# System thinking to analyze the Market penetration of Two-Wheeled vs Four-Wheeled EVs in India

by

**Piyush Kumbhare**
Bachelor of Technology, Mechanical Engineering, Indian Institute of Technology, 2013

Submitted to the System Design and Management Program in partial fulfillment of the requirements for the degree of

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Authored by: Piyush Kumbhare
System Design and Management Program
April 23, 2025

Certified by: Joan S. Rubin
Executive Director, System Design and Management Program

Accepted by: Warren Seering
Weber Shaughness, Professor of Mechanical Engineering

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## ABSTRACT

This thesis analyzes the disparate market penetration rates of electric two-wheelers (E2Ws) and electric four-wheelers (E4Ws) in India, using systems thinking approaches to understand the underlying dynamics and propose strategic interventions. In 2024, while E2Ws have achieved 4.43% market penetration, E4Ws lag significantly at 1.91%, despite similar policy support. Through force field analysis and stakeholder value mapping, this research identifies key factors driving this disparity and evaluates their temporal evolution over three time horizons.

The analysis reveals that E2Ws benefit from stronger driving forces, including urban suitability, favorable total cost of ownership, and simpler charging solutions, with 91% of users relying on home charging. In contrast, E4Ws face more substantial barriers, particularly in upfront costs, charging infrastructure requirements, and range anxiety. Technical modeling of key Figures of Merit (FOMs) demonstrates how different optimization challenges affect each segment's market acceptance.

The research culminates in recommendations for accelerating E4W adoption, emphasizing the need for India-specific models priced similar to internal combustion engine (ICE) vehicle, localized manufacturing ecosystems, robust charging infrastructure, and innovative financing solutions. The findings suggest that while E2W adoption will continue to grow naturally, E4W penetration requires coordinated interventions across manufacturing, technology, infrastructure, policy, and consumer awareness dimensions. This research contributes to understanding how systems thinking can inform strategic planning for electric vehicle adoption in emerging markets, with specific implications for India's goal of 30% EV penetration by 2030.

Thesis supervisor: Joan S. Rubin
Title: Executive Director, System Design and Management Program

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# List of Acronyms

| | |
|---|---|
| E2Ws | Electric 2 Wheelers |
| E4Ws | Electric 4 Wheelers |
| EV | Electric Vehicle |
| BEV | Battery Electric Vehicle |
| FAME | Faster Adoption and Manufacturing of Electric Vehicles |
| ICE | Internal combustion engine |
| PLI | Production Linked Incentive |
| FADA | Federation of Automobile Dealers Associations |
| IPM | Internal Permanent Magnet |
| BLDC | Brushless Direct Current |
| PMSM | Permanent Magnet Synchronous Motor |
| SIAM | Society of India Automobile Manufacturers |
| NHAI | National Highways Authority of India |
| AC | Alternating current |
| DC | Direct current |
| DSM | Design structure matrix |
| OPD | Object Process Diagram |
| FOM | Figure of Merit |
| ACC | Advanced Chemistry Cell |
| ARAI | Automotive Research Association of India |

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# Chapter 1: Introduction

## 1.1 Motivation

Air pollution is a critical public health and environmental challenge in India, contributing to the second highest number of pollution-related deaths globally in 2021 (1) (2). A report from the Global Burden of Disease study indicates that air pollution caused approximately 1.67 million deaths in India in 2019, equivalent to 17.8% of the country's total mortality (1). Major cities like Delhi, Mumbai, and Kolkata consistently rank among the most polluted urban areas worldwide, with transportation being a significant contributor. It is estimated that vehicular emissions account for nearly 30% of fine particulate matter (PM2.5) in India's cities, aggravating respiratory diseases, cardiovascular disorders, and premature mortality.

India's rapidly growing population, which surpassed 1.4 billion in 2023, has driven an unprecedented rise in transportation needs. This growth is reflected in the country's vehicle density: there are approximately 185 two-wheelers and 34 four-wheelers per 1,000 people (3), with the two-wheeler segment dominating the market. The widespread dependence on internal combustion engine (ICE) vehicles exacerbates air pollution, contributing to greenhouse gas emissions and urban smog. Transportation ranks 4th highest on the overall contributor to Greenhouse Gas emissions (GGE) in India in 2023. (4)

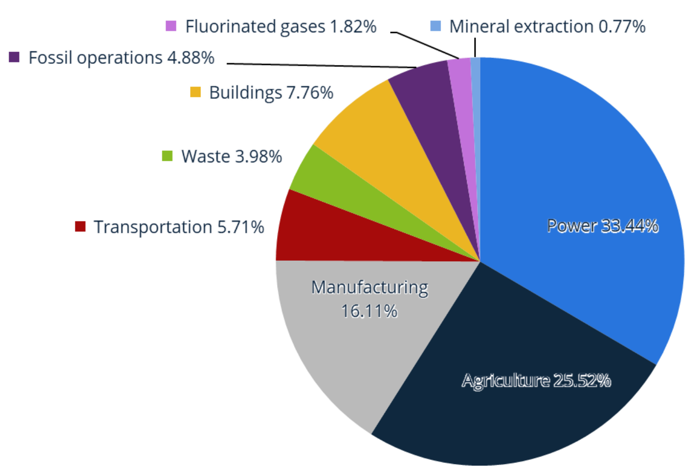


Figure 1: Distribution of greenhouse gas emissions in India in 2023, by sector (4)

To address this, the Indian government has introduced multiple initiatives to encourage the transition to electric vehicles (EVs). Programs such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME I and II), state-level EV policies, reduced Goods and Services Tax (GST) on EVs, and subsidies on battery manufacturing aim to accelerate EV adoption (5). Despite these efforts, the penetration of EVs remains limited. In 2024, electric two-wheelers accounted for only 4.43% of the total two-wheeler market, while electric four-wheelers constituted a mere 1.91% of the car market (6).

The disparity in adoption rates between two- and four-wheelers raises several questions. Two-wheelers, being more affordable and widely used for daily commutes, have seen relatively higher penetration. However, the adoption of electric four-wheelers faces barriers such as high upfront costs, limited charging infrastructure, longer charging times, and lack of consumer awareness.

This study adopts a systems approach to investigate these dynamics, seeking to understand the factors impeding EV penetration in India. Furthermore, it will explore why electric two-wheelers have achieved higher penetration than four-wheelers, considering customer needs and current product offerings. By addressing these critical aspects, the study aims to provide insights for policymakers, industry stakeholders, and researchers to promote EV adoption, reduce vehicular emissions, and ultimately mitigate air pollution in India.

## 1.2 Background

### Evolution of Electric Vehicles (EVs) in India Compared to the Global EV Landscape

The global history of electric vehicles (EVs) began in the early 19th century when Robert Anderson developed the first crude electric carriage in 1832. By the late 1800s, EVs gained significant popularity in countries such as the United States and parts of Europe, as they were quieter, cleaner, and easier to operate compared to steam or gasoline-powered vehicles. However, with the advent of Henry Ford’s mass production techniques in 1913 and the discovery of abundant oil reserves, internal combustion engine (ICE) vehicles soon dominated the market.

Figure 2 : India's first Electric Car (Love bird)

India entered the EV landscape much later; arguably the first EV in India was called Lovebird manufactured by Eddy Electric Series in 1993 in collaboration with Tokyo-based Japanese company Yuskawa Electric Mfg. Co. (7). The "LOVEBIRD" concept electric car was a cute two-seater. It ran on a direct current electric motor which was powered by a rechargeable lead-acid battery. The car could cover up to 60 km with a single full charge. The Lovebird needed around eight hours of charging to attain full charge and there were some limitations (15 degrees as the grade limit). This meant that it could not be legally used on inclines owing to safety concerns. The sales figures did not cross 100 units for this vehicle, leading to it being phased out. (7) The most popular earlier EV vehicle was Reva by the Maini Group in 2001 (8). Despite being one of the earliest electric city cars globally, the Reva failed to gain widespread acceptance, with max 550 units sold (9) in India annually, due to high costs, limited range, and the lack of a charging infrastructure. However, this pioneering car laid the groundwork for India's electric vehicle movement and attracted buyers who prioritized environmental sustainability (10). In comparison, other global EV markets benefited from early government incentives, especially in countries like Norway and China, where policy-driven adoption and infrastructure development played a pivotal role (11). India's market, however, remained predominantly focused on ICE vehicles due to affordability and accessibility.

### India's 2W Market: The Leader in EV Growth

India's unique transportation needs and economic demographics have made two-wheelers (2Ws) the backbone of its automobile market. The country has the highest sales of 2Ws (12), largely due to their affordability, low maintenance costs, and practicality for navigating congested urban roads. In the EV segment, 2Ws dominate the market, accounting for the majority of EV sales.

The Indian EV 2W market offers numerous options across various price ranges and specifications:

- Ola Electric: A recent but major player offering sleek models like the Ola S1 and S1 Pro. Ola Electric sold 4.25M 2W in 2024. (13)
- TVS Motor Company: Offers the TVS iQube, a reliable and affordable option. TVS Motor sold 2.34M 2W in 2024. (13)
- Bajaj Auto: Features the Chetak EV, a modern electric version of the iconic Chetak scooter. Bajaj Auto sold 2.0M 2W in 2024. (13)
- Ather Energy: Known for its high-performance and feature-rich scooters such as the Ather 450X. Ather Energy sold 1.3M 2W in 2024. (13)
- Hero Electric: One of the pioneers in the segment, offering models like Optima, Photon, and NYX. Hero Electric sold 45k 2W in 2024. (13)

Currently, over 30 EV 2W models are available in India, offering options for commuters, cost-conscious buyers, and environmentally conscious consumers. India's focus on affordability and innovation has allowed the country to emerge as a global leader in cost-effective EV 2W solutions (IEA, 2022).

**India's 4W Market: Slow but Promising Growth**

In contrast to 2Ws, the EV four-wheeler (4W) market in India has been slower to develop. 4W EV market in India grew by 1000% compared to 10000% growth in 2W EV from FY18 to FY22. (14) While global manufacturers like Tesla, BYD, and Nissan have been producing advanced EVs for years, India's 4W market is only now catching up. Government initiatives such as the Faster Adoption and Manufacturing of Electric Vehicles (FAME) program and state-level incentives have helped accelerate growth in recent years (5).

The Indian EV 4W market offers a range of vehicles, from compact cars to SUVs:

- Tata Motors: The leader in this segment, offering models such as the Tata Nexon EV, Tata Tiago EV, and Tata Tigor EV. Tata Motors sold 61K 4W vehicles in 2024. (13)
- MG Motor India: Offers the premium MG ZS EV, popular for its long range and advanced features. MG Motors India sold 22K 4W vehicles in 2024. (13)

- Mahindra Electric: Offers the Mahindra XUV400 EV, designed for families looking for affordable EV options. Mahindra Electric sold 7K 4W vehicles in 2024. (13)
- Hyundai: Features the Hyundai Kona Electric, a globally recognized compact SUV. Hyundai sold 61K 4W vehicles in 2024. (13)
- BYD India: Introduced the BYD e6, a spacious and efficient electric MPV. BYD India sold 2.8K 4W vehicles in 2024. (13)

Luxury EVs such as the Audi e-Tron, Jaguar I-PACE, and BMW i4 are also available in India, though their adoption is limited to premium buyers. Globally, manufacturers like Tesla and Rivian dominate the luxury and long-range EV segments, but India's focus has been on developing affordable options for the mass market.

**India vs. the Global EV Market**

Globally, EV adoption has been faster in developed nations, with EVs accounting for 14% of new vehicle sales in 2023 compared to around 2% in India. Countries like Norway have achieved over 80% EV adoption, due in part to strong incentives, extensive charging infrastructure, and policy mandates (11). In contrast, India faces challenges such as inadequate charging infrastructure, high battery costs, and dependence on battery imports.

However, India is making progress, with initiatives like the Production Linked Incentive (PLI) program aimed at localizing EV and battery manufacturing. India's unique focus on 2Ws, affordability, and innovation in cost-effective solutions sets it apart from global trends. With a growing EV ecosystem, India is poised to play a significant role in the global EV market, particularly in the 2W segment, where it already leads in innovation and scale.

## 1.3 Objectives

Looking at the importance of adopting more environmentally friendly and pollution-effective transportation solutions in India, this thesis evaluates the reasons why electric vehicles (EVs) have not been able to penetrate the market effectively, with a specific focus on the passenger vehicle sector. The study recognizes the urgent need to transition from conventional internal combustion engine (ICE) vehicles to electric mobility to address the growing concerns of air pollution, greenhouse gas emissions, and energy security in India. By dividing the passenger vehicle landscape into two-wheeler (2W) and four-wheeler (4W) segments, the thesis aims to answer the following research questions:

Research question 1: Why are 4W EVs in India not able to penetrate the automotive market at the same rate as 2W EVs?

Research question 2: What can the OEMs do to increase the penetration of E4W in Indian market?

The study will perform the following detailed analyses:

1. Develop a technology roadmap for 2W and 4W EVs: The thesis will begin by creating a robust technology roadmap tailored to the unique needs of the Indian market for both 2W and 4W electric vehicles. This roadmap will be developed by considering several critical factors:

- Customer Needs: Understanding the preferences, expectations, and pain points of Indian consumers, such as affordability, range, charging time, and maintenance costs.
- Design Structure Matrix (DSM): Analyzing the interdependencies between various components of EV technology, such as batteries, motors, and charging infrastructure, to identify areas for optimization and innovation.
- Object Process Diagram (OPD): Evaluating key performance indicators like energy efficiency, battery life, and vehicle durability to benchmark current EV models against consumer expectations and global standards.
- Figure of Merit (FOM): Establishing a set of criteria to assess the overall effectiveness of EV technologies, including cost-effectiveness, environmental impact, and scalability.
- Current Market Analysis: Examining the existing market dynamics, including the competitive landscape, market share of EV manufacturers, and the role of traditional ICE vehicle manufacturers transitioning to electric mobility.
- Technical Model: Developing a technical framework to map the current capabilities of EV technologies and identify gaps that need to be addressed to meet consumer demands.
- Current R&D Landscape: Reviewing ongoing research and development efforts in India and globally to identify emerging technologies, innovations, and best practices that can be leveraged to enhance the performance and affordability of EVs.

2. Recommend Strategies to Increase EV Penetration in the Indian Market:

Based on the insights derived from the technology roadmap, the thesis will propose actionable strategies to overcome the barriers hindering the widespread adoption of EVs in India.

## 1.4 Outline

This thesis is structured as follows to facilitate the investigation of the research questions in Section 1.3.

**Literature Review (Chapter 2):**

This literature review examines the transformation of India's automotive market with a focus on electric vehicle (EV) adoption, particularly comparing the two-wheeler and four-wheeler segments. The review begins with an analysis of current market trends in the Indian automotive industry, highlighting key growth patterns and structural changes. It then explores major government initiatives, which have been implemented to accelerate the transition to electric mobility. The review also introduces three essential analytical frameworks that will be used to understand market dynamics and stakeholder relationships. These include the need-goal framework for translating customer requirements into system objectives, the beneficiary-stakeholder framework for distinguishing between value receivers and providers, and force field analysis combined with value mapping for evaluating the forces affecting EV adoption. Through these frameworks, the review aims to provide a comprehensive understanding of the factors influencing differential market penetration between two-wheeler and four-wheeler EVs in India.

**Data and Methods (Chapter 3):**

Chapter 3 presents the analytical framework used to evaluate E2W and E4W penetration in India. It introduces the technical models developed for analyzing key Figures of Merit (FOMs) such as range and torque, incorporating variables specific to the Indian context. The chapter details the methodological approaches used, including force field analysis and stakeholder value mapping, to understand market dynamics and adoption barriers. It also presents the data sources and analytical tools employed in the research.

**Results (Chapter 4):**

The results chapter presents a detailed analysis of E2W and E4W adoption patterns in India using three main approaches. First, it provides a comprehensive force field analysis examining driving and restraining forces across different time horizons.

Second, it presents stakeholder value mapping comparing current and future desired states. Finally, it offers targeted recommendations for both segments based on the analytical findings. The chapter particularly focuses on understanding why E2Ws have achieved higher market penetration than E4Ws and identifies key interventions needed for accelerating adoption.

**Future Work (Chapter 5):**

Chapter 5 outlines opportunities for future research and development in two key areas. First, it suggests extensions to the technical models developed in this thesis, including additional FOMs and dynamic analysis capabilities. Second, it proposes areas for empirical research through data collection and field studies to validate and refine the findings. This chapter provides a roadmap for continuing research in this evolving field.

**Conclusions (Chapter 6):**

Chapter 6 synthesizes the key findings from the analysis and presents strategic recommendations for accelerating EV adoption in India. It provides segment-specific insights and guidance for stakeholders including manufacturers, policymakers, and infrastructure providers. The chapter concludes with a discussion of the broader implications for India's transition to electric mobility.

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# Chapter 2: Literature Review

The Indian automotive market is undergoing a significant transformation with the increasing penetration of electric vehicles (EVs). This literature review aims to provide a comprehensive analysis of the factors influencing the adoption of two-wheeler (2W) and four-wheeler (4W) EVs in India. The review covers market trends, government policies, consumer behavior, technological advancements, and challenges faced by the BEV industry.

