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REVERSE LOGISTICS AND SUSTAINABLE WASTE MANAGEMENT IN MANUFACTURING FIRMS: THE ROLE OF ORGANISATIONAL CAPABILITIES AND INSTITUTIONAL SUPPORT IN NORTHERN NIGERIA

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ABSTRACT

This study examined the determinants of industrial reverse logistics adoption and sustainable waste management among selected manufacturing firms in Northern Nigeria, focusing on Kano, Kaduna, Sokoto and Plateau States. Specifically, it assessed the extent of reverse logistics adoption and sustainable waste-management practices, examined the influence of organizational, technological and institutional factors on effective waste management, and identified the major barriers confronting manufacturing firms. The study adopted a cross-sectional survey research design, using structured questionnaires administered to 200 respondents drawn from selected manufacturing firms. Data analysis involved descriptive statistics and binary logistic regression. The results indicated that reverse logistics adoption, financial capacity, technological readiness, recycling infrastructure, managerial commitment, environmental awareness and stakeholder collaboration were positively and significantly associated with effective sustainable waste management. However, regulatory enforcement showed no statistically significant relationship. In addition, inadequate recycling infrastructure, financial constraints, high collection and transportation costs, limited access to appropriate technologies and insufficient technical skills emerged as major barriers. The study concludes that effective industrial waste management requires coordinated organizational commitment, adequate resources, technological investment and stakeholder cooperation. It recommends strengthening reverse logistics systems, improving recycling infrastructure, providing accessible financing and enhancing regulatory monitoring and technical support. The study contributes to understanding the organizational and institutional conditions necessary for sustainable industrial waste management in Northern Nigeria.

Keywords: Reverse Logistics, Sustainable Waste Management, Manufacturing Firms, Recycling Infrastructure, Northern Nigeria.

1 INTRODUCTION

The manufacturing sector plays a significant role in economic transformation through industrial production, employment generation, technological development and value addition. In Nigeria, its contribution to economic activity highlights the importance of improving the sustainability of industrial operations. The National Bureau of Statistics (NBS, 2026) reported that manufacturing contributed approximately 8.05% to Nigeria's real gross domestic product in 2025. However, manufacturing activities generate different categories of waste, including production residues, defective products, packaging materials, scrap metals, plastics and chemical residues. Inadequate management of these materials can contribute to environmental pollution, resource depletion, public health risks and increased production costs. The World Bank (2026) estimates that global municipal solid waste generation reached 2.56 billion tonnes in 2022 and could increase to 3.86 billion tonnes by 2050. Although these figures relate to municipal rather than industrial waste, they illustrate the increasing pressure on waste-management systems. Consequently, the transition from the traditional linear production model, characterised by the take–make–dispose approach, towards a circular economy has become increasingly important. The circular economy emphasises resource efficiency, waste prevention, reuse, repair, remanufacturing, recycling and material recovery (Assmann et al., 2023; Mallick et al., 2023).

Within this transition, industrial reverse logistics represents an important mechanism for promoting resource recovery and sustainable waste management. It involves the planning, implementation and control of the movement of used, defective, surplus or end-of-life products and materials from their point of use to their point of origin or an appropriate recovery destination. Its activities include collection, sorting, transportation, repair, refurbishment, remanufacturing, reuse and recycling. Unlike conventional logistics, reverse logistics establishes recovery channels through which discarded materials can re-enter production or undergo appropriate treatment. It therefore provides opportunities to reduce waste disposal, recover economic value, conserve natural resources and improve operational efficiency (U-Dominic et al., 2021; Mallick et al., 2023). Mallick et al. (2023), in a systematic review of 116 scholarly articles, identified reverse logistics as an important component of circular economy implementation, highlighting its adoption drivers, barriers and performance implications.

The relevance of reverse logistics is particularly evident across manufacturing subsectors that generate recoverable materials. Textile manufacturers can recover fabric remnants, plastic manufacturers can recycle production offcuts, metal fabrication firms can recover scrap metals, while food-processing companies can utilise suitable production by-products. However, successful implementation requires adequate financial resources, appropriate technologies, accessible recycling infrastructure, managerial commitment, environmental awareness and stakeholder collaboration. Regulatory enforcement also provides an institutional mechanism for encouraging compliance with environmental standards. Assmann et al. (2023), in a systematic review of 67 journal articles, identified regulation, collaboration, organisational culture, strategy, market conditions and knowledge as important considerations in circular business model adoption.

These requirements present particular challenges in developing economies such as Nigeria, where manufacturing firms may encounter financial constraints, inadequate recycling infrastructure, limited technical expertise and institutional weaknesses. The World Bank (2024) estimated that Nigeria generated approximately 44.5 million metric tonnes of municipal solid waste in 2021, with less than 20% formally collected. Although these figures do not represent industrial waste generation, they illustrate broader limitations in the country's waste collection and recovery environment. Similarly, U-Dominic et al. (2021) identified inadequate technical expertise and hazardous-material storage risks among the barriers to reverse logistics implementation in Nigerian manufacturing. These challenges indicate that effective industrial waste management requires more than organisational willingness; it also depends on resources, infrastructure, technology and supportive institutional arrangements.

Despite growing scholarly attention to reverse logistics, three interconnected research gaps remain. First, an empirical gap concerns the limited firm-level evidence examining reverse logistics adoption alongside sustainable industrial waste-management outcomes in Nigeria. Existing Nigerian research, including U-Dominic et al. (2021), has provided useful evidence on implementation barriers, but further investigation is necessary to understand how adoption practices relate to firms' waste-management outcomes. International studies have examined recycling practices, implementation drivers and organisational performance (Kamanga et al., 2022; Le, 2023; Appiah & Owusu-Bio, 2024), but their findings may not fully explain the conditions facing Nigerian manufacturers.

