



# INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

## Green Growth And Energy Sustainability In Indian Railways: A Pathway To Environmental Stewardship

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### Abstract

The Indian Railways, recognised as the world's fourth-largest rail network and India's most extensive mode of mass transportation, plays a pivotal role in the country's economic development, social integration, and regional connectivity. However, it also significantly contributes to environmental degradation through unchecked waste generation and excessive fossil fuel consumption. This study investigates the multifaceted efforts of Indian Railways to transition toward a more sustainable, energy-efficient, and environmentally responsible system in alignment with India's broader climate goals. Drawing from government reports, legal frameworks, operational data, and institutional initiatives, the paper explores key challenges such as the generation of nearly 670 tonnes of solid waste daily, the uncontrolled disposal of plastic and human waste along railway tracks, and the environmental hazards arising from the use of over 2.7 billion gallons of diesel annually. Despite regulatory frameworks like the Solid Waste Management Rules (2016), compliance remains inconsistent due to gaps in infrastructure, inter-departmental coordination, and public engagement. In response, Indian Railways has adopted multiple green growth initiatives including the installation of more than 2,44,000

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bio-toilets across 69,000 coaches, deployment of plastic bottle crushing machines at over 370 stations, introduction of vacuum toilets, and experimentation with converting plastic waste into reusable construction materials. On the energy front, the paper documents IR's ambitious transition to renewable sources, highlighting the electrification of 58,812 km of track as of April 2023 and its growing renewable energy capacity, which currently stands at 220 MW with plans to scale up to 3,450 MW. These steps are projected to reduce transportation-related greenhouse gas emissions by up to 40%. The study further emphasizes the need for eco-smart interventions such as incentivized plastic disposal systems for passengers, AI-based waste monitoring, expanded CSR participation, and regular environmental audits. Ultimately, this research argues that Indian Railways is uniquely positioned to become a global model of sustainable public infrastructure. Its ongoing transformation reflects not only India's technological and administrative capabilities but also its commitment to achieving net-zero emissions and fostering inclusive green growth.

**Keywords:** Indian Railways, Environmental Sustainability, Green Growth, Solid Waste Management, Eco-smart Infrastructure, Net-Zero Emissions.

## 1. Introduction

Indian Railways (IR), often referred to as the "lifeline of India," is one of the largest and most intricate railway systems in the world, operating under a single management structure. With a route length exceeding 68,000 kilometres and daily operations involving more than 23 million passengers and over 12,000 trains, it serves as a critical pillar supporting India's economic growth, regional integration, and social mobility. Despite these achievements, the environmental implications of such a colossal operation are profound. Indian Railways faces formidable challenges concerning energy consumption, carbon emissions, waste management, and ecological degradation.

Historically, the expansion of the railway network has been instrumental in shaping India's economic landscape by connecting remote regions, enabling freight transport, and fostering industrialization. However, the byproducts of this success, pollution, unscientific waste disposal, and high fossil fuel dependency, have raised serious sustainability concerns. According to the Central Pollution Control Board and other studies, Indian Railways is responsible for generating an estimated 670 tonnes of solid waste daily, a substantial proportion of which includes plastic and human waste disposed of improperly along tracks and at stations. Moreover, reliance on diesel for traction has led to the annual consumption of over 2.7 billion gallons, positioning the Indian Railways as one of the highest consumers of fossil fuels within the country's transportation sector.

Recognizing the urgency of environmental stewardship, Indian Railways has embarked on an ambitious journey toward green growth and energy sustainability. Strategic initiatives have been launched, including widespread electrification of routes, deployment of renewable energy systems, installation of bio-toilets, and enhanced solid waste management practices. The target is to achieve net-zero carbon emissions by 2030, aligning with India's commitments under international climate frameworks. These initiatives are not merely technical adjustments but represent a paradigm shift in how Indian Railways conceptualizes its operational model, transitioning from a resource-intensive traditional framework to a sustainable, eco-smart infrastructure.

This paper seeks to critically examine the measures undertaken by Indian Railways to foster environmental sustainability and achieve green growth. It will explore the solid waste management strategies implemented across stations and coaches, assess the transition to renewable energy and electrification, and analyse the effectiveness of policy frameworks and technological interventions. By integrating evidence from government reports, academic research, and organizational case studies, the paper aims to provide a comprehensive evaluation of Indian Railways' sustainability journey. Furthermore, it will assess the challenges, opportunities, and potential pathways for deepening green initiatives to ensure that Indian Railways emerges not only as a transportation giant but also as a global exemplar of sustainable public infrastructure.

