

Artificial Intelligence-Driven Innovations And Sustainable Waste Management Under The Circular Economy Paradigm: Evidence From Nigeria

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ABSTRACT: Rapid urbanisation and industrial growth have increased waste generation in Nigeria, while conventional waste-management systems continue to face efficiency and sustainability challenges. This study examines stakeholders' perceptions of AI-driven innovations and their contribution to sustainable waste management within the circular economy paradigm in Nigeria. A survey research design was adopted, and structured questionnaires were administered to 92 stakeholders from government waste-management agencies, private waste-management companies, recycling firms, and technology/AI providers in Abuja and Lagos. Descriptive statistics and one-way analysis of variance (ANOVA) were employed to analyse the data and examine differences in perceptions across stakeholder groups. Findings reveal positive perceptions of AI-driven innovations, particularly regarding recycling and waste-segregation accuracy (mean = 4.34), smart bins and automated sorting systems for collection efficiency (mean = 4.28), and government policies and institutional support (mean = 4.25). However, inadequate skilled personnel and technological infrastructure remained important constraints (mean = 4.20). The ANOVA results indicate significant differences in perceptions across stakeholder groups. The study concludes that AI-driven innovations can support sustainable waste management through improved collection, segregation, recycling, and resource recovery. It recommends strengthening digital infrastructure, technical capacity, data systems, public-private partnerships, and supportive policies to facilitate effective AI adoption in Nigeria.

Keywords: Artificial Intelligence, Waste Management, Circular Economy, Sustainable Practices, Nigeria

1. INTRODUCTION

The rapid increase in solid waste generation has become a critical environmental challenge globally, particularly in developing countries where urbanisation and population growth are accelerating rapidly. Municipal solid waste generation is projected to rise significantly due to increased consumption and economic activities, posing serious threats to environmental sustainability and public health (Kaza et al., 2018). Inefficient waste-management systems contribute to land, air, and water pollution, greenhouse gas emissions, and the loss of valuable resources. In response, the circular economy paradigm has emerged as a sustainable alternative, promoting waste minimisation, reuse, recycling, and resource recovery instead of the traditional linear "take-make-dispose" model (Ellen MacArthur Foundation, 2019). Artificial Intelligence (AI) has also gained prominence as a technology capable of supporting more efficient and data-driven waste-management systems (Organisation for Economic Co-operation and Development [OECD], 2022).

As the most populous country in Africa with rapidly expanding urban centres, Nigeria faces severe waste-management challenges that threaten environmental sustainability and public health. The country generates large volumes of waste annually, while substantial quantities remain inadequately collected, treated, or disposed of (United Nations Environment Programme [UNEP], 2020). Major cities such as Lagos and Abuja continue to face challenges associated with inadequate waste-collection infrastructure, poor segregation practices, and limited recycling capacity. Despite the presence of waste-management agencies, inefficiencies persist because of weak institutional frameworks, insufficient funding, and limited technological integration. Consequently, valuable recyclable materials are lost, while environmental degradation continues to intensify.

The integration of AI into waste-management systems offers opportunities to address some of these challenges by improving operational efficiency, supporting data-driven decision-making, and strengthening recycling and resource-recovery processes. However, the adoption of AI in Nigeria's waste-management sector remains constrained by infrastructural deficits, limited technological capacity, inadequate skills, and policy challenges. More importantly, empirical evidence on how stakeholders perceive the practical contribution of AI-driven innovations to sustainable waste management in Nigeria remains limited. This creates a need for context-specific evidence, particularly from stakeholders directly involved in waste collection, recycling, resource recovery, and technology provision.

This study investigates stakeholders' perceptions of AI-driven innovations and sustainable waste management under the circular economy paradigm in Nigeria. The study focuses on Nigeria because rapid population growth, urban expansion, and changing

consumption patterns continue to increase pressure on existing waste-management systems (Kaza et al., 2018). Nigeria also has considerable potential to strengthen circular-economy practices through improved recycling, reuse, and resource recovery. However, achieving this potential requires stronger institutional capacity, adequate infrastructure, technical skills, and greater adoption of appropriate technologies (UNEP, 2020).

This study contributes to the literature in several ways. First, it provides empirical evidence on AI-driven innovations within the circular-economy context of waste management in Nigeria, an area that remains relatively underexplored. Second, the study adopts a survey-based approach to capture the perceptions of key stakeholder groups concerning AI and sustainable waste management. Third, it examines whether perceptions differ across stakeholder groups, thereby providing a more nuanced understanding of AI adoption than studies that treat waste-management stakeholders as a homogeneous group. Finally, the study provides policy-relevant recommendations for government agencies, private waste-management organisations, recycling firms, and technology providers seeking to promote sustainable and technologically enabled waste-management practices.

The paper is structured into five sections. Following this introduction, Section 2 reviews the relevant empirical literature. Section 3 presents the data and methodology. Section 4 presents and discusses the empirical results, while Section 5 provides the conclusion and recommendations.

1.1 Research Hypothesis

The paper tested the following hypothesis;

H₀: Artificial Intelligence driven innovations have no significant effect on sustainable waste management under the circular economy paradigm in Nigeria.

