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Review

Decarbonisation of Road Transportation in India—A Round-Robin Review on Low-Carbon Strategies and Financial Policies

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Abstract: India is committed to becoming a net-zero emitter by 2070 to fight climate change; however, road transportation causes a major challenge for decarbonising transport in India. This paper investigates the low-carbon strategy and implementation of fiscal and financial policies in India. The research delves into the innovative strategies to address unique regional hurdles and transportation demands. These strategies include customised policies to incentivise EVs, creating charging infrastructure networks, the integration of renewable energy sources in public transport systems, and the formulation of specific regulations to curb emissions from high-traffic areas. Findings from the review of low-carbon strategies and financial policies in road transportation advocate for penalising high-emitters, subsidising clean technology, and reorienting government expenditure towards sustainable infrastructure for combating climate change and adhering to India's commitment announced at COP26. This paper suggests the efficacy and replicability of these new strategies, thus, providing valuable insights to policymakers and stakeholders for creating a more sustainable and efficient road transportation network in India.

Keywords: decarbonisation; greenhouse gasses; electric vehicles; financial policies; low-carbon strategy

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1. Introduction

The transport sector is one of the largest contributors to global greenhouse gas (GHG) emissions, accounting for nearly 24% of global carbon dioxide (CO_2) emissions [1]. India is currently the world's fourth-largest emitter of GHGs despite being below the worldwide average of per capita emissions. The transport sector contributed 12.9% of CO_2 emissions in India in 2007 [2]. The CO_2 emissions from the transport sector have increased to 14% during the last two decades, causing adverse impacts on air quality, public health, and sustainable urban development [2]. The road and aviation industries are contributing 94.5% and 2.9% of total CO_2 emissions from the transport sector, respectively [3]. Trucks and lorries contribute 25% of the total vehicular emissions in India, of which 28.8% is CO_2, 39% is Nitrogen Oxide (NOx), 27.3% is Sulphur dioxide (SO_2), and 25% is particulate matter (PM), respectively [3]. The two-wheelers are a major source of carbon monoxide (23.7%), methane (46.4%), and hydrocarbon (64.2%), while buses contribute to NOx (30.7%) and PM (20.5%) emissions in India [3].

The decarbonisation of road transportation is crucial for meeting global climate targets, particularly those outlined in the Paris Agreement. India has pledged in the 2015 Nationally Determined Contribution (NDC) to reduce the intensity of GHG emissions by 33–35% to the 2005 emission level [4]. The NDC also aims to generate 40% of electricity from renewable or nuclear energies by 2030. India has demonstrated a longstanding commitment to

address climate change, hosting the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change in 2002. The National Action Plan on Climate Change (NAPCC) recognises the challenges of reducing GHG emissions from the transport sector and initiated various measures to reduce the GHG emissions In the sector, such as creating an enabling policy environment at the national level to develop a sustainable transport system and enhance cities' capacity to improve mobility while reducing GHG emissions. The NAPCC designed two interventions to achieve these goals: the development of a national action plan for low-carbon transport and the design of low-carbon mobility plans (LCMP) for major cities in India, coordinated by the Ministry of Urban Development, Ministry of Environment and Forests, and other relevant Indian ministries. Implementation of the programme is carried out by the United Nations Environment Programme (UNEP) Transport Unit and the UNEP Risø Centre, in collaboration with key local partners such as the Indian Institute of Management, Ahmedabad, Indian Institute of Technology, Delhi, and the CEPT (Centre for Environmental Planning and Technology) University. The government of India (GoI) invested 100 billion Indian Rupee (INR) to subsidise the purchase of new electric vehicles and the installation of charging infrastructure as part of the second phase of the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) plan [5]. The electric buses are in operation in many Indian cities including Delhi, Bengaluru, and Kolkata [6]. The GoI is also offering incentives to scrape old vehicles under the car scrappage programme and has introduced the emission standard known as Bharat Stage VI (BS-VI) since April 2020, aligning with the Euro-6/VI standard [7].