## 2.1 Market Trends in the Indian automotive Industry

The Indian automotive industry has emerged as one of the most dynamic and rapidly evolving markets globally, showcasing remarkable resilience despite global economic challenges. The sector's growth trajectory has been particularly noteworthy in recent years, with the post-pandemic period marking a significant turning point in both domestic sales and export capabilities. According to Society of Indian Automobile Manufacturers (SIAM) data, the passenger vehicle segment achieved, 8.5% year-over-year growth in FY2023-24, with sales reaching 4.2 million units (15)year. This growth momentum has been sustained by a combination of factors, including pent-up demand following the pandemic, improved consumer sentiment, and the introduction of numerous new models across various price segments.

The two-wheeler segment, which has traditionally been the backbone of India's automotive industry, demonstrated strong recovery patterns with sales volumes of 18 million units in FY2024 (15). This segment's performance is particularly significant as it serves as a barometer for both urban and rural economic health. The segment has been driven by increasing urbanization, rising youth population, and growing female participation in the workforce, particularly in urban areas. Furthermore, the changing trend in the 2W market has led to a noticeable shift towards higher-capacity vehicles, especially in metropolitan areas (16).

The government's policy initiatives have played a crucial role in shaping the industry's growth trajectory. The Production Linked Incentive (PLI) initiative, with an allocated budget of ₹25,938 crore (17), has attracted significant investments in domestic manufacturing capabilities. Additionally, the government's focus on developing India as a global automotive manufacturing hub through initiatives like

'Make in India' and the Automotive Mission Plan 2026 has fostered a conducive environment for industry growth. The implementation of a scrappage policy which requires passenger vehicles older than 20 years and commercial vehicles older than 15 years to pass a “fitness and emissions test” to keep their registration (18) has also contributed to market dynamics by potentially creating replacement demand in the coming years.

Infrastructure development has been a key enabler of automotive market growth. India has the second largest road network in the world of about 6.3 million km (19). The expansion of the national highway network has improved connectivity and facilitated easier movement of vehicles across the country (20). Urban infrastructure development, including the expansion of metro networks in various cities, has paradoxically contributed to personal vehicle ownership as last-mile connectivity remains a challenge in many areas.

The market has also witnessed significant structural changes in consumer preferences and purchase patterns. Factors such as increased digital adoption in vehicle purchase journeys, growing preference for SUVs in the passenger vehicle segment, and rising awareness about safety features have influenced product development and marketing strategies across manufacturers. The shift towards premium vehicles across segments indicates the evolving aspirational nature of Indian consumers and their willingness to spend more on vehicles with advanced features and better safety standards (21).

The Indian government has implemented a series of strategic initiatives aimed at transforming the automotive sector, with particular emphasis on electric mobility, advanced manufacturing, and sustainable transportation. These initiatives represent a coordinated approach to position India as a global automotive manufacturing hub while simultaneously addressing environmental concerns. The following analysis examines these initiatives.

### 2.1.1 Production Linked Incentive (PLI) Initiative for the Automobile Industry

The PLI program, launched in September 2021, stands as the cornerstone of India's automotive manufacturing transformation strategy. With a substantial allocation of ₹25,938 crore (22), this initiative has fundamentally reshaped the manufacturing landscape through its innovative two-tier incentive structure. The initiative offers higher incentives of 13-18% for electric and hydrogen fuel cell vehicles, while maintaining an

8-13% incentive rate for other advanced automotive technologies. (23)The program's success is evident in its attraction of 82 approved applications, generating committed investments of ₹42,500 crore. As of September 2024, the initiative has already catalyzed actual investments of ₹20,715 crore, with incremental sales reaching ₹10,472 crore. (23) The mandatory requirement of 50% domestic value addition has effectively stimulated local manufacturing capabilities, creating an estimated 1.4 lakh jobs over five years. The structure has particularly benefited companies investing in new-age automotive technologies, positioning India as a potential global hub for electric vehicle manufacturing.

### 2.1.2 FAME II Initiative

Building on the success of its predecessor, the FAME II program, initiated in 2019 with an outlay of ₹11,500 crore (24), has played a pivotal role in accelerating India's electric mobility transition. The initiative's comprehensive approach encompasses demand incentives across various vehicle segments and charging infrastructure development. By October 2024 (25), the program had utilized ₹8,844 crore, with ₹6,577 crore directed towards subsidies and ₹2,244 crore allocated for capital asset creation. The impact is particularly evident in the electrification of public transportation and personal mobility sectors, having supported the adoption of 16.15 lakh electric vehicles across categories (25). The program's focus on charging infrastructure, with 10,985 sanctioned stations, has addressed one of the critical barriers to EV adoption. The implementation has also catalyzed significant policy reforms, including GST reductions on EVs and the development of state-level EV policies.

### 2.1.3 PM E-DRIVE Initiative

Launched in October 2024, the PM E-DRIVE initiative represents the government's most recent and comprehensive approach to electric mobility. With a total outlay of ₹10,900 crore (26), this program, adopts a holistic approach to EV ecosystem development. The initiative's allocation of ₹3,679 crore for vehicle subsidies aims to incentivize 28 lakh electric vehicles across categories, while ₹4,391 crore has been earmarked for procuring 14,028 e-buses (26). A significant portion, ₹2,000 crore, focuses on developing a robust charging infrastructure network, including 22,100 fast chargers for four-wheelers and 48,400 for two/three-wheelers

(26). The initiatives early implementation has shown promising results, with ₹600 crore in claims processed and ₹332 crore already disbursed as of November 2024 (26).

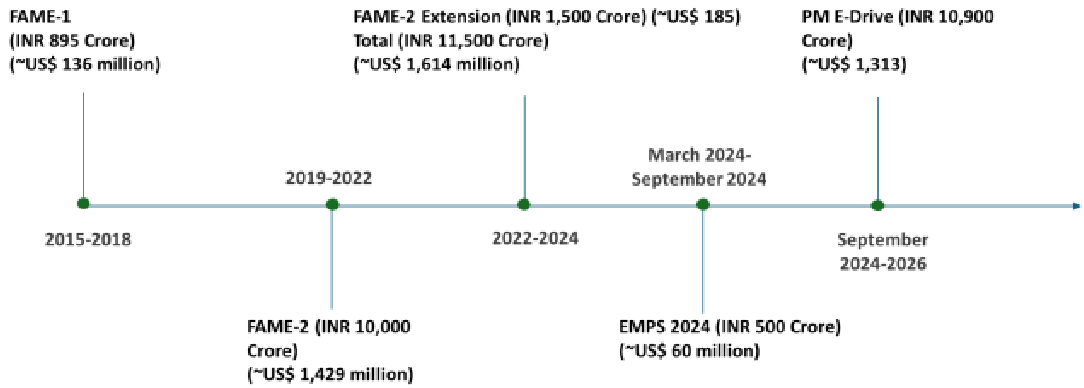


Figure 3 : Timeline of FAME and PM E-Drive programs (26)

| Aspect | FAME II (2019-2024) | PM E-Drive (2024 Onwards) |
|---|---|---|
| Total Allocation | INR 11,500 crore | INR 10,900 crore |
| Focus on E2Ws | High (INR 5,000 crore) | Reduced (INR 3,679 crore) |
| Electric Passenger Cars | Excluded | Excluded |
| Electric Trucks | Excluded | Included (INR 500 crore) |
| Public Transport (E-Buses) Target | 7,090 | 14,028 |
| Charging Infrastructure | No major upgrade focus | INR 2,000 crore for chargers |
| Subsidy Claim Process | Paper-based, less transparent | Aadhaar-based e-voucher |

Figure 4 : Summary of FAME and PM E-Driver Program (26)

### 2.1.4 PLI Initiative for Advanced Chemistry Cell (ACC) Battery Storage

The ACC Battery Storage initiative (27), backed by an ₹18,100 crore outlay, marks India's strategic push into advanced battery manufacturing. This program has successfully attracted three major beneficiary firms, leading to a committed investment of ₹14,810 crore for establishing 30 GWh of manufacturing capacity (28). A significant milestone was achieved with Ola Cell Technologies initiating 1 GWh pilot production at their Krishnagiri facility, generating 863 direct jobs and attracting ₹1,505 crore in investments (28). The program’s expansion through the additional 10 GWh capacity awarded to Reliance Industries Limited demonstrates its success in attracting major industrial players. The recent initiative for Grid Scale Stationary Storage applications, coordinated with the Ministry of New and Renewable Energy, shows the initiative's evolution to address broader energy storage needs (19) (28).

## 2.2 Customer and Stakeholder analysis

### 2.2.1 Need-goal framework (29)

Definition of need: From a customer needs analysis perspective in systems engineering, a need represents a fundamental requirement that drives the creation and implementation of solutions to fulfill specific customer expectations and ensure satisfaction. When assessing customer needs, a necessity refers to the essential features or functionalities that a solution must include to be viable and effectively address the core challenges faced by customers.

Beyond necessities, customer desires or wants reflect broader aspirations and preferences gathered through requirements analysis, market research, and stakeholder engagement. These shape the solution's attributes beyond basic functionality, enhancing its overall appeal. Additionally, the concept of something that is lacking arises from gap analysis, where customers identify inefficiencies, pain points, or missing elements in existing solutions that must be resolved.

A comprehensive understanding of customer needs through these three dimensions—necessities, desires, and gaps—allows systems engineers to design more targeted and effective solutions. This approach not only ensures that fundamental requirements are met but also enhances value and overall customer satisfaction.

The process of identifying needs begins with recognizing the system's stakeholders. Once identified, their needs are prioritized, forming the foundation for establishing system goals. This follows a logical progression, summarized in the needs-to-goals framework illustrated in Figure 5. Initially, we identify stakeholders and beneficiaries, then define their needs. These needs are subsequently translated into goals and prioritized to guide solution development.

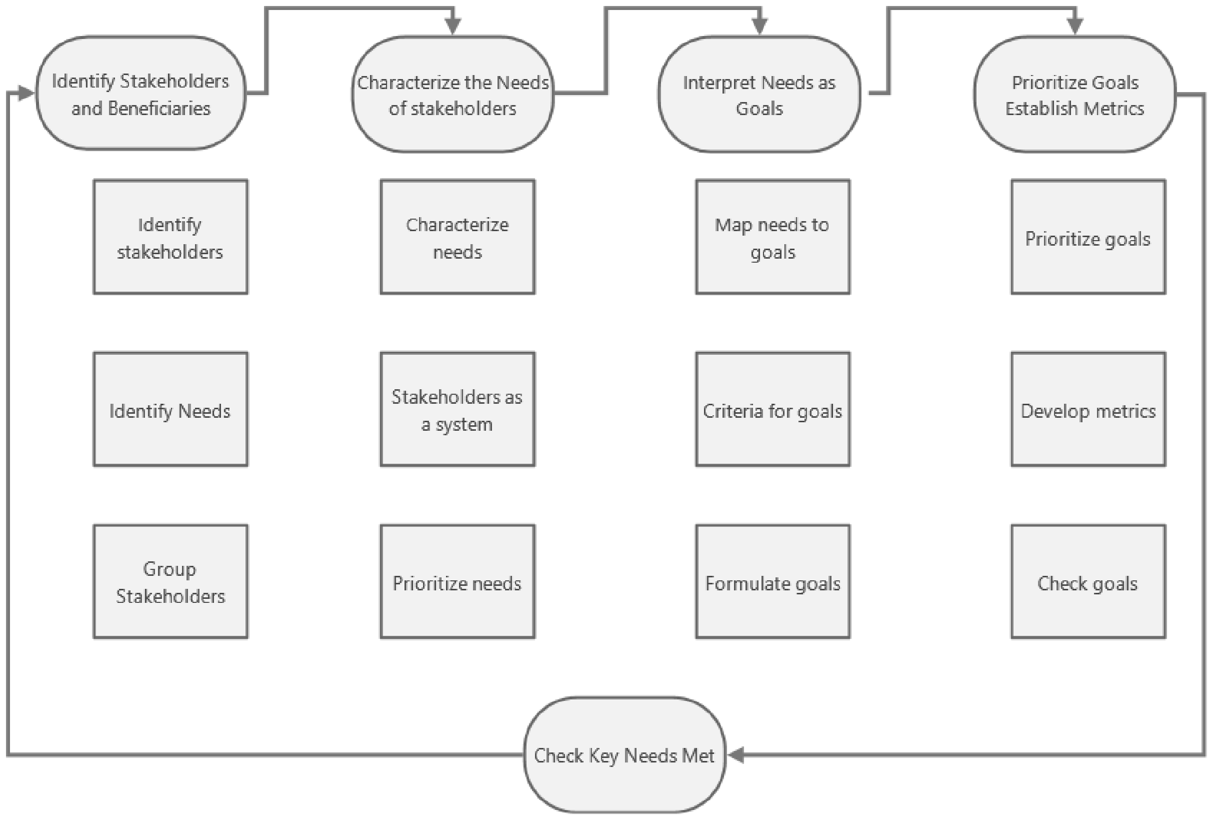


Figure 5 : Needs to goal Framework (29)

### 2.2.2 Beneficiary and Stakeholders framework (29)

Over time, the concept of stakeholders has evolved to encompass all parties affected by a system. This broad interpretation has led organizations to view stakeholder management as a reactive effort rather than a proactive process of identifying and serving potential customers.

To address this challenge, organizations must differentiate between beneficiaries and stakeholders. Beneficiaries receive value from an organization's architecture, products, or services. The system's design specifically addresses their needs, making the organization significant to their success or well-being. Stakeholders, on the other hand, possess something valuable that the organization needs. They provide essential inputs that affect the organization's success, similar to how traditional stockholders supply capital in exchange for profit shares (30).

While these groups remain distinct, they can overlap significantly. Beneficial Stakeholders occupy the intersection, both receiving value from and providing value to the organization. Outside this intersection lie two additional categories: Charitable

Beneficiaries, who receive value without providing direct returns, and Problem Stakeholders, who provide necessary inputs but receive no direct benefits from the organization (29).

Organizations must recognize both internal and external participants in these categories. Internal participants span across various departments, including technology development teams, design groups, implementation specialists, operations staff, sales personnel, service providers, management and strategy teams, and marketing professionals. External participants encompass regulatory bodies, customer base, system operators, supply chain partners, investment groups, and market competitors (31).

The process of stakeholder analysis begins with identification. Organizations identify stakeholders by examining who provides essential project inputs. Similarly, they identify beneficiaries by determining who receives value from project outputs (29). Within this broader framework of stakeholder theory, this thesis will specifically focus on electric vehicle buyers in India as primary stakeholders, examining their needs and influence on the differential market penetration of two-wheeler and four-wheeler EVs.

The importance of focusing on buyers as key stakeholders stems from their dual role in shaping market dynamics. Their decision-making processes, needs, and behaviors directly influence product development, marketing strategies, and overall industry direction. Understanding buyers as stakeholders is essential because they represent both the immediate market and the driving force behind electric vehicle adoption, contributing to broader goals of sustainable transportation and environmental conservation.

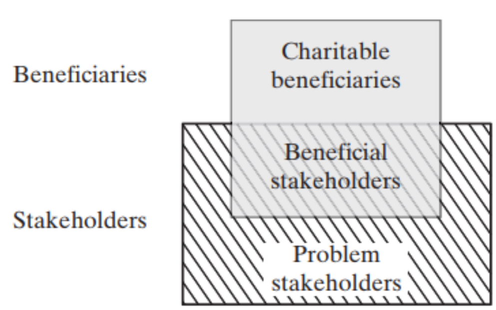

Figure 6 : Beneficiary and Stakeholder mindset (29)

## 2.3 Force Field Analysis and Value Mapping

Force field analysis and value mapping represent critical frameworks in enterprise architecture that enable organizations to understand and manage both organizational change and stakeholder relationships effectively (32). These complementary approaches provide different yet interconnected lenses through which to examine enterprise transformation and value creation, making them particularly valuable for analyzing market dynamics and customer needs in evolving industries.

Force field analysis, a diagnostic technique originally developed by Kurt Lewin (33), helps organizations identify and evaluate the forces that both drive and resist organizational change. The methodology involves a structured approach beginning with proposing a desired change, followed by identifying both driving forces (facilitators) and restraining forces (barriers). Organizations then assign numerical weights to each force to assess their relative impact, analyze how facilitators can mitigate barriers and vice versa, and develop strategies to strengthen driving forces while weakening restraining forces. This weighted analysis creates a visual representation of the dynamic equilibrium between forces promoting and opposing change, enabling organizations to systematically evaluate the likelihood of successful change implementation and identify key leverage points for intervention.

Value mapping focuses on examining the exchange of value between an enterprise and its stakeholders through several key approaches. (34) The stakeholder value exchange assessment documents what value stakeholders expect from and contribute to the enterprise, evaluates current value delivery performance, identifies gaps between expectations and delivery, and prioritizes areas for improvement based on stakeholder importance. Value flow mapping extends this analysis by mapping the network of value flows between stakeholders, identifying both direct and indirect value relationships, highlighting dependencies and potential bottlenecks, and supporting strategic decision-making about resource allocation.

For this thesis, these frameworks will be specifically applied to analyze the EV market, focusing on both two-wheeler and four-wheeler segments. Value mapping will serve as the primary analytical tool to evaluate how well current EV offerings meet customer needs and identify gaps that must be addressed to increase market penetration. The analysis will examine multiple value dimensions that influence customer decisions, including performance characteristics, charging infrastructure, cost considerations, and environmental benefits. By plotting current performance against relative importance for each value dimension, we can clearly visualize where existing EV offerings fall short of customer expectations and where they excel.