## 2. Need for the Research

The pursuit of sustainable development has placed unprecedented pressure on transportation systems globally to reassess their environmental impacts. In India, where rapid urbanization, industrialization, and economic growth continue to escalate energy demands, the transportation sector represents a critical frontier for climate action. Indian Railways, as one of the largest energy consumers and a major generator of solid waste within the public transport ecosystem, occupies a unique position in this discourse. While Indian Railways has historically played an essential role in promoting social equity and economic integration, its environmental footprint, manifested through greenhouse gas emissions, excessive fossil fuel reliance, and unsustainable waste disposal practices—has become increasingly incompatible with India's long-term climate goals, particularly its commitment to achieving net-zero carbon emissions by 2030.

Despite a series of reforms, policy interventions, and technological advancements, existing research on Indian Railways' sustainability initiatives remains fragmented, often focusing on isolated programs such as electrification or waste management in silos. A comprehensive, integrative analysis is necessary to evaluate how far Indian Railways has progressed towards creating a genuinely sustainable operational model and to identify the strategic gaps that must be addressed. Moreover, in the context of global climate change negotiations and India's nationally determined contributions (NDCs) under the Paris Agreement, it becomes imperative to understand the specific contributions of critical infrastructure systems like Indian Railways to national and global sustainability efforts.

Another dimension necessitating this research is the evolving nature of public expectations and stakeholder demands. Passengers, investors, policymakers, and environmental advocates increasingly expect large public institutions not only to deliver services efficiently but also to operate within frameworks of environmental stewardship, social responsibility, and transparent governance. Indian Railways, being a prominent symbol of public service in India, must not only respond to these expectations but also proactively position itself as a leader in sustainable mobility innovation.

Additionally, the literature on organizational turnaround, sustainability transitions, and green growth in public sector enterprises is relatively underdeveloped in the Indian context. Analysing Indian Railways' journey from a conventional resource-intensive enterprise to a sustainability-focused organization can offer valuable theoretical insights and practical lessons for similar transformations in other sectors. It also provides a fertile

ground for evaluating the interplay between regulatory compliance, technological innovation, financial restructuring, stakeholder engagement, and cultural change within large public institutions.

In light of these considerations, this research aims to fill the critical gap by offering a holistic assessment of Indian Railways' environmental sustainability strategies, evaluating the effectiveness of its green growth initiatives, and identifying pathways for deepening its contribution to India's sustainable development agenda. The findings of this study are expected to have significant implications for policymakers, railway administrators, environmental planners, and researchers engaged in the broader quest for building sustainable and resilient infrastructure systems in emerging economies.

### 3. Literature Review

Manimala (1991) discussed organizational turnaround through stage theory, providing a structured framework for analysing how public enterprises can recover from decline. His model, comprising crisis recognition, intervention, reorientation, and stabilization phases, is directly applicable to understanding Indian Railways' transition from financial stress to operational and environmental sustainability.

Expert Group on Indian Railways (2001) identified the financial distress and systemic inefficiencies plaguing Indian Railways at the turn of the century. The committee's comprehensive report recommended operational restructuring, improved asset utilization, customer-centric approaches, and financial discipline as critical strategies for ensuring long-term viability. It highlighted the need for energy optimization, cost control, freight sector reform, and commercialization of services, many of which laid the groundwork for later environmental sustainability initiatives.

Banister (2008) emphasized the emergence of the sustainable mobility paradigm, arguing that future transport systems must prioritize accessibility, energy efficiency, and emissions reduction over mere expansion. His study presents a conceptual framework integrating policy instruments like demand management, land use planning, and public transportation investments to achieve low-carbon mobility. Banister's work is foundational for understanding the theoretical underpinnings of green transportation transitions, including shifts necessary in public infrastructure sectors like Indian Railways.

Sharma and Manimala (2008) analysed the remarkable turnaround of Indian Railways (IR) using a stage theory framework. They argued that IR's recovery from near-bankruptcy was not merely a financial adjustment but a structured progression through stages: arresting sickness, reorientation, institutionalization, and growth. Their study highlighted strategies like enhancing freight capacity, reducing turnaround time, market-oriented reforms, public-private partnerships, and human resource mobilization. The analysis concluded that Indian Railways' turnaround was sustainable, driven by cultural change, leadership vision, stakeholder participation, and systematic operational improvements, positioning it as a unique model for large public sector organizations

OECD (2011) articulated the concept of "green growth," emphasizing that economic expansion can and must be decoupled from environmental degradation. The report offers a policy toolkit aimed at fostering investment in clean technologies, improving resource efficiency, and embedding environmental considerations into growth strategies, principles that underlie Indian Railways' sustainability initiatives.

The Central Pollution Control Board (2015) conducted an assessment of waste management practices across major railway stations in India, highlighting significant lapses in segregation, recycling, and scientific disposal. The report underscored that while waste generation from railway operations is substantial, institutional gaps and weak compliance with Solid Waste Management Rules hinder sustainability outcomes. It called for stronger monitoring mechanisms, infrastructure upgrades, and behavioural interventions among passengers and staff.

