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Supporting the Adoption of EV for Road Freight Transport

May 2024

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Master of Planning
(Transport Planning and Logistics Management)

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Thesis submitted in partial fulfillment of the requirements for the award of the degree of

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By
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Declaration

I **Divyansh Khare**, Scholar No. **2022MTPLM011** hereby declare that the thesis titled **"Supporting the Adoption of EV for Road Freight Transport"** submitted by me in partial fulfilment for the award of **Master of Planning**, at School of Planning and Architecture, Bhopal, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

Signature of the Student

Date: _______________

Certificate

This is to certify that the declaration of **Divyansh Khare** is true to the best of my knowledge and that the student has worked under my guidance in preparing this thesis.

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ACCEPTED

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Abstract

The electrification of medium and heavy-duty trucks (MHDTs) in India represents a crucial step toward achieving sustainable and carbon-neutral road transport, particularly addressing the significant environmental impact of commercial vehicles, which are responsible for 40% of vehicular emissions. The EMHDT's system contributes to reducing harmful emissions and promotes the use of renewable energy sources. A detailed literature review illuminates the current MHDT landscape in India, as well as the global and domestic availability of electric MHDT (EMHDT) technology. The existing ecosystem for EMHDT's has been analyzed through consultations with original equipment manufacturers (OEMs) and market studies. This thesis explores the challenges that hinder the widespread integration of EMHDT's within the Indian logistics sector, taking into account technological, infrastructural, economic, and policy-related factors. Utilizing a comprehensive dataset derived from primary data collection, stakeholder consultations, expert interviews, and policy analysis, the study identifies and examines obstacles to electric truck adoption. It also provides a detailed mapping of stakeholders involved at various levels, defining their roles and responsibilities in the EMHDT ecosystem. Furthermore, the exploration of business models and their benefits, along with a total cost of ownership calculation in different cases, is presented. The results demonstrate that the adoption and operation of EMHDT's in the early phase are significantly dependent on travel characteristics as well as government policy and initiatives. For widespread adoption in the later phase, overcoming technological constraints and developing supporting infrastructure are crucial. Mitigation strategies are provided in the conclusion, which can play an essential role in overcoming identified barriers. Additionally, policy-level recommendations are offered to support the mitigation of existing barriers and promote the widespread adoption of EMHDT's.

Keywords: Electric Medium and Heavy Duty Truck, Charging Infrastructure, Total Cost of Ownership, Business Models, Policy.

सारांश

भारत में मध्यम और भारी-भरकम ट्रकों (MHDT) का विद्युतीकरण टिकाऊ और कार्बन-तटस्थ सड़क परिवहन प्राप्त करने की दिशा में एक महत्वपूर्ण कदम का प्रतिनिधित्व करता है, विशेष रूप से वाणिज्यिक वाहनों के महत्वपूर्ण पर्यावरणीय प्रभाव को संबोधित करता है, जो 40% वाहन उत्सर्जन के लिए जिम्मेदार हैं। इलेक्ट्रिक माध्यम और हेवी-ड्यूटी परिवहन प्रणाली हानिकारक उत्सर्जन को कम करने में योगदान देती है और नवीकरणीय ऊर्जा स्रोतों के उपयोग को बढ़ावा देती है। एक विस्तृत साहित्य समीक्षा भारत में वर्तमान एमएचडीटी परिदृश्य के साथ-साथ इलेक्ट्रिक एमएचडीटी (EMHDT's) तकनीक की वैश्विक और घरेलू उपलब्धता पर प्रकाश डालती है। ईएमएचडीटी के लिए मौजूदा पारिस्थितिकी तंत्र का विश्लेषण मूल उपकरण निर्माताओं (OEM) और बाजार अध्ययन के साथ परामर्श के माध्यम से किया गया है। यह थीसिस उन चुनौतियों की पड़ताल करती है जो तकनीकी, बुनियादी ढांचे, आर्थिक और नीति-संबंधित कारकों को ध्यान में रखते हुए भारतीय लॉजिस्टिक्स क्षेत्र के भीतर ईएमएचडीटी के व्यापक एकीकरण में बाधा डालती हैं। प्राथमिक डेटा संग्रह, हितधारक परामर्श, विशेषज्ञ साक्षात्कार और नीति विश्लेषण से प्राप्त व्यापक डेटासेट का उपयोग करते हुए, अध्ययन इलेक्ट्रिक ट्रक अपनाने में बाधाओं की पहचान करता है और उनकी जांच करता है। यह ईएमएचडीटी पारिस्थितिकी तंत्र में उनकी भूमिकाओं और जिम्मेदारियों को परिभाषित करते हुए विभिन्न स्तरों पर शामिल हितधारकों की विस्तृत मैपिंग भी प्रदान करता है। इसके अलावा, विभिन्न मामलों में स्वामित्व गणना की कुल लागत के साथ-साथ व्यवसाय मॉडल और उनके लाभों की खोज प्रस्तुत की गई है। परिणाम दर्शाते हैं कि प्रारंभिक चरण में ईएमएचडीटी को अपनाना और संचालन यात्रा विशेषताओं के साथ-साथ सरकारी नीति और पहल पर काफी हद तक निर्भर है। बाद के चरण में व्यापक रूप से अपनाने के लिए, तकनीकी बाधाओं पर काबू पाना और सहायक बुनियादी ढांचे का विकास करना महत्वपूर्ण है। निष्कर्ष में शमन रणनीतियाँ प्रदान की गई हैं, जो पहचानी गई बाधाओं पर काबू पाने में आवश्यक भूमिका निभा सकती हैं। इसके अतिरिक्त, मौजूदा बाधाओं को कम करने और ईएमएचडीटी को व्यापक रूप से अपनाने को बढ़ावा देने के लिए नीति-स्तरीय सिफारिशें पेश की जाती हैं।

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Abbreviations

ACC	Advanced Chemistry Cell
ACT	Advanced Clean Trucks
AEEE	Alliance for and Energy Efficient Economy
AISC	Automotive Industry Standards Committee
BET	Battery Electric Trucks
BEV	Battery Electric Vehicles
BIS	Bureau of Indian Standards
CAPEX	Capital Expenditure
CMVR	Central Motor Vehicle Rules
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
COP	Conference of the Parties
DC	Direct Current
DISCOMS	Distribution Companies
DOD	Depth of Discharge
ELV	Electric Light Vehicle
EMHDT	Electric Medium and Heavy Duty Trucks
EOL	End of Life
EU	European Union
EV	Electric Vehicles
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FCET	Fuel Cell Electric Trucks
FCEV	Fuel Cell Electric Vehicles
GDP	Gross Domestic Product
GHG	Green House Gases
GOI	Government of India
GRA	Grey Relational Analysis
GVW	Gross Vehicle Weight

gWh	Gigawatt-Hours
HDT	Heavy Duty Trucks
HGV	Heavy Goods Vehicles
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IIT	Indian Institute of Technology
INR	Indian Rupee
kW	Kilowatt
kWh	Kilowatt Hour
LCA	Life Cycle Analysis
LGV	Light Goods Vehicle
LMO	Lithium Manganese Oxide
LTO	Lithium Titanium Oxide
MDT	Medium Duty Truck
MGV	Medium Goods Vehicle
MHDT	Medium and Heavy Duty Trucks
MNRE	The Ministry of New and Renewable Energy
MoHI	Ministry of Heavy Industries
MoRTH	Ministry of Road Transport and Highways Road Transport
MoRTH	Ministry of Road Transport and Highways
MOU	Memorandum of Understanding
NCA	Lithium Nickel Cobalt Oxide
NEMMP	National Electric Mobility Mission Plan
NHAI	National Highway Authority of India
NIT	National Institute of Technology
NMC	Lithium Nickel Manganese Cobalt Oxide
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturers
OH-ACD	Overhead - Automated Charging Devices
OPEX	Operational Expenditure
Pb-A	Lead-Acid

PESO	Petroleum and Explosives Safety
PLI	Plicy Linked Incentives
PM	Particulate Matter
PPP	Public Private Partnership
R&D	Research and Development
REC	Rural Electrification Corporation Limited
RFID	Radio-Frequency Identification
RTO	Regional Transport Offices
SOH	State of Health
SOx	Sulphur Oxides
TCO	Total Cost of Owneship
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
ULB	Urban Local Bodies
VKT	Vehicle Kilometers Traveled
WRI	World Resources Institutes
ZET	Zero Emission Truck

1. INTRODUCTION

Road freight demand is predicted to become the second largest in the world during the next ten years, so it will be crucial to make sure that new trucks support a more environmentally friendly transportation network in order to meet the nation's 2070 net zero objective. Approximately 71% of India's freight is transported by road.(Sudhendu Sinha, 2022) The transport sector, crucial for economic growth, notably contributes to environmental pollution, particularly in rapidly developing nations like India. Fossil fuels, primarily oil (93%), account for 96% of the transportation sector's energy consumption in 2021. Freight Vehicles represent just 3% of the total vehicle fleet yet are responsible for 34% of road transport emissions and one-third of nation’s diesel consumption (Chandana, 2023).

The Ministry of Road Transport and Highways Road Transport Yearbooks and Vahan, the vehicle-related e-governance application portal, both provide data that show a significant increase in the registration of new trucks 2007 and 2022. In India, over half of all freight vehicle registrations occur in seven states. The clustering of logistics hubs and the existence of high-intensity road freight corridors are responsible for the concentration of registrations, demonstrating the vital role that trucks play in India's transportation system (Vahan Dashboard, 2024).

Electrification of Medium and Heavy-duty trucks (MHDTs) in India is crucial for environmental sustainability and reducing fossil fuel dependence. Electric trucks promise lower greenhouse gas emissions, reduced operating costs, and decreased reliance on imported oil. Emission life cycle assessment provides a better a picture of total emissions via both vehicles i.e. ICE vehicle and electric truck. This shift is also essential for improving air quality in expanding urban areas, addressing public health concerns. However, transitioning to electric trucks faces challenges, including technical and infrastructure issues like the need for robust charging networks and advanced battery technology. Economic and policy barriers, such as higher initial costs and the need for supportive government policies, also pose significant hurdles.

Vehicles that transport raw materials, completed goods, and recyclable materials are essential components of the value chain. They also have a big impact on the economy of the nation. Interestingly, more than half of all freight vehicle registrations occur in seven states in India. The clustering of logistics hubs and the existence of high-intensity road freight corridors are responsible for the concentration of registrations, indicating the crucial role that trucks play in India's transportation landscape. (Chandana, 2023)

This study investigates the challenges associated with the adoption of electric trucks, utilizing a comprehensive dataset derived from primary research, consultations, and expert interviews. Industry experts from reputable organizations such as Alliance for and Energy Efficient Economy (AEEE), International Council on Clean Transportation (ICCT), World Resources Institutes (WRI), and pManifold, along with academicians from esteemed institutions like Indian Institute of Technology (IITs) and National Institute of Technology (NITs), were consulted. In order to grasp the vision and operational intricacies of electric trucks in India, IPL Tech, Ashok Leyland a prominent Electric Truck Manufacturer, generously shared and discussed numerous details during visit and meeting. Additionally, meetings with truck operators provided valuable insights into their expectations and operational costs for Internal Combustion Engine (ICE) trucks. It evaluates policies like State EV policies, FAME II, the National Electric Mobility Plan, and NITI Aayog’s e-Fast Scheme. A key focus is the Total Cost of Ownership (TCO) analysis for electric trucks, assessing capital and operational costs against conventional models. This research aims to provide insights for industry stakeholders, guiding strategy development in India's emerging electric truck sector, a critical move towards a sustainable and environmentally-friendly transportation future.

1.1 Background

India, boasting a $3 trillion GDP and growing, ranks as the world's sixth-largest economy. The freight transportation sector is rapidly expanding to ensure that a growing assortment of goods and products is delivered to an increasing consumer base. Presently, India handles about 4.6 billion tons of freight annually at a cost of

INR9.5 lakh crore, covering 2.2 trillion tonne-kilometres, reflecting a significant demand for transportation.(NITI Aayog Sudhendu Sinha Joseph Teja, n.d.). In India, roads account for more than two thirds of the goods movement.

Rising income levels, e-commerce, urbanization, and population growth are all contributing to an increase in the demand for products. By 2050, associated road freight flow is predicted to reach 9.6 trillion tonne-km due to the continued growth in demand. The majority of such road transportation is carried out by heavy- and medium-duty trucks (HDTs and MDTs, respectively). Additionally, the number of vehicles is predicted to more than quadruple as road freight travel increases, rising from 4 million in 2022 to around 17 million by 2050. (Sinha Sudhendu , Joseph Teja, 2022)

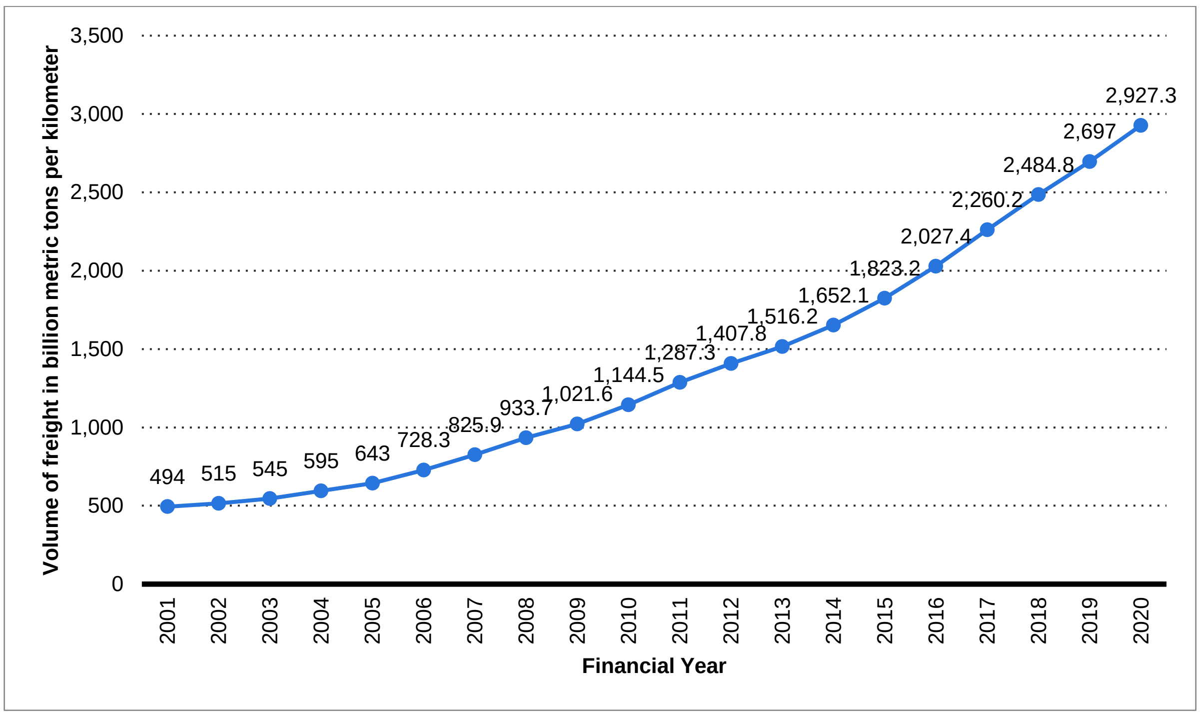


Figure 1: Freight movement by road transportation in India from financial year 2001 to 2020 (in billion metric tons per kilometer)
Source: Ministry of Road Transport and Highways (India); ID 667440

In India, medium and heavy-duty vehicles exhibit lower fuel efficiency compared to similar vehicles in regions such as the USA, China, and Europe, resulting in increased fuel usage and elevated fuel expenses. Approximately 90% of road freight transport, measured in vehicle kilometers traveled (VKT), relies on diesel, a major pollutant. This situation presents a chance to transition towards more environmentally friendly fuel alternatives, such as battery-electric or hydrogen fuel cell electric vehicles.

In the upcoming decades, there will likely be a significant increase in the freight movement due to rising e-commerce, rising consumption, and rising standards of life. Given the expected increase in freight vehicles and their fuel usage, decarbonizing freight transport is crucial due to its impact on the environment and public health. To achieve its goal of net-zero carbon emissions by 2070, India must reduce its CO_2 emissions by 1 billion tonnes by 2030.

Given these market trends, zero-emission trucks (ZETs), Electric Trucks, present a strong substitute for the diesel trucks that currently dominate India's road freight. ZETs offer India a chance to demonstrate how adopting ZETs is both cost-effective and beneficial for the environment, public health, and air quality. ZETs also have no tailpipe emissions.

Although switching from road to rail freight transportation is the most energy-efficient decarbonization technique, this option is not very practical in India. Poor last-mile connectivity and a lack of widely distributed train infrastructure are the main causes of this. This compels India to consider more environmentally friendly vehicle technologies as a workable decarbonization plan for the transportation of freight by road, such as battery and fuel cell electric trucks (EVs).

1.2 Need of Study

As awareness of the economic and environmental benefits of Zero Emission Trucks (ZETs) grows, more countries are shifting away from diesel trucks. The United Kingdom has set a goal for all Heavy-Duty Trucks (HDTs) to be ZETs by 2040, while the European Union plans to have 80,000 ZETs on the roads by 2030 as part of its push to electrify freight trucks. The first international agreement on ZETs was established at COP26. In the United States, California has introduced the Advanced Clean Trucks rule, which requires manufacturers to progressively increase their sales of ZETs. Additionally, forums such as the Zero Emission Vehicles Transition Council are enhancing global dialogue about the capabilities of ZETs. The global transportation sector uses a quarter of the world’s energy and is responsible for 28 percent of greenhouse gas emissions, significantly influencing climate change. Beyond the emission of greenhouse gases, the transport sector also discharges detrimental compounds such as nitrogen oxides (NOx) into the atmosphere, contributing to localized air pollution.

India can establish a unique market position in the international export market by increasing the usage of ZET. The need for freight and haulage will rise most significantly from emerging nations like India as supply chains become more global. India can demonstrate leadership on a worldwide scale by increasing the usage of ZET. Coordinated public and commercial initiatives will be needed to expand the manufacturing supply of ZETs and install the necessary charging infrastructure if India's ZET market is to thrive. To stimulate the market, propel expansion, and quicken the supply and demand of ZET, ambitious measures are needed.

In India, freight vehicles are categorized as light (GVW<3.5T), medium(GVW<3.5T<12T), or heavy(GVW<12T<55T) commercial vehicles based on their gross vehicle weight (GVW). Out of the 16.7 million freight vehicles, light goods vehicles (LGVs) account for 60.39% of the vehicle stock, while heavy goods vehicles (HGVs) and MGV’s make for 34.47% and 5.14% respectively (Vahan Dashboard, 2024). The yearly CO_2 emissions from these freight vehicles are 213 Mt. HGVs make up just 34.47% of all freight vehicles, but they are responsible for almost 80% of these emissions.(Spurthi Ravuri, 2022).

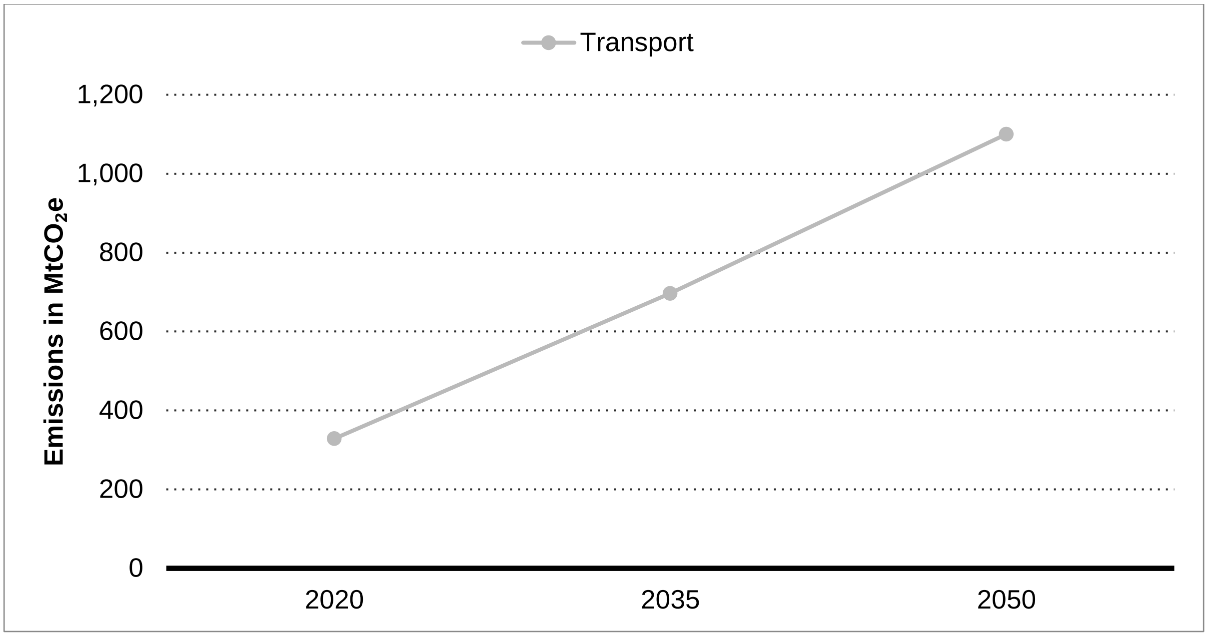


Figure 2: Projected greenhouse gas emissions in India under a business-as-usual scenario from 2020 to 2050, by sector (in million tons of CO_2 equivalent)
Source: World Data Lab; ID 1381668

The broad adoption of Zero Emission Trucks (ZETs) across MHDT's sectors promises to transform India's transport sector. Despite initial higher costs compared to diesel-powered trucks, economies of scale could make the Total Cost of Ownership (TCO) for ZETs in the MDT category more economical than that of diesel trucks. Additionally, the HDT sector is expected to reach TCO parity soon, thanks to technological improvements in vehicles and batteries, coupled with the significantly reduced operating costs per kilometer of ZETs.

The development of a vibrant ZET market could establish India as a leading international center for battery production, aligning with the National Energy Storage Mission. This could create a considerable demand for batteries made within the country, projecting up to 4,000 gigawatt-hours (gWh) by 2050, and marking India's progression towards being a hub for affordable and sustainable manufacturing.

Furthermore, the widespread uptake of ZETs has the potential to markedly enhance air quality in India. By 2050, emissions of particulate matter (PM) and nitrogen oxides (NOx) from trucks could see a reduction of around 40%, significantly impacting public health positively. Considering trucks account for 53% of PM emissions while only making up 3% of the vehicle fleet, transitioning to ZETs becomes a critical move for substantial improvements in air quality.

In addition to environmental benefits, shifting to ZETs can significantly decrease India's reliance on oil imports, supporting the vision of an autonomous nation. With road freight responsible for more than a quarter of oil import costs and expected to quadruple by 2050, adopting ZETs could cut down diesel consumption by a cumulative 838 billion liters by 2050. This shift could result in significant savings, approximately INR116 lakh crore in oil import costs over the same timeframe, underscoring the strategic and economic advantages of moving towards zero-emission transportation.

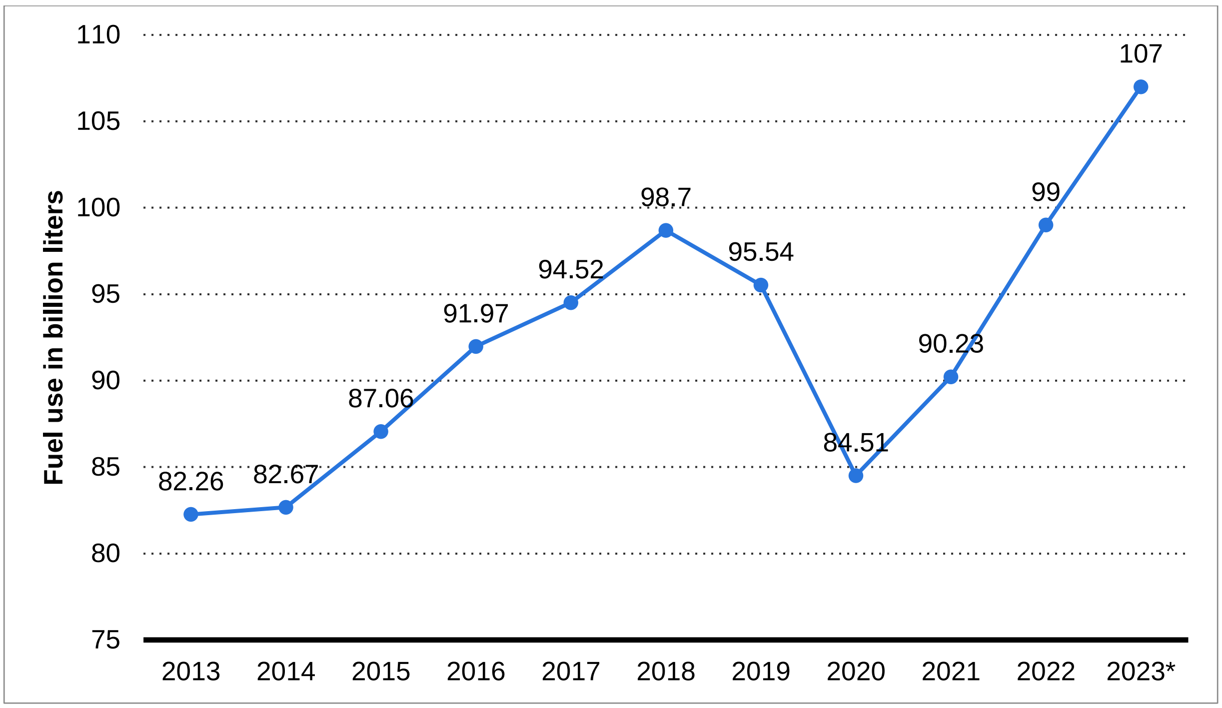


Figure 3: Consumption volume of diesel in India from 2013 to 2022 (in billion liters)
Sources: USDA Foreign Agricultural Service; Petroleum Planning & Analysis Cell; GAIN; ID 1051809

Beyond improving air quality and reducing dependence on oil, the shift towards Zero Emission Trucks (ZETs) plays a critical role in cutting down carbon emissions. The trucking industry, accountable for a third of all transport-related CO_2 emissions in India, stands to see its annual carbon emissions slashed by 46% by the year 2050 if ZETs are widely adopted. This significant change could lead to savings of between

2.8 and 3.8 gigatonnes of cumulative CO_2 by 2050, an amount that equals or even exceeds the total annual greenhouse gas emissions of India's entire economy as of today.

Furthermore, ZETs hold the potential for enduring savings in logistics costs, tackling the economic dimensions of transportation. With transportation expenses making up 62% of total logistics costs and accounting for 14% of India's GDP, the widespread use of ZETs could lead to a substantial reduction in these costs. Savings are particularly notable in the context of diesel fuel expenses, which represent a significant portion of transportation costs and could be reduced by as much as 46% over the lifespan of the vehicle. Such a reduction in costs would have broad and significant economic benefits for India, highlighting the financial as well as environmental advantages of transitioning to zero-emission trucking.

1.3 Research Framework

The research framework defines the aim and objectives of the study. It also mentions the scope and the limitations of the study.

1.3.1 Aim

The Aim is to develop strategies and recommendations to facilitate the widespread adoption of EMHDT’s in road freight transport, addressing sustainability and operational challenges.

1.3.2 Objectives

- To assess the global and Indian EMHDT’s landscape, considering market trends, technology, and regulations.
- To map the involved stakeholders along with their roles and investigate the barriers in the adoption and operation of EMHDT’s.
- To explore business models for EMHDT’s adoption along with Total Cost of Ownership (TCO) calculation and mitigation techniques for the identified barriers.
- To provide recommendations for amendments in policies for sustainable EMHDT’s adoption in India, considering safety and infrastructure needs.

1.3.3 Scope

The study is related to the feasibility check of EMDHT's in India considering technological and operational barriers and drivers and won't be looking into the details of mechanical and electrical equipment's.

The study has initially identified and assessed the overarching roles of stakeholders within the EMHDT ecosystem. Future research could delve deeper into individual stakeholder groups, such as drivers and fleet operators, to explore their specific preferences, behavior and impacts within the ecosystem. This would include detailed consumer preference studies and choice modelling to better tailor the EMHDT deployment strategies to meet needs and expectations of all market.

1.3.4 Limitations

As of now, only a limited number of EMHDT's are available in the Indian market, and their current usage is confined to specific boundaries and routes. Due to these limitations, there is a lack of recorded operator reviews regarding the operations of EMHDT's, because of the scarcity of electric trucks on Indian roads, economic considerations rely on values provided by electric truck manufacturers.

1.3.5 Expected Outcome

The expected outcome of this thesis aims to uncover the multifaceted barriers hindering the adoption of EMHDT's in India and assess their impact on the transportation sector. By examining the roles and relationships of stakeholders involved in EMHDT adoption, including manufacturers, government bodies, logistic companies, and end-users, the study seeks to provide a comprehensive understanding of the dynamics at play. Additionally, the exploration of various business models and their feasibility will shed light on economic factors that influence EMHDT deployment. The thesis is anticipated to culminate in the identification of effective mitigation strategies and policy recommendations designed to overcome these barriers. These strategies are expected to address technological, infrastructural, economic, and regulatory challenges, ultimately paving the way for an increased adoption rate of electric trucks in India. Through this holistic approach, the research aims to contribute significantly to the promotion of sustainable and environmentally friendly transportation solutions in the Indian logistics sector.

1.4 Methodology

The aim of this thesis is to conduct a comprehensive investigation and present a set of strategies and recommendations aimed at overcoming obstacles and encouraging the widespread adoption of EMHDT's within the road freight transport sector. A key focus of this objective is to identify, and address sustainability challenges associated with the adoption of electric trucks, including elevated initial costs and concerns related to operational feasibility. The thesis endeavors to offer a nuanced understanding of these challenges and proposes actionable strategies that encompass both environmental and operational considerations. Through these efforts, the thesis seeks to contribute valuable insights to the ongoing discourse on the integration of electric trucks in road freight transport, ultimately fostering a sustainable and extensive shift toward electric mobility within the freight industry.

The initial objective involves a comprehensive assessment of the global and Indian EMHDT landscape, taking into account market trends, technology advancements, and regulatory frameworks. To achieve this, an in-depth literature review is conducted on international electric truck technology, covering its operation, associated barriers in the targeted landscape, benefits realized through EMHDT technology, and best practices. Additionally, a thorough examination of various policies and schemes related to electric vehicles and freight vehicles, such as FAME, NEMMP, State EV policies, National and State logistics policies, and PM Gati Shakti, is undertaken to understand government initiatives that either promote or hinder the adoption of EMHDT's.

Secondly, the objective is to identify stakeholders engaged in the cradle-to-grave life cycle of EMHDT's. The identification process will be informed by a thorough review of literature and case studies. Conducting meetings and interviews with these stakeholders aims to gather valuable insights into the industry, shedding light on various barriers hindering the widespread adoption of EMHDT's. Additionally, an exploration of recent blogs and articles will be undertaken to discern both barriers and drivers relevant to the Indian landscape in the context of EMDHT's. To identify barriers to the adoption of EMHDT's, a detailed literature analysis is conducted, followed by expert interviews to contextualize these barriers within the Indian framework and understand their impact. To analyze these barriers further, TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and GRA (Grey Relational Analysis) analyses are carried out, followed by an relationship establishment between the identified barriers.

The third is to identify viable business models that can enhance the market penetration of EMHDT's in India. This involves conducting a feasibility check on various business models employed for commercial fleets in the Indian landscape and assessing their economic sustainability. The objective aims to provide total cost of ownership (TCO) analysis for electric trucks and ICE based trucks and shed light of the financial differentiation. Identification of mitigation techniques for previously identified barriers drawing from global best practices and expert advice.

The fourth and final objective of this study centers on formulating recommendations for policy amendments to facilitate the adoption of Electric Medium and Heavy-Duty Trucks (EMHDTs) in India. These recommendations are meticulously crafted, taking into account the financial, technical, and operational barriers that currently hinder the widespread implementation of EMHDTs. The aim is to propose a set of strategic policy interventions that not only address these existing challenges but also promote a self-sustaining development framework for EMHDTs within the country. By adjusting policies to better support technological innovation, financial incentives, and infrastructure development, these amendments will help create a conducive environment for EMHDTs, ensuring their successful integration into India's transportation ecosystem and contributing to the nation's sustainability goals.

