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Smart, Clean, Connected: Emerging Mobility Paradigms in India's Transportation Sector

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***Abstract*-- India's transportation sector is undergoing a rapid and multidimensional transformation driven by urbanization, technological innovation, and the imperative to reduce greenhouse gas emissions. This article examines the key trends shaping this transition such as electric vehicle (EV) adoption, intelligent transportation systems (ITS), multimodal integration, decarbonization pathways, and the emergence of smart infrastructure. Drawing on national policy frameworks, market developments, and recent research, the analysis highlights how India is leveraging digital mobility platforms, expanding metro and bus networks, and deploying smart road technologies to build more efficient and connected mobility systems. At the same time, persistent challenges, including institutional fragmentation, uneven public transport quality, infrastructure deficits, and disparities in access, continue to constrain progress. The article underscores the importance of integrating sustainability and equity into transport planning, given the sector's significant environmental impacts and the disproportionate burden borne by low-income and vulnerable populations. It concludes by outlining strategic policy directions to accelerate India's transition toward a smart, clean, and connected mobility future, emphasizing the need for coordinated governance, long-term investment, and inclusive, low-carbon transport solutions.**

***Keywords*-- Sustainable transportation; Electric mobility; Intelligent Transportation Systems; Digital mobility; Multimodal integration; Public transport modernization**

I. Introduction

India's transportation sector is undergoing a profound transformation driven by rapid urbanization, rising motorization, climate imperatives, and the accelerating adoption of digital technologies. With more than 1.4 billion people and one of the world's fastest-growing economies, India faces a dual challenge: meeting the mobility needs of a diverse and expanding population while simultaneously reducing congestion, emissions, and resource consumption. Traditional transport systems dominated by private vehicles, fragmented public transport, and infrastructure deficits are increasingly strained, prompting a national shift toward smarter, cleaner, and more connected mobility solutions.

Over the past decade, India has positioned transportation as a central pillar of its sustainable development agenda. Ambitious national programs such as FAME II, PM Gati Shakti, Bharatmala, and Smart Cities Mission have catalyzed investments in electric mobility, intelligent transportation systems, multimodal integration, and low-carbon infrastructure. These initiatives reflect a broader policy shift toward decarbonization, digitalization, and resilience aligning India's mobility transition with global climate commitments and national economic priorities.

Yet the path forward is complex. India's transport ecosystem is characterized by institutional fragmentation, uneven technological readiness, and significant disparities between urban and rural mobility systems. While electric two-wheelers and three-wheelers are scaling rapidly, the electrification of buses, freight, and private cars faces cost, infrastructure, and grid-capacity constraints. Similarly, ITS deployments and data-driven mobility platforms are expanding, but challenges persist around interoperability, governance, and long-term maintenance. Multimodal integration remains a policy priority, but operational coordination across agencies and modes continues to lag behind global best practices.

Against this backdrop, the article examines the key trends shaping India's mobility transition and the challenges that must be addressed to achieve a sustainable, technologically advanced, and socially inclusive transport future. By analyzing developments in EV adoption, ITS, multimodal integration, decarbonization pathways, and smart infrastructure, the paper highlights both the opportunities for India to leapfrog traditional mobility models and the systemic barriers that require coordinated policy, institutional reform, and strategic investment. Ultimately, India's ability to build a smart, clean, and connected transportation system will determine not only the efficiency of its mobility networks but also the environmental and economic resilience of the nation in the decades ahead.

II. Current Landscape Of India's Transportation Sector

India's transportation sector is marked by rapid growth, structural complexity, and significant modal imbalance.

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With rising incomes, expanding urban regions, and increasing freight demand, mobility patterns have shifted toward higher private vehicle ownership and road-based transport. Road transport accounts for nearly 90% of passenger traffic and over 60% of freight movement, placing substantial pressure on national and state highway networks (MoRTH, 2023). This road-dominant pattern has contributed to congestion, deteriorating air quality, and escalating greenhouse gas emissions, particularly in major metropolitan regions.

Urban mobility systems face acute challenges. Indian cities exhibit a high dependence on informal and paratransit modes, including auto-rickshaws, shared tempos, and minibuses, which fill critical service gaps but operate with limited regulation and inconsistent service quality (World Bank, 2023). Public transport supply especially city bus services has not kept pace with population growth. Many cities fall short of the benchmark of 60 buses per million population, with several operating at less than half that level (MoHUA, 2023). Metro rail systems have expanded rapidly, yet multimodal integration remains uneven, limiting seamless transfers and reducing system efficiency.

