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Research Article

Transformation of Urban Waste to Renewable Energy: A Sustainable Alternative to Fossil Fuel

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Abstract

The rapid accumulation of urban waste poses significant environmental, economic, and social challenges. Urban waste in several areas is considered as trash. However, its importance in the production of sustainable energy as well as an alternative to fossil fuel cannot be overemphasized. The concept of transforming urban waste to renewable energy offers dual benefits. It mitigates waste-related issues while maximizing the utilization of urban waste to renewable energy production. Renewable energy has been recognized as a solution to overcome the drawbacks of fossil fuels. This study investigates the transformation of urban waste into renewable energy, exploring the complex interplay between technological, economic, infrastructural, environmental, social, and market factors. A quantitative research approach was employed, utilizing a structured questionnaire to elicit responses from 1000 respondents across six target groups. The results of the regression analysis revealed that technological readiness, economic viability, infrastructure compatibility, environmental impact, community participation, and market demand are significant predictors of successful waste-to-energy transformation. Hence a successful waste-to-energy transformation requires a multifaceted approach. The findings indicate that infrastructure and environmental sustainability are pivotal factors, while technological readiness and economic viability play supportive roles. The study demonstrates that urban waste-to-energy projects can significantly contribute to renewable energy generation, environmental sustainability, and economic growth, providing a valuable framework for policymakers, practitioners, and stakeholders seeking to unlock the potential of urban waste.

Keywords

Urban Waste, Renewable Energy, Technology, Economy, Infrastructure, Market Demand, Environmental Impact

1. Introduction

The world is facing a significant challenge in managing urban waste, with millions of tons of waste generated every day. This waste not only poses environmental and health risks but also represents a wasted opportunity for energy generation. Transforming urban waste to renewable energy is an innovative solution that can help mitigate these challenges and provide a sustainable alternative to fossil fuel.

Urban waste, also known as municipal solid waste (MSW), includes a wide range of materials such as food waste, plastics, paper, glass, and metals. The rapid growth of urban popula-

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tions and economies has led to an increase in waste generation, with many cities struggling to manage their waste effectively. Urban areas are confronted with waste generation and management, often resulting in environmental degradation, health hazards and inefficient resource utilization. By the same token, energy demand in this area continues to grow, requiring innovative solutions to meet this demand sustainably. Urban waste, often overlooked as a valuable resource, holds significant potential for sustainable energy production. (Bautista A, et al. 2018). The concept of transforming urban waste into renewable energy offers a dual benefit: it mitigates waste-related issues while maximizing the utilization of urban waste for renewable energy production.

Evidence based studies show that, with continuous increase in global population and socioeconomic activities leading to increased urbanization, and industrialization around the world, the demand for natural energy resources and more so renewable energy is gradually increasing [1].

Nations worldwide have turned to renewable energy technologies as a viable alternative to fossil fuels. Nevertheless, the intermittent and variable nature of renewable energy sources, including biomass, solar, and wind power, poses significant challenges. Unlike traditional energy sources, renewables struggle to meet increasing demand, compromising grid reliability [2] Moreover, the high upfront costs of renewable energy technologies present an additional barrier to adoption, compared to conventional energy sources.

To mitigate the unpredictable nature of renewable energy, Hybrid Renewable Energy Systems (HRESs) have emerged as a viable solution. By combining primary renewable energy sources with backup systems like batteries and mini-grids, HRESs ensure a stable power supply, even when one generation source is interrupted [3].

This research will develop strategies, best practices, economic and appropriate technologies for Transforming Urban waste to Renewable Energy.

1.1. Problem Statement

Rapid urbanization and increase in industrialization have created tremendous problems associated with waste management and energy requirement. Urban waste is often mismanaged. As could be expected, this results to environmental collapse and health threats. With increasing energy demand in urban center, it is important that the search for alternate and renewable sources of supply is established. One solution that can help address these interlinked challenges is converting waste to renewable substitutes.

1.2. Research Questions

The main research questions addressed in this study are;

1) What is the marginal impact of technological readiness and efficiency on the successful transformation of urban waste into renewable energy?
2) What is the marginal impact of economic viability and financial support on the adoption of waste-to-energy systems?
3) Is the existing infrastructure significantly enough for waste-to-energy projects in urban areas?
4) Does urban waste-to-energy projects contribute significantly to environmental sustainability by minimizing waste and reducing emissions?
5) What is the marginal effect of community participation and social responsibility on the acceptance and effectiveness of waste-to-energy projects?
6) To what extent do market demand and distribution capabilities affect the scalability of renewable energy sourced from urban waste?

To answer the research questions, this paper is organized as follows: Section 2 presents waste management in Nigeria, Conversion Technologies, economy and its efficiency, Renewable Energy and current stage of development of RE. Section 3 presents methodology of the study. Section 4 Data presentation and result interpretation. Finally, Section 5. conclusions and recommendations.

2. Waste Management in Nigeria

The collection, transport, treatment, and disposal of solid wastes, particularly wastes generated in medium and large urban centers, have become a relatively difficult problem to solve for those responsible for their management. The problem is even more acute in economically developing countries, where financial, human, and other critical resources generally are scarce [4] Nigeria is not left out, with their cities witnessing high rate of environmental deterioration and are rated among urban areas with the lowest livability index in the world. Although studies have identified various environmental problems in Nigeria, little attention has been given to their implications for sustainable development in literatures [5]. The level of environmental management awareness in Nigeria is still very low, yet, it is the knowledge of environmental management techniques that can guarantee life sustainability in Nigeria [6]. Based on this,[6]. maintains that sustainable Environmental Management is far from being achieved in Nigeria because the activities of man still degrade the environment. Nigeria can only be sustainably developed if it can pay attention to environmental sanitation and conservation.