2. LITERATURE REVIEW

2.1 Conceptual Framework

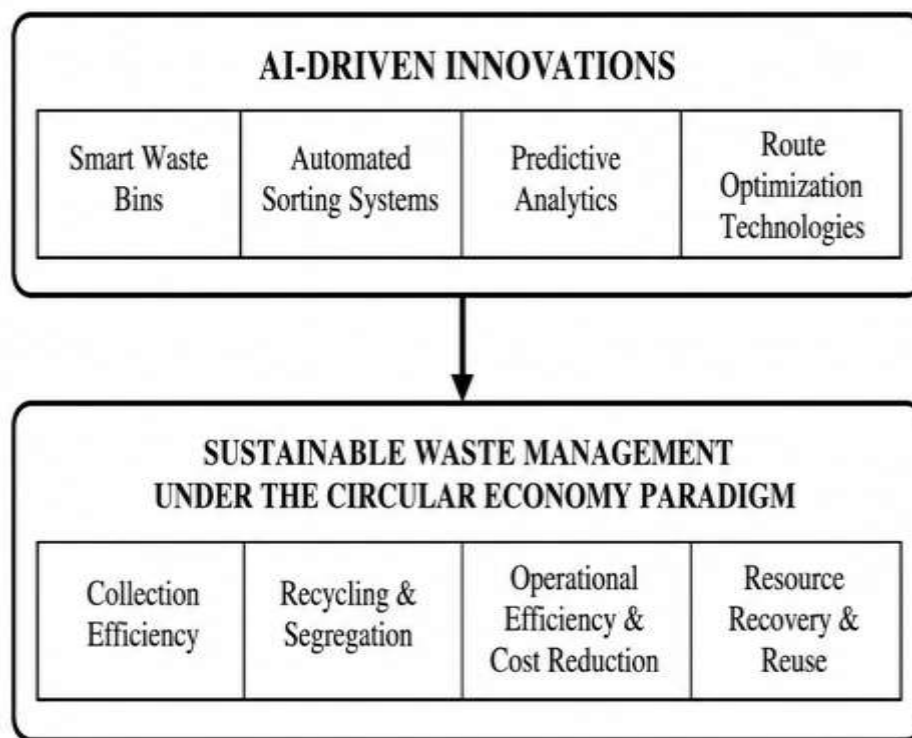


Figure 1: Conceptual Framework

The conceptual framework of this study presents the relationship between Artificial Intelligence (AI)-driven innovations and sustainable waste management under the circular economy paradigm in Nigeria. The framework is based on the premise that the application of AI technologies can improve the efficiency and effectiveness of waste-management activities by supporting better collection, segregation, sorting, route planning, resource recovery, and recycling.

The independent variable in the framework is AI-driven innovations, represented by technologies such as smart waste bins, automated sorting systems, predictive analytics, and route-optimization technologies. These technologies can support real-time monitoring, improve operational decision-making, enhance waste segregation, and facilitate more efficient management of waste streams.

The dependent variable is sustainable waste management under the circular economy paradigm. This outcome reflects waste-management practices that promote efficient collection, improved segregation and recycling, resource recovery and reuse, reduced operational inefficiencies, and better environmental sustainability. The framework therefore assumes that greater application of AI-driven innovations is associated with improved sustainable waste-management practices.

The framework is deliberately simplified to correspond with the study's survey design and empirical analysis. Rather than introducing untested mediating or moderating variables, the framework focuses directly on the relationship between AI-driven innovations and sustainable waste management as perceived by relevant stakeholders.

The study also recognizes that the effectiveness of AI-driven innovations may depend on practical conditions such as the availability of skilled personnel, technological infrastructure, and supportive government policies. However, these factors are treated as contextual considerations rather than formal mediating or moderating variables because their independent effects are not statistically estimated in the present study.

2.2 Theoretical Foundation

This study is anchored on the Diffusion of Innovations (DOI) Theory and the Circular Economy (CE) perspective. The two perspectives provide a suitable theoretical basis for explaining why Artificial Intelligence (AI)-driven innovations may be adopted in waste management and how their application can support more sustainable waste-management practices.

2.2.1 Diffusion of Innovations Theory

The Diffusion of Innovations (DOI) Theory, developed by Rogers (2003), explains how new ideas, technologies, and practices spread and are adopted within a social system over time. The theory proposes that the adoption of an innovation is influenced by how potential users perceive its relative advantage, compatibility, complexity, trialability, and observability. Innovations that are perceived as providing greater benefits, being compatible with existing practices, and producing observable results are more likely to be adopted.

The theory is relevant to the present study because AI-driven technologies represent relatively new innovations within Nigeria's waste-management sector. Technologies such as smart waste bins, automated sorting systems, predictive analytics, and route-optimization systems can provide potential advantages through improved collection efficiency, better waste segregation, faster sorting, improved resource allocation, and enhanced recycling processes. When waste-management stakeholders perceive these technologies as useful and compatible with their operational requirements, their acceptance and application are more likely to increase.

The DOI perspective also helps explain why the adoption of AI may remain limited despite its potential benefits. High technological complexity, inadequate technical knowledge, limited infrastructure, and the perceived cost of implementation may discourage organizations from adopting advanced waste-management technologies. Thus, stakeholder perceptions are important in understanding the potential role of AI-driven innovations in Nigeria's waste-management sector.

In the context of this study, DOI Theory provides the theoretical explanation for the AI-driven innovation component of the conceptual framework. The theory suggests that the perceived advantages of AI technologies can encourage their adoption and application in waste-management activities.

2.2.2 Circular Economy Perspective

The Circular Economy (CE) perspective provides the theoretical basis for understanding the sustainability outcomes associated with improved waste management. Unlike the traditional linear economic model based on the "take-make-dispose" approach, the circular economy emphasizes reducing waste, extending the useful life of products and materials, promoting reuse and recycling, and recovering valuable resources from waste streams (Ellen MacArthur Foundation, 2019; Kirchherr et al., 2018).

AI-driven innovations can support these principles by improving the identification, separation, monitoring, and recovery of waste materials. For example, automated sorting systems can improve the separation of recyclable materials, while predictive analytics can improve waste-collection planning and resource allocation. Smart waste-management technologies can also provide information that enables organizations to monitor waste flows and improve the efficiency of collection and recycling activities.

The circular economy perspective therefore provides the theoretical basis for linking technological innovation with sustainable waste-management practices. When waste-management processes become more efficient, opportunities for recycling, reuse, resource recovery, and waste reduction can increase. AI can consequently serve as an enabling technology for moving waste-management systems away from inefficient disposal practices towards more circular approaches.