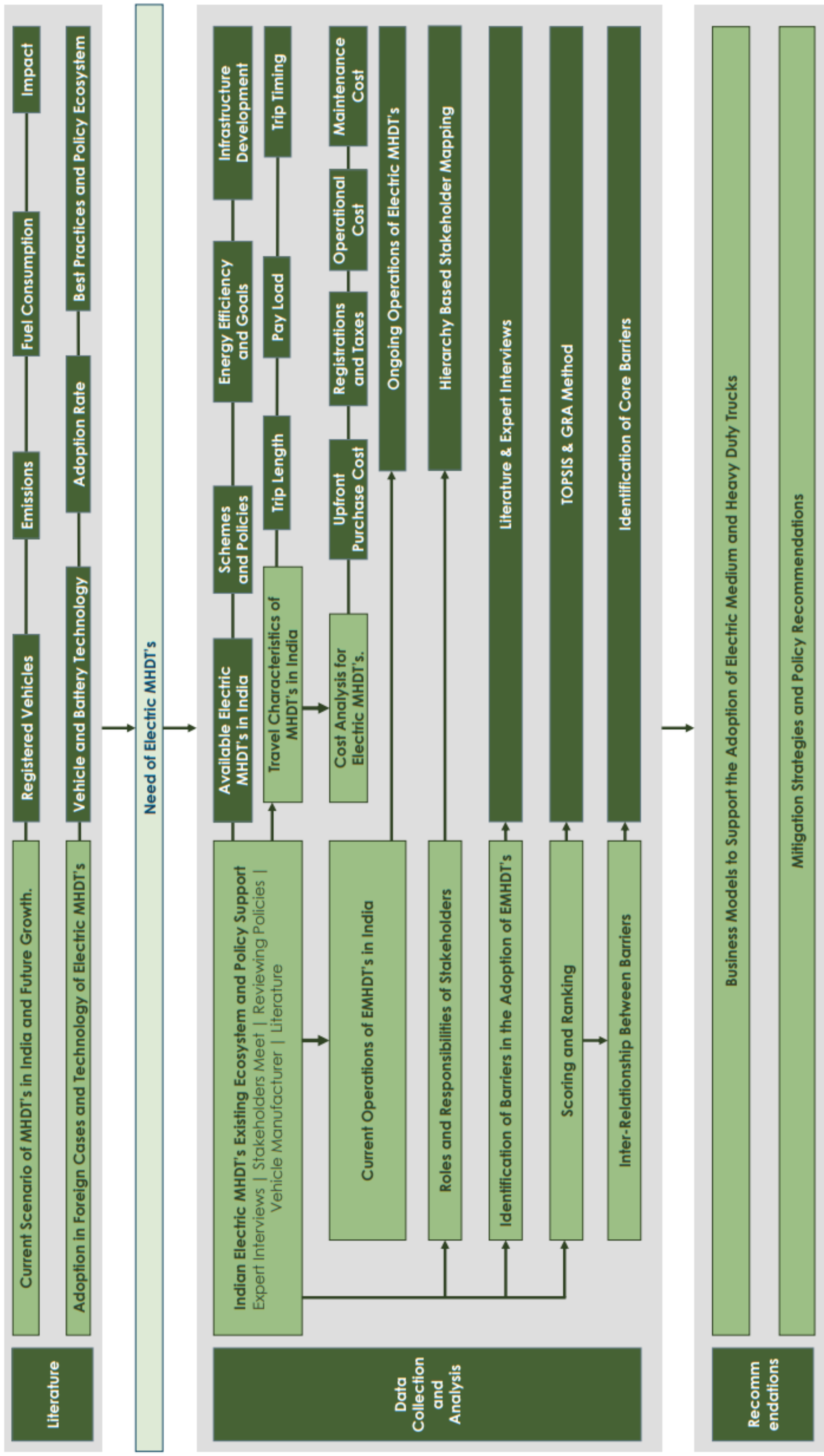


Figure 4: Methodology Followed for Thesis Research
Source: Author Generated

2. LITERATURE

As per formulated research framework and background study. Next step is to identify the relevant literature regarding the domain as per the research objectives. This chapter discusses about the literature studied to understand the topic. The literature study would also help to identify the research gaps, technology, stakeholder, barriers and drivers along with case studies.

2.1 Rapidly Growing Indian Freight Sector

India has risen as the world's fastest-growing major economy in four of the past five years, fueled by an increase in the demand for goods and services. This growth has created significant opportunities for millions of Indian citizens, particularly within the logistics sector. Presently, this sector contributes to five percent of India's Gross Domestic Product (GDP) and employs 22 million people. It facilitates the annual movement of 4.6 billion tonnes of goods, incurring a total cost of INR 9.5 lakh crore, highlighting its crucial importance.

The transported goods span various domestic sectors, including 22 percent from agriculture, 39 percent from mining, and another 39 percent from manufacturing. The majority of these goods are moved by trucks and other vehicles, with the balance being transported via railways, coastal and inland waterways, pipelines, and air transport. In recognition of the logistics sector's critical role in driving the nation's progress, the Government of India (GOI) is implementing several initiatives to boost its efficiency.

Efforts include building dedicated freight corridors for rail, improving the capacity and connectivity of water-based shipping, and embarking on major road infrastructure projects such as Bharatmala and the Golden Quadrilateral. Policy measures are also in place to foster a supportive environment for the logistics sector's growth. With the anticipation of a five-fold increase in freight activity by 2050, India's freight transportation system is essential in advancing national priorities.

These priorities include boosting international competitiveness, generating employment, enhancing urban and rural life quality, and supporting a more sustainable environment with improved air quality. The Government of India is dedicated to developing a strong logistics infrastructure that meets these ambitious goals, acknowledging its vital contribution to the nation's economic progress and sustainability. (Sinha J, 2021a)

2.2 India’s Trucking Market

In India, road transport, primarily through trucks, handles the majority of the country's goods, fulfilling 70% of the current domestic freight requirements and transporting nearly 2.2 trillion tonne-km. Heavy and medium duty trucks (HDTs and MDTs) are the main vehicles used, contributing 76% and 21% to the road freight volume, respectively.

By 2050, the share of HDTs in road freight is projected to rise to 83%, moving about 8.4 trillion tonne-km of long-haul freight. MDTs will also remain crucial, particularly for short intrastate and regional transport, accounting for 1.2 trillion tonne-km by 2050. As the demand for road freight increases, the number of trucks on India’s roads and highways is anticipated to grow significantly, from 4 million in 2022 to approximately 17 million by 2050.(Sudhendu Sinha, 2022)

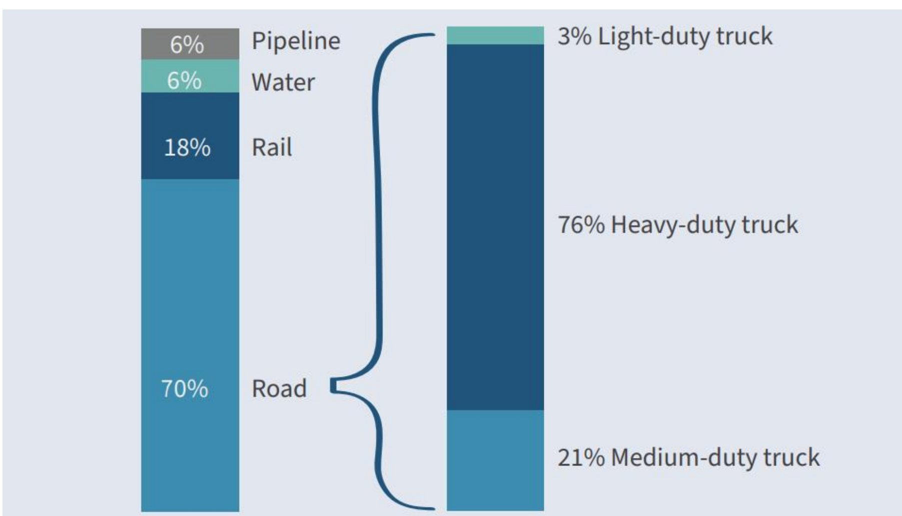


Figure 5: Modal Spilt for Freight Movement in India in 2022(% of Tonne KM)
Source: RMI(Transforming Trucking)

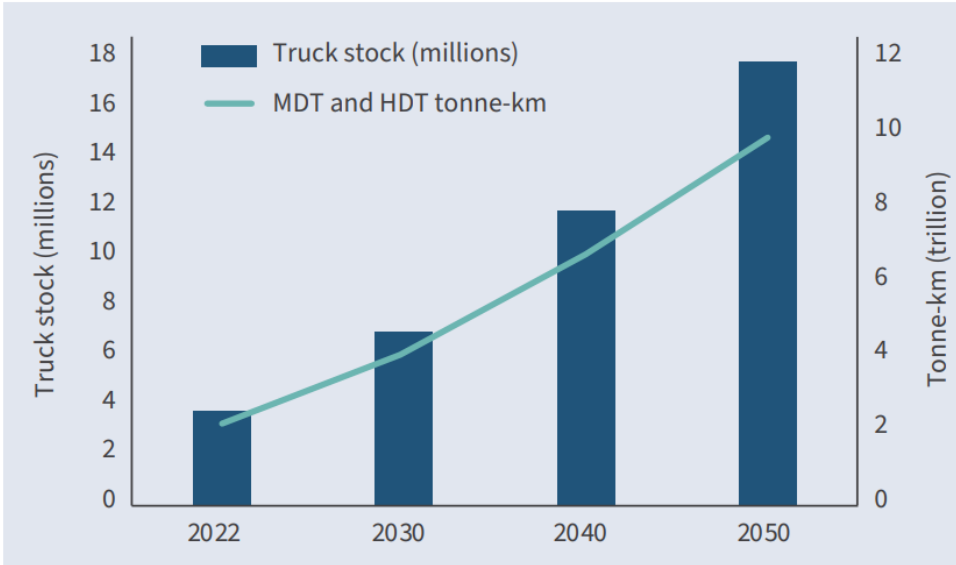


Figure 6: Growth of India's Truck Stock and Road Freight Market Through 2050
Source: RMI(Transforming Trucking)

The expansion of freight demand and the burgeoning trucking industry are crucial components of India's economy and transportation infrastructure. However, the current fleet of diesel trucks significantly adds to ambient air pollution. With anticipated growth in the market, it is essential to ensure that new trucks promote a cleaner and more sustainable transportation system.

The Indian truck transport industry is characterized by dependency and fragmentation. Currently, there are approximately 55 lakh trucks and trailers operating in the country, with a significant portion engaged in medium and long routes under various permits. However, nearly 90% of drivers and helpers lack legal or socio-economic protection, as mandated by the Motor Transport Workers Act, 1961. Ownership patterns have shifted over time, with a growing trend towards fleet consolidation. Diesel and tires account for a substantial portion of variable expenses for truck operators, with deferred payment options available for many. Government initiatives, such as the implementation of GST e-way bill and RFID-based toll payment systems, have contributed to improved efficiency in the industry. Replacement demand for trucks has surged due to limited repossession of older models, leading to a shortage of second-hand trucks and increased prices in the market. Fleet utilization rates have risen, driven by heightened activity in sectors like cement, infrastructure projects, and exports. Despite these improvements, truckers still face significant costs related to insurance premiums and road/toll taxes, which have not been revised upward since 2019 and remained unchanged. (Bhardwaj & Mostofi, 2022)

2.3 Zero Emissions Trucks

Trucks with zero emissions, such as battery electric trucks (BETs) and fuel cell electric trucks (FCETs), present an attractive option over traditional diesel trucks by eliminating tailpipe emissions and providing a pathway to long-term savings on fuel costs. ZETs have the potential to serve as viable replacements for the current fleet of diesel trucks. The following table provides a comparative analysis between ZETs and diesel-powered vehicles, demonstrating how ZETs are well-suited to fulfill the trucking requirements of India.

Criteria	ICE Trucks	BETs	FETs
Fuel Source	Diesel	Electricity	Green Hydrogen
Key Advantages	- Traditional technology - Quicker refueling compared to BETs - Wide selection of models for various applications	- Zero tailpipe emissions - Reduced CO_2 emissions, further decreasing with more renewable energy in the power grid - High efficiency of up to 82% from "tank-to-wheel" - Lowest operation costs - Enhanced driving experience	- Zero tailpipe emissions - Reduced CO_2 emissions with green hydrogen - Good efficiency up to 45% from "tank-to-wheel" - Quick refueling times - Can carry loads comparable to diesel trucks
Main Disadvantages	- Low efficiency - Higher fuel-related operating costs	- Range limitations due to battery size - Potential payload reduction due to heavier batteries	- Emerging technology - Higher total cost of ownership due to expensive hydrogen production

	- Significant air pollution and carbon footprint - Only up to 18% efficiency from "tank-to-wheel"	- Requires 1–8 hours for recharging	- Environmental concerns if hydrogen is sourced from fossil fuels

Table 1: Comparison Table for Truck Technologies
Source: Author Generated

2.4 Indian Landscape for E Freight Vehicles

The Indian government has set ambitious goals for electric vehicle (EV) adoption by 2030, targeting 30 percent of private cars, 70 percent of commercial vehicles, and 80 percent for two-wheelers and three-wheelers. This effort is part of India's broader strategy to promote electric mobility, backed by initiatives like the National Electric Mobility Mission Plan, the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) program, and production-linked incentives (PLIs) for the auto industry. These incentives, which focus mainly on passenger vehicles, have led to the rollout of a diverse range of electric vehicles, including two-, three-, four-wheelers, and buses, and have spurred innovation within the automotive sector. This has enhanced the startup landscape and led to the adoption of nearly 1.9 million EVs by the end of 2022. Despite this progress, electrification in the MHDT sectors is still in preliminary phases. Point-of-sale incentives have made electric vehicles more affordable by reducing the total cost of ownership, which supports early adopters in the passenger segment. Investment in EV technologies is being driven by supply-side policies like PLIs. Other supportive measures include R&D, capacity building, and tax exemptions to foster the early market for electric passenger vehicles. Additionally, for electric freight, various states provide subsidies, including road tax and registration fee waivers, and seventeen states are committed to building fast-charging stations or battery-swapping facilities along highways. However, the move towards zero-emission transport shows varying levels of commitment across different states. (MoHI, 2012), (MoHI, 2019), (MoHI, 2022).

India's initiatives like the Production Linked Incentive (PLI) scheme, commitment to renewable energy, and supportive policies like the Faster Adoption and Manufacturing of Electric Vehicles (FAME) can accelerate the transition to electric trucking. Ambitious targets and policies are essential to attract private investments and drive BET adoption. Mandates on manufacturers, emissions standards, and fuel economy standards can complement subsidies and drive BET adoption effectively. However, strong political support is needed to enforce these targets and regulations.(Abhyankar et al., 2022)

Several states in India, including Andhra Pradesh, Uttar Pradesh, Assam, and Madhya Pradesh, have made significant commitments to combatting climate change and reducing pollution by pledging to phase out all commercial fleets reliant on fossil fuels by the year 2030. Meanwhile, other states such as Maharashtra, Punjab, Andhra Pradesh, Haryana, Madhya Pradesh, Andaman & Nicobar Islands, and Chandigarh have implemented notable policies geared towards the electrification of vehicles, particularly focusing on garbage trucks operated by public authorities. These initiatives reflect a growing recognition of the importance of transitioning to cleaner transportation options. Additionally, Haryana stands out among its counterparts as the sole state offering subsidies specifically for the purchase of medium- and heavy-duty electric vehicles, with incentives tailored towards e-tractors, demonstrating a commitment to promoting sustainable mobility solutions in the agricultural sector. (AEEE, 2023)

To advance the adoption of electric vehicles (EVs) and foster a sustainable transportation ecosystem, collaboration among industry players is paramount. By sharing experiences and expertise in technology solutions, stakeholders can collectively address challenges and accelerate the deployment of EVs and charging infrastructure. Supportive policies and pilot projects play a crucial role in facilitating this transition, providing necessary incentives and frameworks for implementation. Manufacturing high-quality electric vehicles and establishing a robust charging infrastructure network are essential steps in promoting EV adoption. Initiatives like FAME II, a subsidy scheme by the Government of India aimed at accelerating EV manufacturing and deployment, play a significant role in reducing the total cost of ownership (TCO) of EVs through upfront subsidies. With allocated funds for both electric vehicles and charging infrastructure, FAME II underscores the government's commitment to driving sustainable mobility initiatives in the country.(Sinha J, 2021b)

Diesel dominates as the main fuel for 90 percent of road freight vehicles, followed by petrol and compressed natural gas (CNG). Despite this, the uptake of electric vehicles (EVs) and other cleaner alternatives is minimal across all vehicle categories within the freight sector. Notably, EVs hold a negligible market share in MHDT’s, and less than 1 percent in light-duty vehicles, which includes two, three, and four-wheeled freight vehicles. The low adoption rates can be attributed to several factors such as the high initial costs of EVs, a lack of sufficient charging or swapping infrastructure which leads to range anxiety, operational challenges specific to freight transport, a limited selection of vehicle models designed for freight purposes, and poor awareness among drivers and consumers about EVs and alternative fuel options. Together, these issues significantly impede the broader adoption of cleaner fuels and EVs in India's freight transport sector.(Sinha J, 2021a)

2.5 International Market Place of E Freight Vehicles

Since 2010, there have been significant shifts in the landscape of battery electric trucks (BET’s), particularly evident in the dramatic changes in lithium-ion battery prices and energy densities. At that time, prices hovered around $US 750-1000/kWh, (Wolfram & Lutsey, 2016) with energy densities at approximately 110Wh/kg. Fast forward to 2018, prices have plummeted by about fourfold, while energy densities have more than doubled. Batteries have become both affordable and dense enough to be deemed feasible for powering trucks. These trends, marked by cost reduction and enhanced specific density, have fueled a rapid surge in the adoption of not only passenger electric vehicles (which have surpassed 2 million sales globally) and electric urban buses but also heavy-duty trucks (International Energy Agency, n.d.). The initial introduction of BET’s into the market was notably evident in the garbage truck sector, which is ideally suited for electrification because of their consistent routes and frequent stopping and starting. These are conditions under which traditional internal combustion engines (ICE’s) are especially inefficient and produce considerable noise (Spaeth, 2014). A noteworthy example of this transition occurred in preparation for the Beijing Olympics in 2008 when 3000 garbage trucks were replaced with battery electric variants to mitigate noise and pollution. Moreover, China has taken strides in electrifying its urban bus fleets, notably in Shenzhen, where over 16,000 buses were electrified with batteries (Coren, 2018), showcasing the perceived viability and benefits of battery electric heavy-duty vehicles. In continental Europe, the shift towards BETs began with companies like Emoss in the Netherlands converting diesel trucks in 2012, followed by the introduction of electric trucks by traditional manufacturers like MAN, Mercedes, Volvo, and Renault. However, the focus in Europe tends to lean towards urban deliveries and smaller payloads, while the long haul and larger segment sectors present more technical challenge (Truck Daimler, 2023). Yet, some manufacturers are exploring solutions for long haul BETs, such as Nikola Motors with a hydrogen fuel cell range extender and Toyota with a hydrogen fuel cell truck. Notably, Tesla unveiled its battery-powered class 8 truck in late 2017, and BYD expanded its electric truck offerings to include long haul trucks in 2016 (Carter Bob, 2017), (Tesla, 2024), (Douris, 2017).

2.6 Total Cost of Ownership

The Total Cost of Ownership (TCO) offers a method for calculating and subsequently comparing the expenses associated with owning and operating a vehicle over its lifespan. It aggregates data on initial purchase costs, recurring expenses like fueling/charging and maintenance, and financing costs. Given that the expenses for these factors vary across different technologies, the TCO model is designed to aid consumers in recognizing the trade-offs and making more informed choices when acquiring a vehicle.

An automobile purchase entails more than just the initial cost of ownership. According to, "a rational fleet manager should consider every cost related to the vehicle choice, and not only the purchase cost," when making a decision to purchase a vehicle. This means that instead of focusing only on the original purchase price, the TCO should be examined. Other factors than the purchase price, like maintenance costs and fuel efficiency, are taken into account when choosing this method to compare a conventional and electric truck. As a result, an electric car might become more appealing to a buyer.(Tanco et al., 2019)

When comparing internal combustion engine trucks and BETs economically, one of the key factors to consider is the total cost of ownership (TCO). It essentially examines every expense a truck incurs over the course of its lifetime, offering prospective buyers one more tool to help them make decisions. Compared to conventional trucks, the number of TCO studies on electric trucks is not as high as that of passenger cars. A vehicle routing problem model was created by (Davis & Figliozzi, 2013) to assess how competitive electric delivery vehicles are compared to diesel alternatives. In Toronto, Canada, (Zhou et al., 2019) conducted a comparison between a class 6 medium-duty electric truck and its diesel counterpart. They found that, in the base case, the lifetime TCO for the BET is higher. The question of which daily mileage is most cost-effective for light and medium duty electric vehicles was addressed by (Taefi et al., 2017) analyzed and contrasted the life cycle costs of multiple HDTs, including two computer-modeled BETs, using a life-cycle assessment method.

Another key factor in forecasting Total Cost of Ownership (TCO) is the end of life (EOL) of batteries. Battery expenses constitute a significant portion of the overall vehicle cost, and the need to replace them during the lifespan of the vehicle adversely impacts the TCO (Tanco et al., 2019).

Electric vehicles offer several noteworthy advantages, including reduced maintenance expenses and increased overall efficiency. Given how little maintenance is needed for the battery, motor, and electronics, BETs have significant maintenance advantages over ICETs. The number of moving parts on the vehicles is the primary cause of the lower costs. Conventional vehicles have hundreds of moving parts, whereas electric vehicles have few (Johnson, 2014), (Feng & Figliozzi, 2012), (Lebeau et al., 2015), (Quak et al., 2016), (Weldon et al., 2018).

On the TCO of the BETs, the initial investment has a significant percentage of the lifetime expenses. The impact of the initial investment was assessed through a sensitivity analysis, which confirmed its relevance to the competitiveness of BETs.

According to the sensitivity analysis's findings, changes in the purchase price as well as in the cost of fuel and energy can have a significant impact on the TCO equilibrium, delaying the break-even points by up to seven years. The main presumptions made in this work are a last point to take into account as they ultimately add uncertainty to the analysis. The evolution of fuel and electricity prices, which surely have a significant influence on TCO calculation, is one important premise.(Tanco et al., 2019) However, over time, fuel prices are unpredictable due to their constant fluctuation and reliance on world events. Another important premise that is rarely seen in literature is the disregard for the cost of replacing the batteries during the BETs' lifetime. TCO analyses will begin to omit this expense, though, as manufacturers' battery guarantees and technology advance. The TCO for BETs is positively impacted by this assumption, which moves the parity closer to the present. This is especially true for cars with larger battery packs. (Weldon et al., 2018)

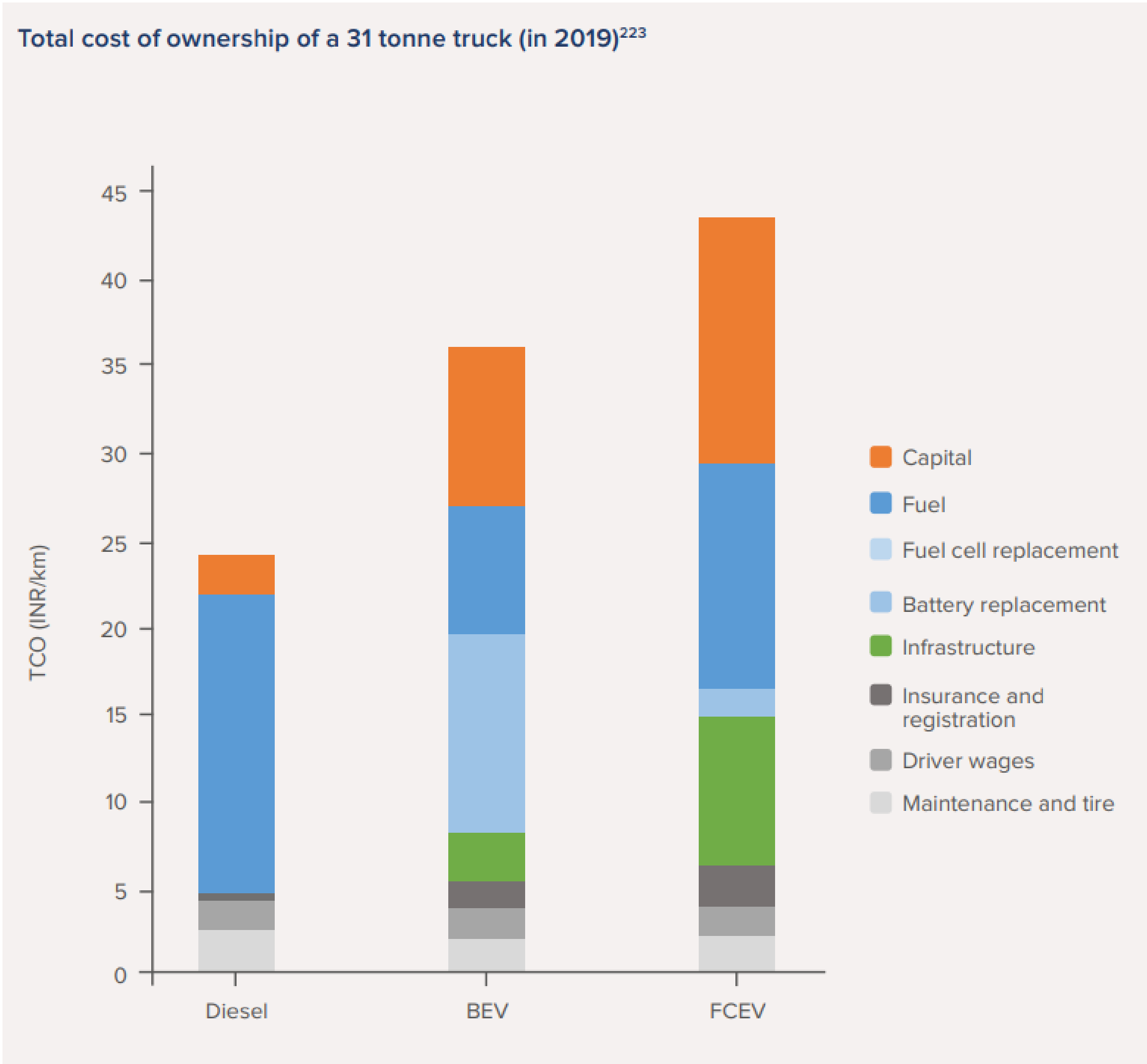


Figure 7: TCO for a 31 Tonner Truck (2019)
Source: RMI

Currently, electric vehicles (EVs) for light-duty (LDV), medium-duty (MDV), and heavy-duty (HDV) applications tend to have a higher total cost of ownership (TCO) compared to their diesel counterparts. This cost disparity stems from several factors. Firstly, EVs incur higher capital and financing costs, primarily due to the expense of fuel cells and hydrogen tanks for fuel cell electric vehicles (FCEVs) and batteries for battery electric vehicles (BEVs). Capital costs constitute over 25 percent of the total ownership cost of EVs, exacerbated by higher interest rates on EV loans. Secondly, while fuel costs are typically lower for EVs compared to diesel trucks, the high capital cost of EVs offsets these fuel-cost advantages. Furthermore, the need for battery replacement in

BEVs and hydrogen infrastructure in FCEVs contributes to additional costs. Despite the potential fuel-cost benefits of EVs, the substantial initial investment required for EVs results in a higher overall TCO compared to internal combustion engine (ICE) counterparts.(Sinha J, 2021b)

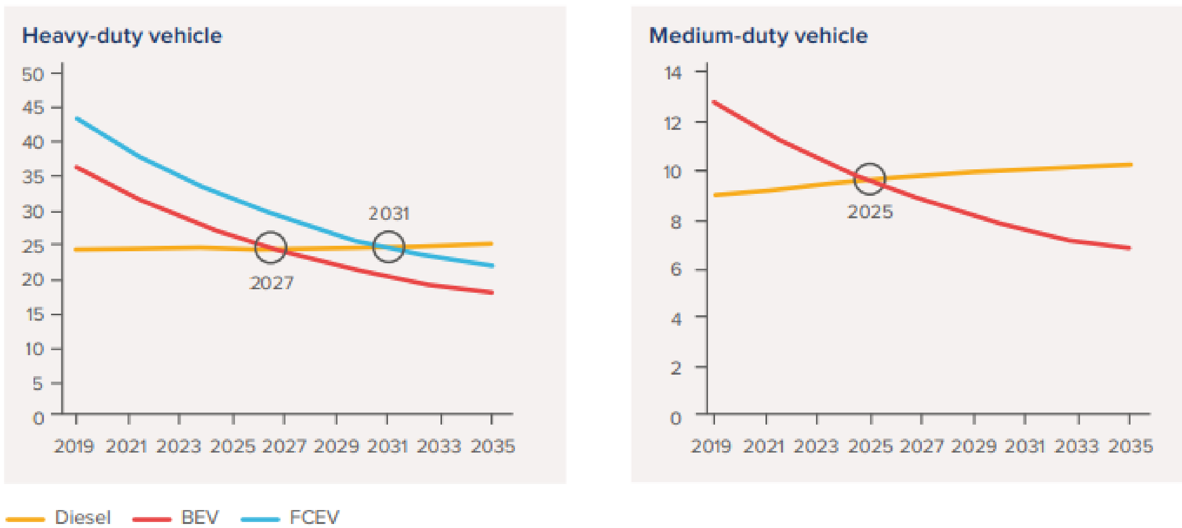


Figure 8: TCO Comparison for MHDT's in INR
Source: RMI

In the near future, electric vehicles (EVs) are expected to achieve cost parity with their internal combustion engine (ICE) counterparts, although the timing of this convergence will vary depending on the type of vehicle and duty cycle. Several factors are driving this trend toward decreasing total cost of ownership (TCO) for EVs. Firstly, significant declines in battery and fuel cell prices are anticipated, with projected reductions of 64 percent for batteries and 61 percent for fuel cells between 2019 and 2030. These cost decreases will lower both vehicle purchase prices and the expenses associated with battery or fuel cell replacement. Secondly, improved infrastructure utilization, such as the deployment of DC fast chargers for BEVs and hydrogen refueling stations for FCEVs, will help reduce costs by spreading fixed infrastructure expenses over a greater number of vehicles as station utilization increases. Lastly, economies of scale in manufacturing will drive down the overall cost of producing EVs and their components as production volumes increase. Overall, these factors are expected to contribute to the eventual cost parity between EVs and ICE vehicles.(Sinha J, 2021b)

2.7 Battery Technology

One more essential component to consider when examining BETs is the batteries. They are the costliest single component of electric vehicles and serve as a replacement for the fuel tank. The cathode material (graphite anode), which distinguishes the most widely used lithium-ion batteries from one another, varies (Helbig et al., 2018).

The cathode material (graphite anode), which distinguishes the most widely used lithium-ion batteries from one another, varies (Helbig et al., 2018), (Pehlken et al., 2017), (Zubi et al., 2018). According to Rohr et al. (2017) and The Boston Consulting Group (2010), the two most prevalent cathode types in BEV battery packs are lithium-nickel-cobalt oxide (NCA) and lithium-nickel-manganese-cobalt oxide (NMC).

According to (Zubi et al., 2018), the composition of the NCA cell cathode is 80% nickel, 15% cobalt, and 5% aluminum, whereas the NMC cell cathode is 33% nickel, 33% manganese, and 33% cobalt. According to (Helbig et al., 2018) the largest supply risks associated with the production of lithium-ion batteries are related to the elements lithium and cobalt, because of the significant increase in demand anticipated in the upcoming years.

Vehicle battery pack EOL is defined by two metrics, according to the United States Advanced Battery Consortium (1996)(Johnson, 2014), when the battery has lost 20% of its power performance or 20% of its rated capacity, which translates to a State of Health (SOH) of 80%. Calendar ageing and cycle ageing are the two components of battery aging. Calendar ageing is the term used to describe how a battery ages over time and is dependent on various conditions, including temperature and state of charge (the amount of battery capacity that can be discharged). On the other hand, cycle aging is determined by the capacity lost during each charge and discharge cycle of the battery and is influenced by voltage, depth of discharge (DOD), and charge/discharge rate. (Ahmadian et al., 2020), (Pehlken et al., 2017), (Pelletier et al., 2017), (Wang et al., 2016).