Rural mobility presents a contrasting picture. While national highway expansion under Bharatmala and state road development programs has improved connectivity, first-mile and last-mile access remains limited in many regions. Rural households often rely on two-wheelers, shared jeeps, and informal services, reflecting affordability constraints and limited public transport availability (ADB, 2022).

Institutionally, the sector is characterized by fragmentation. Responsibilities for planning, operations, land use, and enforcement are distributed across central ministries, state departments, municipal bodies, and parastatal agencies. This fragmentation complicates coordinated decision-making, slows project implementation, and hinders integrated mobility planning (World Bank, 2023). Data availability and governance also remain inconsistent across jurisdictions, affecting the deployment of intelligent transportation systems and evidence-based planning.

Despite these challenges, India is experiencing a period of accelerated transformation. National initiatives such as PM Gati Shakti, Smart Cities Mission, and National Electric Mobility Mission Plan are pushing the sector toward digitalization, multimodal integration, and sustainability. The rapid growth of electric two-wheelers and three-wheelers, expansion of metro networks, and deployment of Integrated Command and Control Centres (ICCCs) signal a shift toward more technologically advanced and environmentally conscious mobility systems (MoHUA, 2022; IEA, 2023).

However, realizing a fully smart, clean, and connected transport ecosystem will require addressing persistent gaps in infrastructure, governance, and service delivery.

III. EV Adoption And Electrification Trends

India's electric mobility transition has accelerated significantly over the past five years, driven by strong policy support, declining battery prices, and rapid uptake of electric two-wheelers and three-wheelers. The country's EV market reached record sales in 2023, with electric two-wheelers and three-wheelers accounting for the majority of adoption due to their lower upfront costs, shorter charging requirements, and suitability for urban and peri-urban mobility (IEA, 2023). These segments have become the backbone of India's early electrification trajectory, supported by targeted incentives under the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme.

3.1 Growth Across Vehicle Segments

Electric two-wheelers have emerged as the fastest-growing segment, supported by subsidies, rising fuel prices, and the expansion of domestic manufacturing under the Production-Linked Incentive (PLI) scheme. Electric three-wheelers particularly e-rickshaws have also seen widespread adoption, especially in northern and eastern states, where they provide affordable last-mile connectivity (SMEV, 2023). In contrast, the electrification of private cars remains limited due to higher upfront costs, limited model availability, and range concerns, though the segment is expected to grow as battery prices continue to fall.

Electric buses represent a critical component of India's public transport decarbonization strategy. Several cities including Delhi, Bengaluru, and Mumbai have initiated large-scale procurement of electric buses through FAME II and state-level programs. However, deployment remains uneven, with many transit agencies facing challenges related to financing, depot electrification, and long-term operations and maintenance (NITI Aayog, 2022).

3.2 Charging Infrastructure and Grid Readiness

Charging infrastructure development has expanded but remains insufficient relative to projected EV demand. Public charging stations have grown rapidly, yet coverage is concentrated in major metropolitan areas and along select national highways (MoHUA, 2023). Slow-charging solutions dominate, while fast-charging networks are still emerging. Grid readiness presents another challenge, particularly in dense urban areas where distribution networks may require upgrades to support large-scale electrification (IEA, 2023).

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Innovative models—such as battery swapping, community charging, and fleet-based charging hubs—are gaining traction, especially for commercial two- and three-wheelers. These models help address range anxiety, reduce downtime, and lower upfront costs for operators.

3.3 Policy Drivers and Market Enablers

India's EV transition is strongly shaped by national and state-level policies. FAME II has provided demand incentives for electric two-wheelers, three-wheelers, buses, and charging infrastructure, while the PLI scheme has catalyzed domestic manufacturing of advanced chemistry cell (ACC) batteries and EV components (Ministry of Heavy Industries, 2023). Many states—including Maharashtra, Delhi, Tamil Nadu, and Karnataka—have introduced EV policies offering purchase incentives, tax exemptions, and manufacturing subsidies.

These policy frameworks have created a favorable environment for investment, with global and domestic manufacturers expanding production capacity and supply chains. However, long-term policy stability, harmonization across states, and clear recycling and end-of-life regulations remain essential to sustaining momentum (NITI Aayog, 2021).