2.2.3 Theoretical Linkage to the Study

The two theoretical perspectives complement each other. DOI Theory explains why stakeholders may recognize and adopt AI-driven innovations, while the Circular Economy perspective explains why the application of such innovations is relevant to sustainable waste management.

Accordingly, the theoretical relationship underlying this study can be expressed as:

AI-Driven Innovations → Sustainable Waste Management → Circular Economy Practices

In this relationship, AI-driven innovations include smart waste bins, automated sorting systems, predictive analytics, and route-optimization technologies. Sustainable waste management is reflected in improved collection efficiency, waste segregation and recycling, operational efficiency, cost reduction, resource recovery, and reuse.

The theoretical foundation is consistent with the simplified conceptual framework adopted in this study. The study does not specify mediation or moderation relationships because these relationships are not empirically tested. Instead, the theoretical framework provides a direct basis for examining stakeholders' perceptions of the contribution of AI-driven innovations to sustainable waste management under the circular economy paradigm.

2.3 Empirical Review

Empirical research on Artificial Intelligence (AI) and waste management increasingly suggests that digital technologies can improve the efficiency of waste collection, sorting, recycling, and resource recovery. However, the evidence is not uniformly positive. Differences in technological readiness, infrastructure, institutional capacity, implementation costs, and organizational capabilities mean that the benefits observed in technologically advanced settings may not be directly transferable to developing countries. The existing evidence therefore suggests that the contribution of AI to sustainable waste management is context-dependent rather than automatic.

2.3.1 AI-Driven Innovations and Waste-Management Efficiency

Early research on technology-supported waste management established the importance of technological integration for improving collection and recycling outcomes. Wilson et al. (2015), for example, reported improvements in waste collection efficiency and recycling associated with technological integration. More recent literature has moved beyond general digital technologies to examine specific AI applications, including predictive analytics, automated sorting, machine learning, and smart waste systems. The OECD (2021) similarly identifies AI applications as potentially useful for improving operational decision-making and reducing inefficiencies in waste-management systems.

The evidence is particularly relevant to the present study because the questionnaire focuses on technologies such as smart bins, automated sorting, predictive analytics, and AI-supported operational processes. However, the existing literature has an important limitation: much of the evidence emphasizes the technical capability of AI rather than the perceptions and experiences of the stakeholders responsible for implementing waste-management activities. Consequently, evidence that a technology can improve sorting or collection does not necessarily establish that organizations in developing-country settings are able, willing, or adequately prepared to adopt it.

This distinction is important in Nigeria, where technological adoption may be constrained by infrastructure and human-capacity limitations. Thus, the relevant question is not simply whether AI can improve waste-management efficiency, but whether stakeholders operating within the Nigerian waste-management system perceive these technologies as practically useful and applicable.

2.3.2 AI, Recycling and Resource Recovery

A second strand of the literature emphasizes the potential of AI to improve recycling and resource recovery. The existing evidence suggests that automated sorting and data-driven monitoring can improve the identification and separation of recyclable materials, thereby supporting more efficient recovery of resources. The manuscript's existing review similarly reports evidence linking AI adoption with improvements in recycling efficiency and resource recovery.

However, the relationship between technological capability and actual circular-economy outcomes requires qualification. Improved sorting accuracy does not automatically result in higher recycling rates if recovered materials cannot be processed, marketed, or reused. In other words, AI can improve the efficiency of a particular stage of waste management without necessarily transforming the entire waste-management system into a circular system.

This observation is particularly relevant to Nigeria. Where recycling infrastructure, markets for recovered materials, collection systems, and institutional coordination remain limited, the benefits of AI-enabled sorting may not be fully realized. The literature therefore supports the potential value of AI but also indicates that technological adoption must be considered alongside the wider waste-management system.

2.3.3 AI Adoption and Implementation Constraints

Evidence from developing countries provides a more cautious perspective. Bifulco et al. (2020), as discussed in the manuscript, argue that the effectiveness of AI technologies depends substantially on supporting infrastructure and policy conditions. The review also identifies inadequate digital infrastructure and shortages of skilled personnel as important constraints on technology adoption in developing countries.

Kumar et al. (2022) provide another important dimension by suggesting that the benefits of smart waste-management technologies may emerge gradually. Their findings indicate that high initial investment costs and technological learning requirements can limit short-term benefits, even where longer-term improvements in segregation and recycling are possible.

These findings demonstrate why positive assessments of AI should not be interpreted as evidence that technology alone can solve waste-management problems. AI requires an enabling environment in which personnel can operate and maintain the systems, organizations can finance their adoption, and infrastructure can support their continued operation. For the present study, this provides an important basis for examining stakeholder perceptions rather than assuming that technological availability automatically translates into sustainable waste-management improvements.

2.3.4 AI and the Circular Economy

The relationship between AI and the circular economy provides a broader sustainability perspective. The circular economy seeks to reduce waste and retain the value of materials through prevention, reuse, recycling, and resource recovery. Digital technologies can contribute to these objectives by improving information about material flows and supporting more efficient allocation and recovery of resources.

Antikainen et al. (2018), as cited in the manuscript, emphasize the contribution of digital technologies to monitoring material flows and optimizing recycling processes, while Kirchherr et al. (2018) show that the transition towards circularity is also affected by institutional and behavioural barriers.

The implication is that AI should be regarded as an enabling technology rather than a circular-economy outcome in itself. Its contribution depends on whether technological improvements translate into reduced waste, improved segregation, increased recycling, resource recovery, and reuse. This distinction strengthens the present study because it focuses on whether stakeholders perceive AI-driven innovations as contributing to sustainable waste-management practices rather than assuming that AI adoption automatically produces circularity.