1) Waste Management Policy

The Federal Environment Protection Agency (FEPA) was set up in 1988 to manage the increasing concern of waste management in Nigeria [7]. Vision 2010 was for FEPA to address environmental problems in the country that would lead to sustainable development. Concerning solid waste management, the report says the objective is to "accomplish at least 80% successful managing of the volume of urban solid waste produced at all levels and guarantee environmentally stable management"[8]. Others sister agencies are Ministry of Environment and Niger Delta Development Commission

(NDDC). At the State level, environmental agencies include State Environmental Protection Agency, (SEPA) and Ministry of Agriculture and Natural Resources while local governments operate through the Department of Community Development, Department of Agriculture and Forestry. Often, these government agencies have laudable plans and program but many of the programs fail because of problems of finance and its management [7].

2) Population and Effective Waste Management

The rate of resource exploitation is a function of human population and the level of technology applied for the exploitation. As environmental raw materials are exploited via the application of various types of technologies and industrially transformed into various types of finished products consumed by man, a host of injurious bye-products are produced which degrade the quality of man's environment.

3) Urban Waste and Quality of Life

The major environmental effects include air pollution, which includes odor, smoke, noise, dust, etc. Improper Waste disposal can lead to flooding because of blocked drains and land degradation. Flooding is a common occurrence in many parts of Nigeria.

4) Waste Management and Sustainable Development

Sustainable development is a development that meets the need of the present generation without jeopardizing the possibilities of the future generation meeting their own needs [9]. Urban solid waste is being disposed of using several methods. However, methods used, are landfill, incineration, composting and anaerobic digestion and recycling [10]. In Nigeria, the existing practice of urban or municipal waste management is open dumping in any available open space, while the incineration technique is rarely put to practice.

5) Types, Sources, method of collection and separation of Urban Waste

i. Urban waste comprises various materials discarded by households, businesses, and institutions. The main types include: Organic Waste, Paper and Cardboard, Plastics: Bottles, Glass, Textiles, E-waste. ii. Waste Collection Methods: Door-to-Door Collection, Community Bins, Drop-Off Centers, Automated Collection Systems: iii. Waste Separation Methods: Source Separation, Centralized Sorting, Composting, Material Recovery Facilities (MRFs),

2.1. Challenges in Urban Waste Collection and Separation

1) Inadequate Infrastructure:
   a) Many cities lack sufficient waste collection and disposal infrastructure to manage the increasing volume of waste.
   b) Insufficient landfill capacity and inadequate disposal facilities exacerbate waste management problems.
2) Poor Waste Separation:
   a) Low levels of waste separation at the source make recycling and proper disposal more difficult.
   b) Lack of public awareness and inadequate incentives for separation contribute to the problem.
3) Logistical Issues:
   a) Inefficient waste collection routes and schedules can lead to inconsistent and unreliable waste pickup services.
   b) Limited financial and human resources constrain the effectiveness of waste management programs.
4) Technological Limitations:
   a) Many cities lack access to advanced waste sorting and recycling technologies, limiting the efficiency of waste management processes.
   b) Integration of automated systems requires significant investment and maintenance, which can be challenging for resource-constrained municipalities.

2.2. Conversion Technologies and Energy Recovery from Urban Waste

Energy recovery from urban waste can be achieved by three different methods;

1) *Biological (e.g. Anaerobic Digestion):* Decomposing organic waste in the absence of oxygen to produce biogas, which can be used as a fuel.
2) *Thermal (e.g. Incineration):* Burning waste to produce heat, which can be used to generate electricity.
3) *Landfill Gas Recovery:* Capturing methane produced from waste decomposition in landfills.

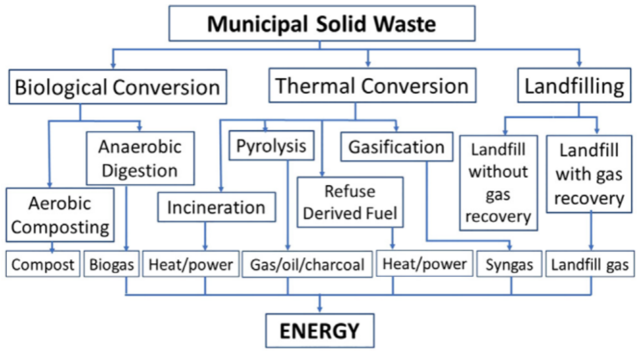

Figure 1. *Different MSW treatment techniques and their products. [11].*

Energy Conversion Efficiency

Assessing the effectiveness of urban waste-to-energy conversion involves examining the process that transforms waste into usable forms of energy, such as electricity, heat, or fuel. Key factors to consider when evaluating efficiency include:

1) Technology used for Conversion

Two prominent Waste-to-Energy (WtE) methods are:

   a) Incineration: Burning waste to generate heat, which produces electricity. This method significantly reduces waste volume, but improper management can lead to pollutant releases.

b) Pyrolysis and Gasification: Thermochemical processes converting waste into synthetic gas for electricity and heat production. Although more complex and costly, these methods are more efficient and environmentally friendly than incineration.

Anaerobic Digestion: A biological process utilizing microorganisms to decompose organic waste, yielding biogas for heating or electricity generation. This method excels in managing wet waste and supports a relatively low environmental footprint.

2) Efficiency Parameter

Plant efficiency varies by technology and waste composition. Incineration plants typically achieve 20-30% energy recovery, while advanced gasification methods can reach up to 60% efficiency [12].

