Decarbonisation of Freight Sector in India

Assessing the Feasibility of Electrification of Medium and Heavy Duty Vehicles

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Authors:

Akash Sharma, Associate Fellow; Sanobar Imam, Research Associate; and Animesh Kumar Tiwary, Research Associate, CUTS International

#2308

Contents

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Lastly, any error that may have remained is solely ours.

Abbreviations

BS	Bharat Stage Emission Norms
CAGR	Compound Annual Growth Rate
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
CSR	Corporate Social Responsibility
EGVI	European Green Vehicle Initiative
EPE	Eastern Peripheral Expressway
ESG	Environment, Social and Governance
EU	European Union
EV	Electric Vehicles
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FCEV	Fuel Cell Electric Vehicle
FMCG	Fast Moving Consumer Goods
GHG	Greenhouse Gas
GST	Goods and Services Tax
HDV	Heavy Duty Vehicles
HVIP	Hybrid and Zero-Emission Truck/Bus Incentive Project
ICE	Internal Combustion Engines
kW	Kilo Watt
kWh	Kilo Watt Hour
LDV	Light Duty Vehicles
LPG	Liquefied Petroleum Gas
MDV	Medium Duty Vehicles

MHDV	Medium and Heavy-Duty vehicles
MoEFCC	Ministry of Environment, Forest, and Climate Change
NCR	National Capital Region
NDC	Nationally Determined Contributions
NH	National Highways
NHAI	National Highways Authority of India
PM	Particulate Matter
SOP	Standard Operating Procedure
TCO	Total Cost of Ownership
TPEM	Technology Platform on Electric Mobility
ZEV	Zero Emission Vehicle

Executive Summary

There is a global shift towards electric vehicles (EVs) due to the need to reduce pollution and combat climate change, replacing internal combustion engine (ICE) vehicles. Notably, initiatives like FAME I (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) and its successor, FAME II, haveplayed a major role in accelerating the adoption of two-wheelers, three-wheelers, electric and hybrid cars, and electric buses. However, they have not included medium-duty and heavy-duty vehicles, which contribute 40 percent of emissions despite accounting for only 2 percent of the total vehicles on the road. To facilitate this transition to electric medium-duty vehicles (MDVs) and heavy-duty vehicles(HDVs), it is crucial to identify and address the specific challenges and loopholes that are hindering progress.

A pilot survey was conducted as part of this project, focusing on corridor analysis for three major highways in India: the Delhi-Jaipur highway, the Delhi-Agra highway, and the Eastern Peripheral Expressways. The findings of this analysis highlighted the major demand for MDVs and HDVs in the transportation of fast-moving consumer goods (FMCGs), courier services, and the distribution of essential supplies like food. Since there is a growing demand for MDVs and HDVs on the consumer side and the demand side is continuously expanding, it is essential to expand the supply-side infrastructure to meet this demand effectively. This expansion primarily requires the development of a robust network of charging stations that are accessible and well- equipped along these highways, as well as ensuring a consistent and reasonable charging tariff. Moreover, initiatives like Faster Adoption and Manufacturing of Electric Vehicles (FAME III), which support the electrification of MDVs and HDVs, can help the adoption process. Also, government mandates that exclusively require industrial clusters to use electric trucks for their transportation and the industry's commitment towards net-zero emissions aligning with their CSR initiatives to sustainability can help in the faster adoption of electric trucks.

We identified five key suggestions for the electrification of MDVs and HDVs

1. **Charging infrastructure must be developed near the truck layout bays**

   Selecting the optimal layout for charging stations involves a comprehensive assessment of various factors. This evaluation extends beyond the mere considerations of investment costs and operational expenses; it also **electrification of MDVs and HDVs** includes important factors such as user satisfaction and ease during the charging process. A significant challenge in the development of charging infrastructure for medium and heavy-duty vehicles is the scattered locations of the charging stations. A significant issue associated with these charging stations is the lack of essential amenities, such as water sources, shelter, and public restrooms, in the vicinity of these charging facilities, which poses significant challenges for the drivers who rely on these stations. Truck lay-bays are strategic hubs for drivers to take a break, rest, and refuel themselves. Since these vehicles often cover long distances, their only viable stopping points are designated truck lay-bays, which are equipped with food and other essential facilities. Therefore, a more convenient approach is to strategically position charging stations near the truck lay-bays. These areas are already equipped with amenities, making them ideal locations for the installation of multiple charging stations. Hence, this strategic positioning of charging stations near truck lay-bays can contribute to increased user satisfaction and efficiency, leading to a more time-effective operational model.

2. **A unified charging tariff is essential for expediting the electrification of MDVs and HDVs**

   The operation of freight trucks involves extensive travel, often spanning various states. One notable hurdle to the widespread adoption of electric medium and heavy-duty vehicles in the freight sector is the difference in charging tariffs across these different states. This tariff difference presents a significant challenge that hinders the electrification of the freight sector. To accelerate the transition to electric medium and heavy-duty vehicles, it is essential that governments address this issue by introducing a uniform and nominal charging tariff structure across states.

   For instance, consider a scenario where a fleet of electric freight trucks operates across multiple states, each with its own distinct charging tariff system. In State A,

the charging tariff may be relatively low and conducive to cost-effective operations, while in neighbouring State B, the charging tariff is substantiallyhigher, significantly increasing the operational expenses for the same fleet. This inconsistency in charging tariffs adds complexity to fleet management and discourages businesses from transitioning to electric trucks due to the uncertainty and potential cost differences. A standardised tariff system would eliminate these uncertainties and potential cost differentials associated with varying charging rates across state borders.

3. **FAME III could be the catalyst for generating interest from potential buyers**

   The FAME I scheme launched in 2015 and FAME II scheme launched by the government in 2019 have played a significant role in advancing the electric mobility of this country. In its four years, FAME I incentivised 2.78 lakh EVs by providing subsidies worth ₹ 343 crore and sanctioned 465 e-buses to various states[1], and more than 90 percent of all e-bikes sold since FY 2019–20 have been subsidised by FAME II.[2]

   Both FAME I and FAME II incentivised the purchase of electric vehicles and prioritised the establishment of essential charging infrastructure. However, both did not include electric 3 and 4-wheelers due to the specific parameters and incentives outlined in these phases. Going forward, the implementation of FAME III will mark a significant shift, as it will specifically target electric medium and heavy-duty trucks. This strategic shift is aimed at significantly accelerating the electrification of the freight sector, making electric trucks more cost-effective and accessible.

4. **Promoting electric trucks in industrial corridors through support from State Industrial Development Corporations can accelerate the adoption**

   Reallocating Corporate Social Responsibility (CSR)/Environment, Social, Governance (ESG) funds from industries towards electric trucks offers another means of promoting the adoption of electric trucks. Through the strategic utilisation of CSR funds, industries can invest in electric trucks, thereby meeting their Net Zero commitments while also enhancing environmental well-being. Also, government mandates that exclusively require industrial clusters to use

1 https://www.ceew.in/cef/solutions-factory/publications/CEEW-CEF-Greening-Indias-Automotive-Sector.pdf

2 https://pib.gov.in/PressReleasePage.aspx?PRID=1576607

electric trucks for their transportation needs can play an important role in aligning with emission reduction goals. By enforcing a transition to electric trucks, governments can significantly mitigate environmental and logistical challenges. Hence, mandating the use of electric trucks in industrial clusters can be a practical measure taken by the government to ensure that industries actively contribute to a greener and more sustainable future.

5. **Fast chargers can minimise charging times during long-haul trips**

   Ensuring efficient operation depends on the availability of fast chargers, which serve as rapid refuelling stations for electric vehicles. These chargers are vital in ensuring that electric trucks adhere to tight delivery schedules without enduring extended periods of downtime for recharging; fast chargers are essential for the rapid adoption of electrified medium and heavy-duty vehicles. Their importance lies in their ability to quickly charge vehicle batteries, a critical factor for long-haul trips where minimising charging time is crucial. The increasing demand for electric trucks and the availability of high-power fast chargers ensure operational efficiency. Fast chargers meet the growing demand for electric trucks and enhance the feasibility of electric vehicles in commercial settings, driving the electrification of medium and heavy-duty vehicles.

Conclusion

The decarbonisation of India's freight sector through the electrification of Medium and Heavy-Duty Vehicles is feasible and imperative. It holds the potential to significantly reduce carbon emissions, improve air quality, and strengthen the country's commitment to sustainable development. However, realising this potential will require a concerted effort from governments, industry stakeholders, and the private sector to overcome operational challenges, drive innovation, and establish the necessary regulatory and infrastructure framework for success. As India continues its journey towards a greener and more sustainable future, the electrification of MHDVs offers a transformative path forward for the country's freight sector.

1 Introduction

The transport sector is the fastest-growing contributor to climate change, accounting for about a quarter (23 percent) of global emissions. It is one of the significant sources of greenhouse gas (GHG) emissions in countries such as the US, the UK and India. Around 14 percent of India's overall CO_2 emissions are attributed to transport, 90 percent of which come from road transport. Accelerated EV uptake is essential to keep the world on a 1.50 Degree Celsius pathway. In India, medium and heavy-duty trucks comprise only 2 percent of the total vehicle population but contribute 30 percent of the overall vehicular road transport emissions. Given this disproportionate share of GHG emissions, there is a critical need for a faster transition for medium and heavy-duty freight vehicles. Decarbonising road transport is essential, especially if India is to meet its goal of having net-zero emissions by 2070.

Accelerated electric vehicle (EV) uptake across industry sectors and vehicle types is essential for India to meet the objectives of the Paris Agreement and ratchet up its ambition on Nationally Determined Contributions (NDCs). Strong decarbonisation goals for the transportation industry, particularly the road sector, will bring other benefits like improved air quality and human health. A demand for medium and heavy-duty vehicle electrification in key Indian applications can spark a transition. Being the third-largest truck market after China and the United States, India's early adoption of zero-emission trucks can be instrumental in accelerating its domestic climate imperatives and supporting global climate action.

Overview of the MDV and HDV Sector

The transportation of goods and passengers across India's vast road network is heavily reliant on medium and heavy-duty vehicles. It encompasses a range of vehicles designed for heavy-duty applications, including trucks, buses, trailers, and commercial vehicles used for freight transportation.


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Types of Vehicles

a) Trucks: Also known as the backbone of India's freight transportation system, carrying goods over long distances. Trucks are classified based on their gross vehicle weight into various categories such as light commercial vehicles, medium commercial vehicles, and heavy commercial vehicles. These are equipped with different configurations, including multi-axle trucks, tractor-trailers, and tipper trucks, to cater to specific transportation requirements.

b) Buses: An integral part of India's public transportation system, providing mobility to millions of people every day. These buses are classified as city buses, intercity buses, luxury coaches, and school buses. Bus designs range from standard rigid buses to articulated buses with higher passenger capacities.

c) Trailers: Used for transporting goods and are commonly attached to heavy-duty trucks. They are designed to carry different types of cargo, including containers, bulk materials, and specialised goods. Trailers are classified based on their design, such as flatbed trailers, refrigerated trailers, and tankers.

Significance in the Transportation Landscape

The usage patterns of HDVs in India vary based on their applications and the sectors they serve. HDVs form the backbone of India's logistics and supply chain, transporting goods from manufacturing hubs to distribution centres and retail outlets. They are used extensively in industries such as manufacturing, agriculture, e- commerce, and construction. Buses, including city buses and intercity buses, are essential for public transportation across cities, towns, and rural areas. They cater to the needs of commuters, providing a cost-effective and efficient mode of transport. They are also deployed for specialised applications, such as carrying hazardous materials, refrigerated transport for perishable goods, and oversized cargo transportation for industries like heavy machinery and infrastructure.

HDVs have significant importance in India's transportation landscape. The sector's significance lies in its contribution to economic growth, employment generation, connectivity, freight movement, and revenue generation for the country. It plays a critical role in facilitating economic growth by ensuring the efficient movement of goods across the country. It supports industries, trade, and commerce, contributing

to the overall development of the economy. It is a significant source of employment, providing opportunities for drivers, mechanics, fleet operators, and support services. It serves as a livelihood for many individuals and contributes to the creation of jobs throughout the value chain. HDVs, especially buses, enhance connectivity and accessibility by providing transportation options to both urban and rural areas. They bridge the gap between regions and ensure people have access to education, healthcare, and other essential services. The efficient movement of goods is essential for trade and commerce. HDVs transport raw materials, finished products, and agricultural produce, supporting industries and enabling the smooth functioning of supply chains. It also generates substantial revenue for the government through taxes, duties, and tolls. This revenue is crucial for infrastructure development, maintenance, and regulatory activities.