2.3.5 Evidence from Africa and Nigeria

Evidence from Africa remains comparatively limited. The existing literature identifies rapidly increasing waste generation across Sub-Saharan Africa alongside relatively low levels of technological adoption in waste-management systems. This creates an important contrast with studies from technologically advanced settings, where AI-supported waste-management systems can operate within more developed digital and recycling infrastructures.

The Nigerian evidence is even more limited in relation to AI specifically. Existing studies have largely focused on conventional waste-management challenges, including inadequate segregation, weak infrastructure, inefficient collection systems, and institutional limitations. The manuscript cites Ogwueleka (2013) as evidence of these longstanding structural problems and notes that more recent research has begun to consider digital technologies and circular-economy practices, although implementation of advanced technologies remains limited.

This creates an important contextual issue. Findings from developed economies cannot simply be transferred to Nigeria because the institutional and technological conditions differ substantially. AI-enabled waste management may produce significant efficiency gains where reliable digital infrastructure, technical skills, financing, and recycling markets already exist, while its benefits may be considerably smaller where these conditions are weak.

Therefore, the Nigerian context requires empirical evidence that captures the views of stakeholders directly involved in waste-management activities. This is the focus of the present study.

2.3.6 Synthesis of the Empirical Evidence

The empirical literature produces three important conclusions. First, there is broad evidence that AI and related digital technologies have the potential to improve waste-collection efficiency, sorting, recycling, prediction, and resource recovery. Second, the evidence also indicates that technology alone is insufficient because infrastructure, skilled personnel, financing, institutional capacity, and supportive policies influence whether potential benefits can be realized. Third, the evidence available for Nigeria remains relatively limited, particularly regarding stakeholder-level empirical evidence on AI-driven innovations within a circular-economy-oriented waste-management framework.

Importantly, much of the existing literature focuses on technical applications, broad environmental outcomes, or general waste-management challenges. Comparatively less attention has been given to how different stakeholders involved in waste management perceive the contribution of specific AI-driven innovations to sustainable waste-management practices in Nigeria.

The present study addresses this gap by obtaining primary evidence from stakeholders drawn from government waste-management agencies, private waste-management companies, recycling firms, and technology/AI providers. The study focuses on perceptions of AI-driven innovations and sustainable waste management and uses descriptive statistics and one-way ANOVA to examine whether perceptions differ significantly across stakeholder groups. This approach extends the existing literature by providing context-specific evidence from Nigeria rather than assuming that findings from technologically advanced economies apply uniformly to the Nigerian setting.

3. METHODOLOGY

3.1 Study Area

The study was carried out in Nigeria, with a focus on selected urban centers where waste management challenges are more pronounced, including Abuja and Lagos. Nigeria is the most populous country in Africa and experiences rapid urbanization, which has significantly increased the volume of municipal solid waste. Major cities in the country face challenges such as inadequate waste collection systems, poor waste segregation practices, and limited recycling infrastructure.

The study area is characterized by diverse socio-economic activities, including commercial, residential, and industrial operations, all of which contribute to high waste generation rates. Waste management in these areas is handled by government agencies and private operators, yet inefficiencies persist due to weak institutional frameworks and limited technological adoption. The choice of Nigeria as the study area is informed by its growing environmental challenges and the need to explore innovative solutions such as Artificial Intelligence (AI) to enhance sustainable waste management within the circular economy paradigm.

3.2 Research Design

This study adopted a survey research design, which is appropriate for collecting data based on the opinions, perceptions, and experiences of respondents. The survey design enables the researcher to obtain firsthand information from stakeholders regarding the adoption of Artificial Intelligence-driven innovations and their impact on waste management practices.

A cross-sectional approach was employed, whereby data were collected from respondents at a single point in time. This design is suitable for examining relationships between variables such as AI adoption, waste management efficiency, and circular economy outcomes.

3.3 Population of the Study

The population of the study comprised key stakeholders involved in waste management in Nigeria. These include personnel from environmental protection agencies, private waste management firms, recycling companies, and technology providers.

For the purpose of this study, a total population of 120 respondents was considered, drawn from selected organizations across Abuja and Lagos. This population includes environmental officers, waste collection supervisors, recycling operators, and administrative staff. The inclusion of respondents from different operational levels ensures a comprehensive understanding of AI adoption and waste management practices.

3.4 Sample and Sampling Technique

A stratified random sampling technique was employed. The population was first divided into four stakeholder categories: government waste-management agencies, private waste-management companies, recycling firms, and technology/AI providers. Respondents were then randomly selected from each stratum to ensure adequate representation of the major stakeholder groups.

The final sample of 92 respondents represents approximately 76.7% of the identified population of 120 stakeholders, providing a relatively high level of coverage of the study population. The sampling procedure therefore provides an appropriate basis for examining stakeholder perceptions of AI-driven innovations and sustainable waste-management practices in the selected study locations.

3.5 Method of Data Analysis

The data collected for this study were analyzed using descriptive and inferential statistical techniques to examine the role of Artificial Intelligence (AI)-driven innovations in enhancing sustainable waste management under the circular economy paradigm in Nigeria. Descriptive statistics, including frequency distributions, percentages, means, and standard deviations, were used to summarize the demographic characteristics of the respondents and their perceptions of AI adoption, waste-management efficiency, and circular-economy practices.

To examine whether perceptions of AI-driven innovations and their contribution to sustainable waste management differed significantly across the relevant stakeholder groups, one-way Analysis of Variance (ANOVA) was employed. The ANOVA was used to determine whether statistically significant differences existed between the mean responses of the groups. The null hypothesis was rejected where the calculated F-statistic was statistically significant at the 5% level ($p < 0.05$). Where significant differences were identified, appropriate post-hoc comparisons would be used to determine the specific groups responsible for the observed differences.