The necessity for implementing the swapping method arose due to several factors. Firstly, long-haul trucks operate on predetermined routes with strict time schedules to ensure timely and reliable delivery of goods to customers. This characteristic presents both advantages and challenges for electrification. Certain companies have devised solutions and made significant progress in maximizing the use of long-haul electric trucks, thereby enabling customers to make purchases. Examples of such service providers include Foton, which introduced its IBLUE truck with a swapping time of 3–5 minutes. An Indian startup, Sun Mobility, offers the Smart bus with a swap time of 3 minutes (Panday, 2019). The Chinese XJ Group Corporation requires 7 minutes to swap batteries for its e-buses (Hinterlands, 2022). A Swedish startup offers battery replacement within 3 minutes, and Next-Gen Battery requires only 6 minutes for swapping (MAN Global, 2024). In Germany, a well-known fashion logistics company, Meyer and Meyer, utilizes two battery packs and takes 15 minutes for battery swapping. As for fast-charging service providers, Tesla requires 30 minutes for a single charge , while MAN trucks use 150 kW DC chargers and take 60 minutes to charge (FREIGHTLINER, 2022). Freightliner's eCascadia (class 8) can charge 80% in 90 minutes (FREIGHTLINER, 2023), and Freightliner's electric truck—eM2—equipped with a 315 kW capacity, can achieve 80% charge in 60 minutes (MERCEDES, 2024). Mercedes Benz's eActros, with a capacity ranging from 336 to 448 kWh, takes between two and eleven hours (at 150 kW or 20 kW) for a full charge and offers a range of 300–400 km (MERCEDES, 2024). Volvo FL, with a power output of 200–395 kWh and a range of 300 km, can be charged in 11 hours with AC (22 kW) or in 2 hours with DC (150 kW) (VOLVO TRUCKS, 2024b). Similarly, Volvo FE, with a power output of 200–395 kWh and a range of 200 km, can be charged in 11 hours with AC (22 kW) or in 2 hours with DC (150 kW) (VOLVO TRUCKS, 2024a), BYD heavy-duty vehicles take 1.4 hours to charge the 350 kWh battery capacity with a 150 kW DC charger and 3.6 hours with a 100 kW charger (BYD, 2020)

2.7.1 Battery Cost and Density

Batteries are a crucial cost component for electric vehicles (EVs), with lithium-ion batteries being the primary choice due to commercial availability. Different lithium-ion battery chemistries, such as lithium titanium oxide (LTO) and lithium manganese oxide (LMO), are utilized in various heavy-duty applications, depending on factors like weight, driving cycle, and lifespan. Material costs, technological advancements, and production volumes significantly influence battery costs, making it essential to consider battery chemistry. While data limitations hinder precise projections, recent years have seen a decline in battery costs, expected to continue with future technological advancements and increased investment. Bloomberg NEF reports a decrease in battery pack prices from $1,100 per kilowatt-hour (kWh) in 2010 to $137 per kWh in 2020, projected to reach $100 per kWh by 2023. Initiatives like India's Production Linked Incentive (PLI) Scheme aim to boost advanced chemistry cell (ACC) manufacturing, reducing import dependency and promoting indigenization of EV production. Achieving higher energy density is crucial for maximizing battery efficiency and running time, emphasizing the importance of battery density in design considerations (Henze, 2020), (MoHI, 2019)

Other than lead-acid batteries (Pb-A) with a power density ranging from 35-50 Wh/kg, nickel batteries have been widely utilized, boasting an energy density of 50-110 Wh/kg (such as Ni-Fe, Ni-Zn, Ni-Cd, Ni-MH), along with various lithium batteries with energy density spanning from 90-200 Wh/kg (including Li-Ion, LiTiO, LiCoO, Li-MnO2, LiMn2O4, LiFePO4, LiSO2, Li-SOCl2, LTO). The future of automotive technology holds promise in the advancement of graphene polymer technology, which could potentially revolutionize electricity storage by nearly tenfold, reducing the current requirement of 1000 Watt/kg, while enabling faster charging and significantly prolonging service life.(Łebkowski, 2017).

2.7.2 Battery Manufacturing

Major players are investing in charging infrastructure and EV research to suit Indian road conditions, crucial due to inadequate EV infrastructure compared to other nations. Fuel availability is essential for widespread EV acceptance, particularly in the

HDV sector, where building an ecosystem is critical. Electrification reduces vehicle payload, affecting travel costs and income opportunities, necessitating high-power-density batteries and fast chargers. Similar to the e-bus segment, the e-trucking sector requires focused efforts, including charging infrastructure development. Despite improvements in battery performance and cost reduction, electrification in the MHDV sector lags due to low volume purchases and custom pack specifications. Indian OEMs can play a crucial role in the growing EV market, learning from China's successful EV strategies, which involved massive investments in R&D, subsidies, and policy regulations. Setting up battery manufacturing units, as per India's PLI scheme, will expedite the transition to EVs in the HDV sector and reduce battery costs, a significant component of vehicle expenses. China's transition from subsidizing to incentivizing the EV market showcased confidence in its strategy and market maturity(Denne, n.d.) (Qamar Sharif, 2021)

2.8 Environmental Impacts (Cradle to Grave)

This section discusses the environmental effects of converting the heavy-duty ICE truck fleet to electric powered fleet. A comprehensive life-cycle analysis (LCA) of a truck would need to consider the energy use and emissions from the fuel or battery, as well as all the components manufactured. Research has shown that for cars, the LCA of electric vehicles (EVs) tends to be more beneficial than that of vehicles powered by fossil fuels, even in areas where the electricity grid is relatively high in carbon intensity. (Maarten, 2015)Therefore, in this section, we focus solely on the emissions within a closed cradle-to-grave system, encompassing the CO_2 emissions linked to the production and transportation of the fuel to its eventual utilization in the engine. From a powertrain perspective, pollutants such as NOx, SOx, and PM are eliminated in BETs, and there are substantial improvements in emissions resulting from brake pad wear. While these factors are not further examined in this analysis, they remain important considerations concerning local air quality.

The average carbon dioxide emissions per kilowatt-hour (kWh) of electricity produced stood at 276 grams (g) CO_2/kWh, with a downward trend observed. Diesel fuel, in addition to being a fossil fuel, often contains a blend of biofuel components sourced from materials like palm oil and rapeseed oil, which can lead to increased emissions due to changes in land use. Moreover, fossil-based diesel can originate from various sources ranging from conventional wells to oil sands, with the latter carrying significant production emissions. To simplify the analysis and provide a conservative estimate for internal combustion engine (ICE) powertrains, we focus on a diesel truck solely powered by conventional fossil diesel extracted from wells. The emissions associated with the extraction and transportation of diesel to the tank are estimated at 55 g CO_2/kWh, while combustion within the engine results in emissions of 263 g CO_2/kWh, totaling 318 g CO_2/kWh. When converted to emissions per kilometer (km) based on calculated efficiencies, this translates to 351 g CO_2/km for long-range electric trucks and 441 g CO_2/km for short-range electric trucks. These figures account for an additional 95% rectification efficiency and assume a 95% transmission efficiency across the electrical grid. In comparison, conventional constant-speed ICE trucks emit 709 g CO_2/km, while standard operation trucks emit 1051 g CO_2/km. (Valin, 2015)

This means that long-range BETs are estimated to be between 51% to 67% more environmentally friendly than equivalent fossil fuel-powered trucks. In the case of Poland, which serves as a high carbon intensity example with 671 g CO_2/kWh, an electric truck would still emit 19% less emissions compared to a fleet average diesel ICE, albeit performing 20% worse than the optimum efficiency of a best-in-class model. In France, where the carbon intensity is lower at 35 g CO_2/kWh, electric trucks would be 94% to 96% cleaner. This disparity in emissions from well-to-wheel is expected to narrow down to 100% as the electricity grid decarbonizes under the EU Emissions Trading System (ETS). (Earl et al., 2018)

Currently, in India, the freight transport sector contributes 220 million tonnes of CO_2 emissions, with road freight accounting for 95 percent of this total. Shifting from road to rail transport represents a highly effective strategy for decarbonizing the freight transport sector, potentially reducing CO_2 emissions by 4.3 gigatonnes between 2020 and 2050. Additionally, optimizing truck usage to minimize empty running and improve load factors could further reduce emissions by 2.8 gigatonnes over the same 30-year period. Utilizing efficient vehicles and electric vehicles (EVs) to enhance vehicle technology has the potential to reduce emissions by an additional 3.2 gigatonnes. Taken together, these measures could result in a cumulative reduction of 52 percent (or 10 gigatonnes) by 2050 compared to a business-as-usual scenario.(Sinha J, 2021b)

Emissions Intensity	Diesel	gCO_2e/Litre	3579			
Lifecycle GHG	Electric	gCO_2e/kWh	701			
		Units	7.5MT	12MT	25MT	40MT
Fuel Economy	Diesel	KM/Litre	8	5.5	3.45	2.2
	BET	KM/kWh	2.50	1.69	0.88	0.49
Emissions	Diesel	gCO_2e/km	446.9	650.0	1036.3	1625.1
	BET	gCO_2e/km	288.3	427.3	820.2	1485.1
GHG Reduction BET			35%	34%	21%	9%

Table 2: Comparison of Lifecycle Greenhouse Gas Emissions Intensity Per KM
Source: Abhyankar

Through analysis of the environmental consequences of electric trucks in this study, leaving this aspect for future research. Nevertheless, basic calculations clearly demonstrate that, based on current grid average emissions, Battery Electric Trucks (BETs) emit 9% to 35% fewer greenhouse gas (GHG) emissions per kilometer compared to diesel trucks. Charging BETs during periods of maximum solar production would essentially make them carbon-neutral (further discussion below). Even under the highest emissions intensity observed in India, BETs result in significantly lower emissions per kilometer compared to diesel trucks. While BETs contribute to air pollution at the power generation source, they have an unequivocally positive impact on air quality in urban areas and congested highways. India's ambitious renewable energy targets imply a continuous decline in grid emissions. The spatial and temporal variations introduced by BETs and the environmental consequences of battery production and disposal are also areas for future investigation.(Abhyankar et al., 2022)

2.8.1 Electricity Generation

India generated nearly 35% of its grid capacity from non-emitting sources in 2021, marking a significant shift towards cleaner energy sources. While coal remains a primary source of electricity, its share is decreasing, leading to reduced emissions from the power sector. The rapid growth of renewables further contributes to lowering the carbon footprint, especially in charging e-trucks. India has substantial untapped solar energy potential, receiving over 5,000 trillion kWh of energy annually, making solar photovoltaics highly scalable. Policies such as the draft electricity rules support increased scalability of solar power by allowing consumers to source green power independently. It's noted that pollution control measures are more manageable in fixed power generation units than in mobile internal combustion engine vehicles, emphasizing the importance of electrifying the MHDT market for emission reduction efforts (IEA, 2020), (CEA, 2024).

2.9 Driving Experience

The NACFE Run on Less (RoL) demonstrations rely on the voluntary participation of real-world drivers who provide invaluable insights and experiences. During three RoL demonstrations, 31 drivers engaged in various activities, including interviews and filming, to document the effectiveness of demonstrated technologies. The feedback from drivers comparing electric vehicles (EVs) to diesel vehicles highlighted several key points. Firstly, EVs were praised for their low interior noise levels, with drivers noting their quietness compared to diesel vehicles, enabling them to hear in-cab radios at low volumes. This contrasted with the noisy diesel engine, particularly from cab-mounted vertical exhausts, which was associated with hearing issues among experienced drivers. Secondly, EVs were perceived to enhance safety due to their low exterior noise levels, allowing drivers to better hear surrounding noises like other vehicles and warning signals. This quiet operation also garnered appreciation from the public and potentially facilitated earlier deliveries without disturbing residential areas. Thirdly, EVs were lauded for their better acceleration, aiding traffic flow and efficiency, especially at traffic lights and when maneuvering trailers. Additionally, drivers found EVs simpler to operate, with features like one-pedal driving and simplified charging processes monitored via smartphone applications. Furthermore, EVs were commended for producing no emissions when idling, allowing drivers to run accessories without emission concerns. All drivers charged their EVs at their fleet's depots, eliminating the need to deviate from routes to find fueling stations. EVs were also noted for their lack of fumes or odors, contributing to a more comfortable work environment, and resulting in less fatigue for drivers at the end of their shifts. Finally, the novelty and positive brand image associated with operating EVs were highlighted by drivers of all ages, reflecting a commitment to improved technologies, employee well-being, and environmental sustainability. In summary, the feedback underscored the numerous advantages of EVs over diesel vehicles, encompassing operational simplicity, environmental benefits, and enhanced safety, which contributed to a positive perception among drivers and the public. (ELECTRIC TRUCKS Have Arrived Have Arrived Documenting A Real-World Documenting A Real-World Electric Trucking Demonstration Electric Trucking Demonstration, 2022)

2.10 International Case Studies

In Shenzhen, China, significant progress has been made in electrifying freight vehicles, thanks to a series of supportive policies introduced by the government since 2015. These policies include upfront purchase incentives for Electric Logistics Vehicles (ELVs), with subsidies provided by both national and city governments based on battery capacity. Additionally, special road privileges have been established in designated green zones, where internal combustion engine (ICE) vehicles are prohibited. EV charging subsidies are also available for companies deploying charging infrastructure, encouraging the expansion of charging networks. Mandates and targets have been set at both provincial and city levels, such as dedicating parking space in new commercial buildings for EV charging and installing EV chargers. As a result of these initiatives, Shenzhen saw a substantial increase in ELV stock from 300 to 70,417 between 2015 and 2019. (Sinha J, 2021b)

California has implemented the Advanced Clean Trucks (ACT) Rule to transition freight vehicles to electric models, aiming to reduce greenhouse gas (GHG) emissions and address environmental justice concerns. This mandate requires truck manufacturers to gradually increase the percentage of electric trucks sold annually, with a target of 100 percent penetration by 2045. To support this transition, California offers incentives through programs like the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), providing direct price reductions for electric vehicle purchases. The ACT Rule is projected to lead to significant public health and economic benefits, including reductions in NOx emissions, avoided premature deaths, and decreased CO_2 emissions. By 2040, California expects to have nearly 500,000 electric trucks on its roads, facilitated by these policy interventions and incentive programs

Norway's National Transport Plan (2018-2029) aims to electrify the country's freight segment, with targets for all new light-freight van sales to be electric by 2025 and 50 percent of new trucks to be electric by 2030. To support this initiative, truck operators conducted various pilots between 2016 and 2019, testing 21 different types of electric freight vehicles (EVs) across different use cases such as waste collection, long-haul freight, and food distribution. These pilots identified barriers to EV deployment, including high upfront costs, range anxiety, and the need for fast charging infrastructure. Proposed solutions include financial incentives, widespread availability of fast charging, technological advancements, and fit-for-purpose vehicle design. EVs were found to be more energy efficient and cost-effective compared to internal combustion engine counterparts, offering noise-free driving experiences and enhancing sustainability efforts. The Norwegian experience demonstrates the importance of public-private partnerships in informing decision-making for widespread adoption of electric freight vehicles (Samferdselsdepartementet, 2018), (Beate et al., 2019), (Hovi et al., 2020)

California has been a pioneer in clean energy initiatives, with a strong focus on transportation and freight electrification. This emphasis stems from the disproportionate impact of ICE vehicles on communities of color and low-income households and the state's ambitious goal to reduce GHG emissions by 40 percent by 2030. California's Advanced Clean Trucks Rule mandates electric truck sales as a percentage of total annual sales, with targets increasing over time to achieve full electrification by 2045. Additionally, the state runs the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) since 2009, offering incentives for electric vehicles, especially in disadvantaged communities. The implementation of clean truck mandates and incentives is projected to lead to significant reductions in NOx emissions, premature deaths, and CO2 emissions, with economic benefits exceeding INR 80,000 crore. Private sector entities like PG&E are also contributing to the transition by providing infrastructure and financial incentives for fleet electrification.

2.10.1 Group of Barriers in International Cases

The need for close collaboration among key stakeholders, including utility companies, grid operators, manufacturers, and truck fleet managers, is underscored. Effective communication between electric truck (BET) manufacturers, utilities, and customers is essential to overcome challenges related to business models and partnerships, which are crucial for operational reliability. Support from the government is critical in enhancing customer acceptance, ensuring operational reliability, addressing technology uncertainties, and bolstering grid resiliency. Investments in research and development, manufacturing, and infrastructure are necessary to enhance the operational reliability and appeal of BETs. Focusing on research and development in fast charging technology is important to mitigate issues such as long charging times and limited product availability. Electric truck manufacturers need to intensify efforts to offer a diverse range of BETs designed to meet the specific requirements of truck fleets, while also promoting awareness and education among stakeholders. Building grid resiliency is essential to foster BET adoption, requiring coordinated efforts from grid operators, utilities, researchers, and policymakers to expand and manage the power grid efficiently and to implement smart charging solutions. Additionally, increasing awareness about the technical capacity of the grid to support the growth of BETs is vital. (Konstantinou & Gkritza, 2023)

2.10.2 Foreign Policies to Support Electric Truck Adoption

The literature outlines several key policy recommendations to facilitate the quick and sustainable introduction of Battery Electric Trucks (BETs) in Europe. These recommendations involve setting CO_2 standards for trucks and trailers to ensure long-term planning certainty, enacting a Zero Emission Vehicle (ZEV) mandate to increase the availability of zero-emission trucks, revising electricity pricing to improve the economic feasibility of BETs, and modifying road charges, tolls, and fuel taxes to promote the adoption of zero or low carbon trucks. Additionally, the paper highlights strategies for cities to encourage investment in electric trucks and underscores the need for infrastructure enhancements to support electrification. It also calls for amendments to weight and dimension regulations to better accommodate alternative technologies. Moreover, it suggests initiatives for battery production, including creating a joint research and development effort for battery technologies, funded by both the EU budget and industry stakeholders, to strengthen the European battery technology market and reduce environmental impacts.(Earl et al., 2018)

A. **Scrappage Policy:** The scrappage policy serves as a vital policy instrument designed to phase out old vehicles that are beyond their service life, thus reducing their adverse environmental effects. This scheme facilitates the removal of unfit vehicles from circulation, decreasing emissions and air pollutants from vehicles, and enabling the adoption of newer, more technologically sophisticated vehicles with better engine standards. China launched a similar initiative in 2009-10 called the 'Old-Swap-New Policy', which mandated the scrapping of trucks after they reached the end of their fitness lifespan. In India, the scrappage policy was officially introduced in the union budget of 2021-22 after extensive deliberations. Its main goals are to reduce the population of aged and malfunctioning vehicles, tackle vehicular air pollution, and improve road and vehicle safety. According to this policy, all old vehicles are required to pass mandatory fitness tests at authorized, automated centers that meet international standards. (Qamar Sharif, 2021).

B. **Fuel Taxes:** Fuel taxes are effective fiscal tools that directly relate to the amount of fuel used and the resulting CO2 emissions, thereby incorporating environmental costs. Diesel, commonly used by heavy commercial vehicles and linked to carcinogenic emissions, often has lower tax rates compared to gasoline. In countries like New Zealand and across Europe, gasoline is heavily taxed, and many European nations also impose significant taxes on diesel, although some Eastern European countries have more moderate rates. In contrast, fuel taxes are generally lower in North and Central America than in Europe, while Japan and Australia have moderate rates. Middle Eastern countries typically provide substantial fuel subsidies, and ASEAN nations have moderate diesel subsidies. In North Africa, there are significant subsidies for gasoline, whereas Central and Southern African countries tend to impose moderate to high fuel taxes. India recently increased its diesel and gasoline taxes, which now make up over half of the total retail price per liter. Meanwhile, in China, taxes on road fuels like diesel and gasoline comprise about 40% of the retail price. India, however, has some of the highest fuel tax rates in the world, with state governments collecting around INR 20 per liter of petrol, in addition to a central levy of Rs 33 per liter. (Gajjar, 2015)(Qamar Sharif, 2021)

2.10.3 SWOT Analysis (International Cases)

Strengths: The swapping method offers significant time savings compared to fast charging, with a quick turnaround time of 3–15 minutes for swapping, eliminating the waiting time associated with charging. This efficiency is particularly advantageous for heavy-duty vehicles, where fast charging can take up to 0.5–1 hour. Moreover, swapping provides an efficient solution for load management by allowing batteries to be charged during off-peak hours, thereby reducing costs related to high power load peaks that occur with fast charging. Additionally, the independence of service fees from electricity price fluctuations makes swapping a predictable and cost-effective option for customers. Unlike fast charging, which may require costly upgrades to power systems, swapping stations typically do not necessitate significant infrastructure changes, making them a more accessible and economical choice.

Furthermore, swapping stations simplify the charging process for customers, requiring minimal manual involvement and enhancing accessibility, especially for older or less educated individuals.

Weaknesses: However, swapping stations face challenges related to the cooling system, especially when dealing with a large number of batteries, which can impact performance and safety. Additionally, logistics complexities arise when transporting batteries between swapping stations, adding costs and operational challenges. The high initial investment required to set up swapping infrastructure, including heavy machinery and battery management systems, poses a barrier to widespread adoption (Sarker et al., 2013).

Opportunities: Despite these challenges, the rise in the EV market presents significant opportunities for swapping stations and fast charging points, driven by growing demand for electric vehicles globally. Government subsidies aimed at reducing EV costs can further incentivize adoption, making electric trucks more competitive compared to diesel vehicles. Addressing environmental concerns, such as reducing CO_2 emissions from road transport, provides an opportunity to promote electric trucks as a cleaner alternative. Moreover, technological advancements in EV technology make electric trucks more economically feasible, driving market growth. Electric trucks with sufficient range coverage for most trips without frequent charging present an opportunity for market expansion. Shifting ownership and responsibility for batteries to station operators can reduce capital expenditure for logistics companies, fostering industry growth. Lower total cost of ownership compared to diesel vehicles in the long term provides a compelling case for investment in electric trucks.(Mostofi, 2021).

Threats: Despite these opportunities, threats such as the lack of standardization in EV batteries complicate infrastructure development and interoperability among different manufacturers. The success of the swapping model depends on demand, and failure to attract sufficient customers may hinder profitability and sustainability. Limited space for constructing swapping infrastructure, especially in urban areas, poses a challenge to expanding the swapping network. Additionally, competition with fast charging solutions, which offer advantages such as concerns regarding battery health, ownership, and infrastructure development, may favor fast charging over swapping in some cases (Mathieu, 2020).

2.11 Multimodal Readiness for Electrification

The development and adoption of electrification in transportation rely on four critical indexes: technological readiness, political readiness, societal readiness, and economic readiness. While technology forms the foundation of electrification, its diffusion and value creation depend on the collaborative efforts of various stakeholders such as industry, academia, politics, and economic institutions. Merely focusing on technology is insufficient for successful transformation; hence, a balanced approach addressing political, societal, and economic dimensions is essential.

Political readiness emerges as a crucial dimension, involving government support through policy development and implementation to promote electrification. This readiness is evident in reshaping regulatory aspects, introducing subsidies, and allocating public funds for research, development, and infrastructure building. Political commitment is observable both in rhetoric and action, with tangible efforts towards policy enactment and implementation being paramount.

Societal readiness pertains to the willingness of society to transition from fossil fuels to electric vehicles (EVs). Motivating people to embrace this shift requires a comprehensive understanding of the costs involved and fostering acceptance until the benefits outweigh those of fossil-based technology.

Economic readiness focuses on the financial aspect, ensuring that subsidies are available to bridge any price disparities between electric and fossil fuel vehicles. Government policies play a pivotal role in this regard, encompassing the economics of infrastructure development, solutions for electrified public transportation, EV rebates, tax exemptions, and levying high taxes on CO_2 emitting vehicles.

The electrification of transportation is viewed through a complex systems perspective, acknowledging its interdependence with energy production, grid distribution, storage, and broader socio-economic contexts. A holistic understanding necessitates considering multiple subsystems beyond technology alone, including politics, society, and the economy. To facilitate this comprehensive perspective, the Multidimensional Readiness Index Model has been introduced

Currently, the depth of electrified transport penetration in society is in its nascent stages, relying heavily on government economic policies. Countries like China and Norway lead in electrification due to strong government commitment and institutional execution power, facilitating rapid transitions. In contrast, Sweden lags behind despite its innovation prowess, attributed to sluggish government actions. Companies like Volvo and Scania are making strides in manufacturing electric vehicles and trucks, indicative of industry collaboration towards electrification goals. (Bhatti et al., 2022)

3. SITE OVERVIEW

This chapter provides a comprehensive overview of the trucking ecosystem, focusing on the impact areas, the current state of truck registrations, and a concise analysis of state-specific electric vehicle (EV) policies. By delving into these aspects, we aim to establish a clear picture of the current landscape within which the trucking industry operates.

Further, this chapter explores the methodology employed for data collection, detailing the processes involved in designing the questionnaire and the selection criteria for respondents. The discussion includes the rationale behind the choice of questions, how they align with the research objectives, and the professional profiles of the respondents. This approach ensures that the data collected is robust and reflective of the sector’s realities, providing a solid foundation for subsequent analysis.

3.1 Site Extent

Entire India is considered as the impact area, recognizing the pivotal role of the Indian trucking system in delivering goods and providing logistics services across the country. The trucking industry is integral to the nation's economic infrastructure, ensuring the smooth flow of commodities from manufacturing sites to markets, both within and beyond regional boundaries.

3.2 Existing MHDT Registration Scenario in Indian States and UT’s

In India, the registration of new Heavy Goods Vehicles (HGVs) and Medium Goods Vehicles (MGVs) has been a significant indicator of economic activity and infrastructure development across various states. These vehicles are pivotal to the logistics and transportation sectors, facilitating the movement of a wide range of goods. Over the years, regions with robust economic growth, such as Andhra Pradesh (Andhra Pradesh + Telangana), have consistently shown high numbers of vehicle registrations, reflecting their central role in the nation's supply chain networks. As India continues to expand its economic horizons, the evolution of the HGV and MGV fleets will be crucial in supporting sustainable development goals and reducing the transportation sector's environmental footprint.

State and UT wise Heavy Goods Vehicle Registration															
S.No	States and UT's	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	ANDAMAN & NICOBAR ISLAND	56	49	42	48	55	87	88	90	102	74	58	96	79	66
2	ANDHRA PRADESH	11,413	10,356	9,608	6,497	5,468	9,725	11,385	11,960	17,670	13,519	4,075	6,959	10,768	10,947
3	ARUNACHAL PRADESH	237	271	377	484	418	666	1,326	1,441	979	1,233	739	774	608	494
4	ASSAM	4,193	5,965	5,203	3,690	3,058	3,810	3,799	5,000	6,152	5,887	3,501	4,168	5,392	5,015
5	BIHAR	7,682	9,890	12,920	9,436	7,495	8,879	7,987	15,925	12,527	7,135	2,485	2,257	4,015	6,907
6	CHANDIGARH	72	89	105	120	175	152	82	67	84	76	53	165	136	103
7	CHHATTISGARH	6,106	7,756	7,924	5,443	6,193	7,880	7,880	10,579	13,523	8,070	2,961	5,446	12,857	17,394
8	DELHI	148	303	576	685	944	1,977	148	382	388	356	495	1,431	1,574	1,073
9	GOA	1,414	2,829	470	260	208	263	194	175	311	195	95	169	252	374
10	GUJARAT	18,236	24,959	20,930	16,767	15,098	20,039	21,037	16,907	22,855	19,269	9,021	14,631	19,279	21,967
11	HARYANA	18,460	21,982	14,665	11,040	11,736	16,676	16,630	17,864	19,447	16,333	7,097	15,421	23,619	26,112
12	HIMACHAL PRADESH	6,383	3,211	2,524	2,921	2,325	2,792	2,815	2,547	2,886	3,470	1,711	2,070	2,783	2,743
13	JAMMU AND KASHMIR	2,634	2,838	2,342	1,606	1,309	2,200	1,559	2,849	3,652	3,227	2,555	3,250	2,217	2,650
14	JHARKHAND	6,148	6,439	6,113	4,982	5,458	6,833	6,480	8,033	10,514	7,067	2,431	3,213	4,827	7,960
15	KARNATAKA	15,490	14,543	15,177	14,353	13,257	16,095	17,452	15,737	19,286	15,027	6,573	9,739	15,815	16,977
16	KERALA	2,794	3,138	3,110	2,962	2,599	3,083	3,425	2,776	4,510	4,311	2,527	3,470	4,281	4,390
17	LADAKH	101	180	179	74	96	20	73	91	42	69	88	125	282	330
18	MADHYA PRADESH	11,685	13,013	13,993	10,127	7,920	7,764	8,472	9,310	10,895	7,993	2,811	3,889	5,099	5,190
19	MAHARASHTRA	23,923	29,473	27,611	21,581	19,415	23,949	27,797	29,077	39,978	33,092	14,229	21,529	35,355	39,194
20	MANIPUR	217	457	442	264	245	337	581	705	496	522	323	461	320	238
21	MEGHALAYA	1,383	1,835	2,051	1,166	526	527	382	563	796	1,125	626	855	1,492	634
22	MIZORAM	179	337	230	321	192	164	284	370	372	367	375	515	388	306
23	NAGALAND	9,552	10,217	9,681	6,993	6,507	8,532	11,741	13,711	14,959	11,448	4,098	6,111	9,094	9,028
24	ODISHA	11,539	11,451	4,748	4,464	6,239	7,971	9,660	11,311	15,746	15,274	7,693	9,837	10,053	16,377
25	PUDUCHERRY	83	53	31	37	10	52	10	28	25	38	17	24	29	34
26	PUNJAB	10,843	11,713	10,090	7,795	6,771	8,436	9,606	8,859	8,760	6,989	2,724	4,920	6,330	6,577
27	RAJASTHAN	20,565	23,635	20,727	14,652	15,913	22,449	26,410	28,336	33,287	23,659	9,521	17,214	28,027	36,059
28	SIKKIM	193	192	301	179	120	218	262	180	219	138	142	289	345	223
29	TAMIL NADU	18,157	21,913	20,536	11,585	14,373	19,191	17,076	15,204	18,752	16,198	6,860	8,786	14,863	16,801
30	TRIPURA	358	472	416	276	366	320	430	328	260	207	162	329	506	324
31	UT OF DNH AND DD	510	467	422	427	340	536	586	606	1,059	1,259	569	2,096	3,433	3,987
32	UTTARAKHAND	2,326	2,736	2,317	1,583	1,574	2,251	1,973	2,041	2,770	2,008	1,094	1,647	1,855	1,807
33	UTTAR PRADESH	16,320	20,589	24,809	14,039	15,140	20,204	21,512	31,799	41,106	20,395	7,451	13,914	22,479	25,789
34	WEST BENGAL	15,531	16,643	13,407	11,197	8,944	12,237	16,096	13,344	17,094	13,249	5,306	7,007	13,738	13,150

Figure 9: State Wise New Registrations of Heavy Goods Vehicles
Source: Vahan Sewa Dashboard

State and UT wise Medium Goods Vehicle Registration															
S.No	State and UT's	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	ANDAMAN & NICOBAR ISLAND	17	16	10	10	8	3	6	7	11	6	11	12	11	7
2	ANDHRA PRADESH	2,111	1,686	1,502	1,018	938	922	941	851	1,310	1,116	708	868	937	858
3	ARUNACHAL PRADESH	42	47	46	66	66	59	59	132	122	153	100	105	75	67
4	ASSAM	581	651	487	335	279	288	317	586	1,123	1,415	1,459	1,031	429	407
5	BIHAR	773	608	736	1,160	1,045	1,374	1,303	1,553	3,342	3,009	980	255	221	228
6	CHANDIGARH	43	71	38	31	22	27	52	43	40	44	34	53	78	85
7	CHHATTISGARH	380	387	440	526	448	367	326	306	448	376	220	217	221	223
8	DELHI	531	637	349	287	209	408	335	864	1,795	2,187	1,502	3,076	2,357	1,113
9	GOA	272	377	320	135	122	149	114	155	127	126	114	157	187	232
10	GUJARAT	5,101	6,135	7,151	3,867	2,985	4,539	4,908	2,555	2,582	2,539	1,215	2,228	1,810	1,979
11	HARYANA	3,080	2,232	1,378	951	895	835	1,451	1,725	2,381	3,026	2,039	5,429	5,218	3,916
12	HIMACHAL PRADESH	1,285	652	461	385	425	430	551	570	533	549	439	560	487	594
13	JAMMU AND KASHMIR	108	151	171	190	192	187	201	215	386	447	591	615	252	232
14	JHARKHAND	641	747	770	923	831	888	1,018	908	1,359	805	658	470	172	191
15	KARNATAKA	5,209	5,325	4,774	4,000	3,312	3,165	3,717	3,318	4,657	3,777	2,208	3,482	4,408	4,282
16	KERALA	5,220	5,488	5,013	3,702	1,742	1,794	2,200	1,503	2,476	2,527	1,328	2,057	1,709	1,499
17	LADAKH	7	4	5	10	12	7	20	27	60	11	25	29	90	134
18	MADHYA PRADESH	1,475	1,474	1,335	970	662	451	503	578	785	575	366	366	400	1,309
19	MAHARASHTRA	6,713	7,408	5,759	3,850	2,697	2,912	3,700	4,046	5,576	4,959	2,619	4,507	5,555	6,218
20	MANIPUR	33	82	50	79	66	59	36	91	53	21	18	31	34	13
21	MEGHALAYA	351	409	307	227	70	83	149	107	58	251	75	43	97	187
22	MIZORAM	101	129	99	62	50	25	38	73	99	114	160	367	125	125
23	NAGALAND	226	181	224	211	104	81	70	149	172	170	62	136	96	138
24	ODISHA	1,525	1,735	1,272	1,063	1,219	1,367	1,500	1,554	1,580	1,390	609	424	336	407
25	PUDUCHERRY	20	20	11	7	9	11	15	10	12	9	20	26	18	21
26	PUNJAB	1,486	846	738	512	446	389	500	457	333	386	366	700	656	653
27	RAJASTHAN	1,082	845	697	559	443	373	293	295	523	366	325	764	1,071	792
28	SIKKIM	41	42	93	65	21	88	43	25	33	63	50	93	107	40
29	TAMIL NADU	6,226	6,218	5,093	3,387	2,346	2,649	3,749	3,266	4,909	5,906	3,304	5,931	6,785	6,807
30	TRIPURA	131	154	113	162	138	139	330	268	226	229	334	350	311	142
31	UT OF DNH AND DD	370	348	335	193	141	153	180	182	237	268	126	166	216	256
32	UTTARAKHAND	903	745	477	471	531	680	740	646	876	905	661	632	345	263
33	UTTAR PRADESH	2,348	2,093	1,338	1,161	1,029	2,061	2,171	2,508	2,788	2,771	1,538	2,644	2,930	3,145
34	WEST BENGAL	1,867	1,368	1,272	1,310	867	979	1,559	1,485	1,661	1,521	1,006	913	731	881

