Comparative Study on Transportation Costs and Environmental Impacts of Construction Materials in International Trade

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Abstract

With the increasing Sino-Thai trade, the transportation of construction materials has become a key focus in international logistics, given its high costs and environmental impacts. This study examines the transportation costs and environmental impacts of construction materials in global trade through a qualitative comparative analysis. It analyzes transportation data and policy contexts between China and Thailand. The findings show significant differences in cost structures and environmental burdens across various transportation modes, highlighting the trade-offs between economic efficiency and ecological sustainability. The study also identifies emerging trends in green logistics and offers strategic recommendations for optimizing transportation planning and promoting low-carbon logistics practices. The study employs a mixed-methods approach, including surveys, interviews, and literature reviews, to construct a three-dimensional green transport decision-making model. This model integrates cost, environmental impact, and policy factors influencing transportation mode choices. The results indicate that ocean shipping is the most cost-efficient but slowest, while road transport is the fastest but most expensive and environmentally harmful. Rail transport offers a balanced solution in terms of cost and speed, and multimodal solutions achieve a moderate cost with acceptable delivery times. Fuel price volatility and emission regulations have a significant impact on total costs, while green logistics practices contribute to reduced carbon footprints and receive incentives under green trade agreements. Future research could expand the dataset to enhance the robustness of the conclusions and explore the role of digital tools in optimizing green logistics. This study offers valuable insights for logistics companies and policymakers seeking to strike a balance between cost efficiency and environmental sustainability in international trade.

Keywords: international trade; environmental impact; green logistics; SINO-Thai corridor

Introduction

The transportation of construction materials in Sino-Thai international trade has become increasingly critical as bilateral trade volumes surge, with the value of goods exported from China to Thailand growing steadily over the past decade (Statista, 2024). However, this growth is accompanied by pressing challenges: high logistics costs and significant environmental burdens, particularly in terms of carbon emissions. Global transportation-related greenhouse gas emissions reached substantial levels in recent years, with road transport contributing disproportionately to this footprint (ResearchGate, 2024). This raises key questions: How do different transportation modes balance cost efficiency and environmental sustainability in the Sino-Thai corridor?. Moreover, what strategies can optimize these trade-offs for construction materials?.

Existing research has limitations. Anas, Rahman, and Yusuf (2023) explored how route planning and vehicle utilization affect transportation sustainability but failed to integrate empirical cost data with environmental impact metrics, especially in Southeast Asian cross-border contexts. Ismail, Wong, and Abdullah (2023) analyzed cost predictability in rail infrastructure but overlooked rail's environmental performance relative to other modes in construction material transport. Putra and Kitamura (2023) focused on minimizing material costs for ship structures, but they overlooked transport mode-specific trade-offs among speed, cost, and emissions. Kalayci and Artekin (2024) linked truck transport to CO_2 emissions but did not address multimodal solutions or regional policy influences on such trade-offs.

This study fills these gaps by systematically examining transportation costs and environmental impacts of construction materials in Sino-Thai trade, integrating cost data, emission metrics, and policy dynamics. Its primary goal is to identify optimal transportation modes that balance economic efficiency and ecological sustainability, providing actionable guidance for logistics practitioners and policymakers.

Research Objectives

1. Compare and analyze the transportation costs and environmental impacts of construction materials exports from China to Thailand.

2. Providing insights and recommendations for effective decision-making when choosing a mode of transport.

Literature Review

Previous studies have explored cost-efficient and sustainable transportation modes in cross-border logistics. However, significant gaps remain. For example, Larrodé and Muerza (2020) proposed integrating light freight with passenger rail networks and deploying electric vehicles to reduce emissions and costs, but their approach lacks large-scale empirical validation. Lin et al. (2024) evaluated the Pan-Asia Railway using the AHP and TOPSIS methods, highlighting the advantages of rail transport for bulk goods; however, their assessment relied heavily on expert judgment. Dixit et al. (2017) examined how social incentives influence transport mode selection using experimental economics, but their framework has limited applicability to international logistics planning.

