on open dumpsites and irregular waste evacuation systems. Studies have shown that waste generation rates in Nigerian urban centers continue to rise with increasing population density and economic activities (Ogwueleka, 2009).

Waste characterization is an essential step in planning sustainable waste management systems because it determines the quantity, composition, moisture content, and calorific value of waste materials. According to Tchobanoglous and Kreith (2002), knowledge of waste composition helps in selecting suitable treatment technologies such as composting, recycling, incineration, or anaerobic digestion. In developing countries, MSW streams are generally characterized by high proportions of biodegradable organic materials, while developed countries tend to have higher shares of packaging materials such as plastics, paper, and metals.

TABLE 1: Estimated Biogas Yield Factors for Some Organic Solid Waste

Waste Type	Average Biogas Yield Factor
Food Waste	150 m^3/ton
Cow Dung	30 m^3/ton
Poultry Manure	80 m^3/ton
Farm Residues	100 m^3/ton

Source: Tchobanoglous, G, & Kreith F. (2002)

Several studies conducted in Nigerian cities confirm the dominance of organic waste in municipal refuse. For example, Ogwueleka (2009) reported that food waste and other biodegradable materials constitute a significant portion of waste generated in Abuja, making composting and biological treatment viable options. Similar findings have been reported in Lagos, Kano, Ibadan, and Port Harcourt, where household and market waste streams contain substantial organic fractions suitable for energy recovery.

Kaduna Metropolis, one of the largest urban centers in Northern Nigeria, faces increasing waste management problems due to population growth and urban expansion. The metropolis comprises Kaduna North, Kaduna South, parts of Chikun, and Igabi Local Government Areas. Waste generated in the city originates from households, markets, schools, hospitals, commercial centers, and small industries. Inefficient collection and disposal systems have led to indiscriminate dumping along roadsides, drainage channels, and vacant lands (Zakka et al., 2021).

A detailed waste characterization study conducted in Kaduna Metropolis found that garbage and food waste accounted for approximately 63.75% of total municipal waste generated, while metals, glass, plastics, paper, and textiles made up the remaining fractions (Nwude et al., 2009). This indicates that Kaduna's waste stream is predominantly organic in nature. Such a high biodegradable fraction is advantageous for biological waste treatment systems including composting and anaerobic digestion.

TABLE 2: Estimated Total Organic Waste deposited in Kaduna Metropolis Based on Published Waste Characterisation Data

Parameter	Value	Unit	Source
Estimated population of Kaduna metropolis	1,800,000	Persons	Population projection
Per-capita waste generation rate	0.30	Kg/person/day	Nwude et al., (2009)
Organic Waste Fraction	63.75	%	Nwude et al., (2009)

Organic waste has significant waste-to-energy potential because biodegradable materials can be converted into methane-rich biogas through anaerobic digestion. Biogas can then be used for electricity generation, cooking fuel, or heating applications. According to Kumar et al. (2017), cities with waste streams containing more than 50% organic matter are particularly suitable for anaerobic digestion technologies. Therefore, Kaduna Metropolis possesses promising potential for decentralized biogas plants and integrated waste-to-energy systems.

The inorganic fraction of municipal waste, including plastics, metals, glass, and paper, also represents an economic opportunity through recycling and material recovery. Recycling reduces pressure on landfills, conserves raw materials, and lowers environmental pollution. However, effective recycling requires source separation, collection efficiency, and market demand for recovered materials (Tchobanoglous & Kreith, 2002).

Despite the opportunities, several barriers hinder sustainable waste management in Kaduna Metropolis. These include poor waste segregation practices, inadequate collection vehicles, weak enforcement of sanitation laws, insufficient dumpsite management, and limited public awareness. Zakka et al. (2021) noted that market areas in Kaduna generate large volumes of biodegradable waste, yet much of it is mixed with other refuse and dumped without treatment.

Given the increasing energy demand in Nigeria and persistent electricity shortages, converting municipal solid waste into useful energy offers a dual benefit of cleaner cities and renewable power generation. Integrated waste management systems combining recycling, composting, and waste-to-energy technologies could significantly improve environmental sustainability in Kaduna Metropolis.

