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Green Hydrogen in Indian Logistics: A Sustainable Leap for Climate and Economy

Aarti Rana and Rajat Agrawal*
Indian Institute of Technology
Roorkee, India
*rajat@ms.iitr.ac.in

Abstract

India's rapid economic growth has led to an increasing demand for energy, making sustainable energy solutions crucial. The logistics sector, which accounts for a significant portion of India's GDP, faces challenges in reducing costs and carbon emissions. Currently, logistics costs are high, and the transportation sector contributes substantially to CO_2 emissions. To address these issues, India aims to reduce logistics costs and achieve net-zero emissions. This study explores how India integrates green hydrogen into its logistics infrastructure to create a more sustainable and efficient system. It examines the challenges in reducing greenhouse gas emissions and logistics costs, with a focus on optimizing green hydrogen-based logistics.

The research uses a descriptive approach, analysing data from secondary sources such as the Open Government Data platform and reports related to India's green hydrogen mission. Furthermore, some international reports and research studies were also analysed to identify the current situation of transitioning in Indian logistics. The study assesses the current infrastructure and its limitations, laying the groundwork for future research on optimized and green hydrogen-based multimodal logistics. Moreover, the study identifies key challenges and critical factors affecting the adoption of green hydrogen in logistics. It highlights the need for robust transportation systems and optimized regional networks using clean fuels like green hydrogen. This research provides a conceptual framework for developing sustainable green hydrogen-based logistics in India. It offers insights for researchers and academics to create mathematical models using AI/ML to optimize green hydrogen logistics costs and efficiency. By focusing on the implementation of green hydrogen in the Indian logistics system, India can achieve its net-zero 2070 and SGD goals simultaneously. India can potentially reduce its reliance on fossil fuels, lower emissions, and enhance its economic growth sustainably.

Keywords
Green hydrogen, Logistics, Net-zero, Sustainable goals, Road transportation

1.Introduction
Global greenhouse gas (GHG) emissions have reached unprecedented levels, with annual carbon dioxide (CO_2) outputs consistently hitting new highs, as highlighted in the International Energy Agency's (IEA) & Emissions Gap Report 2023 (- International Energy Agency 2023). India now ranks as the world's third-largest emitter of GHGs, following China and the United States, according to recent data from Statista (2025). The statistics clearly attribute the majority of these emissions to the continued and overwhelming reliance on fossil fuels, a trend that is visually depicted in Figure 1, which shows the persistent growth in global fossil fuel emissions. Despite mounting evidence of their environmental impact, fossil fuels remain the cornerstone of the global energy system, prompting nations to accelerate the transition toward low-carbon energy alternatives as a critical strategy for mitigating climate change impacts (- International Energy Agency 2023).

