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Analyzing the Barriers to Construction and Demolition Waste Management of the North-South Commuter Railway (NSCR) Phase 1 Project in Bulacan Using PESTLE Framework

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Abstract

Construction and demolition (C&D) waste management remains a critical challenge in large-scale infrastructure projects, particularly in developing countries. The North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan generates substantial waste streams, yet enforcement of Republic Act 9003 and related policies remains fragmented. This study applies the PESTLE framework to analyze barriers and propose strategies for sustainable waste management in railway megaprojects. A mixed-methods design was employed, integrating quantitative surveys and qualitative insights from stakeholders including government agencies, contractors, and consultants. The questionnaire assessed awareness, concern, and implementation of waste management practices across political, economic, social, technological, legal, and environmental dimensions. Data were analyzed to identify relationships among stakeholder perceptions and implementation levels. Findings revealed systemic barriers across all PESTLE dimensions. Political and legal gaps included weak enforcement and overlapping mandates, while economic constraints centered on high costs and limited markets for recycled materials. Social barriers involved low awareness and resistance to change, and technological limitations included inadequate segregation facilities and lack of digital monitoring systems. Environmental pressures, such as landfill scarcity and disaster vulnerability in Bulacan, compounded these challenges. Despite these barriers, stakeholders expressed readiness to adopt digital tools and capacity-building initiatives. The study underscores the need for broader stakeholder inclusion, implementation-oriented training, and adoption of digital monitoring platforms to enhance transparency and accountability. Expanding the scope to future phases of the NSCR and other infrastructure projects will provide comparative insights. By integrating institutional coordination, financial incentives, and technological innovation, sustainable C&D waste management can be advanced in Philippine railway projects.

Keywords: construction waste management, demolition waste, PESTLE framework, railway infrastructure, sustainability, digital monitoring

INTRODUCTION

Construction and demolition operations are essential in national development by supporting urban expansion, infrastructure growth, and economic advancement. In both developed and developing countries, rapid urbanization has resulted in intensified construction activity, which generates substantial volumes of construction and demolition waste (Aslam et al., 2020).

According to Islam et al. (2024a), the amount of construction and demolition waste generated is closely associated with population growth and economic development. As urban areas expand and economies grow, construction activities intensify, producing large volumes of waste. When waste management practices fail to keep pace with this rapid growth, substantial amounts of construction debris are disposed of in landfills, leading to environmental degradation and inefficient resource utilization (Al-Raqeb et al., 2023). Such practices contribute to land consumption, pollution, and the depletion of natural resources, underscoring the growing urgency of improving construction and demolition waste management (Gumusburun Ayalp & Anaç, 2024a).

The Philippine government through the Department of Transportation (DOTr), implementing agency for railway projects, has started rising an infrastructure project called the North-South Commuter Railway (NSCR) Phase 1 project. This massive transportation project is anticipated to increase revenue generation, reduce travel time, and improve connectivity. This railway passes through Bulacan Province, a rapidly developing region in Central Luzon, one of its crucial sections.

Despite its benefits, large-scale projects like the NSCR Phase 1 project typically generate substantial amounts of construction and demolition waste. Excess earthworks, concrete, wood, metal, glass and plastics are among the materials that pose a major threat to the environment. Unmanaged construction and demolition waste sends greenhouse gases into the environment, deteriorates land, pollutes the air and water, and increases the demand for landfills.

The Ecological Solid Waste Management Act of 2000, or Republic Act No. 9003 (RA 9003), has provided the foundational policy framework for waste management programs in the Philippines for more than two decades. Nonetheless there are still issues with the policy's enforcement at the national and subnational levels (Bueta et al., 2024). The Commission on Audit (COA) stated that one of the difficulties was the lack of a Solid Waste Management Fund, a dedicated National Treasury account meant to finance Local Government Units' (LGUs') authorized solid waste management programs (Commission on Audit, 2023). Its enforcement and compliance to the laws continue to be challenging endeavors because of the financial, political, and technological barriers of the relevant authorities and local government units (LGUs) (Senate Economic Planning Office, 2017). However, Véliz et al. (2023a) revealed that enhancing the strategic vision of the government can have downstream effects that ameliorate financial barriers such high production and capital costs and a lack of incentives that make companies and their stakeholders incline in long-term profitability.

Although existing literature has examined barriers to construction and demolition (C&D) waste management, few studies focus specifically on railway infrastructure projects. Most research emphasizes developed countries, leaving limited insights for developing nations such as the Philippines. Dalirazar & Sabzi (2023) highlight the PESTLE framework as a strategic tool for analyzing political, economic, social, technological, legal, and environmental influences, yet it has not been applied to railway megaprojects like the North–South Commuter Railway (NSCR) Phase 1 in Bulacan. Railway projects generate linear, large-volume, and geographically dispersed waste streams, complicating coordination and monitoring. This study addresses the gap by applying PESTLE to identify and prioritize barriers in the NSCR Phase 1 project, offering evidence-based insights for sustainable waste management in large-scale infrastructure. Hence, in this study, the PESTLE framework (political, economic, social, technical, legal, and environmental) is applied as an analytical lens to analyze barriers and offer an in- depth understanding of how they affect the construction and demolition waste management in the context of NSCR Phase 1 in Bulacan Province.

Theoretical Framework. The PESTLE framework is commonly used to investigate external influences on industries such as construction. In this study, Figure 1 illustrates how the framework serves as an analytical tool to identify systemic constraints affecting construction and demolition waste management in the North-South Commuter Railway (NSCR) Phase 1 Project in Bulacan.

Each PESTLE dimension highlights a significant area where barriers may arise. Political factors include policy alignment and government priorities that shape project implementation. Economic concerns involve financial capacity, production costs, and incentives that determine resource allocation. Social aspects reflect stakeholder behavior, community acceptance, and workforce practices that influence compliance. Technological preparedness

addresses the availability of innovations, equipment, and technical expertise needed for efficient waste management. Legal enforcement relates to regulatory compliance, monitoring, and institutional accountability. Finally, environmental pressures encompass land use, pollution, and ecological sustainability, which are critical in large-scale infra projects.

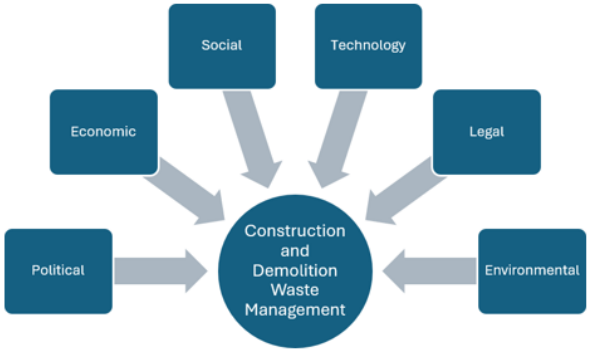

Figure 1
PESTLE Framework

By collectively assessing these dimensions, Figure 1 demonstrates how external variables interact to shape waste management performance and where targeted interventions can be implemented. PESTLE is therefore appropriate in analyzing infrastructure projects, particularly when different external factors converge with internal project dynamics. As shown in Figure 1, issues in large-scale projects like the NSCR Phase 1 stem not from a single component but from the interplay of politics, economics, society, technology, law, and ecology. Thus, the framework ensures that strategies are strategically linked with real-world conditions rather than being one-dimensional.