These studies highlight a critical gap: the insufficient integration of environmental impact metrics with actual transportation cost data in developing regions, such as Southeast Asia. Additionally, few studies focus specifically on the Sino-Thai trade corridor, which has unique policy and infrastructure dynamics. This study addresses these gaps by conducting a comparative analysis of transportation modes for construction materials, integrating environmental performance with cost-efficiency. It provides a more comprehensive and empirically grounded understanding of sustainable logistics in the Sino-Thai corridor.

Conceptual Framework

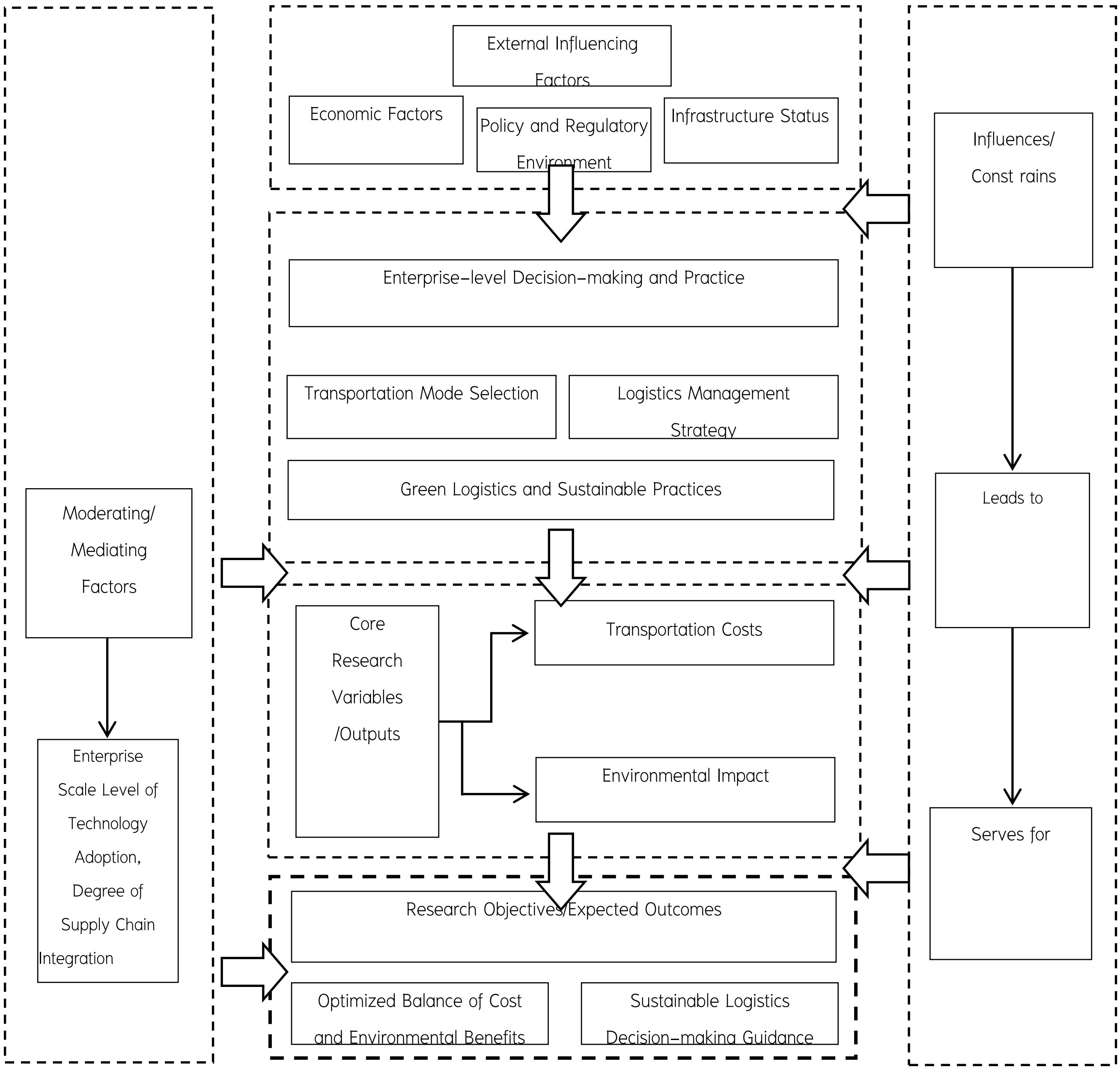
This study employs a mixed-methods approach, incorporating surveys, interviews, and a literature review, to develop a three-dimensional model for green transport decision-making. The model integrates cost, environmental impact, and policy factors, which jointly influence transportation mode choices in the China–Thailand building materials trade.