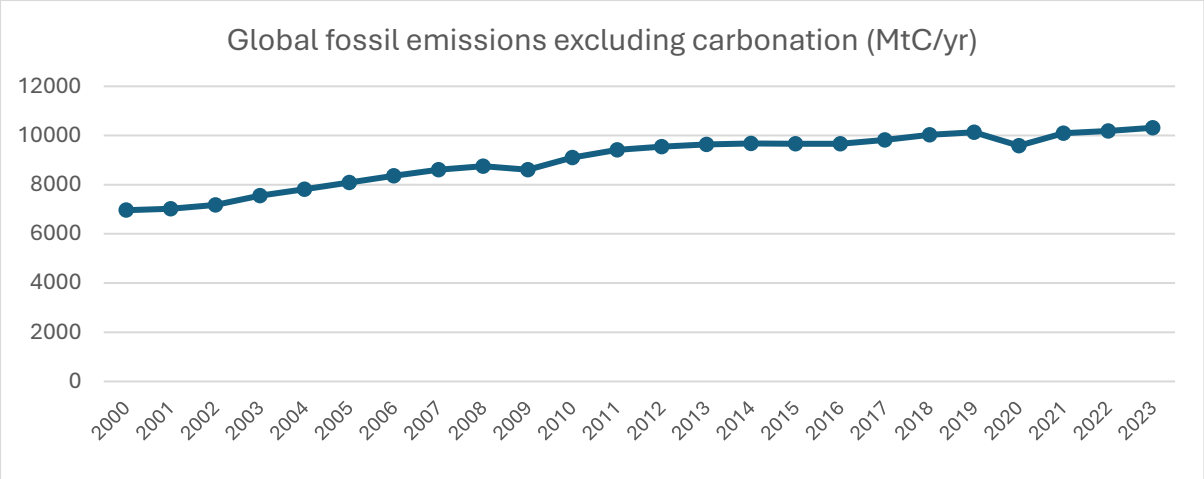

Figure 1. Global trend for GHG emissions from Fossil fuels

India's contribution to global CO_2 emissions stands at approximately 8%, a figure that mirrors the emission levels of many developed countries, even as India's GDP continues its rapid ascent (Filonchyk et al. 2024). Notably, the country experienced a significant 4.6% increase in fossil fuel-based CO_2 emissions in 2024, underscoring the urgency of adopting cleaner energy pathways ((Samsatli, Staffell and Samsatli 2016)). Sectoral analysis reveals that the power sector is the leading source of global GHG emissions, accounting for nearly 26% of the total, followed by the transport sector at 15%, and industrial processes at 20% (Statista, 2024b). In this context, the imperative to transition to sustainable energy is clear, not only to curb emissions but also as an opportunity to unlock substantial economic, social, and environmental benefits (Markert et al. 2017).

Within India, the logistics and transportation sector plays a pivotal role in economic development, with government expenditure on this sector comprising nearly 13-14% of the nation's GDP (National Logistics Policy, no date). This substantial investment positions the logistics network as a critical lever for achieving both economic growth and sustainable development, particularly through the adoption of clean and renewable energy sources. The integration of green and sustainable energy solutions within logistics offers a unique opportunity to address both environmental and economic objectives.

In light of these dynamics, this study is dedicated to exploring the transition of India's logistics sector toward green hydrogen-based energy systems. The research aims to provide a comprehensive understanding of the mechanisms driving this transition and to evaluate its dual impact on environmental sustainability and economic advancement. By systematically analyzing the interplay between green hydrogen adoption and the logistics network, the study seeks to offer actionable insights that can inform policy and strategic decision-making for a more sustainable and resilient Indian economy.

India's logistics system, as illustrated in figure 2, encompassing air, water, and road networks, operates within a vast geographical and coastal landscape, necessitating multimodal approaches for comprehensive analysis (Synchronizing energy transitions toward possible Net Zero for India: Affordable and clean energy for all Indian Institute of Management Ahmedabad 2024). While multimodal studies are critical to understanding systemic challenges and opportunities in transitioning to green hydrogen-based logistics into a single study. The disparity still exists even though road transport dominates freight and passenger movements in India because of its unparalleled flexibility, last-mile connectivity, and capacity to adapt to a variety of terrains. According to the literature currently in publication, road logistics receives relatively less attention than air and ocean transportation.

The underrepresentation of road logistics in research is particularly significant given its environmental and economic implications. While initiatives like dedicated freight corridors and coastal shipping demonstrate progress in rail and maritime decarbonization, road transport remains heavily reliant on fossil fuels, contributing substantially to sectoral emissions (Okyere et al. 2022). This study addresses this gap by narrowing its scope to

India's road logistics network, which faces unique challenges such as fragmented infrastructure, high operational costs, and technological barriers to clean energy adoption.
The research objectives are threefold:

To identify systemic challenges impeding sustainable practices in India's road logistics.
To analyze the viability of green hydrogen as a transitional fuel for road freight.
To assess the economic & environmental implications of integrating green hydrogen into the road logistics ecosystem in India

By concentrating on road logistics—the backbone of India's domestic supply chains- this study aims to provide actionable insights for policymakers and stakeholders navigating the complexities of sustainable transition in a sector critical to both economic growth and climate commitments.