2.3. Economic Analysis of Urban Waste for Energy Generation

The economic analysis of urban waste for energy generation involves several key factors:

1) Waste Composition and Quantity: The type and amount of waste available, including its calorific value and moisture content, are crucial as they directly impact the energy potential and efficiency of the process [3].
2) Technology and Infrastructure Costs: The costs associated with the construction, operation, and maintenance of waste-to-energy (WtE) facilities. This includes the choice of technology (e.g., incineration, gasification, anaerobic digestion) and the required infrastructure [13].
3) Energy Prices and Revenue: The potential revenue from the sale of generated electricity or heat. This includes current and projected energy prices and any incentives or subsidies available for renewable energy production [14].
4) Environmental and Regulatory Factors: Compliance with environmental regulations, including emissions standards and waste disposal laws. The potential costs of meeting these requirements and the benefits of reducing landfill usage and greenhouse gas emissions are also important [14].
5) Economic Incentives and Policy Support: Government policies, grants, and tax incentives that support waste-to-energy projects. This can significantly impact the financial viability of the project [15].
6) Operational Efficiency: The efficiency of the energy conversion process, which affects the overall economic performance of the WtE plant. Higher efficiency can lead to lower operational costs and higher energy output [16].
7) Market Demand for By-products: The potential market for by-products of the WtE process, such as ash, slag, or compost, which can provide additional revenue streams [14].

The economic estimations consider a parameter that measures the minimum rate of energy sale that makes the investment economically viable using equation developed by [17]. It states that if the energy sales tariff is higher than the LCOE, then the proposal is economically viable.

$$\text{LCOE} = \sum_{n=0}^{T}(In + On + Mn)/(1+i)^n \,/ \sum_{n=0}^{T} En/(1+i)^n \tag{1}$$

Where: LCOE = Levelized cost of electricity, n = Project lifetime in years, En = Energy produced in MWh, In = Initial investment (Capital cost) in USD, Mn = Maintenance costs in USD, On = Operation costs in USD i = Discount rate (%).

2.4. The Concept of Renewable Energy

Renewable energy is derived from naturally replenished sources, such as sunlight, wind, water, heat from the earth, and organic matter. Unlike fossil fuels, these clean energy sources - including solar, wind, hydroelectric, geothermal, and biomass - do not emit harmful greenhouse gases or pollutants, making them essential for mitigating climate change and promoting sustainable development.

2.5. Challenges and Future Developments

Despite its numerous advantages, renewable energy faces significant hurdles, including:

Intermittent power supply, High upfront costs, Need for extensive infrastructure upgrades.

To overcome these challenges, continued research and development, combined with supportive government policies, are crucial for seamlessly integrating renewable energy into the global energy landscape [18].

Renewable energy is pivotal for a sustainable future, yielding substantial environmental, economic, and social advantages. As technology continues to evolve and costs decline, the transition to renewable energy is expected to gain momentum, driving progress toward global sustainability objectives.

3. Methodology

3.1. Study Area

The study area is Nigeria, covering an area of 923,769 square kilometers with a population of more than 230 million. Nigeria's rapid urbanization and growing population have resulted in significant urban waste management challenges, making it an ideal case study for transforming urban waste to renewable energy.

3.2. Target Population

The target population for this study includes:

1) Government agencies responsible for waste management and renewable energy
2) Municipalities and local governments involved in waste management
3) Energy companies exploring renewable energy options
4) Waste management organizations and private sector companies
5) Local communities and residents affected by urban waste management
6) Professionals and experts in the fields of waste management, renewable energy, and sustainability

3.3. Data Collection

Data was collected using a structured questionnaire designed to gather information on the current state of urban waste management, renewable energy initiatives, and the potential for transforming urban waste to renewable energy in Nigeria. The questionnaire consisted of 28 questions and was distributed using Google Forms to individuals and group platforms of the target population.

3.4. Sampling Technique

A non-probability sampling technique was used to select 1000 respondents from the target population. The sample size was determined using the Cochran Formula to ensure that the sample was representative of the population.

3.5. Data Analysis

Frequencies, percentages, mean scores, and graphs were used to analyze and represent the respondents' characteristics, perceptions, and opinions on transforming urban waste to renewable energy in Nigeria.

3.6. Validity and Reliability of Instruments

Validity of Instruments

To ensure the validity of the questionnaire, the following steps were taken:

1) *Content Validity:* An expert in survey design and renewable energy reviewed the questionnaire to ensure that the items were relevant, clear, and aligned with the objectives of the study on transforming urban waste to renewable energy.
2) *Face Validity:* A pilot test was conducted with a small group of respondents to ensure that the questionnaire was easy to understand and that the items were relevant to the topic.

3.7. Reliability of Instruments

The reliability of the questionnaire was assessed using:

Cronbach's Alpha (α): This statistical test was used to measure the internal consistency of the questionnaire items. A Cronbach's Alpha value of 0.7 or higher was considered acceptable, indicating that the questionnaire items were reliable and consistent.

Reliability of the questionnaire: Assessed using Cronbach's Alpha (α)

$$\alpha = \frac{K}{k-1}\left(1 - \frac{\sum_{i=0}^{k} \sigma^2 i}{\sigma^2 t}\right) \quad (2)$$

3.8. Questionnaire Design

The questionnaire was carefully crafted to elicit insightful responses from the target population. It comprised three sections:

Section A: General Information

This section gathered demographic information about the respondents, including:

1) *Organization Type:* Respondents identified the nature of their organization (e.g., government agency, private company, non-profit organization).
2) *Role in the Organization:* Respondents specified their role or position within their organization.
3) *Level of Awareness:* Respondents indicated their level of awareness about the research topic, transforming urban waste to renewable energy.

Section B: Explanatory Variables (X Variables)

This section assessed the respondents' perceptions of the factors influencing the transformation of urban waste to renewable energy. It consisted of six sub-sections (B1 to B6), each addressing a specific explanatory variable:

1) *B1: Technological Feasibility:* Respondents evaluated the technological feasibility of transforming urban waste to renewable energy.
2) *B2: Economic Viability:* Respondents assessed the economic viability of transforming urban waste to renewable energy.
3) *B3: Environmental Impact:* Respondents considered the environmental impact of transforming urban waste to renewable energy.
4) *B4: Social Acceptance:* Respondents evaluated the social acceptance of transforming urban waste to renewable energy.
5) *B5: Policy and Regulatory Framework:* Respondents assessed the policy and regulatory framework supporting the transformation of urban waste to renewable energy.
6) *B6: Infrastructure and Capacity:* Respondents evaluated the infrastructure and capacity required for transforming urban waste to renewable energy.

