Green Finance Gap in Sustainable and Equitable Transportation Infrastructure Systems: A Data Driven Bibliometric Analysis

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The transportation sector is crucial in the global economy's decarbonization efforts. In this context, green financing emerges as a crucial strategy for mobilizing financial resources to reduce carbon emissions and address climate change, yet it has received limited academic attention. This paper aims to bridge this gap by offering an overview of the academic development of green financing in transportation, employing a bibliometric analysis approach. Data for this study was sourced from the Scopus database, covering the period from 2007 to 2023. The quantitative analysis of relevant academic literature identifies key green financing mechanisms and their applicability in sustainable transportation. Our findings reveal that this field is gaining increasing academic attention, evidence by publications and citations, with significant contributions from China, the United States, and European countries. Through text mining, certain thematic areas were identified, including carbon pricing and offsetting, ESG, climate policy and change. This research contributes to literature by providing a detailed assessment of the academic interest, current status, and future directions in this domain. It is anticipated that these insights will guide researchers, policymakers, and practitioners, aiding them in capitalizing on emerging investment opportunities, envisioning green outcomes, and promoting more sustainable and equitable communities.

Key Words: Green finance, Sustainable transportation, Bibliometric analysis, Climate change

Introduction

Climate change represents a paramount global issue and poses significant challenges to sustainable development. As per the United Nations, the record-breaking heat in July 2023 symbolizes a transition from 'an era of global warming to an era of global boiling'. Such alarming developments underscore the need for action in various sectors, particularly in transportation infrastructure. As a vital component of economic growth, transportation infrastructure significantly influences climate change, social equity, and environmental sustainability. It is central to the discussion on reducing the U.S. economy's carbon footprint, accounting for approximately 25% greenhouse gas (GHG) emissions and 28% total energy consumption (United Nations, 2021). In response to these challenges, the concept of a sustainable transportation system has gained prominence. Defined as encompassing low- and zero-emission, energy-efficient, and affordable transport options—including electric vehicles and alternative fuel

sources—this approach is pivotal for environmental sustainability. It emphasizes reduced emissions, enhanced public transport, the development of eco-friendly infrastructure, and the integration of renewable energy sources. Parallel to these developments, the concept of green financing has emerged as a potent tool for fostering environmental responsibility. It involves utilizing financial products and services to support environmentally friendly activities. (Sachs et al., 2019). Table 1 offers an overview of major green finance mechanisms in transportation and their applications (Wang et al., 2021; Debrah et al., 2022). Since the European Investment Bank first issued a Climate Awareness Bond, the field has seen exponential growth. Figure 1 illustrates this global development, highlighting the increasing recognition of green financing as an effective strategy to stimulate private investment in environmentally conscious business ventures. To illustrate, in 2020, the United States led globally in green bond issuance, totaling $51.1 billion—a marked increase from the previous year (Katz, 2021).

Despite the rising prominence of green financing in various infrastructure sectors like energy, buildings, and water/wastewater (Muganyi et al., 2021), its integration into transportation infrastructure is not yet fully realized. According to Climate Policy Initiative (2022), global climate finance amounts to about US$650 billion annually, with the transport sector receiving $169 billion. This disparity points to an innovative financing solution: green financing could potentially bridge the sustainable transportation investment gap. Despite its potential, there is a noticeable lack of comprehensive reviews on green financing's role in transportation infrastructure, leading to a gap in understanding both current trends and future needs. Given the unique potential of green financing to enhance both environmental sustainability and social equity in the transportation sector, there is a compelling need for a systematic review of existing knowledge in this discipline. This study, therefore, aims to conduct a bibliometric analysis of the application of green financing in transportation infrastructure systems, focusing on three critical research questions: What are the academic interests in green financing in transportation, as evidenced by citation distribution, authorship, and geographic dispersion? What green financing mechanisms are available, and what are the frequently mentioned risk factors in sustainable transportation infrastructure systems? Lastly, what are the prevailing trends in literature and the anticipated future needs for green financing in the transportation sector?
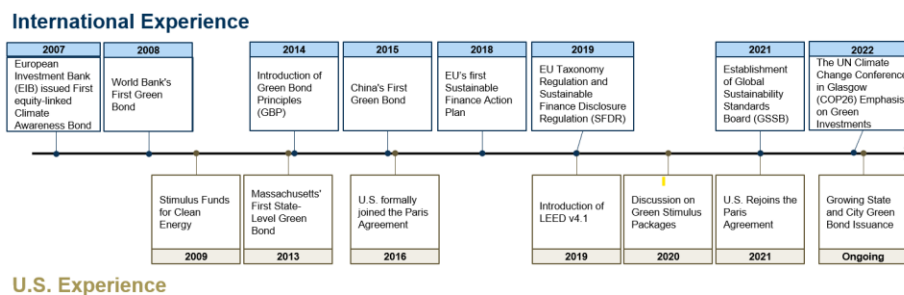

