

Driving Circular Economy Performance through Green Logistics Infrastructure: The Mediating Roles of Recycling Efficiency and the Moderating Role of Waste Segregation and Collection Policy

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Abstract

Purpose: This study evaluates the effect of green logistics infrastructure on the functioning of the circular economy in the Pakistani context. **Methods:** These data were collected using a cross-sectional survey that was carried out on logistics experts, production engineers, and leaders from various private and public manufacturing sectors in Pakistan. A total of 356 valid responses were used for analysis. The study, based on structural equation modeling, attempted to identify ways in which the practice of green logistics infrastructure influences different measures of circular economy performance. **Results:** This empirical study indicates that there is a strong, statistically significant positive relationship between green logistics infrastructure and corporate performance in the supply chain context. In particular, the increase in recycling efficiency, which is the degree of integration of waste recycling activities and the creation of process systems with generative capacity, has a positive impact on the metrics of improved performance. This study contributes to the existing literature by demonstrating how recycling efficiency mediates the relationship between green logistics infrastructure and circular economy performance, while waste segregation and collection policy strengthens this relationship within the context of Pakistan. **Conclusion:** This study suggests that the development of a circular economic system in the developing setting is not facilitated by individual efforts but rather by the coordinated structuring of infrastructure, operations, and governance. In practice, the findings can be useful to policymakers and the stakeholders of the industry when it comes to improving sustainability outcomes by using the policy of integrated infrastructure development and waste management planning.

Keywords: Green Logistics Infrastructure; Circular Economy Performance; Recycling Efficiency; Waste Segregation and Collection Policy, Sustainability

Introduction

The global supply chains, especially those of developing economies, have been subjected to increased environmental pressures owing to the rapid industrialization, urbanization, and rise of consumption patterns. The conventional linear production paradigms, which are founded on the principles of take-make-dispose, have led to unjustified overexploitation of available resources, poor waste management,

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and increased environmental risks (Tariq et al., 2026). In turn, the circular economy has become a strategic model of reducing waste, extending the lifespan of products, and encouraging the recycling of resources through reuse, recycling, and recovery processes (Kirchherr et al., 2017). Logistics systems are at the center of a supply chain, determining its environmental performance. The transportation networks, material handling, and warehousing operations also contribute greatly to carbon emissions, energy use, and waste production (Dekker et al., 2012). As a result, such a concept as green logistics infrastructure has been receiving more and more attention as a way of minimizing environmental impact and facilitating sustainable material flows (Ghisellini et al., 2016). Green logistics infrastructure includes energy-saving types of transportation systems, environmentally friendly practices, reverse logistics warehouse facilities, and digital technologies allowing tracking of waste and recovery of resources (McKinnon et al., 2015). Although the role of the logistics infrastructure in the performance of the circular economy has been identified, its role largely relies on complementary operational and policy mechanisms (Iqbal et al., 2023). Circular practice enablers are considered vital because recycling efficiency, which refers to the effectiveness of transforming waste into reusable materials, is one of the crucial operational enablers.

Investments in green infrastructure will not yield visible benefits without an effective recycling system. In addition, there are waste collection policies that offer the institutional basis needed to guarantee uniform quality of materials and adequate waste for recycling (Guerrero et al., 2013). In poor nations like Pakistan, the inability to implement a circular economy is still marked by structural inefficiencies of waste management systems, the ineffectiveness of regulations, and inadequate investment in infrastructure (Ahmed et al., 2020). Despite the recent policy efforts to focus on sustainable development and environmental protection, there is still limited empirical data on the interactions of green logistics infrastructure with recycling efficiency and waste control mechanisms. This is a gap that must be addressed to come up with appropriate strategies that facilitate sustainable industrial development and resource conservation in the emerging economies. The increasing need to sustain the environment has forced governments and other organizations across the globe to review traditional supply chain and logistics procedures (Table 1).

The growing amount of garbage, resource depletion, and climate change issues have led to the urgent need for systemic shifts towards a more sustainable model of the economy. The circular economy can be viewed as an alternative that is promising, as it encourages closed loops where materials are subjected to repeated recovery, reuse, and recycling to eliminate the use of virgin resources and reduce environmental degradation (Ellen MacArthur Foundation, 2015). Logistics infrastructure is a pillar toward the realization of the goals of the circular economy. Efficient transport systems, green warehouses, and reverse logistics allow the circulation of recyclable goods, assistance with the return of products, and recovery of resources (Genovese et al., 2017).

This research is relevant because it contributes to the growing field of empirical research on the impact of operational arrangements at a system level on the outcome of resource recovery in developing economies, where material losses and environmental pressures are still significant. The study of Pakistan also offers specific context-related evidence of a country with a high rate of urbanization, ineffective institutional coordination, and intensive dependence on informal recovery efforts (Batool & Ch, 2009). The results add to the theory by elucidating how both operational efficiency and policy enforcement have a role to play in forming sustainability-focused results, closing the gaps that have been identified in the literature on this topic, which, to a large extent, has focused on either of these two elements separately (Govindan & Hasanagic, 2018). In practice, the findings provide practical implications to the policymakers and local governments to enhance material recovery rates and environmental performance by using integrated operational and policy interventions (Figure 1). The paper also reinforces evidence-based planning that could be used by developing nations that would want to shift to resource-efficient economic models.

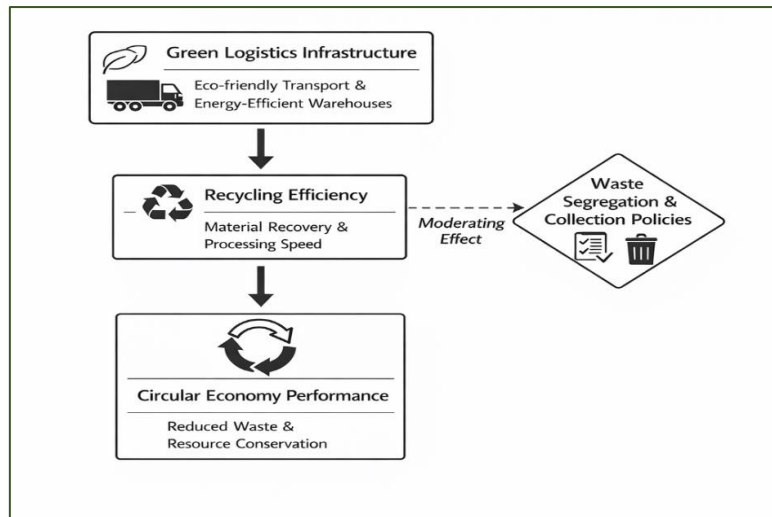


Figure 1: Role of Green Logistics Infrastructure in Facilitating Circular Economy