The research will present detailed value maps for both two-wheeler and four-wheeler EV segments, highlighting current performance levels in meeting customer needs, the relative importance of different value dimensions to customers, gaps between current and desired performance levels, and priority areas for improvement to drive market penetration. This approach will help identify critical intervention points for manufacturers and policymakers to accelerate EV adoption. Understanding the discrepancy between current value delivery and customer expectations will enable stakeholders to better allocate resources and efforts to address the most significant barriers to adoption.

Force field analysis will complement this value mapping by examining the broader forces affecting EV adoption, such as government policies and incentives, infrastructure development, technology advancement, economic factors, environmental consciousness, and market competition. This comprehensive analysis will provide a clear picture of both the internal value propositions and external forces shaping the EV market's evolution.

The effectiveness of these frameworks is supported by research across various contexts in stakeholder analysis. Modern applications often incorporate digital tools and advanced analytics to provide more sophisticated analysis and visualization capabilities, while maintaining the fundamental focus on understanding and managing the forces that shape organizational change and value creation.

Through this integrated analytical approach, our research aims to provide actionable insights for increasing EV penetration in both two-wheeler and four-wheeler segments. The visual representations and systematic analyses offered by these tools will effectively communicate our findings to industry stakeholders, policymakers, and academic audiences, contributing to the broader discussion on accelerating sustainable transportation adoption. This methodology ensures that our research not only advances theoretical understanding but also provides practical value to industry practitioners working to accelerate EV adoption.

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# Chapter 3: Data and Methods

This chapter will create a customer needs analysis using the needs and beneficiary analysis framework. Then the section will conduct the analysis required to build the technology roadmap.

## 3.1 India and fossil fuel

India faces significant economic and energy security challenges due to its heavy reliance on fossil fuel imports for transportation. The country's large imported oil requirements strain its foreign exchange reserves and makes it vulnerable to global oil price volatility and geopolitical tensions. Additionally, concerns about depleting global petroleum reserves make the transition to EVs strategically important.

India's transportation sector relies heavily on imported fossil fuels, with crude oil imports showing a dramatic 5.7-fold increase between 1998-99 and 2019. The financial implications are substantial - crude oil import costs surged from ₹14,917 crore in 1998-99 to ₹783,193 crore in 2018-19, dropping slightly to ₹717,001 crore in 2019-20 (35).

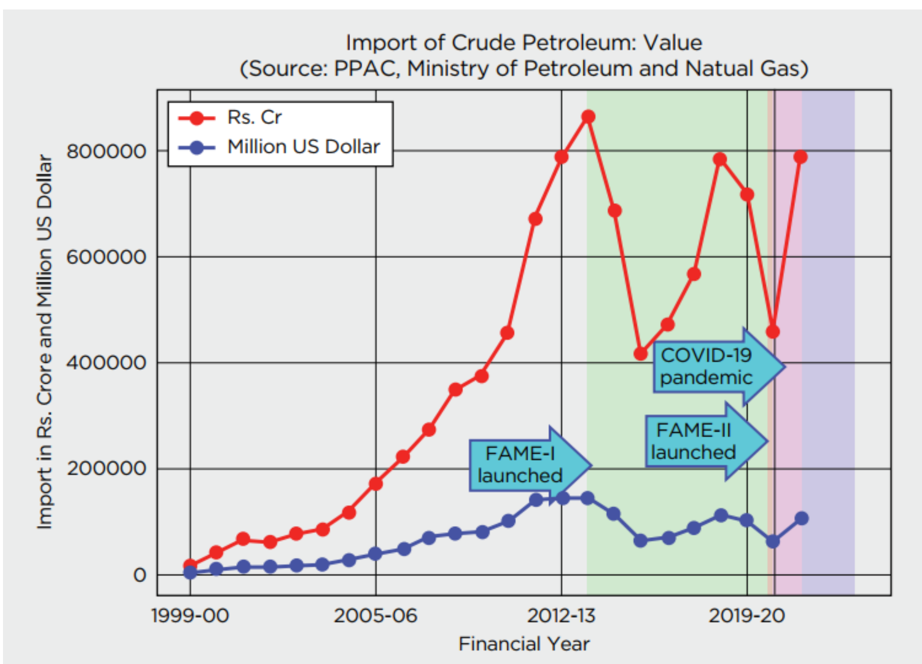



Figure 7 : Amount spent towards crude oil import by India (35)

This massive petroleum expenditure severely impacts India's trade balance. In 2019, India's imports totaled USD 478 billion against exports of USD 323 billion, resulting in a trade deficit of USD 153 billion (35). Petroleum products constitute a major portion of these imports. During FY 2021-22 (until February), petroleum imports accounted for USD 128 billion, representing 23.39% of India's total import bill of USD 551billion (35).

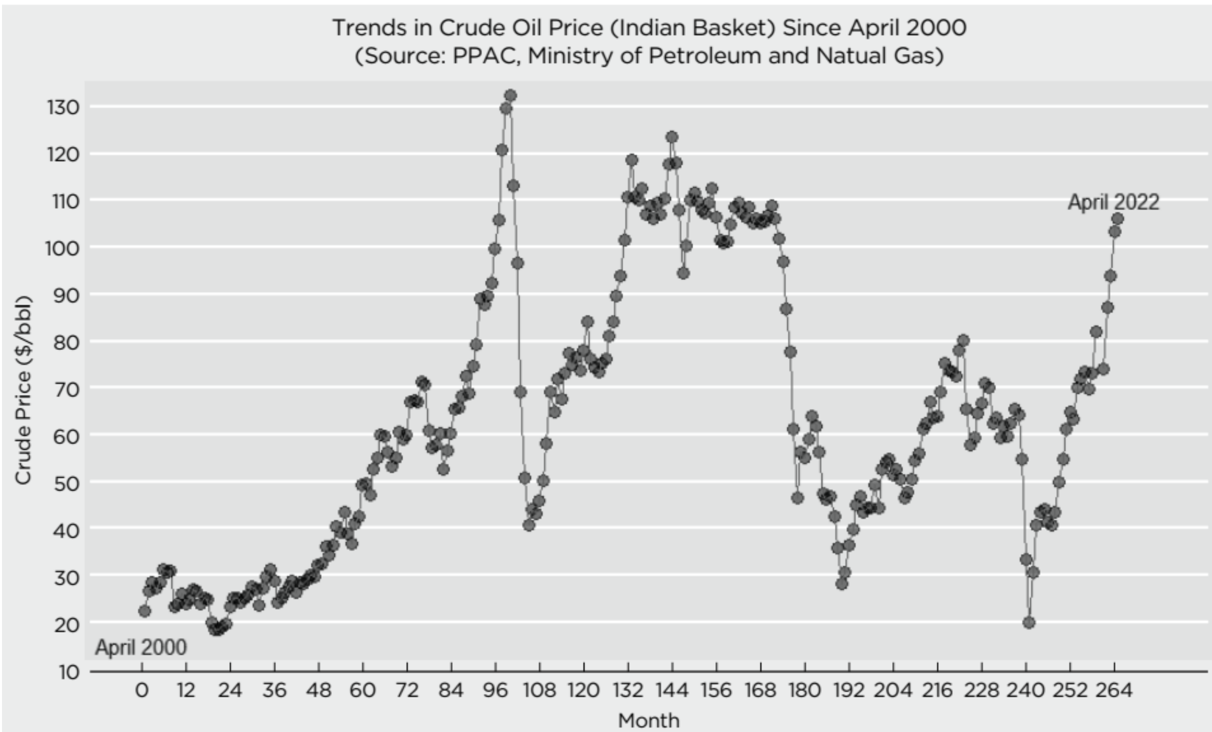



Figure 8 : Variation of international crude prices (Indian basket) (35)

The petroleum market's inherent volatility poses additional challenges. Crude oil prices have experienced several sharp spikes over recent decades (11), threatening economic stability not only in India, but globally. The dependence on crude oil is particularly concerning because the pricing and availability are influenced by various external factors, including geopolitical developments. Furthermore, research suggests that global petroleum reserves are finite, making it imperative for economies to transition toward alternative energy sources in the long term.

## 3.2 Customer and need analysis

Based on the stakeholder, beneficiaries' analysis method discussed in the literature review, a comprehensive stakeholder and beneficiary analysis was conducted to understand the diverse needs and expectations surrounding EV adoption. The analysis employed systematic stakeholder mapping and requirement analysis techniques to identify and categorize key stakeholders based on their roles, interests, and potential impacts on EV implementation. Figure 9. Identifies key stakeholders.

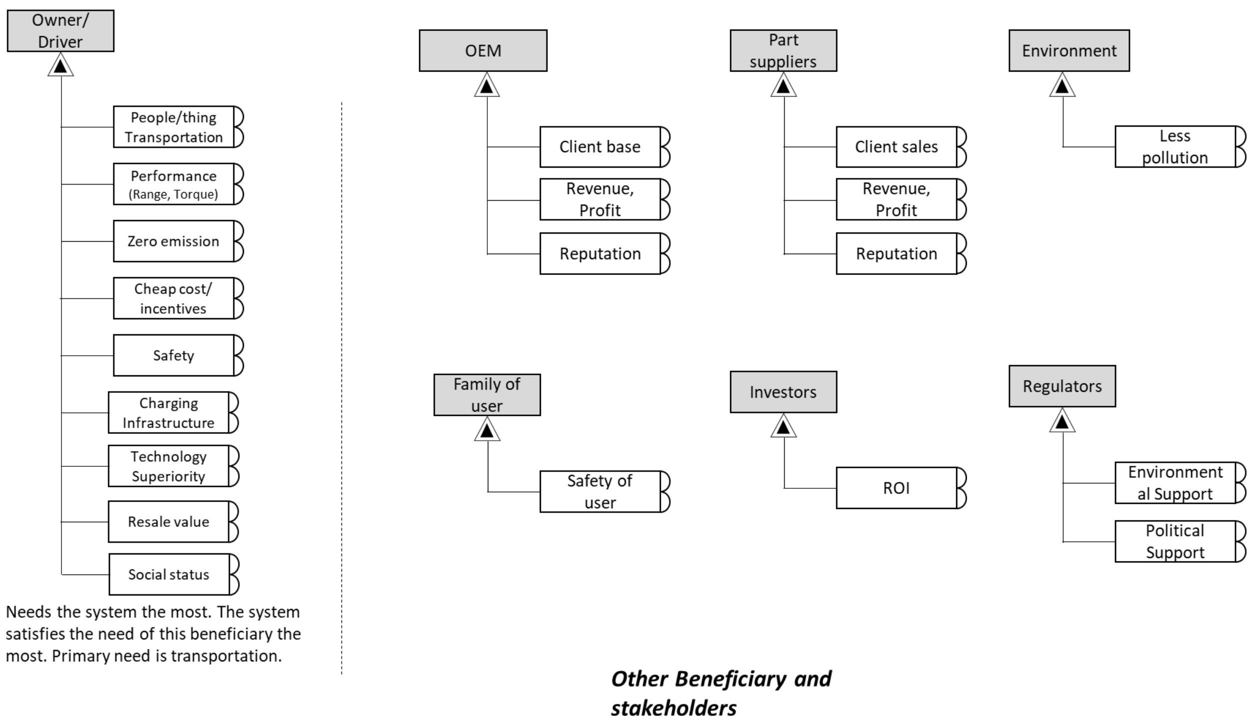



Figure 9 : Identification of principal beneficiary and need of each beneficiary/stakeholder

**Principal Beneficiary - Car Owner/Driver:**

The analysis identified the car owner/driver as the principal beneficiary, as they are both most dependent on the system and have their needs most directly addressed by it. This identification is supported by market research showing that 87% of potential EV buyers in India consider personal transportation needs as their primary decision factor. Their needs are hierarchically structured as follows:

**Primary Need:**

- People/Thing Transportation: Fundamental requirement for mobility
- Daily commuting
- Family transportation (particularly relevant for E4W)
- Cargo carrying capability (essential for commercial users)

**Secondary Needs:**

- Performance (Range, Torque):
- Range requirements
- Torque requirements for Indian road conditions and loading patterns
- Performance in diverse weather conditions

**Zero Emission:**

- Contributing to reduced urban pollution
- Meeting increasing environmental consciousness
- Compliance with evolving emission norms

**Cost/Incentives:**

- Initial purchase price
- Operating cost benefits
- Government subsidies (FAME II, state incentives)
- Total Cost of Ownership considerations

**Safety:**

- Vehicle structural integrity
- Battery safety (particularly relevant given recent incidents)
- Advanced safety features

**Charging Infrastructure:**

- Home charging capability
- Public charging network access
- Fast charging availability

**Technology Superiority:**

- Connected features
- Digital interfaces
- Over-the-air updates
- Battery management systems

**Resale Value:**

- Investment protection
- Secondary market development
- Battery longevity

**Social Status:**

- Brand value
- Design aesthetics
- Early adopter recognition

**<u>Other Important Beneficiaries and Their Needs:</u>**

**Environment**

- Less Pollution: Direct impact on urban air quality
- Zero Emissions: Contributing to India's climate commitments

**OEM Suppliers**

- Client Base: Expanding market
- Client Sales: Volume targets for sustainability
- Revenue/Profit: Business viability in transition period
- Reputation: Brand positioning in emerging EV market

**Family of Users**

- Safety of User: Protection against accidents and battery incidents
- Environmental Benefits: Reduced exposure to pollution
- Economic Benefits: Lower operating costs over vehicle lifetime

**Regulators**

- Environmental Support: Meeting 30% EV penetration target by 2030
- Political Support: Successful implementation of EV policies

**Investors**

- ROI: Returns from growing EV market
- Market Growth: Long-term industry viability

Table 1 below summarizes the findings and Figure 9 presents a detailed breakdown of requirements for each identified stakeholder group.

Table 1: List of key stakeholders and their type

| **Stakeholder** | **Type of Beneficiary** |
|---|---|
| Car owner/ Driver (Primary Beneficiary) | Beneficial Stakeholder |
| Original Equipment Manufacturer (OEM) | Beneficial stakeholder |
| Regulators | Problem Stakeholder |
| Government /NGO | Charitable beneficiaries |
| Local community / Society | Beneficial stakeholder |
| OEM suppliers and infrastructure suppliers | Beneficial Stakeholder |
| Family of user | Charitable Beneficiary |
| OEM investors | Problem Stakeholder |
| Family members | Beneficial stakeholder |

The decision to prioritize owners and drivers as primary beneficiaries is well-supported by recent research, including a 2023 study examining the primary concerns regarding battery electric vehicles (BEVs) in the Indian market (36). The findings of this study, illustrated in Figure 10, align closely with our stakeholder need analysis and reinforce the critical importance of addressing end-user concerns in the Indian EV ecosystem.

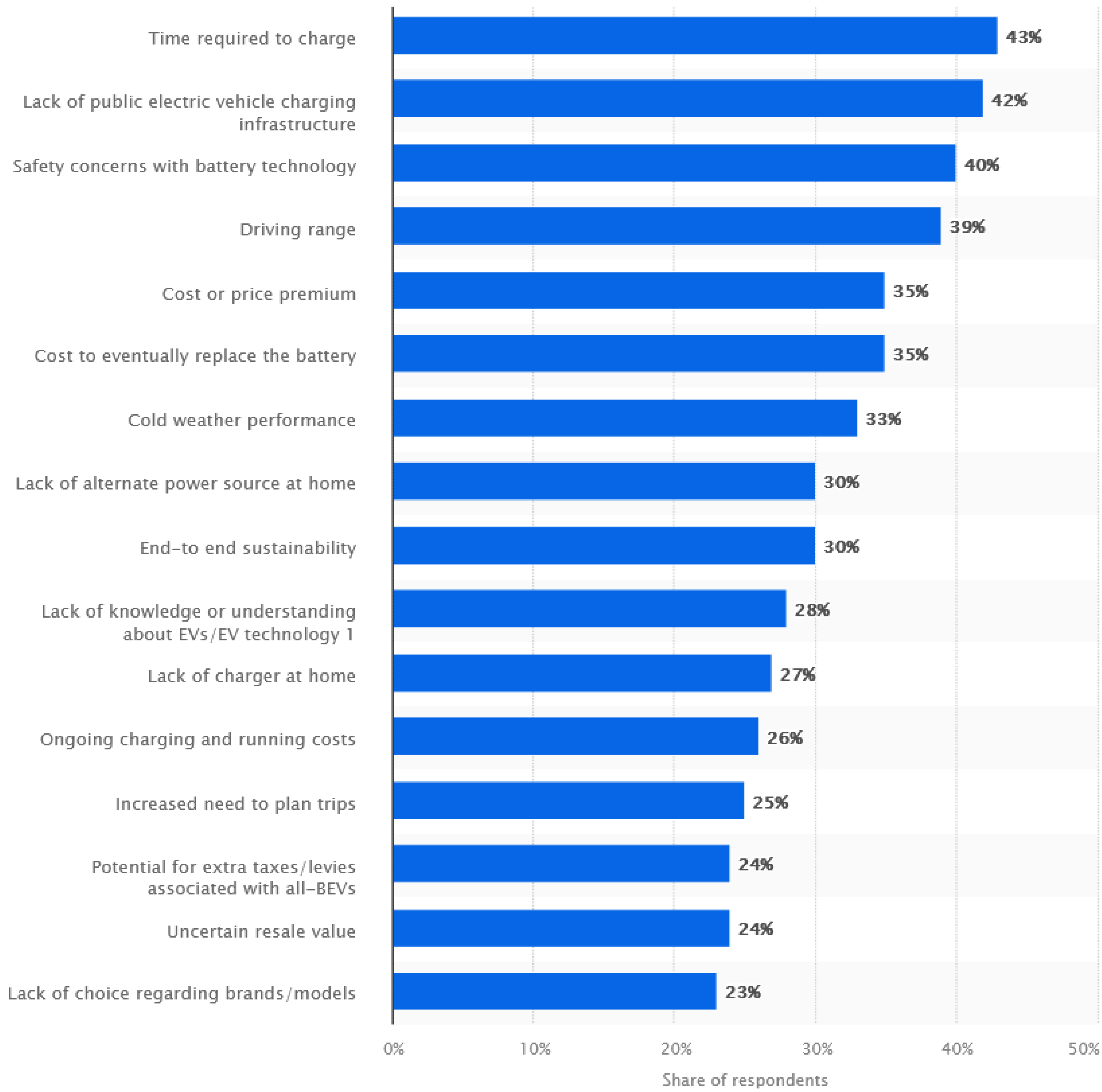



Figure 10 : In a survey conducted in 2023, the leading concern about battery electric vehicle (BEV) in India. 864 respondents; 18 years and older; Participants were of driving age in the country (36)

To better visualize the complex relationships and value flows between different stakeholders, a hub-and-spoke mapping approach was employed, as shown in Figure 11. This visualization technique demonstrates how value is created, transferred, and received among various stakeholders, highlighting the interconnected nature of the EV ecosystem. The map serves as a tool for understanding the mutual dependencies and potential areas for optimization in the stakeholder network.