Despite the low-carbon strategies and financial policies of the GoI, India is observing a slow growth of decarbonisation in the transport sector. India is highly dependent on fossil fuels, urging concerted efforts to shift towards a stable and reliable supply of cleaner fuels. The decarbonisation of the transport sector not only faces the challenges of inadequate infrastructure investment and financing but also domestic manufacturing capacity of advanced EV technologies, policy framework balancing the interests of stakeholders and consumer behaviour towards eco-friendly transport systems, and regional disparities in priorities and challenges. This paper reviews the national and regional low-carbon strategies and fiscal and financial policies for low-carbon transportation of the GoI. This paper proposes long- and short-term strategies to overcome the challenges in implementing road transportation decarbonisation in India.

2. Literature Review

Several studies have explored the link between trade expansion and transport emissions in India. Kumar et al. [8] highlight that increased international and domestic trade has resulted in a surge in freight movement, raising emission levels. The shift from rail to road transport for goods movement has exacerbated the problem due to the lower energy efficiency of road transport compared to rail [9]. Furthermore, port activities and logistics hubs have contributed significantly to emissions through increased fuel combustion and congestion [10]. Cristea et al. [11] observed that the government policies on total tariff liberalisation and growth of GDP have significantly accelerated the GHG emissions from the transport sector in China and India faster than the trade value due to trade shifting towards distant trading partners.

The technologies that improve the carbon intensity of energy and energy efficiency of transportation modes are vital. Studies indicate that EVs powered by low-carbon electricity can significantly cut lifecycle emissions compared to internal combustion engine (ICE) vehicles [12]. Improvements in battery technology, charging infrastructure, and grid integration are critical factors influencing the widespread adoption of EVs [13]. Biofuels, hydrogen fuel cells, and synthetic fuels offer additional pathways for decarbonisation.

Biofuels such as biodiesel and ethanol have been explored as drop-in replacements for fossil fuels, with studies showing their potential for reducing emissions, especially in heavy-duty transport [14]. Hydrogen fuel cell vehicles (FCVs) are considered a promising alternative for long-haul and commercial transport, given their rapid refuelling times and long-range capabilities [15]. However, the sustainability of hydrogen depends on production methods, with green hydrogen (produced using renewable energy) being the most environmentally beneficial [16]. Emerging technologies such as autonomous vehicles, shared mobility, and smart grid integration offer new avenues for decarbonisation. Studies suggest that autonomous electric taxis could reduce emissions through improved efficiency and ridesharing [17]. Moreover, the integration of renewable energy with EV charging infrastructure and vehicle-to-grid (V2G) technology can enhance grid stability and reduce reliance on fossil fuels [18].

The behavioural factors including socio-economic characteristics, urban design, technological advancements, and policy interventions have significant roles in shaping local decarbonisation initiatives [19]. In addition, the policy instruments to achieve emission reductions become a central issue along with addressing both technological and behavioural determinants [20,21]. Research indicates that stringent regulations for vehicle emissions in regions such as the European Union and California have successfully driven innovation and EV adoption [22]. Additionally, urban planning initiatives such as low-emission zones and investment in public transport infrastructure contribute to systemic decarbonisation [23]. Waisman et al. [21] examined the low-carbon pathway for the transportation sector with S1 and S2 scenarios. The S1 scenario represents the mobility demand continuing to grow proportionally with urban sprawl and the freight transport intensity of production remaining constant, indicating limited responsiveness to increased transport costs from energy or carbon prices. Scenario S2 designed measures of the behavioural model for the transition towards a low-carbon society. These measures were the comprehensive policy packages on promoting sustainable transport modes and urban planning and reducing the freight transport intensity in production processes [24,25]. The S1 scenario estimated a 25% decrease in emissions from freight transport by 2100; however, the achievement of this reduction was slow over the long run [21]. On the other hand, the S2 scenario focused on the transportation policies and estimated reduced emissions by 48% by 2100, decreasing both freight transport input per unit of production and the fuel consumption from freight traffic [21]. Dhar and Shukla [26] argued that sustainable transport policies could yield considerable co-benefits by coordinating policies and actions across time and space. The proposed policy interventions are moderating demand for passenger and freight transport, redirecting demand to more sustainable modes, enhancing vehicle technology efficiency and transitioning to cleaner fuels [26].

