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Transport infrastructure environmental performance: the role of stakeholders, technological integration, government policies and lean supply chain management

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The recent past is characterized by heightened environmental awareness, enhancing the environmental performance of transportation infrastructure was of utmost importance. The central purpose of this study was to delve into and comprehend methods for improving the environmental performance of transportation infrastructure. It aimed to investigate three pivotal factors: engagement of stakeholders, integration of technology and formulation of government policies. Furthermore, the study emphasized exploring how Lean Supply Chain Management could act as a facilitator in accomplishing these enhancements. The study's approach involved a mediation analysis, utilizing quantitative methods to collect data from 89 construction firms operating in Pakistan. The customized questionnaire was employed to gather the necessary data, and employed random sampling techniques to select participants. The hypotheses were tested through partial least squares (PLS 4) analysis. The findings of this study highlighted that stakeholder, including government entities, private enterprises, and local communities, significantly shape the environmental outcomes of transport projects. It explored how technological integration influences environmental performance and assesses the effectiveness of current government policies in promoting sustainability. The study also examined the role of lean supply chain management practices. Implications stressed the importance of stakeholder collaboration, the integration of innovative technologies and policies, refining regulations for sustainability goals and adopting a holistic approach for enhancing overall environmental performance in the transport sector.

KEYWORDS

transport infrastructure, environmental performance, stakeholders' collaboration, technological integration, government policies, lean supply chain management

1 Introduction

Transport infrastructure is pivotal in our modern society, connecting people, goods, and services globally (Nwafor and Onya, 2019). However, as the world grapples with pressing environmental challenges, the need to enhance the environmental performance of this crucial infrastructure has become paramount. This study investigates the multifaceted landscape of improving transport infrastructure's environmental sustainability in this context. It investigates the pivotal role of stakeholders, the integration of cutting-edge technologies, and the influence of government policies, all facilitated by lean supply chain management principles (Zachariassen, 2023). The importance of adopting sustainability, called lean Supply Chain Management (LSCM), becomes clear in the face of inadequate environmental practices. LSCM incorporates environmentally responsible principles across the entire supply chain, including product design, material choices, manufacturing processes, product distribution to consumers, and managing products after use through strategies like reverse logistics (Dieste and Panizzolo, 2018).

Previous studies have presented inconsistent results regarding the driving elements for implementing an LSCM approach and its correlation with environmental effectiveness. Various research efforts, including those by (Rakhmawati et al., 2019; Zhu and Wu, 2022). Have underscored a favorable association between adopting LSCM and enhanced environmental performance. This association encompasses a combination of factors, both internal and external. On the external front, factors such as governmental regulations, collaboration with stakeholders, demands from the community, and consumer behavior influence this relationship, a point emphasized by (Rakhmawati et al., 2019; Cui et al., 2022). However, specific transport infrastructure ventures exhibit weak correlations between LSCM and environmental performance (Namagembe et al., 2019; Marusin et al., 2019) discovered limited connections in their research, primarily noting a relationship with internal environmental management. According to (Sharma et al., 2021), the pivotal drivers for LSCM are internal environmental management and governmental regulations (Diabat et al., 2013; Namagembe et al., 2016). Specifically mention their role in the automobile industry; they found that environmental regulations may not significantly predict LSCM adoption. These studies underscore the need for further research in stakeholder collaboration, environmental performance, technological integration, and government policies and regulations.

Studying and enhancing environmental performance in transport infrastructure, considering stakeholders, technology integration, government policies, and lean supply chains, faces multifaceted challenges. These include interdisciplinary complexity, technological integration hurdles, financial constraints, policy alignment difficulties, stakeholder coordination, supply chain optimization, socio-political acceptance, data collection demands, and ensuring long-term sustainability (Despoudi et al., 2021). Overcoming these challenges demands collaborative efforts, innovation, effective communication, and a steadfast commitment to sustainability across all stakeholders involved in the study.

This study is conducted for various reasons: Firstly, research in transport infrastructure often overlooks the stakeholders' roles (e.g., local communities, environmental groups, industry) in shaping environmental performance due to a focus on technology and government policies. Standardized metrics for environmental evaluation are lacking. Secondly, while technological integration is mentioned, there's potential for more in-depth exploration of innovations like electric vehicles, renewable energy, and smart transportation systems and their interaction with LSCM. Thirdly, government policies are pivotal, but further analysis of their implementation and impact on environmental sustainability within transport infrastructure is needed. Fourthly, investigating how LSCM facilitates environmental improvements and understanding context-specific dynamics in stakeholder involvement, technology integration, policy impact, and lean practices are important research areas.

This study aims to delve into ways to improve the environmental sustainability of transport infrastructure. Specifically, it seeks to understand how various factors, including stakeholders (such as government bodies, private companies, and local communities), technological advancements and integration, and government policies and regulations, influence the environmental performance of transport infrastructure. Furthermore, the study will investigate how the principles of LSCM can act as a mediator in this relationship.

Theoretical support for this research draws from several key theories. Stakeholder theory underscores the importance of considering the interests and influence of diverse stakeholders in organizational decision-making. This study forms the basis for comprehending how the engagement of stakeholders such as local communities, environmental groups, and regulatory bodies can impact the decision-making processes and environmental outcomes in transport infrastructure projects (Boaz et al., 2018). Additionally, the institutional theory examines how external factors, particularly government policies and regulations, act as external institutional pressures that shape these projects' environmental practices and overall performance (Lutfi et al., 2023). The "Technological Integration Theory" core aspect incorporates advanced technologies. This study would integrate smart transportation systems, electric vehicles, and sustainable construction materials into the transport

FIGURE 1
Lean supply chain management.

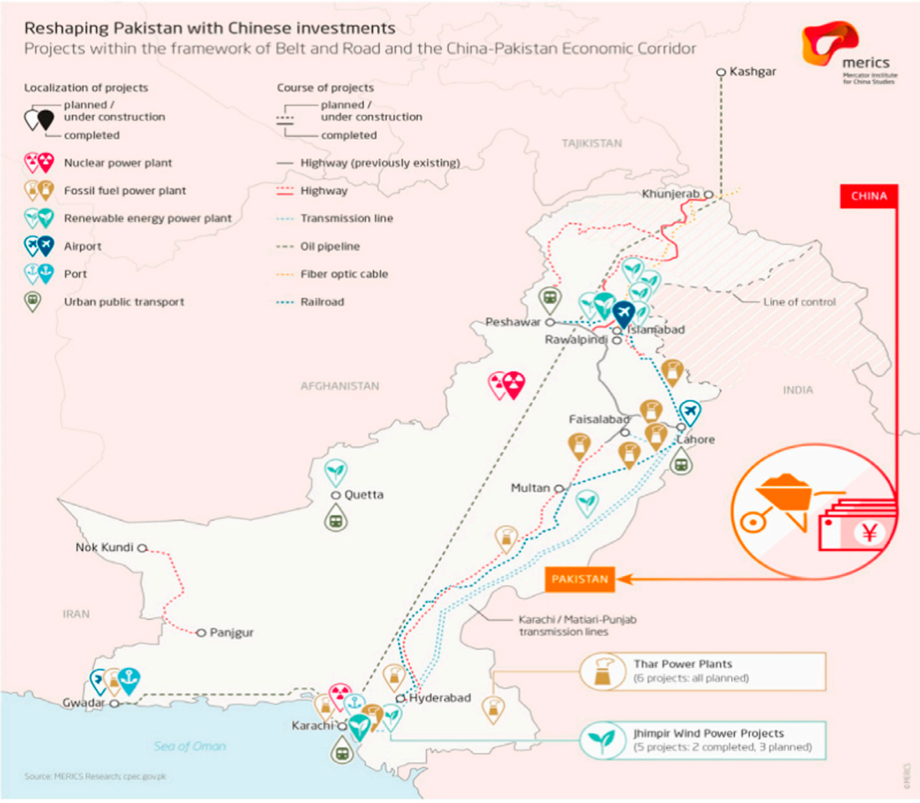

FIGURE 2
Transport infrastructure and industrial output in Pakistan.