Respondents indicated their level of agreement or disagreement with each statement using a 5-point Likert scale.

Section C: Dependent Variable (Y Variable)

This section focused on the dependent variable, transforming urban waste to renewable energy (Y1). Respondents indicated their degree of agreement or disagreement with two statements:

1) *C1: Effectiveness of Transforming Urban Waste to Renewable Energy:* Respondents evaluated the effectiveness of transforming urban waste to renewable energy in addressing energy challenges.
2) *C2: Feasibility of Implementing Transforming Urban Waste to Renewable Energy:* Respondents assessed the feasibility of implementing transforming urban waste to renewable energy in their organization or community.

3.9. Data Analysis

Responses to the Likert-scale items were analyzed using a weighted average method to determine the mean scores and standard deviations. This approach enabled the identification of the most critical factors influencing the transformation of urban waste to renewable energy.

Data Analysis

The data analysis for this study employs a multiple linear regression model to examine the relationship between the dependent variable (Y1) and the independent variables (X1, X2,..., Xp-1). The general form of the equation is:

$$Y1 = \beta 0 + \beta 1X1 + \beta 2X2 + \ldots + \beta p\text{-}1Xp\text{-}1 + \varepsilon$$

Variables Definition.

1) Y1: Transforming Urban Waste to Renewable Energy (dependent variable)
2) X1, X2,..., Xp-1: Independent variables, including:
3) Technological readiness and Efficiency (X1)
4) Economic Viability and Financial support (X2)
5) Infrastructure compatibility and Capacity (X3)
6) Environmental Impact and Sustainability (X4)
7) Community Participation and Social Responsibility (X5)
8) Market Demand and Distribution for Energy produced (X6)
9) β0: Constant term (intercept), representing the degree of success in transforming urban waste to renewable energy without the constraints (i.e., when all X variables are equal to 0)
10) β1, β2,..., βp-1: Coefficients of the independent variables, representing the change in the dependent variable (Y1) for a one-unit change in the corresponding independent variable, while holding all other independent variables constant
11) ε: Error term, representing the random variation in the dependent variable (Y1) that is not explained by the independent variables

4. Interpretation of Results

The results of the multiple linear regression analysis will provide insights into the relationships between the independent variables and the dependent variable. Specifically:

1) The coefficients (β1, β2,..., βp-1) indicate the direction and magnitude of the relationships between each independent variable and the dependent variable.
2) The constant term (β0) provides a baseline value for the dependent variable, representing the degree of success in transforming urban waste to renewable energy without the constraints.
3) The error term (ε) indicates the amount of random variation in the dependent variable that is not explained by the independent variables.

By analyzing the results of the multiple linear regression analysis, this study aims to identify the key factors that influence the success of transforming urban waste to renewable energy, and to provide insights into the relationships between these factors and the dependent variable.

4.1. Data Presentation and Results Interpretation

Table 1. *Frequency Distribution of Socio-demographic Characteristics of Respondents (n = 260) (Ibe R. O & Nnadikwe. J, 2024).*

Nature of Organization	Frequency	Percentage
Energy Company	55	21%
Government Agency	70	27%
Local Community Representative	19	7%
Municipality	22	8%
Others	68	26%
Waste Management Organization	26	10%
Job Role		

Nature of Organization	Frequency	Percentage
Administrative Staff	32	12%
Engineer/Technical Staff	94	36%
Operations Manager	36	14%
Other	50	19%
Policy Maker	48	18%
Awareness Ratings		
Do you know about urban waste management?		
No	4	2%
Yes	256	98%
Do you know that Urban waste can be transformed to Renewable Energy?		
No	7	3%
Yes	253	97%
Do you know about Mini Grids?		
No	34	13%
Yes	226	87%
Do you know that Renewable energy from Urban waste can be integrated into Mini grids?		
No	36	14%
Yes	224	86%

Table 1: The frequency distribution table provides a detailed summary of the socio-demographic characteristics and awareness levels of the 260 respondents in this study. In conclusion, the distribution of respondents suggests that the data is reliable and reflective of key stakeholder insights. The study is well-positioned to provide actionable recommendations, although greater engagement with underrepresented groups, such as local community representatives and those less familiar with mini grids, could further enrich the findings.

4.2. Socio-Demographic Characteristics of Respondents

Nature of Organization

The respondents come from a diverse range of organizations, with the majority being from:

1) Government Agencies (27%)
2) Energy Companies (21%)
3) Others (26%), which includes private companies, NGOs, and research institutions
4) Waste Management Organizations (10%)
5) Municipalities (8%)
6) Local Community Representatives (7%)

Job Role

The respondents have various job roles, with the majority being:

1) Engineers/Technical Staff (36%)
2) Operations Managers (14%)
3) Policy Makers (18%)
4) Administrative Staff (12%)
5) Others (19%), which includes consultants, researchers, and academics

Awareness Ratings

The respondents demonstrate a high level of awareness about:

1) Urban waste management (98% yes)
2) Transforming urban waste to renewable energy (97% yes)
3) Mini grids (87% yes)
4) Integrating renewable energy from urban waste into mini grids (86% yes)

Key Insights and Implications

1) *Diverse range of organizations:* The respondents come from a wide range of organizations, indicating a broad interest in urban waste management and renewable energy.
2) *Technical expertise:* The majority of respondents are engineers or technical staff, indicating a strong technical foundation for implementing urban waste-to-energy projects.
3) *Policy support:* The presence of policy makers among

the respondents suggests that there is a willingness to support and implement policies that promote urban waste-to-energy projects.

4) *Awareness and education:* While there is a high level of awareness about urban waste management and renewable energy, there is still a need for further education and awareness-raising efforts to ensure that all stakeholders are informed and engaged.