Second, an integrative gap exists in the limited examination of financial capacity, technological readiness, recycling infrastructure, managerial commitment, environmental awareness, regulatory enforcement and stakeholder collaboration within a unified explanatory framework. These factors are interconnected: financial resources support technological investment, infrastructure facilitates material recovery, managerial commitment promotes implementation, while collaboration strengthens coordination among manufacturers, suppliers and recyclers.

Examining them together provides a broader understanding of the organisational and institutional conditions associated with sustainable waste management.

Third, a contextual gap concerns limited firm-level evidence from Northern Nigeria. The region provides an analytically relevant setting because manufacturing firms operate across different industrial and institutional environments, with possible differences in industrial concentration, recycling infrastructure, institutional support and access to recovery technologies. Manufacturing activities across Kano, Kaduna, Sokoto and Plateau States include textiles, plastics, food processing, leather and metal fabrication, generating different categories of recoverable materials. These variations provide an opportunity to examine how organisational capabilities and infrastructural conditions relate to reverse logistics and waste-management practices across selected manufacturing settings.

Against this background, the study examines industrial reverse logistics and sustainable waste management among selected manufacturing firms in Kano, Kaduna, Sokoto and Plateau States. Specifically, it assesses the extent of reverse logistics adoption and sustainable waste-management practices, examines the relationships between effective sustainable waste management and eight explanatory factors, and identifies the major implementation barriers. The study contributes by providing firm-level evidence from selected Nigerian manufacturing settings, integrating organisational, technological, financial, infrastructural and institutional factors within an explanatory framework informed by the Natural Resource-Based View, and extending empirical understanding to four states in Northern Nigeria. Its findings are expected to inform manufacturing managers and policymakers on strengthening reverse logistics, resource recovery and sustainable industrial waste management.

2 LITERATURE REVIEW

2.1 Conceptual framework

The conceptual framework illustrates the relationship between eight independent variables and effective sustainable waste management among selected manufacturing firms in Northern Nigeria. Reverse logistics adoption represents the establishment of systems for collecting, returning, reusing and recycling discarded materials. Financial capacity provides the resources required to finance recovery operations, while technological readiness facilitates efficient material identification, sorting and processing. Recycling infrastructure provides the facilities necessary for collecting, transporting and recovering industrial waste. Managerial commitment encourages the integration of reverse logistics into organizational policies and operational decisions. Environmental awareness promotes understanding of the consequences of improper waste disposal, while regulatory enforcement encourages compliance with environmental standards. Stakeholder collaboration strengthens coordination among manufacturers, suppliers, customers, recycling operators and government agencies.

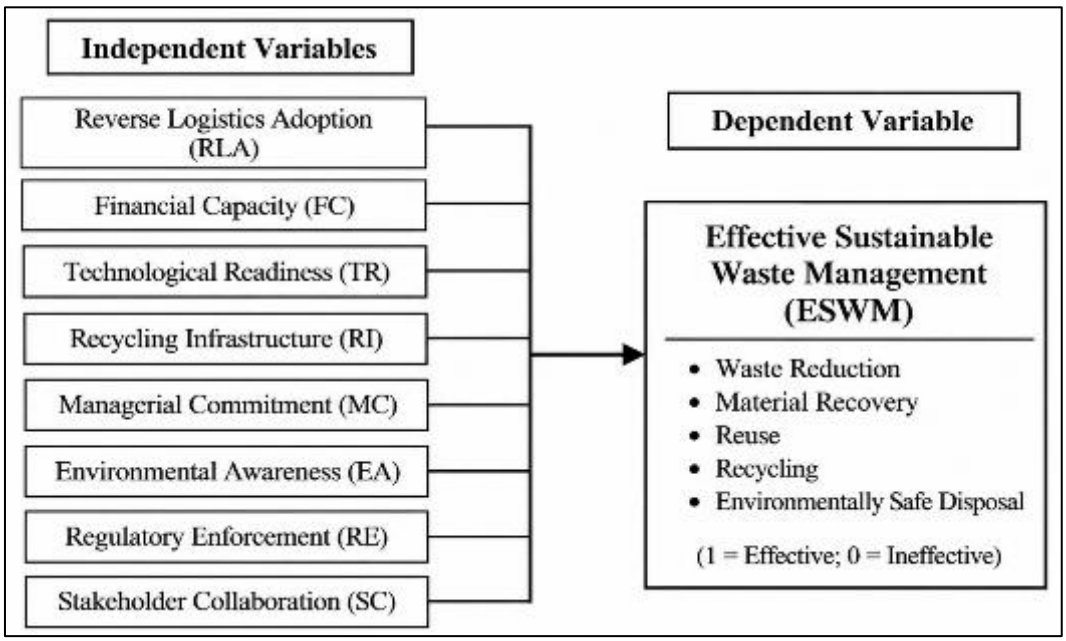


Figure 1: Conceptual framework

Source: Author's conceptualization (2026).

These factors are expected to improve waste reduction, material recovery, reuse, recycling and environmentally safe disposal. This relationship is consistent with Assmann et al. (2023), who identified organizational, regulatory, financial and collaborative factors as important determinants of circular business model adoption. Similarly, Sandamini et al. (2025) highlighted organizational, economic, technological, infrastructural and regulatory influences on reverse logistics in waste management.

2.2 Theoretical framework

This study is anchored on the Natural Resource-Based View (NRBV) proposed by Hart (1995). The theory extends the traditional Resource-Based View by recognizing that a firm's competitive advantage and long-term performance are increasingly influenced by its ability to manage environmental challenges and utilize natural resources efficiently. It identifies three strategic capabilities: pollution prevention, product stewardship and sustainable development. These capabilities emphasize reducing waste at source, improving resource efficiency and integrating environmental considerations into organizational operations. The NRBV is considered the most appropriate theoretical foundation for this study because industrial reverse logistics directly supports the environmental capabilities emphasized by the theory. Through collection, reuse, recycling, remanufacturing and material recovery, manufacturing firms can minimize waste generation, reduce resource consumption and improve environmental performance. Furthermore, the theory provides a basis for examining how financial capacity, technological readiness, recycling infrastructure and managerial commitment facilitate the development of environmental capabilities. Environmental awareness, regulatory enforcement and stakeholder collaboration can also encourage firms to incorporate sustainable practices into their operations. Therefore, the NRBV provides a coherent theoretical explanation of how reverse logistics adoption and organizational capabilities can contribute to effective sustainable waste management among manufacturing firms in Northern Nigeria.