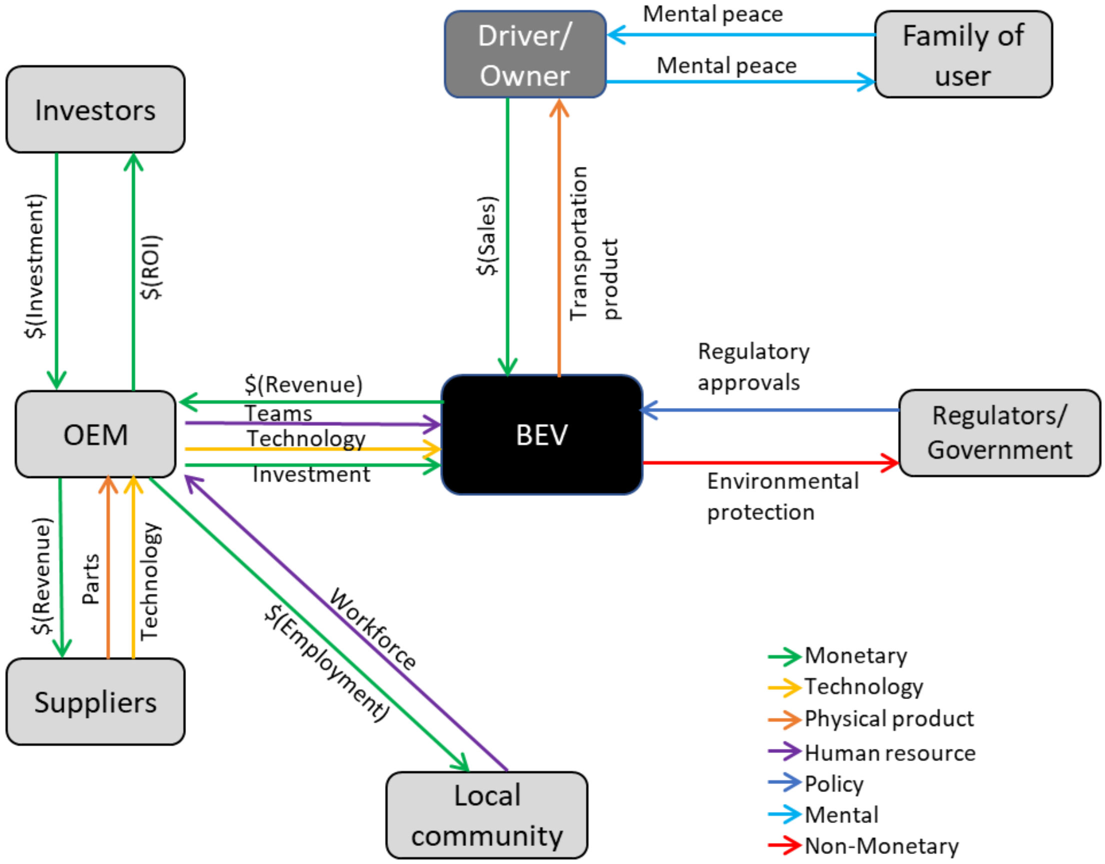



Figure 11 : Hub-and-spoke stakeholder map for BEV. (29)

The integration of these three analytical components - stakeholder needs assessment, market research validation, and value flow visualization - provides a foundation for understanding the complex dynamics of EV adoption in India.

## 3.3 Choosing Figures of Merit (FOM) Based on Need Analysis

In systems engineering, selecting appropriate FOMs is crucial to evaluating a system's performance against identified customer needs. For BEVs, the chosen FOMs directly address key aspects of functionality, efficiency, and sustainability based on customer expectations, market demands, and technical feasibility.

The need analysis for BEVs highlights customer priorities such as driving range, performance, efficiency, charging convenience, cost-effectiveness, and environmental impact. The following FOMs have been selected to quantify these attributes:

1. Range ([km]) – Addresses the fundamental need for long-distance travel without frequent charging, a primary concern for customers seeking practical BEVs.
2. Acceleration Time ([s]) – Measures performance and responsiveness, which are critical for user experience, particularly in urban and highway driving conditions.
3. Motor Torque ([N.m]) – Reflects the power and drivability of the BEV, influencing aspects such as towing capacity and driving comfort.
4. Motor Efficiency ([%]) – Captures how effectively the vehicle converts stored electrical energy into usable mechanical power, impacting overall energy consumption and cost.
5. Kilometers per Kilowatt ([km/kW]) – Represents energy efficiency, helping customers assess how far the vehicle can travel per unit of energy consumed.
6. Vehicle Charge Rate ([km/min]) – Addresses charging speed concerns by quantifying how quickly the vehicle can regain driving range, a key factor in usability and convenience.
7. Power Storage Cost ([$/kWh]) – Represents the cost-effectiveness of the BEV's battery system, directly affecting vehicle affordability and long-term financial viability.
8. Carbon Dioxide Emissions ([g/km]) – Measures environmental impact, an important metric for customers prioritizing sustainability and regulatory compliance.

By aligning these FOMs with customer needs, engineers can ensure that BEV development prioritizes the most critical performance factors. This approach enables a balanced trade-off between efficiency, performance, cost, and sustainability, ultimately leading to a more competitive and customer-centric product. Some of these figures of merit, such as range and acceleration, are very similar to the figures of merit used to evaluate traditional automotive vehicles. Other figures of merit, such as power storage cost and charge rate, are critical to evaluating the battery pack technology employed within the battery electric vehicle as well as the battery electric vehicle platform itself. Finally, FOM's such as carbon dioxide emissions and kilometers per kilowatt are very specific FOM's to battery electric vehicle platform technologies in totality. Summary of FOM (key FOM's are highlighted in bold text) characteristics are in the table below.

| Figure of Merit (FOM) | Unit | Description |
|---|---|---|
| **Range** | [km] | The number of miles the vehicle can travel on a single full charge |
| **Acceleration time** | [s] | Time to accelerate to from 0 to 100 kmh (km per hour) for E4W and 0 to 60 kmh for E2W |
| **Motor Torque** | [N.m] | Torque produced by the electric vehicle motor |
| Motor Efficiency | [%] | Percentage of energy discharged from the battery pack that is converted to mechanical energy |
| Kilometers per kilowatt | [km / kw] | The average distance the vehicle travels based upon the amount of energy used |
| **Vehicle charge rate** | [km/min] | The rate at which vehicle range (in km) is added to the BEV platform during charging |
| **Power Storage Cost** | [$/kWh] | Total cost of power storage within a BEV platform (at the battery pack level) in dollars per kilowatt |
| Carbon Dioxide Emissions | [g/km] | The total amount of carbon dioxide emissions generated by the vehicle platform per mile driven |

Table 2 : List of key Figure of Merit (FOM)s identified. Important FOMs are in bold.

Below are some trends related to the figures of merit listed above. The charts show that the range of battery vehicles has been steadily increasing over the past decade, all while battery prices have rapidly declined. Both of these factors have contributed to increasing adoption of battery electric vehicle platforms, as the cost and performance of these systems continue to rise. Finally, charging trends are improving substantially, as new technology around superchargers enters the market (on both the BEV platform and charging station sides of the interface).

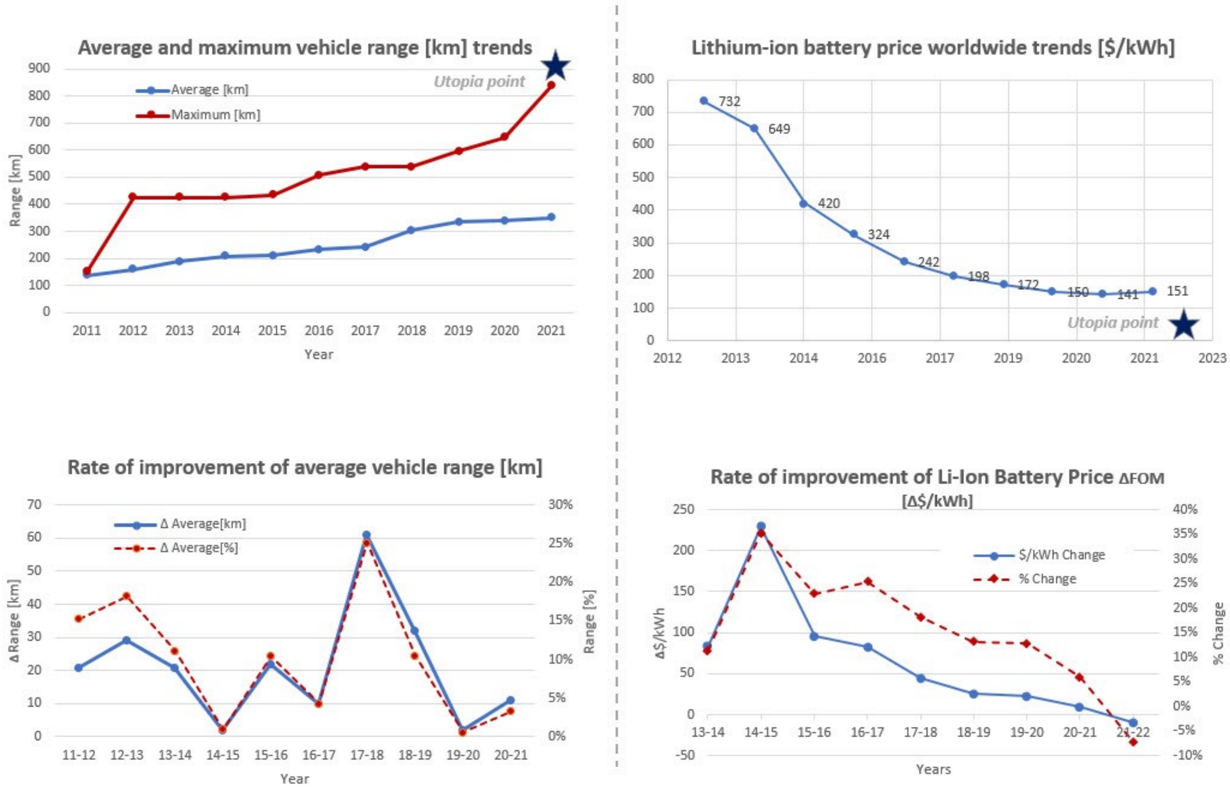



Figure 12 : Trend of FOM change with time (1)

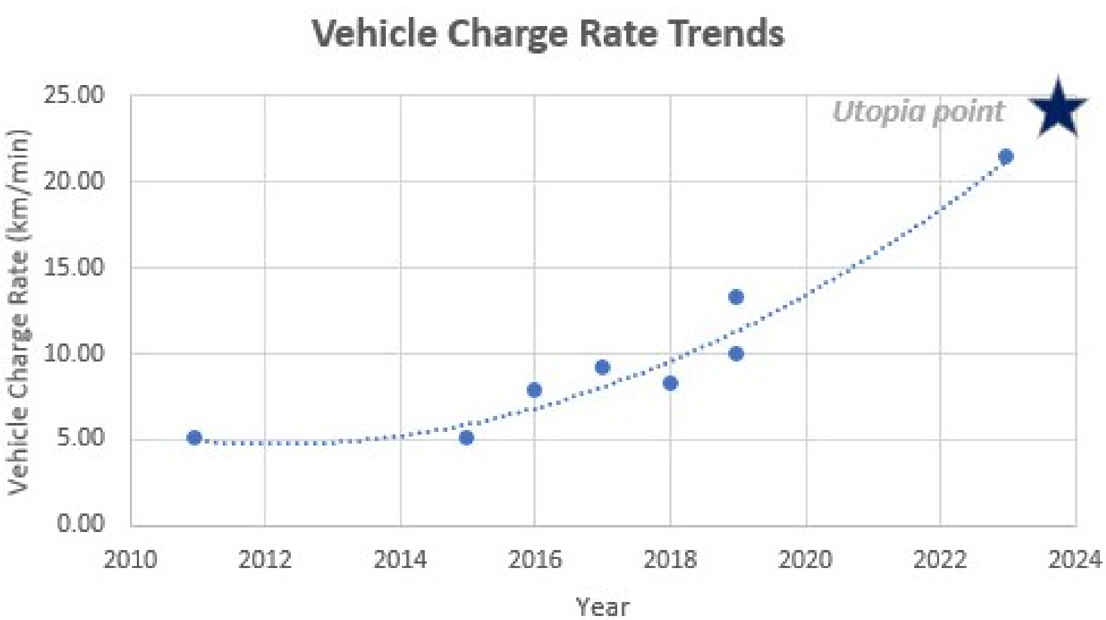



Figure 13 : Trend of FOM change with time

## 3.4 Technical Modelling of FOMs

Technical models have been developed for two of the most critical FOMs in electric vehicle design: range and torque. These FOMs were selected because of their fundamental importance to consumer acceptance and market penetration in India. The range model incorporates variables such as battery capacity, aerodynamic efficiency, and vehicle weight, while the torque model considers factors like motor specifications, gear ratios, and powertrain efficiency. Accompanying these models are comprehensive tornado charts that visualize the sensitivity of each FOM to its constituent parameters.

The primary purpose of these technical models and their associated tornado charts is to provide OEMs with a systematic framework for evaluating and prioritizing technical improvements. By quantifying how changes in specific parameters affect overall vehicle performance, OEMs can make data-driven decisions about where to focus their development efforts. For example, the range sensitivity analysis might reveal that improving battery energy density would yield greater benefits than reducing aerodynamic drag, while the torque analysis could show that motor efficiency improvements would be more impactful than gear ratio optimization.

This analytical approach is particularly valuable in the Indian context, where OEMs must carefully balance performance improvements against cost constraints to achieve broader market acceptance. The models and charts thus serve as strategic tools, helping manufacturers allocate their research and development resources more effectively to achieve meaningful improvements in vehicle performance while maintaining competitive price points.

**Below is the technical Model for Range:**

The governing equation for Range is shown in the equation below (37).

$$R[km]: Range = \frac{B\ [kWh]}{P_{wheel}\ [kW]/\eta_{overall}} \times v\ [m/s]$$

where

$$B[kWh]: Battery\ capacity$$

$$P_{wheel}[kW]: Power\ at\ wheels = \frac{F_{decel}[N] \times v\ [m/s]}{1000}$$

$$v = speed\ [m/s]$$

$$\eta_{overall}: Overall\ efficiency = \eta_{Electric\ system} \times \eta_{Drive\ train} \times\ \eta_{Motor}$$

and

$$F_{decel}[N]: Deceleation\ force$$
$$= Aerodynamic\ drag\ force\ at\ speed$$
$$+ Rolling\ resistance\ force\ at\ speed$$
$$\eta_{Electric\ system}: Electric\ system\ efficiency = 0.92$$
$$\eta_{Drive\ train}: Drive\ train\ efficiency = 0.81$$
$$\eta_{Motor}: Motor\ efficiency = 0.91$$

Moreover,

$$Fdrag[N]: Aerodynamic\ drag\ force = \frac{1}{2} \times \rho \times Cd \times A \times v^2$$
$$\rho[kg/m^2]: Air\ density = 1.21[kg/m^2]$$
$$A[m^2]: Car\ Frontal\ Area$$
$$Fr[N]: Rolling\ resistance\ force\ [N] = g[m/s^2] \times\ M[kg] \times RRC$$
$$g[m/s^2] = 9.81\ [m/s^2]$$
$$M[kg]: Vehicle\ mass$$

$RRC: Rolling\ resistance\ coeffient = 0.012$

The above equation was use to model the Chevy Bolt EV 2023's (38) range based off of publicly available data shown in the table below.

| Variable | Value | Units |
|---|---|---|
| Battery Capacity | 65 | kWh |
| Vehicle speed | 27 | m/s |
| Motor Efficieny | 0.91 | - |
| Electronics Efficency | 0.95 | - |
| Drive Train Efficiency | 0.81 | - |
| Air density | 1.225 | kg/m^3 |
| Car Body Area | 1.8 | m^2 |
| Drag Coefficient | 0.28 | - |
| Gravity | 9.81 | m/s^2 |
| Rolling resistance coeff | 0.012 | - |
| Vehicle Mass | 1600 | kg |

Table 3: Table for typical values of important technical factors for Chevy Bol EV

Based on the equations and variable parameters, the range is determined as follows for the conditions presented above:

$$R[km]: Range = 396.4\ [km]$$

Also, partial derivatives are as follows.

$$\frac{\partial R}{\partial B} = 6.1[km/kWh]$$

$$\frac{\partial R}{\partial M} = -0.1[km/kg]$$

$$\frac{\partial R}{\partial \eta_{Electric\ system}} = 417.2[km]$$

$$\frac{\partial R}{\partial \eta_{Drive\ train}} = 489.3[km]$$

$$\frac{\partial R}{\partial \eta_{Motor}} = 435.6[km]$$

Thus, normalized derivatives are calculated based on the parameters on the table and the partial derivatives and its tornado chart is shown as follows.