Conceptual Framework. This study adopts the Input–Process–Output (IPO) model as its conceptual framework to explain how defined inputs are systematically processed to produce actionable research outputs. In this research, the inputs consist of respondent characteristics, stakeholder perceptions, and PESTLE-based barrier dimensions relevant to construction and demolition waste management of the NSCR Phase 1 Project in Bulacan.

The Input component includes respondent profile variables, stakeholder perception variables, PESTLE barrier dimensions, and context-specific inputs. Respondent profiles give context for stakeholder perceptions, whereas perception variables reflect degrees of concern, awareness, and implementation of measures to address PESTLE-based barriers to construction and demolition waste management.

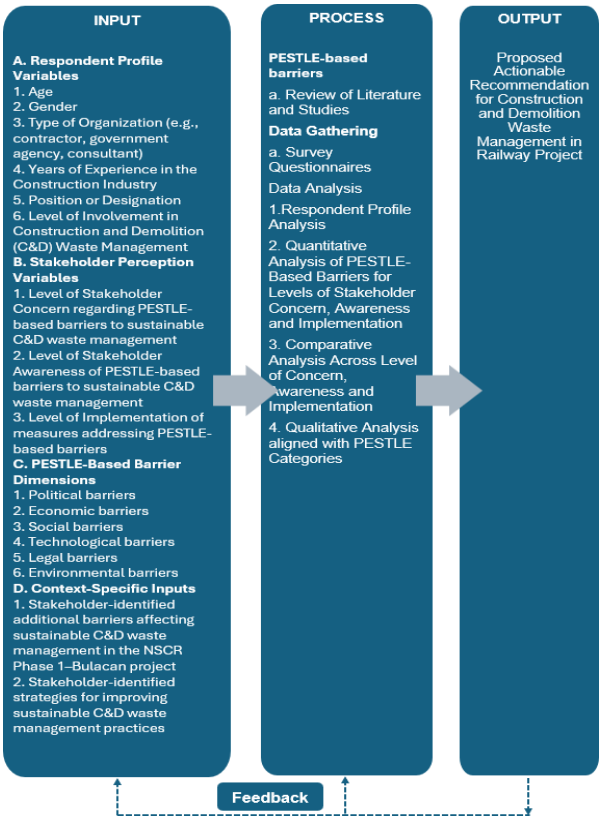

Figure 2
Conceptual Framework using the IPO Model

The Process component details the study's methodological stages, which begin with a review of relevant literature and studies, then proceed with data gathering via survey questionnaires. Quantitative and qualitative analyses are then used to evaluate the linkages and gaps between concern, awareness, and implementation across the PESTLE dimensions. The Output consists of evidence-based and context-specific recommendations, supported by stakeholder insights, as well as a feedback mechanism.

These recommendations inform future policy, capacity-building, and project- level improvements aimed at continuously improving construction and demolition waste management practices.

Statement of the Problem. Large infrastructure projects like NSCR Phase 1 generate substantial construction and demolition waste. However, poor implementation of waste management practices leads to environmental degradation and inefficiencies. This study aims to analyze the barriers to construction and demolition waste management of the NSCR Phase 1 Project in Bulacan using PESTLE Framework. Specifically, it seeks to answer the following questions:

1. What is the profile of the respondents in terms of:
   1.1 Age;
   1.2 Gender;
   1.3 Organization Type;
   1.4 Year of Experience in Construction;
   1.5 Position; and,
   1.6 Involvement in waste management?

2. What are the levels of stakeholder awareness and concern about PESTLE-based barriers to construction and demolition waste management, and to what extent is the implementation of measures to address the barriers of construction and demolition waste management in the NSCR Phase 1 – Bulacan Project?

3. What are the significant relationships among the degree of awareness, degree of concern, and extent of implementation of construction and demolition of waste management practices across the PESTLE dimensions of the NSCR Phase 1 Project?

4. What additional barriers and strategies do stakeholders identify for improving construction and demolition waste management of the NSCR Phase 1– Bulacan project?

5. What actionable recommendations can be proposed for construction and demolition waste management in railway project?

Research Hypothesis. At 0.05 level of significance, the following hypotheses were formulated to guide the analysis and to determine whether the observed relationships are statistically meaningful.

H_0 (Null Hypothesis): There is no significant relationship between stakeholder awareness and concern regarding PESTLE-based barriers and the extent of implementation of construction and demolition waste management practices in the NSCR Phase 1 Project in Bulacan.

H_1 (Alternative Hypothesis): There is a significant relationship between stakeholder awareness and concern regarding PESTLE-based barriers and the extent of implementation of construction and demolition waste management practices in the NSCR Phase 1 Project in Bulacan.

Scope and Limitations of the Study. This study employs a PESTLE framework to analyze barriers to construction and demolition waste management during the construction phase of the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan Province. Based on responses from government agencies, contractors/subcontractors, and consultants directly involved in compliance, monitoring and implementation, it evaluates stakeholder concern, awareness, and implementation of waste management strategies and recommends feasible improvement strategies.

The study's focus on a single project and setting may limit the extent to which the results may be applied. Post-construction and operational waste management concerns are not included. Bias may be introduced and the depth of analysis constrained by time restrictions, limited stakeholder participation, restricted access to private project data, and reliance on self-reported quantitative and qualitative responses. Despite these limitations, the study

offers a focused and contextual assessment relevant to large-scale railway infrastructure projects.

Significance of the Study. The study holds importance for multiple groups of stakeholders in the environmental and construction sectors. Policymakers may use the data to help create more targeted and efficient laws that deal with construction and demolition waste. The study provides contractors and consultants with information on the operational barriers that prevent sustainable practices. The findings can help local government entities and environmental organizations create more effective monitoring and enforcement systems. Academically, the study adds to the limited literature on construction techniques in the Philippines, particularly to extensive railway infrastructure.

This study offers important insights into construction and demolition waste management of the North-South Commuter Railway (NSCR) Phase 1 project or related infrastructure project in an environmentally manner.

LITERATURE REVIEW

Overview of Construction and Demolition Waste. Construction and demolition (C&D) waste has become a pressing global issue due to massive volumes generated by infrastructure activities. Billions of tons of construction-related waste are produced annually, much of it disposed of in landfills (Patil et al., 2024). Limited landfill capacity has prompted strategies emphasizing reduction, reuse, and recycling (Wallis et al., 2020). Infrastructure projects often generate excess excavated soils, which, if unmanaged, pose environmental and health risks (Hale et al., 2021).

In the Philippines, infrastructure expansion intensifies this challenge. The construction sector contributed 9.0% to GDP in Q3 2024 (Philippine Statistics Authority, 2024), yet industrialization and population growth continue to raise waste volumes (Commission on Audit, 2023). Materials such as earthworks, concrete, metals, plastics, and hazardous debris, if unmanaged, cause pollution and greenhouse gas emissions. Globally, buildings and construction account for 38% of emissions, making decarbonization critical (Gillott et al., 2022). Research on barriers to sustainable waste management is therefore essential to ensure strategies are economically viable, socially acceptable, and environmentally sound (Negash et al., 2021).