infrastructure. This integration aims to improve environmental performance by reducing emissions, energy consumption, and overall environmental impact (Ghezzi et al., 2013).

This study on transport infrastructure's environmental performance is crucial due to its significant contribution to pollution, resource depletion, and greenhouse gas emissions. It aligns with sustainable development goals, offering long-term cost savings through energy-efficient systems. Meeting international commitments, like the Paris Agreement, is essential for combating urban pollution and promoting public health. This research explores technology adoption, stakeholder involvement, policy impact, and LSCM to reduce environmental impacts and enhance resilience to climate change.

Figure 1 shows lean supply chain management and Figure 2 shows transport infrastructure and industrial output in Pakistan.

2 Literature review and hypothesis development

2.1 Variables introduction

2.1.1 Lean supply chain management (LSCM)

LSCM is "the extension of traditional supply chains to include activities that aim to minimize environmental impacts of a product throughout its entire life cycle, such as green design, resource conservation, the reduction of harmful materials, and product recycling or reuse (Beamon, 1999). Green supply chains as highlighted (Larsen, 2017) involved the reuse, re-manufacturing, and recycling of goods and resources along a conventional forward supply chain. LSCM is a strategy aimed at minimizing inefficiencies, reducing waste, and optimizing the overall performance of the supply chain. It integrates lean principles across the entire supply chain, aiming to eliminate activities that do not add value, decrease inventory, and enhance the smooth flow of both goods and information (Srivastava, 2007). LSCM emphasizes minimizing waste, cutting costs, and boosting efficiency throughout the supply chain. This approach involves streamlining processes, reducing excess inventory, and enhancing the seamless flow of goods and services (Cudney and Elrod, 2011). LSCM is "the integration of environmental thinking in managing the supply chain, including product design, source and material selection, manufacturing processes, final product delivery to consumers, and management of the product at its end of life," as stated by (Srivastava, 2007).

2.1.2 Stakeholder collaboration (SC)

As defined by (Corazza et al., 2023), Stakeholders in construction projects are people or organizations that might influence or be influenced by the project. Clients, sponsors, buyers, investors, contractors, suppliers, users, small and medium-sized businesses, third parties, governmental organizations, and regulators are all included in this category. Effective collaboration among these stakeholders is crucial for collectively addressing complex issues, as emphasized by (Gray, 1985). Within projects, collaboration is critical in managing internal complexities to align with external challenges and disruptions (Roberts and Bradley, 1991). Project collaboration progresses through different stages involving varying stakeholder engagement and considerations, influenced by the project lifecycle (Pinto and Prescott, 1988). Effective collaboration with stakeholders leads to improved information sharing, faster decision-making, and goal alignment, which is crucial for implementing lean supply chain practices (Hines et al., 2004).

2.1.3 Technological integration (TI)

Technological integration incorporates various organizational technologies and systems to improve efficiency and effectiveness (Christopher et al., 2004). Technology integration in supply chain management automates tasks, reduces errors, and enhances efficiency. Integrating technologies like RFID, IoT and advanced tracking systems improves the efficiency of lean supply chain practices, offering real-time insights into goods' movement. This technological integration is a key focus for evaluating how lean supply chain management optimizes processes, reduces waste, and enhances environmental performance in the transport sector's (Gupta et al., 2022). This real-time data supports lean supply chain management by improving demand forecasting, optimizing inventory, and enabling rapid response to disruptions. Technology also fosters better communication and collaboration among supply chain stakeholders, reducing lead times and enhancing overall operations (Ivanov et al., 2019). Analyzing demand, supplier performance, and production efficiency data helps identify improvement opportunities and implement lean strategies (Garavito-Camargo et al., 2021). Technology can assist in shortening lead times through optimized scheduling, predictive analytics, and faster information sharing. Reduced lead times contribute to lean practices by minimizing waiting times and enhancing responsiveness (Yan et al., 2019).

2.1.4 Government policy and regulation (GPR)

Stringent environmental regulations drive companies to embrace lean practices, reducing waste, optimizing energy use, and enhancing resource efficiency (Fernando and Wah, 2017). Labor rights, safety, and wage regulations impact supply chains, motivating organizations to implement lean practices to ensure compliance and efficiency (Wright and Kaine, 2015). Government policies, including trade regulations and tariffs, influence sourcing and transportation decisions in lean supply chains. Regulations on product quality, safety, and standards drive the adoption of lean practices to ensure consistency, reduce defects, and satisfy customers. Some governments offer incentives for sustainable supply chain practices, motivating companies to align with these goals. Government investments in infrastructure, like transportation networks and digital connectivity, can improve supply chain efficiency (Fernando and Wah, 2017; Wright and Kaine, 2015).

2.1.5 Transport infrastructure environmental performance (TIEP)

The environmental performance of transport infrastructure refers to how transportation systems, including roads, bridges, railways, airports, ports, and associated facilities, impact the environment. It encompasses various aspects related to sustainability, resource conservation, emissions reduction, and the mitigation of negative environmental effects (Correia, 2015). Transport infrastructure environmental performance refers to evaluating and measuring transportation infrastructure systems' environmental impact and sustainability (Khan et al., 2020). Transport infrastructure environmental performance pertains to designing, operating, and maintaining transportation systems to minimize their adverse environmental impacts (Sarkis et al., 2021). Environmental sustainability minimizes construction waste, reduces natural resource consumption using new technologies, and reduces the material demand and energy required to transform goods and supply services (Asghar et al., 2022). Improving the environmental performance of transport infrastructure is essential for mitigating climate change, reducing pollution, conserving natural resources, and creating more sustainable and livable urban environments. It requires a holistic approach that considers the entire life cycle of infrastructure projects and their interactions with the environment (Dunn, 2010).