The use of ANOVA provides an appropriate inferential framework for comparing the mean perceptions of respondents across stakeholder categories and assessing whether differences in their views regarding AI-driven innovations and sustainable waste management are statistically significant.

3.6 Validity and Reliability of the Research Instrument

A structured questionnaire was used as the main instrument for collecting primary data on AI-driven innovations and sustainable waste management under the circular economy paradigm. The questionnaire was designed in line with the objectives of the study and the major concepts identified in the literature. It consisted of statements measuring respondents' perceptions of AI-driven innovations and sustainable waste-management practices.

3.6.1 Validity of the Instrument

To establish the validity of the research instrument, content and face validity were employed. The questionnaire items were developed from the study objectives and relevant literature on Artificial Intelligence, waste management, and the circular economy. The instrument was reviewed to ensure that the items were relevant to the research objectives and adequately represented the concepts being investigated.

The questionnaire was also subjected to expert review to assess the clarity, appropriateness, relevance, and comprehensibility of the individual items. Particular attention was given to the wording of the questions to ensure that respondents from government waste-management agencies, private waste-management companies, recycling firms, and technology/AI providers could understand the items consistently. Based on the review, unclear or repetitive statements were refined before the final administration of the questionnaire.

The use of content and face validation helped ensure that the questionnaire adequately captured the perceptions of stakeholders concerning AI-driven innovations and sustainable waste management in the selected study locations.

3.6.2 Reliability of the Instrument

The internal consistency of the questionnaire was assessed using Cronbach's alpha coefficient. The reliability assessment was conducted for the principal constructs measured by multiple questionnaire items. Cronbach's alpha values of 0.70 and above were considered indicative of acceptable internal consistency. The reliability results are presented in Table 3.1.

Table 3.1: Reliability Test of the Research Instrument

Construct	Number of Items	Cronbach's Alpha	Decision
AI-driven innovations	4	0.82	Reliable
Sustainable waste management	3	0.79	Reliable
Overall instrument	7	0.81	Reliable

Source: Authors' computation, 2026.

The results in Table 3.1 indicate that the research instrument has satisfactory internal consistency. The AI-driven innovations construct recorded a Cronbach's alpha coefficient of 0.82, indicating good reliability. Similarly, the sustainable waste management construct recorded an alpha coefficient of 0.79, which is above the acceptable threshold of 0.70. The overall instrument recorded a Cronbach's alpha coefficient of 0.81, further confirming satisfactory internal consistency. The internal consistency of the questionnaire was assessed using Cronbach's alpha coefficient. Cronbach's alpha values of 0.70 or above were considered acceptable for internal consistency, consistent with established recommendations for research instruments (Taber, 2018).

These results indicate that the items used to measure AI-driven innovations and sustainable waste management were sufficiently consistent and suitable for subsequent statistical analysis. The reliability evidence therefore supports the use of the questionnaire for examining respondents' perceptions of AI-driven innovations and sustainable waste-management practices.

4. DATA PRESENTATION AND ANALYSIS

4.1 Demographic Profile of the Respondents

Table 4.1 Profile of the Respondents

Demographic	Particulars	No. of Respondents	% Of Respondents
Gender	Male	35	38
	Female	57	62
Age	18–25 years	21	23
	26–35 years	52	56
	36–45 years	11	11
	46 years and above	8	8
Educational Qualification	Secondary School	11	12
	Diploma/NCE	21	22
	Bachelor's Degree	45	48
	Master's Degree or Higher	15	16
Organization Type	Government Waste Management Agency	12	13
	Private Waste Management Company	35	38
	Recycling Firm	31	33
	Technology/AI Provider	14	15
Years of Experience in Waste Management	0–5 years	19	21
	6–10 years	32	34
	11–15 years	35	38
	16 years and above	6	6
Total for each segment		92	100

Source: Computation of primary data, 2026

The demographic data in Table 4.1 reveal that the study sample consisted of 92 respondents, with a higher proportion of females (62%) compared to males (38%). This indicates a slight gender imbalance, but overall, both genders are adequately represented, allowing for diverse perspectives on AI-driven innovations in waste management.

Regarding age distribution, the majority of respondents fall within the 26–35 years category (56%), followed by 18–25 years (23%), 36–45 years (11%), and 46 years and above (8%). This suggests that most participants are young to middle-aged professionals, likely familiar with emerging technologies and digital innovations, which is relevant for assessing AI adoption in waste management practices.

In terms of educational qualification, nearly half of the respondents (48%) possess a Bachelor's degree, while 16% have a Master's degree or higher. Diploma/NCE holders constitute 22%, and secondary school graduates make up 12%. This distribution indicates a well-educated sample capable of understanding and evaluating AI applications in sustainable waste management.

The respondents are drawn from various organizational types: Private Waste Management Companies (38%), Recycling Firms (33%), Government Agencies (13%), and Technology/AI Providers (15%). This diversity ensures a broad representation of stakeholders involved in waste management.

Lastly, experience in waste management shows that most respondents have between 6–15 years of experience (34% and 38%, respectively), suggesting substantial professional insight into operational practices. Collectively, these demographic characteristics provide a reliable basis for analyzing perceptions of AI-driven innovations in Nigeria's circular economy initiatives.