Methods of Converting Inorganic Solid Waste to Energy

Inorganic municipal solid waste such as plastics, paper, textiles, and rubber possess significant energy potential due to its high calorific value. Technologies such as incineration, RDF production, and thermal waste-to-energy systems provide

sustainable methods for converting these waste materials into electricity and heat while simultaneously reducing environmental pollution and landfill pressure (Arena, 2012).

III. Materials And Methods

3.1 Study Area

The study was conducted in Kaduna Metropolis, Kaduna State, Nigeria. Kaduna Metropolis comprises Kaduna North, Kaduna South, and parts of Chikun and Igabi Local Government Areas. The area is characterized by rapid urbanization, high population density, commercial activities, markets, institutions, and residential settlements that contribute significantly to municipal solid waste generation.

3.2 Materials Used

The following materials and equipment were used for the study:

Waste collection bags, hand gloves, nose masks, weighing balance, waste sorting containers, shovel and rake, measuring tape, data recording sheets/notebook, camera for site documentation, calculator/computer for data analysis, and personal protective equipment (PPE).

3.3 Methodology

The study adopted a descriptive and analytical research design involving waste characterization and secondary data review. Data were obtained from municipal waste reports, published literature, and field-based waste composition studies conducted within Kaduna Metropolis.

Data for the study were obtained from field observation of dumpsites and waste collection points, waste sampling and sorting, interviews with waste management officials. Other sources of data were; published journal articles, Kaduna state environmental protection authority reports, government publications, previous waste characterization studies, textbooks, and conference papers.

Municipal solid waste samples were collected from selected locations within Kaduna Metropolis including; residential areas, markets, commercial centers, and institutional areas.

Random sampling technique was used to ensure representative waste collection from different parts of the metropolis, collected waste samples were manually sorted into different categories; organic waste, food waste, vegetable residues, fruit peels, leaves and biodegradable materials, inorganic waste, plastics, metals, glass, paper/cardboard, textiles, and rubber materials. Each category was weighed separately using a weighing balance.

The percentage composition of each waste category was calculated using the total organic and inorganic fractions. The energy potential of municipal solid waste was estimated using standard waste-to-energy conversion factors obtained from literature. For Organic Waste (Biogas Route), Biogas yield was estimated using methane conversion efficiency.

The collected data were analyzed using; descriptive statistics, percentage distribution, and tables and charts. the results were used to determine; organic waste percentage, inorganic waste percentage, waste-to-energy potential, and suitable waste management technologies.

Total biogas was estimated using:

$$C_a H_b O_c N_d$$

The methane yields M_y in l/kg of volatile solids can be calculated using;

$$M_y = \frac{4a + b - 2c - 3d}{12a + b + 16c + 14d}$$

The Biogas yield is represented by the formula:

Biogas(m^3/day) = Organic Waste Quantity (Q_0) × Biogas yield ((Y_b) m^3/tons

$B = Q_0 \times Y_b$

Q_0 = organic waste quantity

B = Biogas Volume (m^3/day)

Y_b = biogas yield factor (m^3/ton)

IV. Results and Discussions

The tables below represent the result obtained for both organic and inorganic solid waste experiment.

TABLE 3: Major Organic Waste Component and their Percentage Composition

S/N	Organic Waste	% Organic Waste	Tons/day
1	Animal Dung	35	120.49
2	Farm Residues	40	130.70
3	Chicken Manure	25	86.06
	Total	100	344.25

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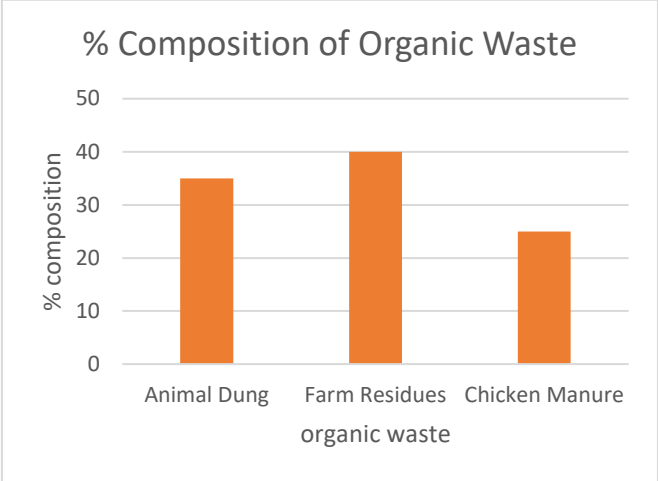

Fig.1: percentage composition of major organic solid waste

The distribution among animal dung is 36% of the total ORGANIC WASTE, farm residues accounted for 40%, poultry manure is 25%. The result indicates that farm residue has the highest percentage of the total organic waste.