2.3 Empirical review

Recent empirical research has increasingly examined reverse logistics as a mechanism for resource recovery, circular production and environmental sustainability. However, findings indicate that its implementation and outcomes depend on firms' organisational capabilities, technological resources, financial conditions and relationships with external stakeholders.

U-Dominic et al. (2021) investigated barriers to reverse logistics implementation in the Nigerian manufacturing sector using an integrated Intuitionistic Fuzzy-DEMATEL-EDAS approach. Their findings identified low product quality, risks associated with hazardous-material storage and inadequate technical expertise as highly prioritised implementation barriers. The study provides important evidence on the Nigerian manufacturing environment, but its multi-criteria decision-making approach prioritised barriers rather than statistically estimating their relationships with sustainable waste-management outcomes among manufacturing firms. This limitation leaves room for firm-level empirical investigation.

Schöggl et al. (2023) examined the role of inter-organisational collaboration and digital technologies in circular-economy implementation among 112 Austrian manufacturing firms using partial least squares structural equation modelling. Their findings showed that collaboration had a strong positive relationship with the implementation of circular-economy practices and that such practices were positively associated with sustainability and economic performance. However, digital technologies did not directly improve circular-economy implementation, although they supported inter-organisational collaboration. This finding suggests that technological readiness may depend on complementary organisational arrangements rather than technology investment alone. Similarly, Rasool et al. (2023), using evidence from German firms, demonstrated the relevance of reverse logistics to firm-level digitalisation and collaboration, further emphasising its strategic role beyond material recovery.

Appiah and Owusu-Bio (2024) examined reverse logistics and financial performance among 200 manufacturing firms in Ghana using partial least squares structural equation modelling. Their results revealed a negative relationship between reverse logistics and financial performance, but analytics capability weakened this negative association and improved the potential financial benefits of reverse logistics. This finding highlights the financial and technological complexities associated with recovery operations, indicating that reverse logistics may impose additional costs where firms lack appropriate information-processing capabilities.

Pan et al. (2024) conducted a meta-analytic structural equation modelling study synthesising 66 empirical studies involving 13,643 manufacturing firms. They found that circular-economy practices generally improved environmental, operational, financial and other organisational performance outcomes. Specifically, eliminating waste and pollution positively affected several performance dimensions, while circulating products and materials improved environmental, financial-market and operational performance. Although this provides strong cumulative evidence for circular production, the study examined broader circular-economy practices rather than the specific contribution of reverse logistics to sustainable industrial waste management.

Hove-Sibanda et al. (2025) investigated reverse logistics practices among 80 South African SMEs using questionnaire data. Their findings showed that waste management, remanufacturing and repackaging practices were positively associated with competitive advantage. Nevertheless, the cost of adopting reverse logistics and limited awareness of available support were identified as major barriers. The findings reinforce the importance of financial capacity and organisational awareness, although the SME focus limits direct generalisation to larger manufacturing firms.

More recently, Yanginlar et al. (2026) examined reverse logistics and sustainable supply-chain performance among automotive suppliers and manufacturers in Türkiye. Using survey data from 120 firms and complementary interviews with 11 managers, the study found that artificial intelligence adoption partially mediated the relationship between reverse logistics implementation and sustainability performance, while top-management support strengthened technology adoption. This provides further evidence that technological capabilities and managerial commitment are complementary conditions for effective reverse logistics implementation.

In general, existing studies establish the importance of reverse logistics, organisational resources, technological capabilities and stakeholder collaboration. Nevertheless, three limitations remain. First, Nigerian evidence is still limited in examining firm-level relationships between reverse logistics adoption and effective sustainable waste management. Second, previous studies have frequently investigated financial, technological, infrastructural, managerial and institutional factors separately or through broader circular-economy frameworks. Third, evidence from manufacturing firms operating across different industrial and institutional environments in Northern Nigeria remains limited. The present study addresses these limitations by jointly examining reverse logistics adoption, financial capacity, technological readiness, recycling infrastructure, managerial commitment, environmental awareness, regulatory enforcement and stakeholder collaboration among selected manufacturing firms in Kano, Kaduna, Sokoto and Plateau States.

3 METHODOLOGY

3.1 Research Design

The study adopted a quantitative cross-sectional survey research design to examine the determinants of industrial reverse logistics adoption and sustainable waste management among selected manufacturing firms in Northern Nigeria. The design enabled the collection of quantitative data from manufacturing firms at a single point in time without manipulating the study variables. It was considered appropriate because the study assessed existing reverse logistics practices and examined how organizational, technological, financial and institutional factors were associated with effective sustainable waste management (Creswell & Creswell, 2023). Primary data were collected exclusively through structured questionnaires administered to knowledgeable representatives of selected manufacturing firms. The data were analysed using descriptive statistics and binary logistic regression. Although the regression model estimated the statistical associations between the explanatory variables and the likelihood of effective sustainable waste management, the cross-sectional design did not establish definitive causal relationships.

3.2 Population of the Study

The target population comprised manufacturing firms operating in four selected states in Northern Nigeria: Kano, Kaduna, Sokoto and Plateau. The study focused on firms engaged in manufacturing and processing activities, including textiles, plastics, food and beverage processing, leather and footwear, metal fabrication, agro-processing and other relevant industrial activities. The firm constituted the unit of analysis because reverse logistics adoption and sustainable waste-management practices were organisational activities. Information was obtained from respondents who possessed adequate knowledge of their firms' production, logistics, procurement, environmental and waste-management operations. These included production managers, operations managers, logistics and supply-chain managers, environmental or waste-management officers, and procurement managers.

