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# Forecasting Electric Vehicle Sales in India using Singular Spectrum Analysis

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**National Centre for Good Governance (NCGG)**
Department of Administrative Reforms and Public Grievances, Ministry of Personnel, Public Grievances and Pensions, Government of India

# CERTIFICATE

This is to certify that **Yash Aggarwal,** a student of Delhi Technological University (DTU), has successfully concluded his research project titled **"Forecasting Electric Vehicle Sales in India using Singular Spectrum Analysis"** as part of the internship program at the National Centre for Good Governance (NCGG) under my mentorship.

I, Dr. Roma Debnath, hereby validate the successful completion of the internship report within the internship program at the National Centre for Good Governance (NCGG). The report submitted by Yash Aggarwal is an authentic work carried out by him under my supervision and guidance. I have reviewed and assessed the intern's performance throughout the internship period.

**(Dr. Roma Mitra Debnath)**
Associate Professor
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Date: 01.07.2024

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# ABSTRACT

The global transition to sustainable mobility is crucial for mitigating climate change, with the transportation sector adopting electric vehicles (EVs) to reduce greenhouse gas emissions. Countries like Norway, China, and the United States lead this shift, integrating EVs into their national strategies. In India, the push for green mobility is driven by severe air pollution, rapid urbanization, and heavy oil import reliance. Despite initiatives like the National Electric Mobility Mission Plan (NEMMP) 2020 and the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) schemes, challenges such as high costs, limited range, and inadequate infrastructure remain.

This paper addresses the scarcity of empirical research on EV demand in India by employing advanced analytical techniques to forecast EV demand, offering insights for policymakers and industry stakeholders. Using monthly sales data from June 2017 to March 2024 for two-wheelers, three-wheelers, and four-wheelers, this study applies Singular Spectrum Analysis (SSA) to decompose sales data into trends, periodic elements, and noise, adapting to the non-linearity and non-stationarity of EV sales data.

The study forecasts significant growth in the Indian EV market across all vehicle categories. SSA captures sales dynamics, indicating potential for accelerated EV adoption driven by technological advancements, regulatory support, and shifting consumer preferences. These findings inform strategic decisions for infrastructure development and policy formulation, emphasising the need for continued government support, innovation, and consumer awareness to achieve sustainability goals.

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# List of Abbreviations

| Abbreviation | Full Form |
|---|---|
| **ACC** | Advanced Chemistry Cell |
| **BEVs** | Battery Electric Vehicles |
| **CEEW** | Council on Energy, Environment and Water |
| **COP26** | 26th UN Climate Change Conference of the Parties |
| **EV** | Electric Vehicle |
| **FAME** | Faster Adoption and Manufacturing of Hybrid and Electric Vehicles |
| **FY** | Fiscal Year |
| **GDP** | Gross Domestic Product |
| **GST** | Goods and Services Tax |
| **HEVs** | Hybrid Electric Vehicles |
| **IEA** | International Energy Agency |
| **LEAP** | Long-range Energy Alternatives Planning |
| **MoRTH** | Ministry of Road Transport & Highways |

| | |
|---|---|
| **NEMMP** | National Electric Mobility Mission Plan |
| **PHEVs** | Plug-in Hybrid Electric Vehicles |
| **PLI** | Production Linked Incentive |
| **RBI** | Reserve Bank of India |
| **SSA** | Singular Spectrum Analysis |
| **SVD** | Singular Value Decomposition |
| **ICE** | Internal Combustion Engine |

# 1. INTRODUCTION

## 1.1 Background

As the world pivots towards sustainable solutions to address the pressing issues of climate change and environmental degradation, the mobility sector stands at the forefront of this transformation. As clearly pointed out by NITI Aayog, “If cities are the “Engines of Economic Growth” its mobility systems are the “wheels of that engine” (Global Mobility Summit, 2018). The urgency for this shift is compounded by the transportation sector's significant contribution to global greenhouse gas emissions, primarily driven by fossil fuels. The advent of electric vehicles (EVs) offers a promising avenue to mitigate these environmental impacts while also revolutionising the mobility landscape.

Globally, the transition towards electric mobility is gaining momentum, driven by a confluence of technological advancements, regulatory policies, and shifting consumer preferences. Nations such as Norway, China, and the United States have made substantial headway, fostering environments where EVs are increasingly becoming the norm. This global shift is not just about adopting new technologies but also about realigning economic and environmental strategies to pave the way for a sustainable future.

In the Indian context, the necessity for transitioning to green mobility is underscored by several critical factors. India, as one of the fastest-growing economies, faces unique challenges that stem from its vast population, rapid urbanisation, and escalating energy demands. India was declared as the third-most polluted country in 2023 in terms of air pollution, after Bangladesh and Pakistan (IQAir, 2024). The country is currently grappling with severe air pollution levels, particularly in urban centres, which poses health risks and economic costs. With India being home to 42 of the world's 50 most polluted cities according to the World Air Quality Report 2023, the need for cleaner transportation options becomes even more critical.

Moreover, India's heavy reliance on oil imports, which accounted for a staggering USD 119.2 billion on crude oil imports in FY 2021-22, which is up from USD 62.2 billion spent in FY 2020-21, further accentuates the need for an indigenous and sustainable energy solution (Petroleum Planning & Analysis Cell, 2023). EVs offer a viable alternative that could reduce this dependency significantly, thus enhancing energy security and economic resilience. Further, India's commitment, as evidenced at the COP26 in Glasgow, to reach a Net Zero target by 2070, further amplifies the relevance of this transition (Ministry of Environment, Forest and Climate Change, 2022).

Historically, India has taken proactive steps towards fostering an electric mobility ecosystem. Initiatives like the National Electric Mobility Mission Plan (NEMMP) 2020 and the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) schemes illustrate the government's commitment to this cause. FAME II, for instance, significantly increased budgetary allocations to bolster EV adoption across various vehicle segments, focusing on public transport and high-usage commercial vehicles to maximise environmental and economic benefits.