Figure 1. Timeline of development of green finance

Methodology

Bibliometric analysis is increasingly recognized as a valuable tool for evaluating scientific production across various disciplines. The approach discovers the latest progress, frontier directions and future research trend in a domain through quantitative techniques on bibliometric data. Through descriptive statistics and graphical representations, bibliometric analysis provides a clear illustration of a domain's evolution over time. It highlights patterns of collaboration among scholars and identifies leading research institutions. Attributed to the emergence of large scientific databases, bibliometric analysis is instrumental in comprehending the broader landscape of a field, and pinpointing knowledge gaps and future research directions (Donthu et al., 2021).

Table 1

Green financing mechanisms for transportation infrastructure systems

Mechanisms	Characteristics and Applications
Green Bonds	Municipal bonds for clean energy projects. Funding green projects and GHG emissions reduction in clean transportation.
Green Loans	Exclusive funding for substantial environmental contributions. Similar to green bonds; ideal for smaller projects at large transit agencies
Carbon Pricing Revenues	Funds from carbon pricing mechanisms. Encourages eco-friendly transportation to reduce carbon emissions.
Public-Private Partnerships (PPPs)	Joint ventures between public and private sectors for environmental sustainability. Sustainable urban and large-scale transport infrastructure.
Innovative Financing Mechanisms	Diverse financial flows and models to fund sustainable transportation. Community solar projects, EV charging networks, green credit allocation in countries like Brazil and China.
Green Infrastructure Banks	Entities driving capital into clean energy projects, overcoming financing barriers. Ambitious emissions targets, job creation, local development, e.g., sustainable transport development.
Tax Incentives	Government incentives (deductions, credits, exemptions) for green investments. Eco-friendly projects like biking/walking infrastructure, sustainable transit, EV infrastructure.
Grants and Subsidies	Direct financial support for specific, environmentally friendly transportation projects. Small-scale energy efficiency projects
Carbon Offsetting Programs	Investments in GHG reduction projects to compensate for emissions. Offsetting transport emissions by investing in renewable energy.
ESG Finance	Investment strategies considering environmental, social, and governance factors to minimize risks and maximize returns. Green transportation initiatives like electric buses, sustainable mobility solutions.
Socially Responsible Investing (SRI)	Investments prioritizing ethical, environmental, social criteria for positive social change. Green transportation infrastructure like pedestrian-friendly spaces and accessible public transit.

For bibliometric analysis, the first step is bibliometric data retrieval, which is critical for defining the scope of investigation. In this study, bibliometric data were collected through the Scopus database with carefully selected keywords combinations. Scopus is an abstract and citation database of peer-reviewed research literature across 240 disciplines. It includes over 26,000 titles from more than 7,000 international publishers, making it an ideal source for comprehensive bibliometric analysis, as demonstrated in similar studies (Bhatnagar and Sharma, 2022; Naeem et al., 2023). Table 2 details the search query used in this study. This query was strategically designed to maximize relevance to the topic and ensure thorough coverage of the body of knowledge. The search was applied to titles, abstracts, and keywords to capture all pertinent studies on the topic. The focus spanned the period from 2007 to 2023, with 2007 chosen as the starting point in line with the European Investment Bank's issuance of the first equity-linked Climate Awareness Bond that year. The screening process yielded a total of 606 articles pertinent to green finance in transportation, adhering to our selection criteria.