3 Hypotheses formulation and research model

3.1 SC and LSCM

Collaboration with suppliers in a lean supply chain is crucial; it helps in optimizing inventory by reducing the need for companies to stockpile excessive inventory as a precaution against unpredictable demand or supply disruptions, which can tie up valuable capital and lead to various forms of waste, it plays a significant role in reducing waste across the supply chain, addressing issues like overproduction, excess inventory, defects, and unnecessary transportation (Vachon et al., 2009). Collaborative customer interactions in a lean supply chain enhance demand forecasting, enabling companies to adjust production and inventory based on real-time customer insights, thereby supporting proactive planning. It can reduce supply chain costs by improving forecasts and aligning production with demand, resulting in savings in inventory, transportation, and production expenses, ultimately creating a leaner and more cost-effective supply chain (Towill and Christopher, 2002). Implementing lean practices requires effective collaboration across procurement, production, and logistics (Pagell and Wu, 2009). Across the supply chain, collaboration among stakeholders, including suppliers, manufacturers, distributors, retailers, and customers, is critical for achieving a well-functioning supply chain. Such efforts promote better communication, goal alignment, and information sharing, which are essential for lean principles (Rich and Hines, 1997). These collaborative efforts lead to benefits like reduced lead times, improved inventory management, enhanced product quality, and greater responsiveness to customer demand, aligning with the goals of LSCM (Narasimhan and Kim, 2002). Collaboration is seen as beneficial, its effectiveness can depend on various factors, including the industry, specific supply chain characteristics, and the nature of the collaboration itself. Based on these, we can hypothesize that:

Hypothesis 1. Stakeholder collaboration is positively associated with LSCM.

3.2 TI and LSCM

LSCM advancements align with the continuous improvement principle in lean management, allowing companies to refine processes, eliminate waste, enhance productivity, and deliver more value to customers while reducing costs (Núñez-Merino et al., 2020). Automation, including robotic systems, minimizes human intervention and streamlines tasks like material handling and order processing, reducing labor costs. This integration aligns with lean principles, emphasizing waste reduction and process improvement, ultimately enabling rapid, reliable, cost-effective product delivery to meet customer demands (Aitken et al., 2002). Data-driven approaches, enabled by technology, boost operational efficiency by leveraging data analytics for accurate forecasting, efficient inventory management, and informed decision-making, fostering lean operations, reducing costs, and enhancing competitiveness (Sanders, 2014). Cutting-edge communication tools facilitate instant interaction among partners in the supply chain, improving coordination, shortening lead times, and enabling swift responses to changes in demand or supply (Taboada and Shee, 2021). The fostering of closer relationships between suppliers and manufacturers is facilitated through collaborative technological integration, leading to the synchronization of production schedules, decreased inventory levels, and an overall enhancement in supply chain performance (Narasimhan and Kim, 2002). Based on these, we can hypothesize that:

Hypothesis 2. Technological integration is positively associated with LSCM.

3.3 GPR and LSCM

Lean practices often rely on seamless and fast movement of goods, which can be facilitated by well-developed infrastructure (Mollenkopf et al., 2010). Government regulations are crucial in ensuring the safety and quality of products and services across various industries. By implementing lean principles, organizations can streamline their operations, eliminate waste, and optimize resource utilization, which in turn helps minimize defects in their products or services. This improved efficiency and transparency lead to compliance with government regulations and foster a culture of continuous improvement within the organization, ultimately benefiting the company and its customers (Famiyeh et al., 2018). Government regulations play a crucial role in upholding safety and quality standards in industries. Implementing lean practices is instrumental for companies to meet these standards by minimizing waste, boosting efficiency, and elevating product quality. Additionally, lean principles underscore the importance of documentation and process control, thereby improving product traceability. This comprehensive approach not only ensures compliance with regulations but also nurtures a culture of continuous improvement, benefiting both the organization and its customers (Torielli et al., 2011). Government regulations related to labor and employment can influence workforce management practices within the supply chain. Lean principles emphasize the value of a skilled and motivated workforce, aligning with regulations that promote fair labor practices (Jaehrling et al., 2018). Based on these, we can hypothesize that:

Hypothesis 3. Government policy and regulations are positively associated with LSCM.

3.4 LSCM and TIEP

Transport infrastructure encompasses systems like roads, railways, ports, and airports, facilitating the movement of goods and people. When integrated with environmental considerations in designing closed-loop supply chain networks, lean principles may shed light on the potential positive association between lean practices and environmental performance (Xu et al., 2020). LSCM aligns with environmental concerns and has become a global trend focused on resource conservation and environmental protection (Sarkis et al., 2021). Globalization and environmental consciousness have driven businesses to improve their environmental performance by adopting energy-efficient transportation practices. It involves reducing energy consumption, enhancing fuel efficiency, and exploring alternative transportation methods to reduce greenhouse gas emissions (Takacs, 2022). Advanced logistics systems also enhance supply chain visibility and enable timely adjustments to delivery schedules, leading to improved efficiency and sustainability in the logistics industry (Alsrehin et al., 2019). Embracing eco-friendly fuel alternatives like bio fuels or hydrogen and investing in cutting-edge propulsion technologies such as fuel cells and electric propulsion systems can play a significant role in enhancing the energy efficiency of transportation (Melton et al., 2016; Cunanan et al., 2021). The adoption of energy-efficient transportation practices, whether by individuals, businesses, or governments, results in a substantial reduction in environmental impact. This is achieved through the lowering of carbon emissions, conservation of energy resources, and the promotion of a greener and more sustainable transportation system (Godil et al., 2021). Based on these, we can hypothesize that:

Hypothesis 4. LSCM is positively associated with transport infrastructure environmental performance.

3.5 SC and TIEP through LSCM

Stakeholder collaboration involves cooperation and engagement among parties interested in or affected by a particular project or initiative. In transport infrastructure, stakeholders could include government agencies, local communities, environmental organizations, businesses, and more (Lindholm and Browne, 2013). Applying lean principles promotes waste reduction, process optimization, and efficiency, reducing construction timelines and costs while cutting energy consumption. Furthermore, focusing on sustainability under lean principles minimizes environmental impact by reducing waste generation, conserving resources, and using eco-friendly construction methods, aligning with economic and ecological objectives (Reyes et al., 2021). Collaboration can result in designs considering reduced energy consumption, lower emissions, and efficient resource utilization (Kiker et al., 2005). Engaging with stakeholders in collaboration can extend beyond the initial planning phase, encompassing continuous monitoring and feedback collection. This iterative feedback loop serves to pinpoint areas for improvement, guiding adjustments to both construction and operational practices and thereby contributing to an even greater enhancement of environmental outcomes (Schuett et al., 2001). The collaboration with stakeholders fosters transparency and accountability in project execution, promoting improved adherence to environmental regulations and a dedicated commitment to sustainable practices across the entire project lifecycle (Salvioni and Almici, 2020). The hypothesis suggests that stakeholder collaboration can positively impact transport infrastructure environmental performance by applying LSCM principles. Based on these, we can hypothesize that:

Hypothesis 5. Stakeholder collaboration positively relates to transport infrastructure environmental performance through LSCM.

