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Pathways to Electrical Mobility: Comprehensive Approach for ZEV mandates & EV Transition in India

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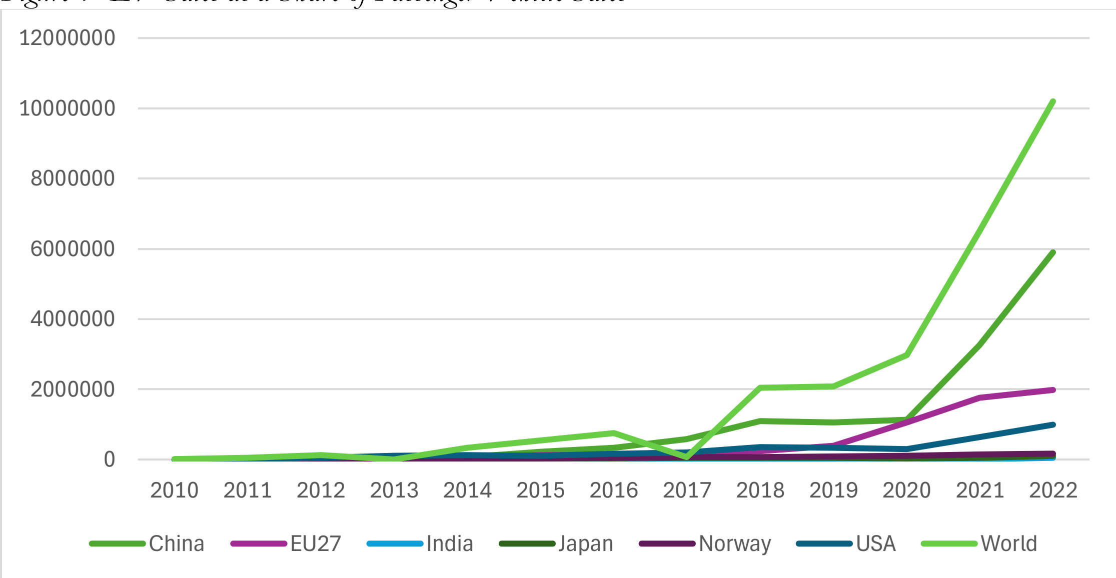
1. Introduction: EV Mobility and ZEV Mandate

Economies around the world have initiated strategic efforts to promote electric mobility, a pivotal response to escalating concerns over climate change, air pollution, reliance on oil imports, and to secure a vantage point within this emerging sector. The transportation industry is anticipated to be the most rapidly increasing contributor to greenhouse gas (GHG) emissions, with projections suggesting it may surpass 30% of total GHG emissions in forthcoming years. In this context, the adoption of electric vehicles (EVs) emerges as a compelling alternative. (United Nations, n.d.), (United Nations, 2015)). Major economies in the world have undertaken significant steps in this direction with notable advancements already evident. The shift toward EVs has been swift, spurred by diminishing costs in certain established markets. It is reported that electric vehicles constituted 10% of global passenger vehicle sales, a tenfold increase from previous years. Notably, Norway leads with 80% of passenger vehicle sales being all-electric in 2022, followed by Iceland (41%), Sweden (32%), the Netherlands (24%), China (22%), the European Union (12%), and the United States (6%). The adoption trajectory in most economies exhibits an S-curve growth pattern, indicative of an exponential adoption rate that accelerates once cost parity with conventional vehicles is achieved. India, albeit starting from a lower base, is advancing along this curve at a rate threefold that of the global average (as of 2021-22). Only those economies with a well-established electric vehicle (EV) market, exhibiting high penetration rates, have managed to sustain the 75-95% growth rate considered essential for meeting established climate goals. This robust growth is the main contributor to the high global average. In contrast, countries such as India and Japan lag behind in achieving the necessary growth rates (Figure 1) (Jaeger, 2023; IEA, 2023; Climate Action Tracker, 2020).

Figure 1- EV Sales as a Share of Passenger Vehicle Sales

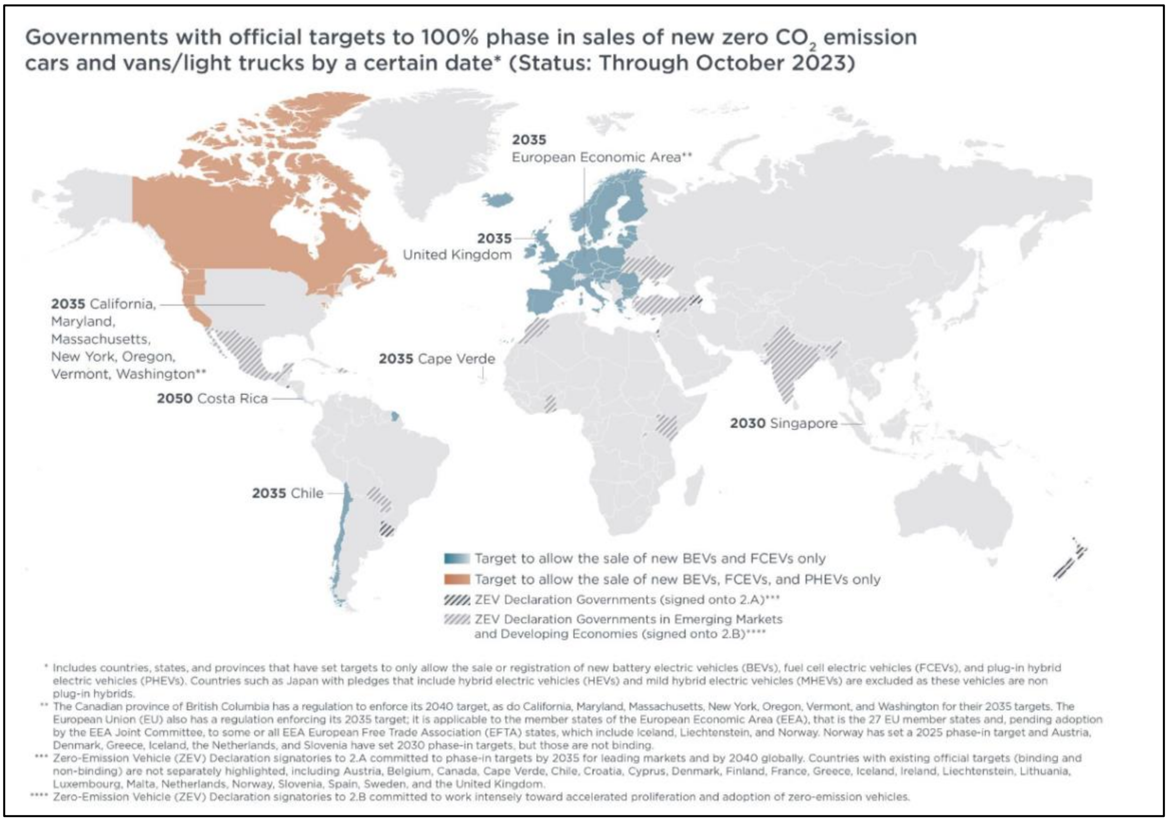


Source - Jaeger, 2023; IEA, 2023; Climate Action Tracker, 2020

The push for electric vehicles (EVs) is gaining momentum, driven by clear goals and cooperative initiatives at both national and international levels. On the National Level More than 14 governments have their own ZEV targets to phase out ICE vehicles (ZEV Transition Council , 2023) (Figure 2). There have been several recent multilateral agreements that are aiding a collective movement in the transition. The Dutch government, with the Drive to Zero program, set a strong example in 2021 by starting a global agreement aimed at making all new buses and trucks zero-emission by 2040, and at least 30% by 2030 which was signed by 27 signatories. This effort was strengthened at the Conference of the Parties (COP) 27 meeting, where the Accelerating to Zero (A2Z) coalition that builds on the Zero-Emission Vehicles Declaration was launched. With, 233 signatories7, the coalition is dedicated to switching all new cars and vans to zero emissions by 2040.

The World Business Council for Sustainable Development also took a significant step at COP 27. They launched an initiative to encourage more collaboration in rapidly developing economies to speed up the move to zero-emission road transport. In 2022, the Climate Group started the EV100+ campaign. This campaign focuses on major markets, including OECD countries, China, and India, committing to make all large vehicles in their fleets zero-emission by 2040. Along with this, in 2022, acknowledging the pivotal influence of national governments through demand signals and leadership, a group of nine countries8 committed to the Zero Emission Government Fleet Declaration. They aim to reach 100% zero-emission cars and vans in government fleets, with an additional aspiration of 100% zero emission trucks and buses, by no later than 2035. It has become increasingly clear that Zero Emission Vehicle (ZEV) mandates and targets have become the cornerstone of EV transition. These recent initiatives, alongside earlier targets and endeavours have not only sustained but also significantly amplified the prominence of these nations in the global EV market. (IEA, 2023)

Figure 2- Targets for EVs across the Globe.



Source- ZEV Transition Council, 2023.

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[7] These 233 signatories include 30 governments in advanced economies, 11 governments in EMDEs, 73 local/regional governments, 14 automotive manufacturers, 47 fleet owners and operators, 15 investors with shareholdings in automotive manufacturing, 2 financial institutions and 31 other signatories. India is one of the 11 EMDEs that are part of this coalition (Source: IEA)

[8] Australia, Canada, Germany, Israel, Netherlands, New Zealand, Norway, Sweden, and the United States.

India, as a proactive participant in global efforts towards environmental sustainability, has made noteworthy commitments. While the country had pre-existing policies with a focus on electric mobility, the recent commitment made at the COP26 summit in 2030 has injected a renewed sense of urgency and purpose into its decarbonisation strategy. This pledge signifies a significant acceleration in India's efforts towards achieving its environmental goals. This plan includes a bold target to cut carbon emissions by 50% within its energy sector and to reach an ambitious renewable energy generation capacity of 500 gigawatts by the end of the decade.

The National Auto Policy (NAP) 2018, for instance, sets forth Corporate Average Fuel Economy (CAFE) standards extending through 2025 and mandates compliance with Bharat Stage VI (BSVI) emissions regulations. Concurrently, the National Electric Mobility Mission Plan (NEMMP) 2020 is designed to bolster annual sales of hybrid and electric vehicles, targeting six to seven million units starting from 2020. Under the NEMMP umbrella, the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles schemes—FAME I and II—were developed to lower the acquisition costs of these vehicles, thereby incentivizing consumer purchase on the production front, two Production Linked Incentive (PLI) Schemes were introduced, focusing on the Automobile sector: one for Advanced Chemistry Cells and another for Advanced Automotive Technology products. These two PLI schemes aim to establish a competitive ACC and EVs manufacturing in the country. Additionally, 26 out of 29 Indian states have formulated their own electric vehicle (EV) policies, which demonstrate variability in targets for different EV segments, offer exemptions on road taxes, enhance charging infrastructure, and provide subsidies for services such as retrofitting and electricity costs. As a result of these efforts, penetration of EVs in India is increasing.

Currently, Two wheeler (2W) EVs form the majority of EV sales today, accounting for 85%–90% of all EV units sold in India, followed by four wheeler (4W) EVs (7%–9% of sales) and three wheeler (3W) EVs (5%–7% of sales) (Seetharaman, et al., 2023). Penetration of EVs is also led by 3 wheelers, with 8% penetration, followed by E-Buses at 7%, E-2wheelers at 5%, and passenger vehicles hovering around 1%. By 2023, E-rickshaws, constituting 90% of the 3 Wheelers, achieved a penetration rate of 53%, driven by factors such as accessibility, low maintenance costs, advancing technologies, and the growing demand for efficient passenger transportation (Vahan Dashboard, 2023) (Economic Times, 2023).

When these developments are juxtaposed with India's ambitious 2030 goals and the broader climate change imperatives, it becomes evident that the country is trailing on the anticipated trajectory, which necessitates a recalibration of policy frameworks. There is an absence of a coherent national directive on EV adoption has resulted in a misalignment of initiatives, impeding the country's ability to fully capitalize on the potential benefits of its EV policies. Like other nations, adoption of a Zero-Emission Vehicle (ZEV) target can be instrumental synchronize fragmented policy efforts across various sectors and states, channelling them toward a unified economic objective. To construct policies that address the blind spots that may impede India's progress towards its envisioned sustainable transportation objectives a deeper analysis of best practices from global leaders in EV adoption, coupled with an in-depth examination of the Indian ecosystem, is imperative.

Outline of the Paper

The current study is structured in following sections:

1. Global Overview of Implemented ZEV Policies:

Conduct an in-depth review of successful Zero-Emission Vehicle (ZEV) policies implemented across nations. This section will provide a comprehensive analysis, drawing comparisons between different global economies and their respective policies.

2. India’s Automobile Sector: Current Landscape

Explore the current landscape of India's automotive industry, emphasizing the evolution of electric mobility policies. This section aims to offer a detailed evaluation of the industry's current standing and its alignment with the broader objectives of sustainability.

3. Examining India's Automotive Value Chain:

Undertake a meticulous examination of India's automotive value chain, encompassing component and structural analyses. This segment will pinpoint policy gaps that pose barriers to Electric Vehicle (EV) adoption, shedding light on areas requiring strategic intervention.

4. Integration of ZEV mandate in Indian Economy: Model Simulation

Develop a robust model designed to assess the feasibility of integrating a ZEV mandate in India, aligning with the nation's electrification targets set for 2030. This model will serve as a tool to gauge the potential impact if a ZEV mandate comes into play and its impact on Indian automotive landscape.

5. A real value options approach to understand Investment timing in the EV Industry:

This section will explore emerging area of interest in understanding EV industry using options approach. This section draws from recent work on the same being explored in China.

6. Limitations and Way forward

This section describes the limitations of this pioneering study of implementing a Zero-Emission Vehicle (ZEV) mandate in India. It elaborates the substantial challenges faced due to data constraints, limited study period, and uncertainties in manufacturing costs during construction of the model.

2. Global Overview of Implemented ZEV Policies

It is evident that in the run for limiting global temperature increase and to reduce the impacts of climate change and air pollution, especially in low and middle income countries, correcting the transport emissions trajectory and undertaking a global shift towards zero emissions electric mobility is crucial (United Nations, n.d.), (United Nations, 2015)).

Global electric markets currently exhibit variations in the levels of policy support, corporate initiatives, and consumer preferences and behaviours. The influence of policy stands out as a pivotal force, actively shaping strategies for the widespread adoption of electric mobility and facilitating consumer engagement. In key markets such as China, Europe, and the United States, a nuanced combination of policies, balancing both consumer and manufacturer-centric approaches, has been incrementally implemented. These policies involve the judicious use of both direct and indirect incentives, complemented by the establishment of electric vehicle (EV) targets through the adoption of zero-emission vehicle (ZEV) mandates (IEA, 2023). The Zero Emissions Mandate (ZEV) mandate is a governmental regulation designed to accelerate the adoption of Electric Vehicles and other zero emission vehicles by requiring automakers to produce and sell a certain percentage of these vehicles. Originating in the United States with California's adoption, the ZEV mandate has subsequently been emulated in various forms by multiple economies. The specific targets set by each country are tailored to their unique economic framework and the structure of their automotive sectors. These targets, which may focus on the electrification of vehicle sales, the existing fleet, or public transportation systems, are strategically aligned on a timeline that best fits the nation's ambitions for climate change mitigation and the transition towards electrification. (Figure 3). ZEV targets have become a cornerstone of policy for transport and decarbonisation.

Table 1- Global Zero-Emission Vehicle Mandates and Internal Combustion Engine bans.

Target Year	Country	Type of Target	Type of Vehicle (LDV= Light Duty Vehicle, HDV= Heavy Duty Vehicle)
2025	Norway	100% ZEV Sales	LDV
	Denmark	100% ZEV Public Buses Sales	HDV
	Ecuador	100% ZEV Public Buses Sales	HDV
2030	Iceland	100% ZEV Sales	LDV
	Austria	100% ZEV Sales	LDV
	Netherlands	100% ZEV Sales	LDV
	Israel	100% ZEV Sales	LDV
	Ukraine	100% ZEV Sales	LDV and HDV
	Slovenia	100% Electrified Sales	LDV
	United Kingdom	100% Electrified Sales	LDV
	Singapore	100% Electrified Sales	LDV
	Netherlands	100% ZEV Public Buses Stock	HDV
2035	United States	100% ZEV Sales	LDV
	Italy	100% ZEV Sales	LDV
	Cabo Verde	100% ZEV Sales	LDV
	Canada	100% ZEV Sales	LDV
	EU	100% ZEV Sales	LDV
	United Kingdom	100% ZEV Sales	LDV
	Austria	100% ZEV Sales	HDV
	Japan	100% Electrified Sales	LDV
	Chile	ICE ban and 100% ZEV Public Bus Sales	LDV and HDV
	Columbia	100% ZEV Public Bus Sales	HDV

	New Zealand	100% ZEV Public Buses Stock	HDV
2040	Argentina	ICE ban	LDV
	Sri Lanka	100% Electrified Stock	LDV
	Cabo Verde	100% ZEV Sales	HDV
	Canada	100% ZEV Sales	HDV
	United Kingdom	100% ZEV Sales	HDV
	Singapore	100% ZEV Public Buses Stock	HDV
2045	Chile	100% ZEV Sales	HDV
2050	Costa Rica	100% ZEV Sales	LDV and HDV
	Mexico	100% ZEV Sales	LDV and HDV
	Dominican Republic	100% ZEV Public Buses Stock	HDV
	Israel	100% ZEV Public Buses Stock	HDV

Source- IEA, 2023.