The Indian EV market has witnessed a remarkable evolution over the past decade. Key milestones include the launch of Mahindra REVAi, India's first electric car, back in 2001. While initial adoption was slow, recent years have seen a surge in consumer interest and market activity driven by factors such as government incentives, declining battery costs, and a growing range of EV models from domestic and international manufacturers.

The current context presents a pivotal moment for India's EV sector. Government policies, technological advancements, infrastructure development, and shifting consumer preferences are converging to create a conducive environment for accelerated EV adoption. The EV market in India includes two primary categories: battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs operate solely on battery power, whereas PHEVs combine electricity and gasoline, offering a flexible approach to reducing oil dependency. Despite their benefits, widespread adoption of EVs in India faces hurdles such as high retail prices, limited battery range, and inadequate charging infrastructure. Therefore, a thorough examination of projected EV demand is essential to guide policymakers and industry participants.

Forecasting EV demand in India holds far-reaching implications. Understanding the trajectory of EV adoption will inform critical decisions regarding the allocation of resources towards charging infrastructure development, ensuring grid stability to meet increasing electricity demand, and formulating policies that encourage both EV production and consumer uptake. Furthermore, accurate forecasts empower stakeholders to proactively address potential challenges and capitalise on emerging opportunities within the rapidly evolving EV landscape.

By delving into the complexities of EV technology, macroeconomic dynamics, policy measures, and market trends, this research paper endeavours to shed light on the future of electric mobility in India. With a particular focus on forecasting EV demand, this research aims to contribute valuable insights to shape a sustainable, accessible, and efficient transportation system for the nation.

## 1.2 Global EV Outlook

The global landscape for EVs is undergoing a remarkable transformation, characterised by rapid growth and evolving market dynamics. In 2022, the electric car market witnessed exponential growth, with sales surpassing 10 million units, representing 14% of all new car sales globally, a significant increase from approximately 9% in 2021 and less than 5% in 2020 (IEA Report, 2023).

This surge in EV adoption is primarily concentrated in three major markets namely Chine, Europe and US.

China continues to lead global electric car sales, accounting for about 60% of the total market. The nation has not only surpassed its 2025 target for new energy vehicle sales but also now hosts more than half of the electric cars currently on the roads worldwide. In Europe, the second-largest market, there was a 15% increase in electric car sales in 2022, with electric vehicles constituting over 20% of new car sales. Meanwhile, in the United States, which ranks as the third largest market, electric car sales grew by 55% in 2022, achieving an 8% market share of total car sales (IEA Report, 2023).

The momentum of electric car sales is expected to continue robustly into 2024. Projections for the end of 2024 anticipate a total of 16.84 million electric car sales, representing a 21% year-on-year increase (ABI research, 2024). This surge is likely to result in electric cars making up 18% of total global car sales by the end of the year. Such growth is supported by national policies and incentives, and potentially further fuelled by high oil prices, which encourage consumers to transition to more economically efficient electric vehicles.

In regions outside the primary markets, the adoption of EV is rising from a smaller base but showing promising growth. In 2022, countries like India, Thailand, and Indonesia saw electric car sales more than triple compared to the previous year, reaching a total of 80,000 units. Government support in India, including a USD 3.2 billion incentive program, has catalysed significant investments totalling USD 8.3 billion, enhancing EV and component manufacturing (IEA report, 2023). Similarly, Thailand and Indonesia are bolstering their policy frameworks, potentially offering valuable lessons for other emerging economies looking to promote EV adoption.

Looking forward, under the International Energy Agency's Stated Policies Scenario (STEPS), the global outlook for electric car sales is optimistic. By 2030, the share of electric car sales is projected to reach 35%, up from an earlier forecast of less than 25%. China is expected to maintain its lead with 40% of the global total, while the United States could double its share to 20% by the decade's end, spurred by recent policy developments. Europe is anticipated to sustain its 25% share.

This shift towards EVs has significant implications for energy markets and climate objectives. According to STEPS projections, oil demand from road transport is expected to peak around 2025, with EVs displacing over 5 million barrels per day by 2030. Consequently, this transition is projected to avoid approximately 700 million tonnes of $CO_2$ equivalent emissions by 2030.

The expansion of battery manufacturing is being accelerated by the optimistic outlook for EVs. As of March 2023, announced expansions in battery manufacturing capacity are projected to not only meet the anticipated demand based on government pledges but also cover potential needs under the Net Zero Emissions by 2050 Scenario. This suggests that higher adoption rates for EVs than currently anticipated by government policies and targets are well within reach, further bolstering the global shift towards sustainable mobility.

## 1.3. EV adoption Scenario in India

The recent surge in crude oil prices, exacerbated by the Russia-Ukraine conflict, Israel-Palestine war and other international tensions, has significantly influenced India's strategic shift towards EVs as a mainstream mode of transportation (Deb et al., 2021). This shift is also supported by stringent environmental regulations, the government's scrapping policy, and increased public awareness of environmental issues (Singh et al., 2022; Jones et al., 2020; Pawar and Ahire, 2020;

Dixit and Singh, 2022). The Indian government's tax policies and incentives have further fuelled consumer interest towards EVs.

India's automotive industry, ranked as the third largest globally in 2023, is experiencing a robust transformation with major domestic manufacturers like Tata Motors and Mahindra & Mahindra Ltd. launching their EV models (Das and Bhat, 2022). The market is also welcoming international EV manufacturers such as Hyundai, Kia, MG, and BMW, enriching the consumer choices with a range of vehicles tailored to diverse needs and price points (Rohini and Asha, 2022). This influx has significantly contributed to the rapid expansion of the EV market in India within a remarkably short timeframe.