3.6 TI and TIEP through LSCM

Evidence shows that technology can positively impact environmental performance by enabling better monitoring, optimization, and control of processes (Christopher et al., 2004). Lean supply chain management focuses on minimizing waste and increasing efficiency throughout the supply chain. This approach can reduce resource consumption, energy use, and emissions, improving environmental performance. Transport infrastructure might involve using advanced technologies for monitoring, optimizing routes, managing traffic, and more (Pagell and Wu, 2009). In the transport infrastructure, lean supply chain management could optimize logistics, minimize idle times, and reduce unnecessary emissions (Ivanov et al., 2019). It relates to how well a transportation system or network performs regarding its environmental impact. It can include carbon emissions, energy efficiency, air and noise pollution, and overall sustainability (Schwartz et al., 2020). Technological integration in the context of transportation can contribute to better traffic management, reduced fuel consumption, and more efficient transportation operations (Chen et al., 2022). Enhancing the environmental sustainability of transportation operations can be achieved through the utilization of real-time data, optimization algorithms, and streamlined processes (Li et al., 2020). The integration of technology and the adoption of lean supply chain management practices in transport infrastructure systems would enhance the environmental performance of the infrastructure. Streamlined processes, improved resource utilization, and enhanced monitoring have the potential to significantly reduce environmental impact. Based on these, we can hypothesize that:

Hypothesis 6. Technological integration positively relates to transport infrastructure environmental performance through LSCM.

3.7 GPR and TIEP through LSCM

Government interventions are crucial in shaping environmental practices and standards within industries. Policies may include emission limits, sustainability goals, or incentives for eco-friendly practices (Hou et al., 2023). Achieving high environmental performance requires a holistic approach, considering not just initial construction and operation but also long-term sustainability and impact mitigation (Ibanez et al., 2016). LSCM involves optimizing the supply chain processes to minimize waste, reduce resource consumption, and improve efficiency (Dües et al., 2013). Transport infrastructure significantly influences overall environmental performance, directly impacting energy consumption and emissions. The government can effectively oversee corporations by exerting influence over their internal and external resources (Nezakati et al., 2016). According to (Coenen et al., 2021), governmental regulations concerning environmental concerns encompass rules binding for all entities involved across a company's complete supply chain. Prior research, such by (Handayani et al., 2022), has affirmed that government regulation plays a substantial role in steering established enterprises' LSCM. Government policies might provide incentives or require the adoption of logistics and supply chain management practices to mitigate environmental impact, thereby enhancing the environmental performance of the transport infrastructure sector (Tate et al., 2010). The hypothesis suggests a positive relationship between government policies and regulations and the environmental performance of transport infrastructure. It also implies that this relationship is mediated or facilitated by implementing LSCM practices within the transportation sector. Based on these, we can hypothesize that:

Hypothesis 7. Government policy and regulation positively relates to transport infrastructure environmental performance through LSCM.

3.8 Research model

The research model is shown in Figure 3.

The research model is substantiated through its emphasis on vital environmental concerns, robust theoretical underpinnings, integration of stakeholder engagement, acknowledgment of technological integration, awareness of government policies, incorporation of LSCM, a comprehensive viewpoint, and tangible, practical implications. It offers a valuable framework for exploring ways to make transport infrastructure projects more environmentally sustainable.

4 Research design

4.1 Sample size and data collection

This research project focused on gathering information from employees within construction firms situated in Pakistan. The methodology involved a survey conducted across 89 construction companies, carefully chosen from a comprehensive database maintained by Pakistan's Registrar's Department. Specificity in this context researcher ensures accuracy, transparency and accountability. Knowing the exact number of construction firms allows for a more precise understanding of the construction

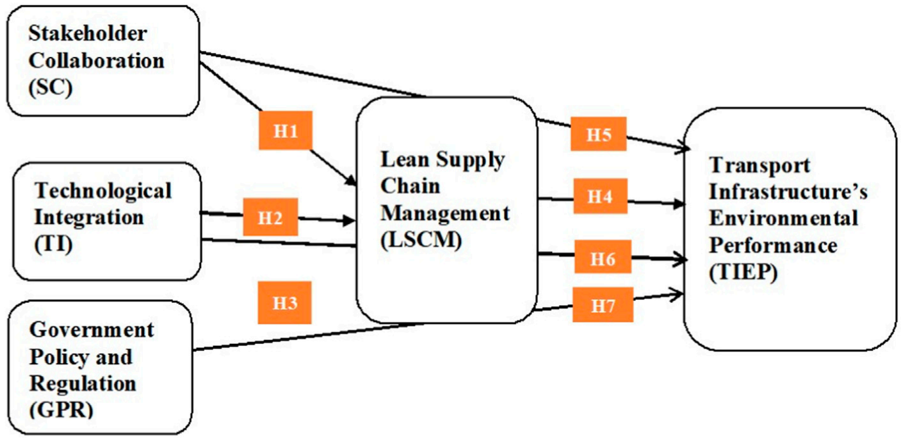

FIGURE 3
Research Model.

landscape, facilitating effective policy-making, resource allocation and regulatory oversight. 89 construction companies were selected that are appropriate for this study. The database contains extensive information about numerous construction-related firms, totaling 250 to 300. The database is dynamic and subject to changes over time due to the entry or exit of construction firms. Out of these, 89 companies were willing to participate in the research. Data collection was facilitated through the distribution of questionnaires and accompanying letters outlining the academic objectives of the study via Google Forum. The respondents were allotted 1 month, from May 18th to 18 June 2023, to complete and submit their responses.

Additionally, we implemented a system of regular reminder messages at 5-day intervals, starting after the first 15 days, to encourage timely participation. 260 questionnaires were distributed, resulting in 217 responses, indicating a significant level of engagement in the survey. Out of 217 collected questionnaires, 206 met the inclusion criteria after applying outlier detection methods (Meyer, 2005). An outlier is an observation that significantly deviates from the rest of the data and may indicate an anomaly or error. 11 questionnaires were incomplete and incorrectly filled out. At the end of the data collection period, we received 206 completed questionnaires, representing 79% of the entire population of construction firms. This response rate is considered sufficient for management research purposes, as existing literature recommends a minimum response rate of 20% (Agyabeng-Mensah et al., 2020). Table 1 displays the demographic information of the survey participants.

4.2 Measures and questionnaire

This study utilizes a quantitative research methodology to explore the environmental performance of transportation infrastructure projects in Pakistan. The analysis relies on quantitative techniques, specifically employing PLS-SEM is a robust measurement method that offers advantages because it can handle intricate relationships among variables without requiring specific scale measurements or a large sample size. The Likert scale is employed for questionnaire assessment and Smart-PLS 4 software is used for data analysis. These instruments analyze the connections between variables inside the structural sub-model (inner model) and the validity and reliability of the measurement sub-model (outer model). Google Forum is used to disseminate the survey, with five response options on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree). For information on the origins of the measuring instruments, see Table 4.