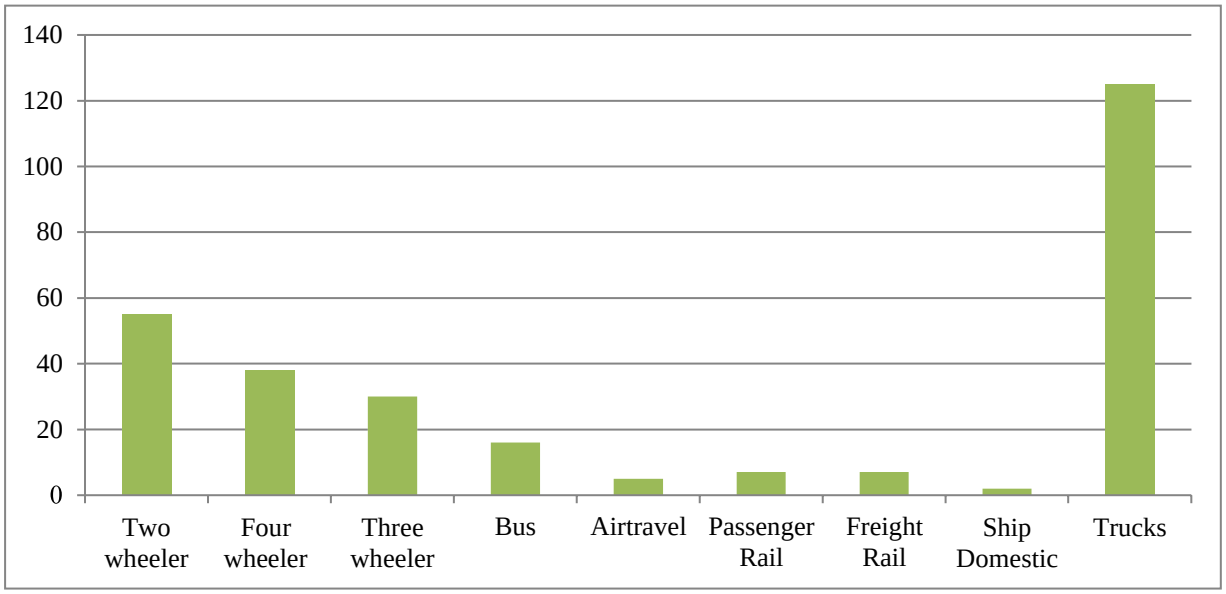
Carbon Emissions from Medium and Heavy-Duty Vehicles

Under the net-zero scenarios, emissions from the transport sector in India should fall significantly. This means that not only should the share of electric vehicles increase, but 79 percent of trucks in India's freight transport should also go electric, the rest being run on hydrogen, according to a 2021 study[3] on the implications of a net-zero target for India's energy transition and climate policies. Over the past two decades, India has invested in road infrastructure, expanding and constructing new national and state highways. This improved road infrastructure has also increased freight delivery by road, and trucking is an easier transport sector for emissions mitigation compared to air travel.

India's Sustainable Habitat Mission in the National Action Plan on Climate Change encourages research and development in biofuels, including hydrogen as a potential future energy source for the transport sector. Two alternatives for zero-emissions trucks are currently being explored in India: battery-charged and fuel-cell electric trucks, which use electricity powered by green hydrogen.

[3] https://www.ceew.in/sites/default/files/ceew-research-transport-energy-use-carbon-emissions-decarbonisation.pdf

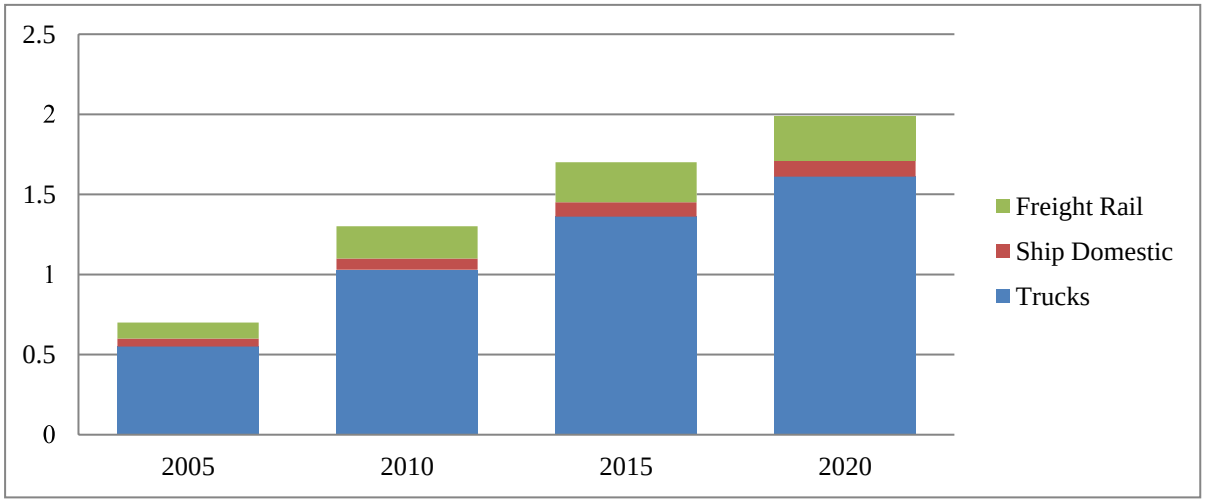
Figure 1: Carbon emissions (MtCO2) by the transport sector in 2020



Source: India Transport Energy Outlook, CEEW, 2022

The largest share of energy consumption in freight transportation is of trucks. The energy consumption of trucks increased more quickly than their respective shares of freight activities between 2005 and 2020. The difference in growth rates is primarily caused by Indian transport fleets' poor fuel efficiency. This imbalance has also been exacerbated by India's sluggish implementation of strict fuel economy rules, particularly for heavy-duty vehicles. Indian truck industry is characterised by individually owned, medium-sized diesel trucks with lower fuel efficiency.

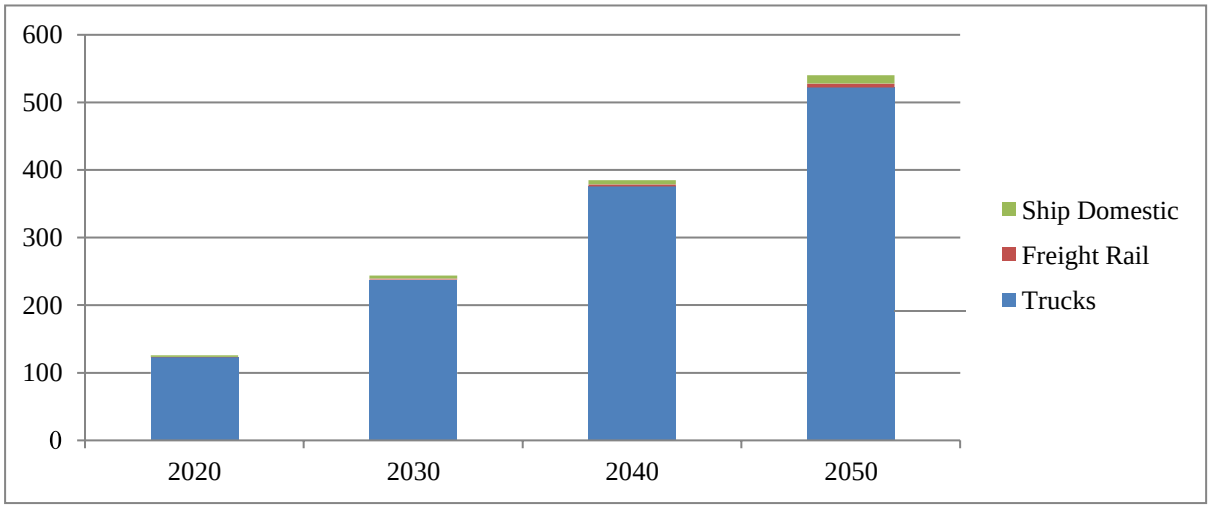
Figure 2: Energy (Exajoule EJ) Consumed by various modes of freight transport from 2005 to 2020



Source: India Transport Energy Outlook, 2022

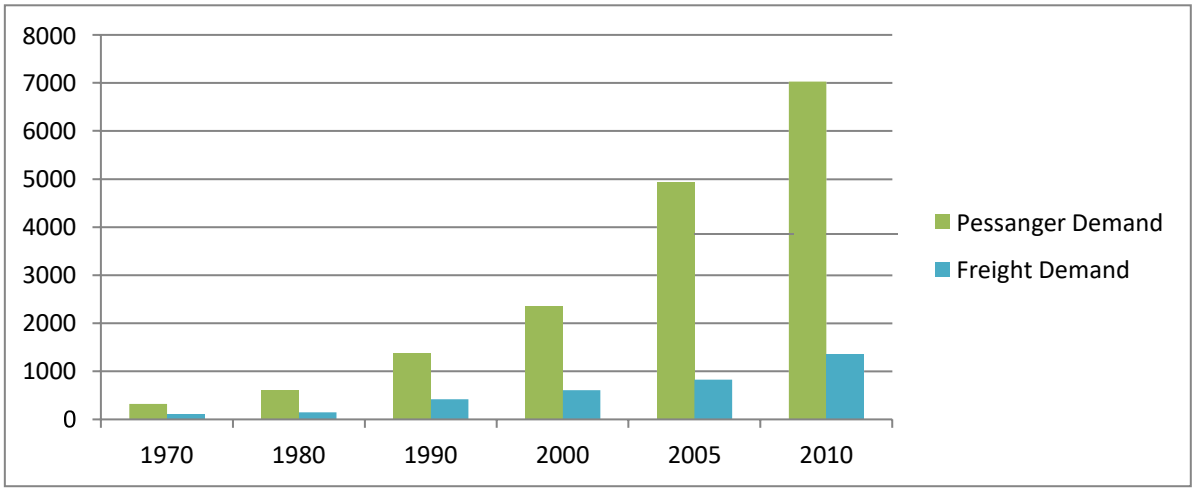
The emissions produced by the transport sector reflect the energy used by various modes of passenger and freight transport. In 2020, direct emissions (tailpipe emissions) produced by the transport sector (excluding international aviation and international shipping) stood at 272 million tonnes of CO_2. The road sector, including passenger and freight, dominates transport emissions, accounting for a share of more than 92 percent. It also significantly contributes to India's air pollution problem. Emissions produced by road transport are growing faster than in any other sector and are expected to be a significant challenge to decarbonising India's energy sector.

Figure 3: Carbon emissions (MtCO2) by various modes of freight transport from 2020 to 2050



Source: India Transport Energy Outlook, 2022

Figure 4: Growing mobility demand (in billion pkm/tkm) in India



Source: Comprehensive mobility plan, 2013

HDVs comprise a relatively small share of vehicle fleets in most countries, but they contribute a disproportionate share of emissions. Globally, on-road diesel vehicles—mostly HDVs—are accountable for 86 percent of nitrogen oxide emissions and 78 percent of black carbon emissions. By 2025, it is anticipated that the worldwide HDV fleet will produce more greenhouse gas emissions than the fleet of light-duty vehicles. The potential to lessen the effects on the climate and air quality, notably in growing markets and developing economies, is offered by zero-emission vehicle technology for HDVs, including battery electric vehicles and fuel-cell electric vehicles.

CO_2 emissions from HDVs in developing countries without a targeted approach and EV policies could surpass emission levels from developed countries along with China by 2050. Still, in a global EV transition scenario leading to 100 percent HDV EV adoption, CO_2 emission from HDVs in developing countries could fall 44 percent below 2020 levels in 2050.

Due to high energy requirements, substantial battery capacity requirements, and a lack of readily available vehicle types, adoption of HDVs adoption has lagged behind that of light-duty vehicles (LDVs). With improvements in battery technology, a wider variety of models and regulations to boost ZEV adoption in the HDV segment, the environment is shifting. There is an anticipation of an increase in demand in the coming years.

2

Policy Landscape

Existing policies and regulations related to HDV decarbonisation in India encompass fuel efficiency standards, emission norms, and incentives for electric vehicles. These measures aim to promote the adoption of cleaner and more sustainable technologies in the HDV sector.

Below is an examination of some key policies and regulations:

Fuel Efficiency Standards for HDVs

Bharat Stage (BS) Emission Standards: India has implemented a series of emission standards known as Bharat Stage norms, aligned with European emission standards. These standards regulate the permissible levels of pollutants emitted by vehicles, including HDVs. Currently, all new vehicles sold and registered in India should be compliant with the BS-VI iteration of emission standards. The standards and timelines for their implementation are set by the Central Pollution Control Board (CPCB) under the Minister of Environment, Forests and Climate Change (MoEFCC). As the Bureau of Standards, they require stricter emission limits, encouraging manufacturers to develop more fuel-efficient and cleaner HDVs.

Fuel Efficiency Norms: The Ministry of Road Transport and Highways introduced fuel efficiency norms for HDVs in 2015. The standards aim at reducing fuel consumption and GHG emissions from diesel-powered freight trucks and buses & apply to domestic manufacturers and importers. Vehicle models are tested for compliance with regulations before manufacturing approval certification is granted.

Electric and Alternative Fuel Incentives

Faster Adoption and Manufacturing of Electric Vehicles (FAME) Scheme: This was launched in April 2015 under the National Electric Mobility Mission to encourage electric and hybrid vehicle purchases by providing financial support. Its first phase ran for four years until 2019. The second phase (FAME II) is a 3-year subsidy programme. It aims at supporting the electrification of public and shared

transportation: around 7,000 electric and hybrid buses, 500,000 lakh electric three-wheelers, 55,000 electric four-wheeler passenger cars, and 1 million electric two-wheelers. This programme also finances charging infrastructures.

State-Level Incentives: Various states in India have introduced additional incentives and benefits for EVs, such as exemptions from road tax, registration fees, and toll charges. These incentives also apply to electric HDVs, making them more attractive to fleet operators and consumers.

Research and Development Initiatives

Technology Platform on Electric Mobility (TPEM): Established by the government's Department of Science and Technology, it focuses on research, development, and innovation in electric mobility technologies. It promotes collaboration between industry, academia, and research institutions to advance electric vehicle technologies, including those applicable to HDVs. Its objectives are to develop technologies & products that specifically address India's need to strengthen the industry technology capability sufficiently to be able to reduce and wean off the consumer subsidy program for electric vehicles in the near future.

Research Grants and Support: The government provides grants and support for research and development projects related to alternative fuels, electric vehicles, and energy-efficient technologies. These initiatives aim to accelerate the development and deployment of cleaner technologies in the HDV sector.

Logistic Efficiency Enhancement Programme: The Ministry of Road Transport and Highways launched the Freight Efficiency Program in 2020. This program aims to enhance the efficiency of freight transportation, reduce emissions, and promote sustainable practices. It includes measures such as fuel-efficient driving practices, vehicle load optimisation, and adopting advanced technologies for fleet management.

The Green Energy Corridor: Green corridors are dedicated lanes or routes for the movement of freight vehicles that comply with specific environmental standards. These corridors aim to reduce congestion, enhance efficiency, and promote the useof cleaner technologies, including electric HDVs.

These policies and regulations demonstrate the Indian government's commitment to HDV decarbonisation and the transition towards cleaner technologies. Continued efforts in strengthening and implementing policies, technological advancements, and stakeholder engagement are crucial to reducing carbon emissions and promoting sustainable transportation in the HDV sector.