Guenther, Hueske, Kumar, and Parthasarathy (2017) investigated how Indian Railways utilized a self-evaluation tool for barrier analysis to advance green procurement practices. Their research revealed key organizational, external, and individual barriers hampering sustainable procurement, such as a lack of green alternatives in the market, insufficient legal frameworks, limited employee awareness, and fragmented organizational structures. Despite these challenges, their work demonstrated that awareness-raising workshops and barrier diagnostics led to important structural changes, including the establishment of new committees, policy frameworks, and greater management receptiveness to sustainability initiatives. The study highlights that proactive barrier analysis can facilitate organizational learning and sustainable transformation in large public-sector enterprises like Indian Railways.

Ali and Mir (2018) explored the multidimensional role of Indian Railways in advancing sustainable development through the integration of social, economic, and environmental pillars. Their analysis emphasized that rail transport is significantly more energy-efficient and eco-friendly compared to road transport, consuming six times less energy and generating lower environmental costs. The study highlighted Indian Railways' contributions to economic development by uniting fragmented markets, promoting industrial connectivity, and providing employment. Socially, the railways fulfil a "social service obligation" by offering passenger services below operational costs, thereby promoting equity. Environmentally, initiatives such as sapling plantations, renewable energy targets, polymer-based sleepers, and low-emission fuel systems were noted as evidence of its commitment to sustainability. The paper concluded that Indian Railways plays a central role in India's sustainable development agenda and must continue addressing energy, safety, and quality challenges to remain an inclusive and efficient transport system.

European Environment Agency (2019) examined sustainability transitions across transportation sectors in Europe, providing comparative insights into policy frameworks, technological adoption, and behavioural shifts. Successful strategies like electrified high-speed railways, the use of solar-powered stations, and circular economy practices in waste management offer applicable lessons for Indian Railways' green growth ambitions.

Gupta and Garg (2020) model India's transition to a low-carbon transport system and identify rail electrification as a key pathway. Their integrated assessment demonstrates how green railways can contribute to India's net-zero goals. The paper provides comparative energy efficiency metrics between rail and road transport.

Rodrigue (2020) explored the geography of transport systems, highlighting how infrastructural scale and complexity can influence environmental impacts. His work stresses that large transport networks must integrate

sustainability at the design, operational, and policy levels to achieve lasting environmental benefits, reinforcing the relevance of Indian Railways' green initiatives.

UN ESCAP (2021) offers a regional perspective on sustainable freight in Asia and highlights Indian Railways' potential as a decarbonization platform. It outlines financing mechanisms, policy bottlenecks, and international cooperation needed to advance modal shift toward low-emission rail freight.

Marik and Dutta (2023) focused on the energy consumption patterns of Indian Railways, identifying traction and non-traction activities as major energy consumers. Their study advocated for aggressive electrification, renewable energy adoption, and improved energy analytics to enhance operational efficiency and meet decarbonization targets. It positioned Indian Railways' energy strategy within the broader context of India's clean energy transition.

Pavković et al. (2023) examine global best practices in energy-efficient and safe railway systems. The review covers regenerative braking, hybrid trains, smart energy systems, and AI for predictive maintenance. Though global in scope, its relevance to Indian Railways lies in its benchmark technologies for sustainability adoption. Dutta and Marik (2023) analyse Indian Railways' long-term sustainability evolution. The paper focuses on institutional reforms, energy strategy, and decarbonization efforts, including electrification and solar deployments. It supports a comprehensive transformation narrative by detailing performance benchmarks and policy trends.

Chintala (2023) explores plastic waste management innovations in Indian Railways, proposing eco-smart waste-to-energy systems that address infrastructure constraints and plastic pollution. The study underscores the feasibility of decentralized plastic conversion units and the integration of renewable energy to power such systems. It offers practical technological pathways aligned with Indian Railways' circular economy ambitions. Kandpal et al. (2024) review the declining market share of Indian Railways in freight and recommend strategies for reclaiming modal dominance. Emphasis is placed on DFCs, last-mile linkages, and freight digitization. The study contributes to understanding how sustainability intersects with logistical modernization.

Prasad and Singh (2024) present a technical model for using solar-powered hydrogen to electrify Indian railway platforms. This aligns with India's green hydrogen roadmap and reflects emerging strategies to decarbonize non-traction energy systems in the railway sector.

Saranga et al. (2024) evaluate policy shifts in India's transport, energy, and agricultural sectors. The study frames Indian Railways as a pivotal actor in India's green industrial future, recommending investment incentives, R&D funding, and green procurement as scalable pathways.