Table 1: Earlier Studies on Green Logistics Infrastructure and its Contribution

Author(s)	Year	Research Context	Methodology	Major Findings	Contribution to Green Logistics Infrastructure
Harris, Naim & Mumford	2007	Infrastructure modelling for green logistics	Literature review and optimization modelling	Demonstrated that logistics infrastructure should be designed to optimize both economic efficiency and environmental performance rather than focusing solely on cost reduction. The study emphasized network optimization, freight consolidation, and environmentally efficient transport infrastructure.	One of the earliest studies recognizing infrastructure as a strategic component of green logistics and sustainable freight systems.
Rodrigue, Comtois & Slack	2017	Sustainable transport and freight geography	Conceptual and empirical analysis	Showed that transport infrastructure, logistics hubs, ports, rail terminals, and intermodal facilities significantly reduce logistics costs, traffic congestion, fuel consumption, and greenhouse gas emissions.	Established that sustainable logistics infrastructure forms the backbone of environmentally responsible supply chains.
Hu et al.	2020	Green and sustainable logistics	Systematic Literature Review (306 publications)	Identified five major research streams including green transportation, warehousing, packaging, logistics infrastructure, and intelligent logistics. Concluded that green infrastructure combined with technological innovation significantly improves environmental and operational performance.	Developed one of the most comprehensive knowledge taxonomies for green logistics research and identified infrastructure as a core research pillar.
Yingfei et al.	2022	Green logistics performance and infrastructure	Empirical study using PLS-SEM	Found that green logistics infrastructure positively influences logistics performance, environmental sustainability, service quality, and firm competitiveness. Green investments were shown to	Provided empirical evidence supporting the direct relationship between green logistics infrastructure and

				improve sustainable economic development.	organizational performance.
Liu <i>et al.</i>	2023	Green logistics in China	Systematic Literature Review	Identified green transportation, eco-friendly warehousing, logistics facilities, and intelligent logistics infrastructure as the principal dimensions of green logistics. The study also highlighted digital technologies as emerging enablers.	Recommended expanding research on smart logistics infrastructure, IoT-enabled logistics, and digital transformation.
Wu <i>et al.</i>	2023	Green logistics optimization	Systematic review of Operations Research models	Reviewed optimization approaches for green transportation networks, vehicle routing, logistics hubs, multimodal transportation, and infrastructure planning. Demonstrated that optimization models significantly reduce emissions and improve logistics efficiency.	Advanced infrastructure planning by integrating optimization techniques into sustainable logistics decision-making.
Chepurna <i>et al.</i>	2025	Green logistics conceptualization	Systematic Literature Review (510 studies)	Clarified the definition and conceptual boundaries of green logistics. Identified logistics infrastructure, renewable energy integration, circular logistics, and reverse logistics as essential elements of modern green logistics systems.	Provided a unified conceptual framework that positions infrastructure as a fundamental enabler of environmentally sustainable logistics.
Mahapatro <i>et al.</i>	2026	Global bibliometric review of green logistics	Bibliometric analysis (1,200+ publications)	Identified green logistics infrastructure, digitalization, Industry 4.0 technologies, AI, blockchain, IoT, and reverse logistics as the fastest-growing research themes. Recommended more empirical studies in emerging economies.	Highlighted future research directions by integrating digital infrastructure with green logistics capabilities and sustainable supply chain management.

Circular Economy Theory

The current research is closely based on the Circular Economy (CE) Theory, where the focus is on the sustainable utilization of resources, the material loops, the waste reduction, and the further circulation of products and materials (Geissdoerfer *et al.*, 2017). Here, the infrastructures of green logistics support the introduction of circular practices, as they enable the efficient collection, transportation, and management of materials, thus increasing the efficiency of recycling, which is the mediator of the increased performance of the circular economy. Additionally, policies on waste collection will enhance the process by making sure that the separation of resources and their collection is done in a systematic manner and that the operational processes are in line with the CE principles. The paper illustrates that well-planned logistics functions, with efficient policy frameworks, operationalize the main principles of CE Theory and transform environmental sustainability into performance deliverables (Figure 2). This congruence supports the significance of logistical and policy intervention in a functional and result-driven circular economy, especially in the face of an emerging economy like Pakistan.

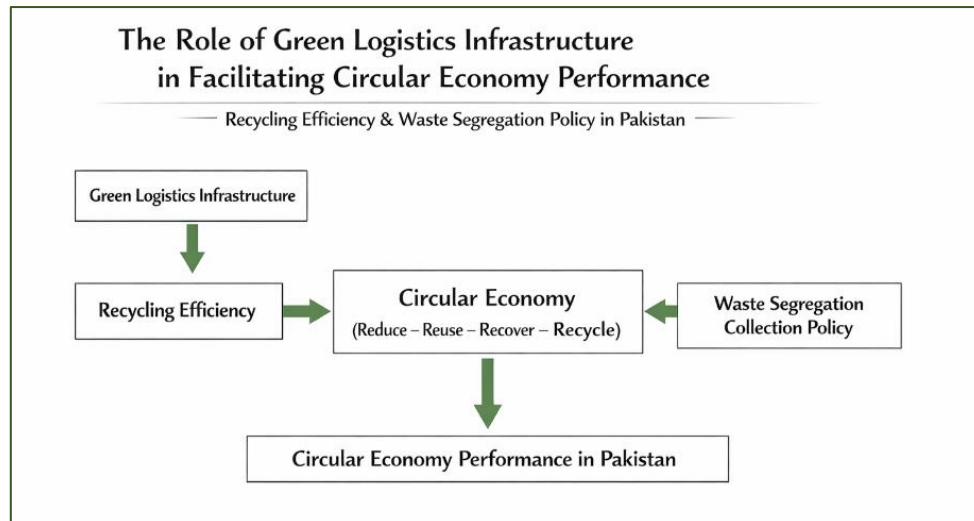


Figure 2: A Holistic Conceptual Framework

Review of Literature

Role of Green Logistics Infrastructure in Facilitating Circular Economy Performance

Prior studies propose that logistics systems that have been developed to make the environment less burdensome have a positive impact on the economic models that focus on reuse and efficiency results. Torasa and Mekhu (2020) also identified that the logistics actions that have minimal economic effects on the environment, like effective transportation and reuse of materials, have a significant effect on resource recovery indicators in the chosen ASEAN economies, indicating a quantifiable relationship between enhanced logistics behaviors and circular logistics performances. It has also been shown that the logistics practices that are environmentally oriented can assist firms to embrace more sustainable production and reuse operations, which in turn results in improved performance in the context of waste reduction and efficiency targets (Ren *et al.*, 2020). Additionally, performance assessment research shows that the metrics and tools created to determine the environmentally enhanced logistics allow organizations to make strategic choices that minimize environmental effects and help to sustain the long-term objectives, thus opening the way to more powerful performance of the systems that are based on repeated material consumption and retention of resources (Do *et al.*, 2024). Locally, the literature emphasizes the fact that environmentally oriented logistics infrastructure is a valuable facilitator of results related to improved material utilization, resource conservation, and operational sustainability.