3

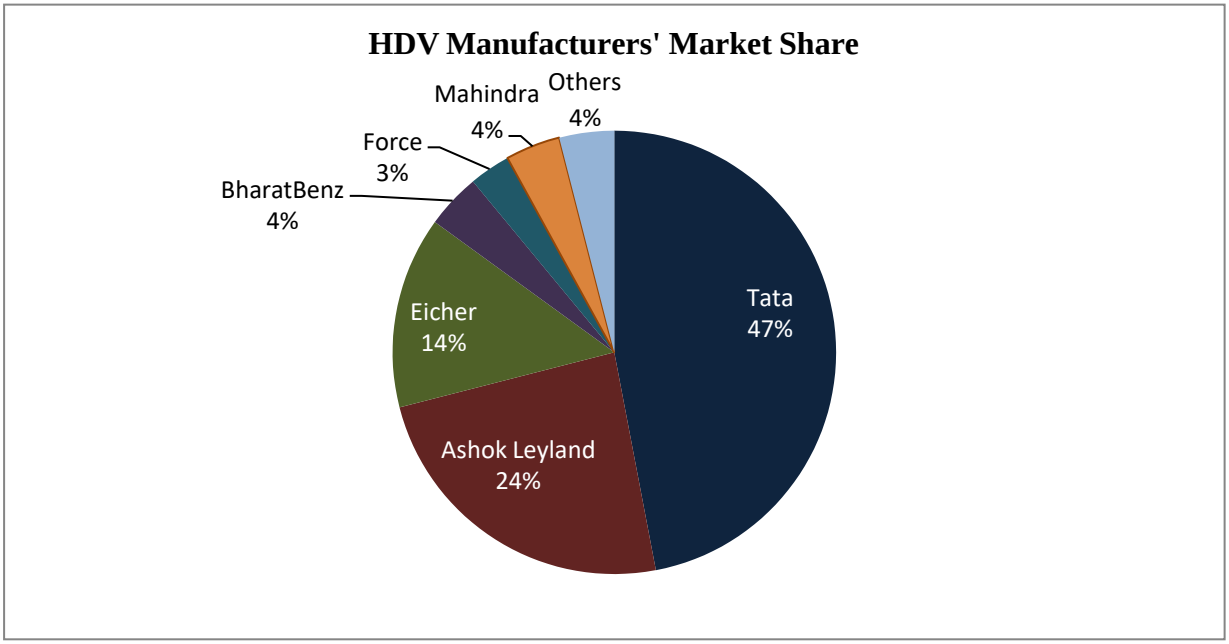
Market Analysis of Medium and Heavy-Duty Vehicles

The HDV market in India is significant, driven by the country's growing economy and extensive road transportation network. The market size is determined by factors such as the demand for goods transportation, infrastructure development, and economic activities. The truck market in India is substantial, with a diverse range of truck categories catering to various applications.

The market size is influenced by factors such as industrial growth, e-commerce expansion, and agricultural activities. In FY 2019–20, total domestic sales of commercial of HDVs were nearly 306,000, and it was approximately 243,000 for FY 2021–22. Most of the commercial activities were affected globally, including in India, due to the COVID-19 pandemic and this impacted sales of HDVs. Between FY 2017–18 and FY 2019–20, sales decreased by 32 percent, and they decreased another 33 percent between FY 2019–20 and FY 2020-21. Though a recovery is on the way, it's still behind the sales of pre-pandemic numbers.

The HDV market in India is competitive, with several key players operating in the sector. These players include domestic and international manufacturers, each with their product offerings and market presence. Major truck manufacturers in India include Tata Motors, Ashok Leyland, Mahindra & Mahindra, BharatBenz, and Eicher Motors. These companies offer a variety of trucks with different capacities andconfigurations to cater to diverse customer requirements. Key players in the bus segment include Tata Motors, Ashok Leyland, Volvo, Eicher Motors, and SML Isuzu. These manufacturers provide various bus models for both urban and intercity transportation.

Figure 5: Market share of HDV manufacturers in India in 2021-22



Source: Segment Y Automotive Intelligence

The HDV market is expected to see steady growth in the coming years. Several factors contribute to this growth, including economic development, infrastructure investments, and increasing demand for transportation services. The truck market is expected to grow at a compound annual growth rate (CAGR) of around 8-10 percent in the next few years. Factors such as the expansion of e-commerce, the implementation of the Goods and Services Tax (GST), and infrastructure projects are expected to drive the growth of the truck market. The bus market is projected to grow at a CAGR of approximately 6-8 percent in the coming years. Increasing urbanisation, government initiatives for public transportation, and the need for sustainable mobility solutions are expected to fuel the growth of the bus market.

The market potential for electric HDVs in India is significant, driven by various factors such as environmental concerns, government support, and advancements in technology.

a) Government Support: The Indian government has implemented policies and incentives to promote the adoption of electric vehicles, including HDVs. The FAME scheme provides financial incentives for electric vehicle buyers, including fleet operators. These incentives reduce the upfront cost and make electric HDVs more attractive.

b) Infrastructure Development: Establishing charging infrastructure is crucial for the widespread adoption of electric HDVs. The government and private entities are investing in developing charging stations across the country, supporting the growth of the electric vehicle ecosystem.

c) Total Cost of Ownership (TCO): Electric HDVs offer advantageous lower operating costs compared to conventional diesel vehicles. The reduced fuel & maintenance costs and favourable government incentives contribute to the attractive total cost of ownership for electric HDVs.

d) Technological Advancements: With ongoing advancements in battery technology, electric HDVs are becoming more viable and efficient. The increasing range of electric vehicles improved charging infrastructure, and faster charging capabilities contribute to the market potential of electric HDVs.

e) Demonstration Projects: Several pilot projects and demonstrations of electric HDVs have been conducted in India, showcasing their feasibility and performance. These initiatives provide valuable insights and build confidence among potential buyers and fleet operators.

Although electric HDVs have promising market potential, there are several challenges to address, including high upfront costs, limited charging infrastructure, and concerns about range and payload capacity. However, with sustained efforts from the government, industry stakeholders, and technological advancements, the market for electric HDVs in India is expected to grow in the coming years, contributing to the overall decarbonisation efforts in the transportation sector.

4 Technology Trends and Innovations

The HDV industry is advancing rapidly to enhance fuel efficiency, reduce emissions, and promote sustainable transportation. Here are some of thelatest technological developments in HDVs, including EVs, hybrid systems, alternative fuels, and energy-efficient technologies:

Electric Vehicles

Advancements in battery technology have led to the development of high-capacity lithium-ion batteries with improved energy density, range, and faster charging capabilities. These advancements contribute to the viability and performance ofelectric HDVs. Equipped with an advanced powertrain system, electric HDVs can optimise energy consumption and maximise efficiency. Regenerative braking systems, motor controllers, and intelligent power management systems enhanceenergy efficiency and range. The expansion of charging infrastructure, including fast- charging networks and high-capacity charging stations, supports the adoption of electric HDVs.

Hybrid Systems

Series hybrid systems combine an electric motor with an internal combustion engine (ICE). The ICE acts as a generator to charge the battery, which powers the electric motor. This arrangement offers flexibility and improved fuel efficiency, particularly in stop-and-go traffic conditions. Parallel hybrid systems combine an electric motor and an ICE to drive the wheels simultaneously. These systems enable power sharing between the electric motor and the ICE, resulting in improved fuel efficiency and reduced emissions.

Alternative Fuels

Compressed Natural Gas (CNG) is gaining popularity as an alternative fuel for HDVs. CNG-powered engines produce lower emissions compared to diesel engines, contributing to a reduced carbon footprint. The availability of CNG infrastructure and

the development of CNG engines for HDVs support its adoption. Liquefied Natural Gas (LNG) is another alternative fuel option for HDVs, particularly for long-haul applications. LNG offers reduced greenhouse gas emissions and improved fuel efficiency compared to diesel. The use of biofuels derived from renewable sources, such as biodiesel and bioethanol, can significantly reduce carbon emissions from HDVs. Biofuels can be blended with diesel or used as standalone fuels, depending on the engine compatibility and infrastructure availability.

Energy-Efficient Technologies

Improved aerodynamic design features, such as streamlined body shapes, aerodynamic fairings, and underbody panels, reduce drag and improve fuel efficiency. Using lightweight materials, such as aluminium, high-strength steel, and carbon fibre composites, helps reduce the weight of HDVs, leading to improved fuel economy and increased payload capacity. Advanced engine technologies, including variable valve timing, direct fuel injection, and turbocharging, enhance combustion efficiency, reduce emissions, and improve fuel economy. Telematics systems and advanced fleet management technologies enable optimised route planning, driver behaviour monitoring, and vehicle maintenance scheduling, leading to improved fuelefficiency and reduced operating costs.

These technological advancements in HDVs, including electric vehicles, hybrid systems, alternative fuels, and energy-efficient technologies, are crucial in addressing the environmental challenges and promoting sustainable transportation in the HDV sector. Continued research, development, and deployment of these technologies will contribute to the decarbonisation efforts and drive the future of HDVs towards cleaner and more efficient mobility.

5

International Practices in HDV Decarbonisation

Heavy-duty vehicles comprise a relatively small share of vehicle fleets in most countries but contribute a disproportionate share of emissions. Globally, on-road diesel vehicles—mostly HDVs—are accountable for 86 percent of nitrogen oxide emissions and 78 percent of black carbon emissions. By 2025, the worldwide HDV fleet will produce more greenhouse gas emissions than the fleet of light-duty vehicles. The potential to greatly lessen the effects on the climate and air quality, notably in growing markets and developing economies, is offered by zero-emission vehicle technology for HDVs, including battery electric vehicles and fuel-cell electric vehicles.

CO_2 emissions from HDVs in developing countries without a targeted approach and EV policies could surpass emission levels from developed countries along with China by 2050. Still, in a global EV transition scenario leading to 100 percent HDV EV adoption, CO_2 emission from HDVs in developing countries could fall 44 percent below 2020 levels in 2050.

Due to high energy requirements, substantial battery capacity requirements, and a lack of readily available vehicle types, the adoption of electric heavy-duty vehicles (HDVs) has lagged behind that of light-duty vehicles (LDVs). With improvements in battery technology, a wider variety of models and regulations to boost ZEV adoption in the HDV segment, the environment is shifting. There is an anticipation of an increase in demand in the coming years.

Table 1: EV Policies of Different Countries

Government	Target Vehicle Type	Target for new sales	Target Year	Source
Norway	Heavy Duty Trucks	50%	2030	National Transport Plan (2017, 2021)
China	Sanitation vehicles	50%	2020	Hainan's Clean Energy Vehicle Development Plan (2019)
Germany	Medium and heavy-duty vehicles	100%	2035	Zero Emissions Government Fleet Declaration (2022)
Austria	Heavy-duty vehicles	100%	2035	Mobility Master Plan (2021)
Canada	Medium and heavy-duty vehicles	100%	2035	Zero Emissions Government Fleet Declaration (2022)
Australia	Light, Medium and Heavy-duty vehicles	100%	2035	National Electric Vehicle Strategy (2023)
Belgium	Medium and heavy-duty vehicles	100%	2040	Memorandum of Understanding on Zero-Emission Medium and Heavy-Duty Vehicles (2021)
California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and the District of Columbia (United States of America)	Medium and heavy-duty vehicles	100%	2050	Memorandum of Understanding (2020)

Government	Target Vehicle Type	Target for new sales	Target Year	Source
France	Medium and heavy-duty vehicles	100%	2040	Memorandum of Understanding on Zero-Emission Medium and Heavy-Duty Vehicles (2021)
Pakistan	Medium and heavy-duty vehicles	90%	2040	National Electric Vehicle Policy (2019)

Source: Global EV Explorer

European Union (EU) has encouraged the adoption of commercial ZEVs through several laws and incentives. The 2019 HDV CO_2 regulations grant participating ZEV manufacturers up to twice the amount of credit as a diesel-fuelled truck through 2024. A benchmarking method that lowers the computation of the manufacturer's average specific CO_2 emissions whenever their ZEV sales share hits 2 percent will replace this "super-credit" approach in 2025. The Clean Vehicles Directive, which combines municipal vehicle purchases to national levels and sets ZEV procurement targets for each member state in 2025 and 2030, also supports the adoption of ZEVs. Additionally, the European Union permits electric heavy trucks to carry 2 tons more than the class maximum.

EU member states are placing policy measures to promote the adoption of electric HDVs. Since 2017, Germany, Spain, Italy, and France have offered incentives for purchasing commercial ZEVs, ranging in value from EUR 9,000 to EUR 50,000 in some cases. Up to 40 percent of the Netherlands' largest cities will adopt zero-emission zones by 2025, which is anticipated to promote the usage of electric commercial vehicles in populated regions. Netherlands and Norway announced the targets for electrifying buses and trucks. Switzerland's road tax on diesel trucks has encouraged the expansion of Fuel Cell Electric vehicle (FCEV) trucks, making them more appealing to Swiss retail associations seeking alternative fuels.

A law was passed requiring major investor-owned utilities to submit ideas for electrifying transport, including plans just for HDVs. Over the next five years, Southern California Edison plans to invest more than USD 300 million in the installation of truck and bus charging stations throughout its service area. A strategy

created by Pacific Gas & Electric calls for a subscription service in place of expensive charges for commercial ZEVs.

The government promised to spend USD 1.1 billion to buy 5,000 zero-emission public buses when it unveiled its Infrastructure Growth Plan in October 2020. Over the next five years, $2 billion will be allocated to electrify school and transit buses nationwide. Programmes to promote the adoption of zero-emission HDV are also available in Canadian provinces. Since 2017, Quebec has offered commercial goods vehicle operators a 50 percent discount off the additional cost of a new electric truck up to USD 56,000.

Intending to decarbonise the public transport bus fleet by 2035, the New Zealand government enacted a stipulation that only zero-emission public transit may be purchased starting in 2025. For this goal, the government would provide regional councils by adding USD 35 million spread over four years. Chile and Colombia set national goals for electrifying their bus fleets by 2040 and 2035, respectively, in South America in 2019.