#### **4. Theoretical Framework**

Understanding the sustainability transformation of Indian Railways requires an interdisciplinary framework that bridges organizational change, environmental economics, and sustainable mobility. This study draws on three foundational theories: Stage Theory of Organizational Turnaround, the Green Growth Framework, and the Sustainable Mobility Paradigm. These theoretical lenses are further contextualized using empirical studies

from recent literature that examine Indian Railways through the prisms of energy efficiency, freight logistics, life cycle sustainability, and public sector reform.

#### **4.1 Stage Theory of Organisational Turnaround**

Stage theory, originally articulated by Bibeault (1982) and later adapted by Manimala (1991), conceptualizes organizational recovery as a phased process: crisis recognition, intervention, reorientation, institutionalisation, and growth. This model was applied directly to Indian Railways by Sharma and Manimala (2008), who analysed the national carrier's remarkable turnaround between 2001 and 2008. They identified a sequence of strategic reforms including market-based freight pricing, enhanced asset utilisation, decentralisation, and cultural transformation under effective leadership. The turnaround was not merely financial, but structural, establishing a foundation for long-term sustainability.

In this study, stage theory is applied to financial recovery and Indian Railways' transition toward sustainability. As per Craven and Philippe (2017), railway-led climate initiatives—including electrification and modal shift, can be seen as part of a “reorientation” and “institutionalisation” phase of environmental transformation. These efforts signal a deep organizational change where sustainability is becoming embedded in the structure, strategy, and values of Indian Railways.

#### **4.2 Green Growth Framework**

The Green Growth theory proposed by the OECD (2011) advocates for economic development that simultaneously preserves environmental integrity. This framework is grounded in the idea that GDP growth and environmental sustainability are not inherently contradictory but can be synergized through technology, innovation, policy instruments, and resource efficiency. In the context of Indian Railways, this means reducing the ecological footprint of passenger and freight services while maintaining economic viability.

Garg and Kashav (2020) applied this logic in their FAHP-based evaluation of sustainability priorities in containerized freight. Their study emphasized that economic interventions like Dedicated Freight Corridors (DFCs), fuel substitution, and private partnerships improve efficiency and reduce emissions, thus serving dual green growth objectives. Similarly, Guenther et al. (2017) showed how green procurement in Indian Railways can align institutional practices with sustainability metrics, enabling resource optimization without compromising service delivery.

This framework also justifies government investment in rail-based infrastructure as a green multiplier, one that stimulates job creation, enhances connectivity, and reduces carbon dependency.

#### **4.3 Sustainable Mobility Paradigm**

Banister (2008) introduced the Sustainable Mobility Paradigm, emphasizing accessibility, equity, energy efficiency, and low emissions as key goals of future transport systems. This framework shifts the focus from expanding vehicle throughput to enhancing people's mobility in an ecologically and socially responsible way. Indian Railways aligns with this paradigm in several ways. According to Ali and Mir (2018), Indian Railways fulfils a social service obligation by offering subsidized passenger fares, thereby promoting equitable access. Moreover, its lower energy intensity and emission profile, as corroborated by Kapetanović et al. (2019), make

it a leading candidate for low-carbon transport transformation. Indian Railways' initiatives in renewable energy, zero-carbon corridors, and sapling plantations illustrate the mobility–sustainability nexus in practice. Craven and Philippe (2017) further linked rail development to multiple SDGs, including SDG 11 (Sustainable Cities), SDG 13 (Climate Action), and SDG 9 (Industry & Infrastructure). They advocate a modal shift from road to rail as essential to urban sustainability and climate mitigation.

#### 4.4 Framework Integration and Application

The integrated theoretical framework applied in this study combines Stage Theory, the Green Growth paradigm, and the Sustainable Mobility model to offer a multidimensional lens for analysing Indian Railways' sustainability journey. Stage Theory, particularly as adapted to public-sector transformation by Manimala (1991) and Sharma and Manimala (2008), provides a structured process of evolution, from crisis recognition through intervention and institutionalization to growth. This framework captures how Indian Railways' sustainability shift is not incidental but reflects a deeper organizational reorientation in its leadership, planning, and operations. Simultaneously, the Green Growth framework as articulated by the OECD (2011) offers an economic rationale for sustainability, showing how investment in electrification, renewable energy, waste management, and efficient freight can deliver both ecological and financial dividends. Garg and Kashav (2020) and Guenther et al. (2017) support this by demonstrating that sustainability-oriented reforms in energy systems and procurement practices can align environmental impact with cost-effectiveness. Complementing these is Banister's (2008) Sustainable Mobility Paradigm, which positions transportation systems not only as logistical mechanisms but as instruments for social equity, accessibility, and environmental resilience. Craven and Philippe (2017) and Kapetanović et al. (2019) affirm that Indian Railways' strategic importance lies in its capacity to simultaneously reduce emissions, ensure equitable access, and enhance urban sustainability. The convergence of these frameworks reveals that Indian Railways is undergoing a systemic shift, from operational modernization to strategic sustainability integration, grounded in theory, policy, and evidence.