Figure 10: State Wise New Registrations of Medium Goods Vehicles
Source: Vahan Sewa Dashboard

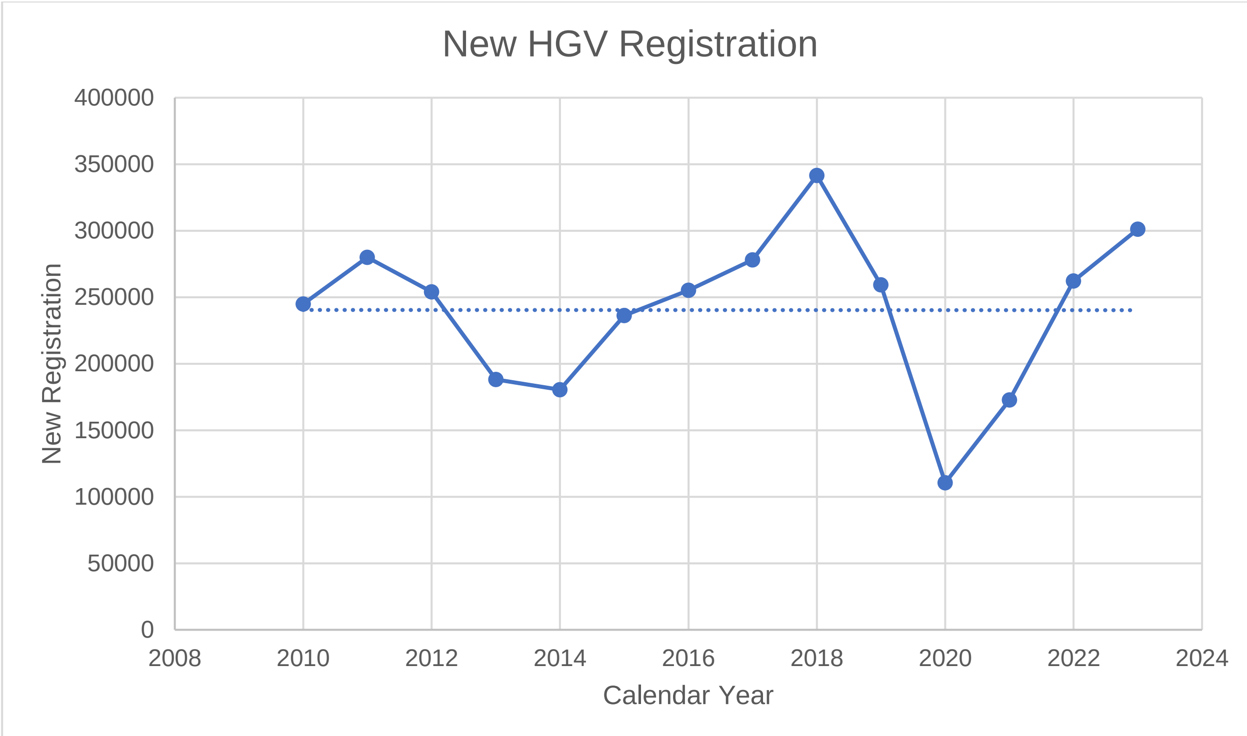


Figure 11: New HGV Registration in Last 14 Years
Source: Author Generated

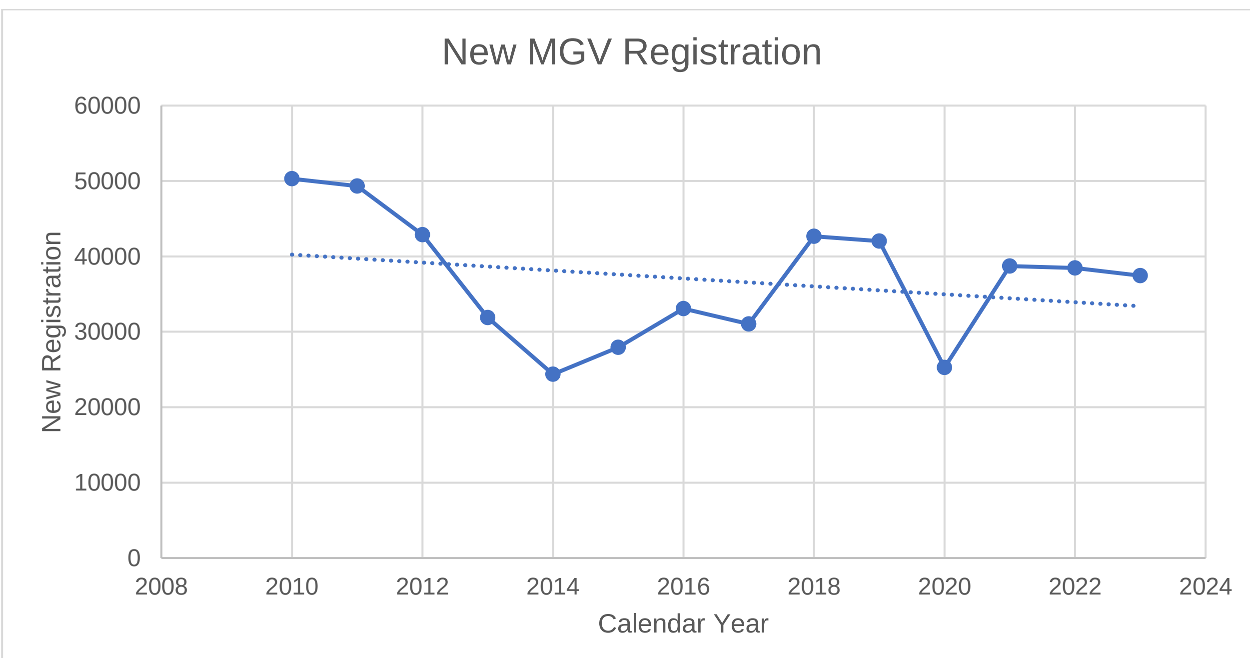


Figure 12: New MGV Registrations in Last 14 Years
Source: Author Generated

3.3 Overview of EV Policies and ZET Transition

India is making significant strides towards adopting zero-emission trucks (ZETs) with several large-scale initiatives underway. Niti Aayog introduced the E-FAST platform in September 2022 to bring together stakeholders from the freight industry to promote and pilot freight electrification. This initiative is designed to gather data-driven insights to shape policies that accelerate this transition.

Additionally, a coalition known as the Zero-Emission Truck High-Level Ambition Group (ZET HLAG) was launched collaboratively by CALSTART, UC Davis, and The Climate Group during the 14th Clean Energy Ministerial meetings in Goa. This group, including major Indian automotive manufacturers and infrastructure providers, aims to drive policy and program development to boost India's zero-emission transport capabilities.

In a related effort, India is planning to develop electric highways that provide power to vehicles in transit through overhead lines or road-embedded cables, primarily powered by solar energy. These initiatives are part of broader demonstrations, like the zero-emission road freight cluster in Maharashtra and Gujarat, which aim to deploy over 550 zero-emission trucks. These clusters and pilot projects on heavily used routes will test new technologies and business models, potentially catalyzing widespread adoption.

At the state level, Telangana and Goa have endorsed a Global MOU on Zero-Emission Medium- and Heavy-Duty Vehicles, setting ambitious targets for the adoption of zero-emission vehicles (ZEVs) by 2030 and 2040. Maharashtra has also set targets for electrifying highways to facilitate long-haul electric truck operations.

These initiatives, complemented by demand aggregation exercises to demonstrate viable market demand to manufacturers, are crucial steps toward decarbonizing India's freight sector and reducing its environmental impact. By prioritizing regions like Telangana for pilot projects and leveraging collaboration between public and private sectors, India is positioning itself as a leader in sustainable freight transportation.(Arora, 2023).

4. DATA COLLECTION

This chapter delves into the data collection process, which was systematically conducted in three distinct phases. Initially, stakeholder consultation was facilitated through both online meetings and in-person interactions, allowing for diverse input and collaborative discussion. The second phase of data collection was executed using a Google Form, which was distributed to relevant participants to gather structured responses efficiently. The final phase once again utilized online meetings. This multi-phased approach ensured a comprehensive collection of data from a variety of perspectives, crucial for the integrity and depth of the analysis.

4.1 Expert Interviews and Stakeholder Consultation

In the course of this study, consultations and interviews were conducted with eleven individuals from a diverse set of professional backgrounds, including industry experts, academicians, original equipment manufacturers (OEMs), and researchers. These experts are affiliated with prestigious institutions and organizations, such as IIT Kharagpur, IIT Guwahati, NIT Meghalaya, and the Alliance for an Energy Efficient Economy, as well as with think tanks and industry bodies like the World Resources Institute (WRI), the International Council on Clean Transportation (ICCT), and pManifold. Additionally, consultations with prominent OEMs such as Ashok Leyland and IPL Tech provided critical insights into the industry perspective, enriching the data collection process with a well-rounded view of the current landscape in their respective fields. This blend of academic and practical expertise ensured a robust foundation for the study's findings.

These interviews were conducted using a subjective approach, which was intentionally chosen to obtain a more detailed and nuanced understanding of the respondents' perspectives, as strictly objective methods can sometimes impose limitations that restrict the depth of the responses. A carefully crafted set of questions was posed in a predetermined order to maintain consistency across interviews. However, it was observed that some respondents, drawing on their specific areas of expertise, chose to omit certain questions. This selective engagement with the questions allowed the respondents to focus more on areas where they could provide the most insightful and substantive contributions. Following questions were asked to the respondents in course of getting and understanding the existing ecosystem in the EMHDT's adoption.

A. What is your perspective on the role of electric mobility in a developing country like India?
B. How do you envision the future of electric mobility in India?
C. Given the current adoption of electric 2-wheelers, 3-wheelers, 4-wheelers, and buses, how do you foresee the electrification of Medium and Heavy-Duty Trucks (MHDT)?
D. Despite constituting only 5% in numbers, MHDTs account for 34% of vehicular pollution and a significant share of fuel consumption in India. What is your perspective on the energy efficiency and emissions of the freight sector in transportation?
E. What technological and operational barriers do we face in the adoption of Electric MHDTs?
F. Currently, state policies do not strongly support the adoption of electric trucks. What initiatives could bridge this gap?
G. The freight sector serves as a revenue generation tool for governments through registrations, toll taxes, and road taxes. If the government incentivizes Electric MHDTs, would it be a financially sustainable step?
H. The electrification of trucks will lead to a substantial increase in electricity demand, especially considering India's reliance on coal-based thermal power plants. How can other renewable energy sources address this in the near future?
I. In electric trucks, the weight of batteries affects the payload capacity, impacting the profit of fleet operators. How can we address this challenge?
J. Government-subsidized electricity tariffs contrast with higher costs at private charging stations, potentially affecting the Total Cost of Ownership (TCO). How can this issue be mitigated?

K. Will the introduction of electric trucks alter the trip behavior of the Indian trucking industry and urban freight regulations, considering that many cities currently restrict heavy trucks during daytime operations?
L. Charging multiple trucks simultaneously could strain the power grid. Can charging tariffs be utilized as a tool to manage traffic at charging stations?
M. In your opinion, what are the alternative practices and business models that can be employed to promote the use of electric trucks in India?

4.1.1 Summary of Expert Interview Responses

India, as a developing nation, stands at a critical juncture in its journey towards sustainable transportation. Electric mobility has emerged as a pivotal solution to address pressing issues such as pollution, energy security, and economic sustainability. In this comprehensive summary, we explore the perspectives of experts on various aspects of electric mobility in India, ranging from its role in the freight sector to policy interventions and technological advancements.

The role of electric mobility in India's development trajectory cannot be overstated. Experts unanimously agree that electric vehicles (EVs) hold immense potential to mitigate the adverse effects of vehicular pollution and reduce the country's dependence on fossil fuels. With ambitious climate goals on the horizon, electric mobility aligns perfectly with India's sustainability objectives, presenting an opportunity for transformative change.

Envisioning the future of electric mobility in India entails overcoming several challenges while leveraging opportunities for growth. While the adoption of electric two-wheelers, three-wheelers, and four-wheelers has gained momentum, the electrification of medium and heavy-duty trucks (MHDTs) presents unique hurdles. Nevertheless, advancements in battery technology, supportive government policies, and collaborative efforts among stakeholders are poised to accelerate the adoption of electric MHDTs in India.

Addressing energy efficiency and emissions in the freight sector is paramount, given the disproportionate contribution of medium and heavy-duty trucks to vehicular pollution and fuel consumption. Transitioning to electric MHDTs not only mitigates environmental impact but also enhances energy efficiency, thus paving the way for a more sustainable future.

However, the adoption of electric MHDTs faces several barriers, including technological limitations, infrastructure gaps, and cost considerations. Overcoming these challenges requires concerted efforts from governments, automotive manufacturers, infrastructure developers, and end-users alike. Policy interventions, incentives, and investments in research and development are essential to drive the widespread adoption of electric MHDTs in India.

In terms of policy support, bridging the gap in state policies and incentivizing the adoption of electric trucks are critical steps. By implementing targeted initiatives such as subsidies, tax breaks, and infrastructure development, state governments can create an enabling environment for the transition to electric mobility while addressing regional disparities.

Financial sustainability is another key consideration, with experts highlighting the potential economic benefits of incentivizing electric MHDTs. Revenue generation opportunities through registrations, toll taxes, and road taxes can offset initial costs, making the transition financially viable for governments in the long run.

Furthermore, addressing the increased electricity demand resulting from the electrification of trucks requires a shift towards renewable energy sources. India's abundant renewable energy potential can mitigate environmental impact while reducing reliance on fossil fuels, thus supporting the transition to electric mobility.

Challenges such as battery weight impacting payload capacity and disparities in charging costs must also be addressed through innovation, policy interventions, and market mechanisms. Additionally, alternative practices and business models, including innovative financing options and last-mile delivery solutions, can promote the widespread adoption of electric trucks in India.

In conclusion, accelerating electric mobility in India requires a multifaceted approach encompassing technological innovation, policy support, infrastructure development, and stakeholder collaboration. By overcoming barriers and seizing opportunities, India can realize its vision of a cleaner, greener, and more sustainable transportation system, driving economic growth and improving quality of life for its citizens.

4.1.2 Details of Available EMHDT in Indian Landscape

These details were meticulously gathered during an in-depth telephonic consultation with IPL Tech and at the Bharat Mobility Expo 2024, which was held at Pragati Maidan in Delhi. At this prominent event, Ashok Leyland unveiled their latest innovations in the electric vehicle sector, launching three electric trucks, each representing the light, medium, and heavy commercial vehicle categories.

Model / Specifications	IPL Tech Rhino 5536	Ashok Leyland AVTR 55 T	Ashok Leyland BOSS 14 T
GVW	55 Ton	55 Ton	14 Ton
Payload Capacity	40 Ton	42 Ton	9 Ton
Approximate Price*	1.15 Cr	1.25 Cr	80 Lakhs
Battery Capacity	258 KWH	301 KWH	201 KWH
Battery Weight*	2.5 T	2.4 T	1.4 Ton
Range	160 KM	185KM	230 KM
Battery Price*	65 Lakhs	70 Lakhs	40 Lakhs
Charging Time	90 Min (20%-100%)	90 Min	120 Min
Charging Equipment Required*	150 KW	240 KW	120 KW
Charging Equipment*	12 Lakhs	18 Lakhs	8 Lakhs

Table 3: Details of Available EMHDT Technology in India
Source: Author Generated
Information Shared by E Truck OEM's during Meeting
** Approximate Cost, *Information not available in public domain*

4.2 Scoring of Identified Barriers

This survey was designed to assess the identified barriers and gauge their impact on the adoption of electric medium and heavy-duty trucks (EMHDT's). The barriers were initially pinpointed through an extensive literature review and further explored through the subjective survey discussed in the previous section. To quantitatively evaluate these barriers, a Google Form was distributed, asking participants to rate each barrier on a scale from 1 to 7. On this scale, a rating of 1 signifies minimal impact on the adoption of EMHDT's, whereas a rating of 7 indicates the most significant impact. The collected data from this survey was then utilized to perform TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and GRA (Grey Relational Analysis) analyses, which helped in ranking the identified barriers according to their severity and impact on the adoption process. This methodical approach ensures a comprehensive understanding of the obstacles hindering the wider acceptance of EMHDT's.

Survey Questions: Rank between 1-7 considering the influence of these barriers in the adoption of EMHDT's.

1: Very low influence

2: Low influence

3: Somewhat low influence

4: Moderate influence

5: Somewhat high influence

6: High influence

7: Very high influence

A. ***Product Availability***
B. ***Operational Reliability***
C. ***Limited Range***
D. ***Long charging Duration***
E. ***Availability of public charging infrastructure***
F. ***The Capacity of the electrical grid to accommodate the Charging Infrastructure of Electric Trucks.***

G. ***Technological Uncertainty***

H. ***Evolving Battery Technology***

I. ***Current Grid Mix***

J. ***Alternative Fuel Technology***

K. ***Governmental and Policy Support***

L. ***Total cost of ownership and High CAPEX Cost***

M. ***Scrap Value***

N. ***Limited Demand***

O. ***Electricity Rate Structures***

P. ***Payload Compromise***

Q. ***The Fragmented Structure of the Freight System***

R. ***Business Model and New Partnerships***

Fifteen expert responses were collected, featuring a diverse group of professionals that included industry experts, logistics firm associates, and research scholars. These experts boast up to 15 years of experience in the fields of logistics and sustainable mobility, encompassing electric mobility. Their extensive knowledge and practical insights in these areas enriched the data collection process, providing valuable perspectives on the current challenges, considering future directions of sustainable transport solutions.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
B1	7	6	5	3	4	7	4	5	6	4	7	7	5	6	5
B2	5	7	6	5	5	3	5	5	2	2	2	7	1	6	6
B3	6	4	7	2	6	7	5	7	4	5	3	6	1	6	4
B4	6	6	7	5	6	7	4	6	5	4	3	6	4	6	6
B5	7	3	5	5	7	7	7	5	6	5	7	7	6	6	6
B6	4	3	5	4	4	2	5	6	1	2	6	5	4	4	3
B7	3	5	4	5	5	2	6	5	2	3	2	5	2	5	3
B8	6	5	4	5	4	2	5	3	2	3	1	7	2	5	5
B9	3	3	5	5	5	6	6	6	2	3	1	6	2	5	2
B10	4	5	3	6	3	4	5	7	4	5	7	5	2	4	5
B11	6	6	6	7	7	5	7	4	7	5	7	7	6	6	6
B12	3	6	3	7	7	6	7	5	6	6	3	5	6	5	6
B13	6	6	6	5	6	6	7	4	6	5	5	4	2	6	5
B14	6	5	6	5	3	6	6	4	5	4	6	4	4	4	5

B15	1	5	6	3	3	2	5	5	2	4	2	5	2	4	2
B16	2	7	6	6	3	7	7	7	4	3	5	5	2	4	5
B17	3	4	4	7	5	5	5	6	5	4	3	4	2	4	6
B18	3	3	4	7	5	4	7	4	6	5	1	4	6	6	5

Table 4: Scores Recorded for Identified Barriers
Source: Google Form Based Questionnaire
B: Barrier
S: Score

4.3 Relationship Establishment

This survey was meticulously orchestrated with the aim of exploring the relationships between identified barriers to EMHDT’s adoption. It was carried out among an expert panel comprising three members from the e-mobility team at the Alliance for an Energy Efficient Economy (AEEE) and one expert from pManifold Business Solution. The primary objective was to establish the relationship between all the identified barriers and understand the root cause behind the various identified barriers. This nuanced understanding is critical for developing effective mitigation strategies and formulating targeted policy recommendations that can address and overcome these barriers effectively.

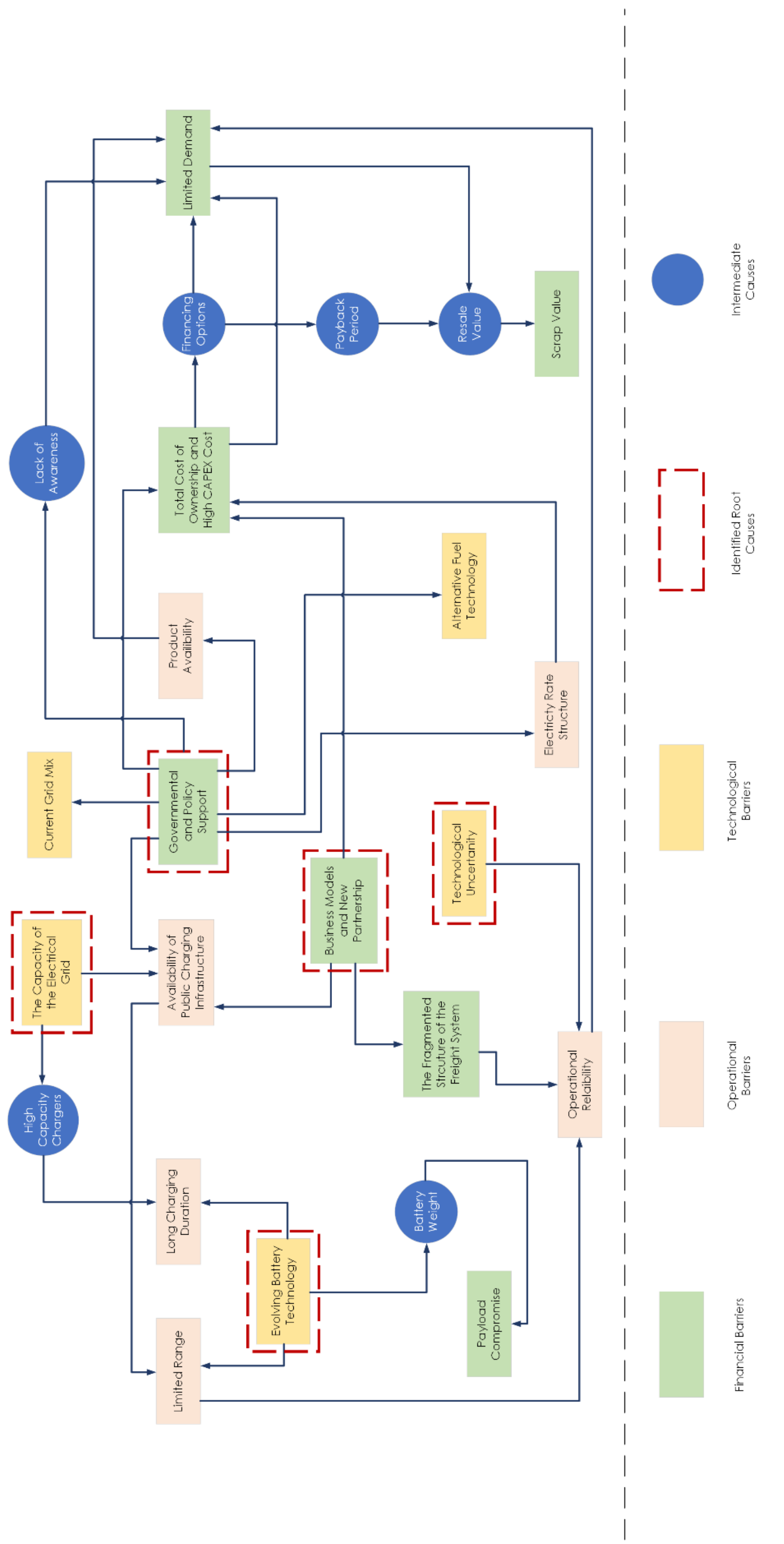


Figure 13: Relationship Between Various Barriers in the Adoption of EMHDT's
Source: Author Generated

5. DATA ANALYSIS AND RESULTS

This chapter offers a comprehensive overview of the data synthesis process, detailing the roles and responsibilities of the various stakeholders involved, as well as the hierarchical mapping that organizes these roles within the broader institutional framework. Following this foundational information, the chapter delves into the methodologies used for scoring and ranking the identified barriers to the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's). This includes the utilization of statistical tools that help quantify and prioritize these barriers based on their impact. Additionally, it explores the relationships established among the various barriers, providing insights into how they interconnect and influence EMHDT adoption.

The latter part of the chapter focuses on the examination of different business models that facilitate the adoption of EMHDT's, alongside a detailed comparison of the Total Cost of Ownership (TCO) between EMHDT's and their Internal Combustion Engine (ICE) counterparts. This analysis not only highlights the economic viability of EMHDT's but also underscores the potential long-term financial benefits of transitioning to electric vehicles within the heavy-duty transport sector.

5.1 Involved Stakeholders

Stakeholders involved in the operations of Electric Medium and Heavy-Duty Trucks (EMHDT's) are categorized into three distinct levels based on their legislative roles and responsibilities. The first level encompasses the central government, including various ministries and their associated departments, which play a crucial role in framing national policies and regulations. The second level consists of state and local government entities, which implement these policies and adapt them to regional contexts. The third level includes stakeholders from private organizations and those engaged in public-private partnerships (PPPs). These entities collaborate to support the deployment and efficient operation of EMHDT's, aligning both public objectives and private interests to foster a sustainable transportation ecosystem.

5.1.1 Central Level

A. **Ministry of Road Transport and Highways (MoRTH)** - The Ministry of Road Transport and Highways (MoRTH) in India is integral to the adoption and regulation of electric medium and heavy-duty trucks, aligning with the national shift towards electric vehicles (EVs). MoRTH's core responsibilities encompass a broad range of activities designed to facilitate this transition. It develops and implements policies that encourage the use of EVs, including crafting regulations to support the necessary infrastructure like charging stations and offering incentives to accelerate adoption. The ministry sets safety, efficiency, and environmental standards for electric vehicles, ensuring they meet international norms to enable technology interoperability. Significant efforts are also made in developing infrastructure, particularly EV charging facilities along major highways and urban areas, in collaboration with other government entities and the private sector. Financial incentives such as subsidies, tax rebates, and reduced toll charges are used to lower ownership costs for businesses and fleet operators. MoRTH also focuses on public awareness, often working with various stakeholders to promote the benefits of EVs and stimulate market uptake. Additionally, it enforces environmental regulations to reduce transportation sector emissions and supports research and development in electric mobility. Finally, MoRTH monitors compliance with these regulations and oversees the overall progress of EV integration into the national fleet, ensuring that the shift to electric transportation aligns with policy goals and regulations.

   i. **Automotive Industry Standards Committee (AISC) -** The Automotive Industry Standards Committee (AISC) in India is pivotal in shaping the manufacturing landscape for electric vehicles, particularly electric trucks. As the body responsible for setting automotive standards, AISC ensures that all vehicles produced or sold in India meet stringent criteria that uphold safety, environmental responsibility, and efficiency. In the domain of electric trucks, AISC's influence is profound. It crafts specific safety standards that cover aspects such as battery safety, structural integrity, and electrical systems, ensuring these vehicles are as safe as those powered by internal combustion engines. Environmental standards set by AISC aim to minimize the ecological footprint of these vehicles, focusing on emission controls pertinent to the production and disposal of batteries and other components. Performance standards are also crucial, as they ensure that electric trucks are competitive in range, efficiency, and load capacity. Moreover, AISC establishes interoperability standards for charging infrastructure, which are essential for the widespread adoption and practical use of electric trucks across India. Standards concerning battery life cycles, storage, recycling, and safety measures address the unique challenges posed by high-capacity batteries. AISC's role extends to the certification and compliance processes, ensuring that electric trucks meet all set standards before they enter the market, thus maintaining public trust and safety. Through these comprehensive standards, AISC not only fosters a safer manufacturing environment but also supports India's goals for sustainable transportation and carbon emission reduction, paving the way for the broader adoption of electric trucks.

ii. **The Central Motor Vehicle Rules (CMVR) Committee** - The Central Motor Vehicle Rules (CMVR) Committee is instrumental in supporting the adoption of electric trucks in India by methodically updating the regulatory framework to address the unique requirements of battery electric vehicles (BEVs). The committee's approach begins with identifying specific regulatory needs, focusing on adapting current standards to accommodate the technological nuances and safety considerations unique to electric trucks. They then update the Central Motor Vehicles Rules to include vehicle-side requirements such as construction norms, functional safety, electrical specifications including resistance and inductance, and protocols for high-power charging systems like OH-ACD. This involves a detailed process of revising dimensional requirements for interoperability, specifying the placement of charging devices, and standardizing internal high voltage wiring connections within the vehicles. The CMVR Committee facilitates discussions among expert panels to deliberate and finalize these updated standards and regulations. These proposed updates are then communicated to relevant ministries to obtain necessary approvals. Once endorsed, these regulations are officially notified and implemented. This comprehensive and collaborative approach ensures that electric trucks are integrated into India's vehicular landscape safely and efficiently, supporting broader environmental and technological advancement goals.

iii. **National Highway Authority of India (NHAI) -** The National Highways Authority of India (NHAI) is essential in fostering the integration of electric trucks into India's transportation framework by using its infrastructure planning and development expertise. NHAI's strategic employment of detailed geographic and traffic data is key to creating an enabling environment for electric vehicles, especially heavy trucks. This includes utilizing traffic density data to pinpoint key routes where electric truck adoption could be most beneficial. By understanding vehicle tonnages and cargo types, NHAI effectively prioritizes infrastructure development on these high-potential routes to enhance the operational efficiency of electric trucks. Mapping of high-tension power lines and substations allows NHAI to judiciously place electric vehicle charging stations, aligning them with existing power sources to support the high-demand charging needs of electric trucks while minimizing installation costs. Additionally, data from fuel stations along these corridors inform the conversion of some sites into hybrid stations that cater to both traditional and electric trucks, a crucial step during the transitional phase. NHAI also ensures that electric trucks have access to necessary maintenance and emergency services by mapping out automotive servicing hubs and fire stations, adapting these facilities to meet the specific requirements of electric vehicles. Moreover, by analyzing traffic composition in areas with non-highway-like conditions, NHAI identifies and mitigates risks, thus crafting safer and more effective traffic management strategies for electric trucks. Through these comprehensive, data-driven strategies, NHAI not only smoothens the operational integration of electric trucks but also supports environmental sustainability goals by promoting cleaner and greener transport solutions.

B. **Ministry of Commerce and Industry** - The Ministry of Commerce and Industry, along with its arm, the Department for Promotion of Industry and Internal Trade (DPIIT), plays a crucial role in facilitating the adoption of electric trucks in India by enhancing the industrial and economic landscape for electric vehicles (EVs). Actively involved in promoting the growth of the EV sector, this Ministry, through DPIIT, spearheads initiatives that span the manufacturing of electric trucks and their critical components such as batteries and electric motors. These initiatives include offering incentives for establishing new manufacturing facilities and supporting research and development aimed at advancing EV technology. Furthermore, DPIIT is instrumental in formulating trade policies that reduce import duties on essential EV components not yet produced domestically, thereby making electric trucks more accessible and competitively priced. It also ensures the development of the necessary infrastructure, such as industrial parks and special economic zones specifically designed for EV manufacturing, along with the growth of ancillary industries crucial to the EV ecosystem. Moreover, the Ministry and DPIIT together foster international collaborations to facilitate technology transfer and attract foreign investments, critical components for strengthening the domestic market for electric trucks. Through these concerted efforts, the Ministry and DPIIT create a supportive environment for the burgeoning electric truck industry, aiming to make India a leader in the global electric vehicle space.

i. **Petroleum and Explosives Safety (PESO) -** On the safety regulation front, the Petroleum and Explosives Safety Organization (PESO) addresses the critical aspects of explosive and hazardous materials associated with electric trucks, particularly focusing on battery safety. PESO is tasked with ensuring that the design, transport, and disposal of EV batteries meet stringent safety standards to prevent hazardous incidents. This includes certifying battery storage and handling facilities and developing comprehensive rules for the safe transportation and handling of hazardous materials found in EV batteries. PESO also establishes emergency response guidelines for accidents involving electric trucks, creating protocols for first responders to efficiently manage incidents related to EV battery mishaps. By setting these safety regulations, PESO plays an essential role in safeguarding public and environmental health, thus supporting the broader adoption of electric trucks in a safe and regulated manner.