Construction and Demolition Waste Management. Many developed countries, including China, the EU, Japan, Spain, USA, and Australia, have recognized the severity of construction and demolition (C&D) waste and promoted sustainable practices to minimize its impact (Dimaculangan, 2023; Yi et al., 2024). The EU has unified techniques to address rising disposal volumes, positioning waste minimization as a driver of the circular economy (Cárcel-Carrasco et al., 2021; Lim et al., 2024). Studies emphasize waste minimization as the most efficient strategy (Hassan & Alashwal, 2024), while environmentally sound approaches to excavated soil and rock remain critical in urbanizing regions such as South and East China (Zhang et al., 2020b). Unsustainable practices directly affect Sustainable Development Goals (Zhang et al., 2023), though positive examples exist: UAE sites adopted minimization strategies (Mawed et al., 2020), Italy consistently achieved the EU's 70% recycling target (Cárcel-Carrasco et al., 2021), and Hong Kong advanced on-site and off-site recycling systems (Bao et al., 2020). Malaysia's high-rise projects generate over 10 million tons annually, with reuse potential but contamination challenges (Umar et al., 2021). In the Netherlands, cost-effective technologies increased recycling rates from 5% in 2015 to 22–32% by 2025 (Zhang et al., 2020a). Recycling reduces greenhouse gas emissions by 15–20% and fossil fuel depletion by 30% (Kanwal et al., 2025), though illegal dumping persists (Hammadhu HaitherAli, 2024).

Factors Influencing Construction and Demolition Waste Management. Construction and

demolition (C&D) waste management is shaped by political, economic, social, technological, and institutional factors across countries. In Chile, rapid urbanization, low public awareness, limited willingness to pay, and inadequate landfill facilities constrain circular economy practices (Véliz et al., 2023b; Abarca-Guerrero et al., 2022). Emerging nations face barriers across political, social, and economic dimensions, requiring stronger recycling standards, incentives, and capacity-building (Bhavsar et al., 2023). Illegal disposal persists due to weak enforcement, reliance on end-of-pipe approaches, limited demand for recycled materials, high transport costs, and poor segregation (Hammadhu HaitherAli, 2024). Economic constraints hinder selective demolition in Italy despite environmental benefits, highlighting the need for incentives (Iodice et al., 2021). Firm capital investment and stakeholder attitudes are critical in combating illegal dumping (Yuan et al., 2023), while site management and supervision remain primary waste sources (Saad et al., 2022). In Saudi Arabia, regulatory gaps, insufficient training, and weak incentives limit circular economy adoption (Alotaibi et al., 2024). China faces inconsistent waste streams, high land-use costs, poor coordination, and lack of tracking systems, alongside behavioral challenges (Ma et al., 2020; Jain et al., 2020). Similar constraints occur in Hong Kong, where limited landfill capacity and complex procedures impede recycling (Kang et al., 2022).

Challenges in Construction and Demolition Waste Management. Sustainable construction and demolition waste management faces persistent challenges worldwide. These barriers, analyzed through the PESTLE framework, reveal interconnected political, economic, social, technological, legal, and environmental constraints that hinder effective implementation in infrastructure projects.

Political Barriers. Political factors significantly shape construction and demolition (C&D) waste management outcomes. In the Philippines, inconsistent policies and overlapping mandates among agencies such as DENR, DPWH, and LGUs weaken implementation (Bhavsar et al., 2023; Estrada et al., 2023). Although legislation exists, gaps in enforcement and monitoring limit effectiveness. Government prioritization of sustainable practices remains low, with limited progress toward SDG 12.5 on waste reduction (Commission on Audit, 2023). Insufficient promotion of recycling and lack of public education further constrain adoption (Izzati et al., 2024; Martin et al., 2024). These political barriers highlight the need for stronger coordination, prioritization, and systematic monitoring to integrate sustainability into infrastructure projects.

Economic Barriers. Economic constraints are among the most persistent challenges. High costs of sustainable waste processing technologies, transportation, and labor discourage adoption (Bhavsar et al., 2023; Shooshtarian et al., 2022; van der Lans et al., 2023). Stakeholders often prioritize financial gains over sustainability, with contractors reluctant to adopt practices that increase project costs (Izzati et al., 2024). The absence of robust markets for recycled materials further undermines incentives, as perceptions of poor quality and high costs persist in Kuwait and Italy (Martin et al., 2024; Al-Raqeb et al., 2023; Cárcel-Carrasco et al., 2021). Limited budget allocations for environmental programs exacerbate these issues, leaving sustainability underfunded (Martin et al., 2024).

Social Barriers. Social dimensions also hinder effective waste management. Low awareness among construction companies, workers, and the public reduces motivation to adopt sustainable practices (Izzati et al., 2024). Resistance to change from traditional disposal habits and entrenched site cultures further impede progress (Mawed et al., 2020; Sheikh Ilmi et al., 2024). A lack of training and seminars on waste management prevents stakeholders from understanding the benefits of recycling and segregation (Al-Raqeb et al., 2023; Low et al., 2020). Without stronger awareness campaigns and education, social barriers continue to undermine the transition toward sustainable practices.

Technological Barriers. Technological limitations remain critical. Insufficient segregation and recycling facilities lead to large volumes of mixed waste entering landfills, reducing diversion capacity and shortening landfill lifespans (Commission on Audit, 2023). The absence of digital solutions for tracking and monitoring waste streams further hampers accurate quantification and assessment, with construction waste often misclassified under industrial categories (Environmental Management Bureau DENR, 2018). High costs of adopting new technologies also discourage investment, particularly in developing contexts (Silva et al., 2024). These barriers highlight the need for affordable innovations and integrated digital systems to strengthen monitoring and recycling efficiency.

Legal Barriers. Legal frameworks in the Philippines remain fragmented and weakly enforced. Although RA 9003 provides a foundation, the absence of specific regulations for C&D waste creates policy gaps (Sheikh Ilmi et al., 2024; Martin et al., 2024). Weak enforcement and low landfill levy rates encourage disposal rather than recycling, while high levies risk increasing illegal dumping (Shooshtarian et al., 2022; Oluleye et al., 2023). OECD (2019) findings suggest that higher landfill taxes reduce disposal rates, but in the Philippines, inconsistent fees and weak monitoring limit effectiveness. Without stricter regulations and enforcement, contractors often treat waste management as secondary, driven only by compliance with green building schemes.

Environmental Barriers. Environmental challenges compound political, economic, and social constraints. Landfills in the Philippines are nearing capacity, with only 245 operational facilities serving 30% of LGUs, insufficient for the 12,000 tons of daily waste generated nationwide (Commission on Audit, 2023). Improper disposal practices contribute to environmental degradation, while poor site management and lack of segregation result in recyclable materials being directed to final disposal sites (Abarca-Guerrero et al., 2022). Climate change and natural disasters further exacerbate waste generation, with typhoons, floods, and earthquakes producing massive volumes of disaster-related debris (Mawed et al., 2020; Raza et al., 2020). Bulacan Province, highly vulnerable to hazards, faces particular challenges in integrating sustainable waste management into disaster recovery efforts.

METHODS

Research Design. This study adopts a mixed-methods research design to analyze barriers to construction and demolition waste management in the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan.