## 1.4. Government Initiatives to Promote EV Adoption

The Indian government has implemented several strategic measures to foster the adoption of EVs, reflecting its commitment to enhancing environmental sustainability and energy efficiency.

**FAME India Scheme**: Initiated by the Ministry of Heavy Industries in 2015, the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME India) Scheme has been pivotal in promoting the adoption of electric and hybrid vehicles. Currently, Phase II of the FAME India Scheme is active, starting from April 1, 2019, with a duration of five years and a total budgetary support of ₹10,000 crores. This phase focuses on supporting the electrification of public and shared transportation and offers incentives for electric buses, passenger vehicles, three-wheelers, and two-wheelers.

**Production Linked Incentive (PLI) for Advanced Chemistry Cell (ACC) Manufacturing**: On May 12, 2021, the government approved the PLI scheme to promote the domestic manufacturing of Advanced Chemistry Cells, aiming to reduce the costs of batteries in India. A decrease in battery costs is expected to directly result in lower prices for EV, making them more affordable for consumers.

**PLI Scheme for Automobile and Auto Components:** Approved on September 15, 2021, this scheme has a budgetary outlay of ₹25,938 crores over five years. It covers EVs and aims to enhance India's manufacturing capabilities by incentivising the production of various automobile components, including those for EVs.

**GST Reductions:** To make EVs and their related components more affordable, the government has reduced the Goods and Services Tax (GST) on EVs from 12% to 5%. Additionally, the GST on chargers and charging stations for EVs has been reduced from 18% to 5%.

**Green License Plates and Permit Exemptions:** The Ministry of Road Transport & Highways (MoRTH) has introduced green license plates for battery-operated vehicles to distinguish them from conventional vehicles. EVs with these plates are exempted from permit requirements, easing operational restrictions and encouraging their use.

**Road Tax Waiver:** MoRTH has also advised states to waive the road tax on EVs. This policy helps decrease the initial ownership costs of EVs, making them a more attractive option for potential buyers.

**Amendment of Model Building Bylaws:** In 2016, the Model Building Bylaws were amended to facilitate the establishment of charging stations in private and commercial buildings. This amendment supports the development of necessary EV charging infrastructure, addressing one of the significant barriers to EV adoption—charging facility availability.

Through these measures, the Government of India aims to accelerate the transition to a more sustainable transportation system by increasing the adoption of EVs. This not only helps in reducing the environmental impact of the transportation sector but also positions India as a significant player in the global electric vehicle market.

## 1.5. Types of EVs in Indian Market

EVs can be classified into several types based on their energy sources and operational mechanisms. Each type offers distinct features and benefits, catering to various consumer needs and environmental objectives.

**Battery Electric Vehicles (BEVs):** Commonly known as All-Electric Vehicles (AEVs), BEVs operate exclusively on electricity stored in high-capacity battery packs. These batteries are charged from an external electrical power source and provide electricity to the motors that drive the vehicle. BEVs produce zero exhaust emissions, significantly reduce noise pollution compared to conventional vehicles, and are seen as crucial in the shift towards sustainable transportation. The environmental benefits of BEVs include the absence of tailpipe emissions and the potential to utilise renewable energy sources for charging.

**Hybrid Electric Vehicles (HEVs):** HEVs combine an internal combustion engine(ICE) with one or more electric motors that utilise energy stored in batteries. Unlike BEVs, HEVs are not plugged into charge, instead, their batteries are charged through regenerative braking systems and by the engine. This dual system allows HEVs to optimise fuel efficiency and lower emissions during operation. HEVs are particularly effective in reducing emissions when used in city driving, where frequent stopping provides opportunities for regenerative braking.

**Plug-in Hybrid Electric Vehicles (PHEVs):** PHEVs share similarities with HEVs but are equipped with larger battery packs that can be recharged by connecting to the electrical grid. This capability allows them to operate significant distances on electric power alone, thereby reducing fuel consumption and emissions. Once the battery is depleted, the vehicle can switch to operate on the ICE, thereby providing greater flexibility and range than BEVs.

**Fuel Cell Electric Vehicles (FCEVs):** Often referred to as Zero-Emission Vehicles, FCEVs utilise hydrogen fuel cell technology to generate electricity that powers the vehicle's motors. Instead of storing energy in a battery, hydrogen gas is converted into electricity through a chemical reaction in the fuel cell, with water vapour as the only emission. FCEVs combine the benefits of quick refuelling and long range, characteristics similar to conventional ICE vehicles, while maintaining minimal environmental impact.

# 2. OVERVIEW OF LITERATURE

## 2.1. Factors Influencing EV Demand

The adoption of EVs is influenced by an intricate matrix of technical, economic, environmental, and social factors, with distinct variances observed across different global contexts. Key vehicle performance attributes such as driving range, speed, and safety, alongside critical economic considerations like purchase price, resale value, and operating costs, substantially shape consumer decisions in diverse markets (Thananusak et al., 2017; Wang et al., 2018). Notably, Thananusak et al. (2017) highlight that in Thailand, performance factors significantly outweigh concerns related to charging infrastructure and costs. Conversely, in denser urban environments such as Shanghai, Wang et al. (2018) found that environmental awareness and technological sophistication are dominant factors swaying consumer preferences towards EVs.

Complicating the landscape for EV adoption are persistent barriers such as limited driving ranges, a narrow range of available models, prolonged recharging times, and prevalent battery issues, which collectively dampen consumer enthusiasm for fully EVs (Zhang et al., 2017; Cheron & Zins, 1997; Hu, X. et al., 2016; Hu, X., Martinez, & Yang, 2017; EPRI, 2010). Further exacerbating these challenges are the high perceived purchasing costs and the general convenience and benefits associated with conventional vehicles (Bockarjova & Steg, 2014). Zhang, Yu & Zou (2011) also identified the scarcity of charging stations and the extended duration required for charging as significant deterrents to EV penetration.