Before stepping into understanding the efficacy of such a mandate in the Indian context, a deeper dive of the ZEV mandate's evolution and its effective implementation in leading economies is imperative to understand its impact on accelerating the shift towards sustainable mobility.

2.1. United States of America- Pioneer of the ZEV mandate

The introduction of the California Zero Emission Vehicle (ZEV) rule issued by the California Air Resources Board (CARB) in 1990 was one of the most impactful and revolutionary policies focusing on air quality and vehicular emission policies. During the late 1980s, both government entities and the automotive industry began to recognize that the potential for reducing emissions from traditional gasoline-powered combustion engines was nearing its maximum. This realization led to an investigation into alternative fuels and the development of new drivetrain technologies to achieve the demanding air quality standards set forth. Los Angeles and the South Coast Air Quality Management District, recognizing the potential of battery electric vehicles (BEVs) to address regional air quality challenges, initiated proposals as early as 1988 for the mass deployment of BEVs. Despite scepticism about its feasibility, the ZEV mandate endured as a segment of the influential Low Emission Vehicles and Clean Fuels program, which set rigorous emission standards for automakers and alternative fuel mandates for oil companies (Collantes & Sperling, 2008). The policy intended to be "technology forcing", i.e. to drive innovation in electric technologies and scale up battery production to reduce costs, setting a performance standard for selling vehicles with zero emissions, that could be met only by battery EVs or fuel cell vehicles (McConnell & Leard, Pushing New Technology into the Market: California's Zero Emissions Vehicle Mandate, 2021).

The mandate has undergone several modifications in order to evolve with the changing technologies and cost dynamics. The mandate can be studied in three phases:

i) Phase I (1990-2004)

The ZEV mandate in the US has At its inception, the ZEV mandate required that by 1998, 2% of new vehicles from major manufacturers had to be ZEVs, with this figure rising to 5% in 2001 and 10% in 2003. CARB made subsequent adjustments, including the introduction of partial ZEV (PZEV) credits in 1998 for vehicles with lower emissions but are not fully ZEV (Collantes & Sperling, 2008). However, even after a decade of the goals not being met, manufacturers and policymakers recognised that the pace of technology, cost to consumers, and infrastructure did not line with each other, leading to a change in the mandate and the launch of consumer-side incentives (e.g., tax incentives). Despite the modifications, several manufacturers sued CARB contending the feasibility of these mandates which led to ban of ZEV mandates in 2003 and 2004 (McConnell & Benjamin, 2021).

ii) Phase II (2005-2014)

A new ZEV mandate in 2005 came into effect leading to innovations in electrifications and introduction of newer models. In addition, the credit trading system that allowed manufacturers to comply to the mandate by buying and selling credits in addition to manufacture of EVs was formalized in 2010 (McConnell & Benjamin, 2021)

In January 2012, the California Air Resources Board (CARB) implemented the Advanced Clean Cars program, setting ambitious targets for electric-drive vehicle sales to exceed 10% by 2025. This program was further bolstered an advanced the zero-emission vehicle (ZEV) initiative, aiming for a significant milestone of 1.5 million ZEVs on California's roads by 2025 as a means to enhance environmental sustainability, economic growth, and overall life quality in the state. Around 2011, fully electric vehicles by Tesla and Nissan began to enter the market. By February 2013, an interagency working group, orchestrated by the Governor's Office, unveiled a detailed ZEV Action Plan. This roadmap outlined the specific actions to meet the 1.5 million ZEV goal, broadening the definition of ZEVs to encompass hydrogen fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). Additionally, several states have aligned with California's rigorous environmental stance, like New York, Massachusetts, Vermont, Maine, Connecticut, Rhode Island, New Jersey, Oregon, and Maryland.

iii) Phase III (2018-2025)

The ZEV mandate was adopted for model years 2018-2025, imposing increasingly stringent credit requirements ranging from 4.5% in 2018 to 22% in 2025. CARB distinguishes between "large-volume manufacturers" and "intermediate-volume manufacturers." Although both categories face identical percentage credit requirements, they differ in the types of vehicles that qualify to meet these requirements. CARB projects that the ZEV mandate program will contribute to achieving a ZEV market share of approximately 8% by 2025. (ICCT, 2019)

In 2022, CARB formulated Advanced Clean Cars II standards for the post-2025 era. With this CARB's vision is to achieve a full transition to electric vehicles (EVs) by 2035, with a proposed sales composition entirely comprised of EVs, including BEVs, FCEVs, and PHEVs—the latter with at least a 73-mile all-electric range per two-cycle tests and the capability for 40 miles under the US06 driving cycle. Limitations have been placed on PHEVs, restricting them to a maximum of 20% of the annual EV sales quota. These regulations present two potential pathways to incrementally reach the EV sales targets, with one scenario considering the possibility of achieving only a 70% target by 2035. Washington, Delaware, Colorado, Minnesota, Nevada, and

Virginia, are anticipated to comply with these progressive ACC II ZEV regulations, marking a nationwide commitment to cleaner automotive standards and sustainable transportation ((TransportPolicy, n.d.) (California Air Resources Board, 2022))

Several supportive incentives have been undertaken to aid the ACC II ZEV improve access to ZEVs for all Californians, including moderate- and low-income consumers. They include:

1) Clean Cars 4 All (allocation of $400 million over three years)- Offers up to $9,500 for low-income motorists who replace their older, less environmentally friendly vehicles with cleaner options.
2) The Clean Vehicle Rebate Project (CVRP) (allocation of $525 million)- Provides up to $7,000 to income-eligible individuals to purchase or lease a ZEV.
3) The Clean Vehicle Assistance Program- Assists low-income purchasers with preferential financing and up to $5,000 in down-payment support for ZEV acquisition.

In addition, $300 million is reserved for expanding the EV charging infrastructure, catering especially to those without home charging capabilities. EVs offer savings due to lower fuel expenses—home charging typically costs about half compared to gasoline for the equivalent distance—and maintenance costs for EVs are approximately 40% lower than those for vehicles with internal combustion engines. ((TransportPolicy, n.d.) (California Air Resources Board, 2022)). Significant investments in PEV research and charging infrastructure were made under initiatives like EV Everywhere, targeting widespread PEV access by 2022. Additionally, the Inflation Reduction Act, 2022[9] has played a significant role by increasing tax credits for qualifying new and used EV purchases, reducing costs for buyers.

In 2022, Registrations for ZEV vehicles reached 3.4 million, capturing a mere 1.2% of the automotive market—a stark contrast to the 276 million gasoline and diesel vehicles (US Department of Energy, 2023). Hence, the newer policies come at a crucial juncture and are evidently in the right direction as projections for 2023 indicate a remarkable surge in electric vehicle sales, potentially achieving 9% of all passenger vehicle sales in the U.S. This marks a considerable rise from the 7.3% recorded in the previous year and signifies the first-time annual sales of EVs could surpass the 1 million mark, with projections ranging between 1.3 and 1.4 million vehicles (Voa News, 2023). Additionally, the Inflation Reduction Act, 2022[10] has played a significant role by increasing tax credits for qualifying new and used EV purchases, reducing costs for buyers.

Despite trailing behind EV adoption rates in countries like China, Germany, and Norway, the U.S. has experienced rapid growth in EV uptake. A key driver of this growth has been the reduction in EV prices, spurred by intense market competition, notably between Tesla and other automakers, which has led to more cost-effective EV options. Contributing factors such as the declining costs of critical materials like lithium and cobalt, coupled with technological advancements in battery efficiency, have played a significant role in enhancing the affordability and appeal of electric vehicles.

[9] The Inflation Reduction Act (IRA) of 2022 aims to reduce domestic Inflation brought by the global energy crisis by reducing carbon emissions by 40% by 2030. For this, IRA includes a combination of grants, loans, tax provisions and other incentives to accelerate the deployment of clean energy, clean vehicles, clean buildings and clean manufacturing. (Source- IEA)

[10] The Inflation Reduction Act (IRA) of 2022 aims to reduce domestic Inflation brought by the global energy crisis by reducing carbon emissions by 40% by 2030. For this, IRA includes a combination of grants, loans, tax provisions and other incentives to accelerate the deployment of clean energy, clean vehicles, clean buildings and clean manufacturing. (Source- IEA)

2.2. China- World's largest EV market and manufacturer

China's commitment to Electric Vehicles (EV) has significantly influenced the global market, with its 22% market share equating to 4.4 million sales in 2023—double the international average and more than 3.3 million sales globally (Jaeger, 2023). China has gone through different phases of implementing a plethora of policies before setting New-Energy Vehicle (NEV) mandate policy to steadfast its EV growth.

China embarked on its EV journey in the early 2000s, with financial incentives in pilot cities and expanded to include a range of vehicles, such as Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). These incentives included exemptions from purchase taxes, reduced electricity tariffs, and production tax reliefs for manufacturers. Collectively, these measures amounted to an investment of over 200 billion yuan (US$28 billion) from 2009 to 2022 (Yu, 2023). The evolution of China's EV policies demonstrates a strategic and responsive approach, adapting over time based on the effectiveness of earlier policies. This holistic strategy has been integral to China's success in the EV market. The extensive path of China leading to the NEV mandate and beyond can be studied in the following three phases.

i) Phase I (1990-2009) – Foundations for Comprehensive Policy

China's EV research traces back to the eighth five-year plan (1991–1995), when initiatives such as the collaboration between Tsinghua University and Tianjin Automotive Industry Company were sponsored to innovate in electric bus and mini-car technology. Progressing through the 1990s and into the new millennium, the State Science and Technology Commission embarked on several EV-centric projects under the National Key Technologies R&D Program. This research gained priority status in the nation's Five-Year Plan as early as 2001 focusing on control systems, electric motors, and batteries—deemed the 'Three Longitudes' (Li, Yang, & Sandu, Electric vehicles in China, 2018). The appointment of Wan Gang, a former Audi engineer, as the Minister of Science and Technology in 2007 marked a pivotal moment, providing significant impetus to the industry (Yang, 2023). The subsequent introduction of the three-year EV pilot program by the Ministry of Finance of the People's Republic of China (MOF) and the Ministry of Science and Technology of People's Republic (MOST) known as the Thousands of Vehicles, Tens of Cities (TVTC) programs aimed to deploy at least 1,000 EVs in selected cities between 2009 and 2012. This initiative initially targeted public procurement and expanded to include private procurement, with subsidies to manufacturers and a focus on fuel efficiency for subsidy levels (Li, Yang, & Sandu, Electric vehicles in China, 2018).

ii) Phase II (2010-2017)- Evolving Policy Landscape in Response to Technological and Market Dynamics

Since 2010, a series of policy measures have been introduced and implemented by the Chinese government, to boost the penetration rate of EVs. Four central ministries and commissions (namely MOF, MOST, the MIIT, and the NDRC) jointly announced the new three-year EV pilot programs in 2013. These programs were aimed to promote the deployment of a total of 300,000 vehicles in 39 select cities and city groups, over the period 2013–2015. The program's broad scope covered both public and private sectors, providing financial subsidies to spur EV procurement. The subsidy framework had three key components: direct payments to certified automakers, subsidy amounts pegged to the mileage per charge rather than fuel savings, and a structured decrease in subsidies by 5–10% annually. Furthermore, in 2014, the MOF enacted supplementary fiscal incentives, such as exemptions from purchase tax, vehicle registration tax, and reductions in import duties for EV parts and equipment.

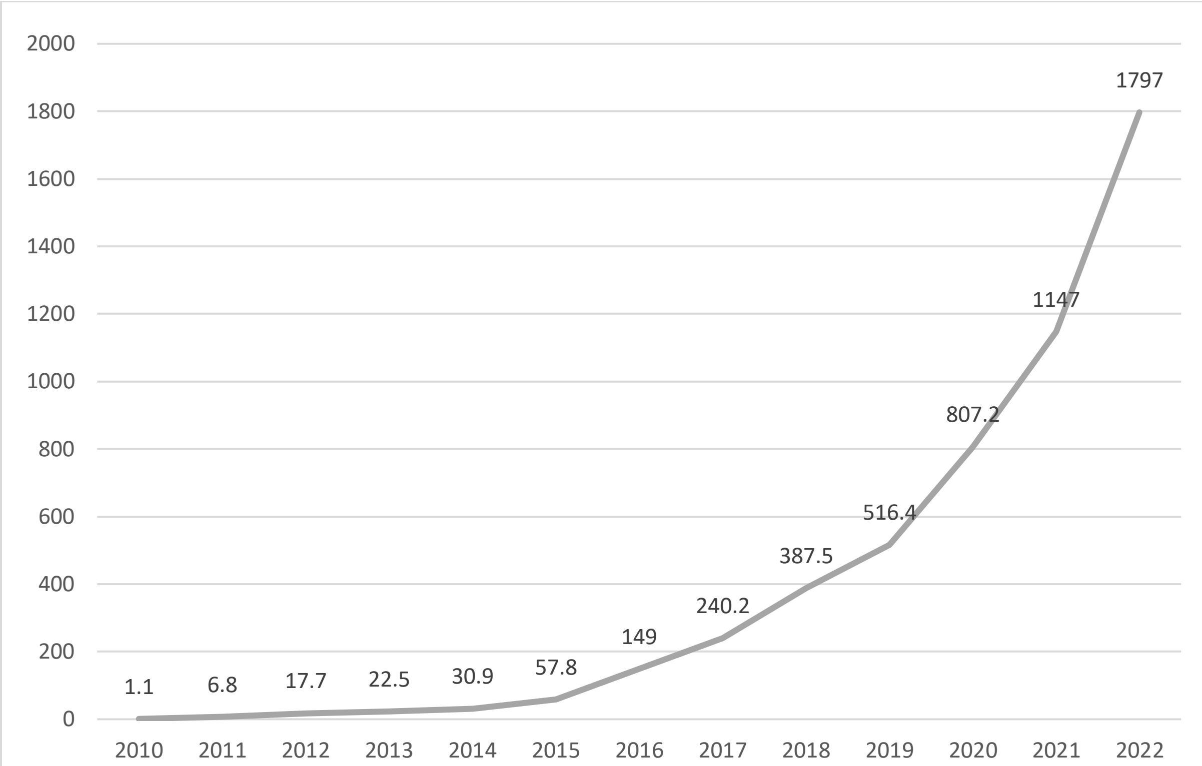
Despite these concerted efforts, the actual production and ownership figures of New Energy Vehicles (NEVs) in 2014 — 84,000 and 12,000 respectively — did not meet the ambitious targets set by the Industry Development Plan for Energy Saving and New Energy Vehicles. (Li, Long, & Chen, Consumers' evaluation of national new energy vehicle policy in China: An analysis based on a four paradigm model, 2016). Additionally, China grappled with multifaceted issues including technological uncertainties and market scepticism on the supply side, and on the demand side, barriers like subpar EV performance — evident in limited driving range and extended recharging times — as well as steep initial costs. Compounding these technical and economic concerns were institutional and socio-political challenges such as decentralized authority, regional protectionism, and policy incentives that inadvertently obstructed cohesive policy formation and execution.

In its second phase, China's strategy pivoted, placing greater emphasis on supply-side measures, and acknowledging the limitations inherent in the previously dominant demand-driven, subsidy-heavy approach. In 2015, four central ministries and commissions (MIIT, MOF, MOST, and the NDRC) jointly extended the programs to its second phase, over the period 2016–2020, with certain changes. Notably, subsidies were considerably reduced (20% in 2017-18, 40% in 2019-20 compared to 2016) and capped for local governments. Additionally, stricter auditing, tougher technical standards (battery density, speed, etc.), and a shift in focus from fuel-saving capacity to driving range for subsidy determination were implemented. There has been a change in the way financial incentives, especially subsidies have changed. In this period, subsidies were determined on the basis of the driving ranges of EVs instead of the fuel-saving capacity of EVs in the prior period (2009-12) (Li, Yang, & Sandu, 2018)

In the second phase, in addition to the monetary incentives stated before, different non-monetary incentives were implemented. In 2015, the municipal government of Beijing exempted EVs from peak-hour traffic control and the vehicle quota system[11], aiming to curb congestion and air pollution. Furthermore, the government actively supported EV infrastructure development through financial aid for charging facilities and regulatory provisions to streamline planning. (Li, Yang, & Sandu, 2018). As a result of such policy support, China witnessed a significant uptick in its EV infrastructure, culminating in nearly 1.8 million public electric vehicle charging piles by the end of 2022, a substantial 56.7 percent increase from the previous year (Statista, 2024).