Table 2: Major Alliances Working for Accelerating the Transition to Zero-emission Freight

	Leading organisation	Geographical scope	Mission
European Clean Trucking Alliance	European Climate Foundation	Europe	EU-wide platform for knowledge sharing and the establishment of best practices to decarbonise road freight.
ENTRANCE project	European Commission, European Shippers Council	Europe	Matchmaking platform to facilitate access to finance and increase market access to sustainable transport solutions.
Sustainable Freight Buyers Alliance	Smart Freight Centre, Business Social Responsibility, World Economic Forum	Global	Matches progressive shippers and freight forwarders with sustainable freight initiatives.
GLEC Framework	Smart Freight Centre	Global	Industry-standard methodology for the calculation of logistics GHG emissions.

	Leading organisation	Geographical scope	Mission
Science-Based Targets Initiative	CDP, the United Nations Global Compact, World Resources Institute, the World Wide Fund for Nature (WWF)	Global	Supports logistics companies in setting corporate targets for GHG emissions reduction.
Road Freight Zero	World Economic Forum	Global	Aims to accelerate the transition to zero-emission freight by providing a clear roadmap and through the establishment of de-risk initiatives and a transition finance framework.

Source: Author's Analysis

European Union

EU has been at the forefront of efforts to decarbonise the HDV sector and transition to more sustainable transportation. It has encouraged the adoption of ZEV HDVs through several laws and incentives. The 2019 HDV CO_2 regulations grant participating ZEV manufacturers up to twice the amount of credit as a diesel-fuelled truck through 2024. A benchmarking method that lowers the computation of the manufacturer's average specific CO_2 emissions whenever their ZEV sales share hits 2 percent will replace this "super-credit" approach in 2025. The Clean Vehicles Directive, which combines municipal vehicle purchases to national levels and setsZEV procurement targets for each member state in 2025 and 2030, also supports the adoption of ZEVs. Additionally, the European Union permits electric heavy trucks to carry 2 tons more than the class maximum.

Horizon 2020: The EU's research and innovation program, Horizon 2020, supports projects and initiatives focused on developing cleaner and more efficient HDV technologies. This includes research into alternative fuels, advanced engine technologies, lightweight materials, and intelligent transport systems.

European Green Vehicle Initiative (EGVI): EGVI is a public-private partnership that promotes research and development in the field of sustainable road transport. The

initiative supports projects related to electric and hybrid HDVs, alternative fuels, and energy-efficient technologies.

Green Freight Programs: The EU has launched green freight programs that encourage the adoption of sustainable practices in freight transport. These programspromote fuel-efficient driving and vehicle load optimisation and use advanced technologies for fleet management to reduce emissions in the HDV sector.

Modal Shift and Intermodal Transport: The EU encourages modal shift initiatives to promote the use of more environmentally friendly modes of transport, such as rail and inland waterways, for freight transportation. Intermodal transport solutions, combining different modes of transport, are also supported to reduce the dependence on long-haul road transport.

These policies, regulations, incentives, and infrastructure development initiatives implemented by the European Union demonstrate a comprehensive approach to decarbonising the HDV sector. By promoting the adoption of cleaner technologies, encouraging sustainable practices, and investing in infrastructure, the EU aims to reduce emissions and foster a more sustainable and efficient transport system.

The United States of America

The United States lacks an effective federal policy to assist electric HDVs. ZEVs are qualified technologies under fuel economy criteria, but no other incentives are in place. Innovative policies have, however, been adopted at the subnational level. For instance, the goal set by 15 states and the District of Columbia is for 30 percent of new commercial HDVs to be ZEVs by 2030, with the goal of 100 percent ZEVs by 2050.

The Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), started by the California Air Resources Board in 2009, lower the point-of-purchase cost of clean cars for fleets. The incentive lowers the incremental cost of commercial cars on a first-come, first-served basis. For qualified ZEV technology, incentives may be up to USD 150,000. More than USD 120 million has been paid out by HVIP for the purchase of ZEV buses and trucks. The programme was adopted in New York, and Massachusetts and New Jersey are slated to follow.

The Low Carbon Fuel Standard, which was created in 2009, rewards clean fuel generators and ZEV owners with credits that can be exchanged for fuel from non-compliant suppliers. The scheme is anticipated to promote zero-emission HDVs in particular since these fleets are more likely to obtain and accrue significant savings from utilising low-carbon fuels. In Oregon, the standard was adopted.

New Jersey adopted the Innovative Clean Transit Rule in 2018, which mandates that all buses sold after that date must be zero-emission vehicles, and the Advanced Clean Truck Rule in 2020, which leverages the LDV ZEV programme design to mandate zero-emission truck sales as a percentage of all vehicles sold for each truck manufacturer. The District of Columbia, along with 13 other states, has expressed interest in following New Jersey's lead and adopting the rule.

China

Drawing on early and ongoing measures over the past ten years, China is the global leader in the deployment of zero-emission HDVs. China has implemented several policies and initiatives to promote HDV decarbonisation, with a particular focus on electric vehicles (EVs), infrastructure development, and research and development (R&D). These measures aim to reduce emissions, improve air quality, and establish China as a leader in clean transportation. To offset higher vehicle prices (relative to ICE vehicles), the government supported the zero-emission HDV sector with large direct subsidies at first for public buses and municipally owned vocational trucks. Fuel economy requirements helped electrified components develop even more. Through the notice on enhancing the promotion and application of financial subsidy policies for New Energy Vehicles, government subsidies for electric HDVs that were scheduled to be phased out in 2019 were instead extended in 2020. The current subsidies have a ceiling of roughly USD 30,000 and are computed as a purchase pricereduction valued per kilowatt-hour (kWh) of battery capacity and adapted for bus length and truck weight. Local governments frequently add to the subsidies byplacing a cap at 50 percent of the price of new vehicles. China's comprehensive approach to HDV decarbonisation, with a focus on promoting electric vehicles, investing in infrastructure development, and supporting research and development efforts, has yielded significant progress in reducing emissions and fostering the growth of clean transportation. These policies and initiatives position China as a global leader in the transition to electric HDVs and contribute to the overall decarbonisation of the transportation sector.

Japan

Japan's HDV decarbonisation policy takes a different approach, focusing on hydrogen. Its 2017 Basic Hydrogen Strategy seeks to hasten the expansion of hydrogen production while increasing the fuel's availability and affordability. The deployment of 1,200 transit buses is among the FCEV goals outlined in its hydrogen roadmap for 2030.

Lessons for India from International experiences in HDV Decarbonisation

International experiences in HDV decarbonisation offer valuable lessons and best practices that can be applied to the Indian context. International experience emphasises the importance of setting ambitious targets and establishing a long-term vision for HDV decarbonisation. Clear and quantifiable targets provide a framework for policy development, drive investment and innovation, and create a sense of urgency in transitioning to cleaner HDVs. It is crucial to encourage various low- emission technologies instead of focusing on a single solution by adopting technology-neutral approaches. Flexibility allows for market competition and technological advancements, enabling the deployment of a diverse range of cleaner HDVs, including electric, hybrid, fuel cell, and alternative fuel vehicles.

Incentives play a crucial role in accelerating HDV decarbonisation. Financial incentives such as subsidies, tax credits, and grants can help offset the higher upfrontcosts of clean HDVs and infrastructure development. Support mechanisms, including research funding, public-private partnerships, and technical assistance, facilitate technology adoption and market transformation.

A robust charging and refuelling infrastructure is essential for the widespread adoption of electric HDVs and alternative fuels. International experiences highlight the importance of early investment in infrastructure development, including charging stations, hydrogen refuelling stations, and alternative fuel stations, to address range anxiety and promote market growth. Investments in research and development are essential for advancing HDV decarbonisation. Support for R&D activities, including technology innovation, material science, energy storage, and intelligent transportation systems, can lead to breakthroughs in the efficiency, performance, andsustainability of HDVs.

Robust regulatory frameworks are crucial for HDV decarbonisation. Emission standards, fuel efficiency standards, and vehicle scrappage policies can incentivise manufacturers to produce cleaner and more fuel-efficient HDVs. Harmonisation of standards with international norms can also facilitate trade and technology transfer. Also, Public-private partnerships play a vital role in driving HDV decarbonisation. Collaboration between governments, vehicle manufacturers, fuel suppliers, infrastructure providers, and research institutions helps leverage expertise, resources, and investments. These partnerships can accelerate technology development, infrastructure deployment, and market uptake.

Consistency and long-term stability in policy frameworks are crucial for creating a favourable investment climate and market confidence. Clear, predictable, and stable policies enable businesses to make long-term investment decisions, spur innovation, and drive market growth.

Raising awareness about the benefits of HDV decarbonisation and engaging stakeholders, including fleet operators, transport associations, environmental groups, and consumers, is vital for building support and driving demand for cleaner HDVs. Education campaigns, pilot projects, and stakeholder consultations can foster a sense of ownership and collective action. Monitoring and evaluating HDV decarbonisation progress is crucial to assess policy effectiveness and identify areas for improvement. Regular monitoring of emissions, fuel consumption, technology uptake, and infrastructure deployment helps policymakers make informed decisions and adjust strategies as needed.

By drawing from these international experiences and applying the lessons and best practices to the Indian context, policymakers in India can develop a comprehensive roadmap for HDV decarbonisation. Customising strategies while considering India's specific challenges, market conditions, and infrastructure requirements will be key to achieving the desired outcomes of reduced emissions, improved air quality, and a sustainable transportation sector.

6

Policy Implementation Challenges and Solutions

Infrastructure Development

Developing the necessary charging infrastructure for HDVs in India poses several challenges. Here are some challenges associated with charging infrastructure for HDVs in India and potential solutions to address them:

Table 3: Challenges Associated with Charging Infrastructure for HDVs in India and Recommendations

Issues	Challenges	Recommendations
Lack of Sufficient Charging Infrastructure	The availability of an extensive and reliable charging infrastructure is crucial for the widespread adoption of electric HDVs. Currently, the charging infrastructure in India is limited and primarily focused on passenger vehicles, posing challenges for HDV charging.	a) Strategic Planning: Develop a comprehensive roadmap for charging infrastructure expansion, taking into account the specific requirements of HDVs. Identify priority locations such as major transport hubs, logistics centres, and highways to ensure efficient coverage. b) Public-Private Partnerships: Encourage collaborations between government agencies, utilities, and private companies to invest in and deploy charging infrastructure for HDVs. Incentivise private sector participation through concessions, grants, or revenue-sharing models. c) Fast-Charging Corridors: Establish fast-charging corridors along major highways to support long-haul HDV operations. These corridors should be equipped with high-power charging stations strategically located at convenient intervals to minimise range anxiety.
Grid Capacity and Power Supply	Scaling up the charging infrastructure for HDVs requires a	a) Grid Modernisation: Upgrade the power grid infrastructure to accommodate the additional load from HDV charging. This includes reinforcing distribution networks, implementing smart grid

Issues	Challenges	Recommendations
	robust grid capacity and reliable power supply. The existing power infrastructure may need upgrades to handle the increased demand from HDV charging stations.	technologies, and integrating renewable energy sources to ensure sustainable power supply. b) Load Management and Demand Response: Implement intelligent charging solutions that prioritise charging during off-peak hours or when the grid has excess capacity. Incentivise fleet operators to participate in demand response programs that help balance the grid and optimise charging patterns. c) Battery Storage Solutions: Integrate battery storage systems at charging stations to manage peak demand and ensure a stable power supply. These systems can store excess electricity during low-demand periods and discharge it during high-demand periods, reducing strain on the grid.
Charging Time and Convenience	Charging time for HDVs is typically longer than refuelling time for conventional vehicles. This could impact the operational efficiency and productivity of HDV fleets, especially for time-sensitive logistics operations.	a) High-Power Charging Solutions: Invest in high-power charging technologies that reduce charging time significantly. Explore technologies like ultra-fast charging and advanced battery systems to enable faster charging without compromising battery life. b) Opportunity Charging: Implement opportunity charging infrastructure at strategic locations such as rest areas, depots, and terminals. This allows for partial charging during short stops, minimising downtime and maximising operational efficiency. c) Wireless Charging: Explore the feasibility of wireless charging technologies for HDVs, which offer the convenience of automatic charging without physical connections. Research and development efforts can focus on improving the efficiency and scalability of wireless charging systems.
Financial Viability and Business Models	Charging infrastructure investments require substantial upfront	a) Public Funding and Incentives: Provide financial support through grants, subsidies, low-interest loans, or tax incentives to attract private investment in charging infrastructure. Government funding can

Issues	Challenges	Recommendations
	capital, and the financial viability of charging stations is a concern, especially in the early stages of HDV adoption.	help offset the initial investment costs and create a more favourable business environment. b) Revenue Diversification: Explore different revenue streams associated with charging infrastructure, such as service fees, advertising partnerships, or integration with energy management systems. Diversifying revenue sources can enhance the financial viability of charging stations. c) Pay-as-You-Go Models: Implement pay-as-you-go or pay-per-use charging models that allow HDV operators to pay for the electricity consumed, similar to fuel purchases for conventional vehicles. This reduces the need for large upfront investments and aligns costs with actual usage.
Standardisation and Interoperability	Ensuring standardisation and interoperability of charging infrastructure is critical for seamless operations and user convenience. A lack of standardised charging protocols and connectors can hinder the widespread adoption of electric HDVs.	a) Adoption of International Standards: Align with global standards for charging protocols and connectors to ensure interoperability across different charging stations and vehicle models. This allows HDV operators to use any charging station without compatibility issues. b) Regulatory Framework: Develop and enforce regulations that mandate standardisation of charging infrastructure. Encourage the use of open-source protocols and promote interoperability to foster competition, innovation, and a thriving charging ecosystem. c) Collaboration and Industry Cooperation: Encourage collaboration between charging infrastructure providers, vehicle manufacturers, and industry stakeholders to develop common standards and protocols. Industry-led initiatives and consortiums can facilitate the development and adoption of interoperable charging solutions.