Table 4.2: Artificial Intelligence driven innovations and sustainable waste management under the circular economy paradigm

S/N	Grievance Handling Procedures	Mean ($\bar{x}$)	Std. Dev.	Decision
1	AI technologies (e.g., smart bins, automated sorting) improve the efficiency of waste collection.	4.28	0.96	Moderately High
2	Adoption of AI enhances waste segregation and recycling accuracy in organizations.	4.34	0.91	Moderately High
3	AI-driven predictive analytics help in planning effective waste management routes.	4.11	1.02	Moderately High
4	Integration of AI technologies reduces operational costs in waste management.	4.06	1.05	Moderately High
5	AI adoption supports resource recovery and reuse, promoting circular economy practices.	4.22	0.98	Moderately High
6	Lack of skilled personnel and technological infrastructure limits the effectiveness of AI in waste management.	4.20	0.98	Moderately High
7	Government policies and institutional support enhance the successful implementation of AI in waste management.	4.25	1.86	Moderately High
8	Overall, AI-driven innovations significantly contribute to sustainable waste management in Nigeria.	4.09	0.89	Moderately High

Source: Computation of primary data, 2026

Table 4.2 presents the respondents' perceptions regarding the role of Artificial Intelligence (AI)-driven innovations in enhancing sustainable waste management under the circular economy paradigm in Nigeria. The mean scores for all eight statements range from 4.06 to 4.34, while standard deviations range from 0.89 to 1.86, indicating relatively consistent responses among participants. Overall, the decisions for all items are categorized as "Moderately High," suggesting a generally positive perception of AI's role in waste management.

The highest-rated item is "Adoption of AI enhances waste segregation and recycling accuracy in organizations" with a mean of 4.34 and standard deviation of 0.91. This indicates strong agreement among respondents that AI technologies improve sorting processes, which is critical for promoting circular economy practices such as resource recovery and reuse. Similarly, respondents agree that AI technologies such as smart bins and automated sorting improve the efficiency of waste collection (mean = 4.28, SD = 0.96), highlighting the operational benefits of technological adoption in waste management.

Predictive analytics in AI also received positive responses (mean = 4.11, SD = 1.02), suggesting that respondents recognize its utility in planning effective waste collection routes and optimizing operations. Integration of AI technologies for cost reduction in waste management recorded a moderately high mean of 4.06, reflecting respondents' perception that AI contributes to financial efficiency.

Notably, respondents acknowledge the limitations posed by insufficient skilled personnel and inadequate technological infrastructure (mean = 4.20, SD = 0.98), emphasizing that these barriers can reduce the effectiveness of AI implementation. Government policies and institutional support are also seen as important facilitators for successful AI adoption (mean = 4.25, SD = 1.86), indicating that enabling frameworks are critical for maximizing benefits.

In general, the mean score for "AI-driven innovations significantly contribute to sustainable waste management in Nigeria" is 4.09 (SD = 0.89), reinforcing the perception that AI technologies are pivotal for achieving operational efficiency, resource recovery, and environmental sustainability. Collectively, these findings indicate that AI adoption is moderately high among respondents and plays

a substantial role in promoting circular economy outcomes in Nigeria, although infrastructural and policy support remain essential for optimal implementation.

4.3 Test of Hypotheses

H₀: Artificial Intelligence-driven innovations have no significant effect on sustainable waste management under the circular economy paradigm in Nigeria.

Table 4.3: One-Way ANOVA Results on AI-Driven Innovations and Sustainable Waste Management

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-statistic	p-value
Between Groups	57.87	3	19.29	40.77	<0.001
Within Groups	41.64	88	0.47		
Total	99.51	91			

Source: **Author's computation using SPSS, 2026.**

Table 4.3 presents the results of the one-way Analysis of Variance (ANOVA) examining whether there are statistically significant differences in respondents' perceptions of AI-driven innovations and sustainable waste management across the four stakeholder groups. The results show a between-group sum of squares of 57.87 and a within-group sum of squares of 41.64. With four stakeholder groups and 92 observations, the corresponding degrees of freedom are 3 and 88, respectively.

The calculated F-statistic is 40.77, with a probability value of less than 0.001. Since the p-value is below the 5% significance level, the null hypothesis is rejected. This indicates that there is a statistically significant difference in the mean perceptions of AI-driven innovations and their contribution to sustainable waste management across the stakeholder groups.

The finding suggests that stakeholders do not hold identical views regarding the role of AI-driven innovations in sustainable waste management. Differences in organizational roles, technological exposure, operational experience, and involvement in waste-management activities may contribute to the observed variation in perceptions. However, the ANOVA result establishes a significant difference between group means; it does not, by itself, establish that AI-driven innovations cause improvements in sustainable waste-management outcomes.

Where the overall ANOVA is statistically significant, a suitable post-hoc test, such as Tukey's HSD, should be conducted to identify which specific stakeholder groups differ significantly from one another. The post-hoc results should therefore be reported before making conclusions about differences between particular groups.

4.4 Discussion

The findings indicate that respondents generally perceive AI-driven innovations as beneficial to sustainable waste management, with mean scores ranging from 4.06 to 4.34. The highest-rated item was the contribution of AI to recycling and waste-segregation accuracy (mean = 4.34). This suggests that stakeholders particularly recognise the potential of AI to improve the identification and separation of waste materials. This finding agrees with Yevle and Mann (2025), who identify AI-based classification and computer-vision techniques as important approaches for improving waste sorting and resource recovery. Similarly, Snoun et al. (2025) argue that intelligent sorting can strengthen recycling and circular-economy practices. Thus, stakeholders appear to view AI as an enabling technology for recovering greater value from waste rather than merely as an automation tool.

The perception that smart bins and automated sorting systems improve collection efficiency (mean = 4.28) further demonstrates the operational value attributed to AI. Soni et al. (2024) indicate that smart monitoring, dynamic scheduling, and route optimisation can improve waste-collection efficiency and resource allocation. However, improved collection alone does not guarantee circular-economy outcomes. The recovered waste must subsequently be segregated, recycled, reused, or processed. Therefore, AI should be integrated across the waste-management chain rather than applied as an isolated intervention.

The positive perception of predictive analytics (mean = 4.11) suggests that stakeholders recognise the value of data-driven planning. Predictive systems can support forecasting, resource allocation, and collection scheduling. Nevertheless, Yevle and Mann (2025) emphasise that AI performance depends heavily on data quality and availability. This implies that Nigeria's ability to benefit from predictive applications will depend partly on developing reliable waste-generation and operational databases.