3.4 Key Barriers to Scaling Electrification

Despite strong progress, several barriers continue to constrain India's EV transition. High upfront costs particularly for electric cars and buses remain a major obstacle, even with subsidies. Charging infrastructure gaps, grid constraints, and limited availability of fast-charging options hinder widespread adoption. Supply chain vulnerabilities, including dependence on imported battery materials, pose additional risks (IEA, 2023). Behavioral factors, such as range anxiety and limited consumer awareness, also influence adoption patterns.

Addressing these challenges will require coordinated action across policy, industry, utilities, and urban transport agencies. Strengthening domestic manufacturing, expanding charging networks, and integrating EVs into broader decarbonization and mobility planning will be critical to achieving India's long-term electrification goals.

IV. Intelligent Transportation Systems (ITS) and Digital Mobility

India's transportation sector is undergoing a rapid digital transformation, driven by the deployment of Intelligent Transportation Systems (ITS), real-time data platforms, and integrated digital mobility services. These technologies are reshaping how cities manage traffic, deliver public transport services, and coordinate multimodal travel.

While progress has been significant, challenges related to interoperability, data governance, and institutional capacity continue to shape the pace and effectiveness of ITS adoption.

Over the past decade, Indian cities have increasingly adopted ITS solutions to address congestion, safety, and operational inefficiencies. Integrated Command and Control Centres (ICCCs), developed under the Smart Cities Mission, now operate in more than 100 cities and serve as hubs for real-time monitoring of traffic, public transport, and emergency response systems (MoHUA, 2022). These centers integrate CCTV networks, adaptive traffic signals, GPS-enabled bus tracking, and incident management systems, enabling more coordinated and data-driven decision-making.

Adaptive traffic control systems (ATCS) have been deployed in cities such as Bengaluru, Delhi, and Pune, resulting in measurable improvements in travel times and intersection performance (World Bank, 2023). However, deployment remains uneven, with many medium-sized cities lacking the institutional and technical capacity to implement and maintain advanced ITS infrastructure.

V. Multimodal Integration and Public Transport Modernization

Multimodal integration has emerged as a central priority in India's mobility transition, reflecting the need to create seamless, efficient, and user-friendly transport networks across rapidly growing urban regions. As cities expand and mobility patterns diversify, the limitations of fragmented public transport systems characterized by disconnected modes, inconsistent service quality, and limited last-mile connectivity have become increasingly evident. National and state-level initiatives now emphasize integrated planning, unified ticketing, and modernization of public transport fleets to improve accessibility, reduce congestion, and support decarbonization goals.

5.1 Metro–Bus–Paratransit Integration

India's metro rail systems have expanded rapidly, with operational networks in more than 15 cities and several more under construction. However, the effectiveness of metro systems depends heavily on their integration with feeder services, particularly buses and paratransit. In many cities, poor physical integration, lack of coordinated schedules, and fragmented institutional responsibilities limit seamless transfers (World Bank, 2023). While some metros such as Delhi and Bengaluru have introduced dedicated feeder buses and improved station-area planning, integration remains inconsistent across the country.

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Paratransit modes, including auto-rickshaws and e-rickshaws, continue to play a critical role in last-mile connectivity. Yet their integration into formal planning frameworks is limited, resulting in operational inefficiencies and congestion around major transit hubs (ITDP India, 2022). Formalizing and regulating these services, while maintaining their flexibility, remains a key challenge.

5.2 Unified Ticketing and the National Common Mobility Card (NCMC)

Digital integration has advanced through the rollout of the National Common Mobility Card (NCMC), an open-loop payment system designed to enable seamless travel across metro, bus, and other public transport modes. Several metro systems including Delhi, Mumbai, and Kochi have adopted NCMC-compliant systems, and bus agencies are gradually transitioning to open-loop ticketing (MoHUA, 2023). Unified ticketing reduces friction for passengers, supports multimodal trip planning, and enhances data collection for transport agencies.

However, widespread adoption remains uneven due to legacy fare systems, limited digital infrastructure, and varying levels of institutional readiness. Achieving full interoperability across states and operators will require coordinated policy action and sustained investment.

5.3 First- and Last-Mile Connectivity Innovations

First- and last-mile connectivity remains one of the most significant barriers to effective multimodal integration. Many metro and bus stations lack safe pedestrian access, dedicated cycling infrastructure, or organized feeder services. Recent initiatives including public bike-sharing systems, e-scooter pilots, and improved pedestrian infrastructure have begun to address these gaps (ADB, 2022). Cities such as Pune and Chennai have implemented non-motorized transport (NMT) plans that prioritize walking and cycling, though implementation varies widely.