4.3 Common method bias, missing outlier, non-response bias, social desirability and multicollinearity

Initially, 6 responses were identified as outliers. Still, it was found that these outliers originated from a group of 11 questionnaires that were either improperly filled out or incomplete, accounting for more than 5% of missing data (Haier, 2001). Consequently, these incomplete questionnaires were excluded from the analysis. Therefore, the final datasets for analysis consisted of 206 fully completed and correctly filled questionnaires. We followed procedural recommendations to address potential common method bias (CMB) concerns (Podsakoff et al., 2012). Our approach prioritized participant confidentiality and anonymity, discouraging insincere responses and reducing the potential for CMB. Furthermore, we followed the guidance of (Podsakoff et al., 2012) by conducting Harman's single-factor test to evaluate CMB within our dataset. The test results verified the insignificance of CMB, as the variance explained by a single factor was less than 50%. Additionally, we gauged multicollinearity using Variance Inflation Factor (VIF) values. All VIF values for the variables were below 5, indicating that multicollinearity was not a concern in this study, as presented in Table 2. Researchers utilized strategies to mitigate social desirability bias in this study, including anonymous questionnaires, employing neutral language in questions, emphasizing participant confidentiality, avoiding hinting at desired responses, and implementing pilot testing to identify and address bias-related issues.

TABLE 1 Demographics of the participants.

Respondent's profile	Construct and items	Frequency	%Age
Job Title	Project Managers	46	22.3
	Environmental Experts	33	16
	Supply Chain Managers	54	26.2
	Stakeholders	37	18
	Government policymakers	36	17.5
Gender	Male	173	84
	Female	33	16
Age	25–30	56	27.1
	31–35	48	23.4
	36–40	58	28.1
	41–45	44	21.4
Education	Bachelor	52	25.3
	Masters	123	59.7
	Doctorate	31	15
Job Experience	Less than 5 years	35	16.9
	6–10 years	76	36.9
	11–15 years	52	25.4
	More than 15 years	43	20.8
No. of Employees	Less than 20 workers	45	21.8
	21–30	70	34
	31–40	52	25.2
	41–50	39	19
Company Years of Working	Less than 5 Years	31	15
	5–10 Years	79	38.4
	11–15 Years	57	27.6
	15-above Years	39	19

Note: The table above presents the respondent's profile and demographic factors regarding construct and items, frequency, and percentage.

4.4 Data analysis

The study employs the PLS-SEM technique, following the guidelines outlined by (Hair et al., 2013) to analyze the data and evaluate the hypotheses. PLS-SEM is well-suited for both exploratory and predictive studies, a point emphasized by (Risher and Hair, 2017) leading to its increased adoption in management research, as observed by (Peng and Lai, 2012). This investigation uses a first-order reflective model to explore the relationships between different constructs. This approach requires a meticulous assessment of the measurement items' reliability and validity, a process detailed by (Henseler, 2017a). Initially, the measurement model is rigorously scrutinized to verify the reliability and validity of the measurement scales. This evaluation involves applying the partial least square algorithm to a dataset of 300 samples, as recommended by (Henseler, 2017b). The structural model entails hypothesis testing and is then examined to validate the constructs' relationships. This validation is achieved through bootstrapping, employing a sub-sample size of 5,000. The specific steps in this analysis are elucidated in the subsequent sections for clarity. The thresholds utilized for conducting these analyses are outlined in Table 3 for easy reference.

4.5 Assessment of the measurement model

The internal consistency and convergent validity assessments suggest a robust measurement model. The decision to retain items with slightly lower factor loadings should prompt researchers to carefully consider the implications of this choice and explore avenues for refinement in future studies. Overall, the findings contribute to the validation of the measurement instrument, but

TABLE 2 Variance inflation factor (VIF).

Constructs	VIF	Constructs	VIF
GPR1	2.244	SC6	1.814
GPR2	3.095	TI1	3.081
GPR3	2.291	TI2	2.176
GPR4	2.582	TI3	1.988
GPR5	2.476	TI4	2.056
GPR6	2.451	TI5	1.553
LSCM1	2.323	TI6	2.265
LSCM2	2.48	TIEP1	2.9658
LSCM3	2.6325	TIEP2	2.307
LSCM4	2.096	TIEP3	2.357
SC3	1.907	TIEP4	2.3145
SC4	1.79	TIEP5	2.6423
SC5	2.122		

Note: Variance Inflation Factor (VIF) values are provided for each construct in the table.

ongoing scrutiny and refinement are advisable for continued model improvement.

The internal consistency reliability is assessed using Cronbach's alpha and composite reliability (Henseler, 2017a). The Cronbach's alpha (0.920–0.919) and composite reliability (0.934–0.904) values are noticeably higher than the advised standards of >0.70 and >0.70, respectively. The range of average variance extracted (AVEs) values used to determine convergent validity is between 0.703 and 0.757, above the advised threshold of >0.50, as proposed by (Hair et al., 2013). While some factor loading (ranging from 0.654 to 0.906) are below the minimum threshold of ≥0.708, according to (Hair et al., 2019), the decision is made to retain items with loadings exceeding 0.600, as they contribute to enhancing the validity and robustness of the model. Table 4 presents the values for composite reliability, factor loading, AVEs, and Cronbach's alpha.

Then, using the Fornell-Larcker criteria and the Heterotrait-Monotrait Ratio (HTMT), we assess the model's discriminant validity. The Fornell-Larcker criteria are based on the idea that average variance extracted (AVE) square roots should be greater than correlations across model components. Table 5's data show that the model satisfies the Fornell-Larcker requirement, proving its discriminant validity.

Meeting the Fornell-Larcker criteria and HTMT are crucial for establishing discriminant validity in a measurement model. The implications include increased confidence in construct purity, reduced risk of measurement error, enhanced model credibility and improved interpretability of the structural relationships within the model.

Additionally, in line with the methodology described by (Henseler, 2017a), we employ HTMT, ratios to assess the discriminant validity of the model. The HTMT, ratios we observed, ranging from 0.129 to 0.532, indicate that the constructs GPR, LSCM, SC, TI, and TIEP, all demonstrate discriminant validity. These ratios comfortably remain below the accepted threshold of 0.85, as outlined. For detailed results, please refer to Table 6.

R-squared (R^2) measures how well independent variables explain the variation in the dependent variable, ranging from 0 (no explanation) to 1 (perfect explanation). In our analysis, LSCM, R^2 of 0.258 explains 25.8% of the variance, while TIEP, R^2 of 0.349 explains 34.9% (Falk and Miller, 1992). Adjusted R-squared corrects for adding unnecessary variables, yielding a lower value when more variables are included. In Table 7, the adjusted R-squared is slightly lower for both models, reflecting the penalty for unnecessary variables.

A low R^2 value underscores the need for a cautious interpretation of the model's findings, encourages further investigation into unaccounted factors and prompts continuous refinement to enhance the model's explanatory capabilities.

Q2 values for LSCM and TIEP, which are 0.321 and 0.372, respectively, are all greater than 0. These findings align with established criteria. The SRMR (Standardized Root Mean Square Residual) suggests that both the saturated and estimated models have a similar level of fit in explaining observed correlations, with an SRMR of 0.102 for both models (Hu et al., 1999). Additionally, d_ULS and d_G statistics, which assess goodness of fit, show minor differences (4.535 vs. 4.521 for d_ULS and 6.918 for both models in d_G) between the saturated and estimated models (Wetzels et al., 2009). The Chi-square values, which evaluate the data's fit to the model, are large for both models but very close (13,946.853 vs. 13,937.922), indicating similar fits. Finally, the NFI (Normed Fit Index) values are also close (0.316 vs. 0.317) for both models, indicating a similar level of fit relative to a baseline model (Hair et al., 2019).