C. **Ministry of Consumer Affairs, Food and Public Distribution -** The Ministry of Consumer Affairs, Food and Public Distribution, in collaboration with the **Bureau of Indian Standards (BIS) Committee**, plays a critical role in facilitating the adoption of electric trucks, particularly those utilizing fuel cell technologies (FC and FCEV). Their joint efforts are pivotal in establishing a robust framework for safety and compliance. The Ministry is responsible for ratifying new standards that ensure electric trucks meet essential safety and performance criteria. This process includes comprehensive consultations with industry stakeholders and other governmental bodies, which helps in refining the standards to cover all pertinent issues. Additionally, the Ministry and BIS identify suitable Indian agencies capable of establishing test facilities for BEV and FCEV technologies. These facilities are critical for the domestic testing and certification of fuel cells and related components, ensuring they adhere to national standards. The BIS Committee then publishes these standards and ensures they are widely notified, making manufacturers aware of the regulatory requirements. The establishment of local testing facilities further supports the industry by providing accessible, cost-effective means for compliance testing, thus accelerating the development and introduction of electric trucks. This strategic alignment between setting, enforcing, and supporting compliance with standards not only propels the technological shift towards cleaner electric vehicles but also safeguards consumer interests by guaranteeing safety and reliability in these advanced vehicular technologies.

D. **Ministry of Education -** The Ministry of Education significantly contributes to the adoption of electric trucks in India by supporting research and development aimed at resolving technological and operational challenges. By fostering educational programs and curricula focused on electric vehicle (EV) technology, the ministry ensures a well-prepared workforce to propel the EV industry forward. It also channels government funding towards university-led research projects that explore innovations in battery technology, power systems, and materials to enhance the performance and efficiency of electric trucks. Additionally, the Ministry facilitates valuable industry-academia partnerships, enabling practical testing and refinement of EV technologies. This comprehensive approach not only accelerates technological advancements but also equips the emerging workforce, supporting India’s transition to sustainable heavy transportation solutions and promoting a cleaner environmental future.

E. **Ministry of Education -** The Ministry of Skill Development and Entrepreneurship is instrumental in promoting the adoption of electric trucks in India by facilitating comprehensive training and skill development for key personnel in the industry. This includes specialized training for equipment manufacturing staff on the latest technologies essential for producing electric trucks, such as advanced battery systems and electric drivetrains. Additionally, the ministry offers targeted programs for maintenance personnel to ensure they are adept at servicing the unique components of electric vehicles, such as electric motors and battery management systems. Furthermore, the ministry conducts educational sessions for drivers and fleet operators, focusing on sustainable and safe driving practices tailored to the nuances of electric truck operation. These initiatives ensure that the workforce is well-prepared to support the growth and sustainability of the electric truck industry, enhancing overall efficiency and safety in operations.

F. **Ministry of Finance -** The Ministry of Finance significantly bolsters the adoption of electric trucks in India by enhancing financial frameworks to support investments from domestic and international entities. By creating incentives for finance product retailers like NBFCs, banks, and other lenders—such as lower interest rates on loans and tax rebates—the ministry makes financing more attractive for purchasing electric trucks and investing in EV infrastructure. Additionally, it plays a crucial role in establishing partnerships with multilateral agencies like the World Bank and the Asian Development Bank, securing capital for large-scale infrastructure projects and advanced manufacturing initiatives. These efforts are supplemented by policies that stabilize the economic environment for EV investments, including risk-sharing mechanisms that reduce investment risks. Together, these strategies facilitate a well-supported financial landscape for the electric truck market, driving forward India's sustainability and emission reduction goals.

G. **Ministry of Heavy Industries (MoHI) -** The Ministry of Heavy Industries in India is instrumental in advancing the adoption of electric trucks through a comprehensive strategy that integrates policy formulation, financial incentives, and infrastructural development. The ministry orchestrates the implementation of pivotal initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, the National Electric Mobility Mission Plan (NEMMP), and the Production-Linked Incentive (PLI) scheme. These programs are designed to reduce the purchase cost and boost the production capabilities of electric trucks. By providing subsidies and tax rebates under the FAME scheme, enhancing technological development and adoption through NEMMP, and encouraging domestic production via the PLI scheme, the ministry not only makes electric trucks more accessible but also economically viable. Additionally, it focuses on setting regulatory standards for safety and efficiency, facilitating industry-wide collaborations, and spearheading R&D to improve critical technologies like battery systems. The ministry also plays a critical role in expanding the necessary charging infrastructure to support these vehicles, ensuring a seamless integration of electric trucks into India's transport ecosystem. This holistic approach helps in monitoring the effectiveness of these policies and adjusting them as needed, thereby fostering a robust environment for the sustainable growth of electric truck adoption in India.

H. **The Ministry of New and Renewable Energy (MNRE) -** The Ministry of New and Renewable Energy (MNRE) in India is pivotal in promoting the adoption of electric trucks through initiatives that focus on integrating renewable energy sources within the transportation sector. The MNRE's role extends to facilitating the integration of solar and wind power into the national grid, ensuring that the electricity for charging electric trucks is sourced sustainably. The ministry fosters this shift by providing financial and policy incentives to stimulate renewable energy projects geared toward EV infrastructure, thus making investments more appealing for businesses and public entities. Additionally, the MNRE supports research and development aimed at improving the efficiency of solar panels and storage systems for use at EV charging stations. It also crafts policies that promote renewable energy usage in transportation, aligning with national emissions reduction goals. Collaborative efforts with other government bodies, industry stakeholders, and international organizations help scale necessary infrastructure and incorporate global best practices. Public awareness campaigns further educate on the benefits of renewable energy-powered vehicles. Furthermore, the MNRE is involved in developing hydrogen generation and dispensation agencies, a move that bolsters the infrastructure for hydrogen fuel cell vehicles (FCEVs), complementing its efforts with electric trucks to create a comprehensive eco-friendly transportation system. Through these multifaceted strategies, the MNRE ensures the adoption of electric trucks is not only viable and technologically advanced but also contributes significantly to India's environmental sustainability objectives.

I. **Ministry of Power -** The Ministry of Power, along with Distribution Companies (DISCOMS) and the Rural Electrification Corporation Limited (REC), plays a crucial role in supporting the adoption of electric trucks in India by enhancing and managing the necessary power infrastructure. They are responsible for expanding grid capacity to accommodate the increased demands of EV charging stations and integrating advanced grid technologies for efficient power management. By setting favorable tariffs and regulations, they encourage EV use and facilitate the installation of charging infrastructure, including in rural areas through REC's financing. These entities also promote partnerships with the private sector to leverage investment and accelerate infrastructure deployment, while supporting the integration of renewable energy sources to minimize the environmental impact. DISCOMS ensure the reliability and quality of the power supply, critical for the operation of high-powered charging stations needed by electric trucks.

J. **Ministry of Science and Technology -** The Ministry of Science and Technology in India plays a crucial role in advancing the technological landscape for electric trucks by promoting research and development, fostering innovation, and facilitating international collaborations. It actively supports R&D in areas such as advanced battery technologies, electric drivetrains, and energy efficiency to overcome the existing technological barriers to electric vehicle (EV) adoption. The ministry also provides grants and incentives to startups and established companies for developing new EV technologies, including improvements in charging infrastructure and vehicle-to-grid systems. Additionally, it encourages the adoption of global technological advancements through partnerships with international entities, ensuring that Indian manufacturers are equipped with cutting-edge technologies. By bolstering educational and training programs at universities and technical institutes, the ministry further enhances the nation’s scientific capacity to support the growing EV sector.

K. **Ministry of Environment Forest and Climate Change of India -** On the environmental front, the Ministry of Environment, Forest, and Climate Change is instrumental in promoting the adoption of electric trucks by implementing regulatory frameworks aimed at reducing pollution and greenhouse gas emissions from the transportation sector. This ministry sets and enforces vehicle emission standards, advocates for the integration of renewable energy sources to power electric trucks, and monitors air quality to ensure compliance with environmental norms. Through public awareness campaigns, it educates both the public and industry stakeholders about the environmental advantages of electric trucks and their role in mitigating climate change. The ministry's efforts in promoting cleaner transport options align with India's commitments under international environmental agreements, thereby contributing significantly to the country's climate change mitigation strategies. These initiatives collectively facilitate a sustainable transition to electric trucks, reinforcing India's goals for a greener transportation infrastructure.

5.1.2 State and Local Level

A. **State Transport Department -** The State Transport Department oversees the implementation of transport policies at the state level, including the registration and regulation of electric trucks. They ensure that these vehicles meet state-specific regulatory requirements and promote the adoption through incentives and subsidies tailored to local needs. Additionally, they collaborate with other state and local agencies to facilitate the necessary infrastructure developments such as charging stations.

B. **Regional Transport Offices (RTO) -** RTOs are primarily responsible for the registration of new vehicles, issuance of driving licenses, and inspection of vehicle standards. In the context of electric trucks, they ensure that these vehicles comply with all national and state regulations before they are allowed on the road. RTOs also play a role in educating truck owners and operators about the specific requirements and benefits of electric vehicles.

C. **Urban Local Bodies -** Urban Local Bodies (ULBs) are crucial for the urban integration of electric trucks. They manage the urban infrastructure necessary for EVs, such as charging stations and dedicated parking spaces. ULBs also enforce local traffic regulations that can prioritize or encourage the use of electric trucks, such as access to low-emission zones or reduced rates on tolls for electric vehicles.

D. **Accidents/Fire Service, Hospitals, Police -** Emergency services and the police department have to adapt their operations to accommodate electric trucks. This includes training for handling accidents involving electric vehicles, which may require different techniques due to the risk associated with high-voltage batteries. Hospitals and emergency responders need protocols for safely dealing with EV accidents, while police will need to enforce traffic laws that pertain to electric vehicle operation.

E. **Traffic Management/Traffic Police -** Traffic Management and Traffic Police play essential roles in the integration of electric trucks into existing road systems, focusing on safety, efficiency, and regulatory compliance. Their responsibilities include enforcing new and existing traffic regulations adapted for electric trucks, optimizing traffic flow by adjusting signals and potentially designating specific lanes for EVs to reduce congestion and enhance operational efficiency. They are also involved in developing safety protocols and emergency response strategies for incidents involving electric vehicles, including handling battery fires and electrical hazards. Additionally, these authorities support public education efforts to raise awareness about electric trucks and collaborate with other agencies to facilitate the strategic placement of EV infrastructure like charging stations. By collecting and analyzing traffic data, they help assess the impact of electric trucks and plan for future traffic infrastructure developments, ensuring that the transition to electric vehicle use is safe and beneficial for all road users.

F. **State Electricity Distribution Companies -** State Electricity Distribution Companies are key to providing the necessary energy infrastructure for electric trucks. They are tasked with upgrading grid capacity to support additional loads from EV charging stations and ensuring that the power supply is stable and reliable. Additionally, these companies may offer special electricity tariffs for EV charging to make the operation of electric trucks more economically viable.

5.1.3 Private and Public Private Partnership Entities

A. **Automotive Original Equipment Manufacturers (OEMs) -** OEMs design, manufacture, and sell electric trucks, integrating the latest technologies into their vehicles to ensure safety, efficiency, and compliance with environmental standards. They also engage in R&D to continually improve vehicle performance and drive down costs.

B. **Charger Manufacturers -** These stakeholders produce the charging units necessary for electric trucks. Their role includes developing reliable, fast-charging technology that can be easily integrated into existing infrastructure and new developments.

C. **Battery Pack Recycling and Repurposing Parties -** These entities manage the lifecycle of battery packs, ensuring environmentally friendly disposal and repurposing of battery materials. Their responsibilities include recycling materials to reduce waste and exploring secondary uses for aged batteries.

D. **Technical Experts in Battery Pack Engineering and Vehicle Engineering -** Experts in battery and vehicle engineering provide the necessary technical expertise to enhance the design, functionality, and integration of batteries into electric trucks, ensuring these components meet specific energy requirements and safety standards.

E. **Component Suppliers for OEMs -** These suppliers provide essential parts for electric trucks, from electrical components to structural elements, ensuring that OEMs have the high-quality materials needed to assemble reliable vehicles.

F. **Power Electronics Manufacturers -** These manufacturers supply critical components that manage the flow of electrical power in electric trucks, including converters and inverters, essential for the vehicle's energy efficiency and overall performance.

G. **Truck Retailers/Suppliers -** Retailers and suppliers connect manufacturers with buyers, providing a critical sales and distribution network for electric trucks and ensuring that customers have access to the latest models.

H. **Spare Dealers and Service Stations -** These stakeholders ensure the availability of parts and maintenance services for electric trucks, critical for the long-term operation and reliability of these vehicles.

I. **Service Teams -** Service teams perform the necessary maintenance and repair work on electric trucks, ensuring they operate efficiently and safely throughout their lifecycle.

J. **Charging Station Operators -** Operators manage the daily operations of charging stations, providing access to power for electric trucks. Their role includes maintaining the infrastructure and potentially expanding charging options as demand increases.

K. **Risk Cover Agencies -** These agencies offer insurance products that cover electric trucks, mitigating financial risks associated with accidents, malfunctions, and other liabilities for owners and operators.

L. **IT, Data Acquisition, and Application Developers -** These technology stakeholders develop software and hardware solutions that enhance the functionality of electric trucks, such as fleet management systems, route planning software, and performance monitoring applications.

M. **Resting Points and Restaurants -** Resting points and restaurants along transportation routes play a vital role in the adoption of electric trucks by serving as strategic locations for charging stations. By hosting these facilities, they become integral nodes in the electric vehicle charging infrastructure, encouraging broader operational routes for electric trucks. This setup not only benefits the electric truck industry by extending range capabilities but also enhances business for the hosts through increased patronage from truck drivers needing to charge their vehicles. Additionally, these establishments can improve the charging experience by offering essential amenities such as food, restrooms, and resting areas, making stopovers more comfortable for drivers during the charging process. Engaging in partnerships with EV charging providers can further streamline the installation and management of charging stations, providing mutual benefits through increased customer flow and service offerings.

N. **Private Electricity Distribution Agencies -** Private electricity distribution agencies also contribute significantly to the electric truck ecosystem, particularly through the provision of energy and the development of necessary infrastructure. These agencies can supply renewable energy to power charging stations, aligning the operation of electric trucks with environmental sustainability goals. Moreover, they are poised to make substantial investments in electrical infrastructure to support robust, fast-charging stations that are crucial for the effective operation of electric trucks. Private electricity providers can offer customized power solutions and innovative tariff plans tailored to the needs of large fleet operators and charging networks, enhancing the efficiency and affordability of electric truck operations. Their capability to innovate quickly and implement new technologies in electric power distribution is essential for advancing the infrastructure needed for a successful transition to electric mobility in the trucking sector.

O. **Professional Application Drivers -** Drivers who specialize in operating electric trucks provide valuable feedback on vehicle performance and usability, which can inform further development and refinement of electric trucks.

P. **First Responders/Early Buyers -** Early adopters of electric trucks can provide critical market feedback and set trends that encourage wider adoption, helping to refine the user experience and demonstrating the viability of electric trucks to a broader audience.

Q. **Fleet Owners and Fleet Operators -** These stakeholders manage large numbers of vehicles and can significantly impact the adoption of electric trucks by transitioning their fleets to electric models, driven by economic factors and environmental regulations.

R. **Drivers -** Drivers of electric trucks need to be well-informed and trained in the specifics of electric vehicle operation, as their day-to-day experiences can influence the perception and acceptance of electric trucks in the wider community.

S. **End Customer Freight Users -** The ultimate customers for freight services provided by electric trucks, their satisfaction with the service quality, reliability, and cost compared to traditional trucks can drive broader market acceptance.

5.1.4 Stakeholder Mapping

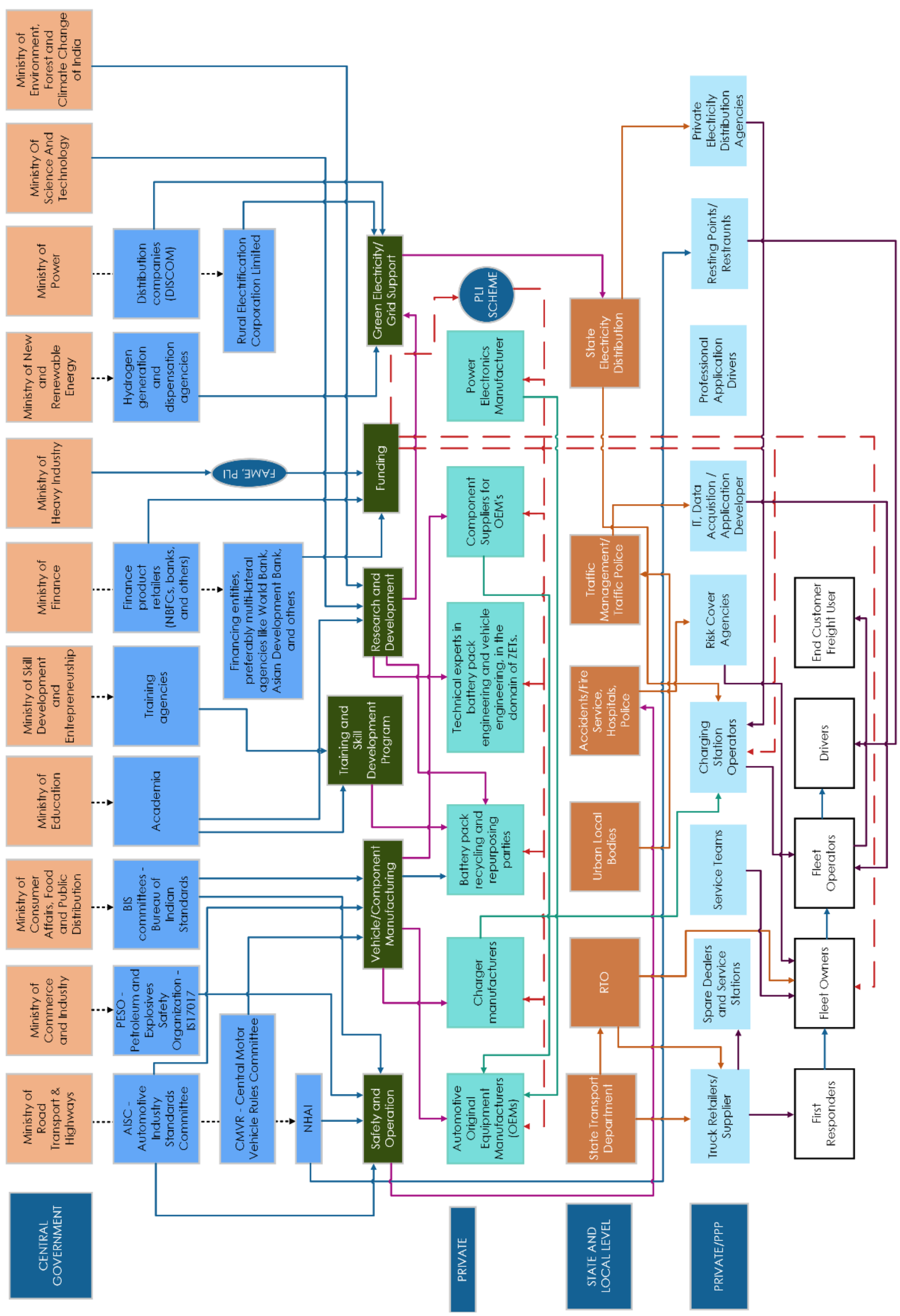


Figure 14: Stakeholder Mapping for Involved Stakeholders in the Adoption and Operation of EMHDT's
Source: Author Generated

5.2 Description of Identified Barriers

The identification of barriers impeding the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's) was methodically conducted in two stages to ensure a comprehensive analysis. Initially, a detailed literature review was undertaken to pinpoint the recurring barriers, capturing frequently mentioned challenges in existing scholarly articles and industry reports. The barriers identified during this first stage include Total Cost of Ownership, Charging Infrastructure, Battery Technology, Charging Duration, Policies and Schemes, Grid Mix, Range Anxiety, Alternative Fuel Technology, and Payload Compromise.

Subsequently, the second stage involved extracting additional barriers through expert interviews. These interviews provided insights into practical challenges and industry-specific obstacles not covered in the literature. The barriers gleaned from these discussions include Product Availability, Operational Reliability, Grid Capacity and Support, Technological Uncertainty, Scrap Value, Heterogeneous Operational Structure, Limited Demand, Electricity Rate Structure, and the Lack of Business Models.

Upon gathering all the data, the barriers were meticulously categorized into three primary domains: operational barriers, which affect day-to-day functionality; technological barriers, which pertain to the limitations in current technologies; and financial barriers, which involve economic factors that influence the cost-efficiency and investment viability. This structured approach to categorization helps in addressing each barrier with targeted strategies and solutions, facilitating a smoother transition to EMHDT adoption.

5.2.1 Operational Barriers

A. **Product Availability (B1) -** Currently in India, there are very few homologated models of medium and heavy-duty trucks available, which limits options for buyers, as most major truck manufacturers in the Indian market offer limited choices. Additionally, EMHDT's from foreign manufacturers tend to be more expensive.

B. **Operational Reliability (B2) -** The uncertainty surrounding operational reliability, particularly regarding power, terrain, performance under various weather conditions, and compatibility with Indian road and traffic conditions, is causing operators to question the viability of these trucks.

C. **Limited Range (B3) -** According to a Mahindra Report, the majority of Indian medium and heavy-duty trucks travel over 400 kilometers daily within a span of 12 hours. However, the available electric medium and heavy-duty trucks offer an average range of only 150-220 kilometers. This disparity in range plays a significant role in the hesitation among operators to shift towards electric medium and heavy-duty trucks.

D. **Long charging Duration (B4) -** According to IPL Tech and Ashok Leyland (Original Equipment Manufacturers), these trucks support DC Fast Charging, enabling them to charge from 20% to 100% in 90 to 120 minutes. While charging with low powered charger increase the charge significantly. This charging time is significantly higher than the refueling time required for Internal Combustion Engine (ICE) medium and heavy-duty trucks.

E. **Availability of public charging infrastructure (B5) -** In India, 80% of fleet operators own 10 or fewer trucks, suggesting that they do not designate specific trucks for particular corridors or routes. However, due to the limited availability of charging infrastructure in India, EMHDT's cannot operate on most routes. This situation raises concerns among fleet operators.

5.2.2 Technological Barriers

A. **The Capacity of the electrical grid to accommodate the Charging Infrastructure of Electric Trucks (B6) -** The installation of high-power charging equipment and the charging of electric medium and heavy-duty trucks (EMHDT's) will consume a significant amount of energy, especially during peak hours, which could potentially lead to grid failures. This scenario is likely to cause anxiety among DISCOMs (Distribution Companies) and other power suppliers.

B. **Technological Uncertainty (B7) -** Since EMHDT's represent a relatively new technology, they rely heavily on electrical equipment rather than mechanical components. Unlike mechanical parts, electrical components often cannot be repaired and require replacement. Procuring these replacements, especially in remote areas, can be time-consuming and challenging. Additionally, current drivers and mechanics may not be adequately trained or equipped to handle these new technologies. These factors contribute to anxiety in operations surrounding the maintenance and repair of EMHDT's.

C. **Evolving Battery Technology (B8) -** Battery technology is advancing rapidly, with significant developments in recent years leading to changes in energy density and noticeable drops in prices. However, this rapid evolution also brings a pause in buyers decision-making processes. On one hand, there are concerns about the current viability of electric vehicles due to these rapid changes, while on the other hand, there is optimism about the potential for cheaper batteries in the near future. This uncertainty is contributing to a slowdown in the transition to electric vehicles.

D. **Current Grid Mix (B9) -** As over 70% of the power is presently generated from non-renewable sources, this leads to a substantial increase in the life cycle emissions of EMHDT's. This presents a major obstacle to the adoption of EMHDT's from the viewpoint of policymakers and the government.

E. **Alternative Fuel Technology (B10) -** Given the existence of various other technologies within the realm of zero-emission trucking or those supporting the decarbonization of the transport sector—such as hydrogen fuel cell vehicles and other fuel-efficient technologies—policy makers and operators are faced with uncertainty regarding whether to wait for the emergence of the optimal technology from the perspective of environmental and economical sustainability.

5.2.3 Financial Barriers

A. **Governmental and Policy Support (B11) -** The absence of government and policy support to provide financial security to early adopters is notable. There is a lack of both fiscal and non-fiscal incentives for EMHDT's from the government, especially when compared to the support provided for electric two-wheelers, three-wheelers, and four-wheelers. This disparity in support influences the mindset of buyers, making EMHDT's appear to be a costly and unsecured option.

B. **Total cost of ownership and High CAPEX Cost (B12) -** The cost of EMHDT's is nearly 2.5 times higher than that of ICE MHDT's. This substantial price difference significantly impacts the payback period, which is a crucial factor in the trucking industry in India. The extended payback period for EMHDT's is primarily influenced by travel behavior and average trip length. Moreover, the lack of clarity regarding on-road operations contributes to the challenge of defining the Total Cost of Ownership (TCO) for EMHDT's in India. Various hidden costs may arise in the future, as indicated by different Original Equipment Manufacturers (OEMs).

C. **Scrap Value (B13) -** In India, it is common practice to sell Medium and Heavy-Duty Trucks (MHDTs) at approximately 30% of their original cost after the completion of their payback period. Consequently, the resale value of the vehicle is a significant consideration for buyers. However, determining the resale value of electric vehicles after their useful life remains a major concern for potential buyers.

D. **Limited Demand (B14) -** The limited demand for Electric Medium and Heavy-Duty Trucks (EMHDT's) is another factor influencing the adoption rate and confidence of potential buyers. This restrained demand not only hampers infrastructure development but also discourages Original Equipment Manufacturers (OEMs) and the government from actively facilitating the adoption of EMHDT's.

E. **Electricity Rate Structures (B15) -** As electricity is a crucial element in charging vehicle batteries, the rates offered for battery charging are a vital consideration. These rates directly influence the total cost of charging and the Total Cost of Ownership (TCO) of electric vehicles. There is a notable disparity between the rates offered by charging stations and the electricity rates provided by DISCOMs (Distribution Companies).

F. **Payload Compromise (B16) -** In currently available Electric Medium and Heavy-Duty Trucks (EMHDT's), the weight of the battery is significant, accounting for almost 10% of the payload capacity. This weight factor is particularly impactful for bulk and heavy-density products, where weight is prioritized over volumetric weight. As a result, the profit margins from transporting such commodities decrease because the available payload capacity is reduced by the weight of the battery.

G. **The Fragmented Structure of the Freight System (B17) -** In India, the trucking industry exhibits significant heterogeneity, which poses challenges for the adoption of new technologies. There is a prevailing fear among trucking operators of potential economic losses associated with adopting new technologies. This fear is particularly pronounced because industries in India are highly price-sensitive, given the intense competition in the market.

H. **Business Model and New Partnerships (B18) -** The absence of diverse new business models and the limited participation of private entities are impeding the growth and adoption of EMHDT's. The introduction of various new business models has the potential to inject capital into this ecosystem, making it a more financially viable option.

5.3 Scoring and Ranking of Identified Barriers

The scoring of identified barriers was meticulously conducted to assess their impact on the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's) in India. To achieve this, statistical methods, specifically the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Grey Relational Analysis (GRA), were performed. This analytical process utilized data collected through a Google Form survey, which incorporated Likert scale responses to quantify the perceptions of the participants regarding each barrier. To ensure the reliability and accuracy of the results, two methods were implemented to cross-verify the consistency and similarities between the findings derived from both TOPSIS and GRA. Due to very few responses during the survey equal weightage has been assigned to all of the respondents.

5.3.1 Results of TOPSIS and GRA Method

Both the TOPSIS and GRA methods revealed substantial similarities in their outcomes, underscoring the consistency across different analytical approaches. Specifically, the top three ranked barriers emerged identically in order, highlighting their primary significance in hindering the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's). However, a minor discrepancy was observed in the ranking order of the subsequent three barriers, indicating a slight variation in their perceived impact.

Further analysis showed that while the set of barriers ranked from 7 to 14 was consistent between the two methods, there were small shifts in their sequential order. Similarly, for the barriers ranked from 15 to 18, although the same barriers were identified by both methods, differences in their ranking sequence were noted. These nuances suggest that while there is agreement on the general impact of these barriers, their relative significance might vary slightly depending on the statistical method used.

Ranks	Barriers	TOPSIS Score	Barriers	GRA Score
1	B11	0.729	B11	6.15
2	B5	0.680	B5	5.92
3	B1	0.591	B1	5.38
4	B4	0.579	B12	5.38
5	B12	0.567	B4	5.31
6	B13	0.562	B13	5.23
7	B16	0.509	B14	4.92
8	B3	0.508	B16	4.92
9	B14	0.485	B3	4.85
10	B10	0.451	B10	4.62
11	B18	0.449	B18	4.54

12	B2	0.434	B17	4.38
13	B17	0.413	B2	4.23
14	B9	0.347	B9	4.08
15	B8	0.344	B6	3.92
16	B6	0.319	B7	3.77
17	B7	0.267	B8	3.77
18	B15	0.232	B15	3.46

Table 5: TOPSIS and GRA Scoring for the Identified Barriers
Source: Author Generated

The results derived from the Z-score analysis have demonstrated notable similarities, with the groups of barriers distinctly divided along the zero Z-score threshold. Specifically, all barriers with a Z-score above zero are consistently grouped together, as are those with a Z-score below zero. This clear demarcation facilitates the categorization of these barriers into broader classes of causes and effects. Such categorization not only simplifies the analysis of the data but also enhances our understanding of the underlying dynamics affecting the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's), allowing for more targeted mitigation strategies.