H1: Green logistics infrastructure has a positive impact on circular economy performance

Green Logistics Infrastructure Influences Recycling Efficiency

The existing studies indicate that logistics systems incorporating environmentally friendly infrastructure, such as optimized transportation systems, dedicated return facilities, and increased storage and handling capacity, are effective. This infrastructure will help streamline recycling activities by making it easier to have a flow of materials and fewer operational obstacles to material recovery (Wang *et al.*, 2025). A well-developed logistics infrastructure facilitates coordinated activities of end-of-life goods into the processing streams, and this improves the effectiveness of the collection and minimizes time delays and losses of handling, ultimately boosting the success of recycling (De Souza *et al.*, 2022). The research also indicates that the specific logistics capabilities, such as reverse and return networks, are the primary factors that determine the effectiveness with which the materials are reclaimed and reused after the initial application, which underlines the strategic significance of logistics systems to the performance of recycling activities (Ali *et al.*, 2018). Moreover, studies regarding the performance of reverse logistics indicate that successful logistics networks play a crucial role in enhancing the sustainability indicators, as they allow increasing the rates of material returns and enhancing the

recycling throughput (Offei, 2025). Collectively, the literature points to the fact that the investments in logistics infrastructure that is environmentally oriented are positively related to the increase in the efficiency of recycling since they alleviate the friction in material returns and processing and thus contribute to the overall sustainability goals in supply chains.

H2: Green logistics infrastructure positively influences recycling efficiency.

Recycling Efficiency Influences Circular Economy Performance

Empirical and theoretical studies indicate that the effectiveness of recycling processes is positively linked to better performance in economic models that focus on the sustainable use of resources. Research shows that increased rates of material recovery and recycling lead to the improvement of the environmental and economic indices, as there is less reliance on virgin resources and secondary materials can be reintegrated into production systems more efficiently (Bongers & Casas, 2022). The assertion that sustainable practices, such as recycling, are positively correlated with firm-level performance outcomes is also substantiated by meta-analytic evidence, indicating that recycling performance has the potential to support the overall sustainability objectives through enhancing operational performance and lowering the cost of waste management (Yingfei et al., 2022). Municipal and sectoral waste management studies also determine that increased recycling rates are linked with improved waste treatment results, although the effects on waste production may be less pronounced (Park & Hong, 2024). Also, the discussions of the circular system dynamics underline that effective recycling and material reintegration can decrease environmental impact and facilitate future performance through maximizing material cycles and decreasing the use of raw materials (García-Valderrama et al., 2024). All of this literature collectively reinforces the idea that the performance of recycling is of critical importance in enabling sustainable economic performance by supporting resource productivity, minimizing losses, and supporting more robust material use journeys.

H3: Recycling efficiency positively influences circular economy performance.

Recycling Efficiency between Green Logistics Infrastructure and Circular Economy Performance

Studies have shown that environmentally designed logistics systems can improve the efficiency of material recovery processes, which contributes to increased performance in economic models with a focus on sustainability and resource reuse. Research indicates that the logistics systems with enhanced infrastructure and operating strategies will enable easier material returns and improved management of the end-of-life products, increasing the material processing, recovery rates and efficiency (Zhang et al., 2022; Seroka-Stolka & Ociepa-Kubicka, 2019). This increased efficiency in recycling and material reintegration has been associated with the performance of models oriented to waste reduction and material retention because an efficient recovery operation ensures minimal losses and minimizes the extraction of primary resources (Jayarathna et al., 2024). Besides, the empirical evidence demonstrates that if the logistics practices are successful in facilitating the return flows and processing activities, the firms will be able to attain broader sustainability goals, such as enhanced material utilization performance and lessened environmental impact (Masudin et al., 2025; Kumari et al., 2025) (**Table 2**). Together, the literature points to the fact that enhanced processing and transfer of recyclable resources through the logistics frameworks lead to the realization of better performance results related to sustainable and regenerative economic patterns (Almelhem et al., 2025).

H4: Recycling efficiency mediates the relationship between green logistics infrastructure and circular economy performance.

Table 2: Current statistics of waste generation areas of Pakistan

Indicator / Aspect	Current Statistics / Figures	Source
Annual solid waste generated	49.6 million tons	Sattar, 2023
Annual plastic waste generated	3.9 million tons	Pakistan Today, 2025
Waste growth rate	2.4% per year	International Trade Administration, 2026
City-level waste (Karachi)	12,000–16,500 tons/day	International Trade Administration, 2026
City-level waste (Lahore)	7,000 tons/day	Pakistan Today, 2025
City-level waste (Islamabad)	1,000 tons/day	Pakistan Today, 2025
Waste collection rate	50–70% of total generated	International Trade Administration, 2026
Formal recycling rate (all waste)	<10%	The Agricultural Economist, 2025
Plastic recycling (formal)	3%	Khan, 2025
Informal recycling contribution	14.4%	Iqbal et al., 2023
Households practicing waste segregation	25%	The Agricultural Economist, 2025
Economic loss due to waste mismanagement	\$1.2 billion annually	Khan, 2025
Investment in waste management infrastructure	\$50 million/year (needed \$500 million)	The Agricultural Economist, 2025
Informal sector workforce in recycling	>1.5 million people	The Agricultural Economist, 2025
Plastic bag reduction after bans	From 80% usage to 58%	Press Information Department, 2025

Waste Segregation and Collection Policy between Recycling Efficiency and Circular Economy Performance

One of the most widely known institutional mechanisms in the literature for connecting recycling efficiency and the overall performance of the circular economy is waste collection policies. The quality and recoverability of the recyclable materials are boosted greatly owing to reduced contamination, decreasing processing costs, and raising the economic value of the secondary raw materials, which improves the downstream recycling systems (OECD, 2019). Empirical and policy-based studies highlight the role of well-constructed collection networks with regulatory imperatives, long-term producer responsibility programs, and landfills in providing systemic inducements that enhance the recovery rates of materials and trigger circular flows of resources (European Commission, 2020). As per a systems approach, the circular economy model by the Ellen MacArthur Foundation (2013) emphasizes that proper waste separation is core to bridging material loops, and in this regard, the quality of input streams is the determinant of the technical feasibility and economic sustainability of the recycling and remanufacturing processes. (Darzi, 2025). However, moderating factors that precondition efficient manifestations of the relationship between recycling efficiency and circular performance are also found in the literature in the form of infrastructure adequacy, enforcement capacity, technological innovation, and the level of public participation. Research indicates that household compliance rates are low, resulting in a high contamination rate without regular household compliance, awareness campaigns, and easy collection mechanisms, yielding low recycling rates and compromising the outcomes of the circular process (Kaza et al., 2018). Moreover, the policy congruence on municipal, national, and supranational levels should be applied to adjust the segregation standards and market development regarding secondary materials and its indicators of monitoring performance so that the benefits of recycling efficiency could be converted to the metrics of a circular economy (Iqbal & Kang, 2024). Javed et al. (2025) analyze that inclusive leadership impacts numerous organizational outcomes (**Table 3**). As such, the waste segregation and collection policy does not just work as a working waste management instrument but as a policy governance tool that balances the extent to which recycling efficiency is effective in generating sustainable resource circulation, protecting the environment, and ensuring economic sustainability over time.