4.6 Assessment of the structural model (testing of hypotheses)

The assessment of the structural model through hypothesis testing is a fundamental process in scientific research, as it helps

TABLE 3 Measurement criteria thresholds.

Measurement criteria	Recommended threshold	Measurement criteria	Recommended threshold
Factor loading (Henseler, 2017b)	>0.70	HTMT ratio (Hair et al., 2013)	<0.85
Composite reliability (Henseler, 2017b)	>0.70	*p*-value (Betensky, 2019)	<0.05
The average variance extracted (Rodgers and Pavlou, 2003)	>0.50	VIF (Kock, 2015)	<3.3
Cronbach's alpha (Henseler, 2017b)	>0.70		

Note: The table presents the recommended threshold values for various measurement criteria.

TABLE 4 Measurement properties of reflective construct.

Construct	Items		Factor loading	α	AVEs	CR	Items source
GPR	GPR1	Government policies play a significant role in encouraging environmentally responsible practices in transport infrastructure	0.836	0.920	0.703	0.934	Mathiyazhagan et al. (2014), Shibin et al. (2018)
	GPR2	Well-defined government policies contribute to integrating green technologies and practices in the transportation sector, enhancing environmental performance	0.895				
	GPR3	Government regulations effectively encourage the adoption of energy-efficient and low-emission transport systems, thus reducing the overall environmental impact	0.834				
	GPR4	Government authorities' enforcement of strict environmental standards significantly influences transport infrastructure projects to prioritize sustainability and environmental responsibility	0.841				
	GPR5	Government policies encourage the adoption of lean principles and practices within supply chain operations	0.848				
	GPR6	Government incentives and subsidies positively influence organizations to adopt lean supply chain practices	0.773				
LSCM	LSCM1	In your opinion, to what extent does Lean Supply Chain Management mediate the relationship between efficient supply chain processes and enhanced environmental performance of transport infrastructure?	0.738	0.882	0.627	0.909	Tortorella et al. (2017), Moyano-Fuentes et al. (2019)
	LSCM2	How do you perceive Lean Supply Chain Management practices to positively influence your organization's transport infrastructure's environmental performance?	0.852				
	LSCM3	How well do you believe that LSCM practices contribute to minimizing resource waste and emissions in your transport infrastructure projects?	0.738				
	LSCM4	Does Lean Supply Chain Management (LSCM) facilitate better collaboration and communication among stakeholders involved in transport infrastructure projects to achieve environmental performance goals?	0.878				
	LSCM5	How much do you think LSCM practices influence the reduction of carbon footprint and energy consumption in your transport infrastructure supply chain?	0.866				
	LSCM6	Integrating stakeholders, advanced technology, government policies, and lean supply chain management positively contributes to enhancing the environmental performance of transport infrastructure	0.654				
SC	SC1	Collaborating with stakeholders, such as government bodies, communities, and industry organizations, positively impacts the development and sustainability of transport infrastructure	0.731	0.863	0.571	0.888	Gericke et al. (2019)
	SC2	Engaging stakeholders in the decision-making process for transport infrastructure projects leads to more environmentally sustainable choices	0.665				
	SC3	Collaborative efforts with stakeholders contribute to identifying and implementing effective environmental mitigation measures in transport infrastructure projects	0.726				
	SC4	How much do you agree with the statement that collaboration with stakeholders, such as suppliers and partners, contributes to the efficiency of a lean supply chain?	0.707				
	SC5	How important do you consider stakeholder involvement in identifying and eliminating waste within the supply chain in a lean context?	0.819				
	SC6	Transport infrastructure projects should involve active participation from diverse stakeholders to achieve better environmental outcomes	0.868				

(Continued on following page)

TABLE 4 (*Continued*) Measurement properties of reflective construct.

Construct	Items		Factor loading	*α*	AVEs	CR	Items source
TI	TI1	Technological integration can improve the efficiency of transport infrastructure, leading to reduced environmental impacts	0.850	0.871	0.607	0.902	Naway and Rahmat (2019), Consoli et al. (2023)
	TI2	Integrating advanced technologies in transport infrastructure is essential for achieving sustainable environmental goals	0.828				
	TI3	Technological integration is crucial for optimizing supply chain processes and reducing waste in the supply chain	0.797				
	TI4	Technological integration in transport infrastructure is crucial for promoting eco-friendly transportation options	0.778				
	TI5	Adopting advanced technologies facilitates better demand forecasting and planning, promoting lean inventory management in the supply chain	0.649				
	TI6	To what extent do you believe that technological integration positively affects the environmental performance of transport infrastructure?	0.756				
TIEP	TIEP1	Integrating sustainability goals and objectives into transport infrastructure development can significantly enhance environmental performance	0.816	0.919	0.757	0.904	Ghosh et al. (2022), Khaskheli et al. (2023)
	TIEP2	Encouraging public transportation is an effective strategy to reduce environmental impact and enhance the sustainability of transport infrastructure	0.906				
	TIEP3	Implementing renewable energy sources (e.g., solar, wind) into transport infrastructure contributes positively to its environmental sustainability	0.816				
	TIEP4	Using eco-friendly materials and technologies in transport infrastructure construction and maintenance is vital for improving its environmental performance	0.904				
	TIEP5	How much do you agree that a combined approach involving stakeholder engagement, technological integration, and supportive government policies is optimal for achieving sustainable environmental performance in transport infrastructure?	0.904				

researchers determine whether their proposed theories or models are consistent with observed data. The structural model and the proposed connections as depicted in Figure 4.

4.7 Results

The study investigates the interconnections between GPR, LSCM, SC, TI, and TIEP. We examined these relationships for statistical significance, using a significance level of less than 0.05. Initially, we assessed the significance of the direct links between GPR, LSCM, SC, TI, and TIEP. The analysis results confirmed hypotheses H1, H2, H3, H4, H5, H6 and H7 Tables 5, 6.

The results suggest a strong and positive association between SC and LSCM, confirming our initial Hypothesis H1 ($\beta = 0.139$, $t = 4.381$, $p = 0$). Furthermore, TI demonstrates a notable and beneficial impact on LSCM, supporting our Hypothesis H2 ($\beta = 0.128$, $t = 4.265$, $p = 0$). Additionally, the findings uphold Hypothesis H3 ($\beta = 0.395$, $t = 9.392$, $p = 0$), affirming that GPR is significantly and positively related to LSCM. Likewise, Hypothesis H4 is validated ($\beta = 0.363$, $t = 11.351$, $p = 0$), indicating a meaningful and positive relationship between LSCM and TIEP. For additional insights into the direct effects, please refer to Tables 7, 8.