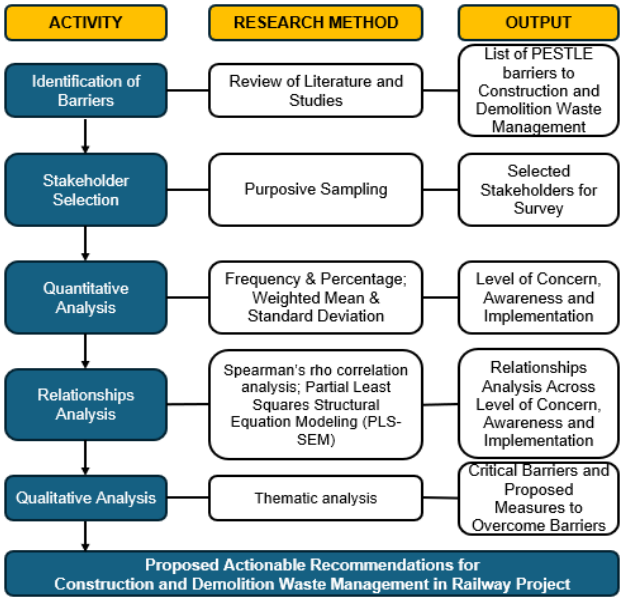

Figure 3
Analytical Framework for Identifying and Assessing PESTLE-Based Barriers to Construction and Demolition Waste Management in the NSCR Phase 1 Project

The mixed-methods approach was appropriate as the study requires quantitative assessment of stakeholder awareness, concern, and implementation of construction and demolition waste management practices across the PESTLE dimensions, as well as qualitative insights to identify additional barriers and strategies for improving waste management practices. This integration enables a more comprehensive understanding of the factors influencing construction and demolition waste management in the project.

Questionnaire Design. The questionnaire covers three (3) sections, as shown in Figure 4. The questionnaire was developed based on a review of literature on construction and demolition waste management and the PESTLE analytical framework to identify relevant barriers affecting waste management practices. The instrument was also designed to collect data from key stakeholders involved in the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan. It consists of three sections: Section A – Respondent Profile; Section B – Assessment of PESTLE-based barriers in terms of awareness, concern, and implementation; and Section C – open-ended questions to capture additional barriers and suggested improvement strategies.

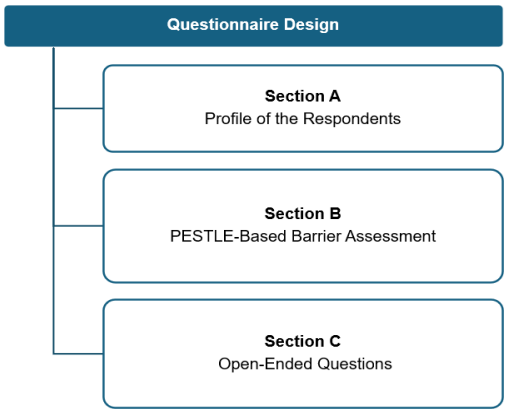

Figure 4
Structure of the Questionnaire for Assessing PESTLE-Based Barriers to Construction and Demolition Waste Management

The questionnaire was structured to capture both the demographic profile of respondents and their perceptions of barriers to construction and demolition (C&D) waste management. Section A gathered background information such as age, gender, organizational affiliation, years of experience in construction, position, and involvement in waste management decisions. This profile data provided context for interpreting the perspectives of different stakeholder groups.

Section B focused on the assessment of PESTLE-based barriers. Measured within the domains of political, economic, social, technological, legal, and environmental, the barriers were anchored from the lens of stakeholder awareness, concern, and implementation practices. Respondents evaluated each barrier using a five-point Likert scale.

Table 1
Degree of Concern

Scale	Verbal Interpretation
1	Very Serious Concern
2	Major Concern
3	Moderate Concern
4	Slight Concern
5	Not a Concern at All

Table 2
Degree of Awareness

Scale	Verbal Interpretation
1	Very Highly Aware
2	Highly Aware
3	Moderately Aware
4	Slightly Aware
5	Not Aware at All

Table 3
Degree of Implementation

Scale	Verbal Interpretation
1	Very Highly Implemented
2	Highly Implemented
3	Moderately Implemented
4	Slightly Implemented
5	Not Implemented at All

For concern (Table 1), the scale ranged from "very serious concern" to "not a concern at all." Awareness (Table 2) was measured from "very highly aware" to "not aware at all," while implementation (Table 3) was assessed from "very highly implemented" to "not implemented at all." These scales ensured consistency across variables and allowed for balanced measurement of stakeholder perceptions. Sample indicators, which are uniformly applied in order to yield a balance measure of the barriers within the variables, included inconsistent policies and lack of government prioritization under political barriers; high costs and absence of financial incentives under

economic barriers; low awareness and resistance to change under social barriers; insufficient facilities and lack of digital monitoring solutions under technological barriers; weak enforcement and absence of specific regulations under legal barriers; and issues such as landfill saturation, improper disposal, poor site management, and vulnerability to climate change under environmental barriers.

Finally, Section C incorporated open-ended questions to elicit qualitative insights. Respondents were asked to identify the most critical barrier affecting C&D waste management in the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan and to suggest solutions or strategies for overcoming these barriers. These qualitative responses provided explanatory depth to the quantitative findings and helped generate practical recommendations for improving waste management practices in the project.

Reliability and Convergent Validity of the Research Instrument. The reliability and convergent validity of the constructs were evaluated using Cronbach's alpha (α), composite reliability (CR), and average variance extracted (AVE) following the criteria presented in Table 4. Cronbach's alpha was used to assess the internal consistency reliability of the three main constructs: degree of concern, level of awareness, and extent of implementation of construction and demolition waste management practices. Composite reliability and AVE were also examined to determine construct reliability and convergent validity.

The results of the reliability analysis are presented in Table 5. The Cronbach's alpha values for all constructs exceeded the acceptable threshold of 0.70, indicating satisfactory internal consistency of the measurement scales. Similarly, the composite reliability values were above 0.70, and the AVE values were greater than 0.50, confirming that the constructs demonstrate adequate reliability and convergent validity.

Table 4
Reliability Criteria used in PLS-SEM (Ringle et al., 2024b).

Measure	Purpose	Acceptable Threshold	Decision
Cronbach's Alpha (α)	Internal consistency reliability	≥ 0.70 (≥ 0.60 Acceptable for exploratory studies)	Construct is reliable if α meets threshold
Composite Reliability (ρa)	Internal consistency (construct level)	≥ 0.70	Construct is reliable if ρa ≥ 0.70
Composite Reliability (ρc)	Indicator consistency without equal loading assumption	≥ 0.70	Construct is reliable if ρc ≥ 0.70
Average Variance Extracted (AVE)	Convergent validity	≥ 0.50	Convergent validity established

Table 5
Reliability Results of the Research Constructs

Construct	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	Interpretation
Degree of Awareness	0.895	0.898	0.920	0.657	Reliable
Degree of Concern	0.954	0.955	0.963	0.814	Reliable
Degree of Implementation	0.950	0.963	0.960	0.800	Reliable

Population, Sample Size and Sampling Techniques Target Population. In this study, selected participants were classified as external and internal stakeholders directly involving in construction and demolition waste management. The population of the study includes engineers, construction managers, site supervisors, environmental compliance officers, and relevant government officials involved in the NSCR Phase 1 in Province of Bulacan.