[11] Also known as the lottery system, this system was introduced in 2011, in order to limit the growth of vehicles on the roads, as a result of growing public concerns about traffic congestion and air pollution

Figure 3- Number of Charging Piles (in thousands)



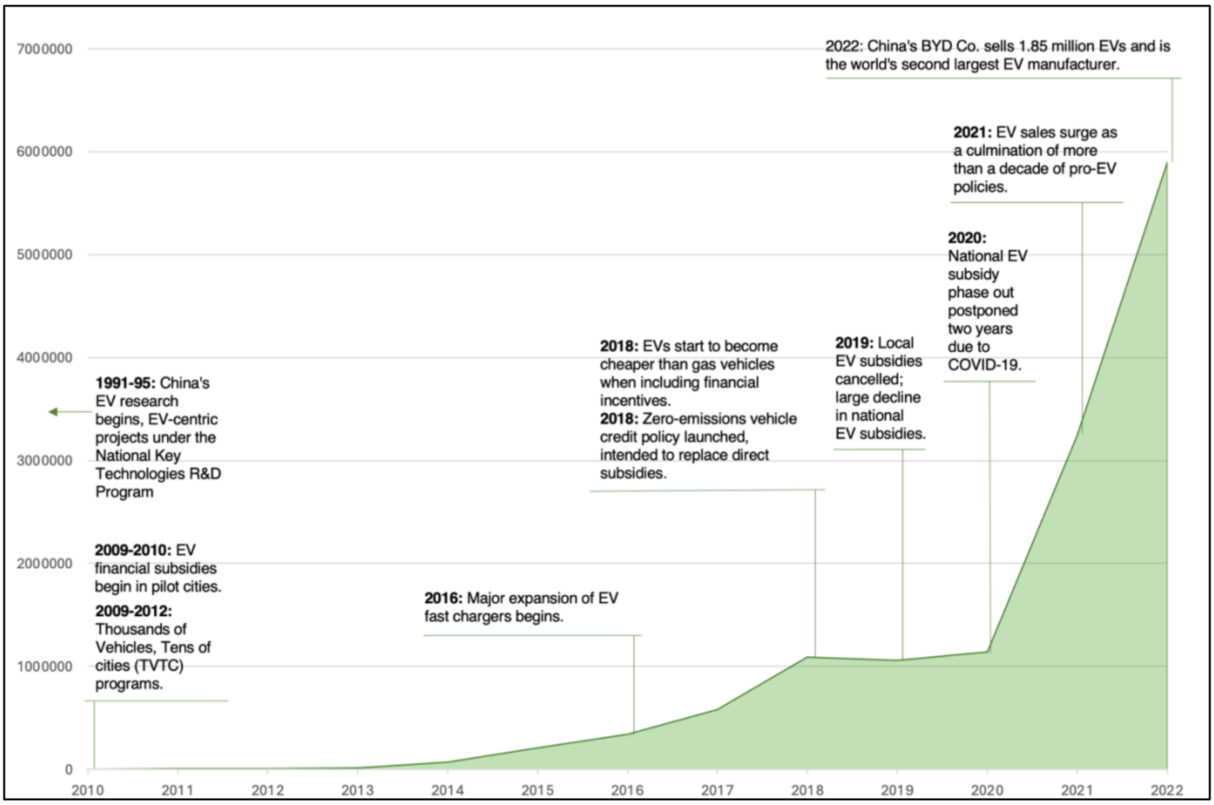
Source- EVCIPA, 2023

iii) Phase III (2018-Present) - NEV Mandate and way ahead

In 2018, China began transitioning to a market-based zero-emissions vehicle credit system, inspired by California's Zero Emission Vehicle Mandate. China learned from California's experience and waited to implement targets until reaching a certain threshold of technological progress and market preparedness. This strategic approach led to streamlined policies with a clear, unified objective. Under this system, New Energy Vehicle (NEV) credit targets are established as a proportion of the traditional passenger vehicle market—specifically, 10% for 2019 and 12% for 2020. Mirroring California's ZEV mandate the annual percentages are set for NEV credits rather than sales. The credits allocated to each NEV are determined by various performance metrics, such as electric range and energy efficiency, with a maximum of six credits per vehicle, thus allowing for a flexible NEV market share dependent on the fleet mix. ((WRI, 2018), (ICCT, 2018)) These NEV credit targets are mandatory for all automotive companies manufacturing or importing over 30,000 conventional cars per year. Companies that exceed their NEV credit requirements can trade their surplus credits, while those falling short can purchase credits to meet their obligations. Additionally, surplus NEV credits can compensate for any deficits in Corporate Average Fuel Consumption (CAFC) credits. This is often referred to as "dual credit" policy, this system aligns manufacturers' fuel economy achievements with their NEV credit scores. Companies that fail to meet NEV credit targets—and exhaust all compliance options—face repercussions from the Ministry of Industry and Information Technology (MIIT), including a halt on approval for new models that do not meet specific fuel consumption standards until they offset their deficits. To date, the dual-credit policy has been successful in fostering the growth of NEVs, and it is anticipated to play a vital role in achieving China's ambitious NEV goal of a 20% market share by 2025 (Chen, 2022) (ICCT, 2019)

China' s current policy suite is robust and includes carmakers exemptions from consumption tax and vehicle & vessel tax for the production, processing, and importation of EVs as well as is phasing away from subsidies on certain vehicles (Jaeger, 2023). A substantial tax incentive package was announced on June 21, 2023, totalling 520 billion yuan (US$72.3 billion) over four years, specifically to offer tax breaks for EVs and other environmentally friendly vehicles. This initiative includes a complete exemption from purchase tax, potentially up to RMB30,000 (US$4,170) per vehicle. However, starting from 2026 until 2027, this exemption will be halved and capped at RMB15,000 (US$2,078) (US$2,078) (WRI, 2018). Additionally, any new EVs purchased by December 31, 2025, will be exempt from the vehicle purchase tax, with purchases between January 1, 2026, and December 31, 2027, enjoying a 50% reduction. These incentives are complemented by discounted electricity tariffs for EV charging and battery-switching facilities, along with government-regulated service fees for EV charging and switching. The grid-conversion costs for these facilities are now integrated into the tariffs for power transmission and distribution (Jaeger, 2023).

Figure 4- Evolution of Policies in China



Source - WRI, 2018; Authors Analysis.

Although the main strategy for achieving a low-carbon transformation in many countries is the use of carbon trading mechanisms for companies and key industries, access to the carbon trading market is unfortunately primarily available to a small group of decision-makers and excludes regular households, educational institutions, small businesses, etc. China is exploring innovative approaches like Personal Carbon Trading (PCT) to incentivize sustainable behaviours at the individual level. Although PCT presents challenges in terms of complexity and fair implementation, it holds the potential for enhancing carbon emission awareness and supporting low-income groups who typically have lower emissions (Xu, et al., 2023) In essence, China's success in the EV ecosystem can be attributed to its evolving policy landscape that adeptly combines infrastructure development, R&D incentives, fiscal policies, pioneering market-based schemes and the NEV mandate to continue driving its EV agenda forward, not only creating a cleaner environment but emerging indispensable in the EV global value chain.

2.3. European Union- Initiatives and Voluntary ZEV Targets

The European Union is at the forefront of addressing vehicle emissions with its rigorous and all-encompassing regulations. Thanks to advanced technologies, the EU has succeeded in reducing exhaust emissions to almost negligible levels (ACEA, 2023). In line with its climate goals, the European Union is advancing towards cleaner transportation, aiming to reduce pollution by 65% from 1990 levels by the decade's end and achieve net-zero emissions by 2045 (Niranjan, 2023). The uptake of electric vehicles (EVs) is a key part of this transition, with EV registrations in 2022 accounting for 21.6% of all new car registrations. This surge in EVs, from over 8 million currently to an anticipated 40 million by 2030, is backed by EU initiatives promoting electric mobility and the expansion of charging infrastructure (European Environment Agency, 2024).

i) EV Initiatives across the European Union

Across the EU, the high upfront costs of EVs present a challenge. To mitigate this, financial incentives across EU member states have been introduced, with 21 offering tax breaks and 20 providing purchase subsidies. For instance, Romania offers up to €11,500 for EV buyers, Belgium focuses on company cars to nourish the second-hand market, and Italy and Spain invest in charging infrastructure. France promotes a €5,000 bonus and a social leasing scheme, while Germany has trimmed subsidies due to a rise in EV adoption. Additionally, two-thirds of EU states incentivize the purchase of electric commercial vehicles, with varied fiscal supports and tax benefits to boost the market. (Niranjan, 2023) (ACEA, 2023).

In February 2023, the European Union introduced the Green Deal Industrial Plan, which revolves around four key areas: accelerating the permitting process, providing financial support, fostering the development of skills, and enhancing trade relations. Central to this initiative is the formation of a Critical Raw Materials Act, proposed in March 2023, emphasizing the security of supply chains, responsible sourcing, and the recycling of materials. (European Commission, 2023) (IEA, 2023)

Facilitating quicker approvals for projects, especially those concerning battery production, is a goal of the Net Zero Industry Act. This act is designed to streamline and predict the planning process. It also temporarily relaxes state aid rules to expedite access to subsidies and loans, which will help businesses cope with high energy costs, preserve cash flow, and lower electricity consumption. Moreover, the plan includes measures to retrain workers impacted by the shift towards a greener economy, such as establishing Net Zero Industry Academies. The trade aspect of the plan is directed at bolstering the EU's supply chain robustness, initiating trade with new partners, and enticing private sector investment. (Europen Commission, 2023) (IEA, 2023) Furthering these efforts, the EU in March 2023 put forth the Net Zero Industry Act, targeting the fulfilment of 40% of the EU's needs for pivotal net-zero technologies through local manufacturing by 2030. This act particularly emphasizes the advancement of battery and energy storage technologies, setting an ambitious goal for the EU to produce nearly 90% of its battery requirements. This aligns with the European Battery Alliance's aim to achieve a manufacturing capacity of at least 550 GWh by 2030. These efforts coincide with the tightening of CO2 standards for car sales in the 2030-2035 period as part of the Fit for 55 legislative package. (Euroepan Commission, 2023) (IEA, 2023)

To support the growing number of EVs, the Alternative Fuels Infrastructure Regulation (AFIR) plays a critical role in ensuring the stability of the EV charging environment. It sets common standards and guidelines for the EU, including provisions such as accessible fast-charging stations and transparent pricing (European Environment Agency, 2024).

ii) EU Voluntary ZEV Targets

The European Union's approach to Zero-Emission Vehicles (ZEVs) differs from the mandates in California and China. Instead of imposing strict requirements, the EU offers car manufacturers the opportunity to meet voluntary ZEV quotas, which can then be used as compliance offsets against the stringent post-2021 corporate average CO2 standards. (ICCT, 2019)

Currently, under EU regulations, car manufacturers must reduce fleetwide emissions to an average of 95 grams of CO2 per kilometre by 2021. Looking ahead, the European Commission aims to further decrease these emissions by 15% by 2025 and by 37.5% by 2030. The voluntary ZEV market share targets for this period are set at 15% for 2025 to 2029 and 35% for 2030. However, the way vehicles contribute to these targets varies: Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) that emit no CO2 are given full credit towards these goals, while vehicles emitting between 0 and 50 grams per kilometre are only partially credited. Vehicles exceeding 50 grams per kilometre do not count towards the voluntary targets at all. (ICCT, 2019)

The European Commission has incorporated these voluntary ZEV targets within the corporate average CO2 standards to offer manufacturers flexibility. By surpassing these targets, manufacturers can benefit from a relaxation of their CO2 standards. For example, if a manufacturer achieves 17% BEV sales in 2025, they will receive a CO2 compliance relaxation factor of 1.02, and if they reach 39% BEV sales in 2030, the relaxation factor would be 1.04. The incentive is designed so manufacturers could aim to exceed their ZEV targets by up to 5%, with a maximum relaxation cap set at a factor of 1.05. Importantly, there are no specified penalties for failing to meet these ZEV targets, emphasizing the voluntary nature of the scheme. (ICCT, 2019)

In the United Kingdom (UK), Prime Minister Rishi Sunak has postponed the ban on new petrol and diesel vehicles to 2035, as confirmed by the Department for Transport's ZEV Mandate, which outlines escalating EV sales targets through 2035. The mandate requires 22% of new car sales in 2024 to be emission-free, increasing annually to 80% for cars and 70% for vans by 2030, aiming for a complete shift by 2035. Manufacturers have been given to rollover excess compliance to the next year or buy compliance in the years they fall short. (Drive Electric, 2023) (Politico, 2023).

iii) Stricter Standards for Greener Transport

Set to take effect in July 2025, the Euro 7 regulations will have stringent standards for vehicle exhaust and non-exhaust emissions, like those from tire wear and brake dust, as well as enforce limits on battery life (European Council, 2024). The introduction of these rules, however, presents a double-edged sword for the European automotive industry. While they aim to facilitate the EU's green ambitions and enhance air quality, they also threaten the viability of certain vehicle models and could potentially impede the industry's progress towards a zero-emission future. This could adversely affect the EU auto industry's global standing, as they struggle to balance stringent regulations with the need to remain competitive and the growing market presence of Chinese electric vehicles. In contrast, other key global players are creating conducive environments for their transport sectors through incentives rather than strict regulations. (ACEA, 2023).

It's clear that the EU has made considerable strides in its environmental efforts and has proposed numerous proactive strategies. The voluntary targets, which have so far supported manufacturers in aligning with evolving standards, illustrate the EU's commitment to a greener future. Moving forward, what Europe needs is a comprehensive and cohesive strategy that not only encourages but also materially supports significant investments in domestically produced zero-emission transport solutions. This approach will help ensure that the transition to a sustainable transport sector is both effective and economically viable. (ACEA, 2023).

2.4. Norway- Remarkable Path Towards E Mobility

Norway stands out as a remarkable success story in Electric Vehicle (EV) adoption, boasting the highest share of EVs, with all-electric vehicles comprising 80% of passenger vehicle sales in 2022 (Jaeger, 2023). Norway's approach to electric vehicle adoption significantly deviates from the strategies employed by China, the USA, and the European Union. Rather than focusing on production, Norway has successfully leveraged consumer incentives to foster a market driven by demand. This distinct strategy is partly due to Norway's limited manufacturing capabilities and its robust financial resources, which surpass those of many other developed and developing nations.

Since the 1990s, Norway has been at the forefront, implementing strategic measures to promote EVs. It started by making EVs the best financial decision for consumers supported by exempting import tax, value-added tax, road tax, toll charges, car tax, investing in charging infrastructure, and so on. These measures were introduced from the 1990s to the early 2010s by various governments with converging objectives which persist to this day in varying forms. However, Norway's journey has been far from smooth, requiring continuous revisions. Despite substantial incentives, the adoption of electric vehicles (EVs) in Norway only gained momentum as technological advancements were realized (Jaeger, 2023). The initial pace was slow, with the first 10,000 EVs taking four years to sell from 2008 to 2011. However, by 2022, the same volume of EVs was purchased within a mere four weeks, signifying a rapid uptick in their acceptance (Békés , et al., 2023). A pivotal shift occurred circa 2012 when the cumulative cost of EV ownership—factoring in purchase, maintenance, and charging—fell below that of conventional gasoline or diesel vehicles, inclusive of tax incentives (Jaeger, 2023). This economic advantage catalysed a surge in the demand for charging infrastructure, hinting at the strategic benefits for investors who expand and enhance EV charging networks in anticipation of electric vehicles reaching price equivalence with internal combustion engine vehicles in their respective markets. As Norway achieved significant EV penetration, the government began to carefully recalibrate and roll back certain initiatives, aligning with its net-zero goals while maintaining a steady momentum in EV adoption. This phased and strategic approach has positioned Norway as a global leader in embracing electric mobility.

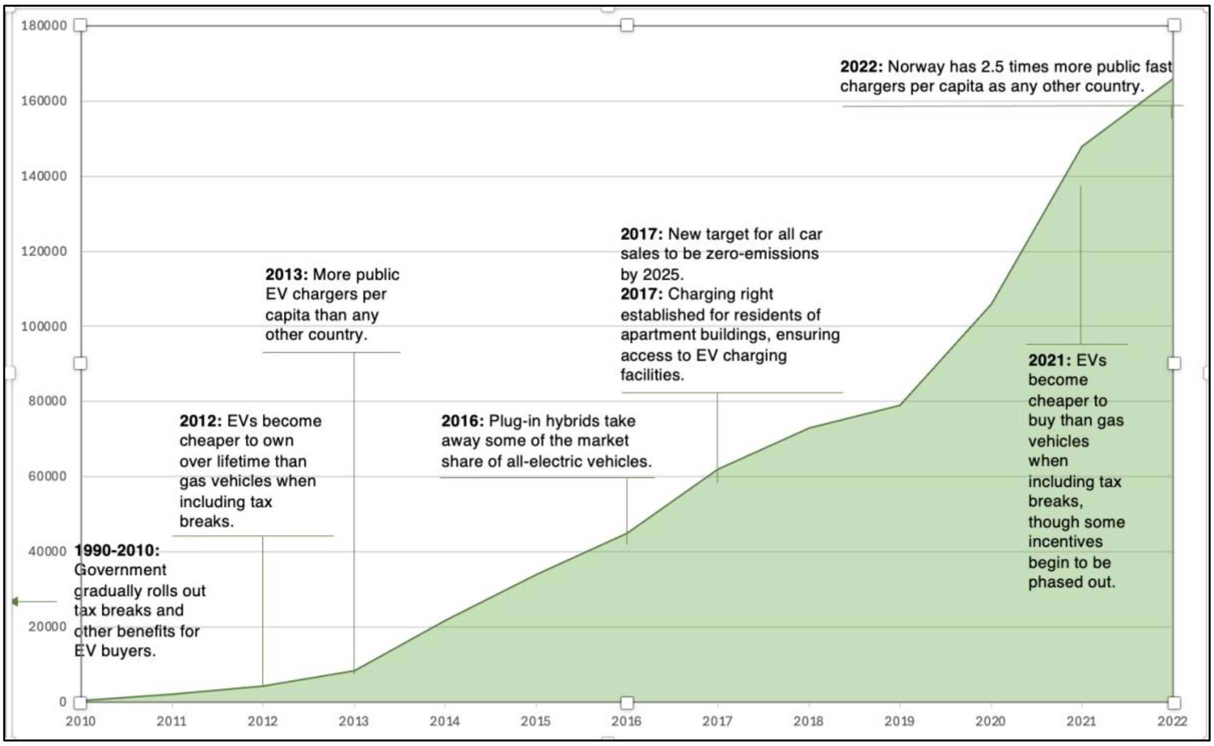
Norway's approach to the development of electric vehicles (EVs) and related policies is informed empirical evidence gathered over the years through numerous studies and business models. EV prototype and propulsion system R&D began in the 1970s, with extensive testing running through 1999. In a significant move in 2008, the Norwegian Ministry of Transport and Communication convened a specialized group, spearheaded by Energi Norge, to formulate a comprehensive action plan aimed at the electrification of road transport. Concurrently, the government initiated Klimakur project conducted a thorough assessment of potential emission reductions across all sectors, with the transport sector's initiatives being directed by the Norwegian Public Roads Administration. The insights from these studies have been instrumental in the creation of policies that have paved the way for electric Mobility in Norway. (Center for Public Impact, 2016).