5.3.2 Z-Scoring and Relative Impact of Identified Barriers

Ranks	Barriers	Z Score for TOPSIS Results	Barriers	Z Score for GRA Results
1	B11	1.953	B11	1.885
2	B5	1.585	B5	1.583
3	B1	0.916	B1	0.878
4	B4	0.819	B12	0.878
5	B12	0.727	B4	0.777
6	B13	0.690	B13	0.677
7	B16	0.289	B14	0.274
8	B3	0.283	B16	0.274
9	B14	0.113	B3	0.173
10	B10	-0.145	B10	-0.129

11	B18	-0.162	B18	-0.229
12	B2	-0.273	B17	-0.431
13	B17	-0.437	B2	-0.632
14	B9	-0.930	B9	-0.833
15	B8	-0.952	B6	-1.035
16	B6	-1.140	B7	-1.236
17	B7	-1.534	B8	-1.236
18	B15	-1.802	B15	-1.639

Table 6: Z-Scoring of Identified Barriers
Source: Author Generated

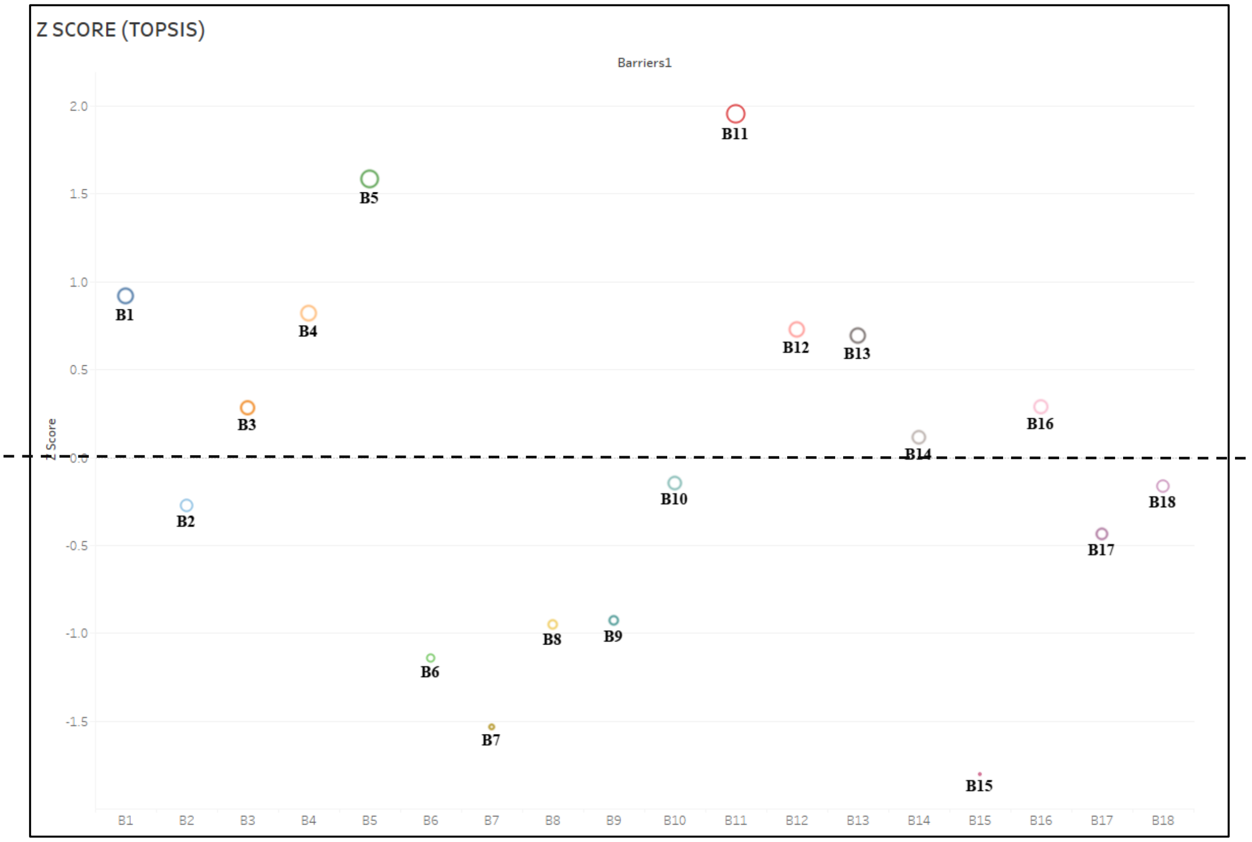


Figure 15: Graphical Depiction of Z Score of TOPSIS Results
Source: Author Generated

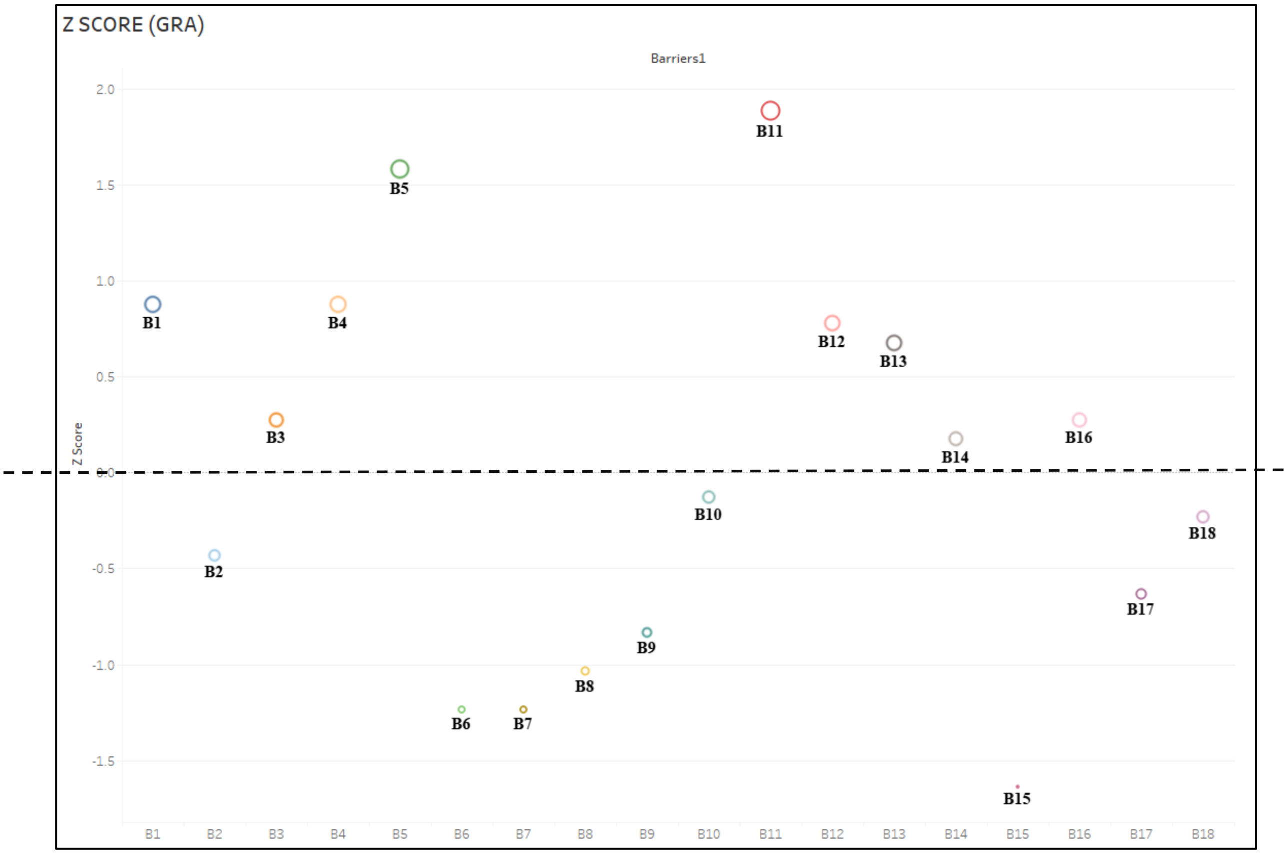


Figure 16: Graphical Depiction of Z Score of GRA Results
Source: Author Generated

As outlined in the previous section, all identified barriers were classified into three primary categories: operational, technological, and financial. To delve deeper into the impact of these barriers on the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's), they were methodically arranged in sequential order based on the results from the statistical analysis and categorized accordingly. This structured arrangement provides a clear perspective on the distribution and significance of each type of barrier. It was noted that among the top nine barriers, five were related to financial issues, while four pertained to operational challenges. In the subsequent set of nine barriers, the distribution shifted, with five barriers being technological, one operational, and three more that also fell under technological issues. This breakdown highlights the varied nature of the obstacles faced and underscores the need for a multifaceted approach to address these diverse challenges effectively.

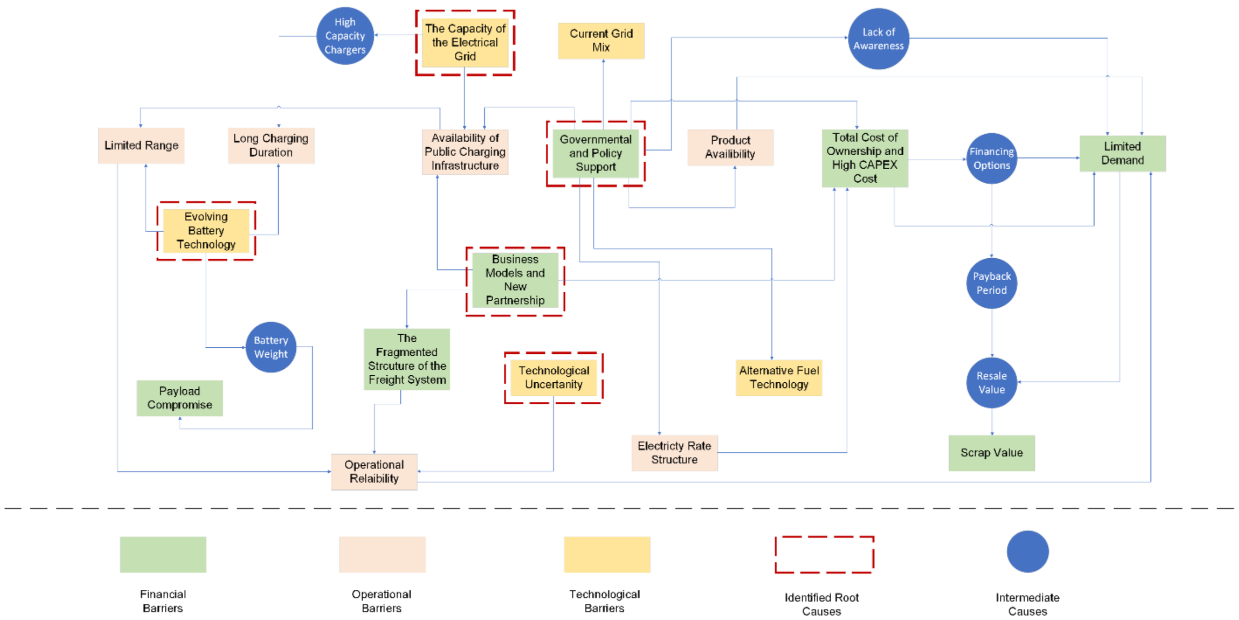
Green – Financial Barrier | Red – Technological Barriers | Orange – Operational Barrier

Causes
B11: Governmental and Policy Support
B5: Availability of Public Charging Infrastructure
B1: Product Availability
B4: Long Charging Duration
B12: Total cost of ownership and High CAPEX Cost
B13: Scrap Value
B3: Limited Range
B16: Payload Compromise
B14: Limited Demand
Effects
B10: Alternative Fuel Technology
B18: Business Model and New Partnerships
B2: Operational Reliability
B17: The Fragmented Structure of the Freight System
B8: Evolving Battery Technology
B9: Current Grid Mix
B6: The Capacity of the electrical grid
B7: Technological Uncertainty
B15: Electricity Rate Structures

Table 7: Barrier Categorization into Financial, Technological and Operational Barrier.
Source: Author Generated

5.4 Relationship Between Identified Barriers

The relationship between identified barriers was meticulously analyzed to unearth the root causes affecting the adoption of EMHDT's. It was discovered that five primary barriers exert a significant influence over many others.



A. The first major barrier is the **evolving battery technology**. Currently, the relatively low energy density of existing lithium-ion batteries increases their weight, which directly compromises payload capacity. Additionally, the inability to enhance battery capacity is primarily hindered by the high costs and the substantial weight of the batteries, which limits the range of the vehicles, range anxiety in EMHDT's causes operational barriers in different climatic and geographical conditions. Furthermore, the extended charging durations required for these batteries can be attributed to both the inherent battery chemistry and the absence of high-capacity charging infrastructure. The evolution of battery technology holds the key to mitigating these issues significantly, potentially revolutionizing the adoption landscape of EMHDT's in India by addressing these interconnected barriers effectively.

B. The second significant barrier pertains to the **capacity of the electrical grid**. As EMHDT's are equipped with high-capacity batteries, they necessitate the use of high-capacity chargers for efficient and rapid charging. Utilizing chargers with inadequate capacity leads to substantially long charging duration, which is a critical impediment to operational efficiency. Moreover, if the electrical grid itself is not sufficiently robust and enhanced, there arises a consequential risk related to the availability and reliability of public charging infrastructure. This is due to concerns over potential grid failures, which could severely restrict the accessibility of necessary charging facilities for these vehicles. Strengthening the grid capacity is thus essential not only for reducing charging times but also for ensuring the widespread feasibility and reliability of charging infrastructure, thereby supporting the broader adoption of EMHDT's.

C. **Governmental and policy support** emerges as the third critical root cause influencing the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's). This factor primarily impacts the current grid mix, where the reliance on non-renewable sources for electricity generation significantly affects the lifecycle emissions of EMHDT's. Furthermore, the absence of adequate government policies and incentives diminishes the profitability and interest of Original Equipment Manufacturers (OEMs) in establishing a comprehensive supply line, which in turn hampers product availability in the Indian market, which further give rise to the limited demand as multiple options are not available for the buyers. Proactive government support through policies that offer both fiscal and non-fiscal incentives to charging point operators is essential to bolster the public charging infrastructure. This would not only enhance the existing charging network but also stimulate the development of a more robust infrastructure, robust charging infrastructure along with high capacity chargers can significantly mitigate the range anxiety. As various alternative fuel technologies evolve, the level of government backing and investment in these technologies will play a pivotal role in determining the rate of EMHDT adoption. Additionally, the cost of electricity, which fuels the operations of EMHDT's, and the rates charged to charging point operators are crucial determinants of the charging costs. These costs directly influence the Total Cost of Ownership (TCO) for EMHDT's. Effective policy interventions that optimize electricity rates for EMHDT charging can significantly reduce TCO, making EMHDT's a more attractive option in the market.

D. The absence of diverse business models and partnerships within the Indian road freight market significantly curtails opportunities for collaboration among public-private and private-private entities. This limitation fosters a fragmented freight system structure, which in turn often leads to economically detrimental empty backhaul trips. Establishing a homogeneous and interconnected network of freight operators could mitigate issues related to operational reliability to some extent, with support provided through various means. Enhancing operational reliability is crucial, as it directly influences market demand by bolstering confidence in the efficiency and dependability of freight operations.

   The introduction of innovative business models could significantly reduce the financial burden of developing charging infrastructure, traditionally borne by a single entity, and strengthen the operation of public charging facilities. These new business models often include various leasing options, which can lower the high capital expenditure associated with setting up and operating Electric Medium and Heavy-Duty Trucks (EMHDT's), making their operation more cost-effective.

   Furthermore, an increase in the demand for EMHDT's is expected to establish a robust resale market for used vehicles, potentially enhancing their scrap value. This emerging market creates a viable economic opportunity, offering substantial returns on the initial investment and contributing to the overall sustainability of the EMHDT ecosystem.

E. Technological Uncertainty represents one of the final core barriers identified, significantly impacting operational reliability. As the technology underpinning EMHDT's is relatively new to the Indian market, there exists a notable gap in expertise among maintenance staff. Many technicians are currently untrained in the specific troubleshooting and maintenance processes required for these advanced vehicles. This lack of familiarity can lead to increased downtime and operational inefficiencies, posing substantial challenges to the widespread adoption and smooth operation of EMHDT's across the country.

5.5 Challenges in Driver Engagement in India's Transition to Electric Fleets

In India, 80% of fleet owners possess fleets of 10 vehicles or fewer. These operators typically do not employ drivers on a monthly salary basis; instead, drivers are compensated based on the kilometers driven or the specific consignments they handle. Due to generally low wage levels, many drivers seek to supplement their income through unofficial means, such as by manipulating diesel consumption. Drivers are a critical component of truck operations, and as highlighted during discussions with truck operators, there is a notable issue with driver availability. This scarcity of drivers could become even more pronounced with the introduction of electric trucks, where the potential for unofficial revenue generation is nullified due to the nature of electric fuel consumption. Addressing these challenges requires innovative business models and partnerships that can create mutually beneficial scenarios for both truck operators and drivers, ensuring operational continuity and job satisfaction in the shift towards electric vehicles.

5.6 Transitioning Skills – Truck Repair Ecosystem

As highlighted in expert interviews, Electric Medium and Heavy-Duty Trucks (EMHDT's) feature significantly fewer moving parts compared to Internal Combustion Engine Medium and Heavy-Duty Trucks (ICE MHDTs). ICE vehicles heavily rely on mechanical processes and fluid dynamics, which necessitate regular maintenance of their numerous and often complex mechanical components. In contrast, while EMHDT's simplify many mechanical aspects, they incorporate sophisticated electrical systems that demand specialized maintenance expertise, or in some cases, complete part replacement.

This shift is poised to disrupt the traditional truck maintenance ecosystem, potentially reducing job opportunities for current truck repair and maintenance workers. To mitigate this, upskilling these workers is essential to foster a more adaptable and proficient workforce in the evolving landscape. Furthermore, the electrical components used in electric vehicles are generally more expensive at present, which raises operational costs. Developing a robust repair ecosystem for these parts could not only help lower these costs but also create new job opportunities within this emerging sector.

List of Major Components in EMHDT's VS ICE MHDT's

ICE Truck	Electric Truck
Electric Motor	Engine
Battery Pack	Fuel Injection System
Power Electronics Controller	Exhaust System
Onboard Charger	Radiator and Cooling System
Regenerative Braking System	Transmission
Thermal Management System	Oil Pump and Lubrication System
DC/DC Converter	Starter Motor and Alternator
Electric-specific Transmission	Air Intake System
High-voltage Electrical Wiring	Turbo Power Supplier
Charging Port	Fuel Tank

Table 8: Components Differentiation between EMHDT's and MHDT's
Source: Secondary Data

5.7 Business Models to Support the Adoption of EMHDT's

This section explains about the various models that were explored to support the adoption of EMHDT's in India. Business models can help in risk mitigation as well distribution of CAPEX cost among various stakeholders. Also, involvement and acceptance of business models support various startups as well as new innovative self-sustainable financial models.

The feasibility of business models for electric trucks was examined to determine their potential adoption, by considering several key aspects including investment in charging infrastructure, partnerships, operational efficiency, and revenue generation. These evaluations aim to guarantee the successful implementation and enduring sustainability of electric truck corridors. Such insights will enable stakeholders to craft strong business models that effectively address the distinct challenges and prospects presented by the shift towards electric vehicles in the freight transportation industry.

5.7.1 Factors Considered for Business Models

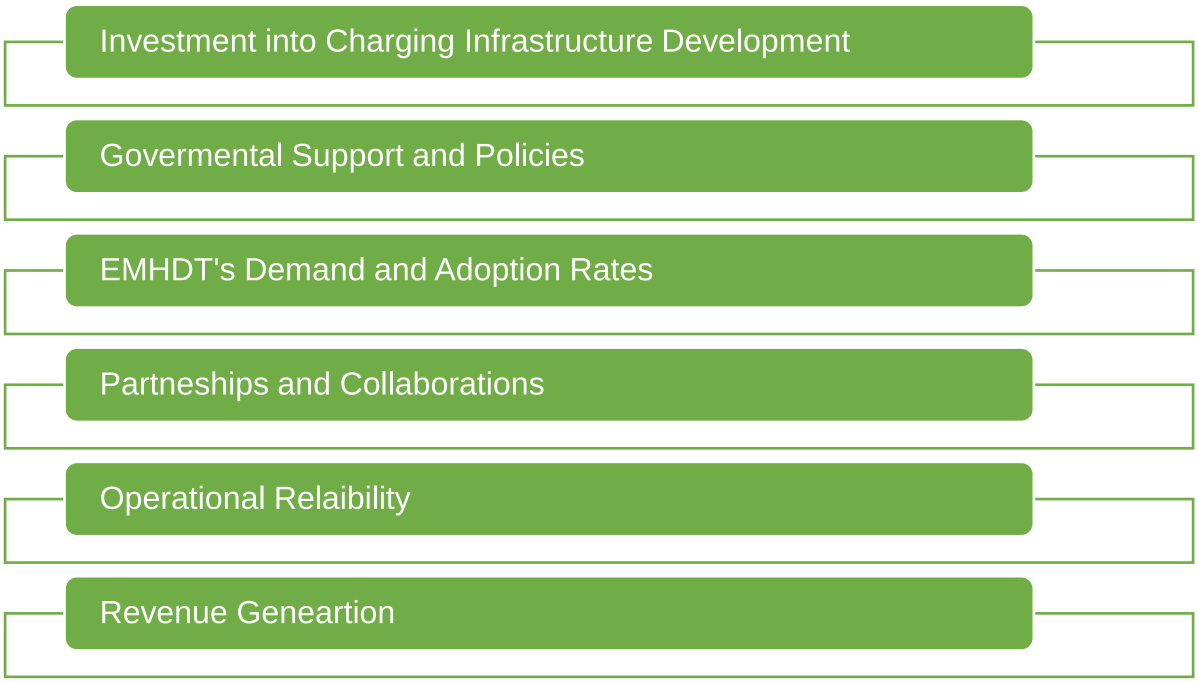


Figure 17: Factors Considered for Business Models
Source: Author Generated

When exploring business models for electric trucks, several crucial factors must be evaluated to ensure their effectiveness and sustainability. Significant investment in charging infrastructure is required, which must account for geographic and logistical challenges unique to freight corridors. Government policies, incentives, and subsidies are vital as they facilitate the adoption of electric trucks and the development of infrastructure, enhancing model attractiveness. Additionally, market demand and adoption rates is important, considering the growth of the logistics sector and increasing environmental awareness. Strategic collaborations with government agencies, logistics firms, and energy providers can extend support and scale business models effectively. Operational efficiency, including maintenance and charging capabilities, directly affects fleet performance, while diverse revenue streams, such as monetizing data and offering premium services, are essential for financial viability.

Collectively, these factors form the foundation for robust and successful business models in the electric trucking industry.

5.7.2 Business Models

A. **Ownership Model –** In the Ownership model, the fleet operator purchases the truck outright, taking advantage of government incentives to offset part of the cost. The responsibility for battery replacement and maintenance falls squarely on the fleet operator. Full ownership grants the operator the right to sell the vehicle after a predetermined period of use, thereby recovering some value through resale. This model is financially advantageous over the long term. Additionally, the owner may invest in charging equipment, which not only serves their own fleet but can also be utilized to charge other trucks. This dual use of the charging facilities can generate significant returns, effectively covering the costs of the charging equipment and providing financial benefits.

B. **Leasing and Rental Models –** This model offers both short-term and long-term leasing options for fleets, enabling operators to benefit from lower operational costs without the burden of substantial capital expenditures (CAPEX). Particularly advantageous for operators with irregular operations, this approach not only provides financial sustainability but also enhances fleet optimization. Through leasing or renting, operators can adapt their fleet size based on current demand, optimizing asset utilization and cost-efficiency. Moreover, the fleet owner can recuperate the investment through various revenue streams, making it a financially viable model that balances initial investment with ongoing returns.

C. **Subscription Based Model –** The subscription-based model is designed for operators who prefer a payment structure based on either kilometer driven or a fixed time period. This approach is especially advantageous as it allows operators to efficiently manage peak seasonal demands and meet specific, occasional needs, such as those during the crop harvesting season for farmers. It facilitates optimal fleet utilization and offers the advantage of lower operational costs. In this model, the subscription fee comprehensively covers various services, including maintenance, access to charging infrastructure, and other value-added services, integrating all necessary expenses into one predictable payment. The primary benefits of adopting this model include predictable costs, a suite of inclusive services, and a significantly reduced financial burden on the operator, enhancing overall operational efficiency and financial predictability.

D. **Charging Infrastructure as a Service –** Setting up and owning a charging infrastructure for Electric Medium and Heavy-Duty Trucks (EMHDT's) involves a substantial initial investment, often approaching INR 20 lakhs. To offset this significant cost, the charging infrastructure can be utilized as a service. This approach allows for the recovery of the initial outlay by offering charging services to other fleets during downtimes, effectively turning the infrastructure into a source of ongoing revenue. Additionally, operators can leverage both fiscal and non-fiscal government incentives to further reduce the upfront costs and operational expenses, such as electricity rates. Non-fiscal benefits, like reductions in land tax, can also significantly lower overhead costs. This strategy not only aids in mitigating the initial financial burden but also promotes the development of a robust and financially self-sustaining charging infrastructure.

E. **Battery Leasing and Swapping Model –** This model significantly reduces the upfront costs associated with acquiring an Electric Medium and Heavy-Duty Truck (EMHDT) by up to 50%, primarily by eliminating the need to purchase the battery. Instead, the battery can be leased, with costs aligned with the usage of the truck. This arrangement establishes a direct correlation between the per kWh charge and the daily mileage under a subscription model. Particularly well-suited for high freight traffic corridors, this approach can facilitate the establishment of multiple battery swapping stations along these routes, effectively mitigating range anxiety. Moreover, fostering collaborations among various swapping station operators could enhance the network's efficiency and offer mutual benefits, creating a more cohesive ecosystem. This strategy also encourages the utilization of batteries in their second life, extending their operational lifespan. The model includes various charges such as the principal cost of the battery, as well as expenses related to the charging infrastructure, alongside charging and handling fees, making it a comprehensive revenue-generating tool.

F. **Fleet Aggregation and Pooling Model –** This model is instrumental in maximizing the use of the existing fleet, which leads to a substantial reduction in the total cost of ownership and a significant shift in the payback period. In this framework, various small-scale fleet operators consolidate their fleet availability on a common platform, enabling it to function as a cohesive, unified system. As a result of this integration, the non-operational periods of the trucks are markedly reduced, enhancing overall fleet efficiency and productivity. This collaborative approach not only optimizes resource use but also improves the economic returns for all participating operators.

G. **Business Opportunity for Land, Restaurants and Fueling Station Owners -** As electric truck adoption gains momentum, the demand for charging stations along highways is increasing. Landowners have a prime opportunity to capitalize on this trend by leasing their properties to companies that construct charging stations. Ensuring a plentiful supply of charging stations along key routes enables electric trucks to operate efficiently. Additionally, landowners can facilitate the integration of renewable energy solutions for these charging stations by entering partnerships with charge point operators to promote eco-friendly transportation systems.

   Landowners also have the option to lease their land to infrastructure companies or CPOs to develop truck depots and service centers. These facilities can offer a range of services, including overnight parking, routine maintenance, and battery swapping or charging for electric trucks. The same properties can be utilized for related services such as warehouses and distribution centers, further integrating them into the transportation and supply chain networks. Landowners can choose to construct these facilities themselves or rent them out, strategically positioning themselves within the logistics ecosystem.

   Additionally, these sites can provide rest areas for electric truck drivers, offering amenities that allow drivers to relax, dine, and access essential services, thereby enhancing the attractiveness of these routes for freight operations. Adjacent lands can be employed for renewable energy projects like solar farms, which not only supply clean power to the charging stations but also to other operational facilities. By leveraging these technologies and forming strategic alliances, landowners can significantly contribute to the advancement of sustainable transportation along these corridors.

5.8 Total Cost of Ownership

The Total Cost of Ownership (TCO) analysis is a comprehensive tool that calculates the overall per kilometer operational cost of a vehicle, incorporating both capital expenditures (CAPEX) and operational expenditures (OPEX). This tool has been developed to include various costs such as the initial purchase price of the vehicle, registration taxes, and applicable financial incentives under capital costs. Operational costs encompass a range of expenses including fuel consumption, maintenance and repairs (including tires), and, specifically for Electric Medium and Heavy-Duty Trucks (EMHDT's), the cost of battery replacement and toll taxes.

The growth rate for diesel, charging, and maintenance expenses is projected at 5% per annum. Additionally, the financial model assumes a discount rate and a resale value depreciation rate of 10% per annum, which influences the overall cost efficiency evaluations over the vehicle's lifecycle.

The daily travel distance for the vehicle is set at 400 kilometers, based on data gathered during site visits and corroborated by a report published by Mahindra Motors. This distance estimation is critical in accurately determining the TCO and ensuring the analysis reflects realistic usage scenarios.

The lifespan of tires is estimated to be 60,000 kilometers, and in this instance, we are considering a 55-ton truck that is equipped with 12 tires. Each tire is priced at approximately INR 20,000. Additionally, the battery's lifespan is projected at nearly 300,000 kilometers, which, given the daily travel distance assumed, should effectively last for about two years. This consideration is crucial for accurately forecasting maintenance and replacement costs within the total cost of ownership analysis.

For this analysis, three distinct scenarios are evaluated to understand the different cost implications and operational efficiencies. The first scenario involves owning a traditional Internal Combustion Engine (ICE) based 55-ton truck. In the second scenario, we consider an electric truck equipped with an owned battery, which accounts for the upfront costs of the battery as part of the initial investment. The third scenario explores the option of an electric truck utilizing a subscription model for a swappable battery. In this model, the initial cost of the battery is excluded from the upfront expenses, potentially lowering the entry barriers and initial capital outlay for the operator. This diversified approach allows for a comprehensive comparison of the financial and operational impacts across different truck technologies and ownership models.

Considerations	ICE Based 55 T Truck	Electric 55 T Truck (Owned Battery)	Electric 55 T Truck (Battery Swapping Subscription)
Vehicle Holding Period	10 Years	15 Years	15 Years
Daily Distance Travelled/Day	400 KM	400 KM	400 KM
Purchase Cost	50,00,000	1,25,00,000	70,00,000
Tax+ National Permit	200000	0	0
Financial Incentive* (As per LCV's in FAME 2)	0	5,00,000	10,00,000
Annual Maintenance + Tires	540000	500000	510000
Battery Replacement (Frequency)	NA	After Every 3,00,000 KM	NA
Battery Replacement Cost	NA	NA	50,00,000
Fuel/Charging Cost	100/Litre	12/kWh	40/kWh
Toll Tax/KM	5/KM	0	0
Insurance	70,000	80,000	1,00,000

Diesel/Electricity/Maintenance Growth Rate	5%
Discount and Resale Rate	10%

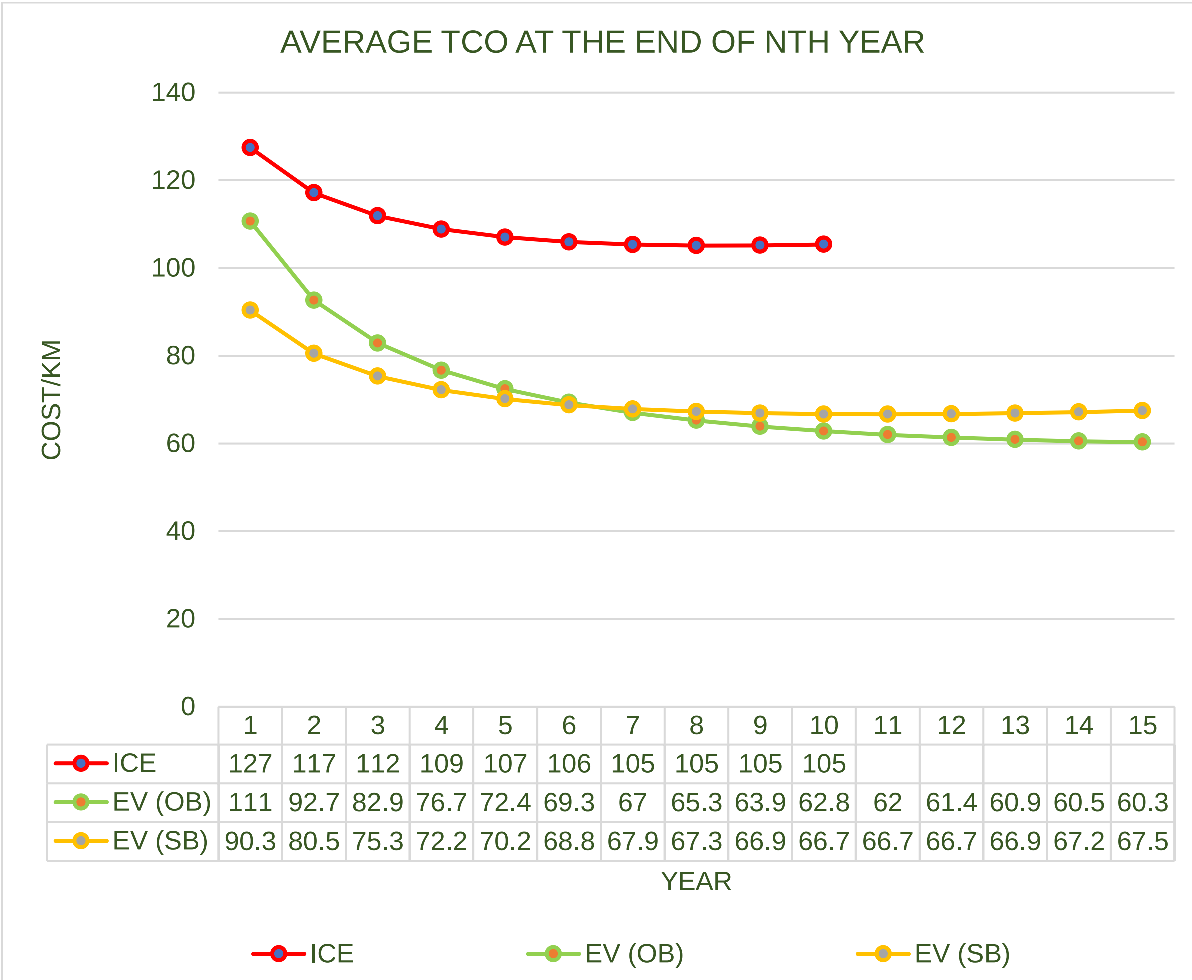
Table 9: Considerations Taken for TCO Analysis
Source: Secondary Sources, OEM Meetings, Truck Operators

The outcomes of this analysis strongly support the financial benefits of owning an electric truck. Due to the higher operational costs associated with ICE trucks, the total cost of ownership (TCO) per kilometer for electric trucks proves to be lower from the very first year compared to ICE trucks. The accompanying graphs clearly illustrate the annual TCO trajectory, initially declining due to the amortization of the capital expenditures. However, beyond the fifth year for ICE trucks, the sixth year for electric trucks with owned batteries, and the seventh year for electric trucks with swappable batteries, the TCO begins to rise. This increase is attributed to escalating maintenance and operational costs over time. This trend underscores the evolving cost dynamics of different truck technologies throughout their lifecycle.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ICE	127	107	101	99.8	99.7	101	102	103	105	108					
EV (OB)	111	74.7	63.3	58.1	55.4	53.9	53.2	52.9	52.9	53.2	53.7	54.4	55.1	56	56.9
EV (SB)	90.3	70.7	65	62.8	62	61.9	62.3	63	63.9	65	66.2	67.6	69	70.5	72.1

Figure 18: TCO at Nth Year
Source: Author Generated

The average total cost of ownership analysis reveals that owning an ICE-based truck is more expensive than either scenario considered for the electric truck. Notably, up to the sixth year, the average TCO for an electric truck with a swappable battery subscription remains lower than that of an electric truck with an owned battery. This cost advantage is primarily due to the absence of initial battery investment and battery replacement costs in the swappable battery model. However, over the long term, the higher costs associated with the battery swapping subscription make owning a battery more economically advantageous. This shift indicates that while the swappable battery model offers initial cost savings, the owned battery scenario provides better financial benefits as the years progress.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ICE	127	117	112	109	107	106	105	105	105	105					
EV (OB)	111	92.7	82.9	76.7	72.4	69.3	67	65.3	63.9	62.8	62	61.4	60.9	60.5	60.3
EV (SB)	90.3	80.5	75.3	72.2	70.2	68.8	67.9	67.3	66.9	66.7	66.7	66.7	66.9	67.2	67.5

Figure 19: Average Total Cost of Ownership by the End of Nth Year
Source: Author Generated

5.8.1 Fuel and Operational Cost

A. Annual Fuel and Charing along with Battery Cost

When calculating the annual fuel cost for the initial scenario involving a 55-ton ICE-based truck, the cost was determined based on the assumption of covering 400 kilometers daily. The total annual fuel cost for this scenario amounted to INR 97.33 lakhs. In comparison, the annual cost for an electric truck with an owned battery was significantly lower, coming in at INR 39.19 lakhs. Similarly, the cost for an electric truck utilizing a swappable battery subscription was also reduced, amounting to INR 58.40 lakhs. These figures highlight the substantial cost savings associated with electric trucks, particularly those with owned batteries, underscoring their economic advantages over traditional ICE trucks.