However, fossil fuels are a crucial contributor to the national economy in India, which creates a unique concern to meet sustainable development and climate goals, and alternative income streams and green tax reform are needed to transition towards a sustainable energy system. India is adopting demand-oriented policies and a systems approach for sustainable transport and climate change; however, complicated institutional capabilities, urban governance issues, and ineffective planning have thwarted numerous government policy projects. There is a need for long- and short-term strategies to overcome the challenges in implementing road transport decarbonisation in India.

3. Methods

This study employed a qualitative exploratory approach, well-suited for analysing complex phenomena that cannot be fully addressed through quantitative methods alone [27]. This framework enabled an in-depth examination of the decarbonisation of road

transportation in India, capturing the intricate processes, experiences, and circumstances involved. Its flexible and iterative nature allowed the research to evolve as data were collected, ensuring a more comprehensive understanding of emerging patterns and insights. By focusing on phenomena within their natural context, this method provided a nuanced perspective, enabling the identification of underlying factors influencing decarbonization efforts. Additionally, the qualitative exploratory approach facilitated the integration of diverse viewpoints, including those of policymakers, industry stakeholders, and researchers, contributing to a more holistic analysis [28]. The adaptability of this method ensured that the study could respond to new findings, refining its scope as necessary to capture the dynamic and multifaceted nature of road transport decarbonisation in India. Ultimately, this approach helped interpret findings through the researchers' lens, offering valuable insights that may inform future policy and decision-making in sustainable transportation.

4. Analysis of Policies and Strategies

The increasing number of cars on Indian roads has resulted in a significant rise in urban congestion. A review of comprehensive mobility plans in 2010 revealed that the average motor vehicle speed on urban roads was merely 15–16 km/h [29]. According to the TomTom Traffic Index, Bengaluru ranked as the city with the worst global traffic congestion, with Mumbai, Pune, and New Delhi following closely in fourth, fifth, and eighth position, respectively [29]. The challenge is exacerbated by limited space in Indian cities, where on-street parking occupies up to 60% of the road width [29]. The car surge on urban roads in India has also attributed to app-based taxi services, a cost-effective alternative to car ownership that has increased the modal shift from public transit to ride-sharing among commuters. The conventional response to traffic growth and congestion, such as additional road space, construction of flyovers, signal-free roads, and ring roads, might be a detrimental cycle of automobile dependency [29].

The GoI has introduced various policies to curb transport-related emissions. The National Electric Mobility Mission Plan (NEMMP) and Faster Adoption and Manufacturing of Electric Vehicles (FAME) schemes aim to promote electric mobility [30]. The NEMMP was created in 2013 with the aim of achieving national fuel security and fostering sustainable growth in the automotive industry. The NEMMP promotes EV adoption through various incentives, subsidies, and investments in charging infrastructure. The NEMMP has been effective in promoting electric mobility, leading to a 4% growth in electric two-wheeler sales as of 2022 [2]. The plan has successfully established a widespread charging infrastructure network and provided financial incentives, resulting in a 5% reduction in EV purchasing costs [2]. The NEMMP projected a decrease in CO_2 emissions from the transportation sector by 10% [2]. The FAME, a part of NEMMP, was started in 2015 to provide financial incentives for purchasing new EVs. The FAME II aims for approximately 7000 electric and hybrid buses, 500,000 electric three-wheelers, 55,000 electric four-wheeler passenger cars, and 1 million electric two-wheelers [2]. The FAME II programme installed 532 charging stations across the country as of July 2022 [2].