### 5. Methodology

This study employs a descriptive and interpretive qualitative methodology, grounded in thematic analysis and guided by theoretical frameworks. The primary approach involves secondary data synthesis from a wide range of credible sources including academic journals, institutional reports, government publications, and working papers. Key documents include assessments by the Central Pollution Control Board (CPCB), reports from Indian Railways, peer-reviewed articles on energy efficiency and sustainability, and international frameworks such as those from the OECD and UNCRD.

The research further integrates case-specific insights from Indian Railways by analyzing sustainability initiatives, progress metrics, and implementation challenges. To guide the interpretation of evidence, three theoretical models were adopted: (i) Stage Theory of Organizational Turnaround to map the transformation of Indian Railways from crisis to sustainability; (ii) the Green Growth Framework to analyze the alignment of economic growth with environmental stewardship; and (iii) the Sustainable Mobility Paradigm to evaluate the role of the railway system in equitable, low-emission mobility.

In addition, content from visual media, such as charts and tables from institutional presentations, was extracted to enhance the analysis. The resulting synthesis is narrative in structure and evaluative in orientation, aimed at understanding the scope, impact, and gaps in Indian Railways' sustainability strategy.

### 6. Analysis and Discussion

Indian Railways (IR), a critical infrastructure institution in India, has undertaken a range of sustainability measures to align with national and international environmental goals. This section analyses key dimensions of IR’s sustainability efforts across energy, environment, operations, and institutional behaviour, contextualized through the theoretical framework and empirical studies discussed earlier.

#### 6.1 Solid Waste Management and Environmental Practices

Despite generating approximately 670 tonnes of solid waste daily, many railway stations continue to lack adequate waste segregation, recycling infrastructure, or end-of-life material management systems (CPCB, 2015). According to Guenther et al. (2017), this reflects institutional and market-level barriers to green procurement and waste minimisation.

Yet, progress is evident. Indian Railways has implemented:

- Installation of over 2,44,000 bio-toilets across coaches
- Use of plastic bottle crushers in 370+ stations
- Initiatives to convert plastic waste into construction materials like tiles and paver blocks

#### Progress of work related to solid waste management

Zonal Railway	Year	No. of waste to compost planned/sanctioned during the year	Cost of waste to compost plant sanctioned (Rs. Crore)	No. of waste to compost plant completed as on 31.03.2020	No. of Waste to Energy plant planned/sanctioned during the year	Cost of Waste to Energy plant (Rs. Crore)	No. of Waste to energy plant completed as on 31.03.2020
CR	2019-20	1	0.15	0	0	0.00	0
ER	2019-20	1	0.95	0	0	0.00	0
ECR	2018-19	0	0.00	0	1	1.02	0
	2019-20	5	0.08	0	1	0.92	0
ECoR	2019-20	13	1.13	1	1	2.01	1
NCR	2019-20	4	0.45	0	0	0.00	0
NER	2018-19	12	0.05	12	0	0.00	0
NFR	2019-20	0	0.00	0	1	0.79	1
NWR	2017-18	2	0.05	0	0	0.00	0
	2018-19	1	0.07	0	0	0.00	0
	2019-20	7	2.93	7	0	0.00	0

SR	2018-19	1	1.18	0	1	0.17	0
	2019-20	6	4.50	1	0	0.00	0
SCR	2019-20	3	0.15	1	0	0.00	0
SER	2017-18	2	0.37	2	0	0.00	0
	2018-19	0	0.00	0	0	0.00	0
	2019-20	18	4.31	1	0	0.00	0
SECR	2018-19	1	0.10	1	0	0.00	0
SWR	2018-19	1	0.02	1	0	0.00	0
WR	2017-18	2	0.50	2	0	0.00	0
	2018-19	1	0.00	0	0	0.00	0
	2019-20	2	0.76	1	0	0.00	0
WCR	2019-20	10	2.52	0	0	0.00	0
TOTAL		93 (14 Zones)	20.59	30	5	4.91	2