A comprehensive and consistently updated population figure for eligible manufacturing firms across the four selected states was not available. Consequently, the sampling frame was developed using available records from relevant state ministries, manufacturing associations, industrial directories and other identifiable business registers. Only firms engaged in manufacturing or industrial processing activities and capable of providing relevant information on their waste-management practices were included.

3.3 Sample Size and Sampling Technique

The study adopted a sample size of 200 manufacturing firms across the four selected states. The sample was intended to provide firm-level observations for descriptive analysis and the estimation of a binary logistic regression model involving eight explanatory variables. The adequacy of the sample was considered in relation to the distribution of the binary dependent variable and the number of effective and ineffective waste-management observations. Particular

attention was given to obtaining adequate observations in both outcome categories to minimise estimation bias and improve the reliability of the regression estimates.

3.4 Sampling Technique and Data Collection

A multistage sampling approach was employed. First, Kano, Kaduna, Sokoto and Plateau States were purposively selected because of their manufacturing and industrial activities. Second, manufacturing firms were identified and classified according to their locations and relevant subsectors. Where sufficiently comprehensive sampling frames were available, firms were selected randomly within the identified state and subsector categories. Where such frames were unavailable, purposive selection was used to identify eligible firms, followed by convenience sampling during questionnaire administration.

One knowledgeable representative was targeted from each participating firm to provide a firm-level response. Where more than one employee completed the questionnaire in a firm, their responses were reconciled into a single firm-level observation before analysis. This procedure ensured that multiple respondents from the same firm were not automatically treated as independent organisational observations.

Questionnaires were administered electronically and. Respondents were informed about the purpose of the study, and participation was voluntary. Informed consent was obtained before questionnaire completion. Returned questionnaires were screened for completeness, inconsistent responses, missing information and possible duplicate submissions. Only valid firm-level responses were retained for analysis. Because purposive and convenience sampling were used where comprehensive sampling frames were unavailable, the sample did not necessarily constitute a probability-based or representative sample of all manufacturing firms in Northern Nigeria. Accordingly, the findings were interpreted within the context of the participating firms in the four selected states.

3.5 Variables and Measurement

The study comprised one dependent variable and eight explanatory variables. The dependent variable was effective sustainable waste management (ESWM), while the explanatory variables were reverse logistics adoption (RLA), financial capacity (FC), technological readiness (TR), recycling infrastructure (RI), managerial commitment (MC), environmental awareness (EA), regulatory enforcement (RE) and stakeholder collaboration (SC).

The explanatory variables were measured using multiple questionnaire items adapted from relevant empirical literature and modified to reflect the manufacturing context of the selected states. Perception-based items were assessed on a five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. Reverse logistics adoption was additionally assessed through questions on the existence and implementation of material collection, return, reuse, remanufacturing and recycling arrangements.

Table 1: Variables and Measurement

Variable	Measurement and indicators
Reverse Logistics Adoption (RLA)	Existence of formal collection and return systems; sorting of returned materials; reuse of recovered materials; recycling and remanufacturing arrangements.
Financial Capacity (FC)	Availability of funds for reverse logistics; budget allocation for waste management; capacity to invest in recovery equipment; affordability of collection and recycling operations.
Technological Readiness (TR)	Availability of appropriate recovery technologies; access to waste-sorting equipment; technical expertise; use of digital systems for tracking and managing recovered materials.
Recycling Infrastructure (RI)	Availability of recycling facilities; access to waste collection and transportation services; proximity to recycling operators; adequacy of material recovery facilities.
Managerial Commitment (MC)	Management support for reverse logistics; inclusion of waste-management objectives in organizational policies; allocation of responsibilities; monitoring of environmental performance.
Environmental Awareness (EA)	Management and employee awareness of environmental impacts; knowledge of sustainable waste practices; understanding of resource recovery benefits; environmental training.

Regulatory Enforcement (RE)	Awareness of relevant environmental regulations; monitoring and inspection; compliance requirements; perceived consistency of regulatory enforcement.
Stakeholder Collaboration (SC)	Cooperation with suppliers, customers, recycling operators, waste-management companies and relevant government agencies.
Effective Sustainable Waste Management (ESWM)	Waste reduction, material recovery, reuse, recycling and environmentally appropriate disposal.

Source: Researcher's conceptualization

The questionnaire items for each explanatory construct were aggregated using arithmetic means to obtain composite scores. For a construct with four measurement items, for example:

$$FC_i = \frac{FC_{1i} + FC_{2i} + FC_{3i} + FC_{4i}}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

The same procedure was applied to the other Likert-scale explanatory variables, depending on the number of valid items retained for each construct. The dependent variable, ESWM, was operationalized as a binary variable. Responses to the waste-management indicators were first combined into a composite score. A theoretically justified cut-off was established before the main regression analysis to classify firms as having effective or ineffective sustainable waste-management practices. Firms meeting the predetermined threshold were coded 1 (effective), while those below it were coded 0 (ineffective). The threshold was not selected retrospectively to produce statistically significant results. Reverse logistics adoption was measured separately from the dependent variable. A firm was classified as an adopter where it had an established and functioning system for recovering or returning materials, rather than merely expressing an intention to adopt such practices.

3.6 Model Specification

The study employed a binary logistic regression model to examine the influence of reverse logistics adoption and the other explanatory variables on the likelihood of effective sustainable waste management. Logistic regression was considered appropriate because the dependent variable was dichotomous, taking the value of one for effective sustainable waste management and zero otherwise.