Beginning in 1990 and extending through 2022, EVs were exempt from purchase or import taxes—a policy that evolved in 2023 to include a variable purchase tax based on vehicle weight.

The "Polluter Pays First" principle led to a long-standing exemption from the standard 25% Value Added Tax (VAT) on purchases, which was modified in 2023 to apply only to vehicles exceeding 500,000 Norwegian Kroner. Other benefits, such as free municipal parking and access to bus lanes, were introduced in 1999 and 2005, respectively, with the latter seeing regulatory adjustments in 2016 to encourage carpooling among EV users. The taxation policies for company cars saw a reduction in benefits over time, with a 50% reduction in company car tax between 2009 and 2017, scaling down to 40% between 2018 and 2021, and further to 20% from 2022. The timeline of incentives also includes the elimination of annual road taxes until 2021, with a phased reintroduction of these taxes from 2022. Ferry charges for electric vehicles followed a similar trajectory. Notably, in 2015, a VAT exemption on leasing was introduced.

In 2017, the Norwegian Parliament set an ambitious national target for all new cars sold by 2025 to be zero-emission. That same year, a "charging right" was established for residents of apartment buildings, ensuring access to EV charging facilities. For longer distance trips, well organised charging infrastructure has been created on all the main roads of Norway. As of 2022, more than 5600 cars could be fast charged at the same time. (Center for Public Impact, 2016) (Norsik elbilforening, n.d.) Along with this Norway exempts electric vehicles from import duties and registration taxes. Additionally, the country predominantly harnesses hydropower for its electricity needs, which enhances the environmental benefits of using electric cars in Norway. (Richter, 2023)

Figure 5- Evolution of Policies in Norway.



Source- WRI, 2018; Authors Analysis.

In the year 2021, Norway witnessed an impressive trend where electric vehicles constituted approximately two-thirds of the new passenger vehicle market (OECD, 2022). Projected figures from the government suggest a potential surge in the zero-emission vehicle (ZEV) stock to 1.25 million by the year 2030, a significant increase from the 225,000 estimated in the absence of incentives (Békés , et al., 2023). In alignment with environmental objectives, the Norwegian

Parliament has established an ambitious target, mandating that by 2025, all newly sold vehicles must be zero-emission, whether powered by electricity or hydrogen (Norsik elbilforening, n.d.). These fiscal incentives have proven pivotal in catalysing the shift in consumer demand towards ZEVs, thereby expanding their prevalence within the national vehicle fleet. The Norwegian government is currently channelling efforts into the creation of a sustainable vehicle taxation framework, reflecting the triumph of electric mobility. The acceleration of the ZEV transition has been further facilitated by public investments aimed at the establishment of an extensive network of charging stations. This includes the strategic implementation of cost-effective batteries and related services. By 2020, the infrastructure boasted in excess of 13,000 charging stations, with close to 1,600 designated as high-speed charging points, funded through public subsidies. Complementing these developments, Enova, a state-operated entity, has contributed to the enhancement of charging facilities for approximately 150 city buses in Oslo (Békés , et al., 2023).

The incentivization of zero-emission vehicles (ZEVs) in Norway, while effective in driving their adoption, has not been without fiscal repercussions. The resulting decrease in revenue from car-related excise duties has been significant, with the foregone tax from the VAT exemption on ZEVs amounting to 11.3 billion Norwegian Kroner (approximately USD 1.3 billion) in 2021. This figure is juxtaposed against the overall financial benefit of electric vehicles, which include fully battery electric and plug-in hybrids, calculated at 30 billion Norwegian Kroner (around USD 3.5 billion) in the same year. These policy-driven incentives have indeed escalated ZEV sales, yet they have concurrently engendered a reduction in tax revenues, comprising nearly one-third of the nation's environmental tax revenues. Thus, these fiscal instruments have paradoxically become victims of their own success, as reducing environmentally detrimental activities has simultaneously eroded the tax base (Békés , et al., 2023). In response to these dynamics, the government is contemplating the imposition of VAT on higher-end electric vehicles, marking a preliminary step in redistributing the financial obligations associated with road maintenance and the expansion of infrastructure, as well as addressing other related externalities. The introduction of a road use tax, adjusted according to time and location, is also proposed as a measure that would be met with approval, suggesting a shift towards a more balanced and sustainable fiscal strategy.

The competitive landscape of Norway's Electric Vehicle Charge Infrastructure (EVCI) market has remained robust, driven by a high level of demand. Despite this demand, the industry has yet to see a definitive market leader emerge, as initial efforts have predominantly catered to the early adopters. Currently, as the market expands and consumer expectations grow more complex, the competitive atmosphere is becoming more acute. Operators are now under increasing pressure to provide superior services. This trend is anticipated to replicate itself globally as electric vehicle (EV) adoption rates increase, technologies advance, and consumer demands evolve. (Békés , et al., 2023)

The development of an ecosystem in Norway that prioritizes electric mobility as the most convenient option for consumers has clearly been successful in Norway. However, when acknowledging the strides made by Norway, it becomes crucial to contextualize its economic backdrop. Norway's ability to allocate substantial subsidies for EVs is somewhat ironic, given its wealth largely stems from extensive oil reserves. This positions Norway uniquely and suggests that replicating its model would be unfeasible for nations with differing economic foundations and political structures. Therefore, it is vital to assess the strategies of other economies that have been successful in the transition to electric mobility with varying conditions when considering the broader application of such systems.

2.5. Takeaways from the Implementation of ZEV in Economies

An examination of the ZEV policies across these nations reveals a set of common strategies that have been instrumental in sculpting the landscape for electric vehicles, making the ZEV mandate effective within their respective domains. These strategies have matured over time, mitigating challenges, and evolving into robust policy frameworks.

Table 2- Key Insights from ZEV Implementation in Economies leading EV transition.

Country	Key Takeaways from ZEV Implementation
United States	Incrementally Increasing Stringent Credit Requirements
	Differentiation Among Manufacturers based on manufacturing capacity
	Long-term Vision of product standards with Sales Compositions
	Monetary Benefits for low Income Consumers
	Emphasis on Long term Fuel savings
	Funding for Infrastructure Expansion
	Legislative Support
China	Strategic Policy Implementation after attaining level of Technological development
	Credit-Based System in the basis of efficiency of vehicle produced
	Mandatory Credit Targets with Trading Option
	Dual-Credit Policy to address fuel efficiency and promote NEVs
	Penalties for Non-Compliance
	Tax incentives and Breaks
	Supportive Infrastructure policies
European Union	Flexibility in Compliance
	Incremental Emission Reduction Goals
	Differential Credits for different types of EVs.
	Relaxation of emission standards on the basis of sales targets
	Rolling Over Compliance:
	Long-Term Vision with Escalating Targets
Norway	Long-Term Tax Exemptions
	Incremental Policy Adjustments
	Making EVs the best choice for consumers through economic advantage
	Charging Infrastructure Investment
	Legislative Support for Charging
	Gradual Introduction of Taxes
	Strategic Financial Planning

Source - Authors Analysis.

By analysing these key takeaways and integrating them within the Indian context, the nation can enhance its existing environmental landscape, thereby laying a solid foundation for the potential implementation of a ZEV mandate.

3. India's Automobile sector: Current Landscape

To comprehensively evaluate the impact of the Zero-Emission Vehicle (ZEV) mandate in India, it is essential to first understand the current landscape of the Indian automobile sector. This includes examining its production, sales, value chain components, and the ongoing shift towards electric mobility. A detailed analysis of these elements within the industry will provide a foundation for assessing the potential influence of the ZEV mandate.

Presently, there is a noticeable imbalance between component manufacturers and Original Equipment Manufacturers (OEMs), with the industry being heavily reliant on demand-side incentives. While production capacity is gradually increasing, the transition to electric vehicles is predominantly driven by a select few OEMs. The introduction of stringent regulations, coupled with mandatory compliance and associated penalties, has the potential to streamline these efforts and bridge the disparities within the sector. Therefore, a thorough examination of the current state of the automobile industry, its policies, and its value chain is imperative to grasp the significance of the ZEV initiative and its prospective impact upon implementation.

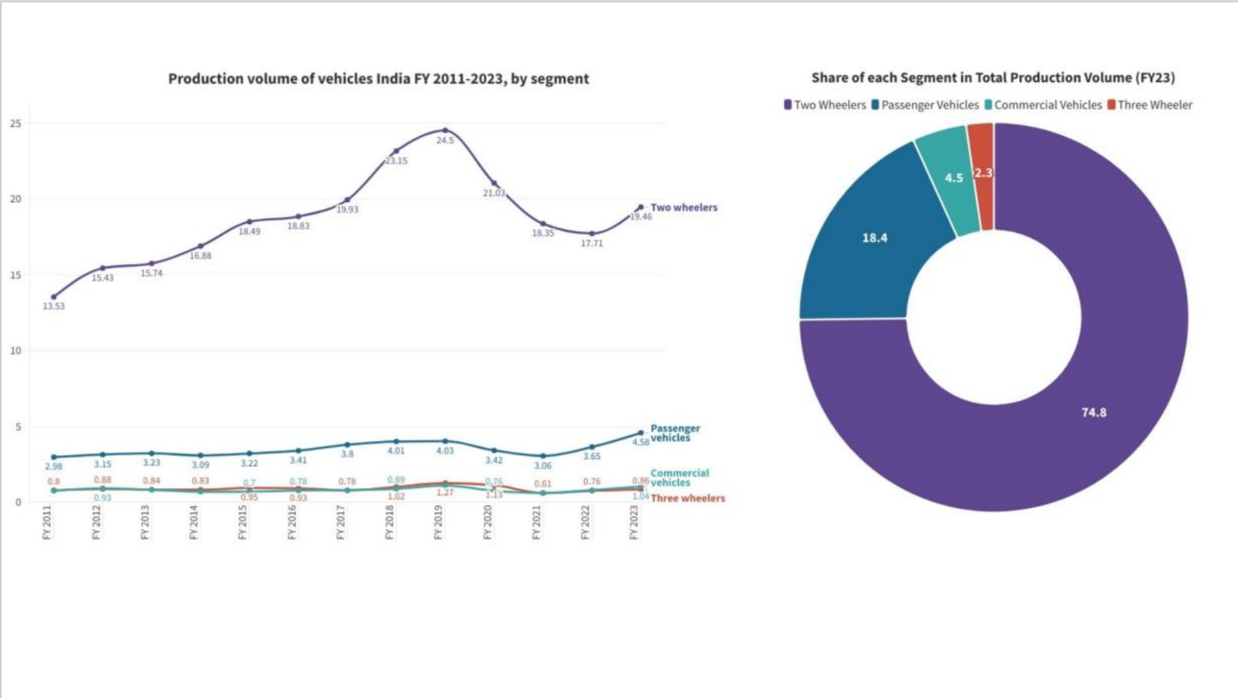
3.1 Indian Automobile Sector

The efficiency of any policy in an economy depends on the current standing and the ecosystem of the industry. The Indian Automobile Industry has held an integral spot in the Indian economy. India achieved the status of becoming the third biggest vehicle market in December 2022 (Ministry of Finance, 2023).

The industry has had significant growth, increasing from 2.77% in 1992-93 to 7.1% throughout the years ((PIB, 2023), (Ministry of Finance, 2023)). The value of India's Automotive market in 2021 was USD 100 Billion and is projected to reach USD 160 Billion by 2027, with an annualized growth rate (CAGR) of 8.1% over the forecast period 2022-2027 (Mordor Intelligence, 2023). In 2021, it accounted for 49 per cent of the manufacturing GDP and produced a total of 3.7 crore direct and indirect jobs (Ministry of Finance, 2023). From April 2000 to March 2023, the industry received a total of US$ 34.74 billion in foreign direct investment (FDI), which accounted for 5.45% of the total FDI in equities during this period (IBEF, 2024).

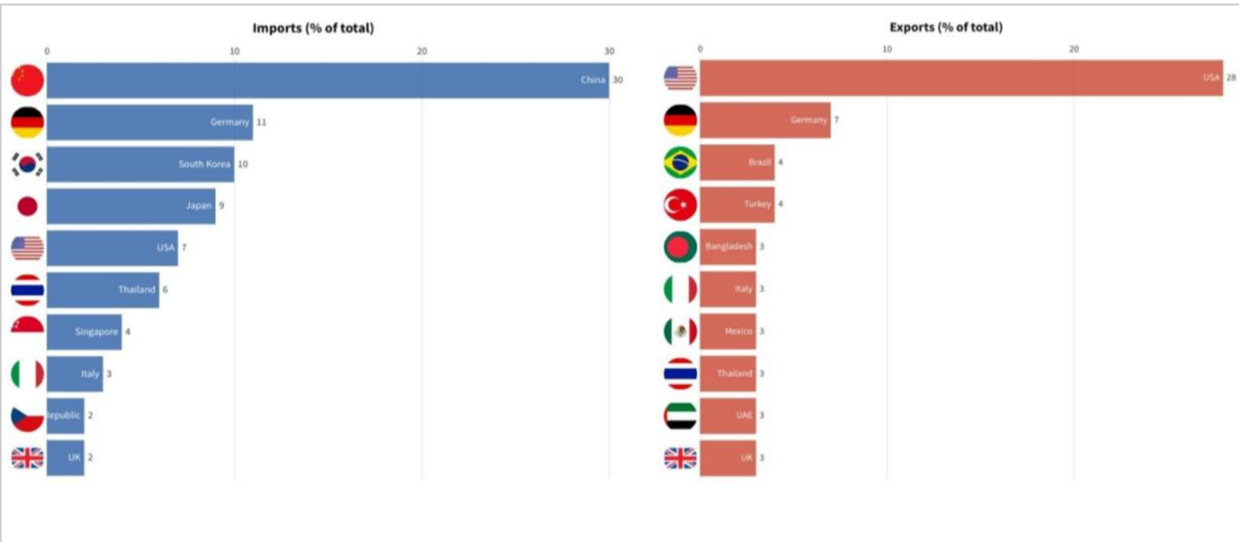
India occupies a major place in the global heavy vehicles industry, being the largest producer of tractors and two-wheelers, second-largest producer of buses, and third-largest producer of heavy trucks worldwide (PIB, 2023) (Invest India, 2023). In the fiscal year 2022-23, the industry manufactured a total of 2,59,31,867 vehicles, comprising Passenger Vehicles, Commercial Vehicles, Three-wheelers, Two-Wheelers, and Quadricycles, signifying significant growth compared to the previous year's output of 2,30,40,066 units. Within this period, two-wheelers dominated the market with a substantial 74.8% share, while passenger cars constituted 18.4%. (SIAM, 2022).

Figure 6- Overview of Indian Automobile Industry Production and Components.



Source - SIAM, 2023

Figure 7- Leading Sources and Destinations of EV Components



Source - ACMA, 2023

The auto components industry adds 2.3% to India's GDP and provided direct employment to 1.5 million people. During the period from FY16 to FY22, despite a CAGR of 6.35% to a value of US$ 56.50 billion, the sector has a heavy reliance on imports, particularly for auto-electronics, which comprises 64% of the demand. (ACMA, Grant Thornton, 2023).

A trade deficit of $20 million in FY 2023 highlights a modest export growth of 5% against an 11% surge in imports, reflecting the nascent stage of EV manufacturing in India The export trajectory of auto components is anticipated to expand, targeting a figure of US$ 30 billion by the fiscal year 2026. (IBEF, 2023). This growth in imports can be primarily attributed to the increasing prominence of electric vehicles (EVs) and the embryonic stage of EV manufacturing within India. An examination on a country-wise basis indicates that the United States stands as the principal destination for exports, whereas China emerges as the primary source for imports (ACMA, 2023).

3.2 A Shift in the Indian Automobile Industry with the Rise of Electric Vehicles

Prime Minister Narendra Modi outlined the vision for the future of mobility in India during the 2018 Global Mobility Summit in New Delhi, emphasizing seven key principles: Common, Connected, Convenient, Congestion-free, Charged, Clean, and Cutting-edge (PIB, 2018). Aligning with this vision, Amitabh Kant, G20 Sherpa of India, stressed the importance of transitioning 100% of 2-wheelers and 3-wheelers, and 65-70% of buses to electric vehicles (EVs) by 2030 to meet the EV30@30 targets. According to a CEEW study (Soman, Kaur, Jain, & Ganesan, 2020) achieving 30% EV sales could result in a 31% reduction in oil imports, generate approximately 121,422 jobs in the EV value chain, create a market opportunity exceeding INR 2 lakh crore (USD 26 billion) for EV powertrain and batteries, and about INR 13,372 crore (USD 1.8 billion) for public charging infrastructure by 2030.