Sampling Size. A total of 35 respondents were included in the survey using purposive sampling, targeting key stakeholders directly involved in construction and demolition waste management activities in the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan. These respondents include representatives from government agencies, contractors, consultants, and project management teams who possess relevant knowledge and experience related to waste management practices in the project.

The sample size is considered appropriate because the study focuses on a specific group of specialized stakeholders involved in a single large-scale infrastructure project, which limits the number of qualified respondents. Moreover, studies employing Partial Least Squares Structural Equation Modeling (PLS-SEM) and exploratory research designs can yield reliable results with relatively small samples, particularly when respondents are information-rich and directly involved in the phenomenon being studied.

Sampling Technique. A purposive sampling technique has been employed to ensure that participants with relevant knowledge and experience regarding construction and demolition waste management in NSCR Phase 1 project are consulted. The researcher obtained specific insights into the barriers to the railways sector's construction and demolition waste effectiveness through to this selection.

Data-Gathering Procedure. The surveys were distributed thru online (via Google Forms). Prior to data collection, informed consent was acquired. The researcher started gathering data as soon as they gave permission to carry out the study. The study only included participants who expressed willingness to participate.

Quantitative Analysis Based on PESTLE Dimensions. Descriptive and inferential statistical methods were used to assess quantitative data collected from thirty-five (35) respondents. Respondent characteristics were described using frequency distribution and percentage analysis, and the degree of political, economic, social, technological, legal, and environmental barriers was assessed using weighted mean and standard deviation. Relationship analysis and prioritization of the main barriers affecting construction and demolition waste management in the NSCR Phase 1–Bulacan Section were made feasible using aggregate weighted mean values per PESTLE dimension.

Relationship Analysis Across Level of Concern, Awareness and Implementation. To examine the relationships among stakeholder perception and operational response, Spearman's rho correlation analysis was conducted to determine the association between the degree of concern, level of awareness, and extent of implementation across the PESTLE dimensions.

To further assess the relative influence of awareness, concern, and implementation on the overall PESTLE-based barrier assessment, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed. PLS-SEM is specifically designed for small sample sizes, exploratory models, and prediction-oriented research. SmartPLS 4 was employed to estimate path coefficients, t-statistics, and p-values using bootstrapping techniques, allowing for the assessment of both the statistical significance and the magnitude of cross-dimensional effects (Ringle et al., 2024a).

Qualitative Analysis aligned with PESTLE Dimensions. Qualitative data from open-ended survey responses were analyzed using thematic analysis and categorized aligned to PESTLE framework to ensure coherence with the quantitative results.

Ethical Considerations. This study was conducted in accordance with the research ethics guidelines of the Polytechnic University of the Philippines (PUP). Prior to data collection, the research protocol was reviewed and granted ethical clearance by the University Ethics Review Committee of PUP, approved on February 11, 2025, ensuring that the study complied with institutional standards for research involving human participants. The following ethical principles were observed throughout the study:

1. ***Informed Consent.*** Participation in the study was strictly voluntary. Respondents were informed about the purpose of the study, and consent was obtained prior to participation.

2. ***Confidentiality.*** All data collected were treated confidentially, and individual responses were anonymized in the analysis and reporting of results.

3. ***Data Privacy and Security.*** Data gathered were managed in accordance with applicable data privacy guidelines and were used solely for the purposes of this research. The collected data will be securely stored and disposed of after the completion of the study.

RESULTS

Profile of the Respondents. The respondents' profile encompassed age, gender, organizational affiliation, years of experience in construction, professional position, and involvement in waste management decisions. These demographic and professional characteristics serve as an essential contextual foundation for interpreting stakeholder perspectives on construction and demolition waste management.

As shown in Table 6, the respondents of the study represent a diverse cross-section of stakeholders in the construction industry, with most falling within the younger age group of 18–30 years (40%), followed by those aged 31–40 years (28.6%). This indicates that a significant portion of participants are early-career professionals already engaged in sustainability-related issues. The gender distribution shows a male-dominated sample (68.6%), consistent with industry demographics, though the presence of female respondents (31.4%) reflects increasing inclusivity in the field. In terms of organizational affiliation, nearly half of the respondents (48.6%) came from contractor or subcontractor firms, highlighting the perspectives of those directly involved in project implementation and waste management operations. Government agency representatives (34.3%) and consultants (17.1%) provided complementary insights from policy and advisory roles, ensuring a balanced view across the construction ecosystem. Regarding experience, most respondents had 5–10 years (37.1%) or less than 5 years (31.4%) in the industry, suggesting a predominance of mid-level professionals who combine practical exposure with openness to new practices. Meanwhile, 22.9% had more than 15 years of experience, thus, with seasoned perspectives.

Table 6

Demographic and Professional Profile of Respondents

	Classification	Frequency	Percent
Age	18-30	14	40.0
	31-40	10	28.6
	41-50	6	17.1
	51 and above	5	14.3
	Total	35	100.0
Gender	Female	11	31.4
	Male	24	68.6
	Total	35	100.0
Organization Type	Consultant	6	17.1
	Contractor/Subcontractor	17	48.6
	Government Agency	12	34.3
	Total	35	100.0
Years of Experience in Construction	11 - 15 years	3	8.6
	5 - 10 years	13	37.1
	less than 5 years	11	31.4
	more than 15 years	8	22.9
	Total	35	100.0
	Classification	Frequency	Percent
Waste Management Involvement	No	13	37.1
	Yes	22	62.9
	Total	35	100.0
Position	Engineers	12	34.3
	Environmental Officers/ Managers	9	25.7
	Project Management/Evaluation	7	20
	Inspectors/Technical Officers	3	8.6
	Architectural/Design	1	2.9
	Special / Other Roles	3	8.6
	Total	35	100

A majority (62.9%) reported direct involvement in waste management decisions, underscoring the integration of sustainability responsibilities in professional roles, though 37.1% without involvement highlight gaps in awareness or accountability. In terms of position, engineers (34.3%) and environmental officers/managers (25.7%) formed the largest groups, ensuring strong technical and sustainability perspectives, while project management/evaluation roles (20%) and smaller groups of inspectors, designers, and specialists provided complementary oversight.

Overall, the respondent profile reflects youthful engagement, operational expertise, institutional oversight, and active sustainability participation, offering a comprehensive foundation for analyzing barriers to construction and demolition waste management.

Analysis of Stakeholder Awareness and Concern of PESTLE-Based Barriers and the Extent of Implementation of Measures to Address the Barriers of Construction and Demolition Waste Management in the NSCR Phase 1 – Bulacan Project.

Stakeholder Awareness of PESTLE-Based Barriers. The results presented in Table 7 highlight the respondents' overall high degree of awareness of PESTLE-based barriers to construction and demolition waste management in the NSCR Phase 1–Bulacan Project.