Overall, the results suggest that there is a strong foundation for implementing urban waste-to-energy projects, with a diverse range of organizations and technical expertise involved. However, further education and awareness-raising efforts are needed to ensure that all stakeholders are informed and engaged.

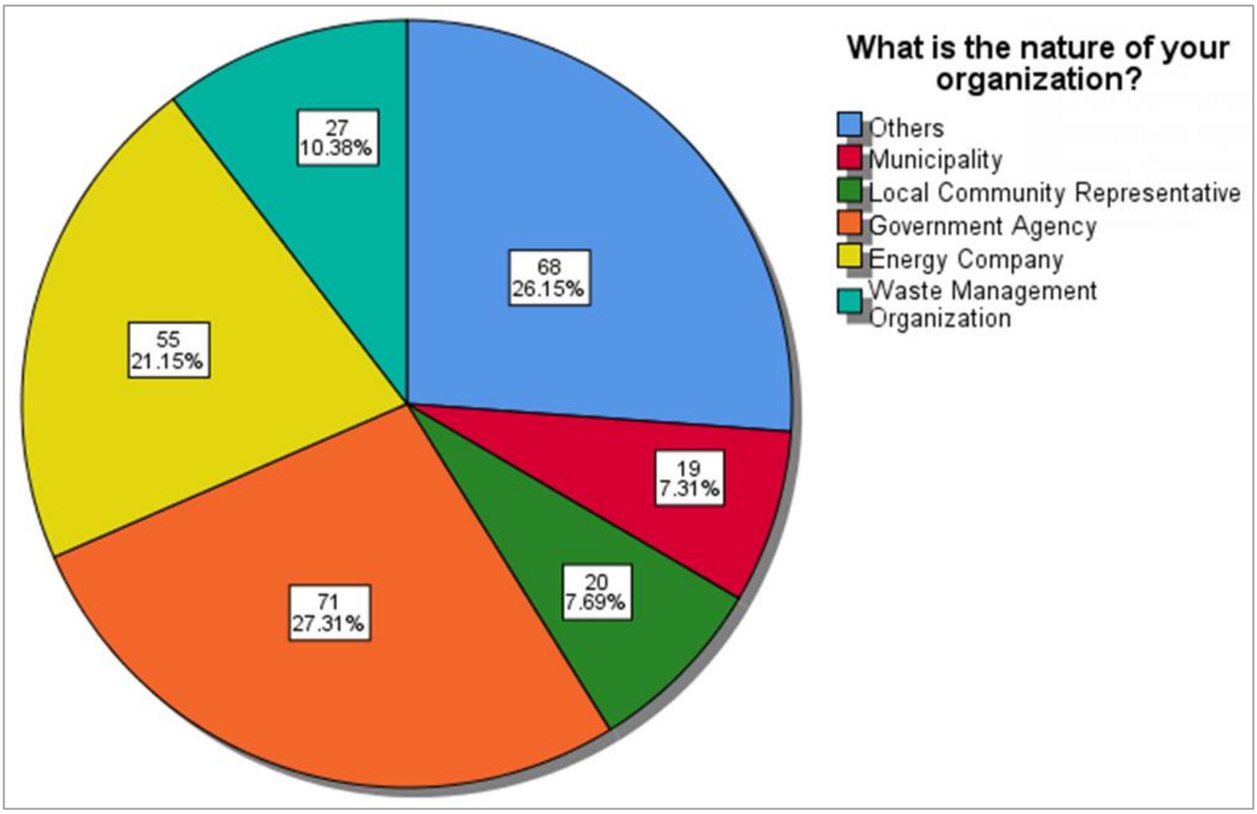

Figure 2. *Distribution of the Nature of the Organization of the Respondent.*

Table 2. *Cronbach's Alpha Reliability Analysis of Responses (Ibe R. O & Nnadikwe. J, 2024).*

Variable	Type of variable	No of questions	Cronbach's Alpha
Technological readiness and Efficiency	Independent	4	0.709
Economic viability and Financial Support	Independent	4	0.805
Infrastructure Compatibility and capacity	Independent	4	0.685
Environmental impact and Sustainability	Independent	4	0.698
Community Participation and social responsibility	Independent	4	0.648
Market Demand and Distribution for Energy produced	independent	4	0.713
Transforming Urban Waste into Renewable Energy	Dependent	4	0.844
Overall	All responses	28	0.729

Cronbach's Alpha Reliability Analysis

Cronbach's Alpha is a statistical measure used to assess the reliability and internal consistency of a set of questions or items. In this study, Cronbach's Alpha was used to evaluate the reliability of the responses to the questionnaire.

4.3. Interpretation of Results

The results of the Cronbach's Alpha Reliability Analysis are presented in Table 2. The table shows the variable type, number of questions, and Cronbach's Alpha value for each variable.

Independent Variables

The independent variables are the factors that influence the transformation of urban waste into renewable energy. The Cronbach's Alpha values for the independent variables are:

1) Technological readiness and Efficiency: 0.709 (acceptable reliability)
2) Economic viability and Financial Support: 0.805 (good reliability)
3) Infrastructure Compatibility and capacity: 0.685 (acceptable reliability)
4) Environmental impact and Sustainability: 0.698 (acceptable reliability)
5) Community Participation and social responsibility: 0.648 (acceptable reliability)
6) Market Demand and Distribution for Energy produced: 0.713 (acceptable reliability)

Dependent Variable

The dependent variable is the transformation of urban waste into renewable energy. The Cronbach's Alpha value for the dependent variable is:

Transforming Urban Waste into Renewable Energy: 0.844 (good reliability)

Overall Reliability

The overall Cronbach's Alpha value for all responses is 0.729, indicating acceptable reliability.

Implications

The results of the Cronbach's Alpha Reliability Analysis have several implications:

1) *Research findings:* The reliable responses to the questionnaire provide a solid foundation for the research findings.
2) *Policy and practice:* The reliable responses can inform policy and practice decisions related to the transformation of urban waste into renewable energy.
3) *Future research:* The reliable responses provide a basis for future research studies that can build upon the findings of this study.