Currently, Two wheeler (2W) EVs form the majority of EV sales today, accounting for 85%–90% of all EV units sold in India, followed by four-wheeler (4W) EVs (7%–9% of sales) and three-wheeler (3W) EVs (5%–7% of sales) (Seetharaman, et al., 2023). Penetration of EVs by 3-wheelers is 8%, followed by E-Buses at 7%, E-2 wheelers at 5%, and passenger vehicles hovering around 1%. By 2023, E-rickshaws, constituting 90% of the 3 Wheelers, achieved a penetration rate of 53%, driven by factors such as accessibility, low maintenance costs, advancing technologies, and the growing demand for efficient passenger transportation (Vahan Dashboard, 2023) (Economic Times, 2023).

Currently, two-wheeler (2W) EVs form the majority of EV sales today, accounting for 85%–90% of all EV units sold in India (Seetharaman, et al., 2023). The proliferation of two-wheeler and three-wheeler vehicles has been significantly propelled by a milieu of innovation and supportive activities, such as retrofitting and the implementation of Battery-as-a-Service (BaaS) models. For instance, Sun Mobility, India's prominent BaaS provider, provides BaaS models for last mile services of two wheelers and three wheelers. Sun Mobility has partnered with various delivery firms like Swiggy and EV manufacturers like Bouncy Infinity to increase proliferation of EV two wheelers through BaaS. The high pace of innovation and adaptation especially among dedicated electric vehicle (EV) manufacturers, is largely attributed to the enactment of progressive policies, alongside the deployment of FAME I and II subsidies. These factors coupled with a vast market has made it profitable for purely EV manufacturers to enter the market (Currently various Pure two-wheeler EV manufacturers like Ather, Ola, Bouncy Infinity are prominent in the market). The coexistence of pure EV manufacturers and manufacturers producing both ICE and EV have ensured consistent supply of evolving products catering to an expanding consumer base.

The three-wheeler market has also witnessed substantial penetration of Electric Vehicles (EVs), primarily led by E-rickshaws, which constitute 90% of this segment. As of 2023, the penetration rate for E-rickshaws reached an impressive 53%, contributing significantly to the overall 8% penetration of EVs in the three-wheeler market. This notable adoption can be attributed to factors such as heightened accessibility, cost-effectiveness in maintenance, continuous technological advancements, and a rising demand for efficient passenger transportation (Vahan Dashboard, 2023) (Economic Times, 2023).

However, the four-wheeler automotive segment remains in a nascent phase, exhibiting high price sensitivity having 7%–9% of sales in the market, with a meagre 1% of penetration. For this market segment, an infusion of technological innovation and a reinforcement of technological capacity are imperative. Presently, the industry has a dependency on the importation of batteries, signifying a deficit in indigenous innovation, particularly in the realms of battery technology, powertrain development, and the cultivation of a skilled workforce. It is of paramount importance that targeted policy reforms be instituted to catalyse advancements in these domains, thereby capitalizing on the growing four-wheeler market and increasing compliance with international standards.

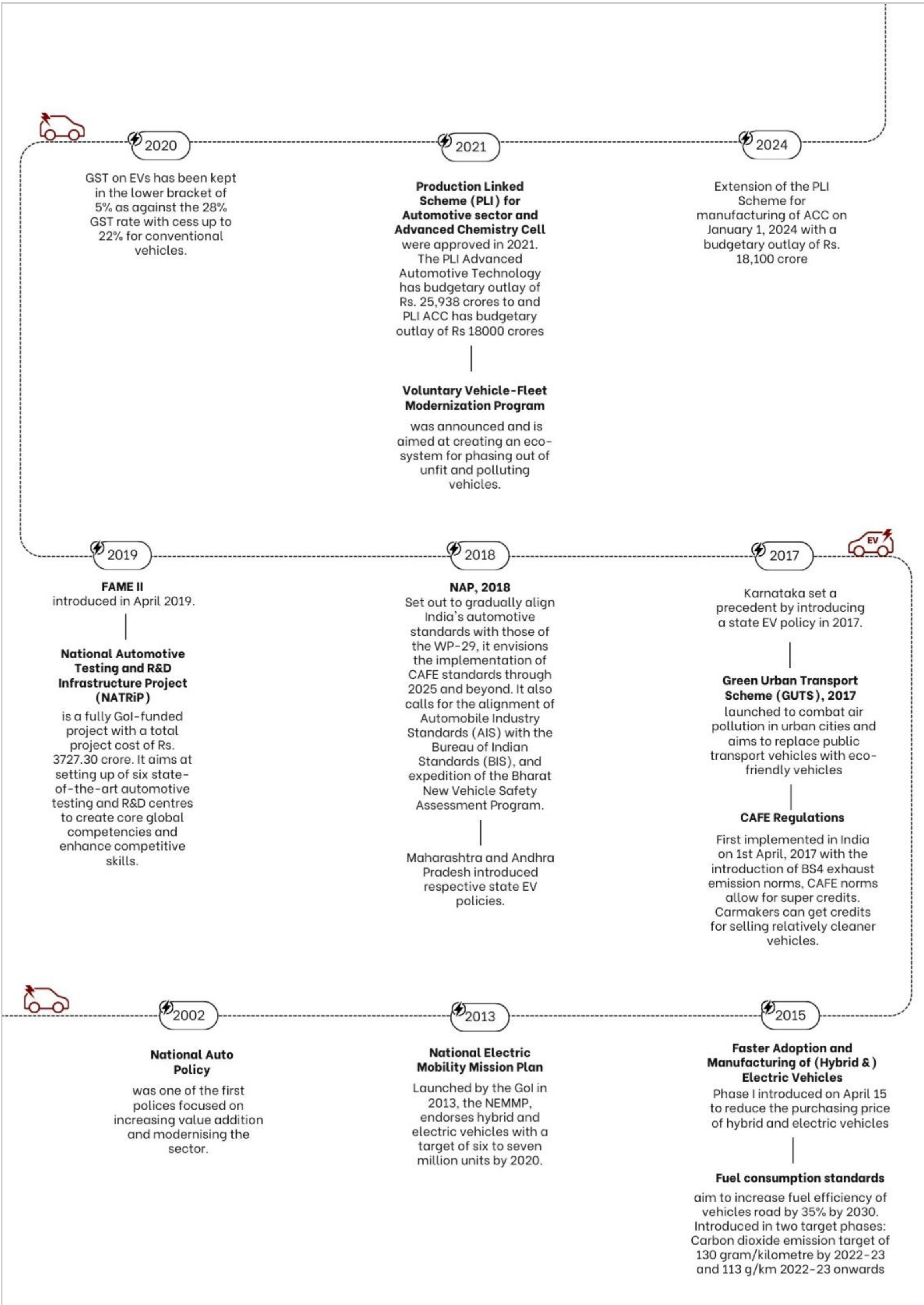
3.3 Government Initiatives Driving the Shift to Electric Mobility

India is embracing e-mobility as a global solution to enhance sustainability and efficiency in the transportation sector. The country has implemented a series of policies to guide the industry's trajectory, addressing technological advancements, infrastructure, regulatory frameworks, and incentives. These policies aim to create a synergistic ecosystem for India's transition to E-mobility. The success of these policies depends on the active engagement of all stakeholders, including manufacturers, consumers, and government bodies. Collaborative efforts among these stakeholders ensure a comprehensive understanding of challenges and opportunities. The establishment of these policies marks a significant step in shaping India's future, positioning it as a global player in sustainable and efficient transportation. The success of these policies depends on continued collaboration and adaptability, paving the way for a robust and dynamic e-mobility ecosystem.

Central Policies

Central policies in India shape the electric vehicle (EV) industry by providing a structured framework, promoting technological innovation, sustainable practices, and seamless integration. They act as catalysts, aligning industry goals with national objectives, contributing to India's sustainable and energy-efficient transportation future by fostering an environment conducive to EV growth and adoption. The following table and flow chart comprehensively illustrates the timeline and objectives of various central policies in the EV Automobile industry.

Figure 8- Evolution of EV policies in India



Source - Ministry of Heavy Industries and Public Enterprises, 2018; ACMA, Grant Thornton, 2023; PIB, 2019; PIB, 2022; PIB, 2024; National Automotive Testing and R&D Infrastructure Project, 2019; GOI, n.d.; Ministry of Road Transport and Highways, 2023; Ministry of Heavy Industries, n,d.

Table 3- Details of EV Policies in India.

Policy	Timeline	Objective
National Auto Policy	2002 onwards	Increasing value addition and modernising the sector
National Electric Mobility Mission Plan (NEMMP) 2020	2013-2020	Bolstering national fuel security through the endorsement of hybrid and electric vehicles with six to seven million units for hybrid and electric vehicles, commencing from the year 2020 onwards
CAFE Norms		First announced in 2014, implemented 1st April 2017 with the introduction of BS4 exhaust emission norms. Car manufacturers were obliged to meet a base target of 130gm of CO_2/km, based on an average industry kerb weight of 1,037kg.
Under NEMMP – FAME I and II	2019-2019, 2019-2024	Increasing adoption by offering immediate price reductions, funding select pilot projects, and investing in research and development as well as public charging facilities
Green Urban Transport Scheme (GUTS)	2017 onwards	Aims to replace public transport vehicles by eco-friendly vehicles
National Auto Policy	2018 onwards	Implementation of Corporate Average Fuel Economy (CAFE) standards through 2025 and beyond, supplemented by a system of incentives and penalties, gradually align India's automotive standards with those of the World Forum for Harmonization of Vehicle Regulations (WP-29) within the next five years, promoting R&D activities and vocational training
National Automotive Testing and R&D Infrastructure Project (NATRIP)	2019 onwards	Fully Government of India funded project with a total project cost of Rs. 3727.30 crore. Aims at setting up of six state-of-the-art automotive testing and R&D centres to create core global competencies, enhance competitive skills, integrate India's IT capabilities with automotive sector
PLI Advanced Automotive Technology products	2021-2024	Budgetary outlay of Rs. 25,938 crores to support domestic manufacturing of vehicles (including EVs) and boost manufacturing of Advanced Automotive Technology products

PLI Advanced Chemistry Cell	2021 onwards	Budgetary outlay of Rs. 18,100 crore, envisages to establish a competitive ACC battery manufacturing set up in the country for 50 GWh
Revision of CAFE norms	2022	In the second phase, from 2022-2023 onwards, manufacturers have to comply with a base industry figure of 113gm of CO2/km, based on an average industry kerb weight of 1,145kg - a reduction in CO2 output of about 13 percent over the earlier period, despite the increase in weight. CAFE norms allow for super credits[12]. Carmakers can get credits by selling relatively cleaner vehicles[13].
Voluntary Vehicle-Fleet Modernization Program (VVMP)	2023 onwards	Aimed at creating an eco-system for phasing out of unfit and polluting vehicles. The program intends to make the Indian scrappage industry organised, transparent, and environmentally friendly and extract value addition from scrappage

Source- Ministry of Heavy Industries and Public Enterprises, 2018; ACMA, Grant Thornton, 2023; PIB, 2019; PIB, 2022; PIB, 2024; National Automotive Testing and R&D Infrastructure Project, 2019; GOI, n.d.; Ministry of Road Transport and Highways, 2023; Ministry of Heavy Industries, n.d.

The aforementioned central policies collectively strive to encompass the entire sector, with the goal of establishing a supportive ecosystem conducive to the transition of the automotive industry.

State-level Policies

Transportation policy in India hinges on a cooperative model between the central and state governments, with states playing a pivotal role in managing policies tailored to local needs, including vehicle and fuel taxes and public transportation. This decentralized approach recognizes the diverse needs of the population across the country, empowering states to formulate and execute policies tailored to their local population. (Ramji & Kankaria, 2022)

In India, the FAME I and II initiatives, PLI schemes stand out as trailblazing schemes that have spearheaded the Electric Vehicle (EV) revolution. These programs provide crucial financial support to manufacturers for establishing facilities and extend assistance to consumers purchasing EVs through subsidies and tax incentives. On the state level, 26 out of 29 states in India have implemented their own EV policies, playing a vital role in fostering innovation and encouraging EV adoption (Times of India, 2023). Karnataka set a precedent by introducing a state EV policy in 2017, with Maharashtra and Andhra Pradesh quickly following suit in 2018.

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[12] The rules regarding super credits in the Corporate Average Fuel Economy (CAFE) standards lack clear details. There is no information in the public domain on the minimum requirements for earning super credits, their benefits, or whether manufacturers can carry over any unused credits to the next period.

[13] This is done by adopting battery electric vehicles (BEV), plug-in hybrids (PHEV) and hybrid electric vehicles (HEV). The credits are awarded as follows: 3 for BEV, 2.5 for PHEV, and 2 for HEV. Currently, there are no penalties for non-compliance to CAFÉ Such norms have nudged manufacturers to increase fuel efficiency in their current fleet and produce EVs.

Notably, only Odisha and Assam have established comprehensive EV targets that span all vehicle categories. Conversely, Bihar has confined its goals to electric three-wheelers. Among the states with specific EV policies, Haryana, Tamil Nadu, and Kerala each have gaps in their targets for certain vehicle segments, such as two-wheelers and passenger vehicles for Haryana, two-wheelers and light commercial vehicles (LCVs) for Tamil Nadu, and passenger vehicles for Kerala. Madhya Pradesh also lacks targets for LCVs.

Delhi, however, is actively advancing the electrification of its last-mile delivery and city logistics fleets, positioning it to potentially surpass the national objective of 20% electrification for LCVs by 2030. If other states adopt Delhi's proactive approach, this ambitious electrification rate could become a nationwide achievement. (Ramji & Kankaria, 2022)

Along with this, 11 states have either waived or subsidized road tax, contributing to a more favourable environment for EV ownership. Several states, such as Maharashtra, Uttar Pradesh, Telangana, Punjab, Madhya Pradesh, and Delhi, are proactively taking steps to establish charging infrastructure. Additionally, Assam, Chandigarh, and Telangana provide a retrofitting subsidy of 15% up to Rs. 15,000. Across India, 21 states have electricity subsidies, with Tamil Nadu offering a notable 100% exemption on electricity tax. Further, states like Punjab, Madhya Pradesh, and Delhi incentivize vehicle scrapping and battery recycling, emphasizing a comprehensive approach to sustainable EV practices at both state and central levels. (Times of India, 2023)

A 2023 study (Climate Trends, 2023) assessed EV policies on 21 parameters that cover targets, allocations, demand and supply side incentives. revealing that only five states (Maharashtra, Haryana, Delhi, Uttar Pradesh and Punjab) have comprehensive strategies. Others show a lopsided focus, impacting balanced stakeholder engagement. Despite setting EV targets, many states are falling short, with achievements ranging from 3-10% of their goals.

It is evident that establishing targets alone is insufficient; it is imperative to couple targets with incentives that embrace a comprehensive and holistic perspective of the entire ecosystem. Achieving this requires a clear understanding of the existing value chain, pinpointing specific areas within the value chain that wield substantial influence on the desired objectives, identifying policy gaps, and incorporating best practices from other nations into our economic framework, tailoring these practices to suit our unique political and economic climate.

4. Examining India's Automotive Value Chain

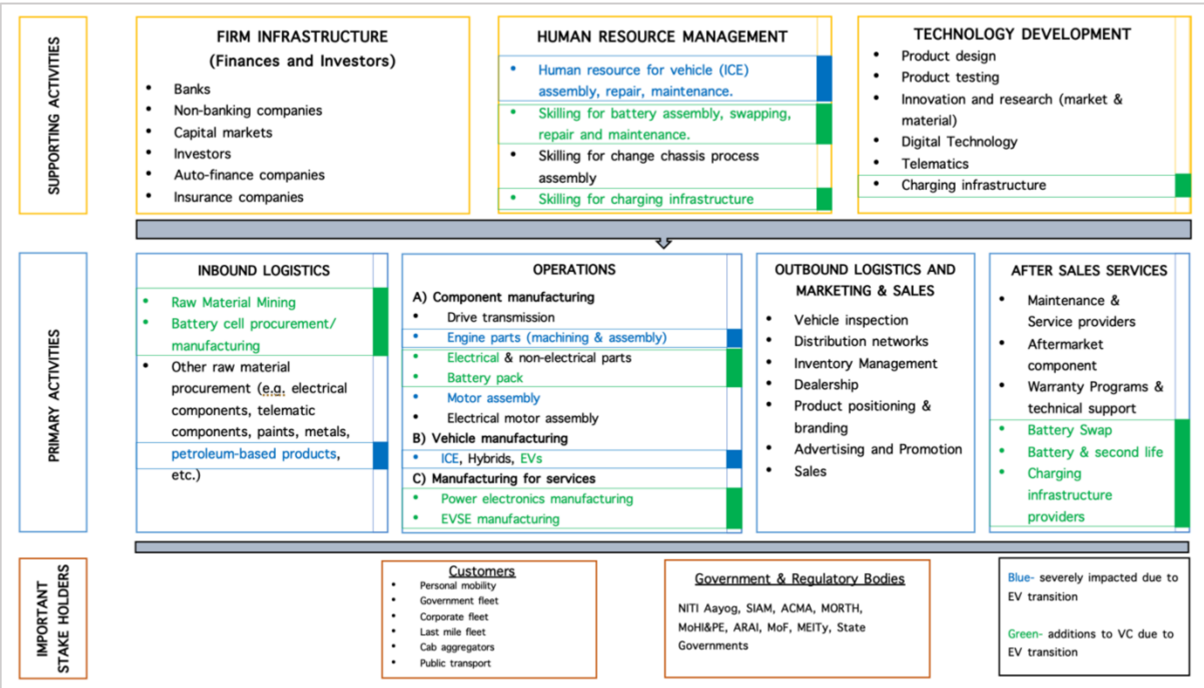
Before embarking on the adoption or evaluation of new policies and initiatives, such as the Zero-Emission Vehicle (ZEV) mandate, it is critical to conduct a thorough examination of the industry's ecosystem and value chain. The successful implementation of these initiatives is contingent upon their alignment with the existing value chain, ensuring they do not lead to adverse disruptions. Therefore, it is crucial to undertake a detailed assessment of the Value Chain of the Indian Automobile Industry. This targeted analysis is specifically aimed at comprehending the structural changes that the industry is facing as it transitions towards Electric Vehicles (EVs).