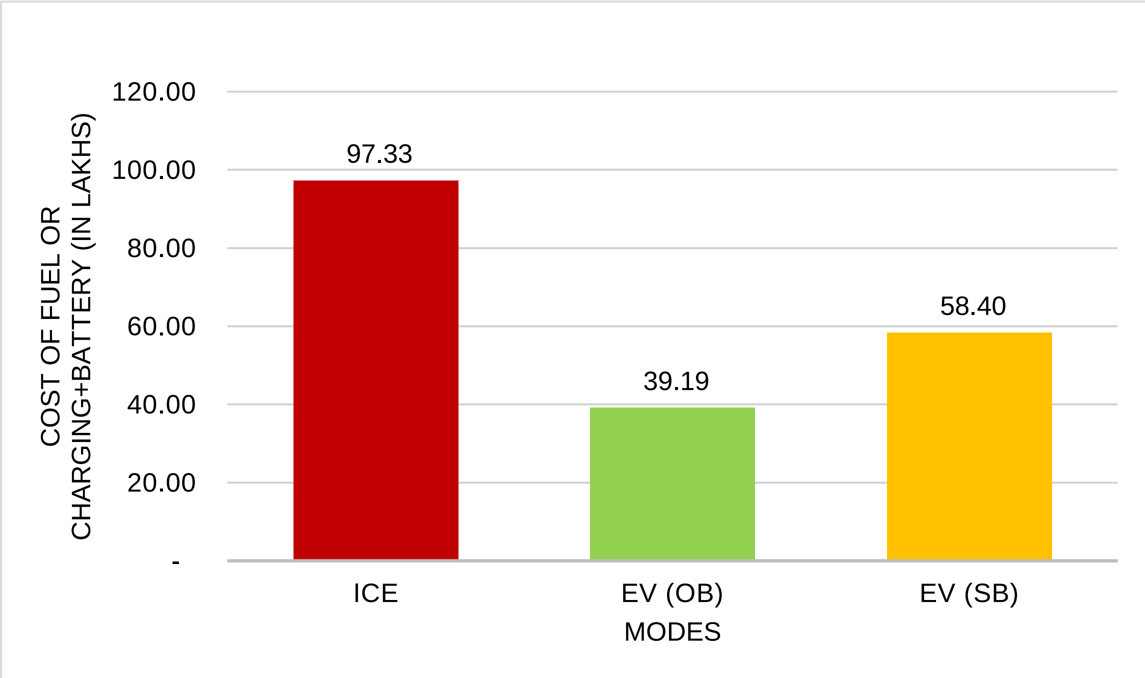


Figure 20: Annual Fuel Cost
Source: Author Generated

5.8.2 Total Operational Cost

When assessing the annual operational cost—which encompasses fuel/charging expenses, maintenance, and toll taxes—for the initial scenario involving a 55-ton ICE-based truck, calculations were based on a daily travel distance of 400 kilometers. The total annual operational cost for this ICE truck scenario reached INR 110.73 lakhs. In contrast, the operational cost for an electric truck with an owned battery was markedly lower, totaling INR 45.29 lakhs. Additionally, the operational cost for an electric truck operating under a swappable battery subscription model also showed a reduction, coming to INR 64.20 lakhs. These figures clearly demonstrate the considerable cost savings provided by electric trucks, especially those with owned batteries, highlighting their financial benefits over traditional ICE trucks in terms of annual operational expenses.

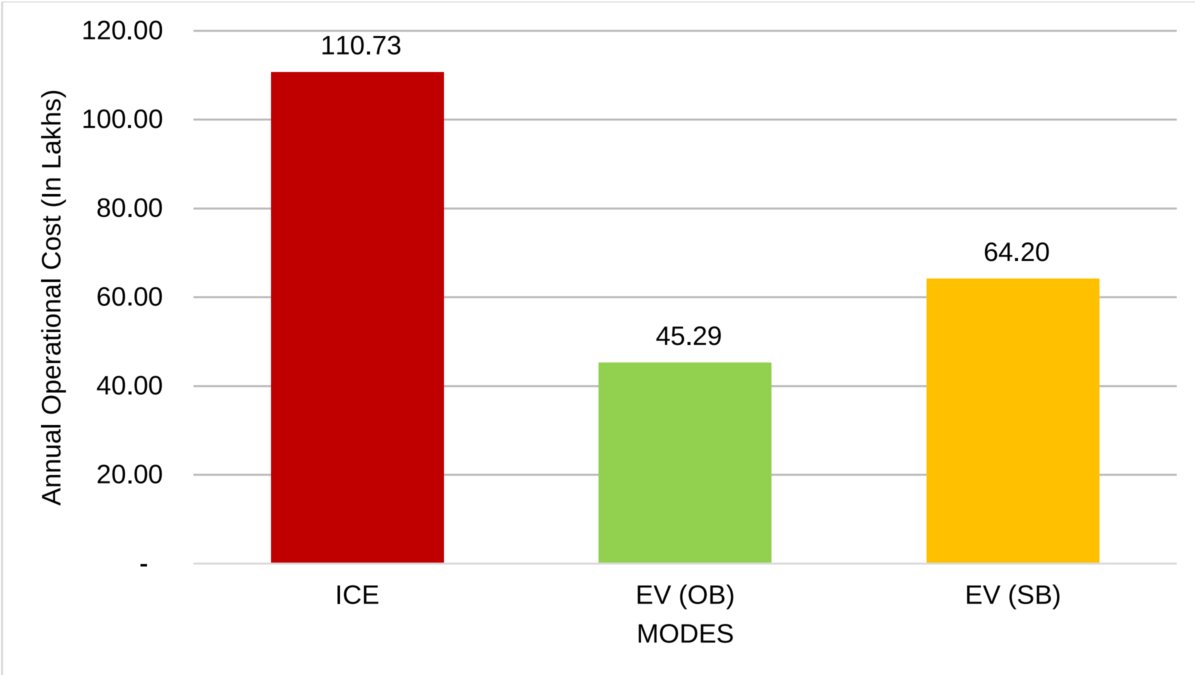


Figure 21: Annual Operational Cost
Source: Author Generat

6. MITIGATION STRATEGIES AND POLICY RECOMMENDATIONS

This chapter delves into the mitigation strategies and recommendations designed to facilitate the adoption and efficient operation of Electric Medium and Heavy-Duty Trucks (EMHDT's). The strategies and recommendations are tailored to address the specific problems identified in the previous chapter. Given the interdependent nature of most barriers, the proposed recommendations are strategically focused on the core barriers. This approach not only targets fundamental issues directly but also ensures that resolving these primary barriers helps alleviate other interconnected challenges. Such a comprehensive strategy enhances the overall effectiveness of the recommendations and supports a smoother transition to EMHDT's in the industry.

6.1 Recommendations for Government Polices and Support Provision

A. **Provision of Fiscal Incentives in Upcoming FAME 3 Policy –** Previously, under the FAME 1 and FAME 2 initiatives, fiscal incentives were granted based on battery capacity, with a specified upper cap for various vehicle categories including 2-wheelers, 3-wheelers, 4-wheelers, and Light Commercial Vehicles (LCVs). To further encourage the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's), it is recommended to extend similar fiscal incentives to these categories as well. By offering targeted incentives for EMHDT's, the policy could significantly enhance the attractiveness of these vehicles to potential buyers, thereby accelerating the transition towards a more sustainable freight transportation sector. This strategic expansion of incentives would not only support environmental goals but also stimulate market demand for electric trucks.

B. **Regulation of Electricity Rate Structures for the Charging of Electric Trucks –** It is essential to implement differentiated electricity rate structures that cater specifically to the needs of both individual and commercial charging infrastructure. By providing lower electricity rates for these purposes, the cost of charging electric vehicles can be substantially reduced. This reduction in charging costs will have a direct and positive impact on the operational expenses and the overall total cost of ownership for electric vehicle operators. Lower electricity rates would not only make the daily operation of electric vehicles more economical but also enhance the financial viability of investing in electric vehicle technology. This strategic adjustment in rate structures would encourage broader adoption of electric vehicles by making them more cost-effective for a wider range of users, from private owners to large commercial fleets.

C. **Introduction of Awareness Programs for Small Fleet Size Operators –** In India, where 80% of fleet operators own 10 or fewer trucks, there is a significant lack of awareness about Electric Medium and Heavy-Duty Trucks (EMHDT's), leading to numerous misconceptions concerning the financial and technical challenges associated with these vehicles. To address this issue, implementing targeted awareness programs is crucial. These programs would educate these operators about the benefits of EMHDT's, including the long-term cost savings and environmental advantages. Additionally, the programs could provide insights into various operational strategies that enhance the return on investment and improve overall fleet efficiency. By increasing awareness, these operators can better understand how transitioning to EMHDT's could positively impact their operations, leading to more informed decision-making and potentially increasing the adoption rate of electric trucks in this significant segment of the market.

D. **Forecast for Market Penetration Share of Various Alternative Fuel Technologies –** As various technologies in the domain of ZET's are currently available and in the emerging phase, there exists a notable level of uncertainty among policymakers and investors. This uncertainty can hinder the strategic deployment of resources and stymie the broader adoption of these technologies. To mitigate this, incorporating a clearly defined and forecasted market penetration share for EMHDT's within policy frameworks is essential. Such clarity would provide a more predictable and structured path for investment, enabling stakeholders to allocate resources more effectively towards the adoption and integration of this technology. A well-articulated policy that outlines expected market shares and growth trajectories for EMHDT's would boost confidence among investors and policymakers alike, facilitating more decisive actions towards embracing sustainable vehicular technologies.

E. **Introduction of Financing Options with Lower Rate of Interest –** The majority of small fleet size operators prefer to finance their fleets to alleviate the burden of high upfront costs. Offering a lower interest rate for early purchasers of Electric Medium and Heavy-Duty Trucks (EMHDT's) can significantly attract investors and facilitate broader adoption. This financial incentive would not only help in reducing the total cost of ownership but would also shorten the payback period for the fleet. Such a strategy would make the transition to EMHDT's more financially viable for small operators by easing the initial investment hurdles and enhancing the overall economic appeal of adopting green technologies in their operations. Implementing such incentives could accelerate the shift towards more sustainable transportation solutions, fostering a more rapid integration of EMHDT's within the logistics and transport industry.

F. **Incentives for the OEM's and Auto Component Manufacturers –** Currently, Production Linked Incentive (PLI) schemes, coupled with supportive state EV policies, are providing the electric vehicle (EV) manufacturing industry with a range of fiscal and non-fiscal incentives. However, to further strengthen the foundation of heavy industries and specifically promote the manufacturing of Electric Medium and Heavy-Duty Trucks (EMHDT's) within India, an additional boost is necessary. By focusing on enhancing domestic manufacturing capabilities, India can overcome significant hurdles related to product availability and also potentially reduce the costs of these vehicles. Local production would not only ensure a steady supply of EMHDT's but also contribute to lowering purchase prices, making these sustainable vehicle options more accessible and appealing to businesses. This strategic enhancement would effectively bolster the entire ecosystem for electric trucks, facilitating a smoother transition to clean transportation solutions across the nation.

G. **Pilots for the Retrofitting of Existing Fleet –** To facilitate the transition from traditional Internal Combustion Engine (ICE) based Medium and Heavy-Duty Trucks (MHDTs) to electric models, the implementation of various pilot projects focusing on retrofitting is essential. Retrofitting not only reduces the cost associated with owning an Electric Medium and Heavy-Duty Truck (EMHDT) but also allows for the repurposing of the existing fleet, thus avoiding the need for scrapping serviceable vehicles. These pilot projects are crucial as they enable the evaluation of retrofitting's practicality within the unique conditions of the Indian landscape. Additionally, they provide an opportunity to identify and implement necessary technical modifications to the retrofit kits, ensuring they are a viable and effective solution. By testing and refining these retrofitting processes through pilot projects, it is possible to enhance the feasibility and attractiveness of converting ICE-based MHDTS to electric, thereby supporting a broader shift towards sustainable transportation solutions in India.

H. **Risk Sharing Interventions for Early Adopters –** The introduction of a risk-sharing mechanism for early adopters is essential to protect them from substantial financial losses. Such a mechanism would distribute potential losses among multiple stakeholders, thereby mitigating the financial burden on any single party. By implementing risk-sharing strategies, investors and adopters would be more inclined to consider the adoption of Electric Medium and Heavy-Duty Trucks (EMHDT's), as the financial risk associated with initial investments would be substantially reduced. This approach not only encourages more stakeholders to participate but also boosts investor confidence in the viability of transitioning to EMHDT's. Overall, a well-structured risk-sharing framework can accelerate the uptake of electric trucks by providing a safety net that makes the financial aspects of such investments more appealing and secure.

I. **Tightening of Fuel Emission Standards –** Various fuel standards are established based on the engine technology and the age of the vehicle.

However, these vehicles often emit pollutants above the stipulated standards, primarily due to improper maintenance and operational practices. By tightening fuel standards and instituting periodic emissions checks for existing Internal Combustion Engine (ICE) trucks, regulatory bodies can significantly encourage fleet owners to transition toward adopting Electric Medium and Heavy-Duty Trucks (EMHDT’s). Strengthening these regulations not only ensures compliance with environmental policies but also highlights the long-term economic and operational benefits of switching to cleaner, more efficient electric vehicles. Such measures will make the adoption of EMHDT’s more attractive by underscoring their advantages in terms of compliance, lower operational costs, and reduced environmental impact.

J. **Skill Development Programs for Technicians –** The existing repair ecosystem for medium and heavy-duty trucks is well-established, featuring a network of trained and experienced technicians alongside a robust supply chain of spare parts. However, the technology utilized in Electric Medium and Heavy-Duty Trucks (EMHDT’s) differs significantly from that in traditional Internal Combustion Engine (ICE) based trucks. This technological shift necessitates the development of new skills among technicians to competently handle the maintenance and repair of EMHDT’s. By equipping existing technicians with these new skills, not only can we address the concerns about operational reliability of electric trucks, but also expand job opportunities for both current and future technicians in the field. This skill development will ensure that the workforce remains relevant and capable in the evolving automotive industry, thereby enhancing both employment prospects and the overall efficiency of the EMHDT repair ecosystem.

K. **Electrification of 7 Major Corridors –** Approximately 50% of India's road freight transport, as measured by vehicle kilometers traveled, occurs on major freight corridors. Developing a robust charging infrastructure along these critical routes is essential for supporting the smooth operation of Electric Medium and Heavy-Duty Trucks (EMHDT’s) without the concern of range anxiety. Furthermore, strategically enhancing these corridors will ensure that the newly developed infrastructure is maximally utilized, thereby generating better financial returns. This focus on targeted infrastructure development not only facilitates efficient and sustainable freight movement but also enhances the overall attractiveness and viability of investing in EMHDT technology by ensuring that essential charging support is both accessible and strategically located to meet the demands of heavy freight operations.

L. **Appreciate Closed Loop Environment Usage –** Promotion and implementation of pilot projects for Electric Medium and Heavy-Duty Trucks (EMHDT's) in closed-loop environments, such as within industrial sectors and on predefined routes with shorter trip distances, are essential for gaining a deep understanding of the intricacies involved in EMHDT operations. Such controlled environments provide an ideal setting to observe and analyze the specific operational challenges and performance metrics of EMHDT's. The insights gathered from these pilot studies will be invaluable in identifying and addressing various operational issues, leading to the refinement and development of more effective strategies for wider deployment. These adjustments will not only enhance the operational efficiency of EMHDT's but also pave the way for broader acceptance and integration of electric trucks in more complex and diverse transportation networks.

M. **Rebate on Toll Taxes –** The toll tax structure for the operation of Medium and Heavy-Duty Trucks (MHDTs) is considerably high, impacting overall operational costs. Offering a rebate on toll taxes for a defined period could significantly encourage the adoption and use of Electric Medium and Heavy-Duty Trucks (EMHDT's). Such financial incentives would not only reduce the operational costs for fleet operators but also promote the transition to more sustainable transport solutions. By implementing these rebates, policymakers could accelerate the integration of EMHDT's into mainstream logistics. This move would make EMHDT's more economically attractive and viable, thereby fostering a quicker shift away from traditional fuel-dependent trucks.

6.2 Recommendations for Technological Uncertainties and Evolving Battery Technology

A. **Mandates of Unified and Standards for Charing and Battery Infrastructure –** Charging infrastructure is a critical element in the successful deployment of Electric Medium and Heavy-Duty Trucks (EMHDT's), highlighting the need for standardization across the industry. It is imperative that mandates be established requiring all Original Equipment Manufacturers (OEMs) and automotive component manufacturers to adhere to a predefined set of designs and specifications for charging systems. Such standardization would greatly enhance the consistency and accessibility of charging facilities across the country, facilitating easier and more efficient charging operations. Additionally, having uniform charging interfaces and protocols would significantly improve the feasibility and practicality of battery swapping systems, enabling smoother transitions and reducing downtime for vehicles. Implementing these standards would not only streamline the infrastructure but also bolster the adoption and operational effectiveness of EMHDT's nationwide.

B. **Research and Development in the Domain of Battery Technology and Clean Manufacturing –** Research and Development (R&D) in battery technology and clean manufacturing is essential for the growth and acceptance of Electric Medium and Heavy-Duty Trucks (EMHDT's) in India. Central to these efforts is enhancing the efficiency and cost-effectiveness of batteries. Innovations such as solid-state batteries and improved lithium-ion technologies are crucial as they aim to extend battery life, increase energy density, and enhance charging speeds. Such technological advancements significantly reduce the cost and expand the operational range of EMHDT's, making them increasingly competitive against traditional internal combustion engine vehicles. Additionally, these improvements in battery technology can impact payload capabilities, as higher energy density reduces the weight of the battery packs, allowing for greater payload capacity. Furthermore, the adoption of clean manufacturing processes plays a critical role in minimizing the environmental impact associated with the production of batteries and vehicles.

These processes help reduce waste, energy consumption, and emissions, aligning production activities with both global and national environmental sustainability objectives. Implementing clean manufacturing techniques also decreases the lifecycle emissions of EMHDT's, thereby enhancing their overall environmental profile.

C. **Funded Pilot Projects for On Road Operations –** Funded pilot projects play a pivotal role in the adoption and optimization of Electric Medium and Heavy-Duty Trucks (EMHDT's) through various critical phases. Firstly, these projects facilitate real-world testing, providing a unique platform for evaluating EMHDT's under the actual operating conditions prevalent on Indian roads. This phase is crucial as it accounts for varied terrain, weather, and traffic conditions that significantly differ from controlled test environments. As these vehicles are deployed on the road, practical and operational issues that are not evident in theoretical setups begin to surface. Key areas such as battery range adequacy, effectiveness of charging infrastructure, vehicle handling, and load capacity are scrutinized under real-world logistics operations. Upon identification of these issues, pilot projects enable iterative testing and modifications, which are essential for rectifying any discrepancies and optimizing the system. This step is fundamental not only in adjusting the vehicles and their supporting infrastructure but also in refining operational logistics to enhance the reliability and efficiency of EMHDT's. Moreover, the successful demonstration of EMHDT's in these real-world tests significantly boosts stakeholder confidence. Fleet operators, regulatory bodies, and investors who witness these practical demonstrations gain assurance about the viability and reliability of electric trucks, reducing apprehensions related to transitioning from traditional ICE trucks. Additionally, these pilot projects are instrumental in data collection and analysis, offering rich insights into vehicle performance, energy consumption, maintenance needs, and overall cost-effectiveness. This valuable data serves to inform and shape future policies, guide investment decisions, and facilitate the scaling of this technology. Ultimately, funded pilot projects not only prove the operational success of EMHDT's but also foster a supportive ecosystem for their broader adoption, ensuring that the transition to electric heavy-duty transportation is both successful and sustainable.

6.3 Recommendations for the Capacity of Electrical Grid

A. **Strengthening of Existing Power Grid and Development of Renewable Power Generation –** Strengthening the power grid is essential for accommodating high-power charging equipment and enabling the simultaneous charging of multiple Electric Medium and Heavy-Duty Trucks (EMHDT's). By enhancing the capacity and stability of the grid, we can significantly reduce the charging times for these vehicles, which is crucial for maintaining the efficiency and viability of electric truck operations. Additionally, integrating power generation from renewable sources into the grid not only supports this increased demand but also plays a pivotal role in reducing the lifecycle emissions associated with the use of EMHDT's.

6.4 Operational Suggestions

A. **Usage of Containers for Freight Movement –** Implementing container usage in Electric Medium and Heavy-Duty Trucks (EMHDT's) can significantly streamline the process of loading and unloading, thereby reducing the total turnaround time for these vehicles. This efficiency gain not only enhances operational throughput but also allows fleet operators to maximize the utilization of their existing fleet. By decreasing downtime and speeding up the cargo handling process, operators can achieve greater fleet optimization. This optimization leads to an increase in revenue as trucks can complete more trips in a shorter period. Additionally, the reduction in turnaround times contributes to a shorter payback period for the investment in EMHDT's, improving the overall financial viability of adopting electric trucks. Such strategic improvements in fleet management and operational efficiency are crucial for companies looking to enhance profitability while transitioning to more sustainable transportation solutions

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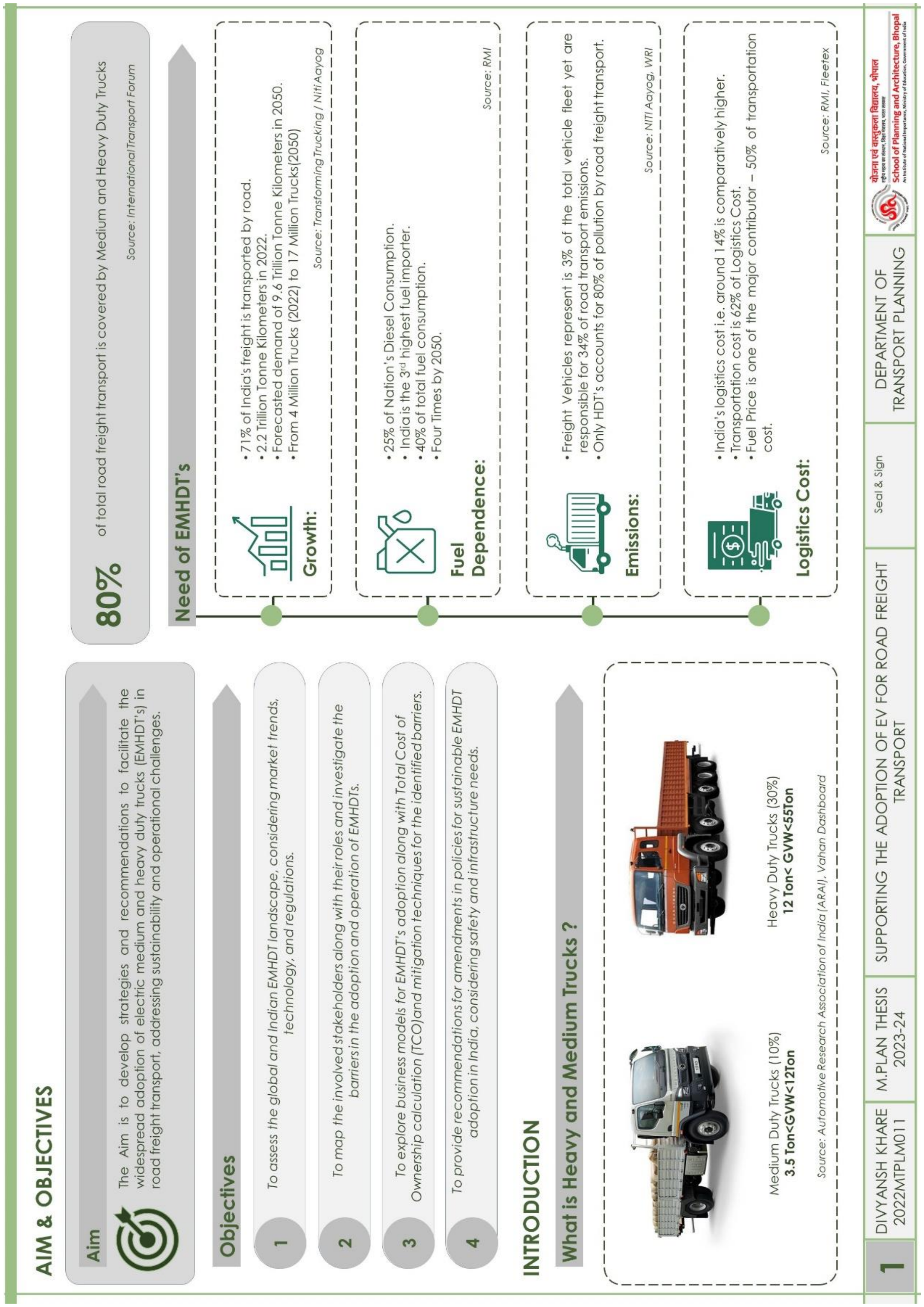
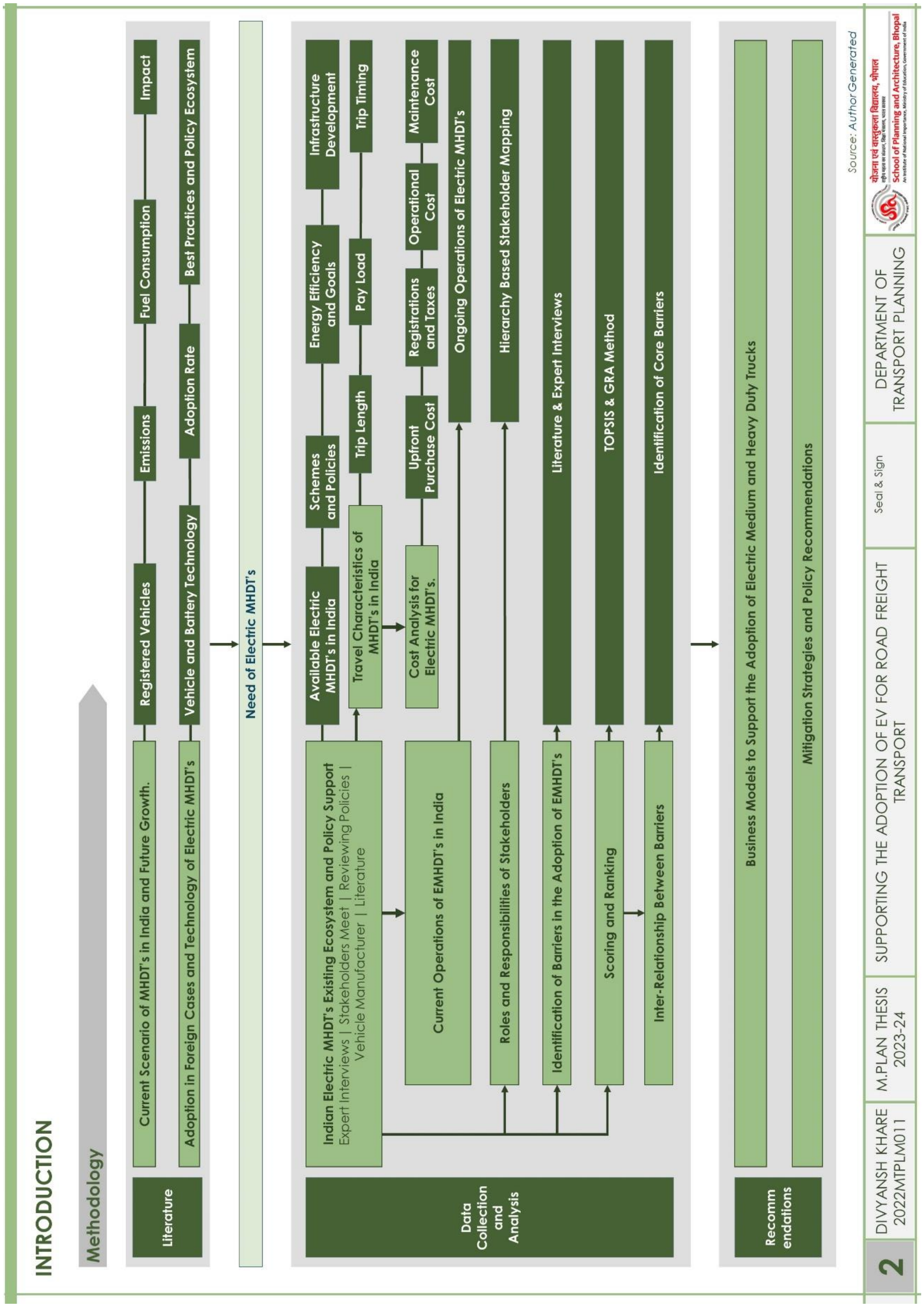
8. ANNEXURES

Sheet 1



Sheet 2



INTRODUCTION
Methodology
Literature
Current Scenario of MHDT's in India and Future Growth.
Registered Vehicles
Emissions
Fuel Consumption
Impact
Adoption in Foreign Cases and Technology of Electric MHDT's
Vehicle and Battery Technology
Adoption Rate
Best Practices and Policy Ecosystem
Need of Electric MHDT's
Data Collection and Analysis
Indian Electric MHDT's Existing Ecosystem and Policy Support
Expert Interviews | Stakeholders Meet | Reviewing Policies | Vehicle Manufacturer | Literature
Available Electric MHDT's in India
Schemes and Policies
Energy Efficiency and Goals
Infrastructure Development
Travel Characteristics of MHDT's in India
Trip Length
Pay Load
Trip Timing
Cost Analysis for Electric MHDT's.
Upfront Purchase Cost
Registrations and Taxes
Operational Cost
Maintenance Cost
Current Operations of EMHDT's in India
Ongoing Operations of Electric MHDT's
Roles and Responsibilities of Stakeholders
Hierarchy Based Stakeholder Mapping
Identification of Barriers in the Adoption of EMHDT's
Literature & Expert Interviews
Scoring and Ranking
TOPSIS & GRA Method
Inter-Relationship Between Barriers
Identification of Core Barriers
Recommendations
Business Models to Support the Adoption of Electric Medium and Heavy Duty Trucks
Mitigation Strategies and Policy Recommendations
Source: Author Generated
2
DIVYANSH KHARE 2022MTPLM011
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Sheet 3

LITERATURE

Battery Technology

Commonly Used Battery Technologies in EMHDT's

- **Lithium-Nickel-Cobalt Oxide (NCA)** – *Energy Density – 230Wh/kg*
- **Lithium-Nickel-Manganese-Cobalt Oxide (NMC).** – *Energy Density – 275Wh/kg*