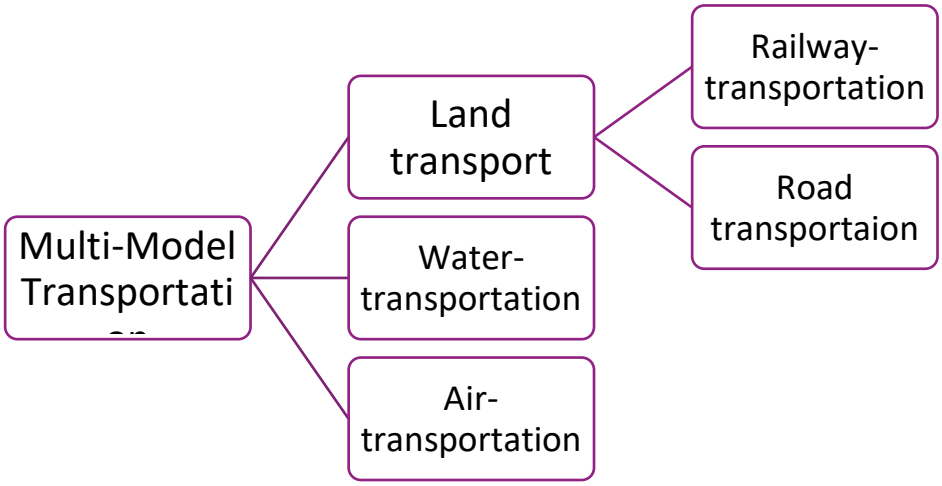

Figure 2. Framework for multimodal transportation network

The remaining part of this research paper is laid out in the following manner: Section 2 discusses the literature review and its highlights. Section 3 covers methodology. The detailed India's logistic scenarios with descriptive study in Section 4, followed by the key insights. At the end conclusion with implications and future scope of the study are presented in Section 6.

2.Literature review:

India's push toward green hydrogen energy aims to address two critical challenges: reducing emissions across energy systems and cutting reliance on imported fossil fuels. Parallel to this, managing waste materials like biomass and plastics presents an opportunity for sustainable energy generation (Rasheed et al., 2021). Green hydrogen emerges as a strategic solution for the logistics sector, offering a pathway to lower greenhouse gas emissions from road transport while easing dependency on costly fuel imports. However, harnessing hydrogen's potential requires overcoming technical and economic barriers. So, Green hydrogen is useful for Indian logistics by reducing the demand for imported fossil fuels as well as GHG emissions from road transportation. Although hydrogen is abundant in compounds like water (H_2O) and methane (CH_4), isolating it for use in fuel cell vehicles involves energy-intensive processes such as electrolysis. When utilized, hydrogen combines with oxygen from the air through a fuel cell, creating electricity and water through an electrochemical process (Maka & Mehmood, 2024). Hydrogen's specific energy (i.e., energy content per unit of mass) is higher than most hydrocarbon fuels. However, while hydrogen boasts high energy content per unit mass, its low density, storage complexities, and underdeveloped infrastructure raise implementation costs, particularly for developing nations like India(Hermesmann and Müller 2022). But by gaining economies of scale, green hydrogen is a game-changer movement for Indian road infrastructure.

To align with global climate goals, India's logistics network is prioritizing cost reduction, emission cuts, and enhancing transportation efficiency(INDIA'S GREEN HYDROGEN REVOLUTION-An Ambitious Approach, 2024). The Ministry of Commerce and Industry has established a logistics division to advance logistics by implementing proper multimodal logistics with a digital infrastructure system to optimize costs, and the National Green Hydrogen Mission is focusing on the implementation of green hydrogen in various sectors such as refinery, logistics, steel, and power etc. The main target of the Indian government is to reduce logistic costs by up to 5% of GDP over the next five years, achieve the net-zero target while simultaneously improving India's ranking in the logistics performance index. To support these goals, the Asian Development Bank (ADB) approved a $250 million policy-based loan to aid the Government of India's comprehensive reforms (ADB 2022). These reforms are designed to strengthen and modernize the country's logistics infrastructure, improve efficiency, and lower costs within the logistics sector. India's vast road network—ranked second globally at 5.9 million kilometers—and significant budget allocations (3.4% of GDP in 2024–25) underscore its commitment to upgrading transport infrastructure.

Moving further, according to World Road Statistics 2018, India held the second position after the USA in terms of the development of total road length, which was 5897671 km, with 1.8 road density, which is huge compared to other developed countries. In the 2024-25 budget, India also spent 3.4% of its GDP on capital expenditure for road infrastructure. While research highlights multimodal freight systems as a cornerstone for sustainable logistics. By combining road, rail, and waterways, such systems can lower costs, emissions, and traffic congestion while improving delivery speeds (Chandra, Christiansen and Fagerholt 2020). For instance, studies in Ghana (Okyere et al. 2019) emphasize policy reforms to attract investment in intermodal transport, a model relevant to India's evolving logistics landscape. European research further links multimodal networks to reduced CO_2 emissions and energy savings, advocating for synchronized transport modes (Knapčíková and Kaščák 2019). Innovations like the Physical Internet concept, a digital framework for optimizing freight movement, could further enhance India's logistics efficiency by integrating real-time data and automation (Ambra et al. 2019). Together, these strategies position green hydrogen, advanced technologies, and multimodal systems as three pillars for building a climate-resilient, cost-effective logistics ecosystem in India.