Table 2

Search query

	Title-Abstract-Keywords
Element 1	"green financ*" OR "climate financ*" OR "sustainable financ*" OR "carbon financ*" OR "environmental financ*" OR "green bonds" OR "green credit" OR "green loans" OR "green infrastructure bank" OR "green investing" OR "green fund*" OR "socially responsible investing" OR "environmental social and governance investing" OR {ESG} OR "carbon pricing" OR "carbon offsetting"

| Element 2 | "transportation" OR "rails" OR "bike" OR "ports" OR "airports" OR "bus" OR "energy efficient ports" OR "vehicle" OR "high occupancy toll lane" OR "HOT lane" OR "high occupancy vehicle lane" OR "HOV lane" OR "eco friendly shipping" OR "urban planning" OR "public transit" OR "cycling pedestrian infrastructure" OR "asset recycling" OR "renewable energy integration" OR "mobility solution" |

Element 1 AND Element 2 AND PUBYEAR > 2006 AND PUBYEAR < 2025

Analysis Results

The analysis of the 606-record dataset investigates the contributions to the field of green finance in transportation from various research constituents, including countries, institutions, journals, and authors. Figure 2(a) illustrates the primary subject areas of focus, revealing a multidisciplinary nature with significant contributions from environmental science, engineering, and social sciences, alongside other fields like energy, economics, finance, and business. The composition of the selected dataset, as depicted in Figure 2(b), includes 69.3% journal papers, 13% conference proceedings, 8.1% book chapters, and 3.8% reviews.
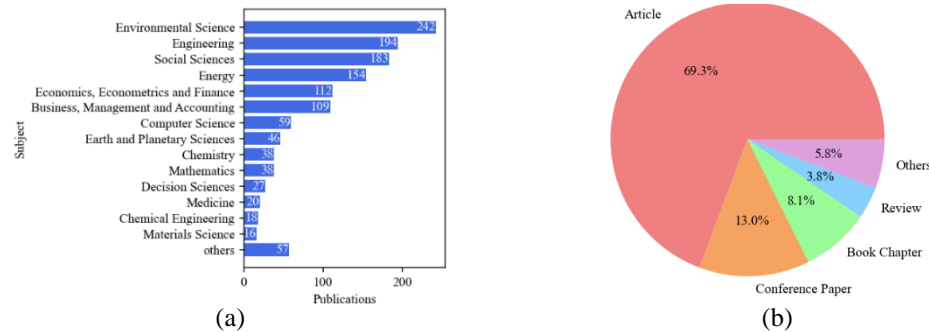

Figure 2. Overview of bibliometric data: (a) subject area; (b) document type

Publication trends, shown in Figure 3, indicate a steady increase in research output, with a notable acceleration from 2016 onwards. This surge in research activity is likely linked to heightened global governmental efforts in emission reduction and climate change mitigation. Key policies and agreements such as the Paris Agreement (2015), the Sustainable Development Goals (2015), and the New Urban Agenda (2016) have played a pivotal role in this uptrend (Tolliver et al., 2020). These initiatives collectively encourage reduced carbon emissions in transportation through the adoption of low-emission vehicles, development of sustainable infrastructure, and promotion of non-motorized transport alternatives like cycling and walking. The citation trend, experiencing a significant upsurge beginning in 2020, and an h-index of 48, underscore the growing attention towards green finance in transportation. This trend suggests an increasing academic interest and anticipates further research and practical implementations in the field.
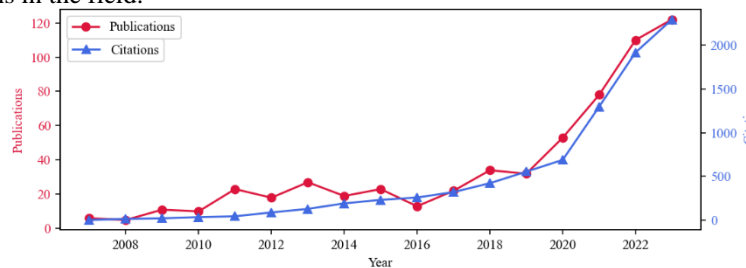

Figure 3. Publication and citation trends

Figure 4(a) provides a comprehensive visualization of the global distribution of scientific production related to green finance in transportation by country and affiliations. The analysis reveals that this research theme is gaining traction in both developed and developing economies. Notably, the largest contributions originate from China (135), the United States (114), and the United Kingdom (72), collectively accounting for over half of the total literature in this domain. This proliferated research output from these countries reflects strong financial resources and policy commitments towards climate change mitigation and reducing carbon emissions in transportation. For example, the United States has demonstrated significant support through the Bipartisan Infrastructure Law, allocating up to $108 billion for public transportation programs. In China, the move towards sustainable transportation is evident in initiatives like Shenzhen's transition to a fully electrified bus fleet of over 16,000 buses by 2018, achieved via financial leasing models and partnerships (World Bank, 2021). The United Kingdom has implemented measures like congestion charges and low emission zones to curb traffic congestion and improve air quality. Furthermore, as indicated in Figure 5, there is a notable collaboration network among European and Asian countries in this research area, with China (33 collaborations), the United Kingdom (30 collaborations), and Australia (23 collaborations) leading in global collaborations. In terms of academic affiliations, the Federal University of Rio de Janeiro (UFRJ), Tsinghua University, and the French National Center for Scientific Research (CNRS) are identified as the top contributing institutions in green finance research within the transportation sector (Figure 4(b)).