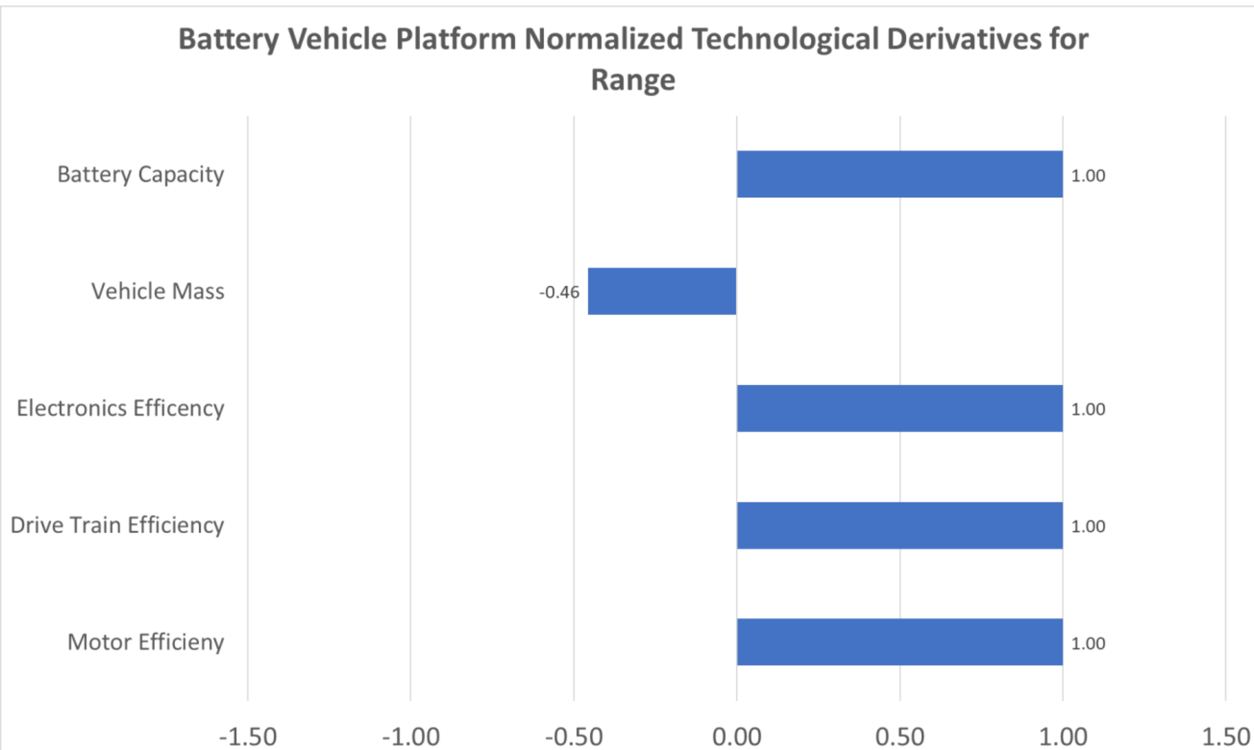



Figure 14 : Tornado chart for technical derivatives for vehicle Range for a typical BEV

**Below is the technical Model for Torque:**

The governing equation for vehicle torque is shown in the equation below [3][4].

$$T_v[N \cdot m]: Vehicle\ torque = (F_{accel} + F_{decel}) \times (1 + 1 - \eta_{Drive\ train}) \times r_{wheel}$$

$$F_{accel}[N]: Acceleration\ force = m[kg] \times a[m/s^2]/g[m/s^2]$$
$$r_{wheel}: Radius\ of\ drive\ wheel[m]$$

Also, the vehicle torque can be calculated using motor torque as follows.

$$T_v[N \cdot m] = T_m[N \cdot m] \times \eta_{overall}$$
$$T_m[N \cdot m]: Motor\ Torque$$

We also looked at the example using Chevrolet Bolt EV 2023[2] and obtained the below information.

$$r_{wheel}[m] = 0.215[m](17 inch\ wheel)$$
$$T_m[N \cdot m] = 360[N \cdot m]$$
$$a[m/s^2] = 3.6[m/s^2](7.5 seconds\ for\ 0[km/h]\ to\ 97.2[km/h])$$

Based on the equations and variable parameters, vehicle torque is determined as follows.

$$T_v[N \cdot m] = 256[N \cdot m]$$

Also, partial derivatives are as follows.

$$\frac{\partial T_v}{\partial M} = 0.1[N \cdot m/m]$$
$$\frac{\partial T_v}{\partial \eta_{Motor}} = 277[N \cdot m]$$
$$\frac{\partial T_v}{\partial T_m} = 0.7$$

Thus, normalized derivatives are calculated based on the parameters on the table and the partial derivatives and its tornado chart is shown as follows.

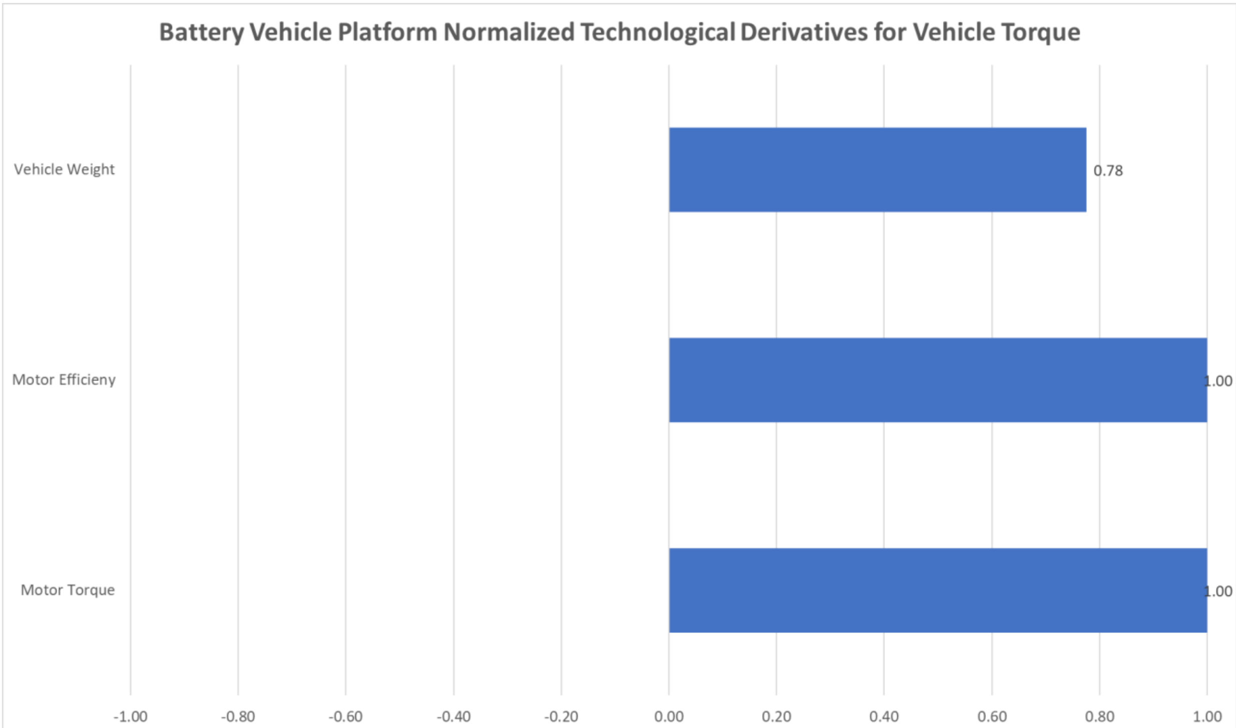


Figure 15 : Tornado chart for technical derivatives for vehicle torque for a typical BEV

The tornado charts for range and torque sensitivity analysis reveal critical insights for EV development in India. For range, the battery's specific energy emerges as the most influential factor, followed closely by aerodynamic drag coefficient and frontal area. This underscores the importance of battery technology advancements and aerodynamic design optimization in extending EV range, which is particularly crucial for E4W adoption. Interestingly, vehicle mass shows a relatively smaller impact, suggesting that lightweight materials may offer limited returns compared to battery and aerodynamic improvements. For torque, the motor's torque constant stands out as the primary driver, with gear ratio and motor current also showing significant influence. These findings highlight the critical role of motor design and power electronics in achieving the performance characteristics demanded by Indian consumers. Notably, the charts demonstrate that E2Ws and E4Ws face different optimization challenges, explaining their divergent market penetration rates. E2Ws, with their lower mass and simpler aerodynamics, can more easily achieve acceptable range and performance, aligning with their higher adoption rates. In contrast, E4Ws face more complex trade-offs, particularly in balancing range expectations with cost and performance, contributing to their slower market uptake. These technical insights provide a clear roadmap for OEMs to focus their R&D efforts and potentially accelerate EV adoption across both segments in the Indian market.

## 3.5 Customer profiles for E2W and E4W in India

The contemporary E2W user landscape in India represents a sophisticated intersection of technological advancement and practical utility, particularly within the urban mobility ecosystem. India's electric two-wheeler market segments into three distinct speed categories: entry-level vehicles reaching speeds up to 25 kmph, mid-range models operating under 40 kmph, and premium variants capable of 60 kmph (39). The market dynamics currently favor the entry and mid-range segments, as their attractive price positioning and superior total cost of ownership (TCO) benefits have captured the majority of consumer interest, in contrast to the higher-speed segment which occupies a smaller market share. The users, predominantly comprising delivery service professionals and mobility service providers operating across major metropolitan centers like Delhi, Mumbai, Bengaluru, and Chennai, demonstrate a nuanced appreciation for both cutting-edge technology and operational efficiency. Their daily usage patterns, averaging 61 kilometers across 17 trips between 10 AM and 7 PM, reflect intensive urban mobility requirements that modern E2Ws are increasingly equipped to handle (40).

The adoption of E2Ws is driven by a multi-faceted value proposition where technological superiority plays a pivotal role alongside economic benefits. While the average investment of INR 104,488 (40) represents a significant upfront cost, users are drawn to the sophisticated technology stack that distinctly differentiates E2Ws from their ICE counterparts. These technological advantages manifest in several forms: advanced digital dashboards providing real-time vehicle diagnostics, sophisticated battery management systems enabling optimal performance, smart connectivity features facilitating seamless integration with smartphones, and over-the-air updates ensuring continuous performance improvements. (41) The integration of regenerative braking technology and smart features like geo-fencing and remote monitoring further elevates the user experience beyond traditional two-wheeler capabilities.

Performance metrics reveal compelling satisfaction levels, with users reporting exceptional satisfaction in driving comfort (100%), noise and vibration control (88%), and design aesthetics (93%) (40). This high satisfaction extends to the technological ecosystem, where connected features enable users to optimize routes, monitor vehicle health, and manage their operations more efficiently through dedicated mobile applications. The strong brand advocacy (81%) and high repurchase intention (82%) underscore the successful marriage of technology and utility in modern E2Ws.

However, the technological journey isn't without its challenges. Users navigate a complex landscape of infrastructure limitations, including restricted public charging networks and extended charging durations. The preference for home charging (91%) (40)reflects both the current infrastructure reality and the need for more sophisticated public charging solutions. The moderate interest in battery swapping (44%) indicates an openness to innovative technological solutions for range and charging challenges. Performance concerns, particularly regarding range anxiety and speed limitations, suggest areas where technological advancement needs to align more closely with user expectations.

The Indian E4W landscape presents a unique technology-market paradox. While these vehicles incorporate globally competitive technology - including advanced powertrains, sophisticated battery management systems, and contemporary connected features comparable to traditional ICE vehicles - their market positioning remains constrained by economic factors. Most E4Ws launched in India are positioned in the mid-premium segment (exemplified by models like Nexon, Kona, and ZS), as current battery costs make it infeasible to offer high-performance electric cars in the crucial sub-INR 1 million category that traditionally drives mass-market adoption.

The technology development for these vehicles primarily occurs outside India, with global R&D centers leading innovations in battery technology, power electronics, and vehicle systems. However, the implementation of these technologies in India matches global standards, offering features and performance comparable to ICE counterparts. This technological parity, though, comes at a cost premium that affects the TCO dynamics differently across user segments.

For private users, with typical daily usage of 30 kilometers (39), the TCO mathematics remains challenging. This daily usage might be impacted by the concern or fear the users have regarding the range of the vehicle and hence drive E4W only for short distance. Premium models like ZS/Kona show approximately 10% higher TCO compared to equivalent ICE vehicles, while the more moderately priced Nexon comes closer to TCO parity with just 2% higher lifetime costs.

However, the commercial segment presents a more compelling case - vehicles covering an average of 120 kilometers daily achieve a 12% lower TCO compared to ICE alternatives. This advantage becomes even more pronounced in high-traffic urban environments, where EVs benefit from regenerative braking while ICE vehicles suffer from idle fuel consumption.

This disparity in range anxiety between E2W and E4W segments is particularly noteworthy in the Indian market context. According to 2023 EV Market Study (42) , E2W users typically purchase these vehicles as secondary transportation options, primarily for short-distance urban commuting, which aligns well with current battery capabilities and charging infrastructure.E2W usage patterns average 61 kilometers (16) daily, fitting comfortably within the typical range of 80-120 kilometers offered by most models. In contrast, E4W purchases represent significant investments intended to serve as primary family vehicles capable of handling both daily commutes and occasional long-distance travel. NITI Aayog's EV assessment report (43) shows that current E4W models in India offer ranges between 250-450 kilometers on a single charge, with real-world conditions reducing this by 20-30%. A joint study by CEEW and SIAM reveals that E4W users express the need for a more robust public charging network for intercity travel, compared to E2W users. This significant difference in charging infrastructure requirements and usage patterns explains why range anxiety remains a more substantial barrier to E4W adoption.

| Customer expectation | 2W | 4W |
|---|---|---|
| **Type of vehicle** | Secondary | Primary |
| **Type of use** | Daily use | Daily +occasional long range use |
| **Max range required (Km)** | 100 | 500 |
| **Performance requirement** | Low | High |
| **Vehicle charge rate** | As high as possible | As high as possible |
| **Initial cost (INR)** | 100,000 | 1,000,000 |
| **Charging infrastructure** | Home and public infrastructure | Home and public infrastructure |
| **Technology advancement** | High | Medium |

Table 4 : Summary of customer expectations

## 3.6 Key components in the EVs

The Object-Process Diagram (OPD) analysis, Figure 16, when integrated with the value chain assessment presented in the Niti Aayog report (43), provides a comprehensive framework for identifying critical components requiring localization in India's electric vehicle ecosystem. The OPD's systematic visualization of component relationships and interdependencies helps prioritize localization efforts by highlighting both technical criticality and current import dependencies.

In the battery pack segment, which represents 35-40% of the total EV cost, several critical components emerge as priorities for localization. Cathode Active Material (CAM) manufacturing faces an 8-10% unit cost disadvantage in India compared to global competitors, while components like copper foil and separators require significant capital investments ($150-250M and $300-500M respectively for 20-30GWh plants). The electrolyte component, facing a 2-3% unit cost disadvantage, and Anode Active Material (AAM) also emerge as critical areas requiring focused intervention. Additionally, electronic components like Battery Management Systems (BMS) and contactors are identified as essential for localization due to their role in battery performance and safety, as visualized in the OPD's control and monitoring pathways.

The electric drivetrain section of the OPD highlights another crucial area for localization - rare earth magnets for electric motors. Currently, India remains heavily dependent on imports for these essential components. The OPD's illustration of power flow from the battery through the drivetrain emphasizes how this dependency could become a critical bottleneck in the EV manufacturing ecosystem. Similarly, power electronics components, which the OPD shows as crucial interfaces between various subsystems, require domestic manufacturing capabilities to ensure supply chain resilience.

In the charging infrastructure domain, the OPD helps identify key components requiring localization by mapping the charging process and its integration with the vehicle system. These include rectifiers, controllers, and various types of connectors (CCS/CHAdeMO, Type 2), along with AC charger assembly units. The OPD's representation of the charging process demonstrates how these components interact with both the grid infrastructure and vehicle systems, underlining their importance in the overall EV ecosystem.

The OPD's value in localization planning stems from its ability to illustrate critical interdependencies, map performance parameters, identify systemic bottlenecks, and demonstrate system integration requirements. By showing how components interact within the complete EV system, it enables a more strategic approach to phased localization while maintaining system functionality. This systematic visualization has been instrumental in formulating India's localization strategy, helping policymakers and industry stakeholders prioritize investments and interventions in domestic manufacturing capabilities.