H5: Waste collection policies moderate the relationship between recycling efficiency and circular economy performance, such that the relationship is stronger when these policies are effectively implemented.

Table 3: Current Waste & Recycling Statistics of Pakistan

Category	Indicator / Statistic	Value / Detail	Source
Total Waste Generation	Annual solid waste	49.6 million tons/year	Safdar, 2025
	Per capita solid waste generation	0.5–0.65 kg/person/day in large urban areas	Azam <i>et al.</i> , 2020
Waste Composition (%)	Organic (food & biodegradable)	60–62% of total waste	Naeem, 2025
	Construction & demolition waste	30%	Naeem, 2025
	Plastic	9% (other estimates 4% of total)	Pecorini <i>et al.</i> , 2020
	Paper	6%	Pecorini <i>et al.</i> , 2020
	Glass	6%	Pecorini <i>et al.</i> , 2020
	Metal	4%	Pecorini <i>et al.</i> , 2020
	Yard/chip/wood/textile/rubber/leather	20–24% combined	Pecorini <i>et al.</i> , 2020
Collection & Disposal	Waste collected by municipalities	60–70%	International Trade Administration, 2026
	Waste burned/open dumped	30–40%	International Trade Administration, 2026
	Sent to engineered landfills	40% of collected waste	Khan, 2025
City Waste Generation (Daily)	Karachi	16,500 t/day	International Trade Administration, 2026
	Lahore	7,690 t/day	International Trade Administration, 2026
	Faisalabad	5,017 t/day	International Trade Administration, 2026
	Rawalpindi	4,500 t/day	International Trade Administration, 2026
	Other cities (Hyderabad, Multan, Gujranwala, Sargodha, Peshawar, Quetta)	716–3,972 t/day	International Trade Administration, 2026
Recycling Rates	Overall recycling share (all waste types)	7.6–9%	Naeem, 2025
	Plastic waste recycled	4–9%	The News International, 2025
	PET bottles recycling (informal)	80–90% of PET bottles collected	Naeem, 2025
	Informal recycling recovery (all recyclables)	13–14% recovered from MSW	cpi.ksbl.edu.pk
Household Behavior	Households segregating waste at source	25%	sdpi.org
Policy and Institutional	Formal recycling/composting infrastructure	Limited/underdeveloped	Naeem, 2025
	Extended Producer Responsibility (EPR) plans	Proposed, limited enforcement	(Nukta)
Economic / Environmental Impact	Estimated economic loss from inefficiencies	\$1.2 billion/year	Khan, 2025
	Waste sector contribution to GHG emissions	3.4% global context (Lahore dumpsite example)	Iqbal, 2024
Green Logistics and Infrastructure Gaps	Lack of formal sorting/supply chain for recyclables	Severe bottleneck	Naeem, 2025
	Composting and biofuel use emerging pilots	Recycling/composting plants introduced regionally	Khan, 2025

Methodology

The current study is based on a quantitative, cross-sectional research approach, which is aimed at investigating the direct, mediating, and moderating effects between the green logistics infrastructure, recycling efficiency, waste segregation and collection policy, and the efficiency of the circular economy. The proposed relationships were tested simultaneously using a variance-based structural equation modeling method and thus guaranteed rigorous evaluation of the predictive validity, path complexities, and interaction effects of latent constructs. The target population of the study was managers, specialists, and senior operational employees working in logistics, supply chain, sustainability, and

production departments of manufacturing and distribution organizations dedicated to environmentally oriented activities in Pakistan. These people were selected based on their direct involvement in the infrastructure planning processes, recycling processes, and performance evaluation. Primary information was collected through an organized sampling plan to collect data (**Figure 3**). The participants must have at least three years of professional experience and be engaged in the decision-making process with respect to sustainability. The last dataset consisted of the responses that met the strict criteria of missing data, response bias, and outliers.

Table 4: Variables Description and Role in the Research Model

Variables Name	Description	Role in Model
Green Logistics Infrastructure	Physical and operational logistics systems that support environmentally sustainable activities, including eco-friendly transportation, energy-efficient warehouses, reverse logistics facilities, and sustainable packaging and handling systems.	Independent Variable
Recycling Efficiency	Effectiveness of recycling processes in terms of material recovery rate, processing speed, quality of recyclables, and cost efficiency in transforming waste into reusable resources.	Mediating Variable
Waste Collection Policies	Governmental and organizational regulations, standards, incentives, and enforcement mechanisms that promote systematic waste efficient collection practices.	Moderating Variable
Circular Economy Performance	Organizational and environmental outcomes reflect circular practices, including waste reduction, resource conservation, material reuse, cost savings, and sustainable operational performance.	Dependent Variable

All measurement items were adopted from previously published and validated studies, and the items were measured using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Green Logistics Infrastructure was measured using a 10-item scale from Green *et al.* (2012), Recycling Efficiency was measured using an 8-item scale from Singh & Ordonez (2016) as a mediator; Waste Segregation and Collection Policy was measured as a moderator using a 10-item scale from Ali *et al.* (2019), and Circular Economy Performance was measured as a dependent variable using a 10-item scale from Kirchherr *et al.* (2017). The information was collected through self-administered questionnaires, which were distributed through electronic means to qualifying respondents (**Table 4**). Participation was voluntary, and to reduce the social desirability problem, it was assured that confidentiality would be maintained. The respondents were informed that the data that would be generated could only be used in academic research. Safeguards were taken in procedures to reduce common method variance. These included accurate instructions, a calculated psychological isolation between predictor and criterion variables in the questionnaire, and assurances of anonymity. The questionnaire was critically reviewed before deployment in terms of conceptual clarity and contextual relevance. Due to the large size of the available population, convenience sampling was used; a total of 356 valid responses were used for analysis (**Table 5**).