However, various incentives have been identified as effective in mitigating these challenges, including tax-based policies, designated lane access, complimentary parking, and enhanced insurance products, which collectively contribute to an improved value proposition for EVs (Zhang et al., 2017). Moreover, advancements in lithium-ion battery technology that prolong battery life up to 2000 charge cycles before significant degradation are also crucial in reducing the frequency and costs associated with battery replacement, thereby enhancing the economic attractiveness of EVs (Jin et al., 2022). A life cycle assessment further illustrates the long-term economic benefits of EVs compared to conventional internal combustion engine vehicles, presenting a compelling breakeven point that enhances consumer adoption (Verma et al., 2021).

The availability and enhancement of charging infrastructure play a pivotal role in alleviating range anxiety and augmenting the attractiveness of EVs. Studies conducted in diverse settings such as the U.S. by Carley et al. (2013) and in Malaysia by Sang & Bekhet (2015) demonstrate that infrastructure readiness significantly boosts EV adoption rates by addressing consumer concerns about charging availability and vehicle range. Extending this analysis to a broader international context, Yong & Park (2017) examined the factors influencing EV deployment across 24 countries, utilising a fuzzy-set qualitative comparative analysis methodology to derive insights from country-based aggregate data. Their findings underscore that robust policy support, environmental factors, and reliable charging infrastructure are essential for the widespread adoption of EVs. This notion is further supported by research indicating that governmental interventions, including financial incentives and supportive policies, are critical in sculpting the EV market landscape (Daziano & Chiew, 2013; Yong & Park, 2017).

Adding a regional perspective, Verma et al. (2019) in their Bangalore study, identified environmental benefits and financial incentives as key motivators for EV adoption. Similarly, Kumar et al. (2020) emphasised the importance of the sharing economy and public utilities in facilitating EV purchases in India, particularly given the high costs and inadequate charging infrastructure. Additionally, a 2020 Castrol study projected the Indian EV market to reach $2 billion by 2025, pinpointing vehicle price, charging time, and driving range as primary adoption challenges. In their study, Dixit and Singh (2022) employed logistic regression to analyse survey data on 245 potential EV buyers in India, identifying age, income, vehicle cost, running cost, and driving range as significant predictors of EV purchases. Interestingly, their findings indicated that education level, employment status, and government subsidies were not significant factors influencing EV adoption in India.

Additionally, socio-cultural factors and consumer psychology significantly affect EV purchasing decisions. Helveston et al. (2015) in their comparative study of the U.S. and China, emphasised how cultural differences impact preferences for EV technologies—U.S. consumers are predominantly influenced by direct financial savings, whereas Chinese consumers are motivated by broader environmental concerns. Similarly, a study by Leabeau et al. (2013) in Belgium found that the ability to charge vehicles at home was deemed a crucial factor by consumers, highlighting the importance of understanding and integrating consumer lifestyle preferences and regional characteristics into EV marketing and infrastructure strategies.

## 2.2. Forecasting Techniques and Models

Forecasting the demand for EVs presents unique challenges, particularly due to the nascent stage of the market and the absence of extensive historical sales data. The complexity in predicting EV markets stems from several dynamic factors, including shifting government policies, fluctuating component costs such as batteries, developing charging infrastructure, and variable technology adoption rates across different regions (Toppr-guides, 2018; Struben & Sterman, 2008). Addressing these challenges necessitates sophisticated forecasting models that can navigate the nuanced interplay of these variables under uncertain market conditions.

Consumer choice models are pivotal in understanding how potential buyers might respond to EVs compared to traditional vehicles. For instance, Struben (2008) integrated discrete consumer choice theory with diffusion models to estimate the adoption rates of PHEVs. This approach described the consumer's predisposition towards EVs as the anticipated utility of the vehicle, taking into account the influence of social dynamics and the availability of infrastructure, using frameworks like the multinomial logit choice model. Similarly, Bolduc et al. (2008) employed a hybrid choice model that melds discrete choice theory with psychometric variables, providing insights into Canadian consumers' preferences for HEVs over traditional vehicles and capturing the psychological traits that may influence their decisions.

Moreover, various traditional and innovative statistical techniques have been utilised to forecast EV demand. Time-series analysis, for instance, has been widely applied with models like ARIMA used by Amini et al. (2016) to predict EV charging demands based on daily usage patterns—helping not only in forecasting demand but also in optimising charging infrastructure to minimise operational costs. Zhang et al. (2017) extended this approach by employing both univariate and multivariate time-series models to predict short-term and long-term EV sales in China. In addition to these methods, Hamed and Eideh (2018) explored the use of an Information Index and Poisson Regression model based on survey data to forecast EV demand in Jordan.

Further expanding the array of forecasting tools, researchers have combined stated and revealed preference data to refine their predictions. This technique has been evident in works by Ida et al. (2014), Brownstone et al. (2000), and Axsen et al. (2009), who have utilised multinomial logit and mixed logit models to explore consumer preferences for alternative fuel vehicles. Additionally, Ziegler (2012) applied multinomial probit models to examine potential car purchasing choices, including EVs, while Helveston et al. (2015) addressed consumer preferences in the U.S. and China using both multinomial logit and mixed logit models.

The integration of diffusion models further enhances our understanding of how EVs might penetrate various market segments over time. Struben & Sterman (2008) discussed how these models could incorporate the effects of policy changes, technological advancements, and social trends to forecast long-term adoption rates, considering the dynamic interactions between consumers, manufacturers, and regulatory environments, ensuring that policy and infrastructure development align with the projected growth in EV adoption.