Emerging Mobility-as-a-Service (MaaS) platforms offer potential for integrated trip planning and payment, but large-scale deployment is still in early stages. Ensuring equitable access to these services will require attention to affordability, digital literacy, and geographic coverage.

5.4 Modernization of Public Transport Fleets

Public transport modernization is accelerating, particularly through the electrification of bus fleets. Under FAME II and state-level programs, several cities have procured electric buses, improving service quality while reducing emissions (NITI Aayog, 2022). Modern buses equipped with GPS, CCTV, and passenger information systems enhance reliability and safety.

However, many transit agencies face challenges related to financing, depot electrification, and long-term operations and maintenance.

Metro systems continue to expand, supported by national funding and state partnerships. Yet the financial sustainability of metro operations remains a concern, particularly in smaller cities where ridership levels may not meet projections (World Bank, 2023).

VI. Decarbonization Pathways

India's transport sector is a major contributor to national greenhouse gas emissions, accounting for nearly 14% of energy-related CO_2 emissions, with road transport responsible for the overwhelming majority (IEA, 2022). Decarbonizing this sector is therefore central to achieving India's updated Nationally Determined Contributions (NDCs) and long-term low-emission development strategy. A combination of **modal shift**, **vehicle electrification**, **alternative fuels**, and **logistics optimization** forms the core of India's decarbonization pathways.

6.1 Modal Shift and Demand Management

Shifting travel from private vehicles to public transport, walking, and cycling is one of the most cost-effective decarbonization strategies. Investments in metro rail, bus rapid transit (BRT), and non-motorized transport infrastructure can significantly reduce per-capita emissions, especially in dense urban areas (ADB, 2022). Demand management tools such as congestion pricing, parking reforms, and transit-oriented development are increasingly recognized as essential to reducing vehicle kilometers traveled (VKT) (World Bank, 2023).

6.2 Electrification of Transport

Electrification remains the most significant long-term pathway for reducing emissions from road transport. India's EV transition is accelerating, particularly in the two-wheeler, three-wheeler, and bus segments, supported by FAME II, state EV policies, and the Production-Linked Incentive (PLI) scheme (Ministry of Heavy Industries, 2023). As the grid becomes cleaner through renewable energy expansion, the emissions benefits of EVs will increase further. However, large-scale electrification requires substantial investment in charging infrastructure, grid upgrades, and battery manufacturing (NITI Aayog, 2021).

6.3 Alternative Fuels: Biofuels and Green Hydrogen

Alternative fuels offer complementary decarbonization pathways, particularly for heavy-duty vehicles and long-distance freight.

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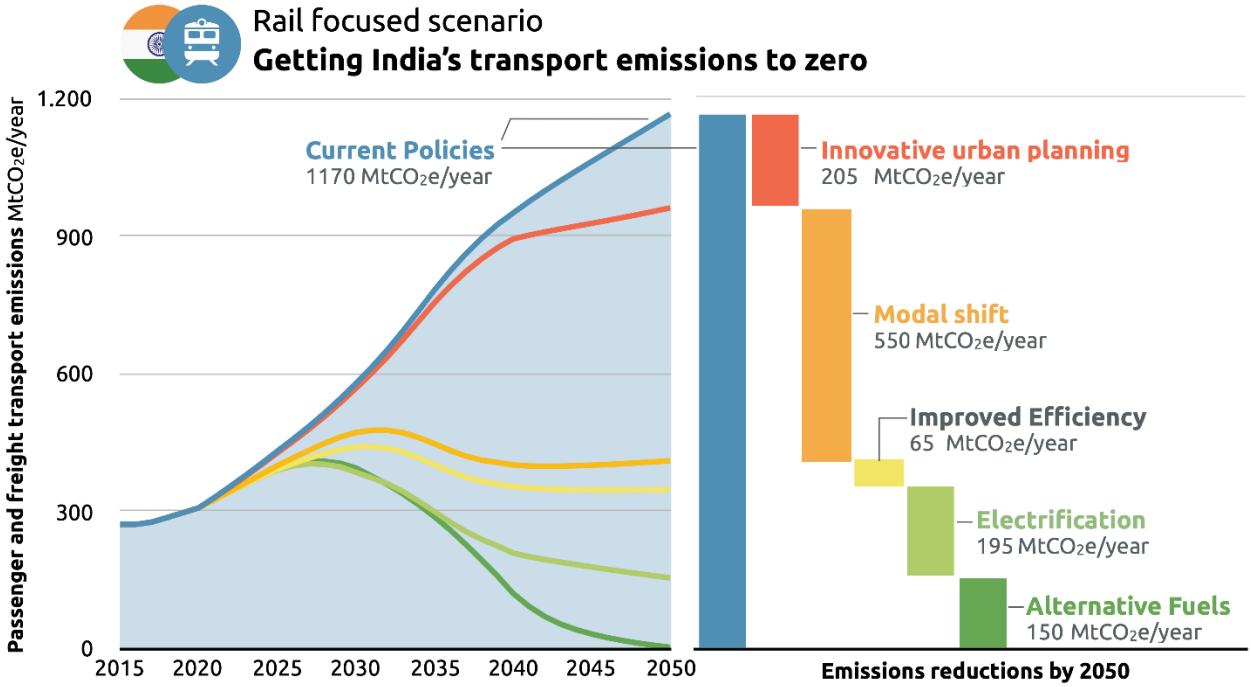
India has expanded ethanol blending targets and is promoting compressed biogas (CBG) under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative (MoPNG, 2022).