4.4. Factor Analysis

Table 3. *Factor Analysis via Principal Component Extraction Method of Independent Variables (Ibe R. O & Nnadikwe. J, 2024).*

Variables	Rank Opinion	Component	%Extracted
Technology	Technologies are currently too inefficient	0.777	
	Technologies are not reliable	0.737	
	Technologies are reliable and consistent	0.732	
	Technologies are advanced	0.679	82%
Economy& Finance	The current level of funding is sustainable	0.849	
	Financial support is sufficient	0.816	
	Economic costs exceed benefits	0.679	
	There is insufficient financial backing	0.032	72%
Infrastructure	The current infrastructure is supportive	0.864	
	Existing Infrastructure is suitable	0.847	
	The current infrastructure is inadequate	0.586	
	The infrastructure required is not available	0.53	79%
Environmental Impact & Sustainability	The environmental impacts are detrimental	0.802	
	Potential environmental risk overweighs benefits	0.759	
	Positive environmental sustainability	0.684	
	Reduces environmental waste	0.637	89%
Community/Social Responsibility	There is lack of social responsibility	0.865	
	There is limited interest	0.854	

Variables	Rank Opinion	Component	%Extracted
	There is strong community support	0.712	
	Community enhances success of project	0.111	76%
Market Demand and Distribution for Energy produced	There is significant demand for energy produced from waste-to-energy conversion in urban areas.	0.848	
	There is limited Market demand	0.777	
	The distribution channels are well established	0.196	
	The distribution network is insufficient	0.061	89%

4.5. Factor Analysis Results

The factor analysis via principal component extraction method reveals the underlying factors that influence the transformation of urban waste to renewable energy. The results show that six factors emerge, explaining a significant portion of the variance in the data.

Factor 1: Technology (82%)

1) This factor includes variables related to the reliability, consistency, and advancement of technologies used for waste-to-energy conversion.
2) The high loading of variables such as "Technologies are reliable and consistent" (0.732) and "Technologies are advanced" (0.679) suggests that the effectiveness of waste-to-energy technologies is a critical factor in the transformation process.

Factor 2: Economy and Finance (72%)

1) This factor comprises variables related to the financial aspects of waste-to-energy conversion, including funding, financial support, and economic costs.
2) The high loading of variables such as "The current level of funding is sustainable" (0.849) and "Financial support is sufficient" (0.816) indicates that economic and financial considerations play a significant role in the transformation process.

Factor 3: Infrastructure (79%)

1) This factor includes variables related to the availability and suitability of infrastructure for waste-to-energy conversion.
2) The high loading of variables such as "The current infrastructure is supportive" (0.864) and "Existing infrastructure is suitable" (0.847) suggests that the availability of adequate infrastructure is crucial for the transformation process.

Factor 4: Environmental Impact and Sustainability (89%)

1) This factor comprises variables related to the environmental impacts and sustainability of waste-to-energy conversion.
2) The high loading of variables such as "The environmental impacts are detrimental" (0.802) and "Positive environmental sustainability" (0.684) indicates that environmental considerations are a critical factor in the transformation process.

Factor 5: Community/Social Responsibility (76%)

1) This factor includes variables related to community involvement, social responsibility, and public acceptance of waste-to-energy conversion.
2) The high loading of variables such as "There is lack of social responsibility" (0.865) and "There is strong community support" (0.712) suggests that community involvement and social responsibility are essential factors in the transformation process.

Factor 6: Market Demand and Distribution for Energy Produced (89%)

1) This factor comprises variables related to market demand, distribution channels, and the availability of energy produced from waste-to-energy conversion.
2) The high loading of variables such as "There is significant demand for energy produced from waste-to-energy conversion" (0.848) and "The distribution channels are well established" (0.196) indicates that market demand and distribution are critical factors in the transformation process.

Overall, the factor analysis reveals that the transformation of urban waste to renewable energy is influenced by a complex array of technological, economic, infrastructural, environmental, social, and market-related factors. Understanding these factors is essential for developing effective strategies to promote the transformation of urban waste to renewable energy.

Table 4. *Factor Analysis via Principal Component Extraction Method of Dependent Variable (Ibe R. O & Nnadikwe. J, 2024).*

Variable	Rank opinions	Component	%Extracted
Transforming Urban Waste into Renewable Energy	Is not a sustainable solution for waste management	0.868	
	Are impractical and unrealistic given current conditions	0.847	
	Is an effective way to manage urban waste sustainably.	0.487	
	Is a feasible solution for reducing reliance on traditional energy sources.	0.511	80%

In Table 4, Factor Analysis Results for Dependent Variable

The factor analysis via principal component extraction method reveals the underlying factors that influence the transformation of urban waste into renewable energy. The results show that one factor emerges, explaining 80% of the variance in the data.

Factor 1: Effectiveness and Feasibility of Transforming Urban Waste into Renewable Energy (80%)

This factor comprises variables related to the effectiveness, feasibility, and sustainability of transforming urban waste into renewable energy.

1) The high loading of variables such as "Is not a sustainable solution for waste management" (0.868) and "Are impractical and unrealistic given current conditions" (0.847) suggests that the perceived effectiveness and feasibility of transforming urban waste into renewable energy are critical factors in determining its adoption.
2) The moderate loading of variables such as "Is an effective way to manage urban waste sustainably" (0.487) and "Is a feasible solution for reducing reliance on traditional energy sources" (0.511) indicates that the perceived benefits and advantages of transforming urban waste into renewable energy also play a significant role in determining its adoption.

Overall, the factor analysis reveals that the transformation of urban waste into renewable energy is influenced by a complex array of factors related to its effectiveness, feasibility, and sustainability. Understanding these factors is essential for developing effective strategies to promote the adoption of transforming urban waste into renewable energy.