Source: Author's Analysis

Overcoming these challenges requires a coordinated effort between government agencies, private sector entities, utilities, and other stakeholders. By implementing these proposed solutions and addressing the specific challenges associated with HDV charging infrastructure, India can create an enabling environment for the widespread adoption of electric HDVs and accelerate the decarbonisation of the HDVsector.

Cost Considerations

Decarbonising the HDV sector in India is a critical step towards achieving the country's climate goals, but it comes with significant costs. Electric HDVs, for example, have a higher upfront cost compared to their conventional counterparts, and charging infrastructure development requires substantial investments. Therefore,it is essential to develop strategies that can make the transition to cleaner HDVs economically viable for stakeholders.

The government can provide financial incentives to HDV operators to offset the higher upfront costs of electric HDVs and charging infrastructure. These incentives could include tax breaks, subsidies, and grants for the purchase and deployment of electric HDVs and charging infrastructure. For instance, FAME scheme offers financial incentives to promote the adoption of EVs, including HDVs. Public-privatepartnerships can also help reduce the financial burden of HDV decarbonisation.Governments can work with private companies to develop and operate charging infrastructure. Private companies can provide the initial investment, and governmentscan offer subsidies and tax breaks to offset the costs. This model can also help drive innovation in charging infrastructure technology, which can further reduce costs overtime.

Regulatory frameworks can encourage the adoption of cleaner HDVs by setting fuel efficiency standards and emission norms. For instance, the Indian government has implemented BS emission standards that mandate the use of cleaner fuels and technologies for vehicles. Adopting more stringent standards can drive the development and adoption of cleaner HDVs, which can reduce operating costs over time. Business model innovation can also make the transition to cleaner HDVs more economically viable for stakeholders. For example, fleet operators can adopt a pay-per-use model, where they pay only for the electricity consumed, similar to fuel purchases for conventional vehicles. This reduces the need for large upfront

investments and aligns costs with actual usage. Lastly, Innovation in battery technology can significantly reduce the cost of electric HDVs. The cost of batteries has been rapidly declining, and further technological advancements could drive costseven lower. Governments can incentivise research and development efforts to drive innovation in battery technology and reduce the cost of electric HDVs.

HDV decarbonisation in India requires substantial investments and is critical for achieving the country's climate goals. Combining financial incentives, public-private partnerships, regulatory frameworks, business model innovation, and battery technology innovation can make the transition to cleaner HDVs more economically viable for stakeholders. These strategies can also create new economic opportunities and spur innovation in the HDV sector, leading to long-term benefits for the country.

Stakeholder Engagement

Engaging various stakeholders is crucial for the successful implementing HDV decarbonisation policies in India. Each stakeholder group plays a unique role and has specific interests and perspectives that must be considered.

Government Agencies

They play a central role in formulating and implementing policies related to HDV decarbonisation. It is important to engage these agencies to ensure effective coordination, policy alignment, and resource allocation. Their involvement helpscreate a supportive regulatory environment, establish emission standards, and provide incentives for adopting cleaner HDVs. Government agencies can also facilitate the development of necessary infrastructure and monitor compliance with regulations.

Vehicle Manufacturers

It is crucial to engage with vehicle manufacturers since they are the ones responsible for the production and supply of heavy-duty vehicles (HDVs). Manufacturers can provide valuable insights into technological advancements, production capabilities, and market trends. Collaboration with manufacturers can help align policy objectives with industry capabilities, ensuring the availability of a wide range of cleaner HDV options. Engaging manufacturers can foster innovation, promote research and development, and facilitate technology transfer.

Fleet Operators

Fleet operators, including logistics companies and transportation service providers, are major users of HDVs. Engaging fleet operators is crucial to understanding their specific needs, operational challenges, and financial considerations. Their feedback can improve policy design and implementation, ensuring practical and effectivesolutions. . Collaborating with fleet operators can also help identify barriers to adoption, provide real-world data on performance and operational costs, and foster a supportive ecosystem for the transition to cleaner HDVs.

Infrastructure Providers

Charging infrastructure providers, fuel suppliers, and other stakeholders involved in infrastructure development are key players in HDV decarbonisation. Engaging these stakeholders is important to address the challenges associated with charging infrastructure deployment, fuel availability, and maintenance. Collaboration can help identify infrastructure gaps, prioritise investment, and develop solutions that meet the specific requirements of HDVs. Engaging infrastructure providers ensures HDV fleets are supported by suitable charging and refuelling networks.

Consumers

Engaging consumers, including businesses and individual vehicle owners, is crucial for creating demand and driving the adoption of cleaner HDVs. Educating consumers about the benefits of decarbonisation, addressing concerns related to range, charging infrastructure, and cost, and providing information on available incentives can help build awareness and increase acceptance. Engaging consumers can also stimulate market demand, which drives industry investment, innovation, and economies of scale.

By engaging these stakeholders, policymakers can understand the challenges and opportunities associated with HDV decarbonisation. It allows for a collaborative approach that considers diverse perspectives, fosters innovation, and builds consensus. Engaging stakeholders also enhances transparency, accountability, and public support for policy initiatives, leading to more effective implementation and a smoother transition to cleaner HDVs in India.

Regulatory Framework

A supportive regulatory framework is crucial for HDV decarbonisation in India as it provides the necessary structure and incentives to drive innovation, attract investments, and ensure compliance with decarbonisation targets. It encourages innovation by setting clear goals, providing incentives, and fostering a competitive environment. Regulations can require emission standards or fuel-efficiency targets, which incentivise manufacturers to invest in research and development of cleaner technologies. By creating a supportive environment, various regulations stimulate innovation, leading to the development of advanced propulsion systems, lightweight materials, and energy-efficient technologies.

A well-designed regulatory framework attracts investments by providing certaintyand stability to the market. Investors, including manufacturers, charging infrastructure providers, and fleet operators, require a predictable regulatory environment to make long-term investment decisions. Clear regulations and policies create confidence, reduce risks, and encourage investments in producing cleaner HDVs, charging infrastructure, and related technologies.

Regulations can also act as powerful drivers for market transformation by setting decarbonisation targets and timelines. By establishing ambitious but achievable targets, the regulatory framework sends a signal to the industry and market participants that a shift towards cleaner HDVs is necessary and inevitable. This encourages stakeholders to align their strategies, business models, and investments with the decarbonisation goals, leading to a more rapid transition to sustainable transport solutions.

A supportive regulatory framework establishes clear guidelines and standards, ensuring compliance with decarbonisation targets. Regulations can set emission standards, fuel efficiency norms, and other performance criteria that HDVs must meet. Robust enforcement mechanisms, such as vehicle inspections, emissions testing, and penalties for non-compliance, create accountability and ensure that the industry adheres to the prescribed standards. Compliance measures promote fair competition, create a level playing field, and incentivise manufacturers and operatorsto invest in cleaner technologies.

International cooperation is essential for technology transfer, knowledge sharing, and harmonisation of regulations. By adopting compatible standards, India can benefit from global research and development efforts, access international markets, and attract investments from multinational companies. Aligning with international best practices also enhances the country's credibility and reputation in the global market.
A supportive regulatory framework is crucial for HDV decarbonisation in India. It encourages innovation, attracts investments, drives market transformation, ensures compliance, and enables international collaboration. Such a framework provides a clear roadmap, certainty, and incentives for stakeholders, facilitating the transition to cleaner HDVs and helping India achieve its decarbonisation targets.

Technological Readiness

Adopting cleaner HDV technologies in India faces technological barriers, including those related to EVs and alternative fuels. However, solutions exist to overcome these challenges.

Table 4: Key Barriers to Adoption of Cleaner HDV Technologies and Recommendations

Issues	Barriers	Solutions
Limited Charging Infrastructure for EVs	Insufficient charging infrastructure is a major hurdle to the widespread adoption of electric HDVs. The lack of a robust charging network, especially for long-haul vehicles, poses range anxiety and limits the operational feasibility of EVs.	**a) Scaling Up Charging Infrastructure**: Implement a comprehensive plan to rapidly expand public and private charging infrastructure, particularly along major transportation corridors and at logistics hubs. This includes deploying fast-charging stations, establishing dedicated EV charging stations at rest areas, and incentivising private businesses to install charging infrastructure. **b) Smart Grid Integration:** Develop smart grid systems that can handle the increased demand from HDV charging. This involves integrating renewable energy sources, energy storage, and demand response mechanisms to optimise grid utilisation and support the charging needs of a growing EV fleet. **c) Battery Swapping and Fast Charging Solutions:** Explore battery swapping models for

Issues	Barriers	Solutions
		HDVs, where depleted batteries can be quickly replaced with fully charged ones. Additionally, advancements in fast-charging technologies can significantly reduce charging time and improve the convenience of EV charging for HDVs.
High Initial Cost of Electric HDVs	Electric HDVs currently have a higher upfront cost compared to conventional vehicles, making them less economically viable for fleet operators.	**a) Financial Incentives:** Provide financial incentives, such as subsidies, tax breaks, and grants, to offset the higher upfront costs of electric HDVs. Government schemes like the FAME can be expanded to include commercial HDVs. **b) Collaborative Procurement Programs:** Collaborative procurement programs can aggregate demand from multiple fleet operators to negotiate lower prices with manufacturers. This reduces the upfront cost for individual operators and increases the affordability of electric HDVs. **c) Battery Leasing or Renting Models:** Explore battery leasing or renting models, where operators pay for the use of batteries rather than purchasing them outright. This lowers the initial cost of electric HDVs and shifts the responsibility of battery maintenance and replacement to specialised service providers.
Limited Availability of Alternative Fuels	The availability and accessibility of alternative fuels, such as biofuels and hydrogen, are limited in India. The inadequate infrastructure for fuel production, distribution, and refuelling poses a challenge to the adoption of these fuels for HDVs.	**a) Fuel Infrastructure Development**: Invest in the development of infrastructure for alternative fuel production, such as biofuel plants or hydrogen refuelling stations. This includes establishing strategic partnerships with fuel suppliers, incentivising private investments, and creating a regulatory framework that promotes the use of alternative fuels. **b) Technology Development:** Support research and development efforts to enhance the production and processing of alternative fuels. This includes developing efficient conversion technologies, exploring advanced feedstocks, and optimising

Issues	Barriers	Solutions
		production processes to increase the availability and affordability of alternative fuels. **c) Policy Support:** Implement policies that mandate a certain percentage of alternative fuels in the HDV sector. This can create a market demand for alternative fuels and incentivise fuel suppliers to invest in infrastructure and production capabilities.
Limited Technological Awareness and Skilled Workforce	A lack of technological awareness and a skilled workforce can hinder the adoption of cleaner HDV technologies. The HDV industry requires technicians, engineers, and operators who are knowledgeable about electric and alternative fuel systems.	**a) Training and Skill Development Programs:** Establish training programs and initiatives to upskill technicians and professionals in the HDV sector. This includes training on electric vehicle technology, alternative fuel systems, and maintenance procedures. **b) Collaboration with Educational Institutions:** Collaborate with universities, technical institutes, and vocational training centres to develop specialised courses and curricula focused on HDV electrification and alternative fuel technologies. This helps create a pipeline of skilled professionals who can drive the adoption of cleaner HDVs. **c) Awareness Campaigns:** Conduct awareness campaigns and outreach programs to educate industry stakeholders, fleet operators, and the general public about the benefits and technology advancements in cleaner HDVs. This fosters acceptance, promotes knowledge-sharing, and encourages early adoption.

Source: Author's Analysis

Overcoming these technological barriers requires a multi-faceted approach that involves infrastructure development, policy support, financial incentives, and skill development. By addressing these challenges, India can pave the way for the widespread adoption of cleaner HDV technologies and accelerate the decarbonisation of the transportation sector.

7

Economic and Environmental Benefits of HDV Decarbonisation

Quantifying the potential reduction in carbon emissions resulting from HDV decarbonisation in India requires considering various factors, including the adoption of cleaner technologies, the scale of deployment, and the timeline for implementation.

Transition to Electric HDVs

Electric HDVs emit zero tailpipe emissions, resulting in significant CO2 reductions compared to fossil fuel vehicles. The magnitude of emissions reduction depends on the share of electric HDVs in the overall HDV fleet and the carbon intensity of the electricity grid. If India's power generation mix includes a substantial proportion of renewable energy sources, the reduction in CO2 emissions will be even more prominent. According to a study by NITI Aayog[4], widespread zero emission trucks adoption could reduce annual trucking carbon emissions 46 percent by 2050 equivalent to 2.8-3.8 gigatonnes of cumulative CO_2 savings.

Additionally, adoption of alternative fuels for HDVs, such as natural gas, biofuels, and hydrogen, can contribute to carbon emissions reduction. Alternative fuels have lower or even net-zero lifecycle emissions compared to fossil fuels. However, the extent of emissions reduction depends on factors such as the carbon intensity of the fuel production process, the availability of sustainable feedstocks, and the efficiency of fuel utilisation. Assessing the precise reduction in carbon emissions from alternative fuels requires detailed analysis considering specific scenarios and implementation strategies.

India has set ambitious climate change goals, including the commitment to reduce the emission intensity of its GDP by 33-35 percent by 2030 from 2005 levels as partof its NDCs under the Paris Agreement. HDV decarbonisation plays a crucial role in achieving these goals by significantly reducing emissions from the transportation

4 https://www.niti.gov.in/sites/default/files/2022-09/ZETReport09092022.pdf

sector, which is a significant contributor to greenhouse gas emissions. The specific contribution of HDV decarbonisation to India's climate change goals depends on the scale and pace of implementation, policy support, and the integration of othersectors.

It's important to note that quantifying the exact reduction in carbon emissionsresulting from HDV decarbonisation requires comprehensive modelling and analysis that considers various factors, including vehicle penetration rates, fuel consumption, fuel efficiency, energy mix, and policy scenarios. Robust data on the HDV fleet, fuel consumption patterns, and energy sources are necessary for accurate calculations.