4.1 Value Chain Analysis

Value chain analysis developed by Michael Porter, has been used across the globe for disaggregating companies, sectors, and industries to identify their sources of competitive advantage through analysing the activities involved in delivering value to customers (Harvard Business School, n.d.). A comprehensive value chain, depicted in figure 10, is developed based on the core principles of this concept by Michael Porter. Inferences are drawn from notable studies examining the Value Chain of the Automobile Industry ((Soman, Kaur, Jain, & Ganesan,

2020) (Kupper, Kuhlmann, Tominaga, Aakash, & Schageter, 2020)). This visual representation illustrates the current activities within the value chain, with a predominance of internal combustion engine (ICE) vehicles and highlights the anticipated changes as India progresses in developing its automobile ecosystem to accommodate Electric Vehicles (EVs).

Figure 9- Indian Automobile Sector Value Chain.



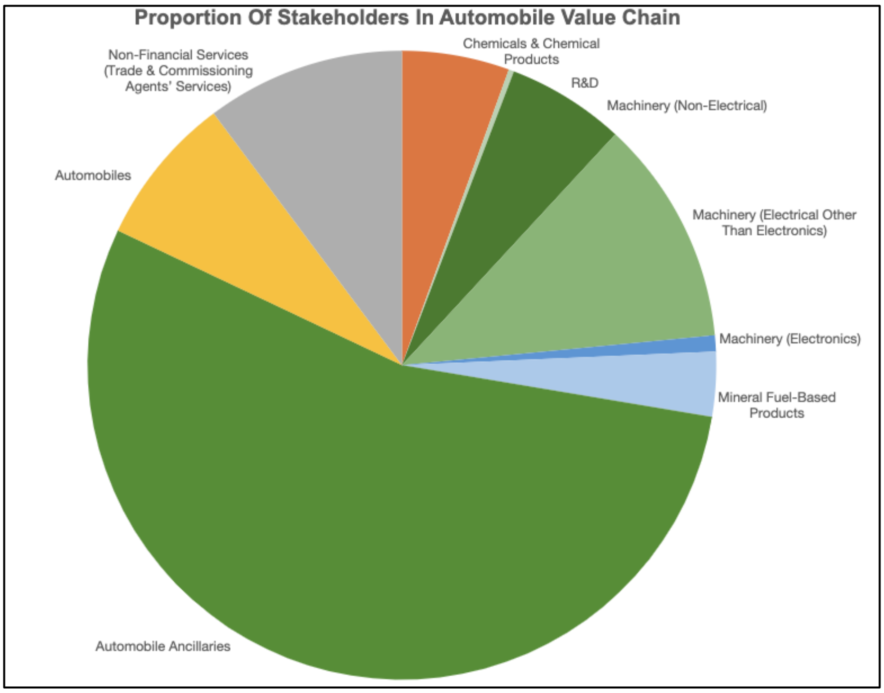
Source – Harvard Business School, n.d; Soman, Kaur, Jain, & Ganesan, 2020, Kupper, Kuhlmann, Tominaga, Aakash, & Schageter, 2020 & Authors Analysis

An examination of current companies in India, utilizing data from ProwessIQ[14], portrays the proportions of various stakeholders within the automobile ecosystem and their value addition. This includes manufacturers of automobiles, automobile components, electrical and non-electrical machinery, mineral fuel-based products, chemical and chemical products, as well as non-financial services such as trade and commission services, and research and development. (Refer to Section 1 of the Appendix).

The data shows that the majority (~54%) of manufacturers are involved in the manufacture of Automobile Ancillaries i.e., transport equipment (e.g. Drive transmission and steering parts, suspension and braking parts, Automobile Engine parts and so on), and the least amount (~3%) are involved in the manufacture of automobiles. However, from 2017-18 to 2022-23 shows that the maximum value addition has been by the meagre 3% involved in the manufacture of automobiles. This disproportionate distribution raises concerns, especially considering that the impending transition will significantly impact component suppliers.

[14] The dataset encompasses records from 364 companies, spanning the years 2018 through 2023. The year 2018 has been designated as the baseline for comparative analysis to integrate the impacts of the FAME I and II policies.

Figure 10- Proportion of Stakeholders in the Indian Automobile Value Chain



Source- Author's Analysis based on ProwessIQ Data Base.

India holds a competitive edge in the auto components sector, particularly in categories such as shafts, bearings, and fasteners, owing to a significant number of players in these segments. This advantage is noteworthy given the persistence of these components in the shift from internal combustion engines (ICE) to electric vehicles (EVs). However, Indian firms face a pronounced deficit in competitive edge across several vital segments, primarily due to investments in research and development (R&D) that fall short in comparison to international counterparts.[15]. A lack of substantial R&D investment, combined with insufficient collaboration between information technology firms and automotive manufacturers, leads to a notable underutilization of India's robust software capabilities within the automotive sector (ACMA, Grant Thornton, 2023).

At a critical point where innovation becomes pivotal to securing a competitive advantage during the ongoing transition, the importance of integrating research and development with technology cannot be overstated. Policies or strategies aimed at facilitating this transition will fall short if the underlying technology fails to evolve concurrently. An analysis of different policies and Zero-Emission Vehicle (ZEV) mandates in various economies reveals that a mismatch between mandates and policies in countries like the US and China have posed a challenge in their transition. Unlike these economies, India does not have the luxury of time. Instead, India should be proactive in learning from these examples and strive to synchronize research, development, and technology with the entire automotive value chain.

To tackle these challenges, strategic initiatives such as the Bharat New Car Assessment Program (BNCAP) have been introduced with the objective of strengthening the automotive value chain and concurrently fostering advancements in manufacturing and innovation (IBEF, 2023). Additionally, in tandem with these efforts, Production Linked Incentive (PLI) schemes specifically tailored for the auto components sector have been implemented, providing vital support for the establishment of manufacturing capabilities in the country. These combined

[15] Indian auto-component manufacturers historically allocated less than 3% of their revenue to R&D, whereas global majors dedicated a more substantial 6-10% of their revenue to research and development initiatives.

measures represent a concerted approach to augmenting the automotive industry with broader objectives of technological advancement and self-sufficiency.

In contrast to global best practices where most Original Equipment Manufacturers (OEMs) are well-integrated or have established robust supply networks (ACMA, Roland Berger, 2018), India has yet to establish a strong supply base. More than 75% of the Indian component Industry players are tier 2 and tier 3 players. Despite their substantial presence, these players contribute proportionally less to the overall value chain compared to Original Equipment Manufacturers (OEMs). With electric vehicle components constituting approximately 60% of the overall EV cost at present and expected to remain above 50% in 2025. This imbalance in stakeholders of the value chain results in OEMs working in silos due to inadequate domestic component manufacturers, pose significant threats to their exports and local markets (ACMA, Roland Berger, 2018). This susceptibility is particularly concerning during transitions to new technologies, where weak linkages within the supply chain impede progress and foster dependency on other countries for crucial parts, components, and technology. It is imperative to establish a balanced value chain where every stakeholder, irrespective of their tier, is sufficiently incentivized to remain in the industry and contribute meaningfully. Only through such incentives can robust linkages be formed, fostering a forward-looking industry capable of navigating technological transitions and reducing dependence on external sources.

To mitigate these risks in the Indian automobile ecosystem, it becomes imperative to incentivize suppliers and enhance their value addition to prevent high imports, and elevated manufacturing costs, resulting in a higher total cost of ownership, and ultimately impeding the goals of a successful EV transition. The implantation of a binding target with a focus on localisation can align the formulation of policies needs to be strategic, ensuring that stakeholders at each level of the value chain are aligned with the transition objective.

4.2 Major Impediments to EV Transition India

The comprehensive analysis of the automobile landscape, current policies, global practices, and the value chain underscores discernible gaps within the Indian automotive system. These gaps are critical impediments hindering the acceleration of India's automotive sector towards its e-mobility goals.

1. ***High Total Cost of Ownership (TCO) From Stakeholders and Policy Misalignment.***

The cost of a product to the consumer is not only dependent on the cost to the manufacturer but by the efficiency of supply and value chain integration, and the degree to which the product aligns with consumer preferences and budget. Cost of Ownership is one of the most important Factors affecting Purchase Intention, Performance Features, Financial Benefits, Environmental concerns, Social Influence, and Infrastructure Support (Mishra & Malhotra, 2019). While analysing the cost of ownership, rather than solely assessing cost efficiency based on upfront expenditures, a more comprehensive perspective emerges when considering operating costs. This approach provides a realistic portrayal of expenses incurred throughout the vehicle's lifecycle. Total Cost of Ownership (TCO) amalgamates both purchase and operational outlays, facilitating the identification of the most economically viable vehicle choice. (Palmer and Tate, 2017).

In this research, an analysis of the Indian 2W and 4W vehicles is undertaken by analyzing the top-selling vehicles in both the two-wheeler and four-wheeler markets[16] considering parameters of purchasing cost, fuel costs, maintenance cost, taxes, subsidies and resale value. The analysis

[16] For Calculations, refer to Section 2 of the Appendix.

shows that demand side subsidies have been successful in pulling down the upfront as well as the TCO for two wheelers. Likewise, the combination of the FAME subsidy and technological advancements in electric three-wheelers has yielded economies of scale. This has not only enhanced competitiveness in terms of TCO but has also diminished the purchase price disparity to less than 1.3 times that of a comparable Internal Combustion Engine (ICE) model, thereby accelerating widespread adoption. (Ramji & Kankaria, 2022). The penetration and cost efficiency of two and three wheelers can also be attributed to the possibility of retrofitting and the ease of Battery-as-a-Service especially for last mile vehicles in these segments, which is difficult in passenger vehicles due to technological complexity.

However, in the case of four wheelers, despite lowering of GST, exemption from other taxes, exemption on registration fee, income tax benefits; TCO remains high, This, in turn, hampers the steady growth of penetration. Table 1 clearly states the differences in upfront costs and TCO of Petrol, Diesel and Electric Car[17]. Electric vehicles (EVs) present a financially attractive option in the long term, primarily due to their substantially lower total cost of ownership (TCO). However, the initial purchase price remains prohibitively high for many consumers. To make EVs more accessible, a significant reduction in the upfront costs—by approximately 30-40%—is necessary to align the purchase price closer to the 8-lakh rupee range. Though this figure overly idealistic, it serves as a valuable benchmark for manufacturers to understand the extent of cost reduction needed to increase consumer affordability.

Table 4- Cost and TCO of different categories of Passenger Cars

Category of Passenger Car based on Fuel Type	Upfront Cost	TCO (Usage Period 5 years at 15,000 km per year)
Petrol	13,32,842	13,19,140
Diesel	15,40,213	14,50,372
Electric (including exemptions)	**15,43,905**	**10,62,843**

Source- Author's Calculations.

An examination of the Top 10 selling ICE passenger cars[18], which collectively represent 53.19% of the market, reveal that only two of the top 10 popular models fall within the Rs 10-20 lakh range, while the majority of vehicles have an initial price ranging from Rs 5-8 lakhs. There exists a stark contrast in price points between conventional ICE cars and available electric options, with just one EV falling within the Rs 8 lakh range. This disparity poses a critical hurdle to the wider adoption of electric vehicles among the general consumer base. The existing scenario underscores a pressing need for the EV industry to strategize and innovate to bridge this affordability gap.

The resolution of the affordability gap mostly rests on whether demand-side incentives are employed to increase market share or whether supply chain and technology innovation are encouraged. The latter approach aims to achieve economies of scale, consequently reducing prices from the supply side. Although demand incentives in India are in line with best practices, improving production process efficiency and putting in place strong supply-side incentives are the keys to cutting upfront costs.

[17] The prices are on the basis of the best-selling EV in 2022 (TATA Nexon)
[18] On the basis of October 2023 data.

2. *Dependency on Demand Side Incentives.*

The current landscape of both central and state policies highlights a significant reliance on demand-side incentives. While there are supply-side initiatives such as the Production-Linked Incentive (PLI) and programs aimed at developing the ecosystem, their impact remains limited in terms of reach and efficiency. It's crucial to recognize that demand-side policies which align with Global best practices, possess inherent limitations. Further amplifying them could strain government finances and prove unsustainable. Moreover, these policies do not directly influence manufacturing costs, technology, or innovation—elements fundamental for cultivating a robust ecosystem.

Addressing this requires a strategic focus on manufacturing incentives that not only streamline processes but also propel India in the direction of sustained growth and innovation.

3. *Lack of singular target and mismatch between state targets.*

In the context of India's endeavours to electrify its vehicular fleets, systemic inefficiencies emerge due to disjointed initiatives across the sector's various components. The government's role is critical in facilitating the attainment of electrification benchmarks through fiscal incentives and subsidies. However, the absence of explicit performance benchmarks for vehicle manufacturers and component suppliers engenders an imbalanced strategic approach. This scenario is reminiscent of the early stages of electric vehicle policy development in other nations. For instance, a deficiency in long-term policy clarity coupled with dispersed regulatory oversight initially led to uncoordinated micro and macro-level policies in China (Li, Yang, & Sandu, Electric vehicles in China, 2018). Analogously, in the United States, a misalignment between policy initiatives and comprehensive market analysis contributed to delayed market penetration, as investments did not resonate with consumer predilections and price sensitivity (Green, Skerlos, & Winebrake, 2013). Subsequent policy restructuring in these countries has been pivotal in establishing more efficacious electric vehicle strategies.

While it is crucial for each state to tailor policies according to its unique political and economic conditions, a coordinated effort is essential to ensure a unified direction and collective goal attainment. Presently, the absence of checks and balances in the overall aims hinders effective monitoring, potentially leading to a misalignment of efforts and stifling progress toward the shared goal. Establishing clearer, measurable targets for all stakeholders and implementing robust monitoring mechanisms will be key to enhancing efficiency and achieving successful electrification outcomes across the nation.

The high discordance between policies, stakeholders and segments within the automobile ecosystem signifies the need for a unified approach in order to keep pace with the climate and economic goals. At this stage, it is important to turn our attention focus to the effects of targeted initiatives such as the Zero-Emission Vehicle (ZEV) mandate, which has been instrumental in the transitional strides of major economies and consider its potential impact within the Indian context.

5. Integration of Zero Emission Vehicle (ZEV) Mandate into the Indian Economy

The introduction of the Zero-Emission Vehicle (ZEV) Mandate signifies a pivotal stride towards the widespread adoption of electric vehicles in numerous countries, all sharing a common objective: to catalyse and expedite the transition to electric mobility. The mandate delineates a comprehensive strategy, encompassing multiple phases, benchmarks, deadlines, and penalties. This meticulous framework ensures that all stakeholders in the automotive industry are collectively steering towards a shared goal, fortified by unwavering governmental policy support.

In the context of India, where the momentum for electric vehicle adoption is gaining traction, it becomes imperative to harmonise and integrate targeted efforts. This integration is crucial for positioning the nation competitively within the global movement towards sustainability. Nevertheless, a discerning perspective must be applied, acknowledging the unique disparities between India and other nations that have implemented the ZEV mandate.

These disparities manifest across various facets, including manufacturing capabilities, integration with global value chains, and a substantial reliance on internal combustion engine (ICE) vehicles. India is thus compelled to tailor its approach judiciously, drawing insights from the triumphs and tribulations of other nations' policies rather than duplicating them verbatim. It is within this context that we delve into the exploration of a mathematical model to scrutinise the potential implementation and ramifications of the ZEV mandate in the Indian context.

This section of the paper will not only shed light on the prospective outcomes but also pave the way for a comprehensive discussion on the requisite investments and policy adjustments. These adjustments are paramount to underpinning the successful transition towards a ZEV-centric automotive landscape in India. The subsequent section of this discourse will expound on the multifaceted dimensions of this transition, examining the intricate interplay of economic, infrastructural, and regulatory factors.

Moreover, it is essential to anticipate and address the implications of a ZEV mandate for India's vehicular policies and automotive aspirations. The dynamic nature of the automotive market, coupled with evolving consumer preferences, necessitates a strategic evaluation of how such a mandate would reshape the landscape. This foresight is essential for coordinating current policies and goals with the ZEV mandate's transformative trajectory in order to ensure a cogent and sustainable evolution of the Indian automotive industry.

5.1 Model

We provide the mathematical model to examine the impact on Indian economy in case a Zero Emission Vehicle (ZEV) comes into effect. The main objective of the model is to evaluate the total influence of ZEV Mandate on prominent vehicle manufacturers in India. We analyse the evolution of the production composition of these automakers using simulation in order to adapt to the regulatory change. This offers insights into the modifications and accommodations that original equipment manufacturers (OEMs) will have to make in order to comply with the required production levels. Furthermore, the model provides information regarding the efficacy of the ZEV Mandate policy in promoting the use of Zero Emission vehicles in India.