Green hydrogen is emerging as a long-term solution for heavy trucks, buses, and industrial logistics, though cost and infrastructure barriers remain significant (IEA, 2022).



Source: Climate Action Tracker, 2020

Figure 1. Climate Action Tracker's Rail Focused Scenario to Getting India's Transport Emissions to Zero

International Journal of Recent Development in Engineering and Technology
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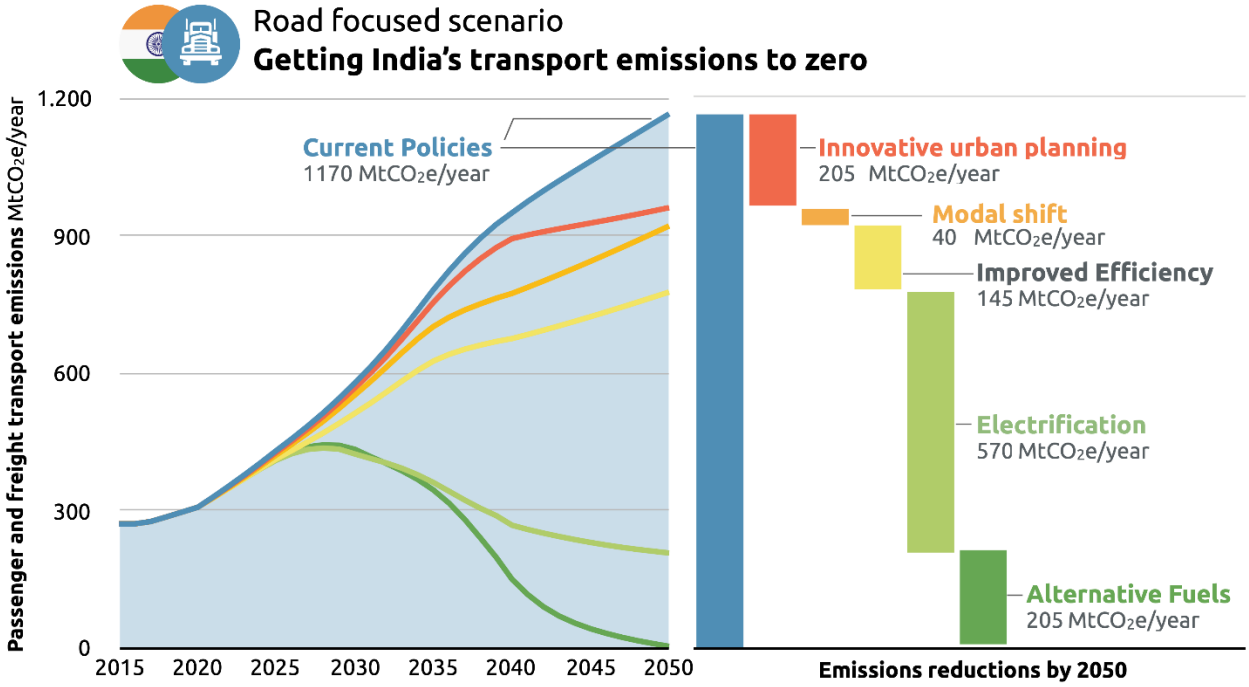

Source: Climate Action Tracker, 2020

Figure 2. Climate Action Tracker's Road Focused Scenario to Getting India's Transport Emissions to Zero

VII. Smart Infrastructure And Technology-Enabled Asset Management

Smart infrastructure is becoming a cornerstone of India's mobility modernization agenda, enabling more efficient operations, predictive maintenance, and data-driven planning. Digital technologies including sensors, IoT devices, digital twins, and advanced analytics are transforming how transport assets are monitored, managed, and optimized.