(a)   (b)
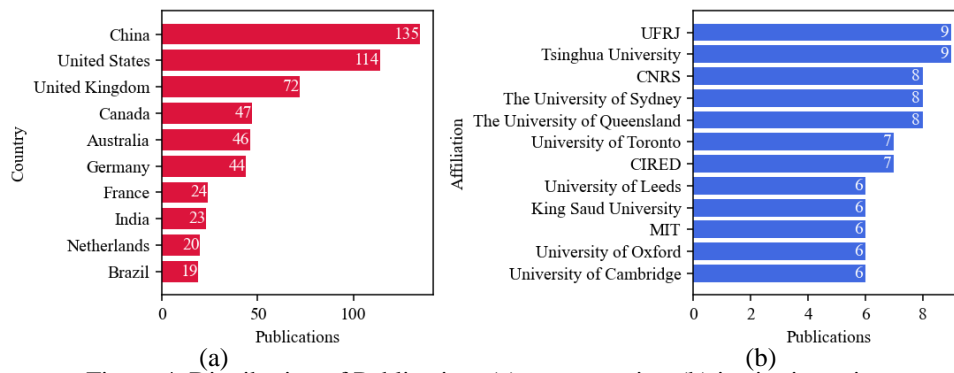
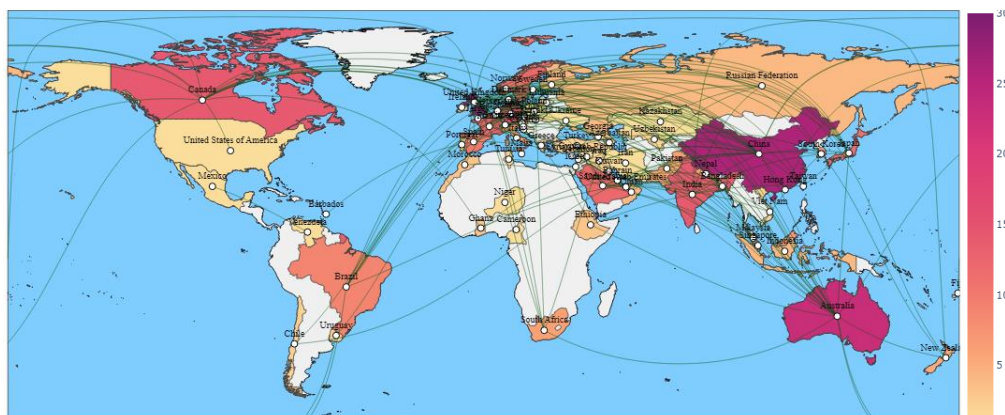Figure 4. Distribution of Publication: (a) country-wise; (b) institution-wise.

Figure 5. Global collaboration network among countries

Table 3 presents a summarized view of the distribution of publication sources in the area of green finance within the transportation sector. The impact of these sources is assessed using the CiteScore metric, which is based on a four-year citation window as provided by Scopus. The International Journal of Electrochemical Science leads in terms of publication volume, with 24 publications garnering 481 citations. This is closely followed by the Journal of Sustainability Switzerland, which has 24 articles with 143 citations. Notably, journals such as the Journal of Cleaner Production and Energy Policy stand out with their relatively high CiteScores, each exceeding 15.

Table 3

Summary of journal analysis: top 8 journals based on publications

Journal sources	Publications	Citations	CiteScore
International Journal of Electrochemical Science	24	481	2.7
Sustainability Switzerland	24	143	5.8
Transportation Research Part D Transport and Environment	16	375	12.3
Climate Policy	13	262	11.9
Journal Of Cleaner Production	13	540	18.5
Energies	11	189	5.5
Energy Policy	8	205	15.2
SAE Technical Papers	6	5	1.2