The higher the organic waste percentage, the greater the biodegradable content. The higher the biogas production potential, the more suitable the waste is for anaerobic digestion.

TABLE 4: Major Inorganic Waste Component and their Percentage Composition

S/N	Inorganic Waste Component	% Composition
1	Plastic/rubber	5.71
2	Paper/cardboard	5.55
3	Metals	5.28
4	Glass	5.44
5	Textile	2.19
6	Miscellaneous/Inert materials	12.08
	Total	36.25

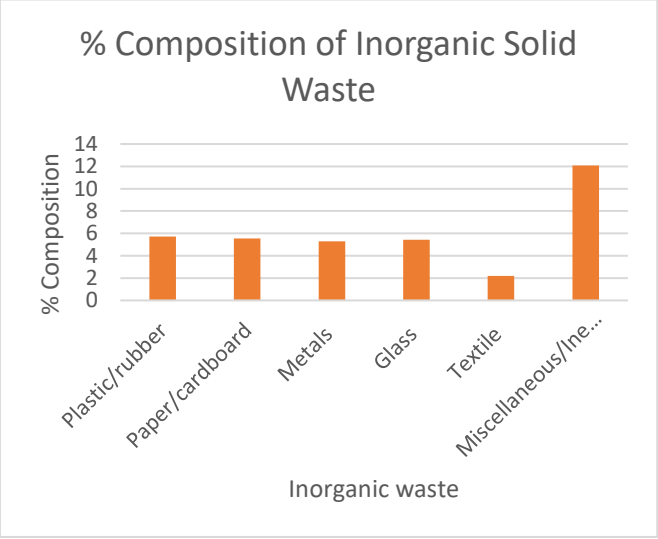

Fig. 2: percentage composition of major inorganic solid waste

The result indicate that inorganic waste constitutes approximately 36.25% of the total municipal solid waste (MSW) generated in Kaduna Metropolis, plastics/rubber 5.71% represent the highest recycle inorganic component suitable for recycling. Paper and cardboard 5.55% can be recycle into paper product. Metals 5.28% have high economic value for recycling industries. Glass is 5.44% mostly non-combustible but can be recycle. Textile material which is 2.19% can contribute to RDF production.

Miscellaneous materials 12.08% include ash, dirt, ceramics and mixed inert materials generally have low energy recovery potential.

The total composition of inorganic municipal solid waste is 36.25% of the total municipal solid waste generated in Kaduna metropolis while that of organic solid waste 63.755% of the total municipal solid waste.

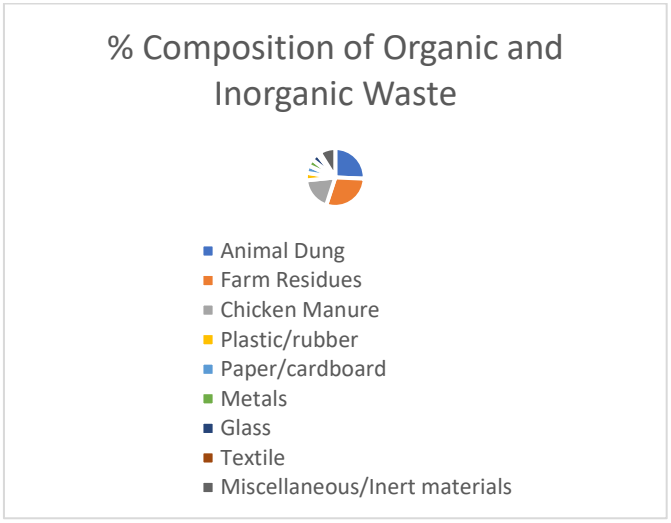

Fig. 3: percentage composition of major organic and inorganic solid waste

V. RECOMMENDATIONS

Based on the findings of the study on municipal solid waste composition and energy potential in Kaduna Metropolis, the following recommendations are proposed:

Households, markets, and commercial centers in Kaduna Metropolis should be encouraged to separate waste into organic and inorganic fractions at the point of generation. This will improve the efficiency of waste collection, recycling, and waste-to-energy processes, particularly anaerobic digestion.