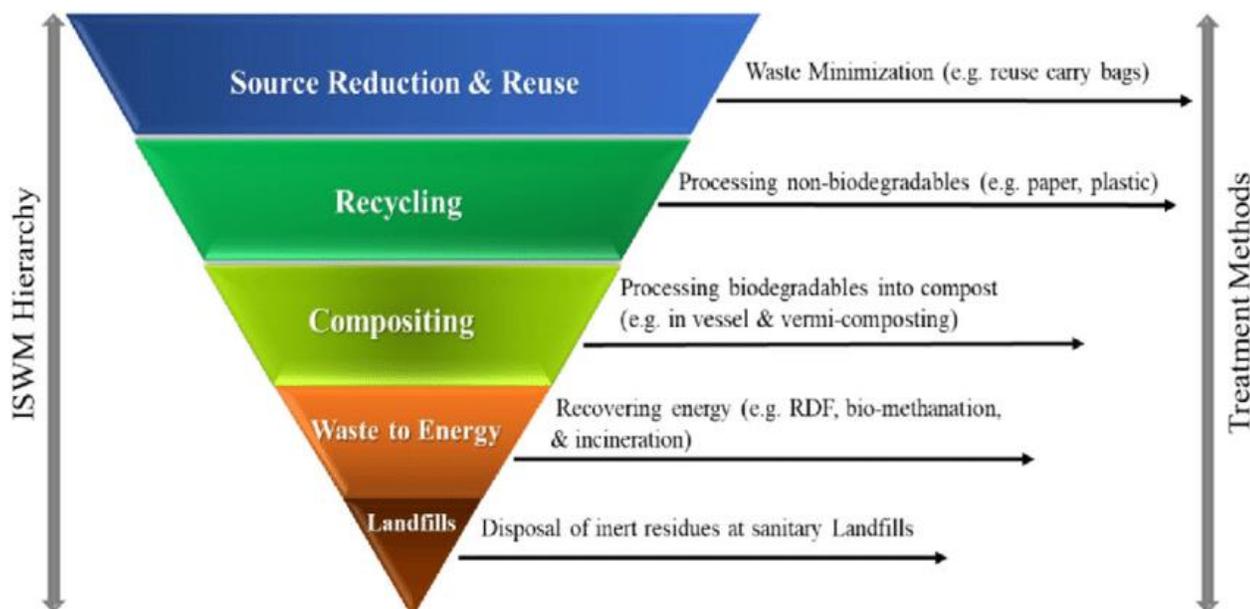
Source: Records of EnHM wing of the Zonal Railways/Production units

This figure highlights the status of key waste management efforts including bio-toilet installations, solid waste treatment facilities, and the deployment of segregated waste bins across stations. It visually reinforces the mixed progress in infrastructure and monitoring capacity that Indian Railways continues to address through green policy reforms

Still, compliance with the Solid Waste Management Rules (2016) remains inconsistent. Awareness among passengers, staff, and vendors is limited, and there is an absence of real-time digital waste tracking. To improve this, smart bins, AI-based monitoring, and decentralized recycling models are proposed under the Sustainable Mobility framework (Banister, 2008).

Waste hierarchy is the priority order in which the solid waste is to be managed by giving emphasis to prevention, reduction, reuse, recycling, recovery and disposal, with prevention being the most preferred option and disposal at the landfill being the least.

Figure 1: Waste Management Hierarchy as Applied to Indian Railways



## 6.2 Energy Consumption and Electrification

As of 2023, Indian Railways has electrified 58,812 km of its broad-gauge network, significantly reducing reliance on diesel. Yet, it remains one of the largest institutional consumers of energy in India, using:

- 18,410 million units for traction
- 2,338 million units for non-traction purposes (Marik & Dutta, 2023)

This transition is not merely operational—it aligns with the Stage Theory of Institutional Change (Sharma & Manimala, 2008). The reorientation phase has seen:

- Shift from diesel to electric and renewable traction
- Introduction of net-zero carbon corridors
- Electrification of routes in strategic corridors like Delhi–Mumbai and Delhi–Howrah

Furthermore, IR's adoption of energy-efficient locomotives, LED lighting, and smart meters reflects the growing institutionalization of energy reforms.

## 6.3 Renewable Energy and Green Growth Metrics

Indian Railways currently generates 220 MW from renewable sources and aims to expand this to 3,450 MW by 2030. Solar panels have been installed on station rooftops, trains (e.g., DEMU coaches), and administrative buildings. Wind energy integration is also underway in southern zones.

The Green Growth Framework (OECD, 2011) is visible in:

- Use of composite sleepers replacing timber
- Fuel-efficient CRDI systems in locomotives
- Carbon budgeting for zonal railways

As Garg & Kashav (2020) observed, aligning environmental outcomes with economic incentives, such as through Dedicated Freight Corridors (DFCs), enhances railways' overall sustainability.

### 6.4 Modal Shift and Freight Strategy

Railways' share of containerized freight is currently only ~18%, despite its lower emission profile (Garg & Kashav, 2020). Comparative LCA studies (Kapetanović et al., 2019) show that rail emits:

- 80% less CO<sub>2</sub> per tonne-km of freight
- 70% less CO<sub>2</sub> per passenger-km than road transport

To reclaim modal share from roadways, Indian Railways is:

- Expanding DFC networks
- Promoting roll-on/roll-off (RoRo) systems
- Offering logistics partnerships and cargo incentives

Yet, challenges remain in last-mile connectivity, turnaround time, and policy coordination across ministries.