In addition, initiatives such as the Dedicated Freight Corridors (DFC) project seek to enhance the efficiency of rail freight transport, reducing dependency on road transport [31]. India's Eastern and Western Dedicated Freight Corridors (EDFC and WDFC) are among the most significant railway infrastructure projects aimed at improving freight movement. Studies discuss the impact of these corridors on reducing transportation time and boosting industrial connectivity, particularly in regions like Punjab, Haryana, and Maharashtra [32]. Several studies indicate that DFCs significantly contribute to cost savings in freight transportation by shifting goods from road to rail, reducing fuel consumption, and improving supply chain efficiency [33,34]. The DFC is also projected to reduce CO_2 emissions by over

450 million tons over 30 years [31]. However, DFC is facing several challenges in India such as legal and compensation disputes for land acquisition, budget escalations due to inflation and unforeseen expenses, and lack of advanced signalling and automation systems [35,36].

The GoI is pursuing laws and programmes to encourage low-carbon road transportation. The GoI is offering financial incentives to both consumers and sellers of EVs and hybrid vehicles, charging infrastructures, and research and development on EV technologies under the FAME programme [5]. The Bangalore Metropolitan Transport Corporation (BMTC) has had tremendous results with electric buses and set a precedent for other Indian cities to follow in terms of reduced fuel usage and carbon dioxide emissions. The Delhi and Maharashtra states in India are providing additional incentives along with federal incentives for purchasing EVs. The National Green Highways Policy 2015 proposed green corridors along with afforestation, waste management, and the promotion of biofuels for transport. The proposal aims to promote eco-friendly national highway corridors across the country involving farmers, the private sector, and government institutions. The National Mission on Transformative Mobility and Battery Storage focuses on the research and development of charging infrastructure and battery technologies in India. The key focuses of the mission are as follows: (1) Encourage the adoption of EVs across various segments including two-wheelers, three-wheelers, passenger cars, and commercial vehicles, through incentives, subsidies, and supportive policies; (2) Establish a robust charging infrastructure network across the country; (3) Support the development and manufacturing of advanced batteries in India; (4) Promote research and development in mobility and battery storage technologies; (5) Formulate policies and regulations that promote sustainable mobility, energy efficiency, and battery storage technologies; (6) Train the workforce in the electric mobility and battery storage sectors.

The fiscal and budgetary policies of GoI are crucial for effectively transitioning to low-carbon road transportation. The GoI has decreased the goods and services tax (GST) on EVs from 12% to 5% and on EV chargers from 18% to 5%, respectively [37]. The Reserve Bank of India (RBI) is encouraging banks to provide green loans for purchasing low-carbon autos promoting green financing. However, the degree and scope of financial incentives and subsidies require regular monitoring with the changing technology and EV market. The IEA predicts that the need for financial incentives may lessen over time as the price of EV batteries falls and economies of scale increase [38]. In addition, the current financial incentives are questionable as these are narrowly focused on car ownership rather than commercial fleets or public transit, which have the potential to significantly reduce carbon emissions [39].

The carbon tax or charging a premium for driving in congested areas might serve as extra financial incentives for customers to switch to low-carbon modes of transportation [40]. However, the carbon tax or road charge should be carefully examined to avoid unnecessary burdens on low-income people and a mechanism should be developed to reinvest the revenue from the carbon tax or road charge into environment-friendly transport infrastructure [41]. Those on low-incomes are less able to afford to buy EVs, resulting in them bearing the price of the change without receiving the benefits of it [42]. The costs to ecology from battery waste must also be treated carefully, otherwise, the environmental benefits gained from the low-carbon transportation transition would be jeopardised [43].

India has drawn significant foreign investment in the fields of EVs and renewable energy, supporting the GoI's initiatives for low-carbon road transportation [44]. In 2024, India introduced a policy allowing foreign carmakers to import EVs at a reduced tariff of 15%, down from the previous rate of up to 100%. This concession is contingent upon a minimum investment of $500 million in local manufacturing facilities within the first three years of operation, with a requirement that 25% of the domestic value addition (DVA)