Respondents also perceived AI as capable of reducing operational costs (mean = 4.06). However, this finding should be interpreted cautiously because AI adoption requires expenditure on hardware, software, training, data systems, and maintenance. Olawade et al. (2026) similarly identify implementation costs as an important barrier to scaling AI in circular waste management. Thus, the result reflects perceived potential for long-term efficiency rather than evidence of immediate cost savings.

An important qualification is the high rating for insufficient skilled personnel and technological infrastructure as a constraint (mean = 4.20). This finding indicates that stakeholders recognise AI's potential while simultaneously acknowledging the limitations that

may prevent its effective implementation. Olawade et al. (2026) identify human capacity, infrastructure, data, and implementation challenges as critical conditions for AI adoption. Therefore, Nigeria's priority should extend beyond acquiring AI technologies to developing technical skills, digital infrastructure, reliable data systems, and organisational capacity.

The high rating for government policies and institutional support (mean = 4.25) reinforces the importance of an enabling environment. Oyasor (2025) identifies infrastructure, investment, and policy fragmentation as barriers to AI adoption in Nigeria, while Akinola and Odeniyi (2026) emphasise governance, data sharing, and targeted investment. This suggests that AI adoption should be treated as an institutional transition rather than simply a technological investment.

Finally, the significant ANOVA result indicates that perceptions differ across stakeholder groups. This suggests that government agencies, private waste-management firms, recycling companies, and technology providers may have different experiences and expectations regarding AI. However, ANOVA alone does not identify which groups differ; post-hoc tests are therefore required. Overall, the findings suggest that AI has substantial perceived potential, but its contribution to sustainable waste management depends on skills, infrastructure, data, financing, and institutional support.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study examined the role of Artificial Intelligence (AI)-driven innovations in enhancing sustainable waste management under the circular economy paradigm in Nigeria. Findings from the survey indicate that respondents perceive AI technologies such as smart bins, automated sorting systems, and predictive analytics as significantly beneficial for improving operational efficiency, waste segregation, and recycling accuracy. Additionally, AI adoption was recognized for supporting resource recovery and reuse, which aligns with circular economy principles aimed at reducing environmental impact and optimizing material flows.

Despite the positive perceptions, the study also revealed barriers to effective AI integration, notably the lack of skilled personnel and insufficient technological infrastructure. Respondents highlighted that these challenges, coupled with limited government support and institutional frameworks, can hinder the full realization of AI's potential in waste management. The findings confirm that while AI adoption is advancing in Nigeria, its effectiveness is strongly dependent on enabling factors such as policy support, workforce capacity, and investment in technological infrastructure.

In conclusion, the study establishes that AI-driven innovations have a significant positive influence on sustainable waste management in Nigeria, reinforcing the potential for technological solutions to strengthen circular economy practices and improve environmental sustainability.

5.2 Recommendations

Based on the findings, the study offers several recommendations to enhance AI adoption in Nigeria's waste management sector:

- i. Government agencies and private organizations should invest in training programs to equip personnel with the technical skills needed to operate and maintain AI systems effectively.
- ii. Adequate technological infrastructure, including smart waste bins, AI-enabled sorting facilities, and data management systems, should be expanded to support seamless AI integration.
- iii. Policymakers should implement supportive regulatory frameworks, incentives, and standards that promote AI adoption while ensuring alignment with circular economy objectives.
- iv. Collaboration between government, private firms, and technology providers should be encouraged to share expertise, funding, and best practices for AI-driven waste management solutions.
- v. Continuous awareness campaigns and stakeholder engagement should be promoted to demonstrate the benefits of AI technologies and encourage community participation in sustainable waste practices.

REFERENCES

- Adebayo, T., & Okeke, C. (2023). Digital innovations in Nigerian waste management: Challenges and prospects. *Environmental Technology & Innovation*, 31, 102241. <https://doi.org/10.1016/j.eti.2023.102241>
- Adepoju, T., & Alabi, O. (2020). Employee participation in decision-making and organizational performance: Evidence from Nigerian firms. *Journal of Human Resource Management*, 8(2), 45–56. <https://doi.org/10.11648/j.jhrm.20200802.11>
- Ahmed, M., & Mensah, J. (2022). Governance and technological innovation for environmental sustainability in Africa. *Sustainable Development*, 30(4), 765–779. <https://doi.org/10.1002/sd.2281>
- Akinola, S. O., & Odeniyi, L. A. (2026). The role of artificial intelligence (AI) in circular economy in a bid to ameliorate global waste crises. *University of Ibadan Journal of Science and Logics in ICT Research*, 15(1).