Table 7

Mean Distribution of PESTLE-Based Barrier Assessment in terms of Awareness

Barrier	Mean	Verbal Interpretation
Political Barriers: Inconsistent policies related to construction and demolition waste management. Lack of government prioritization for sustainable construction. Poor coordination among government agencies.	3.48	Highly Aware
Economic Barriers: High cost of sustainable waste processing technologies. Lack of financial incentives for recycling construction and demolition waste. Limited budget allocation for environmental programs in projects.	3.56	Highly Aware
Social Barriers: Low awareness of sustainable practices in construction. Resistance to change from traditional waste disposal habits. Lack of training or seminars on construction and demolition waste management.	3.75	Highly Aware
Technological Barriers: Insufficient waste segregation and recycling facilities. Lack of digital solutions on tracking and monitoring construction and demolition waste. Cost of new technologies for construction and demolition waste management.	3.54	Highly Aware
Legal Barriers: Weak implementation of waste management laws. Lack of specific regulation on construction and demolition waste in the Philippines. Low monitoring and enforcement from authorities.	3.65	Highly Aware
Environmental Barriers: Landfills are nearing or at full capacity. Improper disposal contributes to environmental degradation. Lack of site management for waste segregation and sustainable methods/practices of construction. Project's vulnerability to natural disasters and climate change.	3.79	Highly Aware
Composite Mean:	3.63	Highly Aware

With a composite mean of 3.63, stakeholders demonstrated strong recognition of challenges across political, economic, social, technological, legal, and environmental dimensions. This suggests that while implementation may be inconsistent, awareness of the barriers is widespread, reflecting a growing consciousness of sustainability issues in the construction sector.

Among the six dimensions, environmental barriers (Mean = 3.79) recorded the highest awareness, particularly regarding improper disposal practices leading to environmental degradation and vulnerability to climate change. Social barriers (Mean = 3.75) followed closely, with respondents highly aware of the lack of training, resistance to change, and limited knowledge of sustainable practices. Legal barriers (Mean = 3.65) were also well recognized, especially weak enforcement and the absence of construction-specific regulations. These findings indicate that respondents are not only aware of ecological risks but also of the human and institutional factors that hinder effective waste management, underscoring the importance of education, regulatory clarity, and enforcement.

Economic (Mean = 3.56), technological (Mean = 3.54), and political (Mean = 3.48) barriers were likewise perceived with high awareness, though slightly lower compared to other dimensions. Respondents acknowledged financial constraints such as high technology costs and limited budgets, as well as infrastructure gaps in recycling facilities and digital monitoring systems. Political barriers, including poor inter-agency coordination and low prioritization of sustainable construction, were also recognized, though awareness of policy inconsistency was moderate. Overall, these results suggest that stakeholders possess a comprehensive understanding of the multifaceted barriers to sustainable waste management, yet translating this awareness into effective practices remains a critical challenge for the project.

Stakeholder Concern of PESTLE-Based Barriers. The assessment of PESTLE-based

barriers reveals that respondents consistently rated construction and demolition waste management challenges as major concerns, with a composite mean of 3.85 (Table 8). Among the six dimensions, environmental barriers (Mean = 4.09) emerged as the most pressing, underscoring the project's vulnerability to climate change, natural disasters, and improper disposal practices. These findings highlight the environmental risks inherent in large-scale railway projects, particularly in Bulacan, where landfill capacity constraints and site management issues exacerbate sustainability challenges. The prominence of environmental concerns reflects the urgency of integrating climate resilience and ecological safeguards into waste management strategies.

Table 8

Mean Distribution of PESTLE-Based Barrier Assessment in terms of Concern

Barrier	Mean	Verbal Interpretation
Political Barriers: Inconsistent policies related to construction and demolition waste management. Lack of government prioritization for sustainable construction. Poor coordination among government agencies.	3.68	Major Concern
Economic Barriers: High cost of sustainable waste processing technologies. Lack of financial incentives for recycling construction and demolition waste. Limited budget allocation for environmental programs in projects.	3.86	Major Concern
Social Barriers: Low awareness of sustainable practices in construction. Resistance to change from traditional waste disposal habits. Lack of training or seminars on construction and demolition waste management.	3.75	Major Concern
Technological Barriers: Insufficient waste segregation and recycling facilities. Lack of digital solutions on tracking and monitoring construction and demolition waste. Cost of new technologies for construction and demolition waste management.	3.70	Major Concern
Legal Barriers: Weak implementation of waste management laws. Lack of specific regulation on construction and demolition waste in the Philippines. Low monitoring and enforcement from authorities.	4.05	Major Concern
Environmental Barriers: Landfills are nearing or at full capacity. Improper disposal contributes to environmental degradation. Lack of site management for waste segregation and sustainable methods/practices of construction. Project's vulnerability to natural disasters and climate change.	4.09	Major Concern
Composite Mean:	3.85	Major Concern

Legal barriers (Mean = 4.05) ranked second, pointing to systemic regulatory gaps and weak enforcement mechanisms. Respondents emphasized the absence of specific construction and demolition waste regulations and inadequate monitoring by authorities, which hinder compliance and accountability. This suggests that institutional limitations in governance remain a critical obstacle to effective waste management implementation. Political barriers (Mean = 3.68) further compound these issues, with poor inter-agency coordination and low prioritization of sustainable construction practices constraining policy coherence. Together, these findings illustrate how governance and regulatory weaknesses undermine the operationalization of sustainability initiatives, despite growing awareness among stakeholders.

Economic (Mean = 3.86), social (Mean = 3.75), and technological (Mean = 3.70) barriers reflect practical constraints that directly affect project execution. Financial limitations, particularly the absence of recycling incentives and restricted budgets, reduce the viability of sustainable practices. Social challenges, such as resistance to change, low awareness, and insufficient training, highlight the need for behavioral interventions and capacity-building programs. Technological barriers, including inadequate recycling facilities and limited digital monitoring tools, reveal infrastructure and innovation gaps that restrict efficiency. Overall, the findings demonstrate that while environmental and legal concerns dominate, economic, social, and technological dimensions equally contribute to the complexity of waste management, requiring integrated solutions that address both systemic governance issues and operational capacity constraints.

Analysis of Implemented Measures to Address the Barriers of Construction and Demolition Waste Management. The results in Table 9 present the degree of implementation of measures addressing PESTLE-based barriers to construction and demolition waste management in the NSCR Phase 1–Bulacan Project. With a composite mean of 3.19,

implementation was generally assessed as moderate, indicating that while several initiatives are in place, they remain uneven and insufficient to fully overcome the identified barriers. This highlights a gap between stakeholder awareness and concern, and the actual translation of these into consistent practices on the ground.

Legal barriers recorded the highest implementation level (Mean = 3.47), reflecting relatively strong monitoring, inspections, and enforcement of existing waste management laws. Respondents noted that enforcement at the project level is comparatively robust, though the adoption of construction-specific regulations remains moderate. Environmental barriers followed (Mean = 3.39), with strong implementation in on-site waste management and sustainable construction strategies. However, landfill capacity management and climate resilience integration were only moderately implemented, suggesting that while immediate site-level practices are addressed, broader long-term risks remain underemphasized.