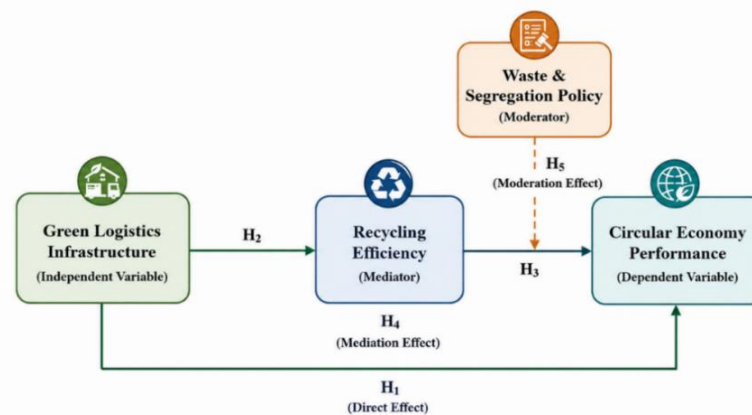


Figure 3: Conceptual Research Model

Table 5: Demographic Particulars (n = 356)

Demographics	Frequency	Percentage
Gender		
Male	278	78.01
Female	78	21.09
Age in years		
20-30	202	56.75
31-40	87	24.43
41 or above	67	18.82
Academic Qualification		
Bachelors	231	64.88
MS/M. Phil	101	28.38
Ph.D.	24	6.74
Work Experience in years		
5-10	165	46.35
11-15	136	38.21
16 or above	55	15.44
Type of Organization		
Private	283	79.51
Public	73	20.49
Industry		
Logistic Firms	89	25.00
Construction Materials	83	23.32
Food Processing	97	27.24
Pharmaceuticals	58	16.29
Electrical and Electronics	29	8.15

Results

Measurement Model Assessment

The measurement model was tested to determine, with maximum accuracy its reliability and validity before the structural relationships could be examined. Internal consistency reliability was also evaluated by means of composite reliability coefficients, which allowed us to guarantee that each construct was coherent enough. The concept of convergent validity was tested through factor loadings and average variance extracted values, thus confirming that the indicators were sufficient to measure what they were meant to measure. Discriminant validity was established according to accepted standards that ensured that every construct was empirically different in the model. The analysis of the structural relationships was only done after reaching satisfactory levels of reliability and validity. This step-by-step method will ensure that future inferential tests are based on a solid measurement base and hence maximize the validity of the findings that follow.

Table 6: Loadings, Composite Reliability and Average Variance Extracted

Construct	Item	Factor loading	Cronbach's α	(CR)	AVE
Circular Economy Performance	CEP1	0.748	0.917	0.930	0.573
	CEP10	0.746			
	CEP2	0.758			
	CEP3	0.709			
	CEP4	0.806			
	CEP5	0.751			
	CEP6	0.789			
	CEP7	0.795			
	CEP8	0.763			
	CEP9	0.695			
Green Logistic Infrastructure	GLI1	0.633	0.898	0.916	0.524
	GLI10	0.768			
	GLI2	0.669			
	GLI3	0.688			
	GLI4	0.699			
	GLI5	0.736			

	GLI6	0.761			
	GLI7	0.720			
	GLI8	0.782			
	GLI9	0.769			
Recycling Efficiency	RE1	0.795	0.916	0.931	0.629
	RE2	0.814			
	RE3	0.763			
	RE4	0.783			
	RE5	0.796			
	RE6	0.812			
	RE7	0.795			
	RE8	0.783			
Waste Segregation and Collection Policy	WSC1	0.789	0.911	0.926	0.558
	WSC2	0.647			
	WSC3	0.770			
	WSC4	0.784			
	WSC5	0.721			
	WSC6	0.802			
	WSC7	0.832			
	WSC8	0.779			
	WSC9	0.658			
	WSC10	0.657			

Note. Cronbach's alpha and composite reliability values above 0.70 indicate internal consistency reliability. Average variance extracted (AVE) values above 0.50 indicate adequate convergent validity (Hair et al., 2022).

Table 7: Discriminant Validity (HTMT Ratio)

HTMT	Circular Economy Performance	Green Logistic Infrastructure	Recycling Efficiency	Waste Segregation and Collection Policy
Circular Economy Performance				
Green Logistic Infrastructure	0.586			
Recycling Efficiency	0.654	0.644		
Waste Segregation and Collection Policy	0.696	0.543	0.665	

Note: HTMT values below 0.85 (strict criterion) or 0.90 (liberal criterion) indicate adequate discriminant validity

Table 8: Discriminant Validity (Fornell - Larcker Criterion)

	Circular Economy Performance	Green Logistic Infrastructure	Recycling Efficiency	Waste Segregation and Collection Policy
Circular Economy Performance	0.757			
Green Logistic Infrastructure	0.533	0.724		
Recycling Efficiency	0.607	0.589	0.793	
Waste Segregation and Collection Policy	0.642	0.485	0.600	

Note. Discriminant validity is considered acceptable when the square root of the average variance extracted (AVE) for each construct is greater than its highest correlation with any other construct (Fornell & Larcker, 1981).

Table 9: Cross Loading

	CEP	GLI	RE	WSC
CEP1	0.748	0.405	0.493	0.491
CEP10	0.746	0.476	0.483	0.497
CEP2	0.758	0.397	0.451	0.450
CEP3	0.709	0.352	0.305	0.392
CEP4	0.806	0.426	0.438	0.507
CEP5	0.751	0.401	0.462	0.504
CEP6	0.789	0.424	0.495	0.511
CEP7	0.795	0.356	0.430	0.525
CEP8	0.763	0.403	0.545	0.520
CEP8	0.695	0.380	0.441	0.433
GLI1	0.407	0.633	0.357	0.366
GLI10	0.373	0.768	0.436	0.379
GLI2	0.339	0.669	0.374	0.298
GLI3	0.367	0.688	0.406	0.349

GLI4	0.358	0.699	0.379	0.301
GLI5	0.416	0.736	0.444	0.364
GLI6	0.431	0.761	0.454	0.355
GLI7	0.412	0.720	0.465	0.372
GLI8	0.353	0.782	0.457	0.354
GLI9	0.401	0.769	0.471	0.369
RE1	0.455	0.486	0.795	0.433
RE2	0.484	0.536	0.814	0.515
RE3	0.468	0.516	0.763	0.444
RE4	0.511	0.455	0.783	0.464
RE5	0.513	0.453	0.796	0.498
RE6	0.497	0.446	0.812	0.496
RE7	0.431	0.397	0.795	0.473
RE8	0.481	0.429	0.783	0.479
WSC1	0.542	0.410	0.448	0.789
WSC10	0.410	0.448	0.527	0.647
WSC2	0.476	0.298	0.405	0.770
WSC3	0.468	0.324	0.426	0.784
WSC4	0.432	0.284	0.435	0.721
WSC5	0.531	0.335	0.424	0.802
WSC6	0.537	0.344	0.414	0.832
WSC7	0.513	0.334	0.421	0.779
WSC8	0.436	0.438	0.506	0.658
WSC9	0.423	0.443	0.523	0.657

Note. Cross-loadings indicate adequate discriminant validity when each indicator loads higher on its associated construct than on all other constructs (Chin, 1998; Hair et al., 2019).