be achieved in the vehicles produced. Additionally, the policy stipulates that only 5% of the total investment can be allocated toward establishing EV charging infrastructure to qualify for tariff relief. This measure aims to prioritise vehicle manufacturing over charging networks, encouraging companies to focus on producing vehicles locally. Several international companies have shown interest in entering the Indian EV market. JSW Group, in partnership with China's SAIC Motor, has acquired a 35% stake in MG Motor India and invested in manufacturing facilities, including a 50 GWh EV battery plant to produce 1 million electric cars in India by 2030. Ola Electric, aided by SoftBank and Temasek, raised $655 million in its initial public offering and plans to use the funds for a new battery factory, debt reduction, and research and development for e-scooter manufacturing in India. Tesla Inc. has selected locations for showrooms in New Delhi and Mumbai, indicating plans to commence sales in India. However, a comprehensive public–private partnership (PPP) is required to efficiently utilise the knowledge and resources of the private sector in the process of scaling up programmes for low-carbon road transportation such as green bonds [45]. The GoI has initiated PPP projects for charging infrastructure, EV manufacturing facilities and renewable energy projects [37]. The PPPs for low-carbon road transportation should work towards achieving the financial, social, and environmental objectives assuring clear contractual agreements, proper risk distribution, and transparent regulatory frameworks [46]. In a nutshell, a continuous process of monitoring, reviewing, and policy amendments is required to accomplish the long-term and pervasive transition towards low-carbon road transportation.

5. Policy Implications and Discussion

The GoI has introduced various policies to curb transport-related emissions. The National Electric Mobility Mission Plan (NEMMP) and Faster Adoption and Manufacturing of Electric Vehicles (FAME) schemes aim to promote electric mobility [30]. The NEMMP was started in 2013 with the aim of achieving national fuel security and fostering sustainable growth in the automotive industry. The NEMMP promotes EV adoption through various incentives, subsidies, and investments in charging infrastructure. The NEMMP targeted 6–7 million EV sales by 2020 (though progress has been slower than expected) and planned to invest 140 billion Indian Rupees (INR) through public–private partnerships. The NEMMP has been effective in promoting electric mobility, leading to a 4% growth in electric two-wheeler sales as of 2022 [2]. The plan has successfully established a widespread charging infrastructure network and provided financial incentives, resulting in a 5% reduction in EV purchasing costs [2]. The NEMMP projected a decrease in CO_2 emissions from the transportation sector by 10% [2]. The FAME, a part of NEMMP, was created in 2015 to provide financial incentives for purchasing new EVs. FAME I (2015–2019) focused on demand incentives, charging infrastructure, and pilot projects with a budget of INR 9 billion. FAME II (2019-Present) expanded with an INR 100 billion budget for 5 years, promoting approximately 7000 electric and hybrid buses, 500,000 electric three-wheelers, 55,000 electric four-wheeler passenger cars, and 1 million electric two-wheelers [2]. The FAME II policy installed 532 charging stations across the country as of July 2022 and planned to set up 2877 charging stations across India, ensuring at least 1 charging station every 3 km in cities and every 25 km on highways [2]. FAME II policy is demand-incentive by promoting domestic production of EV components and indigenous EV technology development, subsidising EV buyers and providing incentives based on the battery capacity. As part of FAME II, the GoI reduced the goods and service taxes (GST) on EVs from 12% to 5% with an additional income tax rebate on EV loan interest, aiming for 30% of all vehicles in India to be electrified by 2030.

5.1. Regional or National Low-Carbon Strategy

Several measures can be implemented at various levels to achieve the low-carbon strategy in India, such as the following: (1) Encouraging the use of low-carbon fuels; (2) Implementing strict vehicle emission standards and promoting the use of energy-efficient vehicles; (3) Promoting the use of public and active transports; (4) Designing cities with mixed land-use, compact development, and better connectivity between residential and commercial areas; (5) Optimising the travel demand management through carpooling, ride-sharing, and flexible work hours; (6) Optimising the transportation systems with efficient traffic flow and better route planning; (7) Promoting efficient supply chain management; (8) Implementing carbon pricing mechanisms to incentivise businesses and individuals who are transitioning to low-carbon transportation options; (9) Raising awareness about the environmental impact of transportation and promoting eco-friendly travel choices; (10) Continuing research and investment in innovative technologies [21,47–49]. A holistic transport action plan is required to implement these measures both at national and local levels.