The three-field plot based on Sankey diagram is employed to effectively visualizes the interconnections among countries, keywords, and publication sources in the field of green finance in transportation (Figure 6). This diagram illustrates the significant contributions and relationships among these components, with the band width indicating the strength of connections (Pereira, 2022). From the diagram, it is evident that "carbon pricing" emerges as the most prevalent topic in global scientific output within this field. The topic garners considerable attention across various countries, notably receiving significant emphasis in academic discussions in the United Kingdom and Canada. Additionally, themes like "carbon offsetting" and "ESG (Environmental, Social, and Governance)" are gaining global prominence. "Climate policy and change" are most frequently addressed in the United States, Canada, and the United Kingdom. China and the United States are observed to have the broadest range of topic contributions in this area. Regarding publication sources, the most frequently identified keywords are predominantly featured in journals such as Sustainability (Switzerland), Climate Policy, Journal of Cleaner Production, and Transportation Research Part D: Transport and Environment. These journals align with the top journals identified in Table 3 based on publications and citations. An interesting observation is the prominence of "COVID-19" as a top keyword (Jinru et al., 2022; Tian et al., 2022). This reflects the increased recognition of the pandemic's impact on transportation sustainability and the heightened need for innovative financing tools to enhance the resilience of transportation infrastructure systems against future threats, including those posed by climate change.

The results of trending topics are further supported by the thematic analysis on author keywords. Leveraging Term Frequency-Inverse Document Frequency (TFIDF) and k-cluster analysis, the thematic analysis elucidates the knowledge structure in green financing for transportation.
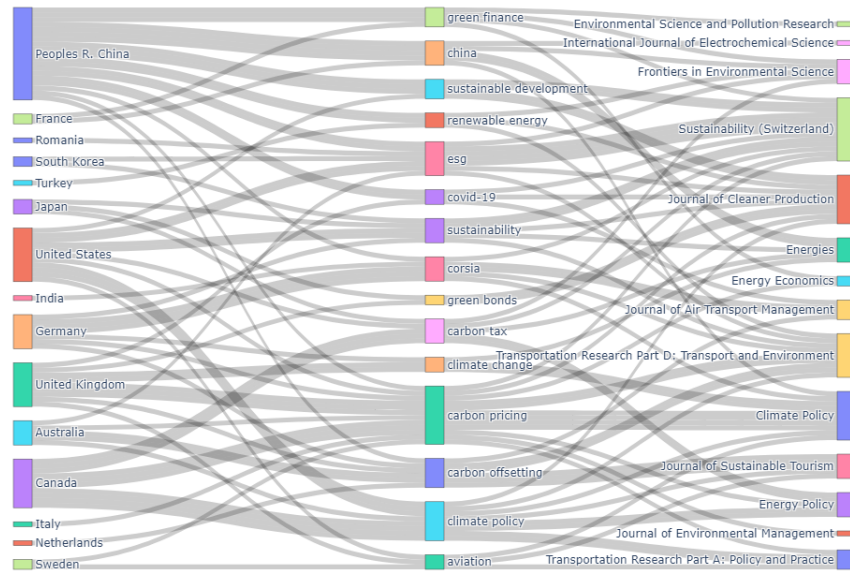
CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
Figure 6. Three-field analysis on green finance in transportation

This analysis, detailed in Table 4, identifies ten key clusters with corresponding common keywords. Figure 7 traces the evolution of research topics from 2007 to 2023, revealing shifts in focus within the field. Initially, discussions centered around sustainable development and financing, reflecting the nascent stage of green finance. Around 2014, the research interest pivoted towards energy consumption and scenario planning, indicating a broader consideration of sustainability factors in transportation. By 2018, a significant shift was observed towards Environmental, Social, and Governance (ESG) reporting and management principles, paralleling ESG's rise in the market (Singhania and Saini, 2023). Concurrently, there was an increasing emphasis on climate policy and change initiatives (Zhang and Fujimori, 2020), green finance, and credit processes (Song et al., 2021). In recent years, the focus has intensified on the financial incentives to promote automotive sector and electric vehicles (Wu et al., 2021), underscoring the sector's pivotal role in reducing carbon emissions. Alongside this, carbon taxation and pricing strategies have emerged as critical areas of research (Green, 2021). These shifts signify a growing consensus on the importance of green financing mechanisms in promoting sustainable transportation infrastructure to mitigate climate change. The most trending topics currently include the automotive sector and electric vehicles, carbon taxation and pricing strategies, and climate policy and change initiatives.