## 2.3. Emerging Trends and Future Projections

EV market is at a critical juncture, with potential growth paths significantly influenced by technological advancements, policy evolution, and shifting consumer attitudes. Global movements towards sustainability and the transition away from fossil fuels are driving substantial policy shifts, as seen in countries like India and UK, where ambitious targets for phasing out ICE vehicles are set (Das & Bhat, 2022; Zhang et al., 2017).

Emerging trends also indicate a significant decrease in the costs of critical components such as lithium-ion batteries, spurred by advancements in technology and scaling production (Jin et al., 2022). As battery costs decline, EVs become more financially accessible to a broader segment of consumers, potentially increasing market penetration. Furthermore, the integration of EVs into smart grids and renewable energy systems presents an opportunity to enhance the environmental value proposition of electric mobility (Guo et al., 2021). With increasing emphasis on sustainable urban planning and the development of smart cities, EVs are poised to play a pivotal role in future transportation ecosystems, especially in densely populated countries like India where urban air pollution is a significant concern.

## 2.4. Research Gap

Despite the growing importance of EVs in the global automotive market, there is a notable absence of empirical research focusing on the demand for EVs in India. Existing literature predominantly addresses EV adoption and demand forecasting in developed markets such as the United States, Europe, and China, where infrastructure and policy frameworks are significantly different from those in India. These studies often utilise time series analytical techniques to predict trends and assess factors influencing EV adoption, providing valuable insights into consumer behaviour and market dynamics.

However, the unique socio-economic landscape, regulatory environment, and infrastructural challenges in India necessitate a localised analysis to accurately forecast EV demand. Current research in India primarily explores the barriers to EV adoption, policy implications, and potential environmental benefits, but lacks robust empirical models that predict future demand.

Therefore, this research paper aims to fill this critical gap by employing Singular Spectrum Analysis to forecast EV demand in India. This research will not only contribute to the academic discourse but also offer valuable insights for policymakers and industry stakeholders striving to promote sustainable transportation solutions in India.

# 3. METHODOLOGY

The theoretical foundation of this paper revolves around forecasting the future sales of EVs in India, segmented into three categories: two-wheelers (2W), three-wheelers (3W), and four-wheelers (4W). The dynamic nature of the EV market, influenced by technological advancements, regulatory changes, and shifting consumer preferences, necessitates a robust methodological approach. Singular Spectrum Analysis (SSA) is employed as the primary tool for univariate time series analysis to forecast EV demand in India.

## 3.1. Rationale of using SSA

SSA aims to decompose a given time series into distinct components, such as trend, periodicity, quasi-periodicity, and noise. This process involves several sequential steps: transformation, decomposition, grouping, and reconstruction (Afshar and Bigdeli, 2011). The objective is to transform the original series into a format where these individual components can be identified and analysed separately (Hassani et al., 2013). The rationale for using SSA is grounded in several theoretical considerations. Firstly, SSA is a non-parametric method that does not require the specification of a predefined model structure, making it adaptable to the inherent non-linearity and non-stationarity of EV sales data. Secondly, SSA excels in isolating trend and periodic components from noise, which is crucial for accurate forecasting in markets characterised by technological and economic fluctuations. Additionally, SSA can be effectively applied in scenarios with incomplete data and is robust against outliers, which are common in emerging market datasets. When compared to traditional time series methods like ARIMA or exponential smoothing, SSA provides a more nuanced analysis of underlying data dynamics. Unlike these methods, which often require data to be stationary or involve extensive pre-processing, SSA directly handles the original series, preserving all vital information.

## 3.2 Mathematical Formulation

Mathematically, SSA follows the following steps-

**Step 1: Transformation to Trajectory Matrix**

The SSA begins with the transformation of the time series into a trajectory matrix, which serves as the basis for extracting significant data structures.

**Formation of the Trajectory Matrix**: Given a time series $x_t$ where $t = 1,2,\ldots,N$, and selecting a window length $M$ (where $M < N$), the trajectory matrix X is constructed as follows-

$$X = \begin{bmatrix} x_1 & x_2 & \cdots & x_{N-M+1} \\ x_2 & x_3 & \cdots & x_{N-M+2} \\ \vdots & \vdots & \ddots & \vdots \\ x_M & x_{M+1} & \cdots & x_N \end{bmatrix}$$

Each column of X represents a lagged version of the time series, embedding it into a $M \times (N - M + 1)$ dimensional space.

**Step 2: Singular Value Decomposition (SVD)**

Decomposition of the trajectory matrix through SVD reveals the principal components of the data, indicating underlying patterns.

**Compute the SVD**: Decompose X into its singular values and vectors:

$$X = U\Sigma V^T$$

where U and V are orthogonal matrices containing the left and right singular vectors, respectively, and $\Sigma$ is a diagonal matrix of singular values $\sigma_i$.

**Lag-Covariance Matrix**: Optionally, one may also compute the covariance matrix C of the trajectory matrix to understand the variance structure:

$$C = \frac{1}{N - M + 1} X X^T$$

**Step 3: Grouping of Singular Components**

This step involves grouping the singular components derived from SVD to separate the signal components from noise.

**Identification of Significant Components**: Components associated with larger singular values represent more significant data structures (e.g., trends and cycles), whereas those associated with smaller singular values typically represent noise:

$$X_{singal}=U_{singal}\Sigma_{singal}V^{T}{}_{singal}$$

where $U_{signal}$, $\Sigma_{signal}$, and $V_{signal}$ are the parts of U, Σ, and V corresponding to significant singular values.

**Step 4: Reconstruction and Forecasting**

The final step involves reconstructing the time series from significant components and using this cleaner, more informative series for forecasting.

**Reconstruct the Series**: The original time series can be reconstructed using only the significant components:

$$\hat{x}_t = \sum_{i=1}^{r} U_{ti} \cdot \sigma_i \cdot V_{ti}^T$$

where r is the number of significant components retained for reconstruction. Forecasting: Extend the decomposition to forecast future values. This involves estimating future singular vectors or extending the time series by applying the patterns found in the decomposition.