- Cost factors (e.g., freight charges, fuel expenses) affect the economic feasibility of different transport modes.

- Environmental factors (e.g., carbon emissions, energy consumption) reflect the ecological sustainability of transport options.

- Policy factors (e.g., subsidies, regulations, customs procedures) shape the external conditions that either encourage or restrict specific transport modes.

By clarifying the interactions among these three dimensions, the model provides a structured framework to guide green and cost-effective transportation decisions in the international logistics of building materials.



Definition of terms

1. Green logistics:

Green logistics refers to a transportation and supply chain approach that aims to minimize environmental impact by reducing carbon emissions and waste of resources. This is achieved through measures such as route optimization, increasing vehicle loading efficiency, and adopting clean energy technologies like electric or liquefied natural gas (LNG) vehicles (Meng et al., 2024).

2. Carbon emissions:

Carbon emissions denote the total volume of greenhouse gases, primarily carbon dioxide (CO_2), released during fuel combustion in transportation activities. It serves as a critical indicator for assessing the environmental impact of logistics operations (Mpuure et al., 2024).

3. Low-carbon economy:

A low-carbon economy is an economic development model that aims to strike a balance between environmental protection and economic growth by reducing greenhouse gas emissions. This transition is typically driven by technological innovation, industrial restructuring, and the adoption of sustainable practices (Meng et al., 2024).

4. Loading efficiency:

Loading efficiency is defined as the ratio of a vehicle's actual load to its maximum capacity. Higher loading efficiency not only reduces fuel consumption per unit of cargo but also lowers transportation costs. For example, optimizing delivery schedules to avoid half-empty trucks can significantly improve energy efficiency in logistics (Meng et al., 2024).

Research Methods

Study Population and Sampling Strategy

This study targeted Chinese and Thai companies involved in the international trade and transportation of building materials. Due to time and budget constraints, purposive sampling was used to select eight firms: two exporters and two logistics service providers from each country. The small sample size limits the generalizability of the findings.

Participants

Mid- to senior-level managers from logistics, trade, operations, sustainability, procurement, and environmental management departments participated. Their diverse backgrounds provided comprehensive insights.

Research Instruments

A mixed-method approach was used, combining structured questionnaires for quantitative data on transportation costs and emissions with semi-structured interviews for qualitative insights. Instruments were validated through expert review and pilot testing to ensure clarity and reliability.

Data Collection

Data was collected over two weeks via online platforms and face-to-face interviews. Participation was voluntary, with confidentiality maintained.

Data Analysis

Thematic analysis was conducted using NVivo software to code and categorize data, identifying key themes such as transportation mode and cost variation, route selection and environmental impact, and efficiency trade-offs. NVivo facilitated detailed tracking and cross-referencing of themes, ensuring transparency and rigor in the analysis.

Research Results

The study identified three core findings regarding the international transport of construction materials between China and Thailand: transportation mode, cost structure, and environmental impact.

1. Cost and Emission Reductions

Rail and multimodal transport (rail + truck) significantly lowered costs and CO_2 emissions compared to full-road transport. Rail transport balanced cost (0.20 USD/kg) and speed (9–12 days), while multimodal solutions offered acceptable delivery times (7–10 days) with lower emissions.