Given the paucity of literature on the impact of a ZEV mandate in a market in context of developing economies, its feasibility and applicability in context of India has been not explored currently. This makes our model the first attempt to understand its applicability to India as a nation. ZEV mandate has not been thoroughly contemplated by legislators and researchers in the country. In China extensive research has been conducted on the impact of its dual credit policy and other measures aimed at increasing the adoption of electric vehicles (EVs) in the market. (Yaoming Li, 2018) analyses the impact of dual credit policy on vehicle manufacturers in the country using a game theory-based optimisation model. The study shows that enacting a ZEV mandate is always better than purely providing production subsidies to the manufacturers in the country. A similar analysis conducted by (Shiqi Ou a, 2018) found the dual credit policy in the Chinese automobile market to be beneficial for increasing the share of Battery Electric vehicles as compared to other policy scenarios in the simulation for the time period 2016-2020. Similar studies have been conducted in other countries too. (Chandan Bhardwaj, 2021) developed an Automaker Consumer model to analyze the demand and supply side effects on the Canadian automobile market upon introduction of a ZEV mandate of 30% EV production. Their study concluded that even with the implication of the mandate, almost all the automakers in the market would be able to meet the target mandated by the government but would lead to a reduction in the profits of the automakers by 7 -44%.

5.2 Model Description

This study employs a non-linear optimization approach to simulate the effects of a mandate policy on the production decisions of various automakers in the market. The objective function of the model is to maximize the total profit for each participating firm. Additionally, linear constraints are incorporated into the optimization problem to accurately illustrate the impact of the mandate. This simulation, designed specifically for the Indian automotive industry, incorporates the Zero Emission Vehicle (ZEV) regulation to assess its potential consequences on domestic four-wheeler producers. The model presupposes that the manufacturers are obligated to meet a ZEV mandate of 30% of their total production. Requiring that at least 30% of vehicles manufactured are Zero Emission Vehicles (ZEVs) is in line with the Indian Government's goal of attaining a 30% market share for ZEVs in the Indian market by 2030. Every car manufacturer is required to comply with this directive, which means they must produce 30% of their vehicles as zero-emission vehicles (ZEVs). Each Zero Emission Vehicle (ZEV) unit produced by a manufacturer earns the manufacturer two ZEV credits from the government, which can be traded in the credit market. This is a new element of the mandate policy in the country as the current super credits earned by the manufacturer based upon CAFÉ regulations in terms of production of Zero Emission Vehicles are not tradable in the current system. The allocation of two credits for Zero Emission Vehicle (ZEV) manufacturing is derived on the practice observed in other nations, where ZEV credits are exchanged and bestowed upon manufacturers. Each country employs its own system for distributing credits based on the classification of vehicles, including BEVs, PHEVs, hybrid vehicles, and others. The paper assumes a constant credit of two units for all types of zero-emission vehicles (ZEVs). The target of Zero Emission Vehicle (ZEV) credits for each automaker is governed by a specific equation:

Target ZEV Credits = 2 * 0.3 * (Total production of vehicles by the firm).

Any excess credits earned can be traded in the market. However, credits earned within a financial year are based solely on the manufacturer's production volumes for that year. Banking or carrying forward credits from previous years is prohibited, rendering redundant any excess credits left with the manufacturer after compliance and trading. Automakers failing to meet their credit targets must purchase the remaining credits from the ZEV credit market. If an automaker fails to fulfil its ZEV credits target, then it would be punished by the Indian government in the form of a heavy monetary penalty.

5.3 Formulation of the Model: Four-Wheeler Market in India

In this research model, the focus lies majorly on the Four-Wheeler Manufacturing Industry. The primary reason for focusing the research on the specific vehicle segment is due to the notably low penetration of Zero Emission Vehicles (ZEVs) in this vehicle segment compared to other segments such as two-wheelers or commercial vehicles. India's ZEV penetration in the four-wheeler passenger vehicle segment stands at a mere 1.64%, far below the government's ambitious target of achieving a 30% market share in ZEVs by 2030. To delve deeper, the model categorizes vehicle manufacturers into two distinct groups based on their current production composition and diversification.

i) Firstly, Category 1 encompasses companies engaged in the production of both ZEVs and Internal Combustion Engine Vehicles (ICEs). This group includes TATA Motors Passenger Vehicles, Morris Garages Motor India, Hyundai Motors India, Kia Motors India, Mahindra and Mahindra Limited, and Mercedes Benz India. On average, these companies produced 6,292 ZEVs and a substantial 245,347 ICEs in the year 2022-23. Notably, TATA Motors Passenger Vehicle Limited boasted the highest ZEV production at 31,723 units, albeit constituting only 7% of its total output. MG Motors led in ZEV proportion, with ZEVs comprising 10% of its total production. Although these companies clearly outperform the segment average, they fall short of the mandate requirement proposed in the model. To comply with the mandate, they will need to significantly scale up their existing ZEV-focused infrastructure. As pioneers of ZEV vehicle production in the country, they have a remarkable opportunity to become key suppliers of ZEV credits in the credit market post-mandate implementation.

ii) On the other hand, Category 2 comprises automakers solely engaged in ICE production as of 2022-23, without any ZEV sales. This group includes Maruti Suzuki India, Renault India, Honda Cars India Ltd., Skoda Auto Volkswagen India Pvt. Ltd., and Fiat India. With an average ICE production of 245,307 units, these companies face significant challenges upon the mandate's introduction, given their current absence of ZEV production. Meeting the proposed ZEV mandate will necessitate substantial investment in R&D and capital infrastructure for such manufacturers in the near future.

i) Assumptions of the model

1. The model simplifies the market dynamics by considering only two key players: Company 1 and Company 2.
2. Company 1 represents the more diversified Category 1 automobile manufacturers, encompassing a range of companies involved in both ZEV and ICE vehicle production. Meanwhile, Company 2 serves as a proxy for Category 2 manufacturers, which solely focus on ICE vehicle production without any current involvement in the ZEV market.
3. The model assumes a simplified market scenario where only one type of ZEV and one type of ICE vehicle are produced by manufacturers in the Indian market.
4. Vehicle prices are considered exogenous in the model, meaning they are determined externally and do not directly affect the interactions between manufacturers. The price of ZEV vehicles is based on the TATA Nexon EV, while the price of ICE vehicles is derived from the average prices of TATA Nexon's Petrol and Diesel variants.
5. ZEV credits earned by manufacturers cannot be carried forward to subsequent years in the model. This assumption reflects the regulatory requirement that credits must be utilized within the same financial year they are earned, preventing manufacturers from accumulating credits over time.
6. The model prohibits manufacturers from borrowing credits against future ZEV production to meet current targets. This restriction ensures that manufacturers cannot rely on hypothetical future production to fulfill their current obligations, promoting transparency and accountability in compliance with the ZEV mandate.
7. Each company in the model is assumed to be a rational player in the market, seeking to maximize its profit within the constraints of the ZEV mandate and market conditions.

8. The model does not differentiate between sales and production activities within the same time period. This simplifying assumption enables a straightforward assessment of the relationship between production levels, sales volumes, and profitability for manufacturers under the ZEV mandate.
9. The time horizon for the model is limited to one year, allowing for a focused analysis of the short-term implications of the ZEV mandate on manufacturers' operations, financial performance, and compliance strategies.

ii) The Objective Function.

The objective function of each firm is equal to its total profit earned by the firm from the sale of ZEVs , ICEs and the trade of ZEV credits. The Profit of the firm i is given by –

$$\pi_i = \pi_{zevi} + \pi_{ICEi} + \pi_{trade\ of\ creditsi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

here i takes values 1 and 2 representing companies 1 and 2.

π_i = Total profit for the firm i.

$\pi_{zevi} = Profit\ of\ firm\ i\ from\ the\ production\ and\ sale\ of\ Zero\ Emission\ Vehicles$

$\pi_{ICEi} = Profit\ of\ firm$ i from the production and sale of Internal Combustion Engine Vehicles

$\pi_{trade\ of\ creditsi} = Profit\ for\ firm\ i\ from\ the\ sale\ and\ purchase\ of\ ZEV\ credits$

The individual equations for the components of the total profit are given below-

$$\pi_{Zevi} = P_{zev} * x_i - (c_i(x_i)^3 + d_i(x_i)^2 + e_i(x_i) + FC_{zev_i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

where, P_{zev} refers to the market price of the Zero emission vehicle in the market.

x_i denotes the quantity of Zero emission vehicles produced by company i in the current year.

c_i, d_i, e_i are the coefficients of the cubic cost function for the firm i.

$FC_{zev_i}\ is\ the\ fixed\ cost\ beared\ by\ firm\ i\ for\ the\ production\ of\ Zero\ emission\ vehicles.$

$$\pi_{ICE} = (P_{ICE} - MC_{ICE}) *\ y_i - FC\_ICE_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where $P_{ICE}\ is\ the\ market\ price\ of\ the\ Internal\ Combustion\ Engine\ Vehicle.$

$MC_{ICE}\ is\ the\ marginal\ cost\ of\ production\ of\ a\ unit\ of\ ICE\ vehicle.$

y_i is the production of Internal combustion vehicles by the automaker i in the current period.

$FC_{ICEi_i}\ is\ the\ fixed\ cost\ beared\ by\ firm\ i\ for\ the\ production\ of\ ICE\ vehicles.$

$\pi_{trade\ from\ credits} = P_{zev\ credits} * (qs_i - qp_i)$ .... (4)

$where,$

$P_{zev\ credits}$ $is\ the\ price\ at\ which\ ZEV\ credits\ are\ being\ traded\ in\ the\ ZEV\ credit\ market.$

qs_i refers to the number of ZEV credits sold by company i in the current financial year.

qp_i refers to the number of ZEV credits purchased by company i in the current financial year.

iii) Constraints

The optimization exercise of the firm encounters various constraints, particularly concerning the significant investment required to increase production levels, especially for Zero Emission Vehicles (ZEVs). Given the strategic nature of transitioning to a substantial proportion of ZEVs, there are limits on the extent to which a manufacturer can scale up its production of both ICE and ZEVs.

We assume that each company can produce a maximum of 200,000 ZEVs in the current year of the model. This assumption is reasonable considering that the companies represented by Company 1 only produced 6,292 ZEV vehicles on average in the year 2022-23, and those in Category 2 did not produce any ZEVs during the same period.

Similarly, companies in the model are constrained to increase their production of ICE vehicles by a maximum of four times compared to the previous period due to constraints of increasing investment and production volumes at a very large scale.

These constraints are expressed in equations 5 and 6 within the model.

$x_i \leq 2{,}00{,}000$ .... (5)

$y_i \leq 4 * (OQ\_ICE_i)$ ....(6)

where OQ_{ICE_i} $refers\ to\ the\ production\ of\ ICEs\ by\ company\ i\ in\ the\ year\ 2022-23.$

Additionally, the implementation of the mandate necessitates strategic decisions regarding ICE vehicle production, potentially leading to reductions in ICE production by the manufacturer. The model assumes that ICE production in the current year cannot fall below 10% of the production in the previous year for both companies. This constraint is represented by equation 7.

$y_i \geq 0.10 * (OQ_{ICE_i})$ ... ... (7)

To prevent firms from engaging in arbitrage within the market, constraints are imposed on the quantity of credits purchased (qp_i) and the quantity of credits sold (qs_i) by each company.

Equation 8 establishes a constraint that prohibits firms from purchasing credits unless they fall short of their ZEV credit target. This restriction ensures that companies only resort to buying credits when necessary to meet their obligations under the mandate, discouraging speculative behavior in the credit market.

$qp_i \leq Max\{ (0.3 * 2 * (x_i + y_i) - 2 * x_i), 0)\}$ …………… (8)

Similarly, equation 9 imposes a constraint that prevents firms from selling credits in the market unless their earned credits exceed their target level. By enforcing this rule, companies are compelled to fulfill their own credit targets before considering selling excess credits, thereby preventing manipulation of the credit market for short-term gain.

$qs_i \leq Max\{ \left(2 * x_i - 0.3 * 2 * (x_i + y_i)\right), 0)\}$ ……………..(9)

These constraints serve to maintain the integrity and stability of the credit market by restraining companies from engaging in unnecessary buying or selling of credits solely for-profit motives. By promoting responsible and strategic utilization of credits, the regulatory framework aims to foster a fair and efficient marketplace conducive to achieving the overarching goals of the ZEV mandate.

Within the model's framework, one constraint stands out as paramount: the fulfillment of the mandate by all automakers in the market. As specified in equation 10, this constraint dictates that the total credits accrued by each automaker from ZEV production and trading in the ZEV credits market must exceed their target level of ZEV credits, under penalty of non-compliance.

$2 * x_i + qp_i - qs_i - 2 * 0.3 * (x_i + y_i) \geq 0$ ……………. (10)

The model's equilibrium hinges on a fundamental constraint outlined in equation 11 serving as the sole equality constraint within the framework. This equation asserts that the aggregate demand for ZEV credits within the market must precisely match the total supply of credits available, ensuring that the credit market is in equilibrium.

$\Sigma qs_i = \Sigma qp_i$ ……………………………………………………. (11)

iv) Estimation of the parameters of the model

The parameters in the model are derived from extensive research on the Indian Four-Wheeler Vehicle Market. The price of a ZEV is set at Rs. 15,43,905, aligned with Total Cost of Ownership (TCO) calculations. Conversely, an ICE is priced at Rs. 14,36,528. The marginal cost of producing an ICE is assumed to be 60% of its market price, equating to Rs. 8,61,917. Historical production data for each company in ZEVs and ICEs is sourced from the Vahaan dashboard by the Ministry of Road Transport and Highways, providing sales numbers for various vehicle segments by automakers in different financial years. Due to the availability of only sales data, the distinction between sales and production is not made.

For historical production, the average production of vehicles of each type by companies in each group is taken. Selection of companies for analysis is based on market share among major automakers and data availability in the Prowess database, used for estimating cost functions. Cost functions, assumed to be cubic, are derived from total costs of automakers in the two groups from 2017-18 to 2022-23. However, bifurcation of costs based on vehicle types is not feasible due to data limitations. ZEV-specific cost functions for each automaker couldn't be derived due to lack of ZEV-specific cost data. Fixed costs for manufacturing ICEs are based on Company 2's cost function, representing a pure ICE manufacturer in the market.

4.7.1 Two-Wheeler Market

The mathematical model used previously will be replicated for the two-wheeler sector. The classification of manufacturers in the two-wheeler market is determined by the specific type of vehicles they make. The model presupposes that the zero-emission vehicle (ZEV) requirement for the producers of two-wheelers is established at 70% of their total production, aligning with the nation's objective of achieving ZEVs by 2030. Therefore, the desired level of Zero Emission Vehicle (ZEV) credits for two-wheelers is determined by:

Target ZEV Credits = 2 * 0.7 * (Total production of vehicles by the firm).

The allocation of credits for two-wheeler zero-emission vehicles (ZEVs) remains comparable to that of producers of four-wheeler vehicles. Credit trading is permitted. The regulations pertaining to banking and the utilization of credits bear a resemblance to the framework established for four-wheeler vehicles. The optimization problem and constraints remain unchanged from the four-wheeler model. The distinction between the two models rests in the classification of companies included in each model.

The classification of manufacturers in the two-wheeler market is as follows:

- Category 1 consists of manufacturers who exclusively produce zero-emission vehicles on the market. The companies listed in the initial category are Ather Energy and Hero Electric Vehicles Pvt. Ltd. The limited inclusion of only two manufacturers in this category is a result of the absence of data pertaining to additional manufacturers of pure ZEVs. The mean production of zero-emission vehicles (ZEVs) for these enterprises during the financial year 2022–23 was 82,777. Since these enterprises exclusively produce electric vehicles, they will have no difficulty meeting the mandate targets in the future.

- Category 2 refers to manufacturers exclusively involved in the production of internal combustion engine (ICE) automobiles. The firms listed in the second category are Hero Motocorp Ltd., Honda Motorcycle and Scooter India Pvt. Ltd., TVS Motor Company Ltd., and Bajaj Auto Ltd. The average production of internal combustion engine (ICE) vehicles for manufacturers in this category is 33,24,633 units. Given the significant magnitude of non-ZEV manufacturing by these enterprises, the implementation of the rule would necessitate substantial investments from manufacturers in the production of ZEV vehicles.

The forthcoming phase of our research will involve the utilization of models designed to simulate the impact of implementing a Zero-Emission Vehicle (ZEV) mandate within the Indian automotive market across two distinct vehicle segments. We will incorporate data sourced from relevant Indian scenarios available in the public domain to enhance the robustness of our analysis. Through this endeavour, we aim to not only discern the shifts in production dynamics for these vehicle categories following the implementation of the ZEV mandate but also to ascertain the resultant alterations in automakers' profitability under a tradable credit-based ZEV mandate policy. Additionally, our investigation seeks to evaluate the efficacy of such a policy in fostering the proliferation of ZEVs within the Indian market landscape in the foreseeable future.

6. A real value options approach to understanding Investment timing in the EV Industry

This section of research pertains to the approach taken in investing in electric vehicles. Utilising data simulation techniques in addition to game theory and optimisation methods is a prevalent strategy for analysing this issue. Given that EV investment possesses its own unique attributes: (1) the cost of non-reversibility associated with investment projects; (2) the unpredictability of the electric vehicle (EV) market and credit price; (3) the flexibility of investment timing, wherein a conventional automaker may opt to make an immediate investment or defer investment until a mature technology emerges or more market information becomes available. Real options are commonly employed to resolve these concerns; they account for greater project management flexibility and quantify the value of delaying irreversible investment decisions in the face of uncertainty. Real options analysis is frequently applied to investments involving uncertainty, primarily in the areas of venture capital, renewable technology, and production investments. Rarely, however, does theory employ a real options approach to evaluate EV investment opportunities. Within this framework, we refer to a recent study conducted by (Liu, 2023) which examines the optimal timing for an automaker to invest in electric vehicles (EVs) despite the unpredictability of FV demand and credit pricing. Analysing, from the perspective of real options, the optimal investment in electric vehicle (EV) investment under dual credit policy is the contribution of this paper. We suggest beginning with an analytical model. The optimal investment timing is determined through the solution of the Hamilton-Jacobi-Bellman equation, as stated by the authors. Second, they derive the option value of the postponed region, an innovation in the literature on EV investments. A number of conclusions are derived from a numerical example utilised as a case study in this paper. By simulating the aforementioned model while making more lenient assumptions, we aim to ascertain the most opportune moment for automotive manufacturers in India to invest in electric vehicles.