This integrated analysis of the OPD and value chain has directly informed policy recommendations for creating a robust domestic EV manufacturing ecosystem. It highlights the need for targeted interventions in high-priority components while considering both technical dependencies and economic feasibility, thereby providing a roadmap for achieving self-reliance in critical EV technologies.

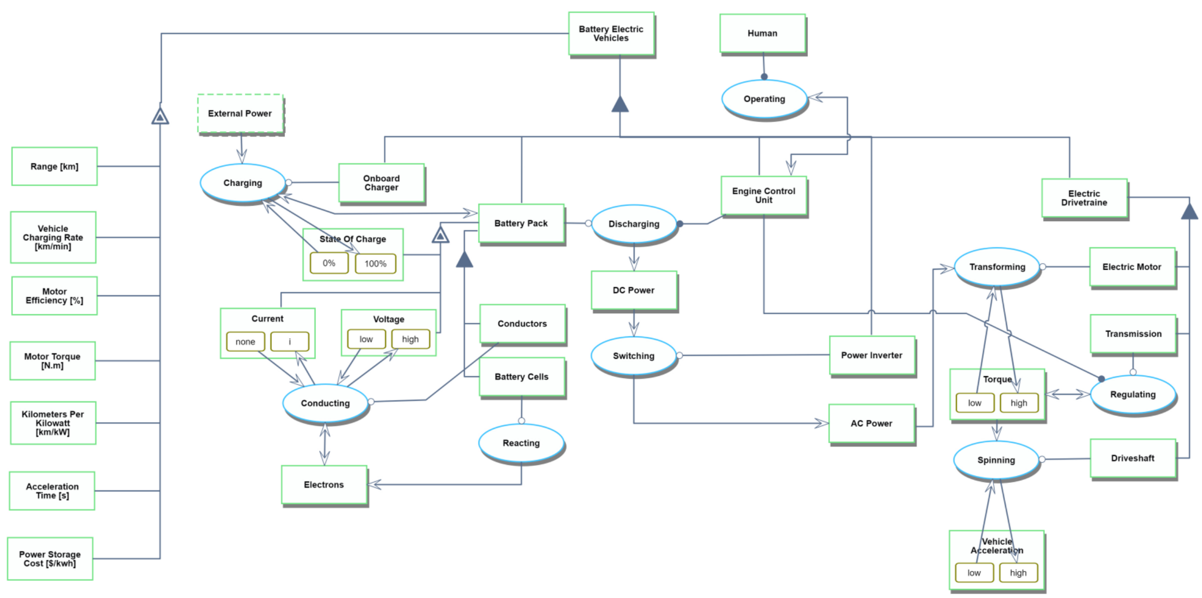



Figure 16 : OPD for 4W and 2W BEV

## 3.7 Positioning: Competition in market on FOM and other key factors

### Top selling E2W for popular OEMs in India:

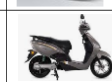
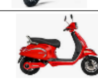
| OEM | Model | Geographical Presence | Model annual sale (2024) | Model Year | Price (USD) | Range (KM) | Battery size (Kwh) | Acceleration time (s) (0-40km/h) | Max torque (N.m) | Top Speed (Km/hr) | Key features | | | | | | | Image |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Motor type | Battery type | Battery Warranty | Fast charging | Removable battery | Mobile connectivity | Anti theft Alarm | |
| Ola | S1 Pro Gen 2 | Domestic | 425,600 | 2023 | 1,529 | 181 | 4 | 4.5 | 58 | 90 | Mid Drive IPM | Lithium-ion battery | 8 Years or 80,000 Km | Yes | Yes | Bluetooth/ Wifi | Yes |  |
| TVS | iQube | International | 234,111 | 2020 | 2,023 | 100 | 3.4 | 4.2 | 33 | 82 | BLDC | 3 Li-ion battery packs | 3 Years | Yes | No | Bluetooth/ Wifi | Yes |  |
| Ather | 450X Gen 3 | International | 133,169 | 2022 | 1,882 | 146 | 2.9 | 3.7 | 26 | 90 | PMSM | Lithium-ion battery | 5 Years or 60,000 Km | Yes | No | Bluetooth/ Wifi | Yes |  |
| Bajaj | Chetak 3501 | International | 81,460 | 2024 | 1,765 | 153 | 3.5 | 2.6 | 20 | 73 | PMSM | Lithium-ion battery | 3 Years or 50,000 Km | No | No | Bluetooth | No |  |
| Hero Electric | Optima HX | Domestic | 45,411 | 2020 | 1,235 | 135 | 2 | 7 | 60 | 55 | BLDC | Lithium-ion battery | 4 Years | No | No | Bluetooth | No |  |
| Ampere | Magnus Pro | International | 35,058 | 2020 | 1,059 | 121 | 2.3 | 10 | 95 | 50 | BLDC | Lithium-ion battery | 3 Years or 30,000 Km | No | No | Bluetooth | Yes |  |
| Pure Energy | Epluto 7G | Domestic | 12,800 | 2023 | 1,118 | 101 | 2.5 | 5 | 30 | 60 | BLDC hub motor | Lithium-ion battery | 14 Years or 80,000 Km | No | Yes | Bluetooth | No |  |
| Revolt | RV400 | Domestic | 9,951 | 2019 | 1,824 | 156 | 3.24 | 3.3 | 54 | 85 | Mid-drive motor | Lithium-ion battery | 15 Years or 80,000 Km | Yes | Yes | Bluetooth | Yes |  |
| Ultraviolette | F77 | International | 576 | 2022 | 5,353 | 211 | 7.1 | 2.7 | 90 | 96 | Permanent Magnet AC Motor | Lithium-ion battery | 16 Years or 80,000 Km | Yes | No | Bluetooth/ Wifi | Yes |  |

Table 5 : Summary of characteristics of top selling E2Ws in India

*Figure from official websites and Vahan dashboard (44) (45) (46) (47) (48) (49) (50) (51) (52) (53) (54)

**Ola Electric** (55)

Ola Electric emerged as a market leader in India's electric two-wheeler (E2W) segment, capturing 35% market share within three years of launch. The company started in 2017 when founder Bhavish Aggarwal pivoted from ride-hailing to electric mobility, becoming India's first EV unicorn in 2019 after receiving $250 million from SoftBank. After acquiring Dutch company Etergo in 2020, Ola established its "Future Factory" and launched its flagship S1 and S1 Pro scooters.

The company has built several competitive advantages, including in-house battery cell manufacturing at its Gigafactory, a direct-to-consumer sales model without traditional dealerships, and benefits from two major government PLI initiatives. However, it faces significant challenges including low-capacity utilization (49%) at its Future Factory, declining government subsidies, dependence on raw materials from China, and India's underdeveloped charging infrastructure. Despite these challenges, Ola Electric generated revenue of ₹5,009 crore in FY24, primarily through scooter sales, with the S1 segment contributing about 60% of sales.

Technologically, Ola Electric has made significant strides with its proprietary "Bharat 4680" battery cell technology, which claims to deliver 5x more energy than current 2170 batteries. The company's technological ecosystem includes their custom MoveOS operating system with OTA updates, advanced manufacturing capabilities using AI and robotics, and a comprehensive R&D program focusing on power electronics, motor design, and thermal management systems. Their charging infrastructure features Hypercharger network development and smart charging solutions, though the charging network remains a work in progress with 248 Hypercharger guns and 764 standard charger guns as of March 2024.

**Ather** (56) **:**

Ather Energy was founded in 2013 by IIT Madras students Tarun Mehta and Swapnil Jain with the vision to revolutionize electric vehicles in India. Initially exploring battery solutions, they pivoted to creating India's first smart electric scooter, inspired by Tesla's approach. The company received a significant boost when Hero MotoCorp invested ₹205 crores, providing both capital and industry connections. By 2024, Ather has established itself as a significant player in India's electric two-wheeler market with an 11.5% market share and annual revenue exceeding ₹1,700 crore.

The company has built several distinctive competitive advantages, particularly through its first-mover innovations in the Indian E2W space. Ather introduced many industry firsts, including the first touchscreen dashboard, Android integration, and 4G connectivity in scooters. Their most significant moat is the Ather Grid, India's largest E2W fast-charging network with 2,500+ chargers across 230+ cities, addressing one of the biggest concerns for EV adoption. The company has also built strong brand loyalty through word-of-mouth marketing, focusing on quality over flashy advertising campaigns.

Technologically, Ather has maintained its leadership through continuous innovation. Their proprietary AtherStack software offers over-the-air updates, ride statistics, and cloud integration. The company has invested heavily in R&D, accounting for 13% of total income, focusing on improving design, technology, and user experience. While facing challenges including low capacity utilization (29%) at their Hosur Factory and the impact of reduced FAME subsidies, Ather's premium positioning and technological excellence have helped maintain its strong market position, though this has sometimes limited its mass-market appeal.

**Hero Motocorp**

Hero MotoCorp is India's and the world's largest two-wheeler manufacturer. Hero MotoCorp's journey in the electric vehicle space began with a strategic shift following its separation from Honda in 2010. The company established significant technological foundations through its ₹760 crore Center of Innovation and Technology (CIT) in Jaipur and Hero Tech Center Germany GmbH, complemented by strategic partnerships with Zero Motorcycles, Ather Energy (39.7% stake (57)), and Gogoro. Its first major EV move came in October 2022 with the launch of the "VIDA" sub-brand, introducing the V1 series with Pro and Plus variants offering ranges up to 165km. The recent addition of the more affordable VIDA V2, priced under Rs 1 lakh, demonstrates Hero's commitment to making EVs accessible while maintaining premium features like removable batteries and connected technology through the VIDA app.

The company's dominance in the ICE market provides substantial advantages for its EV transition. With over 6,000 touchpoints across India, particularly strong in rural areas, and seven manufacturing facilities capable of producing 9 million units annually (58), Hero can leverage its extensive distribution network and manufacturing excellence for EV expansion. The company's leadership in the commuter segment, particularly with the Splendor brand, provides a strong foundation of customer trust and market understanding, supported by robust financial resources from its ICE business to sustain long-term EV investments (58).

Hero MotoCorp is now executing an ambitious EV transformation plan with multiple new models planned for the next 2-3 years. The flagship project, codenamed AEDA, aims to launch an electric variant of the popular Splendor by 2027, targeting 200,000 units annually. Current production of 7,000 EVs monthly is expected to reach 20,000 units by the festive season of 2025, including models like the Lynx dirtmotorcycle EV (2026) and two motorcycles under project ADZA targeting 150cc and 250cc equivalent segments (59).

The company's partnership with Zero Motorcycles will expand its premium EV offerings, with plans for 500-600cc equivalent models in 2026-27. By 2027-28, Hero MotoCorp aims to achieve cumulative annual EV sales exceeding 500,000 units, split equally between motorcycles and scooters (58). This comprehensive strategy, combined with its established ICE market strengths and technological capabilities, positions Hero MotoCorp to maintain its leadership as India's two-wheeler market transitions to electric mobility.

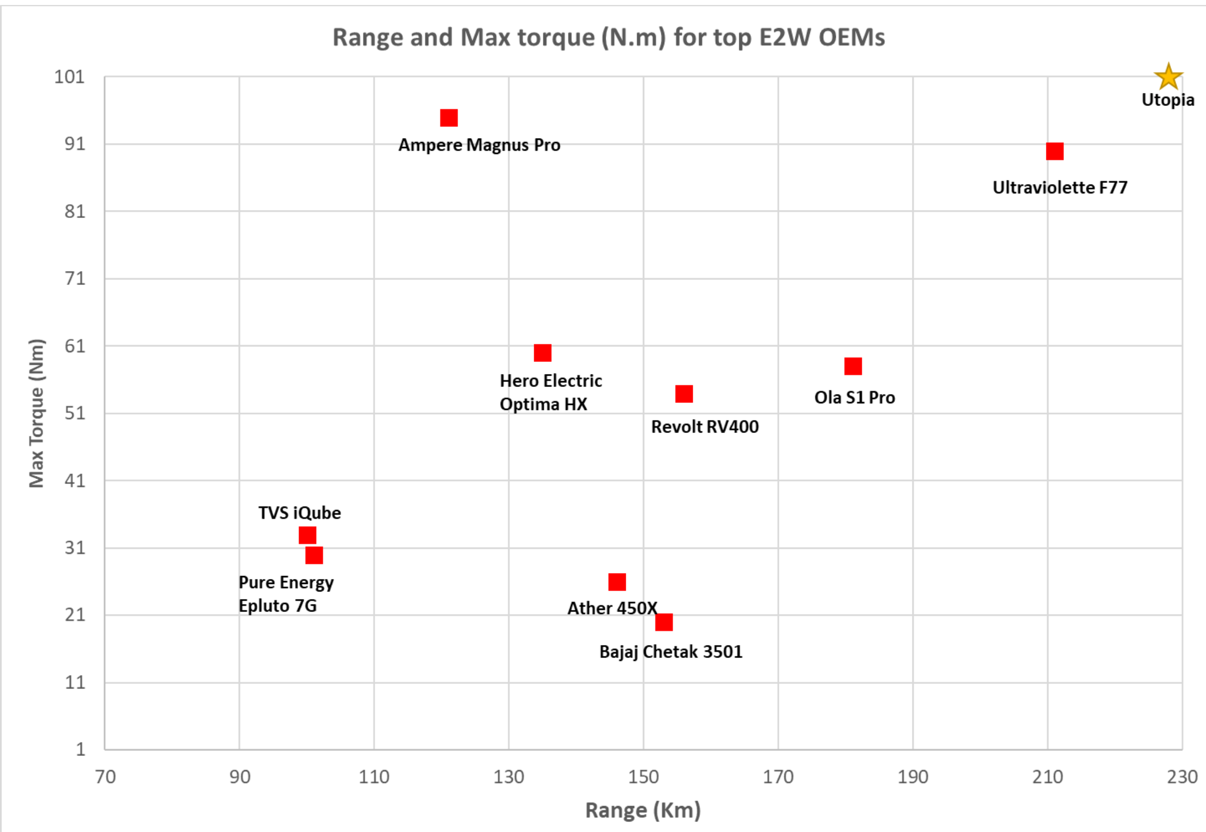



Figure 17 : Max Torque (Motor) vs Range specification of the top models for E2W OEMs in India

The range versus max torque graph analysis (Figure 17) reveals interesting positioning for each manufacturer. The graph shows a general trend where higher range doesn't necessarily correlate with higher torque. For instance, while the Ultraviolette F77 leads in both metrics (211 km range, 90 N.m torque), models like the Ather 450X achieve market success with moderate specifications (146 km range, 26 N.m torque), suggesting that balanced performance characteristics rather than maximum specifications may be more important for market success.

## Top selling E4W for popular OEMs in India:

The competitive landscape of E4W vehicle market can be best understood through the analysis of key performance parameters. These metrics significantly influence customer purchase decisions across different market segments and reveal manufacturers' positioning strategies.

| OEM | Model | Geographical Presence | OEM annual sale (2024) | Model Year | Price (USD) | Range (KM) | Battery size (Kwh) | Acceleration time (s) (0-100km/h) | Max torque (N.m) | Top Speed (Km/hr) | Key features | | | | Image |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Motor type | Battery type | Battery Warranty | Fast charging | |
| Tata | Nexon EV Creative 45 | Domestic | 67,751 | 2020 | 1,399,000 | 489 | 46.08 | 8.9 | 215 | 150 | PMSM | Li-ion | 7 Years/ 160,000 | Yes |  |
| SAIC | MG ZS EV 100 YR edition | International | 21,966 | 2020 | 2,534,800 | 461 | 50.3 | 8.5 | 280 | 175 | PMSM | Li-ion | 9 Years/ 150,000 | Yes |  |
| Mahindra | XUV400 EV EL Pro DT | Domestic | 8,669 | 2023 | 1,769,000 | 456 | 39.4 | 8.3 | 310 | 150 | PMSM | Li-ion | 8 Years/ 160,000 | Yes |  |
| BYD | Atto 3 Superior | International | 2,842 | 2022 | 3,399,000 | 521 | 60.42 | 7.3 | 301 | 160 | PMSM | Li-ion | 8 Years/ 160,000 | Yes |  |
| BMW | iX1 | International | 1,211 | 2023 | 4,900,000 | 531 | 64.8 | 5.6 | 250 | 180 | PMSM | Li-ion | 8 Years/ 160,000 | Yes |  |
| Mercedes | EQA 250+ | International | 940 | 2024 | 6,720,000 | 560 | 71 | 8.6 | 385 | 160 | PMSM | Li-ion | 8 Years/ 160,000 | Yes |  |
| Hyundai | Kona | International | 913 | 2019 | 2,403,000 | 452 | 39.2 | 9.7 | 395 | 167 | PMSM | Li-ion | 8 Years/ 160,000 | Yes |  |

Table 6 :Summary of characteristics of top selling E4Ws in India
*Figure from official websites and Vahan dashboard (60) (61) (62) (63) (64) (65) (66) (44)

## Tata Motors: Pioneering Electric Mobility in India

Tata Motors stands as the undisputed leader in India's electric vehicle market, commanding a dominant 65% market share with 67,751 unit sales in 2024. Through its dedicated subsidiary, TPEML, the company has established a comprehensive ecosystem spanning manufacturing, distribution, and charging infrastructure. The company's manufacturing excellence is demonstrated through its multiple facilities, including the Sanand plant with 10,000 EV annual capacity and a new Li-ion cell factory backed by ₹131.85 million investment (67). Tata's product strategy covers multiple segments with four key models: Nexon EV (₹14.49-19.49L), Punch EV (₹10.99-15.49L), Tiago EV (₹7.99-11.89L), and Tigor EV (₹12.49-13.75L) (67). The company's strategic partnership with Shell India leverages extensive fuel station networks to support over 1.4 lakh Tata EVs on Indian roads (67). Looking ahead, Tata plans to introduce four new EV brands in 2024 and aims to transition 50% of its workforce to EV manufacturing by 2027 (67).