In conclusion, HDV decarbonisation has the potential to contribute significantly to India's climate change goals by reducing carbon emissions. Transitioning to electric heavy-duty vehicles and adopting alternative fuels can reduce CO_2 emissions. However, precise quantification of the reduction requires detailed analysis and modelling, considering specific scenarios and implementation strategies. By prioritising HDV decarbonisation and aligning it with climate change goals, India can make substantial progress in mitigating greenhouse gas emissions and combating climate change.

Improved Air Quality

HDV decarbonisation in India has a significant positive impact on air quality, leading to reductions in particulate matter and other harmful pollutants. It’s powered by fossil fuels, such as diesel and gasoline, are major contributors to particulate matter pollution. Diesel exhaust emissions, in particular, contain fine particles known as PM2.5 and PM10, which have adverse health effects. Decarbonising the HDV sector through the adoption of cleaner technologies, such as electric vehicles or vehicles using alternative fuels, significantly reduces PM emissions. EVs produce zero tailpipe emissions, while alternative fuels, such as natural gas or biofuels, produce lower levels of particulate matter compared to conventional fossil fuels. Electric HDVs and vehicles running on alternative fuels emit significantly lower levels of Nitrogen Oxides, Sulphur dioxide, carbon dioxide and carbon monoxide compared to their diesel counterparts. An 85 percent sales penetration of electric trucks by 2050 could result in the reduction of 750,000 tonnes of PM and 24.5 million tonnes of Nitrogen Oxides emissions through 2050, a reduction of 40 percent from business-as-usual scenario.[5]

[5] https://www.niti.gov.in/sites/default/files/2022-09/ZETReport09092022.pdf

Improving air quality through HDV decarbonisation has direct public health benefits. Particulate matter, nitrogen oxides, sulphur dioxide, and other harmful pollutants released by conventional HDVs are linked to respiratory problems, cardiovascular diseases, and other health issues. By reducing these emissions, especially in highly populated areas and urban centres, the health and well-being of the population can be improved, leading to lower healthcare costs and a higher quality of life.

Economic Opportunities and Job Creation

The growth of the electric HDV industry in India presents significant economic opportunities across various sectors. Here is an assessment of the economic opportunities associated with the growth of the electric HDV industry:

Job Creation

The transition creates new employment opportunities across the value chain. The growing industry of electric vehicles encompasses a wide range of jobs, from manufacturing and assembly to research and development, battery production, charging infrastructure deployment, and maintenance services. As the demand for electric vehicles increases, there will be a corresponding rise in demand for skilled workers in areas such as electric vehicle technology, battery management, and charging infrastructure installation. This will create job opportunities and provide opportunities for upskilling for the workforce.

Technological Advancements

The growth of the electric HDV industry stimulates technological advancements in battery technology, electric drivetrains, power electronics, and energy management systems. This fosters innovation and research and development activities, leading to the development of advanced and more efficient technologies. Integrating artificial intelligence, connectivity, and smart grid solutions in electric HDVs opens up opportunities for tech companies to develop and deploy innovative solutions, further driving economic growth and competitiveness.

Enhanced Manufacturing Capabilities

The electric HDV industry presents opportunities for domestic manufacturers to expand their capabilities and compete in the global market. As the demand for electric HDVs increases, domestic manufacturers can invest in building manufacturing facilities, assembly lines, and supply chains for electric vehicle

components. This strengthens the domestic manufacturing ecosystem, improves technological capabilities, and supports the Make in India initiative. It also attracts foreign direct investment in the electric vehicle sector, which enhances manufacturing capabilities and creates jobs.

Infrastructure Development

The growth of the electric HDV industry necessitates the development of charging infrastructure, including public charging stations, depot charging facilities, and fast-charging networks along major transportation routes. This infrastructuredevelopment creates opportunities for construction companies, electrical equipment manufacturers, and service providers to participate in the deployment andmaintenance of charging infrastructure. Establishing a robust charging network contributes to economic growth and job creation in the infrastructure sector.

Market Expansion and Export Potential

The global market for electric HDVs is growing rapidly, driven by increasing environmental regulations and the adoption of sustainable transportation solutions. As India develops its electric HDV industry, it can tap into this global market by exporting electric vehicles, components, and charging infrastructure. This presents opportunities for Indian manufacturers to expand their market reach, generate export revenues, and enhance their competitiveness in the global electric vehicle market.

Ancillary Services and Support Industries

The growth of the electric HDV industry creates demand for ancillary services and support industries. This includes battery recycling and repurposing, development of charging management systems and software, electric vehicle fleet management solutions, and aftermarket services such as maintenance and repair. These ancillary services and support industries offer economic opportunities for businesses and entrepreneurs, contributing to job creation and economic growth.

The growth of the electric HDV industry in India brings significant economic opportunities, including job creation, technological advancements, enhanced manufacturing capabilities, infrastructure development, market expansion and the growth of ancillary services and support industries. These opportunities contribute to economic growth, promote sustainable development, and position India as a global leader in the electric vehicle industry.

Energy Security and Independence

HDV Decarbonisation in India can significantly contribute to energy security by reducing dependence on imported fossil fuels and promoting the use of domestic energy sources. India heavily relies on imported fossil fuels to meet its energy needs, including diesel and gasoline for the HDV sector. This dependence on imports exposes the country to price volatility, supply disruptions, and geopolitical risks. India can reduce its dependence on imported fossil fuels by transitioning to cleaner HDVs powered by domestic sources, such as electricity, biofuels, and hydrogen. This improves energy security by diversifying the energy mix and reducing exposure to international market fluctuations. Decarbonising the HDV sector creates opportunities to tap into India's abundant domestic energy resources. For example, India has a significant potential for renewable energy generation, including solar and wind power, which can be harnessed to supply electricity for electric HDVs. Bypromoting the use of domestic energy sources, India can leverage its resources, enhance energy self-sufficiency, and reduce reliance on fossil fuel imports.

Transitioning to cleaner HDVs powered by domestic energy sources can stimulate the growth of domestic industries. It encourages the development of a local ecosystem for manufacturing, supplying, and maintaining electric vehicles, charging infrastructure, and alternative fuels. This reduces dependence on imports and promotes the growth of indigenous industries, leading to job creation, economic development, and technological advancement in the energy and transportation sectors.

India can mitigate the risks associated with price volatility and supply disruptions by reducing dependence on imported fossil fuels. Fluctuations in global oil prices and geopolitical tensions can have significant impacts on fuel prices and availability. Decarbonising the HDV sector reduces exposure to such risks and provides a stable and secure energy supply, which is essential for the smooth operation of transportation services, logistics, and the overall economy.

HDV decarbonisation in India contributes to energy security by reducing dependence on imported fossil fuels, promoting the utilisation of domestic energy sources, stimulating indigenous industries, and mitigating price volatility and supply disruptions. India can enhance energy self-sufficiency, create job opportunities, and improve the overall environmental and health conditions by transitioning to cleaner HDVs.

8

Corridor Assessment

Delhi-Jaipur Highway

Delhi-Jaipur Expressway, a section of National Highway (NH) 48, is an 8-lane highway that spans approximately 195 km, connecting Delhi to Rajasthan's capital, Jaipur. Connecting two prominent cities in north India, this is one of the busiest highways in India. It's a vital component of the Delhi-Mumbai Industrial Corridor with several of the industrial townships like Manesar, Pataudi, Bawal and Nangal Choudhary in Haryana and Bhiwadi, Behror, Kotputli, Shahapura and Chomu in Rajasthan connected along the route. This expressway passes through 423 villages of 11 tehsils in 7 districts- Gurgaon, Jhajjar, Rewari, Mahendergarh, Alwar, Sikar and Jaipur of Haryana and Rajasthan. The total land required for the project was 1,755.9 hectares (4,339 acres). The cost includes ₹6,350 crores for civil works, ₹5,000 crores for resettlement and rehabilitation of affected individuals, and ₹50.60 crores for the environment budget.

National Highways Authority of India (NHAI) has set the target for developing EV charging infrastructure by installing charging stations at every 50-kilometre distance along the national highways by 2023.

While the number of charging stations found along the highway during the survey was less than expected, it still had a fair number of charging stations, most of which were situated within 25 kilometres from each other. Delhi-Jaipur highway holds an advantage over other potential highway corridors in terms of the number of charging stations and connectivity to the nearby towns – the highway is along the cities and does not require specific entry and exit points. Most of the charging stations along the Delhi-Jaipur Highway are installed within the premises of food complexes and petrol pumps, providing better visibility and accessibility.

Ensuring sufficient power capacity is crucial when installing charging stations for medium and heavy-duty vehicles. It is critical that all such charging stations must have a rated capacity of 30 kW or above. Of the six fast chargers along the route,

four charging stations had a power rating of 60 kW, which is essential for the fast charging of commercial vehicles. These chargers would usually take 45-50 minutes to fully charge a medium-duty vehicle and 90-120 minutes for a heavy-duty vehicle. A drawback is that for charging a vehicle, the owner/driver needs a mobile application specific to the charging service provider. This not only limits the accessibility to all charging stations but could require further training of generally non-tech-savvydrivers.

The highway has a vast network of supporting infrastructure and is well connected to other state highways of Rajasthan. There are several educational institutes along the highway which can be a proponent for higher sales of commercial vehicles making a case for charging capacity expansion. There were charging stations of different service providers like Zivah Electriva, Tata Power, Statiq, Yahhvi and Alektrify. Most of these charging stations are located near hotels and shopping malls in places like Chandwaji, Raghunathpura, Kherki Daula, Behror, and Neemrana. These charging stations had a Power Rating between 30 kW to 60 kW with a Rated Frequency of 50/60 Hz. Most of these charging stations were installed within the last three years, and the largest EV station in India - equipped with 100 charging points for four- wheelers - is located along this corridor.

SLOT Analysis

STRENGTH	LIMITATIONS
• Adequate number of charging stations • Readily available Infrastructure support • Easy connectivity to towns/ cities along the highway • Proximity to automobile manufacturing hub in Manesar along the highway • The highway serves as a gateway to Rajasthan – a famous tourist destination • Advantage of logistics in charging point installation	• Lack of safety measures • Operation and maintenance challenges - many charging points were dysfunctional • Completely automated charging procedure • Inadequate supporting infrastructure – shading, waiting areas, drinking water facilities, etc. • Location of the charging infra • Unsatisfactory user interface • Unregulated tariff structure

OPPORTUNITY	THREAT
• Great scope for capacity expansion – space availability is not a concern • Multiple partnership opportunities with food and shopping complexes, resorts, etc. • Development of service network • Demand is not limited to vehicles plying on the highway • Higher concentration of two-wheelers on the highway	• High exposure to heat and dust • Growth rate of charging infrastructure not matching up with EV sales • Constantly evolving charging technology • Charging time constraints for commercial vehicle category • Non-tech savvy (generally commercial) vehicle operators may find the charging process cumbersome

Delhi-Jaipur highway has adequate number of charging stations to cater to the demand of current volume of EVs. Moreover, these charging stations are not concentrated in a specific area but distributed equidistantly on both sides of the highway. Majority of the charging stations are along the highway and there is no requirement of exiting the highway and navigating for the charging station. Due to high traffic volume, ample number of restaurants, food complexes, hotels and resorts are along the highway which not only provides land for charging stations but additional infrastructure support. It cuts across the major towns and cities along the route providing an ease of connectivity in inter-city delivery of goods. Automobile and industrial hubs in Manesar, Neemrana, Rewari etc. are along the highway can supplement the development of EV ecosystem. The highway is considered as agateway to Rajasthan and goods from most northern states are transported along the route to Jaipur and inner parts of the state. The development of this highway holds a significant economic value. Currently, majority of the charging service providers operate out of Delhi-National Capital Region (NCR) region and installing charging station along Delhi-Jaipur highway is a cost-effective exercise for these organisations. It was found that standard operating procedures (SOPs) for charging were not clearly defined in any of the charging stations and this could pose a serious safety concern with high voltage cables in operation. Charging stations were not regularly serviced which was evident as many stations were either defunct or had other technical issues. Completely automated charging procedure can be a hindrance for commercial fleet owners in absence of capacity building initiatives. Many charging points were devoid of basic infrastructure facilities such as shade, waiting area with sitting facility, drinking water etc. which could demotivate a

potential buyer**.** An EV owner must have a knowhow of mobile applications for charging which generally differ from one service provider to other**.** The highway cuts across two different states namely Haryana & Rajasthan which may have different tariff structure for charging EVs. This could influence the decision of a where to charge a vehicle.

Given the semi-arid geography of the region, land availability for charging stations is not a big concern in terms of regulatory clearance, hence providing a greater scope for capacity expansion. As stated earlier, there are many food and shopping complexes, resorts, etc., along the highway, and many of the surveyed charging stations were installed within these premises. This provides a degree of comfort to vehicle operators and passengers while charging their vehicles. Charging stations within these complexes create a mutually beneficial business model for every stakeholder involved and will likely be the way forward. The ease of connectivity to towns along the highway and automotive hubs can provide additional support in developing a robust EV service network. Not only do vehicles on the highway benefit from these charging stations, but EV operators from nearby regions also find value inthe installed infrastructure. The demand from this category can also present an opportunity for service providers. The movement of electric two-wheelers is comparatively higher on the Delhi-Jaipur Highway, creating an additional scope for service providers.

The proximity to the highway causes excess dust accumulation on charging stations, which have multiple delicate electronic components and circuits. This could increase the frequency of maintenance required. Furthermore, exposure to natural elements like heat and rain in the absence of a covering structure can accelerate asset deterioration. The lag in growth between EV sales and charging infrastructure can put an additional burden on existing facilities and cause congestion at charging stations. This factor significantly influences the commercial vehicle segment where the timely delivery of goods is associated with revenue generation. Constantly evolving charging technology may render the existing charging infrastructure underutilised or of no value. This was observed for many of the charging points installed before 2020. The average charging time for commercial vehicles ranges from 60 to 120 minutes, depending on the capacity of the charging point. This is a significant amount of time for commercial vehicles, where the time to deliver goodsis proportionate to the revenue generated. All charging points require a mobile

application to access, control, and monitor. Downloading and using applications can be quite challenging for some users, particularly for elderly and non-tech-savvy vehicle operators.