3.Methodology:

The methodology for this study follows a systematic approach, as illustrated in Figure 3. The process begins with a literature review, where existing research on green hydrogen applications and India's logistics framework is analyzed to establish foundational insights. This is complemented by secondary data collection from the Open Government Data (OGD) Platform India, which provides granular datasets on road logistics infrastructure, freight movement patterns, public-private logistic infrastructure, and State Road transport undertakings (SRTUs) details with their liabilities and capitals.

Descriptive analysis forms the next phase, employing statistical tools to identify trends, correlations, and inefficiencies within the road logistics network. For instance, old vehicles & outdated technologies, and fuel usage patterns reveal critical bottlenecks in existing infrastructure. This phase also evaluates the feasibility of green hydrogen adoption by cross-referencing emission hotspots with potential hydrogen production hubs highlighted in the National Green Hydrogen Mission (National Green Hydrogen report 2023). Subsequently, correlation studies link these findings to challenges in transitioning to a hydrogen-based ecosystem. Key limitations, such as fragmented regulatory frameworks, high upfront costs for hydrogen storage infrastructure, and gaps in last-mile distribution networks, are systematically cataloged. The analysis further integrates policy benchmarks from the Green Hydrogen Certification Scheme to assess alignment with India's net-zero targets.

By synthesizing these layers of inquiry, the methodology uncovers actionable insights into scalable pathways for decarbonizing road logistics while addressing economic and operational barriers. This structured approach ensures the study's findings are both empirically robust and strategically relevant to policymakers and industry stakeholders.

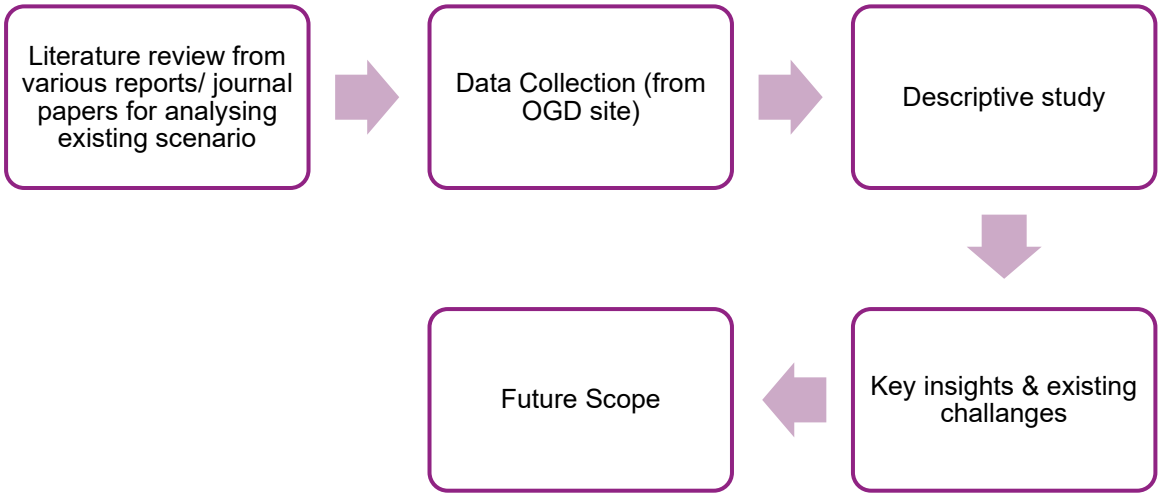

Figure 3. Framework for the methodology of the study

Descriptive study:

According to Open Government datasets, India's road infrastructure investments and ownership patterns reveal significant shifts between the public and private sectors. Before 2012–2013, public and private funding for road development were nearly equal. However, post-2012, public investments surged to 82.63%, while private participation declined sharply. This trend contrasts with bus ownership dynamics: between 1961 and 2012, the private sector dominated bus fleets, while public-sector ownership remained negligible, as illustrated in Figure 6.