7. Limitations of the study

Our study represents a pioneering effort to explore the possibility of implementing a Zero-Emission Vehicle (ZEV) mandate in India, a discourse previously unexplored in the context of the Indian economy. Building on foundational research centred around ZEV mandates in Chinese and US markets, this paper seeks to craft an initial framework for India, providing theoretical optimal strategies as a touchstone for policymakers and stakeholders.

However, the construction of our model encountered significant challenges, primarily attributable to data constraints. The relative infancy of the Indian economy in this domain, coupled with the recency of policy implementations, limited our study period (2018-2023), posing a constraint when compared to the extensive datasets available for more developed economies spanning nearly two decades. The unavailability of granular data, particularly regarding manufacturing costs, posed challenges in understanding the supply-side ecosystem. Inconsistencies in data further reduced the data pool, impacting the precision of our results. The experimental nature of current production processes, wherein manufacturers are adapting assembly lines for EV production, added complexity in ascertaining investment and cost structures.

The nascent stage of the market presented further challenges in observing intricate interplays among different stakeholders within the value chain, particularly regarding the high dependency on imports by Indian manufacturers. These constraints make it challenging to deliver a model with precise and conclusive outcomes. Despite these challenges, our model is informed by the most reliable data currently available and incorporates assumptions to simulate a realistic scenario. It is a constructive step toward understanding the potential implementation of a ZEV mandate in India, offering a platform for refining strategies as more detailed data becomes available.

Another aspect of our paper's scope focuses on personal mobility, excluding public transportation due to distinct dynamics. Further inquiry into this aspect would present a more accurate picture of the EV automobile ecosystem. The finalized paper will include a quantitative aspect, offering targeted recommendations to address policy shortcomings hindering the swift transition to electrified transportation in India. Despite the constraints, conducting research at the initial stages of market development holds immense value. Early investigations are crucial for shaping national policies and enabling prompt course corrections. The experiences of leading nations highlight this, emphasizing the need for agility in policymaking. As India advances along a progressive path, maintaining a regimen of regular assessment and adaptation is essential. The insights gained from this study contribute to a growing body of knowledge that can inform policy refinements and strategic decisions moving forward.

It is important to note that this is a working paper, and the finalized paper will include refined model parameters and numerical simulations. This ongoing research and analysis aim to contribute to well-informed policies that anticipate future trends and catalyse sustainable growth in the EV market.

8. Way forward

In the context of India's transition to electric vehicles (EVs), a significant differentiation exists between nascent and existing industries. Nascent industries, like EVs, possess the advantage of shaping their practices around sustainability principles from the start, unburdened by legacy systems. Their initiatives align naturally with global sustainability goals such as the Sustainable Development Goals (SDGs). In contrast, existing industries, deeply entrenched in traditional practices, face challenges in adapting to EVs due to their existing infrastructure, supply chains, and workforce. Transitioning these sectors requires careful planning, collaboration, and policy support to mitigate disruptions. Recognising this distinction is pivotal in guiding India's strategy of nurturing innovation and policy support for nascent industries and facilitating gradual adaptation for existing industries while ensuring workforce skill development. By understanding and addressing these dynamics, India can progress towards sustainable transportation while minimising social and economic impacts.

Overall transformation toward sustainable mobility, necessitates bridging the gap in the four-wheeler segment. Evidence from all the countries around the world suggests ZEV mandate is a key to enable this transformation. This will lead to current disruption in supply chains of Indian automotive sector, and assessment of environmental goals in India. However, this all hinges on a collaborative effort from all stakeholders. A proactive approach from automakers, meticulously crafted government policies, strategic incentives, and the removal of impediments on both the demand and supply fronts can propel India towards the realization of its ambitious environmental and mobilization targets.

In its pursuit of zero-emission vehicles (ZEV), India can draw valuable insights from successful strategies implemented by major economies, shaping a comprehensive mandate to propel its electric vehicle (EV) penetration initiatives. A fundamental pillar of these strategies involves long-term strategic planning, fostering a consistent and robust approach to ZEV implementation while ensuring market readiness. The efficacy of financial incentives, such as tax breaks and credit systems, has been demonstrated in leading nations like the United States and Norway. India could leverage similar mechanisms to incentivize both consumers and manufacturers, fostering a seamless transition to EVs. Taking cues from countries like China and the European Union, prioritising infrastructure development is pivotal. Allocating funding and legislative support for the expansion of EV charging networks will play a crucial role in shaping India's EV landscape.

Additionally, India can embrace a strategy of incremental policy adjustments, ensuring a sustainable and well-paced shift towards ZEV that aligns with the nation's technological and economic evolution. By adopting this approach, India can navigate the complexities of transitioning to ZEV while accommodating domestic needs and capacities. In essence, by integrating these best practices, India can accelerate its EV journey, aligning with global trends while simultaneously addressing the unique challenges and opportunities within its domestic landscape. This strategic approach will position India as a proactive contributor to the global movement towards sustainable mobility.

9. Appendix

Section 1- Value Chain Analysis based on ProwessIQ data.

Data was extracted from ProwessIQ data base, based on NIC codes that are required under the Automobile Industry. The following tables detail the data and formula used for Value Chain analysis.

Table- 1 Formula Used for Value Addition Calculations

Formula for Value Added	Total Income- (Total Expenses (Intermediate costs) + Change in stock)
Components of Total Expenses	Raw Material
	Stores, spares and tools consumed
	packaging and packing expenses
	Purchase of finished goods
	Power, Fuel and water charges
	Compensation to employees
	Indirect Taxes
	Royalties, technical know-how fees
	Rent and Lease Rent
	Repairs and Maintenance
	Insurance premium paid
	Outsourced manufacturing Jobs
	Outsourced professional Jobs
	Non-executive directors fees
	Selling and Distribution expenses
	Travel Expenses

Table- 2 NIC Codes used in Value Chain Analysis

NIC Codes	Description
6101	Off shore extraction of crude petroleum
6102	On shore extraction of crude petroleum
7100	Mining of iron ores
729	mining of other non-ferrous metal ores
19201	Production of liquid and gaseous fuels, illuminating oils, lubricating oils or greases or other products from crude petroleum or bituminous minerals
22111	Manufacture of rubber tyres and tubes for motor vehicles, motorcycles, scooters, three-wheelers, tractors and aircraft

22113	Retreading of tyres; replacing or rebuilding of tread on used pneumatic tyres
22119	Manufacture of rubber tyres and tubes N.E.C.
22192	Manufacture of rubber conveyor or transmission belts or belting
26105	Manufacture of display components (plasma, polymer, LCD, LED)
27320	Manufacture of other electronic and electric wires and cables (insulated wire and cable made of steel, copper, aluminium)
28120	Manufacture of fluid power equipment
28140	Manufacture of bearings, gears, gearing and driving elements
28192	Manufacture of air-conditioning machines, including motor vehicles air- conditioners
29101	Manufacture of passenger cars
29102	Manufacture of commercial vehicles such as vans, lorries, over-the-road tractors for semi-trailers etc.
29103	Manufacture of chassis fitted with engines for the motor vehicles included in this class
29104	Manufacture of motor vehicle engines
29109	Manufacture of motor vehicles N.E.C.
29201	Manufacture of bodies, including cabs for motor vehicles
29209	Manufacture of other attachments to motor vehicles N.E.C.
29301	Manufacture of diverse parts and accessories for motor vehicles sucs as brakes, gearboxes, axles, road wheels, suspension shock absorbers, radiators, silencers, exhaust pipes, catalysers, clutches, steering wheels, steering columns and steering boxes etc.
29302	Manufacture of parts and accessories of bodies for motor vehicles such as safety belts, airbags, doors, bumpers
29303	Manufacture of car seats
29304	Manufacture of motor vehicle electrical equipment, such as generators, alternators, spark plugs, ignition wiring harnesses, power window and door systems, assembly of purchased gauges into instrument panels, voltage regulators, etc.
30911	Manufacture of motorcycles, scooters, mopeds etc. and their engine
30912	Manufacture of three-wheelers and their engine
30913	Manufacture of parts and accessories of three wheelers and motorcycles including side cars
45101	Wholesale and retail sale of new vehicles (passenger motor vehicles, ambulances, minibuses, jeeps, trucks, trailers and semi-trailers)
45102	Wholesale and retail sale of used motor vehicles
45200	Maintenance and repair of motor vehicles
45300	Sale of motor vehicle parts and accessories
45401	Wholesale or retail sale of new motorcycles, mopeds, scooters and three wheelers
45402	Wholesale or retail sale of parts and accessories of motorcycles, mopeds, scooters and three wheelers
45403	Maintenance and repair of motor cycles, mopeds, scooters and three wheelers

47300	Retail sale of automotive fuel in specialized stores [includes the activity of petrol filling stations.

Source- Ministry of Statistics and Programme Implementations

Table- 3 Percentage of Stakeholders in Indian Automobile Value Chain

Category	**Percentage of Stakeholders in the Value Chain**
Chemicals & Chemical Products	5.49
Construction	0.27
Machinery, Non-Electrical Machinery	6.04
Machinery, Electrical Machinery Other Than Electronics	11.54
Machinery, Electronics	0.82
Mineral Fuel-Based Products	3.30
Transport Equipment, Automobile Ancillaries	54.12
Transport Equipment, Automobiles	7.69
Non-Financial Services, Trade & Commissioning Agents' Services	10.17

Source- Author's Analysis based on ProwessIQ Data Base

Stakeholders involved in Transport Equipment (Automobile Ancillaries) can be further broken down. These components, comprise of the Tier 2 and Tier 3 manufacturers that are potentially most vulnerable to the transition from ICE to EV.

Table- 4 Percentage of Stakeholders in Transport Equipment

Components of Transport Equipment- Automobile Ancillaries	Percentage of Stakeholders in Transport Equipment
Drive Transmission & Steering Parts	28.43
Suspension & Braking Parts	6.01
Automobile Ancillaries, NEC	38.58
Automobile Engine Parts	13.71
Electrical Automobile Parts	4.06
Automobile Equipment	9.14

Source - Author's Analysis based on ProwessIQ Data Base

Section 2- Total Cost of Ownership Analysis

There has been considerable literature evaluating the TCO for various powertrain systems such as ICE, EV, PHEV, HEV, BEV and their variants, across locations and spanning over different periods of time. Early studies, provided in-depth TCO assessments for vehicles like hybrids and electric cars in developed nations, considering factors beyond initial costs, such as depreciation and fuel efficiency (Palmer, Tate, Zia, & Nelthorp, 2018).Further, research in this domain has been extended this to electric buses, two wheelers and three wheelers, adding infrastructure and environmental costs into the equation, suggesting their viability with mass production ((Kumar & Subrata, 2020) (Orhan & Nakir, 2018))

More recent studies (Deloitte, 2021) analysed electric mobility in Southeast Asia, focusing on TCO related to upfront costs, taxes, and service expenses. This study highlighted the influence of cost proportions on EV adoption and the role of energy prices. The IIT Kanpur study (Agarwal, 2023) used the World Resources Institute India's TCO evaluator to examine life cycle emissions and TCO for various vehicles in India, suggesting that HEVs with E-fuels could be economically viable with appropriate subsidies.

These TCO studies underline the importance of factoring in diverse costs and market-specific conditions. However, the literature often overlooks policy influences and cost incentives, which are crucial for understanding consumer preferences and encouraging the adoption of innovations like EVs, particularly in the Indian context. Incentives directly affect TCO and are key to integrating new technologies within the automotive sector.

a. Method for TCO analysis

Upon examination, the key components of the Total Cost of Ownership (TCO) formula include purchasing cost, resale price, taxes, energy costs, and maintenance costs. Considering these main components and insights literature, the following formula has been formulated

Formula

TCO = Vehicle Cost + Energy Costs + Maintenance Costs

Here,

Vehicle cost = On-road price (Inclusive of one-time charges (e.g. Taxes like GST, Road Tax, TCS charges and Insurance Costs) – Resale Value

Energy costs = Petrol, diesel, charging costs

Maintenance cost = Service Charges and Potential Battery Replacement costs in case of EV.

All expenses are standardized for a specific region, taking Delhi as a reference due to cost variations across different regions of India. For two wheelers, time span of 10years, with an annual distance of 10,000km is considered on the basis of average life and usage in the current market. For four wheelers, the evaluation considers 5 years, and an annual distance of 15000 km is considered, based on average usage of four wheelers in India based on market analysis (add sources). All the costs are base level, i.e. minimum price that will be required. Energy cost, annual kilometers and life of the vehicle will be ultimately depending on consumers usage. The market is subject to innovation, inflation and are subject to change according to socio economic conditions. The TCO calculations aim to illustrate the cost effectiveness of vehicles and their variants in Business-as-usual conditions. An increase in efficiency of EVs can be expected with the rise of innovation.

The evaluation of four wheelers is done in 3 different scenarios. These scenarios are based on the current scenario including the current tax exemptions, a further exemption of taxes (like practices in some major automobile markets such as China) to evaluate its impact on TCO and the ideal scenario for adoption of vehicles for consumers. The specifics of these scenarios are explained in detail in the analysis of TCO (next subsection).

For the analysis, the top-selling vehicles in both the two-wheeler and four-wheeler markets have been considered. For fairness in evaluating four-wheelers, variants of the same car (TATA Nexon Creative Plus) have been considered.

As equivalent variants are unavailable in the two-wheeler market, we opted for two different models, the best-selling petrol (Activa 6G) and electric (Ola S1 Pro (2nd Gen)) options. The eAMRIT website served as a resource for calculating the cost per kilometer for EVs. Since EVs are relatively new in the market.

There is a lack of data on resale values of latest EV models. Hence, resale value of four -wheeler EVs has been estimated based on diesel cars and based on the resale value of previous models in the case of two-wheelers.

Table- 5 TCO Calculations for Two Wheelers.

Vehicle	Model	Vehicle Cost		Energy Cost	Maintenance Cost	TCO
		Purchase Cost (₹)	Resale Value (₹)	Cost Per Km (₹)	Cost Per Year (₹)	Usage Period 10 years, at 12000 km per year
Two Wheelers	Activa 6G	₹89,843	₹62,300	₹1.75	₹2,160	₹2,31,600.00
	Ola S1 Pro (2nd Gen)	₹1,37,110	₹1,10,000	₹0.13	₹87,928	₹1,03,528.00
		₹159378 (cost) - ₹22268 (subsidy)				

Table- 6 Table- 5 TCO Calculations for Four Wheeler Passenger Cars.

Vehicle	Model	Vehicle Cost		Energy Cost	Maintenance cost	TCO
Four Wheeler		Purchase Cost (₹)	Resale value (₹)	Cost per km (₹)	Cost per year (₹)	Usage Period 5 years at 15,000 km per year
Scenario 1- Current Scenario (5% GST and tax exemptions)	Tata Nexon Creative Plus Petrol	13,32,842	4,53,482.5	5.54	4856.2	13,19,140
	Tata Nexon Creative Plus Diesel	15,40,213	4,06,198.4	3.8	6271.6	14,50,372
	Tata Nexon Creative Plus EV	15,43,905	5,61,523	0.8	4092.2	10,62,843
Scenario II- (No GST and road tax for EVs)	Tata Nexon Creative Plus EV	14,57,960	5,61,523	0.8	4092.2	9,76,898
Scenario III- (40% subsidy on purchase price and no GST & road tax.)	Tata Nexon Creative Plus EV	8,96,436.8	3,36,913.8	0.8	4092.2	6,39,984

In the case of two wheelers the subsidies due to FAME I and II have sufficed to reduce the TCO and EVs have an evident advantage and have a huge cost efficiency advantage.

However, in the four-wheeler segment, variants, large number of components the evaluation becomes complicated. Scenario 1 considers the current situation. Currently, EV cars fall in the 5% GST tax slab and 11 of the major states in India (Andhra Pradesh, Bihar, Delhi, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Tamil Nadu, Telangana, Uttar Pradesh and Uttarakhand) have exempted or subsidised the road tax. As this analysis is done on the basis of Delhi, road tax is taken as per the region.

In the second scenario, we explore the impact on the initial cost and Total Cost of Ownership (TCO) by envisioning a scenario where all taxes, akin to China's elimination of the purchase tax, are removed. Notably, the TCO of Electric Vehicles (EVs) is lower in both scenarios. However, in the first scenario, should a battery exchange become necessary due to wear and tear, the TCO experiences a significant increase. Despite these variations, the upfront cost remains prohibitively high for the majority of Indian consumers in both scenarios, a challenge that we address in the subsequent scenario.

Moving on to the third scenario, it envisions the optimal conditions for Electric Vehicle (EV) adoption. An analysis of the latest available sales data (refer section- India's Automobile Industry Value Chain) consumers prefer passenger vehicles in the Rs 6-10 lakh range. Scenario 3 indicates that a subsidy of approximately 30-40% in price is needed to align with the initial cost within consumers' financial reach. However, such a significant subsidy poses financial challenges for both the government and producers, potentially hindering production and innovation in the EV sector. Therefore, the industry needs to focus on reducing costs from the supply side by increasing production efficiency.

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