- Akinwale, A. (2022). Circular economy awareness and technology adoption in Nigerian cities. *Journal of Environmental Management*, 321, 115831. <https://doi.org/10.1016/j.jenvman.2022.115831>
- Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an enabler of circular economy. *Procedia CIRP*, 73, 45–49. <https://doi.org/10.1016/j.procir.2018.04.027>
- Armstrong, M., & Taylor, S. (2020). *Armstrong's handbook of human resource management practice* (15th ed.). Kogan Page.
- Barteková, E., & Börkey, P. (2022). Digitalisation for the transition to a resource efficient and circular economy. *OECD Environment Working Papers*, No. 192. OECD Publishing. <https://doi.org/10.1787/6f6d18e7-en>
- Bifulco, F., Liguori, M., & Palomba, G. (2020). AI in environmental management: Opportunities and barriers. *Journal of Cleaner Production*, 263, 121456. <https://doi.org/10.1016/j.jclepro.2020.121456>
- Boxall, P., & Purcell, J. (2016). *Strategy and human resource management* (4th ed.). Palgrave Macmillan.
- Brewster, C., Chung, C., & Sparrow, P. (2016). Globalizing human resource management. *International Journal of Human Resource Management*, 27(9), 897–919. <https://doi.org/10.1080/09585192.2015.1101194>
- Budhwar, P., & Debrah, Y. (2019). *Human resource management in developing countries* (2nd ed.). Routledge.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
- Dessler, G. (2021). *Human resource management* (16th ed.). Pearson.
- Ellen MacArthur Foundation. (2019). *Completing the picture: How the circular economy tackles climate change*. <https://www.ellenmacarthurfoundation.org>
- Ellen MacArthur Foundation. (2019). *The circular economy in detail*. Ellen MacArthur Foundation.
- Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). SAGE Publications.
- Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage.
- Jabbour, C. J. C., Neto, A. S., & de Sousa Jabbour, A. B. L. (2021). AI adoption in environmental management: Impacts on resource efficiency. *Journal of Cleaner Production*, 315, 128117. <https://doi.org/10.1016/j.jclepro.2021.128117>
- Kaufman, B. E. (2020). Theoretical perspectives on work and the employment relationship. *Industrial Relations Research Association*, 72(1), 23–41. <https://doi.org/10.1111/irel.12234>
- Kaza, S., Yao, L. C., Bhada-Tata, P., Van Woerden, F., & Levine, D. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank. <https://doi.org/10.1596/978-1-4648-1329-0>
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221–232. <https://doi.org/10.1016/j.resconrec.2017.09.005>
- Kochan, T. A., Katz, H. C., & McKersie, R. B. (2018). *The transformation of American industrial relations*. Cornell University Press.
- Kumar, P., Singh, R., & Sharma, A. (2022). Longitudinal analysis of AI-driven smart waste management systems. *Sustainable Cities and Society*, 82, 103910. <https://doi.org/10.1016/j.scs.2022.103910>
- Lu, Y., Li, X., & Zhao, H. (2020). Digital innovation and environmental sustainability: Evidence from 50 countries. *Technological Forecasting and Social Change*, 160, 120231. <https://doi.org/10.1016/j.techfore.2020.120231>
- Mensah, J. (2019). Employee grievance management and productivity in organizations: Evidence from Ghana. *African Journal of Management*, 5(1), 67–82. <https://doi.org/10.33423/ajm.v5i1.230>
- Nzeadibe, T. C., & Anyadike, R. N. C. (2012). Urban waste management in Nigeria: The state of play. *Environmental Development*, 2(1), 93–105. <https://doi.org/10.1016/j.envdev.2012.02.002>
- Ogwueleka, T. C. (2013). Municipal solid waste characteristics and management in Nigeria. *Iranian Journal of Environmental Health Science & Engineering*, 10, 36. <https://doi.org/10.1186/1735-2746-10-36>
- Olawade, D. B., Yadav, R. N., & Wada, O. Z. (2026). AI-driven circular economy optimization in waste management: A review of current evidence. *Environmental Progress & Sustainable Energy*, 45(3), e70322. <https://doi.org/10.1002/ep.70322>
- Oluwafemi, A., & Adeyemi, S. (2021). Impact of grievance handling procedures on employee satisfaction and retention: Evidence from Nigerian telecom firms. *International Journal of Business and Management Studies*, 13(2), 89–102. <https://doi.org/10.34104/ijbms.021.089102>

- Organisation for Economic Co-operation and Development. (2021). *Artificial intelligence in public service delivery: Opportunities and challenges*. OECD Publishing. <https://www.oecd.org>
- Organisation for Economic Co-operation and Development. (2021). *OECD business and finance outlook 2021: AI in finance*. OECD Publishing.
- Oyasor, E. I. (2025). Artificial intelligence, circular economy, and sustainable waste management in Nigeria. *International Journal of Social and Educational Innovation*, 12(24), 438–461. <https://doi.org/10.5281/zenodo.17987962>
- Pallant, J. (2020). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS* (7th ed.). McGraw-Hill Education.
- Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- Snoun, A., Mufida, M. K., El-Cadi, A. A., & Delot, T. (2025). AI-driven innovations in waste management: Catalyzing the circular economy. *Engineering Proceedings*, 97(1), 12. <https://doi.org/10.3390/engproc2025097012>
- Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48, 1273–1296. <https://doi.org/10.1007/s11165-016-9602-2>
- United Nations Environment Programme. (2019). *Dark skies, bright future: Overcoming Nigeria's e-waste epidemic*. United Nations Environment Programme.
- United Nations Environment Programme. (2020). *Nigeria: Waste management and environmental challenges*. UNEP. <https://www.unep.org>
- Wilson, D. C., Rodic, L., Cowing, M. J., Velis, C. A., Whiteman, A. D., Scheinberg, A., Vilches, R., Masterson, D., Stretz, J., & Oelz, B. (2015). 'Wasteaware' benchmark indicators for integrated sustainable waste management in cities. *Waste Management*, 35, 329–342. <https://doi.org/10.1016/j.wasman.2014.10.006>
- Wilson, D. C., Velis, C., & Cheeseman, C. (2015). Role of technology in improving global waste management systems. *Waste Management & Research*, 33(9), 797–798. <https://doi.org/10.1177/0734242X15597884>
- World Bank. (2022). *Solid waste management in Nigeria: Challenges and opportunities*. World Bank Group. <https://www.worldbank.org>
- Yevle, D. V., & Mann, P. S. (2025). Artificial intelligence-based waste management: A review of classification, techniques, issues, and challenges. *WIREs Data Mining and Knowledge Discovery*, 15(2), e70025. <https://doi.org/10.1002/widm.70025>
- Zhang, H., Li, Y., & Liu, J. (2021). AI adoption and recycling efficiency: Evidence from developed and emerging economies. *Journal of Environmental Management*, 292, 112755. <https://doi.org/10.1016/j.jenvman.2021.112755>