## 3.3 Data

The dataset used in this research comprises a range of variables critical to understanding and forecasting the sales of EVs in India. The data spans a monthly timeframe, ensuring sufficient granularity for detailed time series analysis. In this research, Singular Spectrum Analysis (SSA) is utilised as a univariate time series model, focusing on sales data of electric Vehicles in India, spanning a monthly timeframe to ensure detailed and granular analysis. The key variables include the monthly sales figures for electric two-wheelers (Y1), electric three-wheelers (Y2), and electric four-wheelers (Y3). All data is sourced from the Society of Manufacturers of Electric Vehicles (SMEV), providing a reliable basis for the analysis. This comprehensive dataset allows for an in-depth examination of sales trends and dynamics in the Indian EV market.

# 4. EMPIRICAL ANALYSIS

## 4.1. Data Transformation

Initially, the raw sales data were converted into time series format and adjusted via logarithmic transformation to mitigate issues related to non-linearity and heteroscedasticity.


Figure 1: Raw Sales data of 2W, 3W and 4W

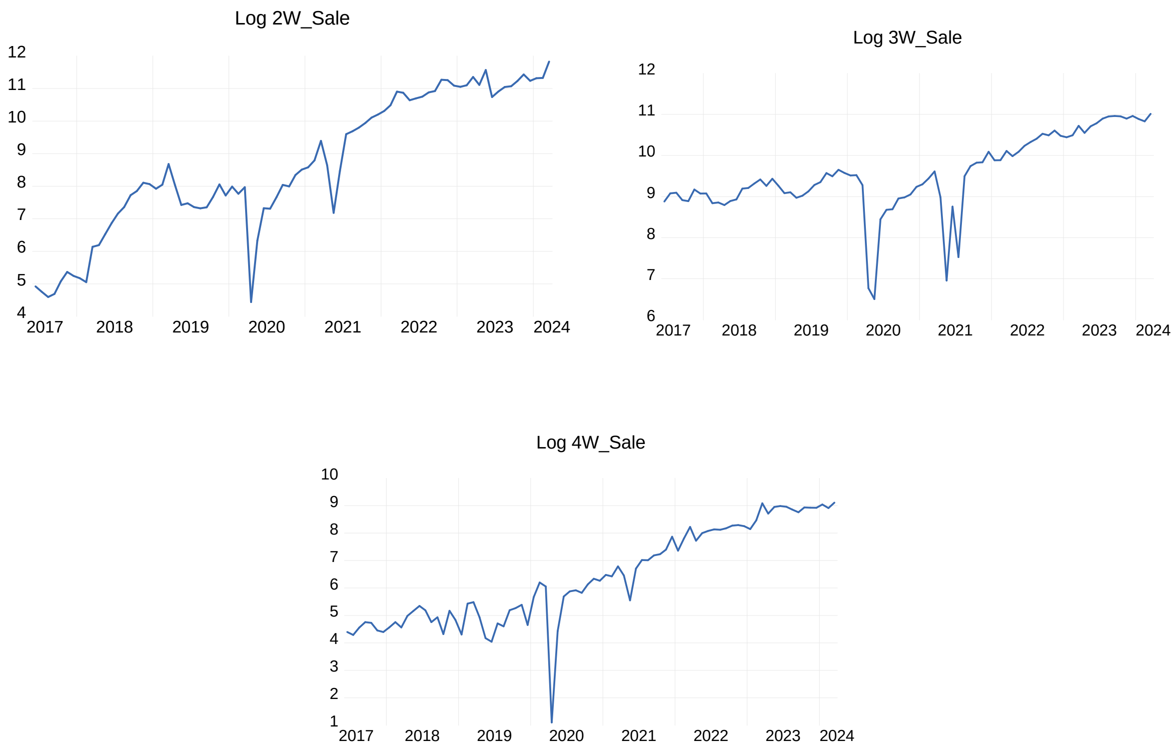


Figure 2: Logarithmic Transformed Sales data of 2W, 3W and 4W

## 4.2. SSA Decomposition

SSA was then applied to each transformed series with a window length of eight, aiming to decompose the series into various intrinsic components.

**2-Wheelers EV Sales Analysis**

For the 2W segment, the decomposition exhibits a steep decline in the eigenvalues from the very first component, suggesting a pronounced aggregation of variance within the initial components. This trend indicates that the predominant share of the sales dynamics can be effectively captured and explained by these leading components. Such a pattern is indicative of a strong, underlying trend within the data, with subsequent components likely reflecting lesser oscillations or seasonal effects, which are comparatively minor in their contribution to the overall sales dynamics.

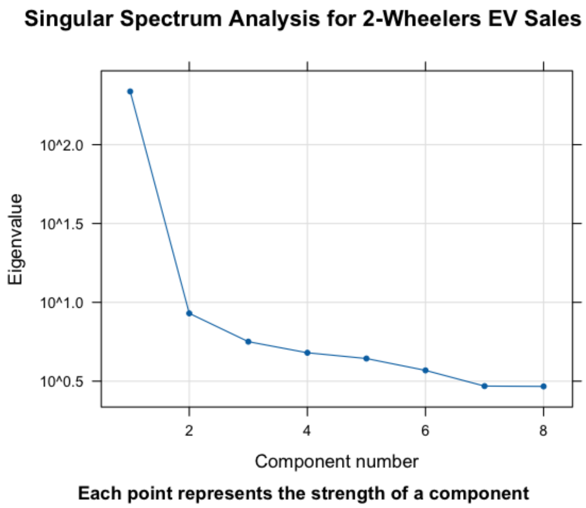


Figure 3 : Singular Spectrum Component : 2 Wheeler

**3-Wheelers EV Sales Analysis**

The eigenvalue plot for the 3W category mirrors the characteristics observed in the 2W segment, displaying a rapid decline in eigenvalue magnitude. This drop signifies that the major underlying trend and periodic components are predominantly captured by the initial few singular values. The swift decrease in eigenvalue size highlights the effectiveness of the leading components in summarising the principal sales trend, with minimal contribution from the noise or less significant oscillatory components.