Table 4

Identified 10 clusters and most common keywords

Clusters	Keywords
Transportation Systems and Road Taxation	road transport; road taxes; decarbonizing road transport
Green Finance and Credit Processes	green finance; green bonds; green credit; green recovery; green economy
ESG Reporting and Management Principles	ESG; ESG standards; ESG principles
Carbon Taxation and Pricing Strategies	carbon pricing; carbon tax; carbon offsetting; carbon footprint
Climate Policy and Change Initiatives	climate change; climate policy; climate finance

| Sustainable Development and Financing	sustainable development; sustainable finance; sustainable transport; sustainable mobility; sustainable shipping
Transportation CO2 Emissions and Waterway Transport	transportation; air travel; air pollution; EU transportation policy
Energy Consumption and Scenario Planning	renewable energy; energy transition; energy policy; energy economics
Automotive Sector and Electric Vehicles	electric vehicles; aviation; decarbonization; life cycle assessment
Infrastructure Development and EV Infrastructure	transportation infrastructure; green infrastructure; financing infrastructure
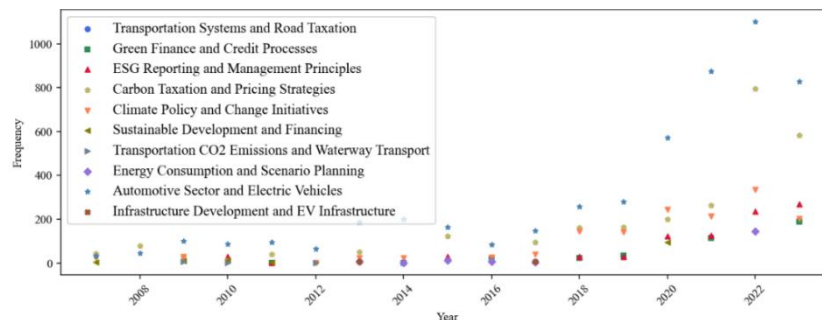
Figure 7. Trending topics based on author keywords

Conclusions

Recent years have witnessed a burgeoning academic interest in green finance within the transportation sector, recognizing its potential to transform traditional transportation systems into sustainable alternatives. The present study employs a bibliometric analysis approach to investigate the evolution of green finance in transportation. This study adopts a bibliometric analysis approach to explore the academic evolution of green finance in transportation, analyzing 606 documents sourced from the Scopus database through carefully designed screening criteria. The publication and citation analysis reveals an upward trend in academic discourse since 2007, with a significant increase from 2016 onwards. The involvement of both developed and developing economies is evident, with China, the United States, and the United Kingdom leading in academic contributions. Key publication outlets for this topic include the International Journal of Electrochemical Science, Sustainability Switzerland, and Transportation Research Part D: Transport and Environment, predominantly covering environmental science, engineering, and social sciences. The most relevant subject areas of the publications span environmental science, engineering, and social sciences, highlighting the inherently interdisciplinary nature of this research area. The collaboration network analysis reveals a notable trend of increased cooperation between Asian and European countries, with China, UK and Australia as the most active countries engaged in collaboration. The Sankey diagram and thematic analysis unveil trending topics and prospective research directions, indicating a shift from general sustainable development and financing themes to more focused areas like carbon taxation, pricing strategies, and innovative financial tools. Relative to other infrastructure sectors, the transportation sector is a predominant consumer of energy and a major contributor to carbon emissions. There has been an escalating academic discussion surrounding carbon pricing and offsetting mechanisms, as well as advancements in the automotive sector, especially in electric vehicles these years. The growing urgency for a transition in financial systems towards sustainability, particularly to support green objectives in the transportation sector, is increasingly evident. Such a transition in financial strategies is essential to support and accelerate the

shift towards more sustainable and eco-friendly transportation systems. This study enriches the academic understanding of green finance in transportation, offering insights into its evolution, current trends, and future directions. While this study primarily addresses green financing applications in transportation, its findings hold significant relevance for the sustainable built environment. Transportation systems are integral to the built environment, directly influencing its sustainability and energy efficiency. Investments and policies in the transportation sector, guided by green financing, contribute to more energy-efficient urban planning, reduced carbon emissions, and overall enhanced sustainability. The insights gained from this research extend beyond the transportation sector, offering valuable perspectives for broader infrastructure systems. It is anticipated that this analysis will aid researchers, stakeholders, and policymakers in deepening their comprehension of green finance's role in sustainable built environment, unlocking its potential to foster environmental sustainability and social equity in the transportation and broader infrastructure sector.

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