Government and private sector stakeholders should invest in waste-to-energy plants, particularly anaerobic digestion facilities, due to the high proportion of organic waste (63.75%). This will support biogas production for electricity generation and reduce reliance on fossil fuels.

Recyclable materials such as plastics, metals, glass, and paper (36.25% of total waste) should be recovered through the establishment of material recovery facilities (MRFs) and recycling industries. This will reduce landfill pressure and create economic opportunities.

Kaduna State environmental authorities should improve waste collection efficiency by providing adequate waste bins, collection trucks, and optimized routing systems to reduce illegal dumping and environmental pollution.

There is a need for continuous public enlightenment on proper waste management practices, environmental sanitation,

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and the benefits of waste-to-energy systems. Community participation is essential for sustainable waste management.

Government should enforce environmental laws and sanitation regulations to discourage indiscriminate dumping, open burning, and improper waste disposal practices within the metropolis.

Private sector participation should be encouraged in waste management services, including collection, recycling, and energy recovery projects, to improve efficiency and attract investment.

Detailed technical and economic feasibility studies should be conducted to determine the most suitable combination of waste-to-energy technologies for Kaduna Metropolis, considering waste composition and energy demand.

Continuous waste characterization studies should be conducted to monitor changes in waste composition over time, which will support better planning and optimization of waste management systems.

VI. Conclusion

This study assessed the composition and energy potential of municipal solid waste in Kaduna Metropolis, Nigeria, with particular emphasis on the organic and inorganic fractions. Findings revealed that the metropolis generates approximately 540 tons of municipal solid waste daily, with a dominant organic fraction of about 63.75% and inorganic/mixed waste accounting for 36.25%. The high proportion of biodegradable waste indicates that Kaduna Metropolis has significant potential for biological waste treatment systems such as anaerobic digestion and composting.

Energy recovery analysis further showed that the organic waste fraction alone could generate approximately 2.6–6.3 MW of electricity through biogas production, while the entire waste stream could yield about 11–16 MW using thermal waste-to-energy technologies such as incineration or refuse-derived fuel systems. These results demonstrate that municipal solid waste in Kaduna Metropolis is not only an environmental burden but also a valuable resource for renewable energy generation.

However, the effective realization of this potential depends on improved waste segregation at source, efficient collection systems, investment in waste-to-energy infrastructure, and strong policy enforcement. The current practice of indiscriminate dumping and poor waste management limits resource recovery and exacerbates environmental problems.

In conclusion, Kaduna Metropolis possesses a strong technical basis for implementing integrated waste management systems that combine recycling, composting, and waste-to-energy technologies. Proper development of these systems will contribute to environmental sustainability, reduction of greenhouse gas emissions, improved public health, and enhanced energy security in the region.

References

[1] Arena, U. (2012). Process and technological aspects of municipal solid waste gasification: A review. Waste Management, 32(4), 625–639.
[2] Kumar, A., Samadder, S. R., & Khan, D. (2017). Municipal solid waste management and waste-to-energy in developing countries: A review. Renewable and Sustainable Energy Reviews, 72, 1289–1301.
[3] Nwude, M. O., Igboro, S. B., Otun, J. A., & Okuofu, C. A. (2009). Solid waste generation and characterization in Kaduna Metropolis, Nigeria. Academy Journal of Science and Engineering, 3(1), 45–53.
[4] Ogwueleka, T. C. (2009). Municipal solid waste characteristics and management in Nigeria. Iranian Journal of Environmental Health Science & Engineering, 6(3), 173–180.
[5] Tchobanoglous, G., & Kreith, F. (2002). Handbook of solid waste management (2nd ed.). New York, NY: McGraw-Hill.
[6] UNEP. (2015). Waste-to-energy technologies: Global assessment and guidelines. United Nations Environment Programme.
[7] World Bank. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. Washington, DC: World Bank.
[8] Retrieved May 1, 2026 from Alamy stock photo data base, image ID: 3D65884. www.alamy.com
[9] Zakka, U. B., Ibrahim, A., & Musa, H. (2021). Analysis of solid waste composition and management in selected markets and residential areas of Kaduna Metropolis. African Journal of Environmental Engineering, 7(2), 15–28.