5.1.1. Transport Action Plan at the National Level

- Incorporate comprehensive macro indicators that cover economic, social, environmental, technical, and strategic aspects related to low-carbon transport. These indicators will serve as benchmarks for assessing progress and guiding policy decisions.
- Conduct a long-term integrated assessment, extending up to 2050, to envision the transitions required in infrastructure, vehicle technologies, and fuels to achieve a low-carbon transport system.
- Include case studies of specific projects like Dedicated Rail Freight Corridors and large infrastructure initiatives, analysing their low-carbon impact and offering valuable insights for future projects.
- A detailed road map for establishing a sustainable low-carbon transport system in India to address technology needs, research and development requirements, technology transfer, financing mechanisms, and pathways for international cooperation.

5.1.2. Low-Carbon Mobility Plan

- Incorporate city-specific indicators to promote sustainable transport options, considering factors like emissions reduction, mode sharing and efficient land-use;
- Examine the key transport technologies and practices at the city-level through case studies, showcasing successful implementations and lessons learned for replicability;
- Design a well-defined methodology for developing low-carbon mobility plans with a systematic approach to identify and prioritise relevant interventions;
- Formulate the funding proposals for implementing the identified projects and initiatives within the low-carbon mobility plans;
- Create an online network for information sharing and coordination, facilitating collaboration with stakeholders and promoting public engagement.

5.2. Fiscal and Financial Policies for Low-Carbon Road Transportation

The incentives and subsidies provided by GoI may be able to offset to some extent the high initial costs of EVs, the uncertainty of EV reselling value, and the lack of charging infrastructure; nevertheless, these fiscal policies are not sustainable to be maintained throughout the course of time. It is of the utmost importance to investigate market-based solutions that have the potential to make low-carbon transport commercially viable [38]. On the social front, the attitudes and preferences of consumers regarding the degree of mobility show a lack of awareness about EVs. The public's conduct and views towards

EVs are influenced by several factors, such as the cost of automobiles, driving range, the availability of charging infrastructure, and the performance of vehicles.

A large financial commitment and meticulous planning are required to construct a charging network that is both efficient and thorough for all types of EVs and advancing battery technology and vehicle performance [50,51]. The public transit and commercial fleet vehicles not only reduce carbon emissions at a higher rate but also have higher utilisation rates and can quickly offset their higher upfront costs through savings in fuel [52]. The political and institutional intentions, capability and local circumstances are pivotal for a low-carbon strategy for road transportation as its implementation at the state and municipality levels may differ significantly in India [53].

The GoI is investing in low-carbon transportation projects and harnessing the financial resources of the private sector via PPPs and innovative financing structures such as green bonds to raise funds for ecologically appropriate transportation projects. Local automobile companies such as Mahindra & Mahindra and Tata Motors are manufacturing EVs, and energy producers are significantly contributing to the construction of charging infrastructure. This would provide more financial flexibility along with foreign direct investment in EVs and renewable energy [37]. The low-carbon strategy of road transportation enables the formation of new sectors, notably EVs, battery technology, and renewable energy, resulting in economic development and job opportunities. Improvement in energy security and balance of payments might result from a decrease in India's dependence on fossil fuels imported from other countries [54]. The GoI should take concrete fiscal and financial policies for implementing the low-carbon strategy for road transportation.

- The FAME efforts have been of great assistance in expanding EV usage in the Indian market. Despite this, there is a need for an increase in finance, for the development of charging infrastructure, and the provision of incentives for customers of EVs [5]. A multi-faceted financing approach should be adopted to accelerate the deployment of EV charging infrastructure. The PPPs can attract investment while ensuring government incentives reduce risks for private stakeholders. Green bonds and ESG-focused investment funds can provide sustainable financing options. Additionally, innovative models like revenue-sharing agreements, subscription-based charging networks, and government-backed loan guarantees can enhance financial viability. Policymakers should also explore tax credits, grants, and low-interest loans to support infrastructure expansion, especially in underserved areas. A well-structured financial ecosystem will ensure widespread EV adoption and long-term sustainability.
- Increase financial and other incentives for R&D promoting innovation in low-carbon technologies, such as advanced battery systems and charging techniques. GoI should enhance funding for clean energy startups, university research programmes, and public–private partnerships to accelerate breakthroughs in energy storage, carbon capture, and renewable energy systems. Incentives such as tax credits, grants, and subsidies for companies engaged in green technology innovation can attract private investment. Additionally, fostering international collaboration and knowledge-sharing platforms can help scale innovations globally. Prioritising R&D in low-carbon solutions will ensure long-term sustainability, economic growth, and a successful transition to a net-zero future.
- The transition to low-carbon road transport will need many human capabilities, including investments in educational and training programmes to accelerate the transition process towards a low-carbon strategy for road transportation. This includes skills in the manufacturing and maintenance of EVs and the management of power grids. GoI and private sectors should collaborate to develop specialised courses in EV technology, battery management, and sustainable transportation. Vocational training programmes,