7.1 Smart Roads and Sensor-Based Monitoring

Several Indian cities and highway authorities are deploying smart road technologies such as automated traffic counters, weigh-in-motion systems, pavement condition sensors, and real-time incident detection (NHAI, 2023). These systems improve safety, reduce congestion, and support proactive maintenance. On national highways, FASTag-enabled tolling has streamlined traffic flow and generated valuable mobility data for planning (MoRTH, 2023).

7.2 Digital Twins and Predictive Maintenance

Digital twin technology, virtual replicas of physical infrastructure, is increasingly used for planning and asset management.

Cities such as Surat and Bengaluru have piloted digital twin platforms to simulate traffic patterns, evaluate infrastructure investments, and optimize maintenance schedules (MoHUA, 2022). Predictive maintenance, enabled by IoT sensors and machine learning, helps reduce lifecycle costs and prevent infrastructure failures.

7.3 Smart Public Transport Infrastructure

Public transport modernization includes the deployment of GPS-enabled buses, automated fare collection systems, real-time passenger information systems, and integrated operations control centers. These technologies improve reliability, safety, and user experience (ITDP India, 2022). Metro systems are adopting advanced signaling, platform screen doors, and energy-efficient rolling stock to enhance operational efficiency.

7.4 Integration with PM Gati Shakti and National Digital Platforms

The PM Gati Shakti National Master Plan provides a unified digital platform for integrated infrastructure planning across transport, logistics, and utilities. By consolidating geospatial data from multiple ministries, the platform supports coordinated decision-making and reduces project delays (Government of India, 2021).

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Integration of smart infrastructure with national digital platforms such as the India Urban Data Exchange (IUDX) is enabling more interoperable and scalable solutions (World Bank, 2023).

7.5 Challenges and Future Directions

Despite progress, several challenges persist. Many cities lack the technical capacity and financial resources to deploy and maintain advanced digital systems. Data governance, cybersecurity, and interoperability remain major concerns, particularly as infrastructure becomes increasingly connected (MoHUA, 2023). Ensuring equitable access to smart mobility services will require careful planning and inclusive design.

Nonetheless, India's rapid digitalization, expanding metro and bus networks, and national initiatives provide a strong foundation for scaling smart infrastructure. Continued investment in digital platforms, capacity building, and integrated planning will be essential to realizing a resilient, efficient, and future-ready transport system.

VIII. Sustainability, Equity, And Environmental Impacts

Sustainability and equity considerations are central to India's transport transition, given the sector's significant environmental footprint and the uneven distribution of mobility benefits across regions and socioeconomic groups. Transport emissions have risen sharply due to rapid motorization, with road transport accounting for 94% of transport-related CO_2 emissions (Dawda, 2024). This has contributed to worsening air quality in major cities, where particulate matter ($PM_{2.5}$) levels frequently exceed national and WHO standards. The environmental burden is disproportionately borne by low-income communities living near major roads, freight corridors, and industrial clusters.

Equity challenges are also evident in access to mobility. While wealthier households increasingly rely on private vehicles, low-income and marginalized groups depend on overcrowded buses, informal paratransit, and non-motorized modes. Limited first- and last-mile connectivity, inadequate pedestrian infrastructure, and safety concerns further restrict mobility for women, children, and the elderly (TERI, 2021). Ensuring equitable access requires integrating social inclusion into transport planning, prioritizing affordable public transport, and improving non-motorized transport infrastructure.

Sustainability also encompasses resource efficiency and climate resilience. India's transport infrastructure is vulnerable to extreme weather events such as flooding, heatwaves, and landslides which disrupt mobility and disproportionately affect vulnerable populations. Building resilient, low-carbon transport systems is therefore essential to long-term sustainability.