Assessment of Delhi-Jaipur Highway

Delhi-Jaipur highway is an important link between the national capital and state capital of Rajasthan for socio-economic development. Additionally, it is a lifeline and livelihood opportunity for many people from 423 villages with an estimated population of 2 million, which are along the highway or close.

Although the highway has a comparatively strong network of charging infrastructure, it still has scope for further strengthening the daily traffic volume. With the Delhi NCR region being the hub of EV manufacturing and Delhi having the highest penetration among all other states, the number of EVs on this highway are going to increase rapidly, suggesting an underlying need for rapid deployment of charging stations.

Delhi Jaipur highway is well connected to many industrial towns, which makes it a hotbed of economic opportunities. Setting charging infrastructure here would not just support help in decarbonising transport but will also boost tourism from the green tourism perspective. With all the factors considered, the highway is the most preferred choice for the pilot project.

Yamuna Expressway (Delhi-Agra)

Stretched along the Yamuna River, the Yamuna expressway connects the cities of Noida and Agra in the state of Uttar Pradesh. The six-lane expressway was inaugurated in 2012 to reduce congestion on NH-19 (Delhi-Mathura-Agra) and provide uninterrupted freight and passenger traffic movement for the towns and commercial centres on the eastern side of the Yamuna Expressway. It also provides better connectivity to Lucknow as well, the capital of Uttar Pradesh, as it extends to the Agra-Lucknow expressway starting from Agra. The expressway was constructed to serve the infrastructure development in the Greater Noida region. It significantly reduces the travelling time between Agra and Delhi by at least two hours.

The total cost of construction of the highway was ₹ 13,300 crore. There are very few traffic junctions on the highway, roughly 50 flyovers, and only 60 places where pedestrians can cross, making the highway strictly vehicle-prone. For safety, security cameras and SOS booths have been installed all along the route. Thirteen service roads, totalling 168 km, were constructed for local commuters along the expressway. Rest areas with parking, restaurants, gas stations, auto repair shops, payphones, public restrooms, and drinking water kiosks are available along the route.

Though Yamuna Expressway is among the several routes considered under the electrification of highway programme and a trial run for an Electric Bus was undertaken by National Highways for Electric vehicles in November 2022, it was observed that there are still major developmental blocks that need to be addressed before electric commercial vehicles can run on this route. Some of the major findings were the majority of the charging points were either installed near the entry point (Greater Noida) or at the exit (Agra). The facilities for charging along the route were not satisfactory. A few charging stations which were along the route were installed a few years back and had less rated power capacity. The charging stations were not maintained and were either dysfunctional or had other technical issues. Locating the charging stations was difficult as they were not along the route but on service roads. From a commercial vehicle perspective, the existing charging infrastructure lacked both capacity and volume. The cities along the expressway are not in proximity to the route and their exit routes stretch several kilometres; not a viable alternative for freight vehicles to use this expressway when commuting between say Delhi and Mathura. The toll charges are also on the higher side on this route which can further influence the decision of a commercial fleet owner. The alternate option of NH-19 which connects Delhi with Agra and well connected to cities along the route seems a better choice. There were only two charging stations of different service providerslike Exicom and Tata Power. Both of these charging stations are installed in Noida. There was another charging station at Vrindavan exit which was installed by REIL. These charging stations had a Power Rating between 30 kW to 60 kW with a Rated Frequency of 50/60 Hz.

SLOT Analysis

STRENGTH	LIMITATIONS
• Connects two major industrial and tourist hubs • Better road infrastructure • Preferred route for vehicles heading from Delhi to Agra • Government support for developing the expressway into an e-highway • Connected to other important freight corridors (Agra-Lucknow) • Uncongested traffic movement	• Expressway specifically designed for passenger vehicle movement • Underdeveloped charging infrastructure along the expressway • Locating charging stations is a challenge • Long exit routes to cities along the expressway • Demand limited to vehicles plying on the expressway • Unregulated tariff structure
OPPORTUNITY	**THREAT**
• Great scope for charging infrastructure development • Readily available infrastructure support • Possibility of shifting freight movement from an alternate route • Additional support from tourism • Economical for transportation of agricultural products	• High toll charges can limit the development of freight movement • Remote location is a challenge for the development of the service network • Connectivity to the grid can be a major issue in some land pockets • Preference of service provider to install charging points within city limits due to logistical constraints

The expressway connects two major industrial hubs and tourist attractions – Delhi & Agra. The traffic movement along the route will grow subsequently the movement of electric vehicles. There are also several planned projects alongside the highway like Jewar International Airport, the Uttar Pradesh-Film City project, the Toy Park, the Medical Device Park and the Leather Park which will give a further boost to economic activities and can play a crucial part in the installation of charging infrastructure. Existing infrastructure support like rest areas with parking and shelters, hotels and restaurants, gas stations, auto repair shops, pay phones, public restrooms, and drinking water kiosks can aid the charging infrastructure development**.** The expressway is supported through policy and regulatory framework for transforming into an e-highway**.** The expressway further extends to the Agra-Lucknow expressway which can attract long-term freight movement given the charging infrastructure is well developed**.** However, the charging infrastructure along the expressway is underdeveloped with very few charging points. The existing ones were either defunct

or were installed for two-wheelers. The expressway was specifically designed to decongest the NH-19 and reduce travel time with a focus on passenger vehicles. Incorporating freight vehicles into the fold has many challenges. Locating charging points along the expressway is another weakness as the few that are installed are along the service roads/ exit routes. The connectivity to cities along the route is goodbut quite far from the expressway which demotivates commercial vehicle owners to operate on this route. The demand for charging stations on Yamuna-Expressway will remain limited to vehicles running on the road which can affect the decision of charging service providers.

Land availability is not a concern and plenty of partnership opportunities for charging service providers already exist. As stated earlier, existing infrastructuresupport in the form of public amenities can be a booster for charging infrastructure development. Given that charging infrastructure is developed, the long-distancefreight movement could see a gradual shift to the expressway as it is well connected to other major cities of Uttar Pradesh and does not cross through inner city regions. With the area being a major tourist attraction with famous heritages like the Taj Mahal and Fatehpur Sikri, electrification of the Yamuna expressway can aid in faster and smoother related supply chain operations. As the area is one of the biggest producers of Sugarcane in India, promoting electric medium and heavy-duty vehiclesfor agro-transport can go a long way and serve the economic benefits of farmers andthe agriculture value chain.

Since the expressway is well-built and has a few additional features as well, the road tax is on the higher side. This can demotivate commercial fleet operators fromputting vehicles on the expressway. Given the remoteness of the expressway, the development of a service network is a big challenge. Service providers may also shy away from investing in this region due to revenue loss concerns owing to higher logistical costs. Some pockets of areas along the expressway have very poor or no grid connectivity. Additional efforts would be required, for a uniform development of charging infrastructure leading to increased cost.

Assessment of Yamuna Expressway

The success of the Yamuna Expressway can be attributed to its robust infrastructure and the presence of modern facilities. However, in terms of providing support for electric vehicles, many other national and state highways have performed far better.

The upside is that infrastructure support and land availability are not a concern, which is essential for transitioning into an e-highway. There are several infrastructure projects in the planning stage in this region, including the Noida International Airportin Jewar, which will enhance transportation across all categories. A well-developed charging infrastructure on the Yamuna expressway can promote electric vehicles not only in the passenger segment but also in goods movement. The Uttar Pradesh government issued the state EV policy in October 2022 and can further assist in the development of charging infrastructure on the Yamuna expressway. At the present stage, it can be assumed that the expressway is not yet ready for electric vehicles, especially in the commercial vehicle segment.

Eastern Peripheral Expressway

The Eastern Peripheral Expressway (EPE) is a 135 km long expressway alongside the eastern periphery of the National Capital Region of Delhi. Along with the Western Peripheral Expressway, it is part of the largest ring road surrounding Delhi. It starts from Kundli, Sonipat, in Haryana, where it separates from the Western Peripheral Expressway and traverses across Baghpat, Aligarh, Ghaziabad, Noida districts of Uttar Pradesh, and Faridabad in Haryana. It reconnects the western stretch at Palwal. It was built with the aim of preventing pollution from a large number of commercial vehicles entering Delhi. It was expected that it would help divert more than 50,000 trucks away from Delhi and reduce air pollution by 27 percent. It was also constructed to relieve traffic congestion on the Ghaziabad-Faridabad route. It has a total of 406 structures, including 46 minor bridges, 4 major bridges, seven interchanges, 3 flyovers, 8 railway overbridges, and 221 underpasses. The Eastern Peripheral Expressway is the first green and smart highway in India, with solar panels installed along the route to provide power to toll plazas and other facilities. Rainwater harvesting systems have been installed at every 500-meter distance. The construction of EPE has led to a boost in the development of real estate, with cities like Baghpat, Palwal, and Kundli becoming hotspots for real estate investment. Of thethree highway corridors surveyed (the other being Delhi-Jaipur and Yamuna Expressway), EPE is least suitable for carrying out a pilot project to assess the feasibility of electrification of medium and heavy-duty vehicles. Though the ring roadis specifically designed to keep commercial vehicles away from inner city regions dueto pollution and traffic congestion constraints, the total absence of charging stations on the expressway and nearby regions does not sit well with the concept of running electric commercial vehicles on this route.

Moreover, EPE is distantly connected to the cities along the route and has noadditional infrastructure support for the development of charging infrastructure.Scouting for charging stations on the expressway could be a tedious task, with charging stations only within inner regions of adjoining cities and none on the expressway itself. The potential for deploying charging stations on EPE is quitemassive in terms of land availability and charging stations powered by solar. However, the absence of infrastructure support, poor accessibility to nearby cities, which is somewhat essential for capacity and service network expansion and fragmented traffic movement make the expressway the least favoured choice for carrying out a pilot project

SLOT Analysis

STRENGTH	LIMITATIONS
• India's first green and smart highway with modern facilities like a Highway Traffic Management System (HTMS) and an intelligent Video Incident Detection System (VIDS) • Huge potential for charging infrastructure development • Policy and regulatory support	• Absence of charging infrastructure • Poor accessibility to cities along the expressway • Expressway specifically designed for distant goods transportation • Comparatively less traffic movement
OPPORTUNITY	**THREAT**
• Development of not just charging infrastructure but the whole EV ecosystem • Land availability and access to power • Scope for establishing manufacturing units • Infrastructure specifically designed for heavy-duty vehicles	• Possibility of investments turning into non-revenue generating assets • Limited scope for medium-duty vehicles • Unregulated tariff structure as the expressway passes through different states • Safety concerns for charging infrastructure

EPE is India's first green and smart highway that connects some of the major cities in Delhi NCR region. This expressway has some very modern facilities which are rarely found om other highways across the country such as a Highway Traffic Management System and an intelligent Video Incident Detection System. The area along the

expressway is sparsely populated mostly consisting of villages. The land can be availed at far cheaper rates as compared to peri-urban areas. It is also on the list of 16 highways on which Convergence Energy Services plans to set up charging stations. Presently, there are no charging stations along the route and mostly concentrated in inner regions of adjoining cities. The cities along the expressway are distantly connected to EPE which creates a possibility of poor service network. Mostly, vehicles on long-distance trips use this expressway to avoid the huge urban areas of NCR. This limits the demand only to such vehicles. The traffic movement is also less as compared to other corridors further limiting the expansion of demand.

There is an opportunity for heavy investment-backed infrastructure projects which, under its ambit, take food and shopping complexes, resorts, recreational facilities, EV charging stations, etc. Delhi NCR is host to a lot of EV manufacturing companies, which have their manufacturing plants in cities around EPE. Better charging infrastructure can bring a whole lot of economic opportunities for these organisations and can give a boost to the economic potential of this region. Since this area is also an industrial hub, this would help them lower the cost of transportation of goods.

Though this expressway has a range of modern infrastructure with amenities, it still seems unprepared for the extension of charging infrastructure. The charging infrastructure on this expressway is inadequate, with most charging stations being inside the cities. Reports of theft, kidnapping and accidents on the Eastern Peripheral Expressway have increased recently. Though patrolling vans are at every 25 km to avoid criminal activities, it points out the lacklustre approach of administration with alack of modern facilities like automatic vehicle number plate readers and speed readers.

Assessment of Eastern-Peripheral Expressway

The Eastern Peripheral Expressway, which was built in only 17 months, presents multiple opportunities and benefits to all concerned stakeholders. In the case of the development of the EV ecosystem, EPE has great potential but lags far behind the other highway corridors studied. Several limitations, as highlighted in the SWOT analysis, make EPE the least preferred choice for the pilot project.

Probably, with more development in the EV space and policy-level interventions, the expressway can become investors' topmost choice for establishing manufacturing units, installing charging stations, and service centres, but that scenario is still a few more years ahead.

9 Pilot Project

Parameters for conducting pilot projects

The corridor assessment exercise helped in identifying the Jaipur-Delhi highway as most conducive for conducting the trial runs, and two sets of trial runs with different categories of electric cargo vehicles (three and four-wheeler) were executed.

The baseline data generated under certain parameters was compared with conventional cargo vehicles to make a case for the economic advantage of electric vehicles over conventional cargo vehicles. The set of parameters on which the assessment was based are as follows:

- **Total lifecycle cost (with an estimated life cycle of 10 years for electric three-wheeler and 12 years for electric four-wheeler))**

  This included the following details:

  - Total landed cost of the vehicle: Market price for cargo vehicles in both categories with similar power output and load capacity, finance cost and different financial mechanisms, insurance cost, registration cost, taxes, subsidies, etc.
  - Operating cost: Based on pilot runs, an estimate of the total kilometres covered during the life cycle of the vehicle will provide data on fuel expenditure for both electric and conventional vehicles.
  - Maintenance cost: Yearly maintenance costs along with auto component replacement costs, including batteries and tyres, will be considered based on kilometres covered.
  - Asset utilisation factor: Electric vehicles take longer to charge than conventional ones, which can impact time-sensitive assignments and revenue generation. This loss can be compared against the fuel-saving benefits of electric vehicles.
  - Salvage cost: Both categories of vehicles will be evaluated based on their resale value after 10 years. This is a significant aspect of the study since the

salvage value of electric vehicles will depend on whether the battery was recently replaced or not, while conventional vehicles depreciate at an average rate.