Structural Model Evaluation

The structural model was tested using path coefficients, t-values, and level of significance, which were computed by using a very large bootstrapping process with a lot of resamples (**Figure 4**). By doing so, the coefficient of determination was also tested to determine the overall explanatory power that the endogenous constructs contribute to the overall model fit. The mediation was evaluated by examining the indirect impact of green logistics infrastructure on the performance of the circular economy through recycling efficiency. This indirect path was found to be statistically significant using bootstrapped confidence intervals, and thus the mediation effect is not an accident due to sampling variability. The hypothesis of moderation was tested by forming an interaction term between the efficiency of recycling and the ability of the workforce to be skilled (**Figure 5**). Through evaluating the importance as well as the extent of this interaction effect, we sought to determine whether the relationship between recycling efficiency and performance outcomes is being strengthened by an increment in workforce ability. Lastly, the effect sizes were used so as to evaluate the substantive influence of every predictor. The predictive relevance of the model was also explored and this enabled us to assess the ability of the model to predict future performance considering the constructs assessed.

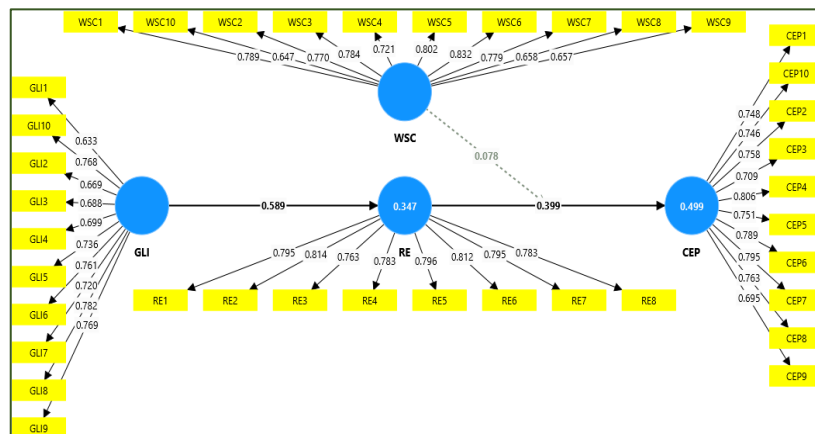


Figure 4: Measurement and structural model results with standardized estimates and explained variance (R²). (Smart - PLS)

Table 10: Structural Model Path Coefficients

Hypothesis	Path	β	t-value	p-value	CI (5%-95%)	Decision
H1	GLI $\rightarrow$ CEP	0.235	4.772	0.000	0.158, 0.318	Supported
H2	GLI $\rightarrow$ RE	0.589	11.909	0.000	0.508, 0.669	Supported
H3	RE $\rightarrow$ CEP	0.399	5.580	0.000	0.277, 0.513	Supported
H4	GLI $\rightarrow$ RE $\rightarrow$ CEP	0.245	4.875	0.000	0.168, 0.330	Supported
H5	WSC x RE $\rightarrow$ CEP	0.442	6.955	0.021	0.343, 0.552	Supported

Note. Path coefficients (β) were tested using bootstrapping with 5,000 subsamples. Paths are significant at **p-value** < 0.05 and **t-value** > 1.65. Confidence Intervals (CI) for path coefficients (β) were computed using bias-corrected bootstrapping with 5,000 subsamples. Paths were considered significant if the 95% CI did not include zero.

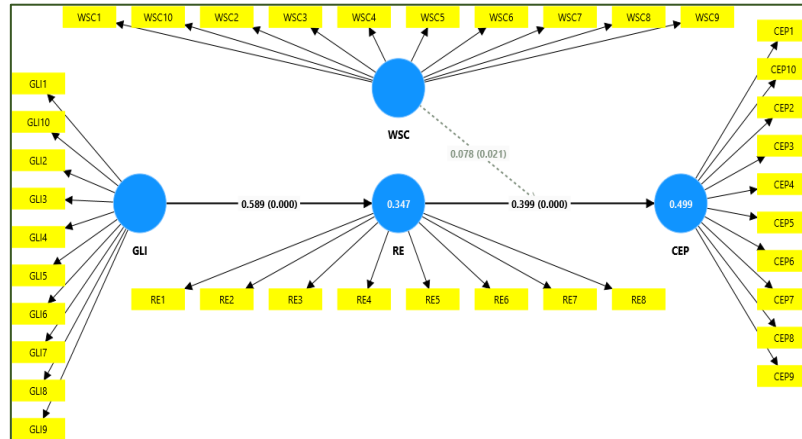


Figure 5: Structural and measurement model results obtained through PLS-SEM, showing standardized path coefficients with associated *p*-values, outer loadings, and R² values for endogenous constructs. (Smart – PLS)

Discussion

Based solely on the empirical evidence provided, the findings demonstrate a strong and well-specified measurement framework and structural model that jointly explain the differences in circular economy performance. The constructs showed good internal consistency and convergent validity in terms of high factor loadings, Cronbach's alpha, composite reliability, and average variance extracted exceeding the recommended values, showing that the indicators were good measures of their intended latent variables (**Table 6**). HTMT ratios, the Fornell-Larcker criterion, and cross-loading analysis were all used to establish discriminant validity, and it was clear that each construct was empirically different and without problematic overlap (**Tables 7 and 8**). The evaluation of the structural model demonstrated that the impact of green logistics infrastructure on the performance of the circular economy is direct and statistically significant, as it becomes strategic in promoting resource productivity and sustainable operational performance. Moreover, green logistics infrastructure positively impacts recycling efficiency, which in turn significantly enhances the level of the circular economy, demonstrating that recycling efficiency is a crucial factor in converting logistics investments into sustainability advantages. The indirect effect is also important in confirming that the mediating effect of recycling efficiency is effective, which means that improvements in infrastructure are not enough unless they are properly directed towards the current recycling activities. In addition, the effect of moderated mediation that is supported by waste segregation and collection policy implies that the presence of the policy-determined segregation practices enhances the relationship between recycling and its efficacy of performance, and consequently, the total effect on the outcomes of the circular economy (**Tables 9 & 10**). Taken together, these results suggest that the entire process of achieving a circular economy performance is not predetermined by the individual interventions but by a harmonious alignment of the policy of development of infrastructures, the efficiency of their operation, and the supportive policy of waste management. The high path coefficients and nonzero confidence intervals of the model indicate the

stability of the relationships proposed and their predictive significance, which is empirically supported by the fact that there is no relationship between the use of integrated logistics systems and the policy frameworks as the levers that make the difference in the practice of a circular-economy operation.