IX. Key Challenges

India's transport transition faces several structural, financial, and institutional challenges. Rapid motorization continues to outpace infrastructure development, with registered vehicles increasing from 115 million in 2009 to nearly 296 million in 2019 (Dawda, 2024). This growth exacerbates congestion, emissions, and road safety risks.

Institutional fragmentation remains a major barrier. Responsibilities for planning, operations, and enforcement are distributed across multiple agencies, leading to coordination gaps and inconsistent implementation of policies (WRI India, 2024). Financial constraints further limit the ability of cities to modernize public transport fleets, expand metro networks, and maintain ITS infrastructure.

Decarbonization challenges include slow electrification of heavy-duty vehicles, limited charging infrastructure, and dependence on imported battery materials. Scenario analyses show that electrification alone could reduce transport CO_2 emissions by 57% by 2050, but only under high-ambition policy pathways (WRI India, 2024). Achieving deeper reductions requires modal shift, fuel efficiency improvements, and clean energy integration.

Equity and affordability also pose challenges. Without targeted subsidies and inclusive planning, low-income groups risk being excluded from emerging mobility solutions. Ensuring that sustainable transport investments benefit all segments of society remains a critical policy priority.

X. Policy Recommendations

India's transport decarbonization and modernization agenda requires coordinated, multi-level policy action. Based on current evidence, three strategic directions emerge:

10.1 Strengthen Integrated, Low-Carbon Mobility Planning

Policies should prioritize modal shift toward public transport, walking, and cycling. Integrated land-use and transport planning, transit-oriented development, and congestion management can significantly reduce vehicle kilometers traveled (Climate Action Tracker, 2020).

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10.2 Accelerate Electrification and Clean Energy Integration

Scaling EV adoption requires expanding charging infrastructure, supporting domestic battery manufacturing, and electrifying public transport fleets. Electrification should be paired with rapid decarbonization of the power sector to maximize emissions reductions (TrafficInfraTech, 2025).

10.3 Enhance Institutional Capacity and Governance

Strengthening Unified Metropolitan Transport Authorities (UMTAs), improving data governance, and ensuring interoperability across ITS platforms are essential for efficient mobility management. Long-term funding mechanisms and public-private partnerships can support sustainable infrastructure investments (TERI, 2021).

10.4 Promote Equity and Inclusive Mobility

Policies must ensure that sustainable mobility solutions remain affordable and accessible. Investments in safe pedestrian infrastructure, women-friendly transport design, and rural connectivity are critical to achieving equitable outcomes (Dawda, 2024).

XI. Conclusions

India stands at a pivotal moment in its transportation transition. The country's rapid urbanization, rising mobility demand, and growing climate commitments have created both urgency and opportunity for reimagining how people and goods move. Across the preceding sections, this article has shown that India's transport sector is undergoing a profound transformation driven by electrification, digitalization, multimodal integration, and the expansion of smart infrastructure. These shifts reflect a broader national ambition to build mobility systems that are not only efficient and technologically advanced but also sustainable, inclusive, and resilient.

Yet the transition is far from straightforward. Persistent challenges including institutional fragmentation, uneven public transport quality, infrastructure deficits, and disparities in access continue to shape mobility outcomes. Decarbonization pathways offer significant potential, but achieving deep emissions reductions will require coordinated action across sectors, long-term policy stability, and substantial investment in clean energy, public transport, and logistics modernization. Similarly, the promise of intelligent transportation systems and digital mobility can only be realized through robust data governance, interoperability, and strengthened institutional capacity.

Despite these barriers, India's trajectory is one of momentum and possibility. National initiatives such as FAME II, PM Gati Shakti, and the Smart Cities Mission have laid a strong foundation for integrated, technology-enabled mobility systems. The rapid uptake of electric two- and three-wheelers, expansion of metro networks, and deployment of digital platforms signal a shift toward a more connected and environmentally conscious transport ecosystem. Importantly, the growing emphasis on equity and sustainability ensures that the mobility transition is not only technologically driven but also socially grounded.

Looking ahead, India's ability to build a smart, clean, and connected transportation future will depend on sustained political commitment, cross-sectoral collaboration, and inclusive planning. By aligning infrastructure investments with climate goals, strengthening governance frameworks, and prioritizing accessible public transport, India can chart a path toward a mobility system that supports economic growth while safeguarding environmental and social well-being. The choices made today will shape the nation's mobility landscape for decades, offering a unique opportunity to create a transport system that is efficient, equitable, and resilient for all.

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