2. Impact of Fuel Prices and Policies

Fuel price volatility and emission regulations notably affected logistics costs. Carbon surcharges in Thailand increased shipping costs by 6–10% in Q1 2024, with diesel fleets experiencing higher fluctuations than those using electric or LNG-powered trucks.

3. Enhanced Sustainability and Efficiency

Green logistics practices, such as eco-friendly packaging and optimized routing, reduced carbon footprints and improved operational efficiency. Companies adopting these practices received incentives under green trade agreements, promoting sustainable operations.

Table 1 Transport Mode Performance Summary

Mode	Cost (USD/kg)	Time (days)	CO_2 Emissions	Environmental Score
Ocean	0.12	18–21	Low (–)	+
Rail	0.20	9–12	Very Low (– –)	++
Road	0.35	4–6	High (+ +)	–
Multimodal	0.25	7–10	Medium (±)	+

Discussion

This study highlights the crucial role of transport mode selection in striking a balance between cost and environmental performance in the China–Thailand trade of building materials. The findings align with previous research, such as Putra and Kitamura (2023), who emphasized the importance of matching shipping methods to cargo characteristics for cost efficiency. Similarly, Ismail et al. (2023) confirmed that rail transport offers stable pricing and reduced emissions, which is consistent with our results showing rail as a cost-effective and environmentally friendly option. Conversely, Lee (2024) reported significant cost fluctuations in road transport due to variable fuel prices and toll charges, a concern echoed in our findings.

The study highlights that rail and multimodal transport solutions are particularly advantageous for mid-range logistics needs, offering a balanced trade-off between cost, speed, and environmental impact. This insight directly informs logistics strategies by suggesting that companies should consider rail and multimodal options for bulk shipments to optimize both economic and environmental outcomes.

For small and medium-sized enterprises (SMEs), the findings suggest that adopting green logistics practices, such as the use of electric vehicles and optimized routing, can significantly reduce carbon footprints while enhancing operational efficiency. Despite higher initial investments, these practices offer long-term benefits through regulatory compliance and market differentiation. However, SMEs face challenges in transitioning to green logistics due to resource constraints and a lack of technical expertise. The study indicates that SMEs are increasingly exploring outsourcing and intermodal strategies to mitigate these challenges while maintaining cost competitiveness.

In summary, this study not only confirms prior research on transport mode efficiency and cost variability but also adds new insights into how environmental and policy factors interact with business strategies. These insights are particularly relevant for logistics companies, which may benefit from developing multimodal service offerings, and for policymakers, who should consider supporting green transport infrastructure and offering incentives for the adoption of clean energy in freight services.

New Knowledge

This study develops the Green Tri-Dimensional Transport Decision Model, a novel analytical framework tailored to the Sino-Thai construction material trade, integrating empirical insights on cost, environmental impact, and policy dynamics to optimize transport mode selection.

Model Structure

The model is anchored in three interdependent dimensions, each operationalized with corridor-specific metrics:

1. Economic Dimension: Encompasses transport costs (0.12–0.35 USD/kg across modes), fuel price volatility, and infrastructure accessibility. It quantifies trade-offs such as ocean shipping's low cost (0.12 USD/kg) vs. long transit (18–21 days) and road transport's high speed (4–6 days) vs. high expense (0.35 USD/kg), extending Ismail et al. (2023)'s rail cost analysis with multimodal cost benchmarks (0.25 USD/kg).

2. Environmental Dimension: Focuses on CO_2 emissions per ton-kilometer, energy types (diesel, LNG, electric), and sustainability practices. It validates rail (25–40% lower emissions than road) and multimodal transport as low-carbon alternatives, building on Kalayci & Artekin (2024)'s truck emission findings by linking emissions to cost efficiency.

3. Policy Dimension: Integrates regional regulations, including Thailand's 6–10% carbon surcharges (Q1 2024) and ASEAN green logistics policies (Liu & Nguyen, 2023), to map how policy incentives (e.g., green trade agreements) reduce barriers to adopting low-emission modes.