### 6.5 Social Service Obligation and Equity

Indian Railways subsidizes many passenger routes, bearing a social service obligation of ₹25,000 crore annually (Ali & Mir, 2018). This fulfils its role under the Sustainable Mobility Paradigm, ensuring affordable access to mobility for marginalized populations.

Such subsidies contribute to:

- Passenger equity and national integration
- Employment for over 1.3 million workers
- Socioeconomic inclusion through connectivity

However, these obligations create a trade-off with capital for green investments. Balancing social equity with financial sustainability is essential.

### 6.6 Institutional Learning and Governance Transformation

According to Guenther et al. (2017), Indian Railways has begun integrating barrier analysis tools to identify institutional, policy, and market barriers in its green procurement strategies. Organizational learning, awareness campaigns, and training have led to:

- Creation of Green Committees in zones
- Revision of procurement guidelines to prioritize eco-friendly materials
- Inclusion of CSR-based waste and energy projects

Response under CSR Initiative				
Work Provided	Numbers	Division	Zone	Cost involved (in Rs. Crore)
Dustbins	1906	CSMT, Delhi, Agra, Mumbai Central, Vadodara & Waltair	CR, NR, NCR, WR, ECOR	0.86
Waste to Compost plant	10	Sealdah, Secunderabad, Central & Waltair	Bikaner, Mumbai, ER, NWR, SCR, WR, ECOR	

Trolleys	10	Bilaspur	SECR	0.05
Waste to Energy plant	1	Jaipur	NWR	0.91

This figure illustrates the growing role of CSR partnerships in addressing railway-based sanitation and waste infrastructure gaps. Corporate involvement has supported efforts such as the installation of bottle crushers, waste segregation systems, and renewable energy pilots at stations. It reinforces the importance of multi-stakeholder engagement in achieving scalable and decentralized sustainability outcomes.

These shifts illustrate the move from "intervention" to "institutionalization" in Stage Theory terms, confirming that sustainability is now embedded in IR's governance DNA.

### 6.7 Alignment with SDGs and Global Climate Goals

Craven and Philippe (2017) assert that railway development contributes to at least 7 of the 17 SDGs, especially:

- SDG 7: Affordable and Clean Energy
- SDG 9: Industry, Innovation, and Infrastructure
- SDG 11: Sustainable Cities and Communities
- SDG 13: Climate Action

By shifting from high-emission transport to electrified, renewable-driven railways, India can:

- Reduce transport emissions by 40%
- Improve air quality in 100+ urban centres
- Position itself as a global leader in sustainable infrastructure

Indian Railways has made notable progress across key sustainability domains, particularly in energy, waste management, freight operations, social responsibility, and governance. Electrification now covers over 58,000 kilometres of the broad-gauge network, and renewable energy generation has begun to expand, although reliance on diesel persists in select zones. Waste management initiatives such as bio-toilets, plastic repurposing units, and smart bin deployment are gradually transforming sanitation standards, yet challenges like inconsistent segregation and limited monitoring remain. In freight, reforms like Dedicated Freight Corridors and RoRo services are being implemented to improve efficiency and reduce emissions, though rail continues to lose market share to road transport due to last-mile connectivity issues. Socially, the Railways fulfill a significant inclusion role, offering subsidized services valued at ₹25,000 crore annually, but this places financial strain on modernization initiatives. Governance reforms, including green procurement policies and environmental committees, show increasing institutional commitment, yet implementation varies across zones and requires continued leadership support. Together, these efforts illustrate a maturing but uneven transition toward a more sustainable railway system.

## 7. Findings

The assessment of Indian Railways through the integrated lenses of green growth, organizational turnaround, and sustainable mobility reveals a multifaceted transformation toward sustainability. The findings can be categorized into environmental, economic, social, and institutional domains, reflecting the railways' role as a systemic enabler of sustainable development in India.

### 7.1. Environmental Sustainability is Transitioning from Compliance to Innovation

Indian Railways has significantly advanced beyond regulatory compliance to initiate innovative environmental interventions, including:

- Massive electrification (over 58,000 km),
- Deployment of over 2,44,000 bio-toilets,
- Renewable energy integration (targeting 3,450 MW),
- Waste repurposing for tiles and construction material.

These initiatives show alignment with the OECD's green growth framework and illustrate that Indian Railways is moving from reactive compliance to proactive ecological innovation. Yet, monitoring gaps and uneven implementation across zones remain challenges to system-wide ecological modernization.