university partnerships, and online certifications can equip engineers, technicians, and mechanics with the necessary skills. In addition, financial incentives such as scholarships and grants can encourage students to pursue careers in the EV sector. Investing in a skilled workforce will ensure the long-term growth of the EV industry, drive innovation, and support the shift towards clean mobility.

- A high degree of coordination among different governmental agencies is needed to monitor the execution and coordination among the different stakeholders to assess the degree of progress achieved in implementing the policy. GoI, automakers, charging infrastructure providers, energy companies, and policymakers must collaborate to establish standardised regulations, interoperable charging networks and supply chain resilience. A centralised task force or governing body can streamline decision-making, ensuring alignment on incentives, policies, and technology standards. Regular industry forums, PPPs, and digital platforms for real-time data sharing can enhance communication and coordination. In addition, the collaboration will accelerate EV adoption, improve infrastructure deployment, and create a sustainable mobility ecosystem.
- Changes in consumer behaviour and preferences for low-carbon vehicles might result from the implementation of carbon or congestion pricing. The price signal must be set high enough to encourage action, but low enough to avoid exacerbating economic inequalities. GoI and automakers should conduct market research to identify barriers such as cost concerns, charging infrastructure availability, and range anxiety. Incentives like subsidies, tax rebates, and lower-interest financing can make EVs more attractive. In addition, increasing consumer awareness through educational campaigns on the environmental and economic benefits of EVs can shift preferences. Automakers should focus on diverse vehicle options, improved battery technology, and user-friendly charging solutions to align with consumer needs. These factors will drive demand and ensure a smooth transition to low-carbon transportation.
- Develop an efficient End-of-Life Vehicle (ELV) management for recycling and discarding old EVs and batteries. A well-structured ELV management system is crucial for the sustainable recycling and disposal of old EVs and their batteries. GoI and industry stakeholders should implement clear regulations and incentives for EV dismantling, battery recycling, and repurposing. Investment in advanced recycling technologies, such as hydrometallurgical and direct recycling methods, can maximise material recovery from lithium-ion batteries. GoI is required to create a network of certified recycling facilities and battery second-life applications (e.g., energy storage) reducing waste, minimising environmental impact, and supporting a circular economy.

5.3. Affordable Public Transport and Transport Decarbonisation

Integrating affordability with decarbonisation in India's public transport system is imperative for sustainable urbanisation. However, the high costs of metro and bus services, lack of subsidised transport options, and economic disparities impede accessibility for lower-income groups to EVs, high-speed rail services, and decarbonisation initiatives for public transport. The GoI has enacted several policies to improve affordable public transport. For instance, the PM-eBus Sewa scheme deploys 10,000 electric buses in cities for affordable urban transport and the Pradhan Mantri Gram Sadak Yojana connects rural areas to urban centres with low-cost road networks. A multi-stakeholder approach, combining policy reforms, technological advancements and financial incentives, can ensure that public transport remains accessible, efficient, and environmentally sustainable. The government is required to expand subsidies for low-income groups through direct benefit transfer or targeted fare reductions and implement integrated ticketing and fare capping systems to

ensure cost-effective multimodal transport. To improve the affordability, the policy should improve the last-mile connectivity with non-motorised transport options such as cycling and pedestrian-friendly pathways.