Innovation

Unlike Larrodé and Muerza (2023)'s theoretical green transport strategies or Lin et al. (2024)'s expert-judgment-based rail assessments, this model grounds each dimension in empirical data from Sino-Thai trade, capturing corridor-specific dynamics (e.g., infrastructure gaps, bilateral policies) that have been overlooked in prior research.

Practical Value

For logistics firms, especially SMEs, it clarifies multimodal combinations (e.g., rail + truck) to balance cost and emissions amid fuel volatility.

For policymakers, it identifies leverage points (e.g., subsidizing LNG infrastructure) to accelerate green transitions, aligning with the findings of Meng et al. (2024).

This model offers a replicable tool for sustainable transport decision-making, bridging theoretical gaps with actionable, context-specific insights.

Conclusion

This study highlights the significant impact of transport mode selection on both cost efficiency and environmental performance in the Sino-Thai trade of construction materials. The analysis reveals that the suitability of each mode hinges on specific logistics needs: ocean shipping proves ideal for bulk, non-urgent cargo due to its low cost, while road transport, despite its speed, imposes higher expenses and greater environmental burdens, making it more appropriate for short-distance, time-sensitive shipments. Rail transport emerges as a balanced solution, striking a pragmatic equilibrium between cost, speed, and carbon emissions. Meanwhile, multimodal combinations—such as rail-truck integration —offer an efficient compromise, achieving moderate costs, acceptable delivery times, and a reduced ecological impact.

Beyond mode-specific dynamics, the findings highlight that fuel price volatility and environmental policies have a significant impact on logistics outcomes. Thailand's carbon surcharges and evolving ASEAN green regulations, for instance, amplify the economic rationale for low-emission transport, reinforcing the strategic value of rail and multimodal strategies. Green logistics practices, including eco-friendly packaging and optimized routing, further enhance sustainability while boosting operational efficiency; incentives under bilateral green trade agreements add impetus to their adoption, even amid higher initial investments, by yielding long-term benefits through regulatory compliance and market differentiation, for small and medium-sized enterprises (SMEs), which face resource constraints in transitioning to green logistics, outsourcing and intermodal approaches emerge as practical pathways to balance cost competitiveness and environmental responsibility.

In essence, sustainable logistics in the Sino-Thai corridor demands a flexible, context-aware strategy that leverages mode-specific strengths, responds to policy signals, and integrates green practices. Enterprises are advised to adopt adaptive multimodal planning supported by data-driven insights. At the same time, policymakers should prioritize investments in low-emission infrastructure and targeted incentives to accelerate the shift toward sustainability. Together, these measures can foster a logistics ecosystem that balances economic viability and environmental stewardship, thereby supporting the long-term growth of cross-border trade in construction materials between China and Thailand.

Suggestions

Suggestions from research and application

1. Logistics enterprises should adopt differentiated transport strategies based on cargo traits: use ocean shipping for bulk, non-urgent materials to exploit its low cost (0.12 USD/kg); prioritize rail or multimodal transport for mid-urgency goods to balance cost (0.20–0.25 USD/kg) and emissions; and limit road transport to time-sensitive, small-batch shipments to mitigate its high cost and environmental impact.

2. SMEs should leverage outsourcing and intermodal partnerships to reduce green transition barriers, such as collaborating with rail-specialized third-party logistics providers to avoid upfront fleet investments, and utilizing bilateral green trade incentives to offset sustainable practice costs.

3. Policymakers should enhance cross-border rail infrastructure and streamline multimodal customs procedures to cut delays, while offering subsidies for electric/LNG trucks and carbon surcharge rebates for low-emission modes to accelerate green transport adoption.

Suggestions for future research

1. Expand the sample to include more ASEAN countries to strengthen the generalizability of the results, considering regional infrastructure and policy variations.

2. Explore digital tools (e.g., blockchain for emission tracking, AI route optimization) to refine the green transport decision model, addressing technology-related research gaps.

3. Conduct material-specific analyses (e.g., steel vs. concrete) to develop tailored strategies, given differing cost-emission sensitivities across construction materials.

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