The probability of effective sustainable waste management was specified as:

$$P(ESWM_i = 1) = \frac{1}{1 + e^{-Zi}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where:

$$Z_i = \beta_0 + \beta_1 RLA_i + \beta_2 FC_i + \beta_3 TR_i + \beta_4 RI_i + \beta_5 MC_i + \beta_6 EA_i + \beta_7 RE_i + \beta_8 SC_i + e_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where: ESWM is the Effective sustainable waste management of firm i (1 = effective; 0 = ineffective). RLA is the Reverse logistics adoption, FC is the financial capacity, TR is the technological readiness Recycling infrastructure, MC is the Managerial commitment. EA is the Environmental awareness, RE is the Regulatory enforcement, SC is the Stakeholder collaboration. β_0 is the Constant term. $\beta_1 - \beta_8$ are Parameters estimated. e_i is the Error term and i is the Individual manufacturing firm.

3.7 Method of Data Analysis

Data obtained from the questionnaires were coded, cleaned and analyzed using the Statistical Package for the Social Sciences (SPSS), version 29. Descriptive statistics, including frequencies, percentages, means and standard deviations, were employed to summarize the characteristics of participating firms and the extent of reverse logistics adoption and sustainable waste-management practices. Binary logistic regression was subsequently employed to examine the influence of the eight explanatory variables on the likelihood of effective sustainable waste management. The model was estimated using the maximum likelihood method. Statistical significance was assessed at the 5% level. The results were presented using descriptive tables and logistic regression estimates. Interpretation focused on the statistical significance, direction and magnitude of the estimated relationships.

3.8 Research Instrument

The primary instrument for data collection was a structured questionnaire developed to obtain quantitative information from representatives of the selected manufacturing firms. The questionnaire contained two main sections. Section A obtained information on the characteristics of participating firms, including state of operation, manufacturing

subsector, years of operation, number of employees, ownership structure and respondents' managerial positions. Section B contained measurement items relating to reverse logistics adoption, financial capacity, technological readiness, recycling infrastructure, managerial commitment, environmental awareness, regulatory enforcement, stakeholder collaboration and sustainable waste-management practices.

The questionnaire predominantly employed a five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. Additional categorical questions were included where necessary to establish whether firms had functioning reverse logistics arrangements and to obtain information on their waste-management activities.

To minimize potential common method bias arising from collecting information on both explanatory and dependent variables through the same instrument, procedural measures were incorporated into questionnaire design and administration. These included clear and neutral instructions, simple and unambiguous wording, voluntary participation and assurances of confidentiality. Respondents were also encouraged to provide honest responses without any expectation of particular answers. Following data collection, Harman's single-factor test was conducted as an initial statistical assessment of common method bias. However, the result was interpreted cautiously because the test alone could not conclusively establish the absence of common method bias.

3.9 Validity and Reliability of the Research Instrument

The questionnaire was subjected to face and content validity through expert assessment by specialists in logistics and supply-chain management, environmental management, manufacturing and research methodology. Their recommendations were incorporated to improve the clarity, relevance and adequacy of the measurement items. A pilot study was conducted among manufacturing firms outside the final sample, preferably in a location with comparable industrial characteristics. The pilot exercise helped identify ambiguous questions, assess the appropriateness of the measurement scales and establish the time required to complete the questionnaire. Necessary modifications were made before the main survey. Reliability was assessed using Cronbach's alpha for the multi-item Likert-scale constructs. A coefficient of 0.70 or above was considered acceptable evidence of internal consistency (Nunnally & Bernstein, 1994). Reliability was examined separately for each construct rather than relying on a single overall coefficient because the study measured conceptually distinct variables. Where appropriate, exploratory factor analysis was also used to examine the underlying structure of the measurement items.

3.10 Ethical Considerations

The study observed relevant research ethics throughout the data collection and analysis processes. Appropriate institutional approval was obtained before questionnaire administration. Participation was voluntary, and respondents were informed about the purpose of the research and their right to withdraw without penalty. Informed consent was obtained before participation. The questionnaire did not require respondents to disclose confidential business information or personally identifying details unless essential and appropriately justified. All responses were treated confidentially, used strictly for academic purposes and reported in aggregate form to protect participating firms and individuals.

4 DATA PRESENTATION AND ANALYSIS

Table 2: Demographic Profile of the Respondents

Demographic characteristics	Particulars	Frequency	Percentage (%)
State of Operation	Kano	50	25.0
	Kaduna	50	25.0
	Sokoto	50	25.0
	Plateau	50	25.0
	Total	200	100.0
Manufacturing Subsector	Textiles and garments	28	14.0
	Plastics and rubber	32	16.0
	Food and beverage processing	42	21.0
	Leather and footwear	24	12.0

	Metal fabrication	30	15.0
	Agro-processing	34	17.0
	Other manufacturing activities	10	5.0
	Total	200	100.0
Years of Business Operation	Below 5 years	26	13.0
	5–10 years	62	31.0
	11–15 years	54	27.0
	16–20 years	34	17.0
	Above 20 years	24	12.0
	Total	200	100.0
Number of Employees	1–10	22	11.0
	11–50	68	34.0
	51–100	48	24.0
	101–200	36	18.0
	Above 200	26	13.0
	Total	200	100.0
Position of Respondent	Production/Operations Manager	52	26.0
	Logistics/Supply Chain Manager	40	20.0
	Environmental/Waste Management Officer	34	17.0
	Procurement Manager	30	15.0
	General Manager/Director	36	18.0
	Other relevant officers	8	4.0
	Total	200	100.0
Designated Environmental/Waste Management Unit	Yes	118	59.0
	No	82	41.0
	Total	200	100.0
Existing Reverse Logistics System	Yes	86	43.0
	No	96	48.0
	Not sure	18	9.0
	Total	200	100.0

Source: Author's computation (2026).