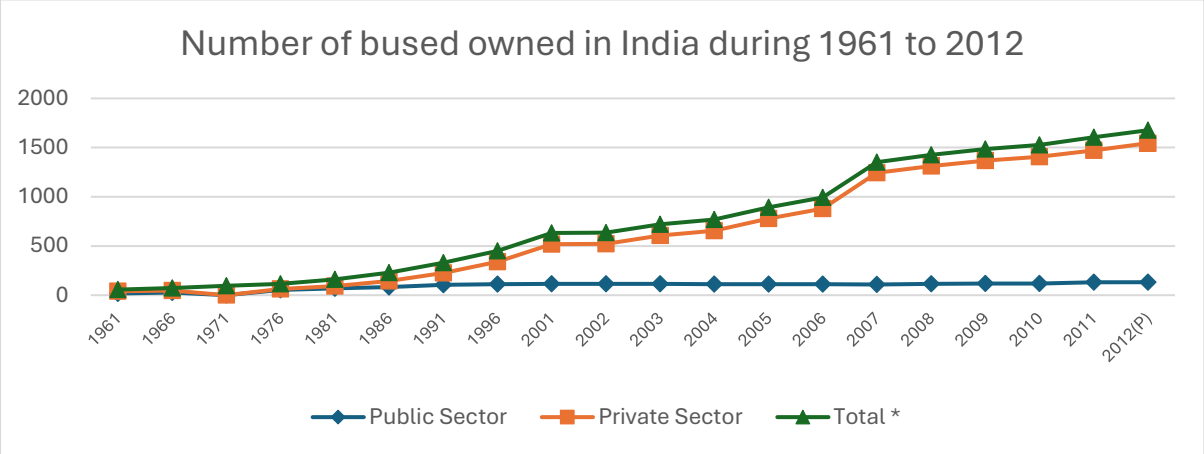

Figure 4. Trend for the number of buses owned by the public and private sectors from 1961 to 2012

A closer look at government contributions highlights disparities between central and state funding. Central government support between 2016 and 2019 focused narrowly on specific regions like Tamil Nadu State Transport Corporation (TNSTC, Madhurai), Thane Municipal Transport, and northeast Karnataka, leaving most State Road Transport Corporations (SRTCs) with minimal central aid. In contrast, state governments such as Haryana, Delhi, and Maharashtra allocated comparatively higher resources to local road infrastructure. These funding patterns raise questions about asset management, revenue distribution, and policy coherence in advancing sustainable logistics.

Central government revenue from road transportation reached ₹121,297.4 crore in 2018–19, reflecting the sector's economic scale. India is a broad area for logistics, and the country spends a significant share of its GDP on

logistics, but apart from that, the condition of state road transport net profit or income from SRTUs could be better. Despite India's heavy logistics spending, most SRTCs struggled financially between 2016 and 2019. It is seen that only UP SRTC, Odisha SRTC, Tripura Transport Corporation, and PUNBUS reported net profits, while others operated at a loss. Even before tax adjustments, profitability remained bleak, with minor exceptions in Bihar, Rajasthan, and Maharashtra. These financial challenges underscore systemic inefficiencies in public transport operations, complicating efforts to modernize infrastructure for green hydrogen adoption.This analysis underscores the need for balanced investment strategies and governance reforms to align road logistics with sustainability goals. Addressing funding gaps and operational losses in SRTCs will be critical to supporting India's transition to low-emission freight systems.

Key Insights:

India's road logistics sector faces pressing challenges that underscore the urgent need for a green hydrogen transition. Despite significant government spending 3.4% of GDP in 2024–25 on road infrastructure, financial returns remain bleak, with most state-run transport corporations reporting persistent losses. Existing systems grapple with inefficiencies such as congested networks, high operational costs, and outdated infrastructure, which contribute to delays, increased emissions, and diminished competitiveness. Figure 5 highlights how these limitations exacerbate environmental and economic strain. Heavy reliance on fossil fuels in freight transport, responsible for 44% of India's oil consumption, worsens air quality and aligns poorly with net-zero targets. Figure 6 highlights how integrating green hydrogen into India's logistics system can help address and overcome the current limitations faced by the sector.