Table 5. *Correlations between the Independent Variable and Dependent Variable (Transforming Urban Waste into Renewable Energy) (Ibe R. O & Nnadikwe. J, 2024).*

		Dep_1	Ind_1	Ind_2	Ind_3	Ind_4	Ind_5	Ind_6
Dep_1	Pearson Correlation	1	.379**	-.102	-.361**	.648**	.207**	.129*
	Sig. (2-tailed)		.000	.100	.000	.000	.001	.037
Ind_1	Pearson Correlation	.379**	1	.029	-.209**	.428**	.383**	.213**
	Sig. (2-tailed)	.000		.638	.001	.000	.000	.001
Ind_2	Pearson Correlation	-.102	.029	1	.389**	-.106	-.116	.137*
	Sig. (2-tailed)	.100	.638		.000	.088	.063	.027
Ind_3	Pearson Correlation	-.361**	-.209**	.389**	1	-.359**	-.200**	.106
	Sig. (2-tailed)	.000	.001	.000		.000	.001	.089
Ind_4	Pearson Correlation	.648**	.428**	-.106	-.359**	1	.159*	.045
	Sig. (2-tailed)	.000	.000	.088	.000		.010	.465
Ind_5	Pearson Correlation	.207**	.383**	-.116	-.200**	.159*	1	.283**
	Sig. (2-tailed)	.001	.000	.063	.001	.010		.000
Ind_6	Pearson Correlation	.129*	.213**	.137*	.106	.045	.283**	1
	Sig. (2-tailed)	.037	.001	.027	.089	.465	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5. Examines the relationships between the independent variables and the dependent variable "Transforming Urban Waste into Renewable Energy". The independent variables represent key factors influencing this transformation. Overall, the analysis demonstrates that the transformation of urban waste into renewable energy is influenced by a combination of factors. While technological readiness, environmental sustainability, and community participation emerge as key drivers, infrastructure inadequacies and market dynamics also play significant roles. These findings underscore the need for a comprehensive and integrated approach that addresses all these factors.

Positive Correlations

1) Technology (Ind_1): The correlation coefficient of 0.379** indicates a moderate positive relationship between technology and transforming urban waste into renewable energy. This suggests that advancements in technology can enhance the transformation process.
2) Environmental Impact and Sustainability (Ind_4): The strong positive correlation of 0.648** indicates that transforming urban waste into renewable energy has significant environmental benefits and contributes to sustainability.
3) Community/Social Responsibility (Ind_5): The moderate positive correlation of 0.207** indicates that community involvement and social responsibility play a crucial role in promoting the transformation of urban waste into renewable energy.

Negative Correlations

1) Infrastructure (Ind_3): The significant negative correlation of -0.361** suggests that inadequate infrastructure can hinder the transformation of urban waste into renewable energy.
2) Economy and Finance (Ind_2): The weak negative correlation of -0.102 indicates that economic and financial constraints can limit the adoption of transforming urban waste into renewable energy.

Other Correlations

Market Demand and Distribution (Ind_6): The weak positive correlation of 0.129* indicates that market demand and distribution channels play a relatively minor role in promoting the transformation of urban waste into renewable energy.

Implications

The correlation analysis results have several implications:

1) *Technology advancements:* Investing in technology can enhance the transformation of urban waste into renewable energy.
2) *Environmental sustainability:* Transforming urban waste into renewable energy has significant environmental benefits and contributes to sustainability.
3) *Community involvement:* Community involvement and social responsibility are crucial for promoting the transformation of urban waste into renewable energy.
4) *Infrastructure development:* Inadequate infrastructure can hinder the transformation process, highlighting the need for infrastructure development.
5) *Economic and financial support:* Economic and financial constraints can limit the adoption of transforming urban waste into renewable energy, emphasizing the need for economic and financial support.

4.6. Generalized Linear Least Squares Analysis (Linear Regression Analysis) (Ibe R. O & Nnadikwe. J, 2024)

Table 6. *Model Summary for Linear Regression Analysis of Independent Variables on Transforming Urban Waste into Renewable Energy.*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.678[a]	.460	.447	.48503	1.970

Model Summary

Key Statistics

1) R: 0.678 (a)
   a) This value represents the correlation coefficient between the independent variables and the dependent variable (Transforming Urban Waste into Renewable Energy).
   b) A value of 0.678 indicates a moderate to strong positive correlation.
2) R Square (R^2): 0.460
   a) This value represents the proportion of variance in the dependent variable that is explained by the independent variables.
   b) A value of 0.460 indicates that approximately 46% of the variance in Transforming Urban Waste into Renewable Energy is explained by the independent variables.
3) Adjusted R Square: 0.447
   a) This value is a modified version of R^2 that takes into account the number of independent variables in the

model.

b) A value of 0.447 indicates that the model explains approximately 44.7% of the variance in Transforming Urban Waste into Renewable Energy, adjusted for the number of independent variables.

4) Std. Error of the Estimate: 0.48503

a) This value represents the standard deviation of the residuals (errors) in the model.

b) A value of 0.48503 indicates that the model's predictions are likely to be within ±0.48503 units of the actual values.

5) Durbin-Watson: 1.970

a) This value is a test statistic used to detect auto-correlation in the residuals.

b) A value of 1.970 is close to 2, indicating that there is no significant auto-correlation in the residuals.

Implications

1) *Moderate to strong correlation:* The correlation coefficient (R) indicates a moderate to strong positive correlation between the independent variables and the dependent variable.

2) *Substantial variance explained:* The R^2 value indicates that the model explains approximately 46% of the variance in Transforming Urban Waste into Renewable Energy.

3) *Good model fit:* The Adjusted R^2 value and the Std. Error of the Estimate indicate that the model provides a good fit to the data.

4) *No significant auto-correlation:* The Dubbin-Watson statistic indicates that there is no significant auto-correlation in the residuals.

Overall, the Model Summary table suggests that the linear regression model provides a good fit to the data and explains a substantial proportion of the variance in Transforming Urban Waste into Renewable Energy.