- Any other costs will be based on interactions with several vehicle operators, both in the conventional and electric segments.

- **Charging infrastructure**
  - Different categories of electric vehicles require different power capacities for efficient charging. During trial runs, charging stations will be evaluated based on the charging time for batteries to power up from 20 percent to 80 percent for different categories of vehicles.
  - The concentration of charging stations (charging stations per 100 km) will be evaluated and compared against estimated cargo traffic along the route. This will provide data points on the adequacy/inadequacy of charging infrastructure to cater to electric cargo vehicles.
  - Location of charging infrastructure: This is a critical aspect of charging infrastructure from the freight sector's point of view. A depot-based system is more conducive for cargo vehicles, and qualitative aspects of the location of charging stations will be evaluated.

- **Environmental benefits**
  - The carbon reduction potential of electric vehicles in different categories will be calculated per kilometre and over the life cycle.
  - The current percentage of renewable components in electricity generation will be factored into the data for accuracy and will be escalated to 50 percent by 2030 and beyond to showcase the decline in the trend line for carbon emissions from fuel sources for electric vehicles.

- **Build Quality**
  - Overall build quality for similar power capacities and load capacities in both segments will be evaluated. This will include vehicle body material, operator comfort, robustness, cabin body quality, and IT-enabled features, including safety, etc.

- **Socio-economic Benefits**
  - Employment generation: The creation of livelihood and entrepreneurship opportunities, especially in the last mile connectivity of goods, will be considered as a parameter for comprehensive evaluation.
  - Gender inclusivity: The scope for increasing the participation of women in the mobility transition, pertaining to the freight sector, in this case, will be observed. Again, it will be safe to assume that more opportunities will lie in the last-mile connectivity of goods.

Table 5: Vehicle Specifications of Electric Three-Wheeler Cargo

Vehicle type	
Variant	Delivery Van
Vehicle Category	L5N
Vehicle Roof type	Hard Panel
Dimension - length x width x height - mm	3,100x1,460x2,175
Vehicle dimension and weight	
Wheelbase - mm	2,216
Ground clearance - mm	123
Rear track - mm	1,220
Turning radius - mt	3.05
Vehicle kerb weight - kg	495
Gross vehicle weight - kg	995
Payload - kg	500
Box size - length x width x height (inside dimensions) - mm	1,564x1,452x1,494
Performance	
Top speed km/h	50
Driving range - km	80
Gradeability - degree	7
Battery type, voltage - V	Lithium-ion, 48 V
Battery capacity - kWh	7.37
Charging time at standard conditions	3 h 50 mins (15-18% - 97-98%)
Drivetrain	
Peak power - kW	8
Peak torque - Nm	42
Transmission type	Direct drive technology
Suspension & brakes	

Suspension-front	Helical spring + damper + hydraulic shock absorber
Suspension-rear	Rigid axle with leaf spring
Brakes-front/rear	Hydraulic brakes
Parking brake	Mechanical lever type
Features: Windscreen wiping system, spare wheel provision, Driving modes -FNR (Forward, Neutral, Reverse), Economy and boost mode, Lockable glove box, 12 V socket, Telematics unit and GPS, 15 A off-board charger, Hazard indicator, Reverse buzzer	

Table 6: Cost Estimations for Electric Three Wheelers

Cost of Financing	14% at 90% debt financing
Operating and Maintenance cost	8% of the total vehicle cost
Salvage Value	10% of the total vehicle cost
Asset Utilisation	300 days a year

Table 7: Vehicle Specifications of Electric Four-Wheeler Cargo

Vehicle Type	
Variant	Container
Container volume - m^3	5.88
Seating capacity	2
Vehicle dimensions and weight	
Length - mm	3,800
Width - mm	1,500
Height - mm	3,800
Wheelbase - mm	2,100
Ground clearance - mm	160
Cargo box dimensions - mm	2,163x1,475x1,847
Minimum TCR - mm	4,300
Gross vehicle weight - kg	1,840
Kerb weight	1,240
Payload	600
Performance	
Top speed - km/h	60
Driving range	110-120 km*
Maximum power - kW	27
Maximum torque - Nm	130
Battery	Lithium-ion iron phosphate (LFP)
Battery capacity - kWh	21.3

Maximum grade ability - %	22
Charging time at standard conditions	1h 45 mins Fast charging (10%-80%), 6-7h Normal charging (20%-80%)
Clutch and transmission	
Gearbox type	Single speed gearbox
Clutch	Clutch-free rear-wheel drive
Steering	Mechanical, variable ratio
Suspension & brakes	
Brakes	Dual circuit hydraulic brakes front
Suspension	Right front & rear suspension - with leaf springs
Tyres	155 R13 LT 8PR

Table 8: Cost Estimates for Electric Four Wheelers

Cost of Financing	11% at 90% debt financing
Operating and Maintenance cost	10% of the total vehicle cost
Salvage Value	15% of the total vehicle cost
Asset Utilisation	300 days a year

For electric three and four-wheelers, three consecutive trial runs were conducted on the Delhi-Jaipur highway to assess the potential operational constraints for regular usage of such vehicles. The following table represents the parameters considered during the trial runs.

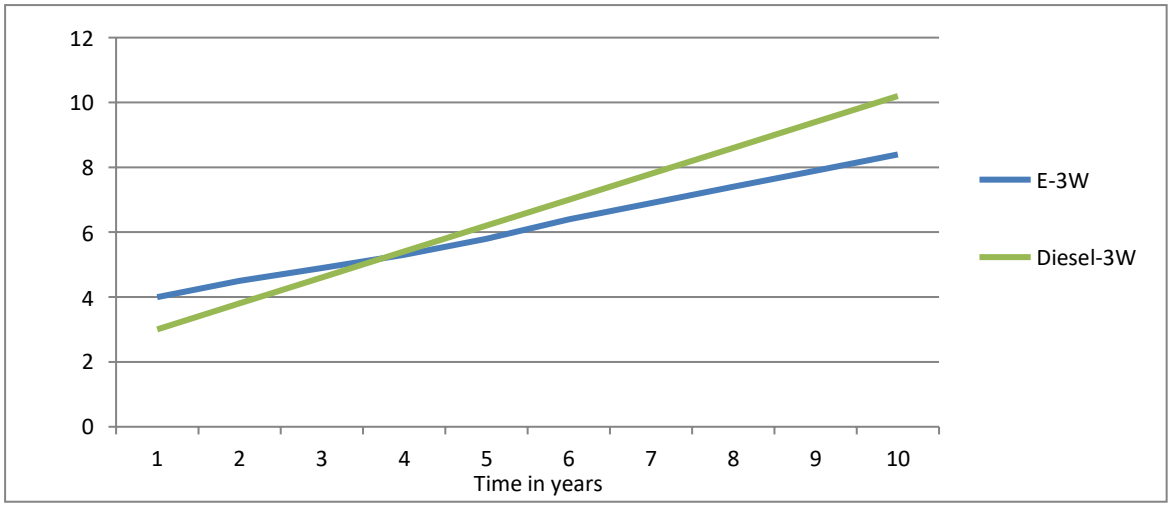
Table 9: Data from Trial Runs

Parameters	Three Wheeler	Four Wheeler
Total distance	175 km x 3 days	192 km x 3 days
Payload	250 kg	380 km
Average speed	26 km/hr	37 km/hr
Running cost	₹ 0.8 /km	₹ 1.15/km
Per day mileage	100 km	140 km
Electricity tariff	₹ 6.66/kWh	₹ 6.66/kWh
Lifecycle of vehicle	10 years	12 years

After analysing the data, we compared the total cost of ownership for electric three and four-wheeler cargo vehicles with that of conventional counterparts. The cost assumptions for conventional vehicles were derived from the consultations with

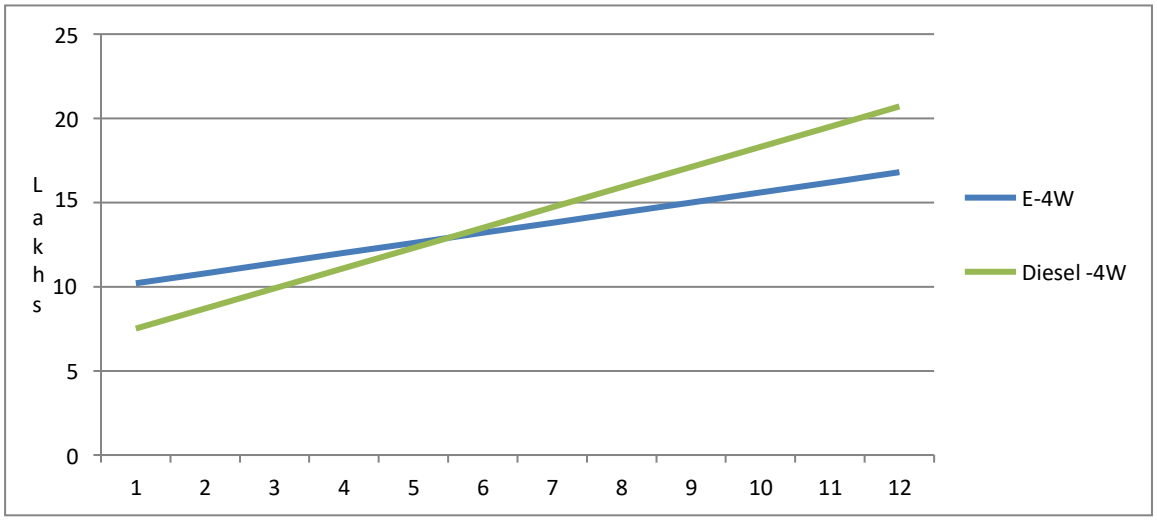
automotive dealers and operators. Other factors included- Financing and insurance costs, maintenance costs, operation and maintenance costs, asset utilisation and salvage costs.

Figure 6: Total Cost of Ownership Comparison between Conventional and Electric Three-Wheeler



The above figure highlights the difference in the upfront cost which is around ₹ 100,000 but the differential breaks even at somewhere around the three-and-a-half-year mark. There on, the monetary benefits continue to increase due to savings in operating costs and at the end of the 10th year, the overall cost-benefit touches the ₹ 200,000 mark.

Figure 7: Total Cost of Ownership Comparison between Conventional and Electric Four-Wheeler



In the four-wheeler category, the upfront cost differential between conventional and electric vehicles is much higher compared to three-wheelers. The difference is above ₹ 250,000, and the break-even cost is achieved at the six-year mark. Since four-wheelers provide greater mileage, the monetary benefits accrued after the sixth year are much higher. This amounts to ₹ 400,000 at the end of the 12th year.

In conclusion, the overall cost economics favour electric three and four wheelers over conventional three and four wheelers in the commercial automotive segment. The need is to look into the ancillary aspects of cost of financing, insurance cost, and resale values associated with EV which is on the higher side as compared with conventional vehicles due to several market factors. FAME III could absorb these market differentials by subsidising medium and heavy duty commercial vehicles.

10

Way Forward

There are multiple challenges in promoting electrification of medium and heavy duty vehicles in the freight sector. The market is nascent and currently limited to intra-city B2B and B2C markets especially online platforms. To expand, several factors ranging from charging infrastructure to low-energy density of batteries must be evaluated addressed through policy and market interventions.

Charging Infrastructure

The existing charging infrastructure regulations for may not prove to be effective for medium and heavy duty trucks and special category of regulations must be introduced that addresses the charging requirement of freight vehicles including location, volume and manned support. The tariff must also be harmonised to counterthe almost uniform tariffs for conventional fuels like diesel across different states. Charging hubs that can cater the demand of more than 25-30 trucks at a time and also provide affordable services of resting, food, auto repair, etc. at regular intervals of 100-150 kilometres can significantly contribute in developing electric freight sector from the demand side.

State Industrial Development Corporations

State Industrial Development Corporations can play a crucial role in creating demand for electric trucks by introducing regulations for industries for having an electric fleet for in-house operations in industrial zones. This can be supported by CSR/ESG funds of the industries. In doing so, charging infrastructure, the biggest challenge for electrifying MDV & HDVs, can be tackled effectively by deploying few charging stations in each industry within the industrial zone. The entire fleet of trucks that transports goods within a limited periphery in and around the industrial zones can beelectrified which will further boost demand.

FAME III

Introduction of subsidies for medium and heavy duty trucks can be an incentive for potential buyers to negotiate the higher cost of financing for electric vehicles as compared conventional vehicles. But even a 5-10 percent subsidy for heavy duty trucks could amount to huge amount of sums. Rolling out targeted and phase wise subsidies could reduce the burden of exchequer. Promoting domestic manufacturing can sometimes have a trade-off of slow market development and higher product price. Any subsidy scheme must not entirely link itself with domestic production and there should be enough space for free market trade.

Research & Development

This is another critical aspect of making MDV and HDV industry emission free. With trucks, the high battery capacity results in higher weights of battery that hampers their load carrying capacity. With similar rated power capacity, conventional trucks can carry more loads and hence more revenue generation. This phenomenon is somewhat less with MDVs but these are not generally preferred for longer routesdue to cost economics. Investing in research and development to produce better batteries at lower costs or an introducing altogether different technology as a better alternate can generate the push required to get the markets for electric MDVs and HDVs progress in coming years.

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CUTS International

D-217, Bhaskar Marg, Bani Park, Jaipur 302016, India
Ph: +91.141.2282821, Fax: +91.141.2282485
Email: cuts@cuts.org, Web Site: www.cuts-international.org

Also at Delhi, Calcutta and Chittorgarh (India); Lusaka (Zambia); Nairobi (Kenya); Accra (Ghana); Hanoi (Vietnam); Geneva (Switzerland), and Washington DC (USA)