Key Insights	The vehicles are nearly overaged, resulting in high direct and indirect costs for fuel, lubrication, and maintenance, as well as reduced efficiency and comfort.
	Low level of technology and warehouse management or the high indirect costs of an unpredictable road network are major reasons for high logistics costs and a higher no of accidents.
	Rising logistics costs, declining vehicle and staff efficiency, and the environmental impact of aging vehicles highlight the urgent need to shift towards green hydrogen infrastructure. Integrating emerging digital technologies across processes, facilities, services, and vehicles will be essential for this transition.
	Research has indicated that integrating green hydrogen into various modes of freight transportation, including road logistics, can significantly improve the sustainability of freight transport. This approach can lead to cost savings, reduced emissions, less damage, and decreased traffic congestion, while also speeding up delivery times by increasing the efficiency of shipments.

Figure 5. Key insights from the descriptive study

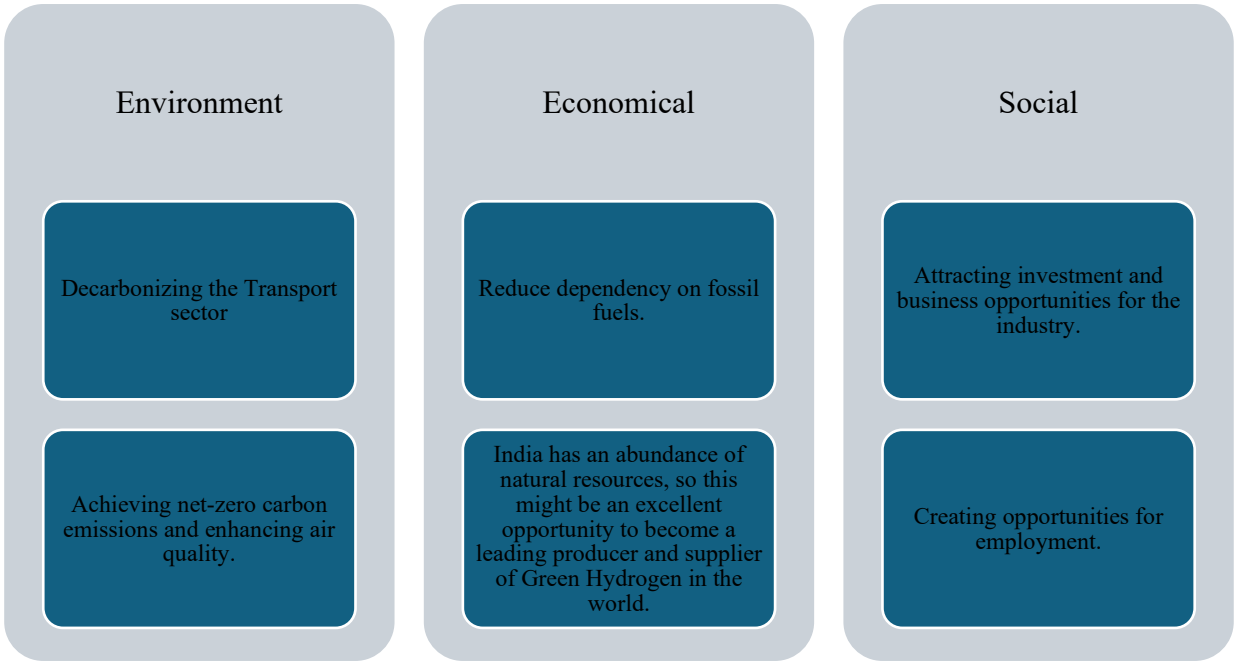

Figure 6. Benefits of introducing Green Hydrogen energy in the logistics sector

Conclusion:

India's logistics sector currently faces significant challenges, with logistics costs accounting for 13–14% of the country's GDP, much higher than the global average of 8–9%. Freight transport remains essential for economic growth, business development, and improving quality of life, but it is also a major contributor to CO_2 emissions. While railways offer more cost-effective logistics options, road transport continues to dominate both freight and passenger movement, leading to higher expenses and environmental concerns.

Introducing green hydrogen into India's logistics sector could bring a range of benefits, including environmental improvements, economic growth, and positive social impacts. Green hydrogen has the potential to reduce greenhouse gas emissions and lower dependence on imported fossil fuels, while also supporting India's broader goals of reducing logistics costs to 5% of GDP and achieving some Sustainable Development Goals, as well as net-zero emissions by 2070. Building a green hydrogen ecosystem supported by modern infrastructure and strong public-private partnerships can help India overcome financial losses in state transport units, attract global investment, and establish itself as a leader in sustainable logistics.