### 7.2. Economic Sustainability is Strengthened through Electrification and Freight Reforms

Freight modernization strategies such as Dedicated Freight Corridors (DFCs), Roll-on/Roll-off logistics, and rationalization of freight classification have enabled energy-efficient bulk transport, as highlighted by Garg & Kashav (2020). Electrification and lower operating ratios in key sectors signal long-term cost savings. However, the shrinking modal share of rail in containerized freight (currently ~18%) underlines the need for logistics modernization and private investment.

### 7.3. Social Inclusion is Achieved at a Fiscal Cost

Indian Railways bears a ₹25,000 crore social service obligation annually to ensure affordable access to transport for marginalized communities. While this affirms its role in SDG 11 (Sustainable Cities and Communities) and aligns with the Sustainable Mobility Paradigm, it also limits capital availability for infrastructure modernization. Strategic balancing between equity and efficiency is essential for long-term resilience.

### 7.4. Railways' Role in SDGs is Expanding, But Not Yet Fully Quantified

The empirical work of Craven and Philippe (2017) suggests that Indian Railways directly contributes to at least 7 Sustainable Development Goals (SDGs). However, a standardized SDG audit or framework to evaluate its impact across zones does not yet exist. This represents a missed opportunity for performance benchmarking, donor engagement, and global collaboration.

### 7.5. Life Cycle Thinking is Emerging but Needs Institutional Mainstreaming

As per Kapetanović et al. (2019), life cycle assessment (LCA) frameworks that include upstream and downstream emissions are crucial for accurately understanding transport sustainability. Indian Railways is

beginning to consider these in new rolling stock procurement and electrification projects. However, LCA is not yet institutionalized in planning, budgeting, or vendor evaluation.

### **7.6. Organizational Change is Real, But Requires Broader Cultural Embedding**

Indian Railways has made tangible progress in governance, including the use of barrier analysis tools, green procurement policies, and the establishment of green committees (Guenther et al., 2017). These reflect a clear shift toward “institutionalization” in Stage Theory terms. Still, sustainability adoption is uneven across zones, and success depends heavily on leadership, training, and sustained political will.

### **7.7. Indian Railways is an Unparalleled Platform for Green Growth in Public Infrastructure**

The combined evidence across all reviewed studies positions Indian Railways as a strategic national asset for green transformation. No other public transport system in India has comparable reach, energy leverage, and social equity impact. However, unlocking its full sustainability potential will require:

- Strengthening private sector partnerships,
- Measuring cross-sectoral SDG impact,
- Enhancing life cycle integration in operations,
- Maintaining the balance between affordability and innovation.

## **8. Conclusion**

Indian Railways stands at a historic inflection point, no longer merely a symbol of connectivity and industrial might, but increasingly a cornerstone of India’s sustainability transformation. This research has demonstrated that Indian Railways is undergoing a deliberate and multifaceted evolution aligned with the principles of green growth, environmental stewardship, and social inclusion. Through electrification, renewable energy integration, waste minimization, and low-carbon freight initiatives, the Railways is emerging as a platform for achieving several of India's Sustainable Development Goals (SDGs), including climate action (SDG 13), clean energy (SDG 7), and inclusive infrastructure (SDG 9).

The theoretical framework employed in this study, drawing on Stage Theory, the Green Growth paradigm, and the Sustainable Mobility model, confirms that Indian Railways has moved beyond crisis management into an institutional phase of sustainability-oriented governance. From the deployment of barrier analysis tools for green procurement to the establishment of low-emission freight corridors, Indian Railways exemplifies a structured and strategic transition. However, uneven implementation, limited life cycle integration, and the continued tension between financial sustainability and social service obligations remain critical challenges.

The reviewed literature substantiates that while Indian Railways’ environmental interventions are commendable, they must now be scaled and embedded across all operational layers. Studies such as those by Craven & Philippe (2017), Garg & Kashav (2020), Kapetanović et al. (2019), and Guenther et al. (2017) underline the importance of systemic planning, inter-agency coordination, and capacity building to move from fragmented initiatives to integrated sustainability.

The road ahead involves deepening partnerships with the private sector, implementing standardized sustainability audits (especially for SDG alignment), expanding freight electrification, and adopting life cycle

thinking across all major procurement and infrastructure projects. Balancing equity, affordability, and innovation will be essential as Indian Railways continues to fulfil its social obligations while modernizing its energy and service delivery infrastructure.

Ultimately, Indian Railways is not just a national transporter, it is a national transformer. Its ability to align environmental, economic, and social goals positions it as a global exemplar of sustainable public infrastructure. By sustaining momentum, deepening reform, and embedding sustainability into its DNA, Indian Railways can lead India, and perhaps much of the developing world, into a greener, more inclusive future.

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