Earlier empirical evidence reinforces this interpretation. Based on 117 food industry companies in Romania, Nastase *et al.* (2025) concluded that green logistics positively influences the results of the circular economy. The study results also indicate that the connections between logistics and the circular economy are not sufficiently established, including in relation to the means by which logistics activities lead to circular effects. The 2026 MENA evidence is particularly relevant to the current study. El-Nakib & Elzarka (2026) have created an improved Green Logistics Performance Index (GLPI) for 20 countries in the Middle East and North Africa for the years 2018-2024, including logistics indicators and environmental indicators. Their results suggest that an increase in renewable energy use is positively associated with green logistics performance, which, in turn, could be a positive step towards more sustainable logistics systems in the region, provided that appropriate structural and environmental conditions are in place. Another piece of evidence is especially relevant for Saudi Arabia (Islam, 2026), which reviewed the policies employed in Saudi Arabia for waste management and circular economy development and concluded that policy architecture, resource recovery, recycling, extended producer responsibility (EPR), public-private partnership (P-P), and institutional coordination are key factors that will contribute to the circular transition in Saudi Arabia. These results show the need for a concerted infrastructure, policy, and resource-recovery approach rather than fragmented sustainability efforts to develop circular economy systems. Ahatsi and Olanrewaju (2026) studied the awareness of green logistics and the implementation of green logistics practices and found that the awareness level was moderate to high, with a higher level of awareness in Ghana than in South Africa. That's supported by other emerging-economy evidence in the recent past in Ghana and South Africa, using a sample of 285 logistics companies. The results are important because they show that knowing about sustainability and having institutional knowledge are not enough to make it work in logistics. In general, these studies provide recent empirical evidence regarding the structural and operational conditions that enable logistics to enhance the performance of the circular economy, particularly concerning resource recovery and the institutional arrangements that facilitate this process.

Theoretical Contribution

The research contributes to the literature of the circular economy as it goes beyond the existing emphasis on direct, linear relationships to empirically verify a conditional process model. It shows that the green logistics infrastructure is not necessarily associated with the creation of circular performance, but the value is realized through the mediating process of recycling efficiency, which shows the channel through which physical assets are transformed into material recovery. More importantly, by declaring a waste segregation and collection policy as a key moderator, the results qualify the technological determinism of much of the sustainable logistics discussion. These findings suggest that even efficacious recycling procedures will be limited in their effectiveness without the institutional framework, which guarantees feedstock quality and flow. By doing so, the paper ushers circular economy theory to the developing country situation, where it is shown that the sealing of material loops is neither an engineering issue nor solely a policy issue but a systemic phenomenon that is determined by the extent to which infrastructure capability, operational performance, and governance can be strategically aligned.

Practical, Policy and Managerial Implications

The results reposition green logistics to industry practitioners as a strategy, rather than a checkbox tactic of corporate social responsibility. Unless companies build the internal capacity to recycle materials and redirect them into production processes at the same time, investments in eco-friendly transportation or reverse logistics warehouses will deliver minimal returns. It is thus the responsibility of the managers not to regard recycling efficiency as an outer waste management concern but as a fundamental operation activity that is directly associated with the cost-saving and resilience of supply chains. To policymakers, the moderating nature of waste collection policies sends an obvious message: that

infrastructure spending is not enough. The source separation regulations, together with investments in separate collection systems, are what turn technically efficient recyclers into economically viable actors in the circular economy. This institutional base will make the use of the most advanced logistics networks work against polluted material flows, and the financial losses reported in the waste industry in Pakistan (more than a billion dollars per year) will continue. What this situation means is that both public and private investments need to follow suit, and the policy should establish the environment within which operational efficiency could thrive.

Table 11: Current and Future Impact Metrics

Dimension	Indicator	Current Statistics (2023–2025)	Future Impact (2030–2050)	Strategic Implications	Key Sources
Environmental Sustainability	Transport CO ₂ emissions	8.6 Gt CO ₂ in 2023, representing approximately 23% of global energy-related CO ₂ emissions	Net-zero transport emissions by 2050 through electrification, hydrogen fuel, and green logistics infrastructure	Green logistics infrastructure (GLI) reduces fuel consumption, emissions, and environmental degradation by promoting clean transportation and efficient freight movement.	International Energy Agency (2024a)
	Logistics sector emissions	Logistics activities contribute approximately 11–12% of global greenhouse gas emissions	Reduce logistics emissions below 5% through renewable energy, digital logistics, and multimodal transport	Investment in sustainable logistics infrastructure is critical for meeting global climate targets.	World Economic Forum (2025)
	Municipal solid waste generation	2.24 billion tonnes/year	Expected to reach 3.88 billion tonnes/year by 2050 without improved waste management	GLI supports efficient collection, segregation, recycling, and reverse logistics systems.	Kaza <i>et al.</i> (2018)
	Global recycling rate	Approximately 19–20% of municipal waste is recycled	Increase recycling rates beyond 50% through advanced circular economy systems	Recycling efficiency directly reduces landfill use and virgin resource extraction.	Lenkiewicz (2024)
	Global material consumption	Over 106 billion tons of raw materials consumed annually	Reduce virgin material dependence through circular production and recycling	Green infrastructure enables sustainable resource utilization and material recovery.	Circular Economy (2024)
Economic Performance	Global logistics market	Estimated at US\$11–12 trillion annually	Continued expansion driven by sustainable infrastructure investment	Green logistics lowers operational costs while improving long-term competitiveness.	World Economic Forum (2025)
	Circular economy opportunity	Estimated global economic value of US\$4.5 trillion	Significant growth through circular manufacturing and sustainable supply chains	Circular economy investments generate productivity gains and new business opportunities.	Accenture (2014)
Operational Performance	Delivery performance	Logistics optimization improves delivery reliability by 10–20%	AI-enabled autonomous logistics and predictive routing	Green infrastructure improves service quality and customer satisfaction.	Rodrigue, Comtois & Slack (2017)

	Vehicle utilization	Average freight utilization around 70–80%	More than 90% through AI-based fleet optimization	Intelligent transport systems improve fleet productivity while reducing emissions.	OECD (2024)
Circular Economy Performance	Circularity rate	Only 6.9% of materials are cycled back into the global economy	Significant increase through closed-loop supply chains	GLI strengthens reverse logistics, remanufacturing, and resource recovery systems.	Circle Economy (2024)
	Waste diversion from landfill	Less than 30% globally	More than 80% in advanced circular economies	Recycling efficiency and segregation policies improve landfill diversion rates.	Bruyninckx <i>et al.</i> (2024)
	Recovery rates	Recovery rates remain relatively low in many developing economies	Large-scale recovery through industrial symbiosis and recycling technologies	Green logistics infrastructure facilitates efficient material circulation.	Ellen MacArthur Foundation (2024)
Green Infrastructure Development	Green warehouses	Rapid adoption worldwide	Net-zero carbon logistics facilities become industry standard	Sustainable infrastructure reduces operational emissions and energy consumption.	U.S. Green Building Council (2024)
	EV charging infrastructure	Millions of charging points installed globally	Extensive freight charging networks supporting electric logistics fleets	Accelerates decarbonization of freight transport.	International Energy Agency (2024b)
	Smart logistics parks	Rapid expansion across Asia, Europe, and GCC	AI-integrated logistics hubs supporting digital supply chains	Smart infrastructure enhances logistics resilience and efficiency.	OECD (2024)
	Reverse logistics capability	Moderate adoption across industries	Circular logistics networks become standard business practice	Efficient reverse logistics supports recycling and circular economy performance.	Govindan <i>et al.</i> (2015)
Digital Transformation	AI and IoT adoption	Increasing adoption for routing, forecasting, and warehouse automation	Autonomous logistics supported by AI, blockchain, and digital twins	Digital infrastructure maximizes operational efficiency and sustainability performance.	McKinsey & Company (2024)
Social and ESG Performance	Green employment	Millions employed in renewable energy and sustainable logistics sectors	Continued growth in green jobs and sustainability-related skills	Green logistics contributes to ESG objectives and Sustainable Development Goals (SDGs 9, 11, 12, and 13).	International Labour Organization (2018)