**MG Motor: Technological Innovation with International Expertise**

SAIC's MG Motor has established itself as a strong second player with 21% market share and 21,966 unit sales in 2024. Operating from its Halol, Gujarat facility, MG has adopted a dual-segment strategy with the Comet EV (₹6.99-9.24L) targeting urban mobility and the ZS EV (₹18.98-25.20L) competing in the premium segment (67). The company's recent joint venture with JSW Group, involving a ₹5,000 crore investment, aims to expand annual production capacity to 300,000 units. MG's technological prowess is evident in its models' specifications, with the ZS EV offering 461km range and 353 N.m torque. The company's partnership with Jio-BP for charging infrastructure demonstrates its commitment to building a comprehensive EV ecosystem (67). MG's future plans include introducing models like the Cyberster and targeting one million EV sales by 2030.

**Mahindra & Mahindra: Leveraging SUV Heritage in Electric Mobility**

Mahindra & Mahindra has carved out a significant position with 8% market share and 8,669 unit sales in 2024. The company's EV strategy builds on its strong SUV heritage, currently led by the XUV400 (₹15.49-19.39L). Mahindra's commitment to EV development is evidenced by its ₹500 crore additional investment in Tamil Nadu for EV infrastructure and a comprehensive R&D program at Mahindra Research Valley (67). The company's technical capabilities are demonstrated through the XUV400's specifications of 456km range and 310 N.m torque. Mahindra's partnership with ATEL for charging infrastructure and plans to launch five new electric SUVs under the INGLO platform showcase its long-term commitment to the sector. The company has also established a new facility in Zaheerabad, Telangana, with a ₹10 billion investment for electric vehicle production (67).

### Hyundai Motor: Premium Technology Focus

Hyundai has made significant strides in the Indian EV market through its premium offerings. Hyundai sold only 913 (1% market share) in 2024. The sale of Hyundai Kona is low because Hyundai discontinued in India in 2024. Hyundai plans to launch 4 new mass market EVs in India by 2028 (68). Hyundai is the 2nd biggest automaker in India if we include ICE vehicles (69). The company plans a ₹200 billion investment over the next decade to expand its EV ecosystem in Tamil Nadu, including a battery pack assembly unit with 178,000 units annual capacity (67). The IONIQ 5, with its impressive 631km range and 350 N.m torque, positions Hyundai in the premium technology segment. The acquisition of GM's Talegaon factory, adding 130,000 units annual capacity, and plans to launch five EV models by 2032 demonstrate Hyundai's long-term commitment to the Indian market.

### Mercedes-Benz and BMW: Defining Luxury EV Standards

In the luxury segment, Mercedes-Benz leads with the EQS, offering benchmark specifications of 857km range and 855 N.m torque. BMW complements the luxury segment with the i4, providing 590km range and 430 N.m torque, targeting performance-oriented luxury buyers. These manufacturers have established the premium benchmark for the Indian EV market, though their sales volumes remain relatively modest compared to mass-market players.

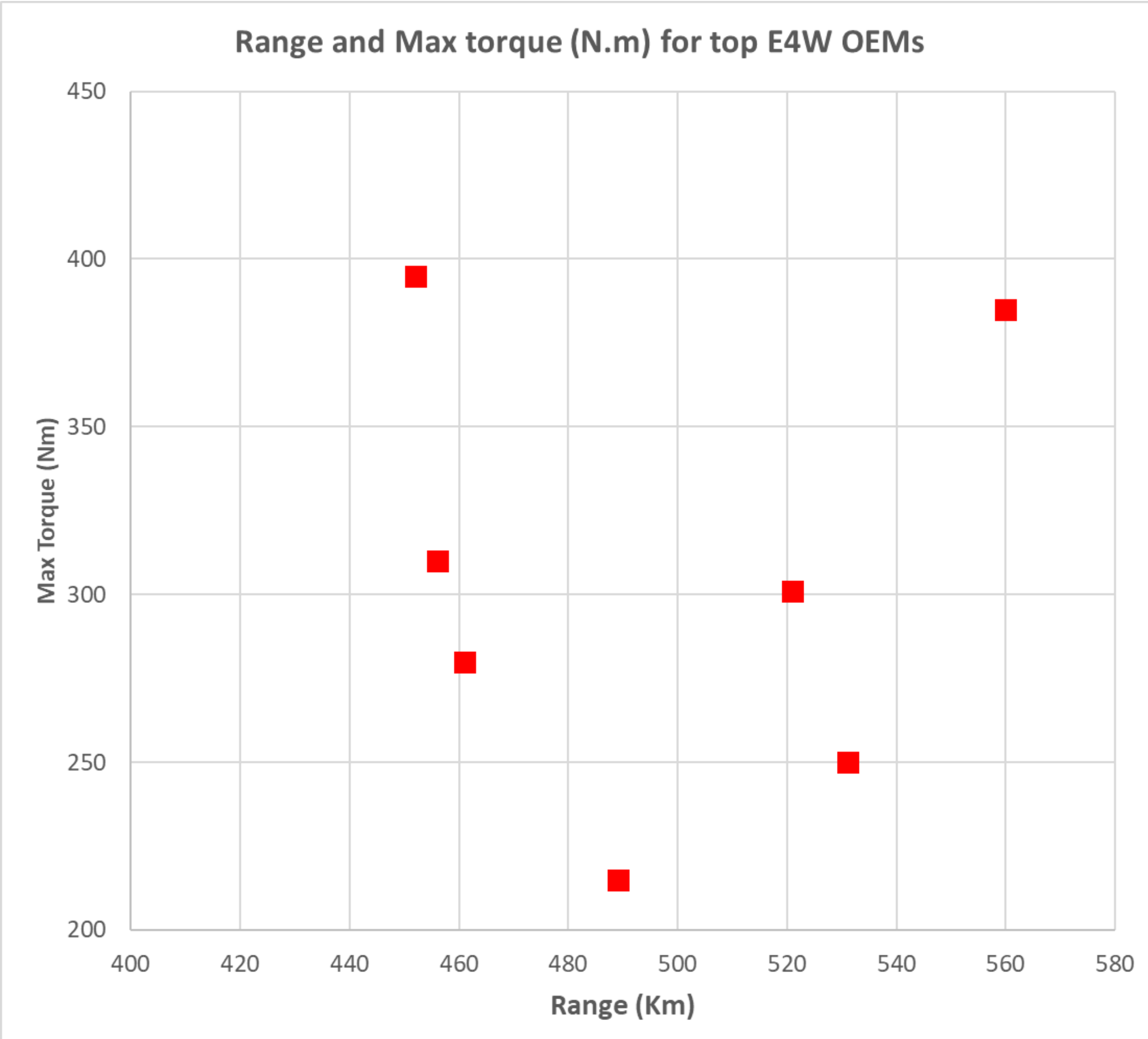



Figure 18: Max Torque (Motor) vs Range specification of the top models for E4W OEMs in India

The range versus max torque graph (Figure 18) for E4W vehicles in India reveals a diverse positioning of different manufacturers, with no clear correlation between range and torque. Unlike the E2W market, where balanced performance seemed key, the E4W market shows a wider spread of specifications. For instance, the Mercedes EQA 250+ leads in range (560 km) with a high torque (385 N.m), while the Mahindra XUV400 EV offers the highest torque (310 N.m) with a moderate range (456 km). Interestingly, the market leader Tata Nexon EV positions itself in the middle with balanced specifications (489 km range, 215 N.m torque). This suggests that in the E4W market, factors beyond just range and torque, such as brand reputation, pricing, and overall vehicle features, play crucial roles in determining market success.

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# Chapter 4: Result

This section presents the results for the analysis. The findings are organized into three main components: First, a detailed Force-Field Analysis examines the driving and restraining forces affecting EV adoption across different time horizons. Second, a Stakeholder Value Map comparison illustrates the evolving relationships and value propositions between current and future scenarios. Finally, the analysis culminates in targeted recommendations for both E2W and E4W segments. The results draw from extensive market data, industry reports, and stakeholder insights to provide a nuanced understanding of India's EV transition dynamics and their implications for future growth.

## 4.1 Force-field analysis

The transformation of India's automotive sector towards electrification presents a complex interplay of technological, economic, and social factors that significantly influence adoption rates across different vehicle segments. As India positions itself to achieve its ambitious goal of 30% electric vehicle penetration by 2030 (70), understanding the dynamics of market adoption becomes crucial for both policymakers and industry stakeholders. To systematically analyze these dynamics, a Force Field Analysis framework has been employed to evaluate the driving and restraining forces affecting E2W and E4W adoption in the Indian market. This analytical approach, originally developed by Kurt Lewin in 1940s (71), provides a structured method to understand the forces that either support or hinder change in a given system.

In the context of India's EV transition, this analysis is particularly relevant as it helps identify the critical factors that create momentum towards electrification while also highlighting the barriers that must be addressed for successful market penetration. The distinction between E2W and E4W segments is especially noteworthy, as these categories exhibit markedly different adoption patterns and face unique challenges in the Indian context. While E2Ws have shown promising growth with increasing market penetration and consumer acceptance, E4Ws continue to face significant barriers despite technological advancements and policy support. The following analysis draws from comprehensive market data, consumer behavior patterns, technological capabilities, and infrastructure considerations presented in Chapter2 and Chapter 3 to present a detailed examination of the current state of EV adoption in India's automotive landscape.

The analysis incorporates a temporal dimension by categorizing the impact of each driving and restraining force across three distinct time horizons: short-term (0-5 years), medium-term (5-10 years), and long-term (10-15 years). This temporal stratification enables a more nuanced understanding of how different forces evolve and interact over time, helping stakeholders anticipate and prepare for future challenges and opportunities. The classification of impacts as low, medium, or high across these time periods provides valuable insights into the changing dynamics of EV adoption and helps identify which factors require immediate attention versus long-term strategic planning.

By understanding these forces and their relative strengths, stakeholders can better strategize interventions and policies to accelerate the transition to electric mobility while addressing sector-specific challenges.

**E2W Force Field analysis:**

**Growth drivers**

| Drivers | 1-10 years | 10-20 years | 20-30 years |
|---|---|---|---|
| Indian automotive market:<br>• Overall automotive market growing by 9.7% (72) from 2023 to 2030<br>• Increase in purchasing power of people in India. India's gross domestic product (GDP) per capita rose by 40% (73) from 2024 to 2022.<br>• India's desire to reduce dependence on fossil fuels | Medium | Medium | Medium |
| Strong Economic Benefits:<br>• Options of model available in affordable range (~100000INR)<br>• Lower operational costs<br>• Attractive TCO for commercial users<br>• Reducing battery costs over time | High | Medium | Low |
| Technology Advantages: | High | High | High |

| | | | |
|---|---|---|---|
| • Companies like Ola Electric and Ather Energy offer advanced features such as touchscreen dashboards, connected apps, and over-the-air updates.<br>• Regenerative braking improves energy efficiency in stop-and-go traffic.<br>• High user satisfaction | | | |
| EV Market & Infrastructure:<br>• Strong market leaders (Ola 35%, Ather 11.5%)<br>• 91% home charging capability<br>• Growing charging network<br>• Direct-to-consumer sales models | High | Medium | Medium |
| Government Support:<br>• PLI initiatives<br>• FAME subsidies<br>• Environmental regulations | High | Medium | Medium |
| Increasing investments :<br>• Various investors are showing interest in e2W start-ups in India, resulting in equity investments in start-ups such as Ather Energy and River | High | High | High |
| Urban Suitability:<br>• E2Ws are ideal for short-distance urban commutes, with an average daily usage of 61 km. Hence, less range anxiety.<br>• E2W compact size makes them practical for navigating congested city roads. | High | High | High |
| Charging Convenience:<br>• 91% of E2W (40) users prefer home charging, reducing dependency on public infrastructure. | Low | Low | Low |

| | | | |
|---|---|---|---|
| • Battery swapping options (44% user interest) provide an alternative to slow charging. | | | |

Table 7: Growth drivers for E2Ws in India

**Growth Restraints**

| Restraints | 1-10 years | 10-20 years | 20-30 years |
|---|---|---|---|
| Infrastructure Limitations:<br>• Charging infrastructure remains a significant hurdle for e2W adoption, especially in Tier III and Tier IV cities.<br>• Home charging is not feasible for users without dedicated parking spaces.<br>• Restricted public charging networks<br>• Extended charging durations<br>• Limited battery swapping adoption (44%) | High | Medium | Medium |
| Cost Factors:<br>• Upfront cost (INR 104,488 average). E2Ws are more expensive than comparable ICE two-wheelers.<br>• Reducing government subsidies<br>• Battery replacement costs remain a concern for long-term ownership | Low | Low | Low |
| Technical Limitations:<br>• Range anxiety - Most E2Ws offer a range of 80-120 km, which may be insufficient for some users.<br>• Speed limitations<br>• Battery performance concerns – Ola recently faced battery accident (74) | Medium | Medium | Medium |
| Inadequate Local Battery Manufacturers:<br>• Insufficient local manufacturing leads India to import lithium cell batteries | High | Medium | Low |

| | | | |
|---|---|---|---|
| from China or Taiwan and the batteries are assembled locally, increasing costs. | | | |
| Absence of Rural Awareness and Lack of Road Infrastructure:<br>• With approximately 66% of the population in India's rural areas, significant ignorance about e2W vehicles and their availability exists. Furthermore, the lack of or inadequacy of road infrastructure has lessened the possibility of e2W penetration in rural India. | Medium | High | High |
| Dependence on imports<br>• Critical components like batteries and power electronics are often imported, increasing costs and supply chain risks. | High | High | High |
| Safety<br>• There were recent incidents of E2W catching fire. | High | Low | Low |

Table 8 : Growth restraints for E2Ws in India

**Additional Insights**

- User Profile: E2W users are primarily urban commuters, delivery professionals, and mobility service providers.
- Technological Satisfaction: Users report high satisfaction with driving comfort (100%), noise control (88%), and design aesthetics (93%).
- Market Trends: Entry-level and mid-range E2Ws dominate the market due to affordability and practicality.

**E4W (Electric Four-Wheelers):**

**Growth drivers**

| Drivers | 1-10 years | 10-20 years | 20-30 years |
|---|---|---|---|
| Indian automotive market:<br>• Overall automotive market growing by 9.7% (72) from 2023 to 2030<br>• Increase in purchasing power of people in India. India's gross domestic product(GDP) per capita rose by 40% | Medium | Medium | Medium |

| | | | |
|---|---|---|---|
| (73) from 2024 to 2022.<br>• India's desire to reduce dependence on fossil fuels | | | |
| Economic Benefits:<br>• High upfront cost<br>• Lower operational costs<br>• Reducing battery costs over time | High | High | Medium |
| Technology Advantages:<br>• Advanced powertrains<br>• Sophisticated battery management<br>• Connected features comparable to ICE<br>• Regenerative braking improves energy efficiency in stop-and-go traffic. | High | High | High |
| EV Market & Infrastructure:<br>• Tata Motors leads the E4W market with models like the Nexon EV and Tiago EV.<br>• Global players like Hyundai and MG Motor are introducing affordable and feature-rich E4Ws. | High | High | Medium |
| Government Support:<br>• FAME II and PLI subsidies and state-level incentives reduce the upfront cost of E4Ws.<br>• Reduced GST rates (5%) make E4Ws more affordable compared to ICE vehicles (28%). | High | High | High |
| Increasing foreign investments:<br>• Alterations in import duty concessions will favor OEMs such as Tesla, and its entry will provide significant impetus to the overall EV market. | High | Medium | Low |

Table 9: Growth drivers for E4Ws in India

**Growth Restraints**

| Restraints | 1-10 years | 10-20 years | 20-30 years |
|---|---|---|---|
| High Upfront Costs<br>• E4Ws are significantly more expensive than ICE vehicles, with prices starting around INR 1,000,000.<br>• Battery costs contribute to the high initial price, despite declining trends. | High | High | Medium |
| Range Anxiety:<br>• Most E4Ws offer a range of 250-450 km, which is insufficient for long-distance travel.<br>• Real-world conditions reduce the range by 20-30%, exacerbating range anxiety. | High | High | Medium |
| Limited Charging Infrastructure:<br>• Public charging infrastructure is underdeveloped, especially for long-distance travel.<br>• Home charging is not feasible for users without dedicated parking spaces.<br>• Inadequate intercity charging network | High | High | High |
| Longer Charging Times:<br>• Despite improvements, charging times for E4Ws are longer than refueling times for ICE vehicles.<br>• Fast-charging options are limited and expensive. | High | Medium | Low |
| Consumer Perception:<br>• Lack of awareness about EV benefits and government incentives.<br>• Skepticism about E4W performance, reliability, and resale value. | Medium | Medium | Medium |
| Dependence on Imports:<br>• Critical components like batteries, power electronics, and rare earth magnets are often imported, increasing costs and supply chain | High | High | High |

| | | | |
|---|---|---|---|
| risks. | | | |
| Competition from ICE Vehicles:<br>• ICE vehicles dominate the market, with well-established supply chains, service networks, and consumer trust.<br>• Price sensitivity makes ICE vehicles more attractive in the short term.<br>• Premium segment positioning<br>• Limited local R&D<br>• Dependence on global technology | High | Medium | Low |
| .Policy Challenges:<br>• Reductions in FAME subsidies have increased E4W prices.<br>• Delays in charging infrastructure development hinder adoption. | High | High | Medium |

Table 10 : Growth restraints for E4Ws in India

## Additional Insights

- **User Profile:** E4W users are primarily urban families and commercial fleet operators.
- **Technological Parity**: E4Ws offer features and performance comparable to ICE vehicles but at a higher cost.
- **Market Trends**: The commercial segment shows higher adoption rates due to lower TCO and operational costs.