The results demonstrate support for hypotheses H5 ($\beta = 0.069$, $t = 2.151$, $p = 0.000$), H6 ($\beta = 0.115$, $t = 3.716$, $p = 0.000$) and H7 ($\beta = 0.136$, $t = 5.156$, $p = 0.000$) confirming the presence of mediating effects of H5 LSCM between SC and TIEP and H6 shows the mediating effect of LSCM between TI and TIEP also H7 shows the mediating effect of GPR and TIEP through LSCM. Table 9 provides comprehensive information on the indirect pathways (mediating effects) connecting SC, TI, and GPR via LSCM on TIEP.

5 Discussions of findings

5.1 Direct effect

The study's findings indicate that SC has a noteworthy and favorable impact on LSCM. It validates the study's initial hypothesis (H1 in Table 8). The study conducted by (Kitsis and Chen, 2021) analyzed several companies to investigate the impact of stakeholder engagement on lean supply chain performance; the study's findings revealed a strong positive association between effective collaboration with stakeholders and improved performance in LSCM (Agyabeng-Mensah et al., 2022). Discovered a strong and meaningful correlation

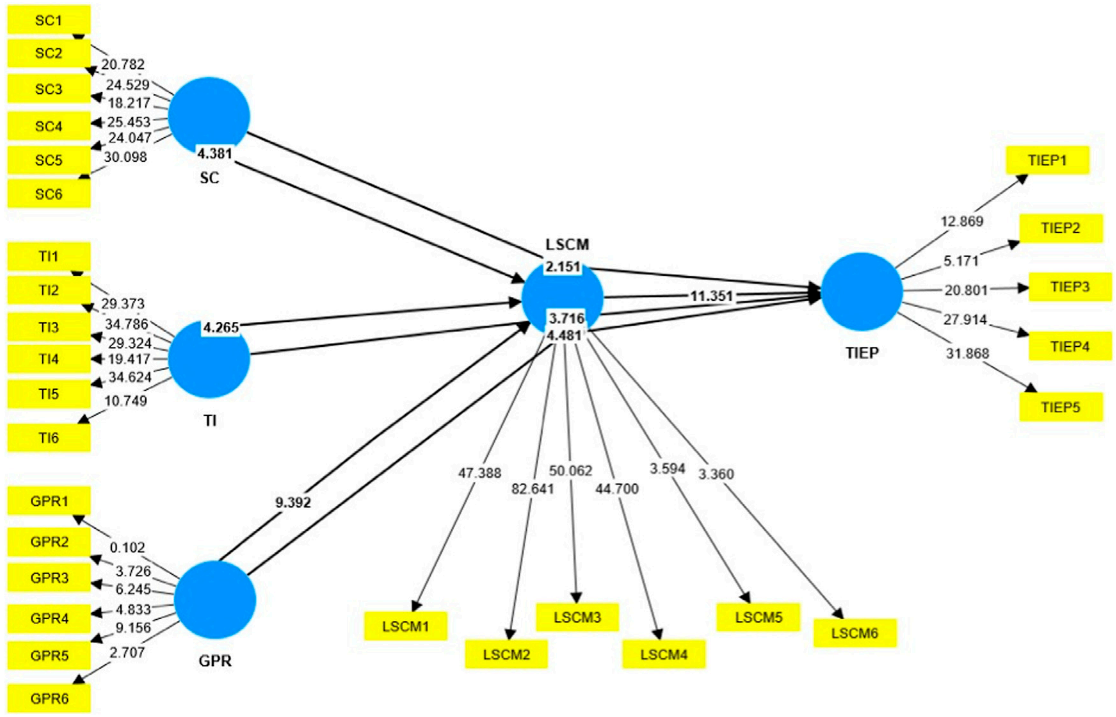

FIGURE 4
SEM analysis results with bootstrapping.

TABLE 5 Fornell–Larcker criterion.

Constructs	GPR	LSCM	SC	TI	TIEP
GPR	**0.838**				
LSCM	0.466	**0.792**			
SC	0.267	0.247	**0.756**		
TI	0.417	0.294	0.192	**0.779**	
TIEP	0.196	0.502	0.155	0.287	**0.87**

The bold and diagonals values are the square root of AVE values.

TABLE 6 Heterotrait–monotrait ratio (HTMT).

Constructs	GPR	LSCM	SC	TI	TIEP
GPR					
LSCM	0.451				
SC	0.296	0.225			
TI	0.418	0.327	0.233		
TIEP	0.176	0.532	0.129	0.306	

between active stakeholder engagement and the advancement of LSCM, supported by statistical evidence. Their study involved analyzing data from a cohort of companies over 5 years to investigate how integrating stakeholders is linked to developing efficient supply chain practices.

The study's findings indicate that TI has a noteworthy and favorable relation to LSCM. It validates the study's initial hypothesis (H2 in Table 8). (Ding et al., 2023) conducted an empirical analysis to explore the relationship between technological advancements and LSCM. The results demonstrated a significant positive association between the level of TI and the efficiency and effectiveness of LSCM practices. Another research reinforces this idea, emphasizing a strong and

TABLE 7 R-square and R-square adjusted.

	R-square	R-square adjusted
LSCM	0.258	0.256
TIEP	0.349	0.346

TABLE 8 Direct effect.

Path	Hypotheses	β	Standard deviation	T statistics (|O/STDEV|)	*p* values	Results
SC -> LSCM	H1	0.139	0.032	4.381	0.000	Supported
TI -> LSCM	H2	0.128	0.03	4.265	0.000	Supported
GPR -> LSCM	H3	0.395	0.041	9.392	0.000	Supported
LSCM -> TIEP	H4	0.363	0.032	11.351	0.000	Supported

TABLE 9 Mediation effect.

Path	Hypotheses	β	Standard deviation	T statistics (|O/STDEV|)	*p* values	Results
SC -> LSCM -> TIEP	H5	0.069	0.031	2.151	0.000	Supported
TI -> LSCM -> TIEP	H6	0.115	0.03	3.716	0.000	Supported
GPR -> LSCM -> TIEP	H7	0.136	0.026	5.156	0.000	Supported

beneficial correlation between the proficient utilization of information technology and the effective execution of streamlined supply chain strategies (Gu et al., 2021).

The study's findings indicate that GPR has a noteworthy and favorable relation to LSCM. It validates the study's initial hypothesis (H3 in Table 8). (Bohle and Johnson, 2019) conducted a comparative analysis to assess the impact of government policies on LSCM in different regions. The research demonstrated a positive association between supportive government policies and the successful adoption and implementation of LSCM practices. Another study by (Hong et al., 2020) investigates the relationship between government regulations and LSCM practices in various industries. The results support Hypothesis H3.

The study's findings indicate that LSCM significantly and satisfactorily influences TIEP. It validates the study's initial hypothesis (H4 in Table 8) (Hsu et al.). (Chen et al., 2017), research proposed a framework to integrate LSCM principles with environmental performance in transport infrastructure. The research provided empirical evidence showing a positive association between adopting lean supply chain practices and improved transport sector environmental performance. Another research conducted by (Wang et al., 2020) examines the environmental implications of LSCM in the transportation sector; research provided evidence of a positive association between implementing lean practices and improving environmental performance in transportation.