The demographic distribution in Table 2 presents the organizational characteristics of the 200 manufacturing firms covered in the study. The geographical distribution shows an equal representation of Kano, Kaduna, Sokoto and Plateau States, with each accounting for 25.0% of the sample. This balanced distribution provides coverage across the four selected states. Regarding manufacturing subsectors, food and beverage processing recorded the highest representation (21.0%), followed by agro-processing (17.0%) and plastics and rubber (16.0%). Other manufacturing activities had the lowest representation (5.0%), indicating that the sample covered different industrial activities. In terms of business experience, the majority of firms (58.0%) had operated for between 5 and 15 years, suggesting that most were established businesses with considerable operational experience. Similarly, 58.0% employed between 11 and 100 workers, indicating a substantial representation of small and medium-sized manufacturing firms. Regarding respondents' positions, production and operations managers constituted the largest proportion (26.0%), followed by logistics and supply-chain managers (20.0%). This suggests that the respondents occupied positions relevant to the study. Furthermore, 59.0% of firms had designated environmental or waste-management units, while 43.0% reported

having existing reverse logistics systems. Notably, 48.0% had no such system, suggesting potential gaps in reverse logistics adoption. In general, the profile provides a useful organizational context for examining sustainable waste management practices among the selected manufacturing firms.

4.1 Pre-estimation Test

Table 3: Descriptive Statistics

Variables	N	Mean	Std. Deviation	Minimum	Maximum
RLA	200	3.42	0.91	1.00	5.00
FC	200	3.18	0.88	1.00	5.00
TR	200	3.36	0.85	1.00	5.00
RI	200	2.94	0.96	1.00	5.00
MC	200	3.71	0.79	1.00	5.00
EA	200	3.63	0.82	1.00	5.00
RE	200	3.05	0.93	1.00	5.00
SC	200	3.27	0.87	1.00	5.00
ESWM	200	3.31	0.84	1.00	5.00

Source: Author's computation (2026).

Table 3 presents the descriptive statistics of the study variables based on 200 observations. Managerial commitment (MC) recorded the highest mean of 3.71, followed by environmental awareness (EA) at 3.63, indicating relatively favorable management support and environmental consciousness among the firms. Reverse logistics adoption (RLA) also recorded a mean of 3.42, while technological readiness (TR) stood at 3.36. Sustainable waste management (ESWM) had a mean of 3.31, suggesting a moderately positive level of adoption. Stakeholder collaboration (SC) recorded 3.27, whereas financial capacity (FC) and regulatory enforcement (RE) had means of 3.18 and 3.05, respectively. Recycling infrastructure (RI) recorded the lowest mean of 2.94, indicating a potential infrastructural constraint. Standard deviations ranged from 0.79 to 0.96, suggesting moderate variation in responses.

Table 4: Reliability Test of the Research Variables

Variables	Items	Cronbach's Alpha
Reverse Logistics Adoption (RLA)	5	0.842
Financial Capacity (FC)	4	0.816
Technological Readiness (TR)	4	0.858
Recycling Infrastructure (RI)	4	0.831
Managerial Commitment (MC)	4	0.879
Environmental Awareness (EA)	4	0.824
Regulatory Enforcement (RE)	4	0.805
Stakeholder Collaboration (SC)	4	0.847
Sustainable Waste Management (ESWM)	6	0.886

Source: Author's computation (2026).

Table 4 presents the reliability results for the nine research constructs. The Cronbach's alpha coefficients range from 0.805 to 0.886, exceeding the recommended threshold of 0.70. Managerial commitment recorded the highest reliability coefficient (0.879), followed by sustainable waste management (0.886), which actually represents the highest coefficient overall. Regulatory enforcement recorded the lowest value (0.805), although it remains within the acceptable range. These results indicate satisfactory internal consistency among the measurement items for each construct. Therefore, the research variables demonstrate acceptable reliability and are suitable for subsequent descriptive and inferential statistical analyses.

Table 5: Multicollinearity Test

Variables	VIF	Tolerance
RLA	1.82	0.549
FC	1.74	0.575
TR	2.16	0.463
RI	1.93	0.518
MC	2.08	0.481
EA	1.89	0.529
RE	1.67	0.599
SC	2.21	0.452

Source: Author's computation (2026).

Table 5 presents the multicollinearity test using Variance Inflation Factor (VIF) and tolerance values. The VIF values range from 1.67 to 2.21, which are considerably below the conventional threshold of 5. Similarly, the tolerance values range from 0.452 to 0.599, exceeding the minimum acceptable level of 0.10. Stakeholder collaboration recorded the highest VIF (2.21), while regulatory enforcement had the lowest (1.67). These results indicate that the explanatory variables do not exhibit problematic multicollinearity. Therefore, the predictors are sufficiently independent to be included simultaneously in the logistic regression model without serious concerns about inflated standard errors arising from high correlations.

Table 6: Omnibus Test and Model Summary

Omnibus Test	Chi-square	df	Sig.
Model	76.842	8	0.000
Model Summary		Value	
-2 Log Likelihood		164.327	
Cox and Snell R Square		0.319	
Nagelkerke R Square		0.432	
Number of observations		200	

Source: Author's computation (2026).

Table 6 indicates that the logistic regression model is statistically significant, with an omnibus chi-square value of 76.842 ($df = 8$, $p < 0.001$). This suggests that the explanatory variables jointly improve the prediction of effective sustainable waste management. The −2 Log Likelihood value of 164.327 reflects the model's fit. Furthermore, the Cox and Snell R-square (0.319) and Nagelkerke R-square (0.432) indicate that the model accounts for approximately 31.9% to 43.2% of the variation in sustainable waste management. Based on 200 observations, the results demonstrate that the model has significant explanatory power.

Table 7: Hosmer–Lemeshow Goodness-of-Fit Test

Chi-square	Df	Sig.
6.284	8	0.615

Source: Author's computation (2026).

Table 7 presents the Hosmer–Lemeshow goodness-of-fit test, which assesses the adequacy of the logistic regression model. The chi-square statistic is 6.284, with 8 degrees of freedom and a significance value of 0.615. Since the p-value exceeds the 0.05 significance level, the test indicates no statistically significant difference between the observed and predicted outcomes. Therefore, the model demonstrates an acceptable goodness of fit and is considered suitable for explaining the determinants of sustainable waste management among the sampled manufacturing firms.