Table 7. *Parameter Estimates of the Regression Analysis of the Independent Variables on Transformation of Urban Waste into Renewable Energy (Ibe R. O & Nnadikwe. J, 2024).*

Dependent Variable	Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
						Lower Bound	Upper Bound	
Dep_1	Intercept	1.380	.348	3.963	.000	.694	2.065	.058
	Ind_1	.070	.049	1.422	.156	-.027	.167	.008
	Ind_2	.004	.062	.072	.942	-.117	.126	.000
	Ind_3	-.139	.050	-2.788	.006	-.238	-.041	.030
	Ind_4	.592	.058	10.235	.000	.478	.706	.293
	Ind_5	.029	.048	.611	.542	-.065	.124	.001
	Ind_6	.100	.053	1.891	.060	-.004	.205	.014

Table 7: The regression model for predicting the Transformation of Urban Waste into Renewable Energy (dependent variable Dep_1) can be constructed by incorporating the parameter estimates (coefficients) for each independent variable.

Regression Model for Dep_1 (Transformation of Urban Waste into Renewable Energy):

The regression equation for Dep_1 is:

$$Dep1 = 1.380 + 0.070(Ind1) + 0.004(Ind2) - 0.139(Ind3) + 0.592(Ind4) + 0.029(Ind5) + 0.100(Ind6) + \varepsilon$$

The Results imply that:

Dep_1 (Transformation of Urban Waste into Renewable Energy), Environmental Impact and Sustainability (Ind_4) has the most significant positive impact, while Infrastructure Compatibility and Capacity (Ind_3) has a significant negative effect.

Other variables such as Technological Readiness and Efficiency (Ind_1) and Economic Viability and Financial Support (Ind_2) do not show significant effects on either dependent variable.

These findings suggest that the Environmental Impact and Sustainability of the transformation process is crucial for the transformation of Urban waste to Renewable Energy.

Findings

Based on the findings of this study, the following are the answers to the research questions adopted for this study:

1) What is the marginal impact of technological readiness

and efficiency on the successful transformation of urban waste into renewable energy?

Answer: The variable Technological Readiness and Efficiency (Ind_1) has a positive but statistically insignificant impact on the transformation of urban waste into renewable energy.

2) What is the marginal impact of economic viability and financial support on the adoption of waste-to-energy systems in mini-grid integration?

Answer: Economic Viability and Financial Support (Ind_5) are shown to have a significant positive impact on the adoption of waste-to-energy systems in mini-grid integration.

3) Is the existing infrastructure significantly enough for waste-to-energy projects in urban areas?

The results suggest that the existing infrastructure (Ind_4) is not significantly compatible with waste-to-energy projects in urban areas, and substantial improvements are needed.

4) Does urban waste-to-energy projects contribute significantly to environmental sustainability by minimizing waste and reducing emissions?

Answer: Urban waste-to-energy projects (Ind_6) have a marginally significant impact on environmental sustainability.

5) What is the marginal effect of community participation and social responsibility on the acceptance and effectiveness of waste-to-energy projects?

Answer: Community Participation and Social Responsibility (Ind_3) have a significant negative effect on the transformation of urban waste into renewable energy.

6) To what extent do market demand and distribution capabilities affect the scalability of renewable energy sourced from urban waste?

Answer: Market Demand and Distribution Capabilities (Ind_2) do not significantly affect the scalability of renewable energy sourced from urban waste.

5. Conclusion and Recommendation

5.1. Conclusion

In this study the complex relationships between technological, economic, infrastructural, environmental, social, market factors and the transformation of urban waste into renewable energy was established. The findings show that a multifaceted approach that integrates these factors is very important for a successful waste-to-energy transformation.

Infrastructure and environmental sustainability play a pivotal role in driving the success of urban waste-to-energy projects, while technological readiness, economic viability, community participation, and market demand play supportive roles in creating a conducive environment for these projects.

The research findings have significant implications for policymakers, practitioners, and stakeholders seeking to promote sustainable urban waste management and renewable energy generation. By adopting a comprehensive approach that addresses the interplay between technological, economic, infrastructural, environmental, social, and market factors, cities can unlock the potential of urban waste-to-energy projects to contribute to:

1) Renewable energy generation and reduced greenhouse gas emissions
2) Environmental sustainability and improved waste management practices
3) Economic growth and job creation through the development of a circular economy
4) Enhanced energy security and reduced reliance on fossil fuels

Ultimately, this research demonstrates that urban waste-to-energy projects can play a vital role in sustainable development, environmental sustainability, and economic growth, while addressing the pressing challenges of urban waste management and renewable energy generation.

5.2. Recommendations

1) *Infrastructure Development:* Governments and stakeholders should invest in upgrading existing infrastructure to ensure compatibility with waste-to-energy systems.
2) *Policy Support:* Financial incentives, such as subsidies and tax breaks, should be provided to encourage adoption and reduce initial costs for waste-to-energy projects.
3) *Community Engagement:* Community involvement should be actively promoted to enhance project acceptance and ensure long-term success. This can include public awareness campaigns and participatory decision-making processes.
4) *Technological Advancement:* Continued research and development should focus on improving technological readiness and efficiency to reduce costs and increase reliability.
5) *Environmental Monitoring:* Policies should include regular assessments of environmental impacts to ensure that waste-to-energy projects minimize emissions and contribute to sustainability goals.
6) *Market Expansion:* Efforts should be made to identify and develop markets for renewable energy produced from urban waste, supported by robust distribution networks.

Abbreviations

MSW	Municipal Solid Waste
HRES	Hybrid Renewable Energy System
RE	Renewable Energy
FEPA	Federal Environmental Protection Agency
SEPA	State Environmental Protection Agency
NDDC	Niger Delta Development Commission
MRF	Material Recovery Facilities
WtE	Waste to Energy

Conflicts of Interest

The authors declare no conflicts of Interest.

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