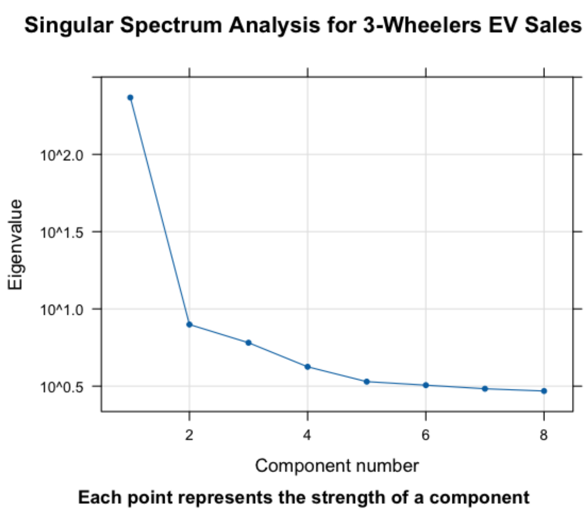


Figure 4 : Singular Spectrum Component : 3 Wheeler

**4-Wheelers EV Sales Analysis**

Similar to the previous categories, the 4W sales data analysis through SSA reveals a significant encapsulation of information within the first few components. The eigenvalue plot for this segment shows that these components capture the essential dynamics of the series, thus providing a clear depiction of the primary sales trends and cycles. The pattern observed in the eigenvalue decline is consistent with the 2W and 3W analyses, reinforcing the presence of strong, dominant sales trends that can be succinctly described by the initial singular values.

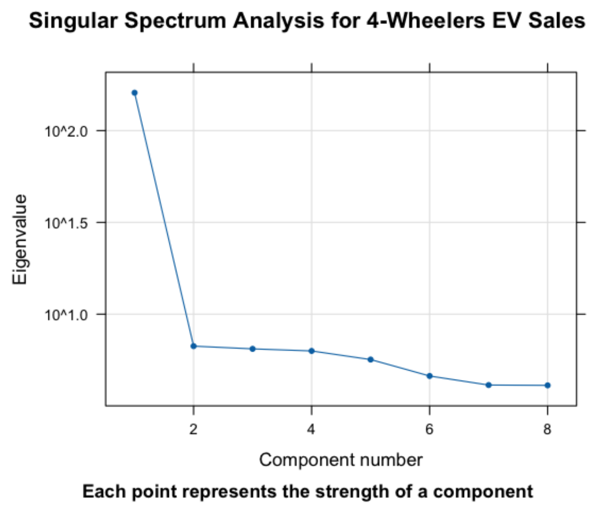


Figure 5 : Singular Spectrum Component : 4 Wheeler

## 4.3. Trend Extraction and Forecasting

Following the decomposition and analysis of singular values, the next crucial step in our empirical study involves extracting and examining the trend components from the time series of EV sales in India. This phase focuses on isolating the underlying trends and assessing the residuals to understand the systematic growth patterns and irregular fluctuations.

The trend and residual analysis for EV sales across different categories provides a comprehensive view of the market dynamics. For 2W, the analysis reveals a clear and steady increase in sales, depicted on a logarithmic scale to better illustrate exponential growth, with minor residuals pointing to occasional market disturbances or seasonal variations. The 3W segment similarly shows significant growth, with a smooth trend line that underscores the effectiveness of SSA in capturing long-term market movements. Minimal residuals in this segment suggest deviations might be influenced by external factors or policy changes. The 4W segment displays a consistent and smooth upward trend, indicating stable growth, which is significant given the higher costs and investments associated with 4W compared to 2W and 3W.