Table 9

Mean Distribution of Measures to Address the Barriers of Construction and Demolition Waste Management

Barrier	Mean	Verbal Interpretation
Political Barriers: Consistent enforcement of construction and demolition waste management policies. Government involvement in supporting sustainable construction efforts. Inter-agency coordination for waste management.	3.30	Moderately Implemented
Economic Barriers: Use of cost-effective waste processing technologies. Provision of financial incentives for recycling initiatives. Adequate environmental budget in project planning and implementation.	2.85	Moderately Implemented
Social Barriers: Promotion of sustainable practices within construction activities. Programs to reduce resistance to traditional waste disposal habits. Conduct of trainings/seminars on construction and demolition waste management.	3.28	Moderately Implemented
Technological Barriers: Availability and use of waste segregation/recycling facilities. Implementation of digital tracking systems for construction and demolition waste. Integration of cost-effective technologies in waste processes.	2.86	Moderately Implemented
Legal Barriers: Enforcement of existing waste laws in the project. Adoption of specific regulations or policies for construction and demolition waste. Active monitoring and inspections by authorities.	3.47	Highly Implemented
Environmental Barriers: On-site management of landfill usage and disposal limits. Measures to minimize environmental degradation. On-site waste management and sustainable construction strategies. Inclusion of climate-resilient strategies in project execution.	3.39	Moderately Implemented
Composite Mean:	3.19	Moderately Implemented

Political (Mean = 3.30) and social (Mean = 3.28) barriers were both moderately implemented. Policy enforcement showed stronger performance compared to government support and inter-agency coordination, reflecting institutional fragmentation in governance. On the social dimension, promotion of sustainable practices within construction activities was highly implemented, but training programs and behavioral change initiatives were less emphasized. These findings suggest that while sustainability is promoted in practice, institutionalization of capacity-building and collaborative governance remains limited.

Economic (Mean = 2.85) and technological (Mean = 2.86) barriers ranked lowest in implementation. Financial incentives for recycling were weakly implemented, and budget allocations for environmental programs were only moderate, constraining the scalability of sustainable practices. Similarly, while basic waste segregation facilities exist, digital tracking systems and cost-effective technologies were poorly adopted. These results reveal that economic and technological constraints continue to hinder progress, underscoring the need for stronger financial support mechanisms and investment in modern infrastructure. Overall, the findings emphasize that implementation remains partial, with stronger performance in legal and environmental but persistent weaknesses in economic and technological measures.

Correlation Analysis Across Levels of Concern, Awareness, and Implementation. This section presents the correlation results of stakeholder concern, awareness, and implementation of construction and demolition waste management practices in the NSCR Phase 1–Bulacan Project. The analysis draws on three key statistical outputs: Spearman rho correlations (Table 10), structural path results (Table 11), and coefficient of determination (Table 12). These aim to evaluate and describe how these dimensions interact and whether the study's hypotheses are supported.

Correlation Results. Table 10 shows that overall concern and overall awareness have a statistically significant and moderately strong positive correlation (ρ = 0.607, p = 0.0001). This indicates that stakeholders who express greater concern about construction and demolition waste management barriers also tend to demonstrate higher awareness of these issues. In contrast, no significant correlation was found between implementation and either awareness or concern. This suggests that while stakeholders recognize and worry about systemic barriers, these perceptions do not consistently translate into practical implementation. The results highlight a critical awareness–implementation gap, where institutional, financial, and organizational constraints prevent knowledge and concern from becoming operationalized practices.

Table 10
Correlation using Spearman Rho

Correlation	Spearman Rho	Computed p-value	Decision	Remarks
Overall Concern vs Overall Awareness	0.6070	0.0001	Accept the Alternative Hypothesis	Significant
Overall Concern vs Overall Implementation	0.2328	0.1784	Do not reject the null hypothesis	Not Significant
Overall Awareness vs Overall Implementation	0.1371	0.4322	Do not reject the null hypothesis	Not Significant

Structural Path Results. Table 11 presents the PLS-SEM structural path analysis, which clarifies the relative influence of awareness, concern, and implementation on PESTLE-based barrier assessment. Awareness showed the strongest effect (β = 0.50, t = 10.99, p < .001), followed closely by concern (β = 0.47, t = 11.60, p < .001). Implementation, while statistically significant (β = 0.26, t = 2.27, p = 0.02), exerted a weaker influence compared to the perception-based constructs. These findings confirm that cognitive and attitudinal dimensions—knowledge of barriers and concern about their impacts—are the primary drivers of how stakeholders evaluate systemic challenges. Implementation contributes to barrier recognition but plays a secondary role, reinforcing the conclusion that awareness and concern dominate stakeholder assessments.

Table 11
Structural Path Results (PLS-SEM)

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistics (|O/STDEV|)	P-values	Remarks
Degree of Awareness -> PESTLE-Based Barrier Assessment	0.50	0.50	0.05	10.99	0.00	Significant
Degree of Concern -> PESTLE-Based Barrier Assessment	0.47	0.46	0.04	11.60	0.00	Significant
Degree of Implementation -> PESTLE-Based Barrier Assessment	0.26	0.23	0.11	2.27	0.02	Significant

Model Explanatory Power. Table 12 reports the coefficient of determination (R^2), showing that the PESTLE-based barrier assessment achieved an R^2 value of 0.999. This indicates that nearly all variance in barrier assessment is explained by awareness, concern, and implementation. The exceptionally high explanatory power validates the robustness of the model and confirms that these three constructs collectively provide a comprehensive framework for understanding stakeholder evaluations of political, economic, social, technological, legal, and environmental barriers. Importantly, while implementation contributes less strongly, it remains an integral part of the model, ensuring that experiential insights complement cognitive and attitudinal perspectives.

Table 12
Coefficient of Determination (R^2)

Endogenous Construct	R-square	R-square adjusted
PESTLE-Based Barrier Assessment	0.999	0.999

Hypothesis Testing and Interpretation. The results allow for direct evaluation of the study's hypotheses. The null hypothesis (H_0), which states that there is no significant relationship between stakeholder awareness and concern regarding PESTLE-based barriers and the extent of implementation of waste management practices, is rejected in part. The correlation analysis shows a significant relationship between concern and awareness, supporting the alternative hypothesis (H_1) that perception dimensions are linked. However, because implementation did not show significant

correlation with awareness or concern, the null hypothesis is not fully rejected. Instead, the findings reveal a nuanced outcome: awareness and concern are significantly related and strongly influence barrier assessment, but implementation remains weakly connected. This confirms that the challenge in NSCR Phase 1–Bulacan lies not in stakeholder recognition of barriers but in translating awareness and concern into effective on-site practices. Bridging this gap requires stronger institutional support, financial incentives, and technological infrastructure to align perception with action.

Identified Barriers and Strategies as Basis for Improving Construction and Demolition Waste Management. The thematic analysis of open-ended responses revealed several recurring barriers that hinder effective construction and demolition waste management (CDWM) in the NSCR Phase 1–Bulacan Project. These barriers are primarily institutional, behavioral, and operational, reflecting systemic challenges beyond technical limitations. The following themes summarize the key issues:

Lack of Specific and Enforceable Policies. Respondents emphasized the absence of clear, project-specific guidelines. Existing laws such as RA 9003 and RA 6969 provide general waste provisions but lack detailed mandates for CDWM, resulting in voluntary rather than enforced practices.