The combined effects of the hypotheses presented in the study suggests that effective collaboration in the supply chain, technological integration, and supportive government policies positively impact Lean Supply Chain Management. Furthermore, the mediating roles of LSCM in the relationships between SC, TI, GPR, and TIEP indicate that adopting lean practices contributes to the improvement of environmental performance in transport infrastructure. The collaborative efforts and technological advancements within a lean supply chain play crucial roles in achieving sustainable and environmentally friendly transportation systems.

Businesses can enhance sustainable supply chain management through stakeholder engagement and technological investment. Collaborating with government agencies, communities, environmental organizations, and industry partners is crucial for implementing sustainable practices, policies, and technologies. Advanced technology integration within a lean supply chain improves resource allocation and enhances visibility into environmental impacts. Policymakers play a key role by developing supportive regulations, such as emissions standards and incentives, fostering an environment for successful adoption of lean supply chain practices. Environmental sustainability efforts should prioritize lean principles, extending waste reduction and efficiency to transport infrastructure. Collaboration with stakeholders is essential for identifying and implementing sustainable practices. Further research into the mediating roles of Lean Supply Chain Management is recommended to deepen understanding and inform strategies. Educational initiatives, including training programs and awareness campaigns, are vital for fostering a sustainability culture within organizations, aligning values with environmentally responsible practices.

5.2 Mediation effect

Another noteworthy contribution of this research is exploring the mediating roles LSCM plays between SC, TI, GPR and TIEP. Hypothesis H5 suggests a positive mediating relationship between stakeholder collaboration and transport infrastructure environmental performance through implementing LSCM practices. It validates the initial hypothesis (H5 in Table 9). (Seman et al., 2019), study explores how collaborative efforts involving various stakeholders, such as government agencies, local communities, environmental organizations, and industry partners, can enhance the environmental performance of transport infrastructure. Effective collaboration can lead to developing and implementing sustainable practices, policies, and technologies that mitigate environmental impact. According to (Zhu et al., 2013), LSCM emphasizes efficiency, waste reduction, and sustainability. Organizations can enhance their environmental performance and reduce their carbon footprint by minimizing waste, optimizing processes, and improving resource utilization. Collaborating with stakeholders of LSCM can lead to developing more sustainable and environmentally friendly transportation systems. Stakeholder insights and contributions can help identify opportunities for waste reduction, resource optimization, and sustainable practices within the supply chain (Seuring and Müller, 2008).

Hypothesis H6 suggests a positive mediating relationship between TI and TIEP through implementing LSCM practices. It validates the initial hypothesis (H6 in Table 9). Technological integration within a lean supply chain can lead to better resource allocation, enhanced visibility of environmental impacts, and improved management of sustainability goals, ultimately positively impacting the environmental performance of transport infrastructure. (Amiri Khorheh et al., 2015).

Hypothesis H7 suggests a positive mediating relationship between GPR and TIEP through implementing LSCM practices. It validates the initial hypothesis (H7 in Table 9). According to (Stavins, 2003), GPR plays a significant role in shaping the environmental performance of transport infrastructure. These policies can include emissions standards, fuel efficiency requirements, environmental impact assessments, and incentives for sustainable practices. Research by (Pagell and Wu, 2009), LSCM principles focus on reducing waste, optimizing processes, and enhancing efficiency. When applied to transport infrastructure, lean practices can lead to resource conservation, reduced emissions, and improved environmental performance.

6 Conclusion

Supported by findings, the H1 hypothesis concludes that when stakeholders collaborate effectively, it positively associates with the implementation and effectiveness of LSCM. The H2 hypothesis concludes that integrating technology into supply chain processes is conducive to adopting and succeeding LSCM practices. The H3 hypothesis concludes that Government policy and regulation are positively associated with LSCM. Government policies and regulations can incentivize or facilitate the adoption of LSCM practices in the context of transport infrastructure. H4 concludes that effective implementation of LSCM practices is linked to improved environmental performance in the transport infrastructure sector. H5 implies that stakeholder collaboration indirectly contributes to better environmental performance in transport infrastructure by promoting LSCM practices. H6 concludes that when facilitated by LSCM, technological integration improves environmental performance in the transport infrastructure sector. H7 concludes that government policies and regulations and LSCM positively influence environmental performance in transport infrastructure.

6.1 Implications for theory and practical applicability

The study advances sustainability theories by exploring how stakeholders, technology integration, policies, and supply chain management enhance environmental performance in transport infrastructure. It integrates diverse theoretical frameworks, highlighting their interconnectedness and showcasing a holistic approach to drive sustainability. Additionally, the study can lead to a theoretical framework for designing sustainable transport infrastructure, incorporating stakeholder involvement, technological integration, policy alignment, and LSCM for optimized environmental performance.

The practical applicability of this study lies in diverse stakeholders, offering valuable guidance in the realms of business strategy, policy development, environmental sustainability, research, and education within the field of supply chain management. For businesses, active engagement and collaboration with stakeholders, alongside strategic investments in advanced technologies for a lean supply chain, can optimize resource allocation and bolster environmental goals. Policymakers can draw on the study's insights to shape supportive regulations, such as emissions standards and incentives, fostering the successful adoption of sustainable supply chain practices. Organizations aiming for environmental sustainability can implement lean principles, emphasizing waste reduction and efficiency, while collaborative efforts with stakeholders become instrumental in identifying opportunities for sustainable practices. The study also prompts further research into the mediating roles of Lean Supply Chain Management, encouraging exploration of dynamic relationships between collaboration, technology, policies, and environmental performance. Finally, the study advocates for educational initiatives, suggesting that training programs and awareness campaigns can enlighten workforces about the benefits of lean supply chain practices, nurturing a culture of sustainability within organizations. Overall, the study's practical implications offer a comprehensive roadmap for stakeholders to navigate the intersection of supply chain management and environmental sustainability.

6.2 Limitations and future research

Limitations of this research include challenges related to data availability and quality, potential difficulties in establishing causality rather than just correlation between studied factors, contextual specificity that may limit generalizability, and variations in measurement and operationalization across researchers. Moreover, the dynamic nature of variables over time poses a limitation. Future research should consider longitudinal studies, cross-regional comparisons, qualitative research to delve deeper into underlying mechanisms, in-depth case studies for significant insights, policy analysis to evaluate the effectiveness of regulations, incorporation of broader sustainability metrics, simulation models to assess long-term impacts, and benchmarking of best practices for sustainable outcomes in the transport infrastructure sector. These approaches can enhance the robustness and applicability of research findings in the pursuit of improved environmental performance.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JF: Conceptualization, Funding acquisition, Supervision, Writing–review and editing. SM: Conceptualization, Data curation, Formal Analysis, Methodology, Writing–original draft. IH: Methodology, Project administration, Writing–review and editing. SN: Data curation, Formal Analysis, Investigation, Software, Writing–review and editing. AB: Formal Analysis, Software, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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