### Summary of Force Field Analysis

Relative Strength Analysis:

**E2W:**

- Driving forces currently outweigh restraining forces.
- Strong market momentum if safety concerns are resolved.
- Clear path to mass adoption.

**E4W:**

- Restraining forces currently stronger.
- Significant barriers to mass adoption.
- Limited to premium/commercial segments

| Aspect | E2Ws | E4Ws |
|---|---|---|
| **Driving Forces** | Affordability, urban suitability, government incentives, technological advancements, environmental benefits, market leadership, charging convenience | Government support, environmental benefits, technological advancements, economic benefits, corporate initiatives, commercial adoption |
| **Restraining Forces** | Range limitations, charging infrastructure, high upfront costs, consumer perception, policy challenges, dependence on imports, Safety | High upfront costs, range anxiety, limited charging infrastructure, longer charging times, consumer perception, dependence on imports, policy challenges, competition from ICE vehicles |
| **Key Challenges** | Range anxiety, charging infrastructure, consumer awareness | High costs, range anxiety, charging infrastructure, consumer awareness |
| **Opportunities** | Battery swapping, home charging, urban commuter market | Commercial segment, fast-charging solutions, localization of manufacturing |

Table 11: Summary of force field analysis for E2W and E4W

## 4.2 Stakeholder Value Map – Now vs Future

The Stakeholder Value Map analysis provides a comparative visualization of current versus desired future states for electric vehicle buyers in India, mapped against two critical dimensions: the current performance in delivering value and its relative importance to business success (measured in sales). This analysis has been conducted separately for E2W and E4W segments, revealing distinct patterns and priorities for each category.

**E2W Buyer Value Map Analysis:**

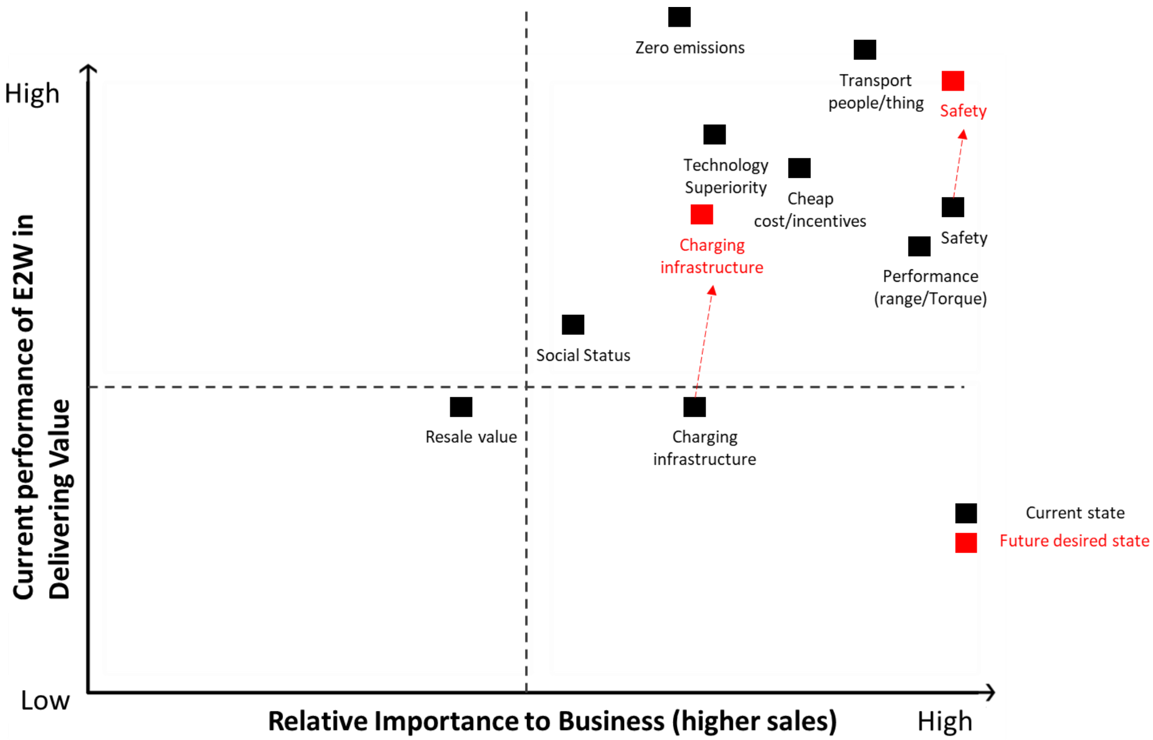


Figure 19 : Current vs desired future value map for higher penetration of E2W in India

For E2W buyers, the current state analysis reveals several interesting patterns. While certain aspects like zero emissions, basic transport functionality, and safety features are well-addressed in the current market, significant gaps exist in other crucial areas. Charging infrastructure, resale value, and cost incentives emerge as key areas requiring improvement. The future desired state indicates that while maintaining the current strengths, the market needs to evolve particularly in areas of enhanced performance metrics including range and torque capabilities, more robust charging infrastructure, better cost advantages through incentives, and improved social status value proposition. These shifts suggest a maturing market where buyers are moving beyond basic functionality to expect a more comprehensive value proposition.

**E4W Buyer Value Map Analysis:**

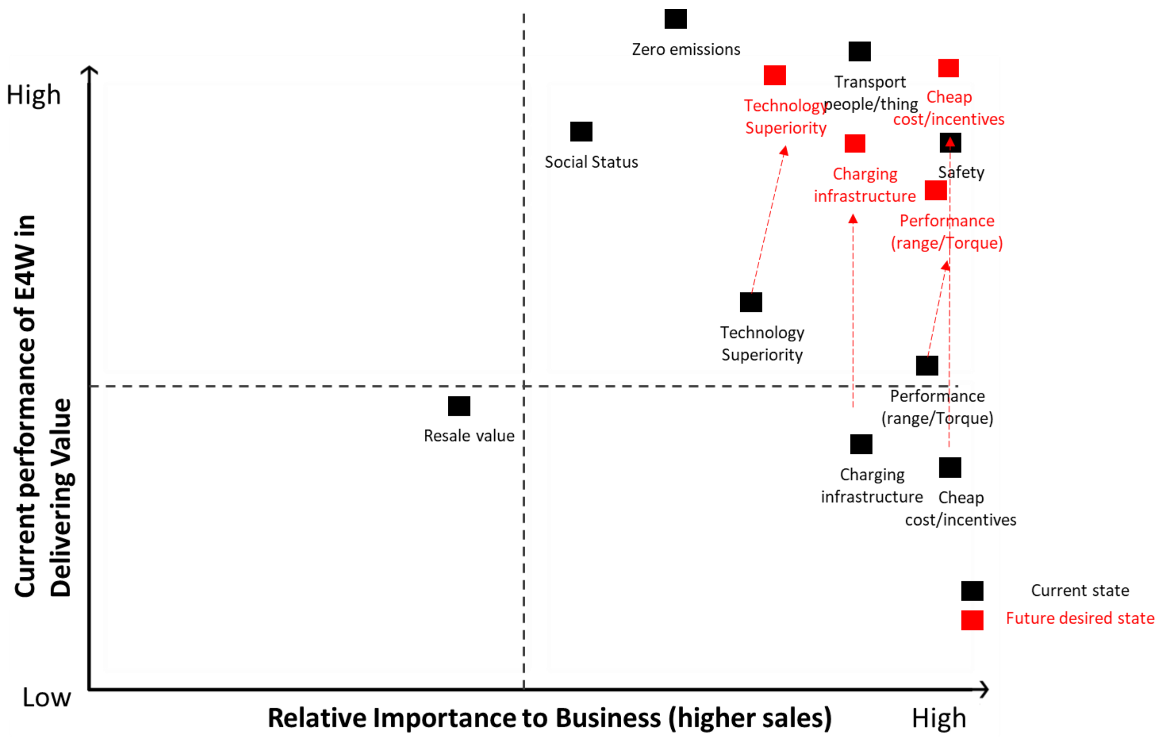


Figure 20 : Current vs desired future value map for penetration of E4W in India

The E4W segment presents a distinctly different value proposition pattern. In the current state, technology superiority and zero-emission capabilities are relatively well-delivered, but substantial improvements are needed in charging infrastructure accessibility, cost incentives and overall affordability, and performance parameters. The future desired state for E4W buyers emphasizes the need for better alignment between charging infrastructure availability, cost accessibility, and enhanced performance capabilities, while maintaining premium aspects such as technology superiority and social status.

This comparative mapping serves multiple strategic purposes. First, it clearly identifies areas where buyer expectations are not being met in the current market. Second, it highlights specific improvements needed to achieve optimal customer satisfaction in the future. Finally, it provides manufacturers and policymakers with a clear roadmap for prioritizing investments and interventions that will bridge the gap between current market offerings and future customer expectations, ultimately driving higher EV adoption rates in both segments.

The analysis particularly emphasizes how the evolution of buyer needs differs between E2W and E4W segments, suggesting the need for segment-specific strategies in product development, marketing, and policy support to accelerate EV adoption in India. The distinct patterns observed in both segments underscore the importance of tailored approaches to address segment-specific challenges and opportunities in the Indian EV market.

## 4.3 Recommendations for E2Ws and E4Ws

Based on the force-field analysis and stakeholder value mapping conducted in the previous sections, several strategic investment opportunities emerge that could accelerate the adoption of both E2Ws and E4Ws in the Indian market. These recommendations are tailored to address the key barriers identified while leveraging existing market drivers and stakeholder interests. The proposed interventions are categorized separately for E2Ws and E4Ws, recognizing their distinct market dynamics, consumer preferences, and infrastructure requirements. These recommendations focus on four critical areas for each segment: infrastructure development, cost reduction, market development, and policy support. While some recommendations overlap across both segments, their implementation approaches differ based on segment-specific challenges and opportunities.

**E2Ws:**

1. **Expand Charging Infrastructure**: Develop public charging stations and promote battery swapping.
2. **Increase Subsidies**: Extend subsidies like FAME to make E2Ws more affordable.
3. **Consumer Awareness**: Educate consumers about the benefits of E2Ws and available incentives.
4. **Localize Manufacturing**: Reduce dependence on imports, invest in domestic battery and component production to reduce costs.

**E4Ws:**

1. **Enhance Charging Infrastructure**: Focus on fast-charging solutions for long-distance travel.
2. **Reduce Costs**: Reduce dependence on imports, localize battery and component manufacturing to lower prices.
3. **Target Commercial Segment**: Promote E4Ws for fleet operators and ride-hailing services.
4. **Policy Support**: Streamline regulations and provide incentives for E4W adoption.

By addressing the restraining forces and leveraging the driving forces, India can accelerate the adoption of both E2Ws and E4Ws, contributing to reduced air pollution, enhanced energy security, and global climate goals.

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# Chapter 5: Future work

## 5.1 Technical models

Building on the technical modeling and tornado chart analysis presented in this thesis, several promising directions for future research emerge. A critical next step would be to develop complementary cost sensitivity analyses that integrate economic parameters alongside technical variables, providing a more complete picture of price-performance trade-offs in the Indian market. The current analysis of range and torque FOMs could be expanded to include other crucial performance metrics such as charging time, energy efficiency, and acceleration performance, offering a more comprehensive understanding of EV adoption barriers. Furthermore, developing separate technical models for E2Ws and E4Ws would better account for their distinct requirements and market expectations, enabling more targeted optimization strategies. The static nature of current models could be enhanced through dynamic analysis that considers how technical sensitivities evolve over time as technology advances and costs decrease, helping predict future optimization opportunities. Finally, incorporating charging infrastructure parameters into the technical models would provide valuable insights into the relationship between infrastructure development and vehicle performance, particularly relevant for E4W adoption. These extensions to the current work would provide OEMs and policymakers with more robust tools for accelerating EV adoption in India, while accounting for the unique characteristics of both E2W and E4W segments.

## 5.2 Data Collection and Field Research

While this thesis has provided an analysis of EV penetration in India using available market data and technical modeling, future research would benefit significantly from extensive ground-level data collection. The following areas of investigation would enhance our understanding and validate the findings presented in Chapter 4:

## 5.3 Consumer Research

A comprehensive survey program across India's diverse regions (metropolitan, tier-2 cities, and rural areas) is needed to understand:

- Daily usage patterns and driving behaviors of current E2W and E4W owners
- Decision-making factors in EV purchases across different demographic segments

- Specific barriers preventing potential buyers from transitioning to EVs
- Post-purchase satisfaction levels and challenges faced by early adopters

**Infrastructure Assessment**
Detailed mapping and utilization studies of charging infrastructure should examine:

- Usage patterns of public charging stations in different urban settings
- Real-world experiences with home charging solutions
- Charging behavior differences between E2W and E4W users
- Infrastructure gaps in intercity corridors and urban areas

**Economic Analysis**
Empirical data collection on actual ownership costs should include:

- Operating costs under Indian conditions
- Maintenance requirements and associated expenses
- Battery performance degradation over time
- Resale value retention compared to ICE vehicles

**Commercial Sector Study**
Given the potential of the commercial segment, especially for E4Ws, focused research should investigate:

- Fleet operator experiences and challenges
- Cost-benefit analysis for different business use cases
- Infrastructure requirements for commercial operations
- Impact of government incentives on business adoption

This additional data would strengthen the force field analysis presented in Chapter 4 and provide quantitative validation for the stakeholder value mapping. It would also help refine our understanding of why E2W adoption has outpaced E4W adoption in India, potentially revealing previously unidentified factors influencing this disparity. The insights gained would enable more targeted recommendations for accelerating EV adoption across both segments while accounting for India's unique market conditions and consumer needs.

By incorporating these real-world insights, future research could provide a more nuanced understanding of EV adoption dynamics in India, ultimately contributing to more effective strategies for achieving the country's electric mobility goals and environmental objectives.

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# Chapter 6: Conclusion

The analysis of India's EV market reveals distinct adoption patterns and challenges between E2W and E4W segments. E2Ws have achieved higher market penetration (4.43%) compared to E4Ws (1.91%) due to several key factors identified through both force field and stakeholder value map analyses.

For E2Ws, the force field analysis shows that driving forces currently outweigh restraining forces, with particularly strong positive influences from urban suitability, technological advantages, and economic benefits. The value map analysis reinforces these findings, showing that E2Ws effectively deliver on basic transportation needs and zero-emission goals, though gaps remain in charging infrastructure and resale value. The temporal analysis indicates that while safety concerns and infrastructure limitations pose significant short-term challenges, these are expected to diminish over time as the market matures.

In contrast, E4Ws face more substantial barriers to adoption. The force field analysis reveals that restraining forces, particularly high upfront costs and charging infrastructure limitations, currently dominate. The value map analysis further illustrates this challenge, showing significant gaps between current and desired states in critical areas such as cost accessibility and charging infrastructure. While E4Ws excel in technology superiority and performance features, these advantages are overshadowed by practical limitations in the Indian context.

The temporal dimension of the force field analysis suggests that many E4W challenges, particularly those related to cost and infrastructure, will persist through the medium term (5-10 years) before showing significant improvement. This indicates the need for sustained, long-term interventions to accelerate adoption.

Key differences in adoption patterns can be attributed to:

- Usage Patterns: E2Ws align well with urban commuting needs and have lower range requirements
- Infrastructure Dependency: E2Ws benefit from simpler charging solutions, with 91% of users relying on home charging
- Economic Factors: E2Ws offer more favorable total cost of ownership and require lower upfront investment
- Market Positioning: E2Ws have successfully targeted mass-market segments,

while E4Ws remain primarily in premium segments

To accelerate E4W adoption in India, manufacturers must implement a comprehensive strategy addressing multiple market challenges simultaneously. This includes developing India-specific models priced under INR 800,000 with optimized range (300-400km), establishing local battery manufacturing and supply chains to reduce costs, and creating extensive fast-charging networks through public-private partnerships. The industry should initially focus on fleet operators and commercial segments to build scale while developing innovative financing solutions including battery leasing options. Manufacturers must also work closely with government bodies to extend FAME subsidies, rationalize GST on EV components, and standardize charging infrastructure. Additionally, comprehensive consumer education campaigns addressing range anxiety, demonstrating real-world performance, and providing transparent TCO comparisons with ICE vehicles will be crucial. Success will require balancing these initiatives while maintaining product quality and reliability through extended warranties and robust service networks. By implementing this holistic approach, the E4W industry can overcome current adoption barriers and accelerate market penetration in India's automotive sector, moving beyond its current premium positioning to achieve broader market acceptance.

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