4.2 Binary Logistic Regression Estimates

Table 8: Binary Logistic Regression Results

Variables	B	S.E.	Wald	Sig.	Exp(B)
Constant	-6.218	1.482	17.610	0.000	0.002
RLA	0.932	0.341	7.472	0.006	2.540
FC	0.518	0.237	4.775	0.029	1.679
TR	0.684	0.271	6.373	0.012	1.982
RI	0.761	0.293	6.747	0.009	2.140
MC	0.593	0.267	4.935	0.026	1.810
EA	0.427	0.211	4.094	0.043	1.533
RE	0.192	0.205	0.877	0.349	1.212
SC	0.549	0.244	5.063	0.024	1.732

Source: Author's computation (2026).

Table 8 presents the binary logistic regression results examining the determinants of effective sustainable waste management among manufacturing firms. The results reveal that seven of the eight explanatory variables have positive and statistically significant relationships with sustainable waste management.

Reverse logistics adoption (RLA) has a positive coefficient of 0.932 (p=0.006; OR=2.540). This indicates that firms adopting reverse logistics practices have approximately 2.54 times the odds of effective waste management compared with non-adopting firms, holding other factors constant. Financial capacity (FC) is also significant (B=0.518; p=0.029), suggesting that firms with adequate financial resources are better positioned to finance waste collection, transportation, recycling and recovery activities. Technological readiness (TR) positively influences sustainable waste management (B=0.684; p=0.012), implying that access to appropriate equipment, monitoring systems and technical capabilities improves waste-handling efficiency. Similarly, recycling infrastructure (RI) is significant (B=0.761; p=0.009), indicating that accessible collection, storage, transportation and recycling facilities facilitate effective material recovery. Managerial commitment (MC) (B=0.593; p=0.026) demonstrates that management support, resource allocation and clear organizational responsibilities encourage sustainable waste practices. Environmental awareness (EA) (B=0.427; p=0.043) suggests that employee knowledge and environmental training promote waste reduction, reuse and recycling. Stakeholder collaboration (SC) also has a significant positive effect (B=0.549; p=0.024), indicating that cooperation among manufacturers, suppliers, customers, recyclers and relevant institutions strengthens reverse logistics activities.

However, regulatory enforcement (RE) is positive but statistically insignificant (B=0.192; p=0.349). This suggests that regulatory pressure alone does not significantly explain effective waste management when other organizational and infrastructural factors are considered. In general, the findings identify reverse logistics adoption, recycling infrastructure and technological readiness as particularly important determinants.

4.3 Analysis of Barriers to Reverse Logistics Adoption and Sustainable Waste Management

Table: 9: Barrers to Reverse Logistic Adoption and Sustainable Management

Barriers	Mean	Std. Deviation	Rank
Inadequate recycling and waste-recovery infrastructure	4.12	0.83	1
Inadequate financial resources	4.03	0.88	2
High collection and transportation costs	3.94	0.91	3
Limited access to appropriate technologies	3.88	0.86	4
Limited technical skills	3.76	0.94	5
Poor stakeholder collaboration	3.69	0.89	6
Weak managerial commitment	3.54	0.97	7
Limited environmental awareness	3.42	0.92	8

Weak regulatory enforcement	3.31	1.02	9
Limited market demand for recovered materials	3.25	0.96	10

Source: Author's computation (2026).

Table 9 identifies the major barriers to reverse logistics adoption and sustainable waste management among the sampled manufacturing firms. Inadequate recycling and waste-recovery infrastructure ranked first, with a mean of 4.12, indicating that limited access to recycling facilities, collection centres and recovery systems represents the most significant constraint. Inadequate financial resources ranked second (mean=4.03), reflecting firms' difficulties in financing waste collection, sorting, storage and recycling operations. High collection and transportation costs ranked third (mean=3.94), suggesting that logistical expenses discourage the recovery and return of used materials. Limited access to appropriate technologies (mean=3.88) and technical skills (mean=3.76) ranked fourth and fifth, respectively. Poor stakeholder collaboration and weak managerial commitment also constituted important organizational barriers. Conversely, limited market demand for recovered materials ranked tenth (mean=3.25). Therefore, the findings suggest that infrastructural, financial and technological constraints are the most pressing obstacles requiring policy and managerial attention.

5 DISCUSSION

The findings provide evidence that sustainable waste management among manufacturing firms in Northern Nigeria is influenced by operational, financial, technological and organisational conditions. The overall logistic regression results indicate that the explanatory variables jointly contribute to understanding differences in firms' sustainable waste-management practices. The model's explanatory power also suggests that these factors are important, although other institutional and operational conditions may influence firms' environmental performance. The discussion is consistent with recent empirical research, particularly studies examining reverse logistics and environmental management in developing-country manufacturing contexts.

Reverse logistics adoption emerged as an important determinant of effective sustainable waste management. This suggests that manufacturing firms with arrangements for collecting, sorting, returning, reusing and recovering materials are better positioned to minimise waste and improve resource utilisation. Reverse logistics enables materials that would otherwise be discarded to re-enter production processes or be transferred to recycling organisations. This finding is consistent with U-Dominic, Orji and Okwu (2021), whose investigation of the Nigerian manufacturing sector explains that reverse logistics supports resource recovery, reduces environmental consequences and improves the productive use of discarded materials. Their study also identifies important implementation challenges that can prevent firms from fully benefiting from reverse logistics.