Weak Political Will and Regulatory Enforcement. Sustainability is often deprioritized in favor of economic growth and project delivery. Limited political ***commitment*** and weak enforcement mechanisms undermine compliance, even when policies exist.

Time Pressure from Aggressive Project Schedules. Tight construction timelines lead contractors to prioritize speed over sustainability. Waste segregation and monitoring are often skipped during peak construction periods, reducing environmental oversight.

Insufficient Budget Allocation and Contractual Provisions. Many contracts lack explicit CDWM requirements, resulting in inadequate funding for material recovery facilities, training, and monitoring. This financial gap limits the adoption of sustainable technologies.

Poor Stakeholder Coordination and Self-Monitoring. Weak collaboration among project actors and reliance on self-monitoring hinder accountability. Without stronger alignment and external oversight, waste management practices remain inconsistent.

Low Awareness and Behavioral Resistance. Limited education and training contribute to resistance to change. Workers often revert to traditional disposal methods, with convenience and fatigue driving non-compliance.

Inadequate Facilities and Technology. The lack of nearby recycling facilities, incomplete on-site MRFs, and limited use of monitoring technologies make segregation and recovery costly and inefficient.

Overall, the barriers identified highlight systemic weaknesses in policy, governance, financing, behavior, and infrastructure. Addressing these requires integrated strategies, such as strengthening regulations, enhancing political commitment, allocating sufficient budgets, improving stakeholder collaboration, and investing in facilities and training, to ensure sustainable CDWM implementation in large-scale projects.

Proposed Actionable Recommendation for Construction and Demolition Waste Management in Railway Project.

Rationale. Large-scale railway infrastructure projects, such as the North–South Commuter Railway (NSCR) Phase 1 project in Bulacan Province, require careful and systematic management of construction and demolition waste. The findings indicate that, although stakeholder awareness is generally high, the implementation of construction and demolition waste management remains fragmented due to interrelated political, economic, social, technological, legal, and environmental (PESTLE) barriers, including policy

inconsistencies, inadequate monitoring mechanisms, limited incentives, and climate-related risks.

Given the range and environmental impact of railway construction, effective construction and demolition waste management involves systematic, project-specific, and enforceable procedures rather than simply raising awareness. In response, these actionable recommendations are based on the study findings and arranged using the PESTLE framework. These proposals seek to transform identified barriers into actionable measures for improving institutional coordination, compliance, and sustainable construction and demolition waste management practices in railway infrastructure projects. Details of the recommendations are presented in Table 13.

Objectives. The proposed actionable recommendations aim to:

1. Improve policy coherence and institutional coordination within implementing agencies, regulators, and local government units to overcome discrepancies and overlapping jurisdictions in construction and demolition waste administration.

2. Promote economically feasible and sustainable construction methods by reducing waste, reusing and recycling materials, and including construction and demolition waste criteria into contracts and Bill of Quantities (BOQs).

3. Increase stakeholder understanding and behavior change by providing focused training, capacity building, and awareness initiatives on most effective construction and demolition waste management.

4. Enhance monitoring, reporting, and compliance methods by implementing digital tracking systems, standardized reporting, and performance benchmarking.

5. Improve monitoring, reporting, and compliance methods through the use of digital tracking systems, standardized reporting, and performance benchmarking.

Table 13

Matrix of Proposed Actionable Recommendations for Construction and Demolition Waste Management in Railway Project

Domains	Objective	Actionable Recommendation
Political	To reduce inconsistencies to existing laws	Implementing agency to institutionalize waste management requirements across project phases to reduce policy inconsistency.
	To address overlapping jurisdiction among government agencies and local government unit	Bolster inter-agency coordination of Department of Transportation (implementing agency), Local Government Unit and Department of Environment and Natural Resources (regulator).
Economic	To encourage the contractors to adopt sustainable practices and strategies in construction site.	Introduce economic incentives for contractors such as bid evaluation advantages or recognition for high recycling performance.
		Encourage contractors for local recycling facilities to reduce transportation and disposal costs.
		Integrate waste minimization strategies (accurate take-offs, just-in-time delivery) to control material waste and costs.
		Project Specific Construction and Wate Management Plan (CWMP) must integrate into contract clauses and Bill of Quantities (BOQ) items for future projects
Social	To enhance awareness and behavioral change toward sustainable practices.	Conduct training and capacity building programs for engineers, supervisors, and site workers for waste management.
		Promote awareness campaign emphasizing environmental and operational benefits of waste reduction.
Technological	To monitor the construction and demolition waste generated and disposed of.	Adopt digital tracking systems to monitor waste generation, disposal, and recycling rates.
		Standardized data reporting templates to support performance evaluation and benchmarking.
Legal	To have specific guidelines for Construction and demolition waste management.	Implementing agency must develop railway-specific construction and demolition waste management guidelines distinct from building construction policies.

DISCUSSION

The findings of this study highlight the multifaceted barriers to construction and demolition (C&D) waste management in the North–South Commuter Railway (NSCR) Phase 1 Project in Bulacan, as analyzed through the PESTLE framework. Political and legal constraints emerged as critical challenges, particularly the fragmented enforcement of Republic Act 9003 and the absence of project-

specific regulations for C&D waste. These findings align with Bhavsar et al. (2023) and Estrada et al. (2023), who emphasized that overlapping mandates and weak monitoring mechanisms undermine sustainability efforts in infrastructure projects. The results confirm that while stakeholders demonstrate awareness of waste management issues, actual implementation remains limited due to systemic governance gaps. This underscores the need for stronger institutional coordination and clearer accountability mechanisms to ensure compliance and integration of sustainable practices in railway megaprojects.

Economic and technological barriers were also pronounced, with stakeholders citing high costs of sustainable waste processing and limited access to digital monitoring tools. Similar to Shooshtarian et al. (2022) and Silva et al. (2024), the study found that financial constraints discourage investment in advanced recycling technologies, while the absence of systematic tracking systems hampers accurate quantification of waste streams. These barriers reinforce the perception that sustainability increases project costs, thereby reducing contractor willingness to adopt innovative practices. However, the study also revealed stakeholder openness to digital solutions, echoing Gao et al. (2024) and Li et al. (2020), who demonstrated the potential of machine learning and integrated platforms in improving waste quantification. This suggests that adoption of digital monitoring and data management tools, as recommended, could bridge technological gaps and enhance transparency, accountability, and decision-making in C&D waste management.

Social and environmental dimensions further complicate waste management practices. Low awareness, resistance to change, and insufficient training among workers and contractors mirror findings by Izzati et al. (2024) and Mawed et al. (2020), who noted that entrenched site cultures and lack of education hinder sustainable transitions. Environmental pressures, including landfill scarcity and Bulacan's vulnerability to natural hazards, exacerbate these challenges, consistent with Abarca-Guerrero et al. (2022). To address these interconnected barriers, the study recommends expanding stakeholder involvement to include regulatory agencies, LGUs, waste service providers, and communities, thereby fostering broader accountability and collaboration. Moreover, implementation-oriented capacity building, through targeted training, on-site segregation, and performance evaluations, should be prioritized to move beyond awareness toward operational compliance. By integrating these strategies with digital monitoring systems, future railway and infrastructure projects can achieve more resilient, efficient, and sustainable waste management outcomes.

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