6. Conclusions

The low-carbon strategy for road transportation in India is manifested in a range of measures for reducing carbon emissions and fostering sustainable mobility. The incentives, subsidies, and tax benefits for EVs and the establishment of charging infrastructure through programmes like FAME have not only reduced carbon emissions but also enhanced India's energy security by reducing dependence on imported fossil fuels. The future of India's road transportation is at a pivotal juncture with a rapidly expanding economy and a growing need for mobility. The GoI efforts to incentivise EV adoption through financial support and policy measures have yielded tangible results. The growing EV market and increasing number of charging stations across the country are indicative of the positive response from consumers and stakeholders alike. The advancement of battery technology and the declining costs of EVs further bode well for the prospects of electric mobility in India. Continued government support and investment in research and development (R&D) will be instrumental in accelerating this transition and reducing the overall carbon footprint of the transportation sector.

In addition, the expansion and enhancement of public transportation systems have been instrumental in curbing emissions. The development of metro rail networks, the introduction of Bus Rapid Transit (BRT), and the implementation of last-mile connectivity solutions have improved accessibility and convenience for commuters, thereby encouraging a shift from private vehicles to public transport options. India has operational metro systems in over 20 cities with the expansion plan of the Regional Rapid Transit System and introduction of the Vande Bharat trains (semi-high speed) to improve intercity connectivity and journeys. The Mumbai–Ahmedabad bullet train project is currently under construction to improve long-distance connectivity and more corridors are planned under the National Rail Plan 2030. In addition, cities like Ahmedabad, Pune, Indore, and Surat have implemented BRT and dedicated bus corridors to improve bus efficiency by reducing travel time and congestion. India has also targeted 100% electrification for India Railways by 2030 to become carbon neutral. This has not only contributed to reduced traffic congestion but also led to notable emissions reductions. However, India needs to explore alternative funding sources and engage in PPPs to ensure the longevity and quality of public transport systems. Strategic partnerships between the public and commercial sectors are needed to attract private investment and expertise into the business, in addition to government backing.

Integration of renewable energy sources into the electricity grid is a critical aspect of India's low-carbon strategy. The country's emphasis on solar and wind energy has significantly reduced the carbon footprint associated with electric vehicle charging and power generation. The ongoing expansion of renewable energy capacity provides a strong foundation for the sustainability of electric mobility and supports the vision of a greener transportation future. The fuel efficiency standards and advanced emission norms have contributed to reducing emissions from the existing vehicle fleet. As the automotive industries continue to innovate, vehicles are becoming more energy-efficient, aligning with global standards and emission reduction goals. The behavioural change initiatives have played a pivotal role in complementing technological interventions. Public awareness campaigns, incentives for sustainable travel options, and shared mobility services have all contributed to shaping more environmentally conscious commuting patterns. State-specific projects and measures have highlighted the adaptability and flexibility of India's low-carbon strategy. Tailored to address regional pollution concerns and unique needs,

initiatives like electric rickshaws and two-wheelers have demonstrated the potential for scalable solutions nationwide. However, despite the progress made, several challenges persist. The high upfront costs of EVs and the need for robust charging infrastructure in some regions hinder widespread EV adoption. Addressing these obstacles requires innovative financing solutions and effective collaboration between the government and private sector.

Effective policy coordination among various government departments and agencies is paramount. A cohesive regulatory framework that encourages innovation, supports research and development, and incentivises sustainable mobility solutions will be essential in fostering the transition towards a low-carbon road transportation system. India's regional and national low-carbon strategy for road transportation represents a significant milestone in addressing the challenges of climate change and environmental sustainability. The promotion of electric mobility, development of public transportation, integration of renewable energy, and behavioural change initiatives have all contributed to reducing carbon emissions and fostering sustainable mobility practices. India has the potential to emerge as a global leader in low-carbon road transportation by building on existing successes, addressing challenges, and leveraging state-specific models. The successful implementation of a low-carbon road transportation system will not only contribute to achieving national climate goals but also serve as an inspiration for other developing nations in their pursuit of a sustainable and environmentally responsible transportation sector.

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