Financial capacity was also identified as an important determinant. This indicates that sustainable waste management requires adequate funding for collection, transportation, storage, sorting equipment, recycling and material recovery. Firms with limited financial resources may be unable to establish dedicated reverse logistics systems or maintain existing waste-management facilities. This interpretation is supported by U-Dominic et al. (2021), who identified financial constraints as a major organisational barrier to reverse logistics implementation in Nigerian manufacturing. Their findings particularly emphasised the importance of financial resources and management support in overcoming implementation difficulties. Similarly, Kaviani et al. (2020), in their study of the automotive industry, identified financial and economic limitations among the important barriers to successful reverse logistics implementation. Technological readiness was another important determinant of sustainable waste management. Appropriate technologies enable manufacturing firms to identify, separate, process, monitor and recover waste materials more efficiently. Access to modern equipment and information systems can also improve the coordination of returned materials and reduce operational inefficiencies. The finding agrees with U-Dominic et al. (2021), who identified low technical expertise and technological limitations as significant challenges to reverse logistics implementation in Nigeria. It also reflects the argument of Kaviani et al. (2020) that effective reverse logistics requires appropriate technological and operational capabilities. These studies demonstrate that technology investment must be accompanied by technical expertise to ensure that waste-recovery systems function effectively.

Recycling infrastructure emerged as a particularly important factor, while inadequate recycling and waste-recovery infrastructure ranked as the most serious barrier. This suggests that firms' willingness to adopt sustainable practices may not translate into effective implementation where collection centres, recycling facilities, storage systems and transportation networks are inadequate. The availability of such facilities determines whether recovered materials can be collected, processed and redirected into productive activities. This finding is consistent with Kaviani et al. (2020), whose research emphasised the importance of operational and infrastructural arrangements in reverse logistics implementation. It also supports the findings of Obamen et al. (2021), who established that environmental management practices contribute positively to the sustainability of selected manufacturing firms in South-East Nigeria.

Managerial commitment and environmental awareness were also important organisational determinants. Management commitment is necessary for incorporating environmental objectives into corporate strategies, allocating resources, assigning responsibilities and monitoring waste-management performance. Without management support, reverse logistics activities may remain informal, poorly coordinated or inadequately funded. Environmental awareness, on the other hand, encourages employees to understand the consequences of improper waste disposal and participate in waste reduction, reuse and recycling activities. Obamen et al. (2021) similarly found that environmental management practices were positively associated with manufacturing sustainability in South-East Nigeria. Their study also emphasised the importance of organisational knowledge in translating environmental management initiatives into sustainable outcomes. This suggests that management commitment and employee awareness should operate together to improve environmental performance.

Stakeholder collaboration was another important determinant. Reverse logistics involves activities that frequently extend beyond individual manufacturing firms, requiring coordination among suppliers, customers, transport operators, recycling organizations and government institutions. Collaboration facilitates the return of used materials, information exchange, collection arrangements and the development of markets for recovered products. This finding agrees with Cricelli, Greco and Grimaldi (2021), who established that collaboration with customers, suppliers, competitors and research institutions positively influences reverse logistics innovation. Their study demonstrates that inter-organizational relationships can strengthen reverse logistics activities, although the benefits depend on the nature and extent of collaboration. In contrast, regulatory enforcement did not emerge as a statistically significant independent determinant. This suggests that regulatory requirements alone may not sufficiently explain differences in firms' sustainable waste-management practices when organizational, financial and technological conditions are considered simultaneously. Possible explanations include inconsistent inspections, limited monitoring capacity and differences in firms' ability to comply with environmental requirements. However, this finding differs from Cricelli et al. (2021), who identified regulation as one of the relevant drivers of reverse logistics innovation. The difference suggests that the influence of regulation may depend on the effectiveness of enforcement and the institutional environment in which manufacturing firms operate.

Finally, the barrier analysis reinforces the regression findings by identifying inadequate recycling infrastructure, financial constraints, high collection and transportation costs, limited technological access and insufficient technical skills as major obstacles. U-Dominic et al. (2021) reported similar challenges in the Nigerian manufacturing sector, particularly financial constraints, low technical expertise and organizational commitment. In general, the findings suggest that improving sustainable waste management requires coordinated investment in infrastructure, technology, employee capabilities and inter-organizational collaboration. They also demonstrate that reverse logistics should be integrated into manufacturing operations as a strategic approach to resource recovery, waste reduction and environmental sustainability.

6 CONCLUSION

The study examined the determinants of industrial reverse logistics adoption and sustainable waste management among selected manufacturing firms in Northern Nigeria, focusing on Kano, Kaduna, Sokoto and Plateau States. The findings suggest that reverse logistics adoption, financial capacity, technological readiness, recycling infrastructure, managerial commitment, environmental awareness and stakeholder collaboration are important factors associated with effective sustainable waste management. In particular, the results highlight the importance of adequate recycling infrastructure, financial resources, appropriate technology and cooperation among stakeholders in improving the recovery, reuse and recycling of industrial waste. However, regulatory enforcement did not demonstrate a statistically significant relationship with effective sustainable waste management in the estimated model, suggesting that regulatory requirements may not translate into effective practices without adequate institutional support and organizational commitment.

The study is limited by its cross-sectional survey design, which restricts the ability to establish causal relationships or capture changes in waste-management practices over time. Furthermore, its geographical coverage of four states limits the generalization of findings to all manufacturing firms in Nigeria. The reliance on questionnaire responses may also introduce response and measurement biases.

Recommendations

Based on the findings, the study recommends that:

- Manufacturing firms should establish formal reverse logistics systems for collecting, sorting, reusing, recycling and recovering production waste and returned materials.
- Government and relevant agencies should improve access to recycling and waste-recovery infrastructure through investment, incentives and public-private partnerships.

- Financial institutions and development agencies should provide affordable financing to support manufacturers' investment in reverse logistics equipment, transportation and waste-management technologies.
- Management of manufacturing firms should strengthen environmental commitment through staff training, designated waste-management responsibilities and regular monitoring of environmental performance.
- Manufacturers, suppliers, recyclers and industry associations should strengthen collaboration to improve material recovery, waste collection and the market for recycled products.
- Regulatory authorities should complement existing environmental regulations with consistent monitoring, technical assistance and practical compliance support.

Future studies should employ longitudinal designs and broader geographical coverage to examine changes in reverse logistics adoption and sustainable waste-management performance over time.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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