Battery Ageing

- Calendar Ageing – Based upon Time
- Cycle Ageing – Based Upon Charge Cycles

Change in Cost of Batteries

- 2010 - $1100/kWh
- 2020 - $137/kWh
- 2023 - $100/kWh

Source: Bloomsberg

Available EMHDT's in India

Model / Specifications	IPL Tech Rhino 5536	Ashok Leyland AVTR 55 T	Ashok Leyland BOSS 14 T
Gross Vehicle Weight (GVW)	55 Ton	55 Ton	14 Ton
Payload Capacity	40 Ton	42 Ton	9 Ton
Approximate Price*	1.15 Cr	1.25 Cr	80 Lakhs
Battery Capacity	258 KWH	301 KWH	201 KWH
Battery Weight*	2.5 T	2.4 T	1.4 Ton
Range	160 KM	185KM	230 KM
Battery Price*	65 Lakhs	70 Lakhs	40 Lakhs
Charging Time	90 Min (20%-100%)	90 Min	120 Min
Charging Equipment Required*	150 KW	240 KW	120 KW
Charging Equipment*	12 Lakhs	18 Lakhs	8 Lakhs

Information Shared by E Truck OEM's during Meeting
** Approximate Cost , *Information not available in public domain*

Source: Author Generated

Environmental Impact – Cradle to Grave

Emissions Intensity (Lifecycle GHG)	Diesel	GmCO2/Litre	3579			
	Electric	GmCO2/kWh	701			
		Units	7.5MT	12MT	25MT	40MT
Fuel Economy	Diesel	Km/Litre	8	5.5	3.45	2.2
	BET	Km/kWh	2.50	1.69	0.88	0.49
Emissions	Diesel	Km/Litre	446.9	650	1036.3	1625.1
	BET	Km/kWh	288.3	427.3	820.2	1485.1
GHG Reduction BET			**35%**	**34%**	**21%**	**9%**

Source: Freight Trucks in India are Primed for Electrification | 2022 | Nikit Abhyankar

Government Schemes and Policies

NEMMP	Incentives – Vehicle/Charger , Formulation of State EV Policies
PLI	Make in India, Advanced Chemistry Cell, Auto Components
FAME	Fiscal and Non Fiscal Incentives, EMHDT's not Included
State EV Policies	Infrastructure Development and Incentives

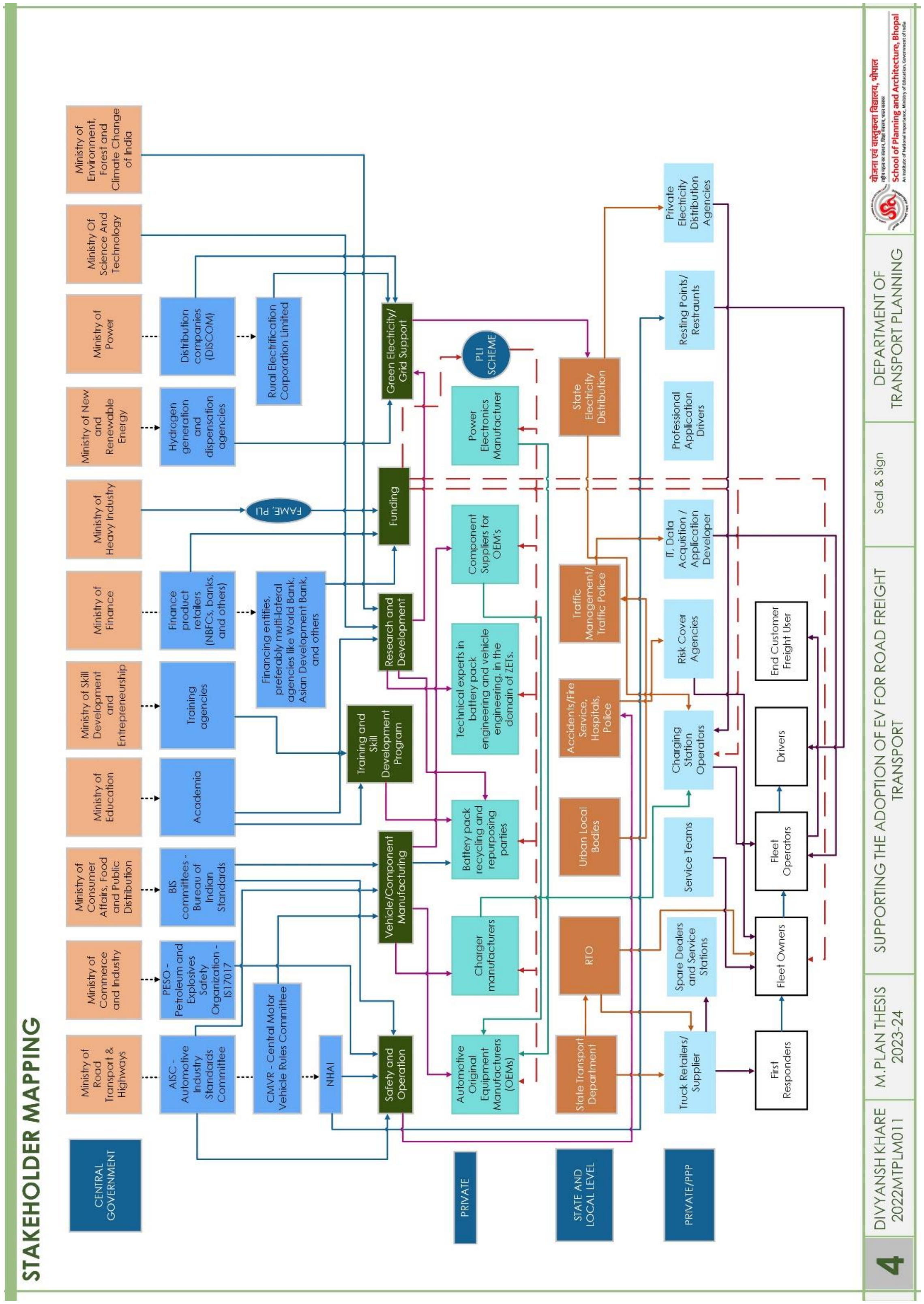
- NEMMP: Ministry of Heavy Industries
- PLI: Ministry of Heavy Industries
- FAME: Ministry of Heavy Industries
- State EV Policies: State Transport Departments

Current Operations of EMHDT's

- Operations in Closed Loop Environment.
- In Cement Industries and Other Mining Sites.
- In House Charging Equipment.
- Proposed Charging Infrastructure development between **Mundra and Morbi Port**(200KM) – Freight Traffic.

3	DIVYANSH KHARE 2022MTPLM011	M.PLAN THESIS 2023-24	SUPPORTING THE ADOPTION OF EV FOR ROAD FREIGHT TRANSPORT	Seal & Sign	DEPARTMENT OF TRANSPORT PLANNING	योजना एवं वास्तुकला विद्यालय, भोपाल School of Planning and Architecture, Bhopal

Sheet 4


STAKEHOLDER MAPPING
CENTRAL GOVERNMENT
PRIVATE
STATE AND LOCAL LEVEL
PRIVATE/PPP
Ministry of Road Transport & Highways
Ministry of Commerce and Industry
Ministry of Consumer Affairs, Food and Public Distribution
Ministry of Education
Ministry of Skill Development and Entrepreneurship
Ministry of Finance
Ministry of Heavy Industry
Ministry of New and Renewable Energy
Ministry of Power
Ministry Of Science And Technology
Ministry of Environment, Forest and Climate Change of India
AISC - Automotive Industry Standards Committee
PESO - Petroleum and Explosives Safety Organization - IS17017
BIS committees - Bureau of Indian Standards
Academia
Training agencies
Finance product retailers (NBFCs, banks, and others)
Hydrogen generation and dispensation agencies
Distribution companies (DISCOM)
CMVR - Central Motor Vehicle Rules Committee
NHAI
Financing entities, preferably multi-lateral agencies like World Bank, Asian Development Bank, and others
FAME, PLI
Rural Electrification Corporation Limited
Safety and Operation
Vehicle/Component Manufacturing
Training and Skill Development Program
Research and Development
Funding
Green Electricity/ Grid Support
Automotive Original Equipment Manufacturers (OEMs)
Charger manufacturers
Battery pack recycling and repurposing parties
Technical experts in battery pack engineering and vehicle engineering, in the domain of ZETs.
Component Suppliers for OEM's
Power Electronics Manufacturer
PLI SCHEME
State Transport Department
RTO
Urban Local Bodies
Accidents/Fire Service, Hospitals, Police
Traffic Management/ Traffic Police
State Electricity Distribution
Truck Retailers/ Supplier
Spare Dealers and Service Stations
Service Teams
Charging Station Operators
Risk Cover Agencies
IT, Data Acquistion / Application Developer
Professional Application Drivers
Resting Points/ Restraunts
Private Electricity Distribution Agencies
First Responders
Fleet Owners
Fleet Operators
Drivers
End Customer Freight User
4
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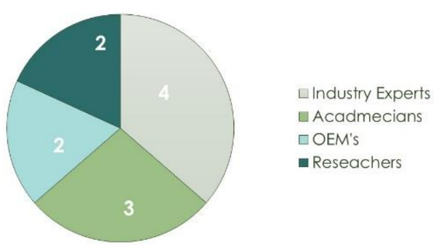
Sheet 5

DATA COLLECTION AND ANALYSIS

Identified Barriers from the Literature

Barriers	Publication 01	Publication 02	Publication 3	Publication 04	Publication 05	Publication 05
Total Cost of Ownership	Martín Tanco (2019)	Thomas Earl (2018)	Qamar S(2021)	Theodora Konstantinou (2022)	Nikit Abhyankar (2022)	Bjorn Nykvist (2021)
Charging Infrastructure	Chandana K (2023)	Qamar S(2021)	Lisa Melander (2022)	Muhammad Qasim (2021)	Harrison John Bhatti (2022)	Claire Sugihara (2023)
Battery Technology	Chandana K (2023)	Shishir Bhardwaj (2022)	Harrison John Bhatti (2022)	Lisa Melander (2022)	Heikki Liimatainen (2018)	Burke, Andrew (2022)
Charging Duration	Shishir Bhardwaj (2022)	Theodora Konstantinou (2022)	Claire Sugihara (2023)	Burke, Andrew (2022)	Jimmy O'Dea (2020)	Behyad Jafari (2021)
Policies and Schemes	Thomas Earl (2018)	Lisa Melander (2022)	Harrison John Bhatti (2022)	Theodora Konstantinou (2022)	Burke, Andrew (2022)	Sudhendu Jyoti Sinha (2021)
Grid Mix	Theodora Konstantinou (2022)	Nikit Abhyankar (2022)	Xizhao Zhang (2022)	Burke, Andrew (2022)	Marissa Moultak (2017)	Jimmy O'Dea (2020)
Range Anxiety	Claire Sugihara (2023)	Heikki Liimatainen (2018)	Rahul Bagdia (2021)	Shishir Bhardwaj (2022)	Aviral Yadav (2023)	
Alternative Fuel Technology	Xizhao Zhang (2022)	Burke, Andrew (2020)	Marissa Moultak (2017)	Jimmy O'Dea (2020)	Rahul Bagdia (2021)	Andrzej Łebkowski (2017)
Payload Compromise	Bjorn Nykvist (2021)	Claire Sugihara (2023)	Marissa Moultak (2017)	Andrzej Łebkowski (2017)	Aviral Yadav (2023)	

EXPERT INTERVIEWS



Professors and Researchers
- IIT Kharagpur
- IIT Guwahati
- NIT Meghalaya

OEM's
- Ashok Leyland
- IPL Tech

Industry Experts
- AEEE
- ICCT
- WRI
- pManifold

Set of Questions

- Role of Electric Mobility in India
- Fuel Consumption and Emissions
- Vision for Electrification of Heavy Duty Vehicles
- Trip Behavior of Indian Trucking Industry
- Revenue Generation by HDV's
- Schemes and Polices
- Electricity Generation
- Business Models
- Grid Support
- Charging Infrastructure and Costs

Extracted Barriers from the Interviews

Product Availability	Operational Reliability	Grid Capacity and Support
Technological Uncertainty	Scrap Value	Heterogeneous Operational Structure
Limited Demand	Electricity Rate Structure	Lack of Business Models

5	DIVYANSH KHARE 2022MTPLM011	M.PLAN THESIS 2023-24	SUPPORTING THE ADOPTION OF EV FOR ROAD FREIGHT TRANSPORT	Seal & Sign	DEPARTMENT OF TRANSPORT PLANNING	योजना एवं वास्तुकला विद्यालय, भोपाल School of Planning and Architecture, Bhopal

Sheet 6

ANALYSIS

Segregation of Identified Barriers

Operational Barriers

- B1 – Product Availability
- B2 – Operational Reliability
- B3 – Limited Range
- B4 – Long Charging Duration
- B5 – Availability of Public Charging Infrastructure

Technological Barriers

- B6 – Capacity of the Electrical Grid
- B7 – Technological Uncertainty
- B8 – Evolving Battery Technology
- B9 – Current Grid Mix
- B10 – Alternative Fuel Technology

Financial Barriers

- B11 – Governmental and Policy Support
- B12 – Total cost of ownership and High CAPEX Cost
- B13 – Scrap Value
- B14 – Limited Demand
- B15 – Electricity Rate Structures
- B16 – Payload Compromise
- B17 – Fragmented Structure of the Freight System
- B18 – Business Model and New Partnerships

Process of Scoring and Ranking

Scoring on the Scale of 1-7 (Google Form) → Attempted by 15 Experts with up to 10+ Year of Experience → Rank Identified by TOPSIS and GRA

Results of Google Form Based Survey

818	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Score 8	Score 9	Score 10	Score 11	Score 12	Score 13	Score 14	Score 15
B 1	7	6	5	3	4	7	4	5	6	4	7	7	5	6	5
B 2	5	7	6	5	5	3	5	5	2	2	2	7	1	6	6
B 3	6	4	7	2	6	7	5	7	4	5	3	6	1	6	4
B 4	6	6	7	5	6	7	4	6	5	4	3	6	4	6	6
B 5	7	3	5	5	7	7	7	5	6	5	7	7	6	6	6
B 6	4	3	5	4	4	2	5	6	1	2	6	5	4	4	3
B 7	3	5	4	5	5	2	6	5	2	3	2	5	2	5	3
B 8	6	5	4	5	4	2	5	3	2	3	1	7	2	5	5
B 9	3	3	5	5	5	6	6	6	2	3	1	6	2	5	2
B 10	4	5	3	6	3	4	5	7	4	5	7	5	2	4	5
B 11	6	6	6	7	7	5	7	4	7	5	7	7	6	6	6
B 12	3	6	3	7	7	6	7	5	6	6	3	5	6	5	6
B 13	6	6	6	5	6	6	7	4	6	5	5	4	2	6	5
B 14	6	5	6	5	3	6	6	4	5	4	6	4	4	4	5
B 15	1	5	6	3	3	2	5	5	2	4	2	5	2	4	2
B 16	2	7	6	6	3	7	7	7	4	3	5	5	2	4	5
B 17	3	4	4	7	5	5	5	6	5	4	3	4	2	4	6
B 18	3	3	4	7	5	4	7	4	6	5	1	4	6	6	5

Source: Google Form Based Survey

Results of TOPSIS and GRA

By TOPSIS Method
Technique for Order Preference by Similarity to the Ideal Solution

Barriers	TOPSIS Score	Z Score
B11	0.729	1.953
B5	0.680	1.585
B1	0.591	0.916
B4	0.579	0.819
B12	0.567	0.727
B13	0.562	0.690
B16	0.509	0.289
B3	0.508	0.283
B14	0.485	0.113
B10	0.451	-0.145
B18	0.449	-0.162
B2	0.434	-0.273
B17	0.413	-0.437
B9	0.347	-0.930
B8	0.344	-0.952
B6	0.319	-1.140
B7	0.267	-1.534
B15	0.232	-1.802

By GRA Method
Grey Relational Analysis

Barriers	GRA Score	Z Score
B11	6.15	1.885
B5	5.92	1.583
B1	5.38	0.878
B12	5.38	0.878
B4	5.31	0.777
B13	5.23	0.677
B14	4.92	0.274
B16	4.92	0.274
B3	4.85	0.173
B10	4.62	-0.129
B18	4.54	-0.229
B17	4.38	-0.431
B2	4.23	-0.632
B9	4.08	-0.833
B6	3.92	-1.035
B7	3.77	-1.236
B8	3.77	-1.236
B15	3.46	-1.639

Source: Author Generated

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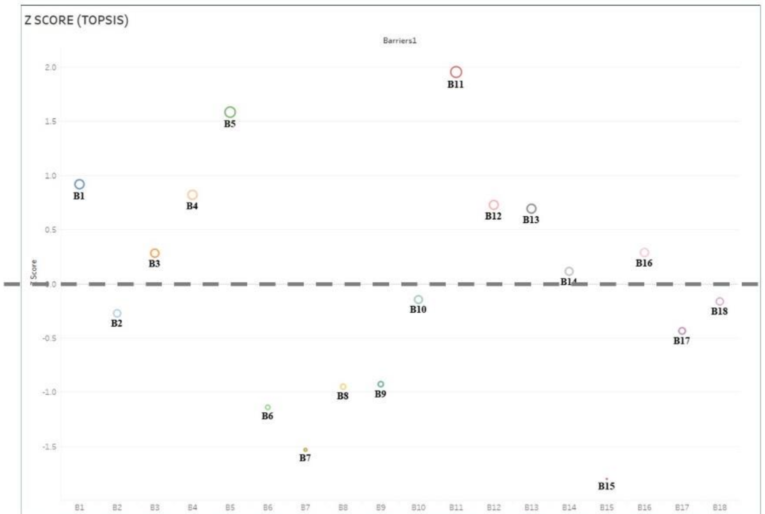
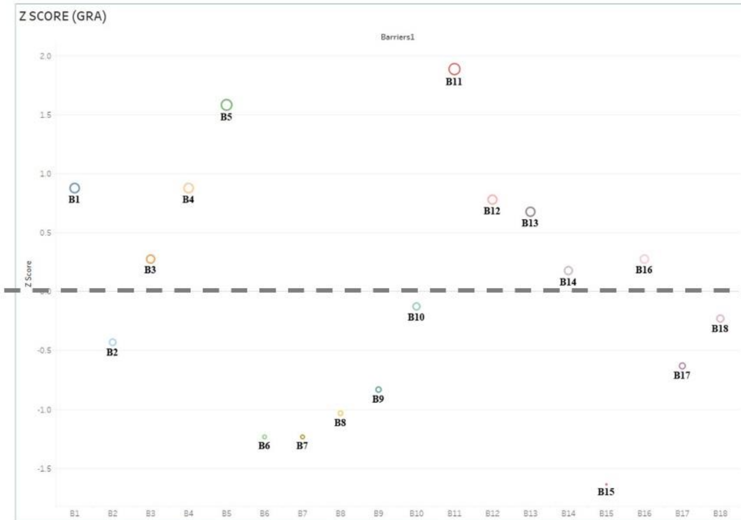
Sheet 7

ANALYSIS

Comparison of Results



Source: Author Generated



Source: Author Generated

Ranking of Barriers

Barriers	
1.	B11: Governmental and Policy Support
2.	B5: Availability of Public Charging Infrastructure
3.	B1: Product Availability
4.	B4: Long Charging Duration
5.	B12: Total cost of ownership and High CAPEX Cost
6.	B13: Scrap Value
7.	B3: Limited Range
8.	B16: Payload Compromise
9.	B14: Limited Demand

Barriers	
10.	B10: Alternative Fuel Technology
11.	B18: Business Model and New Partnerships
12.	B2: Operational Reliability
13.	B17: The Fragmented Structure of the Freight System
14.	B8: Evolving Battery Technology
15.	B9: Current Grid Mix
16.	B6: The Capacity of the electrical grid
17.	B7: Technological Uncertainty
18.	B15: Electricity Rate Structures

Financial Barrier | Operational Barrier | Technological Barrier

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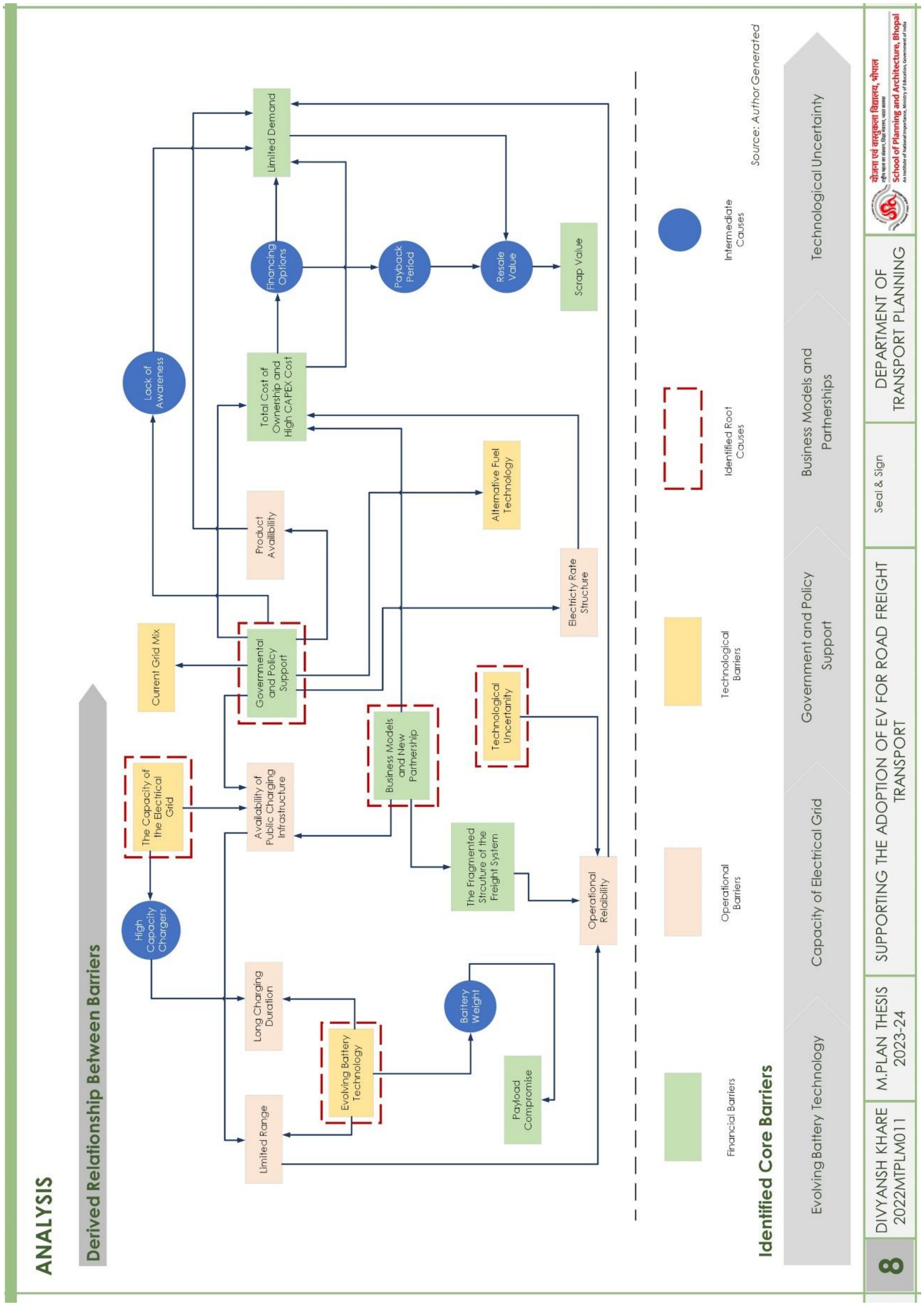
Sheet 8


ANALYSIS
Derived Relationship Between Barriers
Current Grid Mix
Lack of Awareness
Limited Demand
Financing Options
Payback Period
Resale Value
Scrap Value
Total Cost of Ownership and High CAPEX Cost
Product Availibility
Alternative Fuel Technology
Electricty Rate Structure
Governmental and Policy Support
Technological Uncertainity
Business Models and New Partnership
The Capacity of the Electrical Grid
Availability of Public Charging Infrastructure
The Fragmented Strcuture of the Freight System
Operational Reliability
High Capacity Chargers
Long Charging Duration
Battery Weight
Evolving Battery Technology
Payload Compromise
Limited Range
Financial Barriers
Operational Barriers
Technological Barriers
Identified Root Causes
Intermediate Causes
Source: Author Generated
Identified Core Barriers
Evolving Battery Technology
Capacity of Electrical Grid
Government and Policy Support
Business Models and Partnerships
Technological Uncertainty
8
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SUPPORTING THE ADOPTION OF EV FOR ROAD FREIGHT TRANSPORT
Seal & Sign
DEPARTMENT OF TRANSPORT PLANNING
School of Planning and Architecture, Bhopal

Sheet 9

ANALYSIS

Total Cost of Ownership Calculator

Considered Values for TCO Analysis

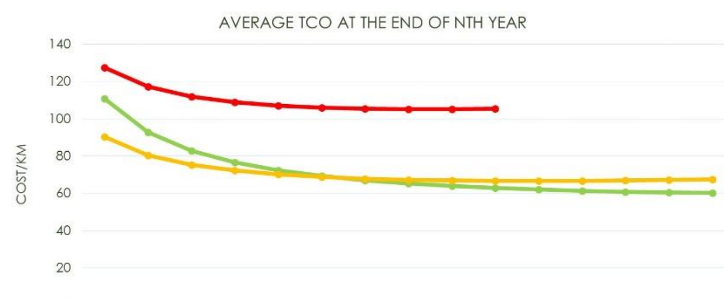
Considerations	ICE Based 55 T Truck	Electric 55 T Truck (Owned Battery)	Electric 55 T Truck (Battery Swapping Subscription)
Vehicle Holding Period	10 Years	15 Years	15 Years
Daily Distance Travelled/Day	400 KM	400 KM	400 KM
Purchase Cost	50,00,000	1,25,00,000	70,00,000
Tax+ National Permit	200000	0	0
Financial Incentive* (As per LCV's in FAME 2)	0	5,00,000	10,00,000
Annual Maintenance + Tires	540000	500000	510000
Battery Replacement (Frequency)	NA	After Every 3,00,000 KM	NA
Battery Replacement Cost	NA	NA	50,00,000
Fuel/Charging Cost	100/Litre	12/kWh	40/kWh
Toll Tax/KM	5/KM	0	0
Insurance	70,000	80,000	1,00,000
Diesel/Electricity/Maintenance Growth Rate	5%		
Discount and Resale Rate	10%		

*Data Collected during the Meeting with ICE Truck Operator and Electric Truck Manufacturer

Source: Author Generated

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ICE	127.4	106.8	101.4	99.77	99.73	100.5	101.8	103.5	105.4	107.5					
EV (OB)	110.7	74.69	63.31	58.1	55.37	53.9	53.16	52.89	52.95	53.25	53.73	54.36	55.12	55.98	56.94
EV (SB)	90.35	70.69	64.97	62.76	61.98	61.94	62.34	63.04	63.95	65.02	66.23	67.55	68.98	70.51	72.12

Source: Author Generated



YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ICE	127.45	117.14	111.89	108.86	107.03	105.95	105.36	105.13	105.16	105.39					
EV (OB)	110.65	92.671	82.885	76.688	72.424	69.337	67.026	65.259	63.891	62.827	62	61.363	60.883	60.532	60.293
EV (SB)	90.349	80.522	75.339	72.195	70.153	68.784	67.864	67.261	66.892	66.705	66.662	66.736	66.909	67.166	67.496

Source: Author Generated

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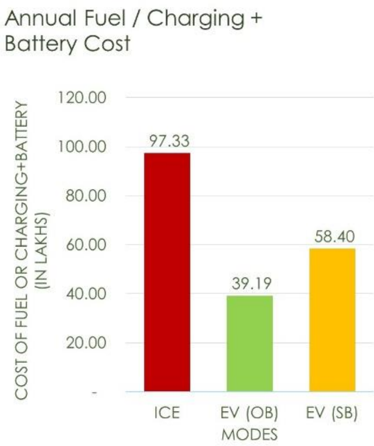
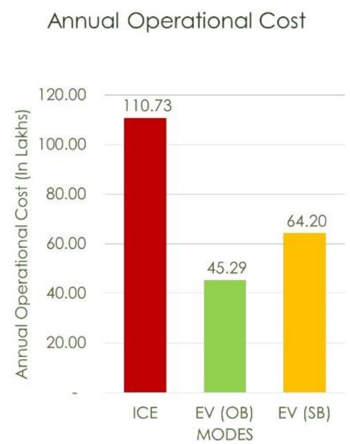
Sheet 10

ANALYSIS

Annual Fuel Cost Expenses and Overall Operation Cost





*Driver Wages are not Involved into Calculation

Source: Author Generated

Business Models in the Ecosystem of EMHDT's

Ownership Model

1. Government Incentives to Reduce the Upfront Cost.
2. Resale Rights
3. Long Term Advantages – Lower TCO
4. Usage of Charging Equipment to Charge Other Vehicles.

Leasing and Rental Model

1. Short Term and Long Term Leasing.
2. Zero Upfront Cost
3. Benefits of Lower Operational Costs.
4. Benefits of Lower Maintenance Costs.

Business Models in the Ecosystem of EMHDT's

Subscription Based Model

1. Subscriptions Based on KM Driven or Time Period.
2. Advantageous for Occasional Needs
3. Optimal Fleet Utilization.
4. Subscription Fee Comprehensively Covers All Services.
5. Financial Predictability.

Charging Infrastructure as Service

1. Offset Significant CAPEX Cost.
2. Government Fiscal and Non Fiscal Incentives.
3. Promotes Development of Robust Charging Infrastructure.
4. Maximum Utilization of Created Infrastructure.

Battery Leasing and Swapping Model

1. Reduces Upfront Cost by Almost 50%.
2. Subscription Based Upon KM Driven.
3. Direct Relation Between KM Driven and Per kWh Charge.
4. Initially Effective for Fleet Operates of Major Freight Corridor.

Fleet Aggregation and Pooling Model

1. Instrumental in Maximizing the use existing fleet.
2. Reduction in Total Cost of Ownership.
3. Creation of Common Platform is Required.
4. Formulation of Unified Operations.

Business Opportunity for Land Owners/ Resting Stop Owners

1. Land Leasing to Charging Point Operators.
2. Truck Depots and Service Centers.
3. Resting Stops Can Be Equipped with modern Facilities and Charging Infrastructure.

Source: Author Generated

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Sheet 11

MITIGATION STRATEGIES AND POLICY RECOMMENDATIONS

Government Policies and Support

- Fiscal Incentives for EMHDT's buyers in FAME 3
  - Reduce upfront cost, it will directly impacts buyers choice.
- Regulation of Electricity Rate Structures for the Charging of Electric Vehicles
  - Directly reduce the charging cost and impacts total cost of ownership.
- Introduction of Awareness Programs for Small Fleet Size Operators.
  - Remove misconceptions between fleet operators and increase demand of EMHDT's.
- Defining the Forecasted Market Penetration of Various Alternative Fuel Technologies for ZET.
  - Bring confidence between policy makers and investors to fuel up the process financially.
- Introduction of Financing Options with Lower Rate of Interest.
  - Directly attract the fleet owners to invest into the technology.
- Incentives for the OEM's and Auto Component Manufacturers.
  - Push manufactures for the production which will directly brings multiple options to the buyers.
- Pilots for Retrofitting of Existing Fleet
  - Conversion of existing fleet which will reduce the upfront cost significantly. Along with the benefits of low operational cost .
- Risk Sharing Interventions for Early Adopters
  - Financial risk will divide into multiple stakeholder and safeguard buyers from loses.
- Tightening of Fuel Emission Standards
  - Push fleet owners to shift towards ZET's.
- Skill Development Programs for Technicians
  - Create a better repair and maintenance ecosystem to mitigate breakdown issues.
- Electrification of 7 major Corridors – Caters 50% of road freight transport.
  - Major Fleet will affect and maximum utilization of developed infrastructure.
- Appreciate closed loop environment usage.
  - Bring confidence in buyers as well as testing of EMHDT's will be carried out.
- Rebate on Toll Taxes for Defined Period of Time
  - At early adoption stage, reduction in toll tax will attract fleet operators to use EMHDT's

Technological Uncertainty and Evolving Battery Technology

- Mandates for Unified and Standards for Charging and Battery Infrastructure
  - Allow easy charging and battery swapping process.
- Research and Development in the Domain of Battery Technology and Clean Manufacturing.
  - Limited Range, charging duration, payload compromise.
  - Cheaper and environmentally sustainable manufacturing process. – Life cycle emissions will reduce.
- Funded Pilot Projects for On road Operations
  - Identification and rectification for Indian usage of EMHDT's.

The Capacity of Electrical Grid

- Strengthening of Existing Power Grid and Development of Renewable Power Generation
  - Charging duration will reduce with the usage of high power charging equipment.
  - Emissions reduction in power generation will directly reduce life cycle emissions of EMHDT's

Operational Suggestions

- Usage of Containers for Cargo Movement
  - Reduce the turn around time to improve efficiency and usage of EMHDT's.

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