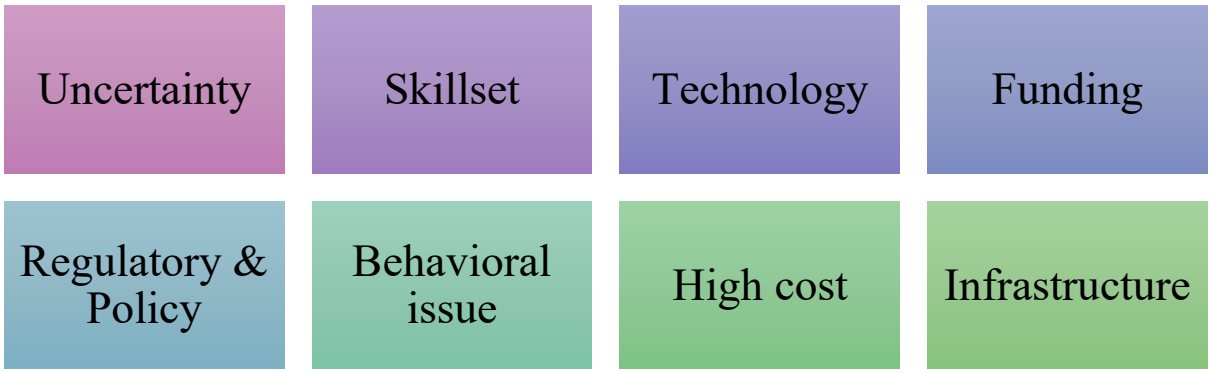

Figure 7. Challenges for implementing green hydrogen into the logistics sector

However, several challenges must be addressed to implement green hydrogen in logistics successfully. These include weather uncertainties, the need for skilled labor, technological advancements, behavioral barriers, funding constraints, infrastructure gaps, high initial costs, and regulatory and policy hurdles, such as:

Fluctuations in renewable energy supply due to weather conditions can impact hydrogen production.
Green hydrogen remains expensive compared to other fuel alternatives.
Building hydrogen-related infrastructure in densely populated urban areas is complex.
There are no clear guidelines or policies regarding green hydrogen infrastructure development.
Storage and transportation of hydrogen pose safety risks.
Societal reluctance to adopt new technologies adds another layer of difficulty.

In the future, there is a need to create strong policies and clear rules for producing, storing, and using green hydrogen. Apart from that, raising public awareness is also a critical step so that more people support green hydrogen technologies. The study also suggests that by working collaboratively, the government, research institutes, and private companies can speed up building the necessary technologies & infrastructure. Finally, the study suggests connecting green hydrogen with other renewable energy sources to make sure the supply remains steady and reliable.This study provides valuable insights for researchers and academics interested in road logistics and the development of green hydrogen-based multimodal transport networks. It highlights the importance of identifying key factors for optimizing logistics costs and efficiency, as well as the main challenges facing the sector. Future research can build on these findings by developing mathematical models to further enhance the performance and sustainability of India's logistics industry.

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Biographies:

Ms. Aarti Rana is a research scholar at the Department of Design, Indian Institute of Technology, Roorkee. She has completed his M.Tech from National Institute of Technology, Hamirpur. Her research interests are Green hydrogen, Logistics & Supply chain Management, and Machine learning.

Dr. Rajat Agrawal is a professor and head of the Department of Management Studies, Indian Institute of Technology, Roorkee, with joint faculty roles in the Department of Design and affiliations at the Center of Excellence for Disaster Mitigation and Management and the Center of Excellence for Transportation Management at IIT Roorkee. He has guided 15 Ph.D. theses, published over 100 research papers in esteemed journals, and more than 25 conference proceedings, and developed 20+ case studies spanning diverse subjects such as supply chain management, social entrepreneurship, and value co-creation. His academic contributions underscore his pivotal role in research, innovation, and education within the institution.

Research Interest*: Operations Management: Supply Chain Management, Quality Management, Inventory Management, Manufacturing Strategy, IPR, Innovation, Business Models, Entrepreneurship: IP Management, General Management: Indian Models of Management, Ethics in Management, Spirituality.