The implications of the findings are different yet interrelated, both to the regulators and the operations. To policymakers, the moderating nature of the waste segregation and collection policy indicates that legislative efforts should shift from being overly aspirational regarding goals to becoming more enforceable through mechanisms such as mandatory household sorting, separate collection fleets, and extended producer responsibility schemes that hold manufacturers accountable for managing post-use materials. These interventions create the conditions necessary for effective recycling. To managers, they would be advised to consider the mediating effect of recycling efficiency, indicating that green logistics infrastructure cannot be perceived as an independent sustainability program but as the front end of a closed-loop system (**Table 11**). Companies should spend the same amount on processing facilities, collaboration with recyclers, and tracking of materials that turn returned products into useful outputs. The strategic implication is evident, as circular economy performance is not a spontaneous occurrence caused by only green investments or good intentions. It involves a concerted effort in which regulatory structures guarantee the quality and uniformity of material flows, and the value of such flows is seized by operational abilities. In the Pakistani case, a solution to this implementation gap would

open billions of dollars in economic value and legitimize the enormous informal workforce that keeps recycling alive using nothing but brute manual labor.

Limitations and Future Research

The study has several limitations that create gaps, which future research can address. To begin with, the cross-sectional design limits causal modeling and does not reflect the dynamic development of the green logistics infrastructure, recycling effectiveness, and circular economy effectiveness; the longitudinal or panel-based design should be implemented in future studies to investigate changes over time with a higher degree of rigor. Second, the use of self-reported survey data creates the potential of response and common-method bias; future research should triangulate such results with objective data of performance, e.g., audited recycling rates, data on emissions, and policy compliance history. Third, the situation being examined as a one-country setting and Pakistan-based restricts the generalizability of the results; comparative or multi-country research would be helpful in measuring the strength of the suggested relationships to a variety of institutional and regulatory settings. Lastly, the model is unable to explicitly apply the essential elements of behavioral, technological, or informal-sector factors critical to circular systems; further research may expand the model by adding digitalization, stakeholder involvement, and informal-recycling dynamics to facilitate a more holistic perspective of the performance of the circular economy.

Conclusion

This paper suggests that the development of a circular economic system in the developing setting is not facilitated by individual efforts but rather by the coordinated structuring of infrastructure, operations, and governance. The results demonstrate that the environment-based logistics systems generate concrete sustainability value when they are successfully transformed into workable recycling practices, which would allow achieving greater rates of material recovery and additional reuse of resources. Meanwhile, policy-based waste collection systems act as a determining factor in enhancing these impacts by guaranteeing the quality and permanence of recyclable material streams. Combined, the findings highlight that the concept of circular performance is the result of the combination of physical systems, operational strength, and institutional support and provide clear indicators that the coordinated investments and regulation will produce lasting environmental and economic benefits in economies that face resource limitations.

Declaration of Competing Interests

The authors confirm that there are no known conflicts of interest associated with this publication and that no significant financial support was received that could have influenced its outcome.

Participant Consent Statement

This study employed a survey-based quantitative research design involving human participants. In compliance with ethical research standards, the following consent procedures were implemented:

- 1. Informed Consent Process:** Before participation, all potential respondents received a detailed cover letter accompanying the questionnaire. This letter clearly outlined the purpose of the study, the nature of the questions, the estimated time required for completion, and the intended use of the data for academic publication and research purposes.
- 2. Voluntary Participation:** Respondents were explicitly informed that their participation was entirely voluntary. They were assured that they could decline to participate or withdraw from the study at any point without providing any reason and without facing any negative consequences.
- 3. Anonymity and Confidentiality:** To protect participant privacy, no personally identifiable information (such as names, employee numbers, or organizational details) was collected. All responses were anonymized during the data collection process. The data were stored in a secure, password-

protected database accessible only to the research team. The findings are reported in aggregate form only, ensuring that no individual respondent or organization can be identified.

4. Implied Consent: By completing and returning the questionnaire, respondents provided their implied consent to participate. This method was approved by the Institutional Review Board as appropriate for low-risk survey research. Contact information for the corresponding author was provided in the cover letter, allowing respondents to ask questions or request further information about the study at any time.

5. Data Usage: All data collected were used exclusively for scholarly purposes, including the preparation of this manuscript and related academic outputs. Data will be retained for a period of five years following publication and subsequently destroyed.

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This research did not receive any special grants from public, commercial, or not-for-profit agencies. The authors state that they did not receive any financial assistance in conducting the research, writing or publishing this article. The study was independent and unfunded, which could have affected its design, data collection, analysis, interpretation, and manuscript writing.

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Data Availability

The data used in this study are available from the corresponding author on request. The data are not publicly available due to confidentiality agreements with the respondents. The article contains measurement information to facilitate replication of the results.

Authors Contribution

S.T.: Conceptualization, research framework development, methodology, data analysis, interpretation of findings, and writing the original draft. S.A.K.: Methodology development, theoretical framework refinement, supervision, and critical review and editing of the manuscript. S.A.S.: Data management, manuscript revision, formatting, and proofreading. A.J.: Data collection and analysis on Smart PLS. F.A.O.: Statistical analysis, validation, interpretation of findings, and critical evaluation of the results.

Ethics-Human Participant

This research was carried out in accordance with the ethical norms and guidelines for research on human participants. All participants signed informed consent forms before data collection, and their confidentiality and anonymity were respected during the research. This study was done with consent, and the respondents were told they could leave at any time. There were no animals used in this study.

Ethical Approval

The study was carried out in an ethical way as per the academic standards of human studies. All the ethical principles associated with voluntary participation, informed consent, confidentiality and anonymity were adhered to throughout the study. Participants were made aware of the purpose of the research, and their responses were only for academic purposes. No animals were used for this research.

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