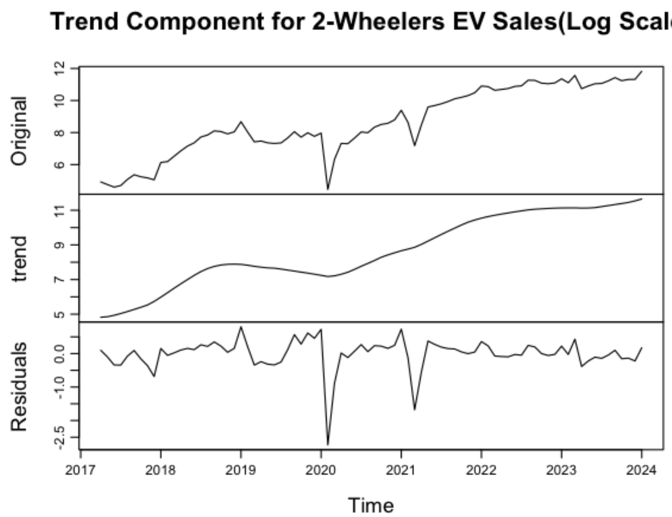


Figure 6 : Trend Extraction : 2 Wheeler

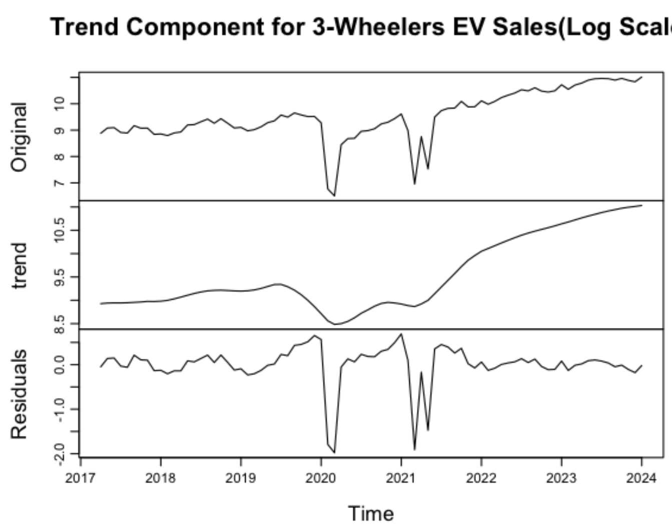


Figure 7 : Trend Extraction : 3 Wheeler

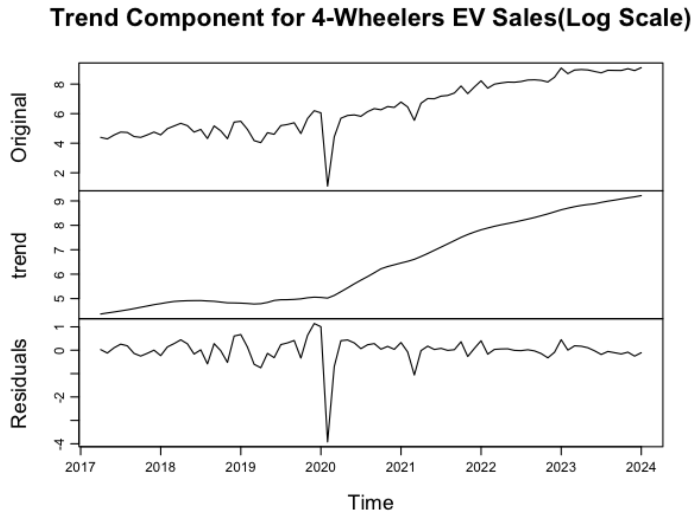


Figure 8 : Trend Extraction : 4 Wheeler

## 4.4. Forecasting Future Sales for Electric Vehicles

The following graphs illustrate the short-run forecast of 2W, 3W, and 4W EV sales, respectively, using SSA. Initially presented in a logarithmic scale, these forecasts highlight the relative changes and expected growth rates across each vehicle segment, showcasing a consistent upward trajectory. Subsequently, the forecasts were transformed from the logarithmic scale back to absolute sales figures through exponentiation. This step renders the projections in more tangible terms, offering direct insights into the expected sales volumes. The absolute number forecasts reveal substantial growth in the 2W segment from 1.5 Lakh to more than 3 Lakh by the end of 2024, which can be attributed to the increasing popularity of electric 2W as affordable and efficient urban transport solutions. Similarly, the 3W and 4W segments as shown in figure 8 and figure 9, demonstrating a significant growth potential, with the forecasts indicating robust increase in sales, driven by the broader acceptance of EVs in commercial transport and personal use due to technological advancements and growing environmental consciousness.

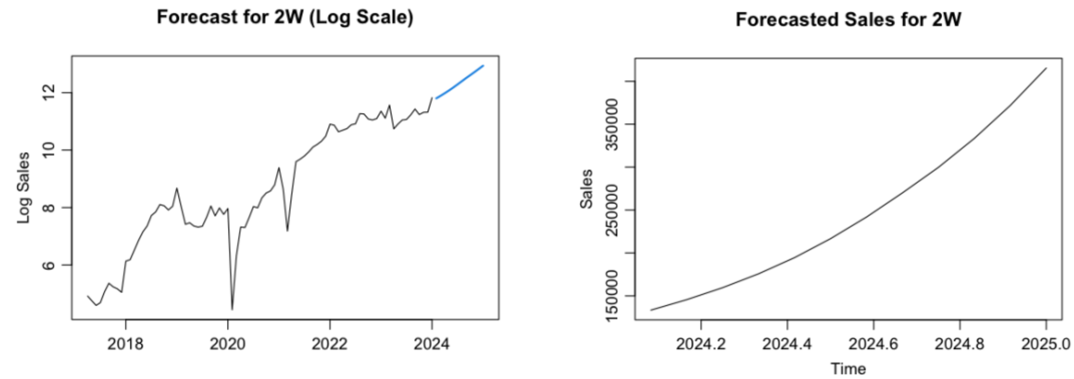


Figure 7 : Forecasted Sales using SSA : 2 Wheeler

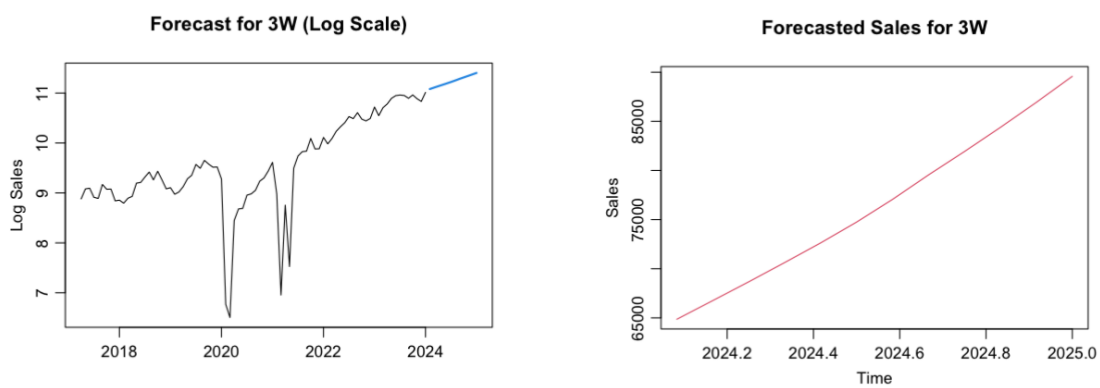


Figure 8 : Forecasted Sales using SSA : 3 Wheeler

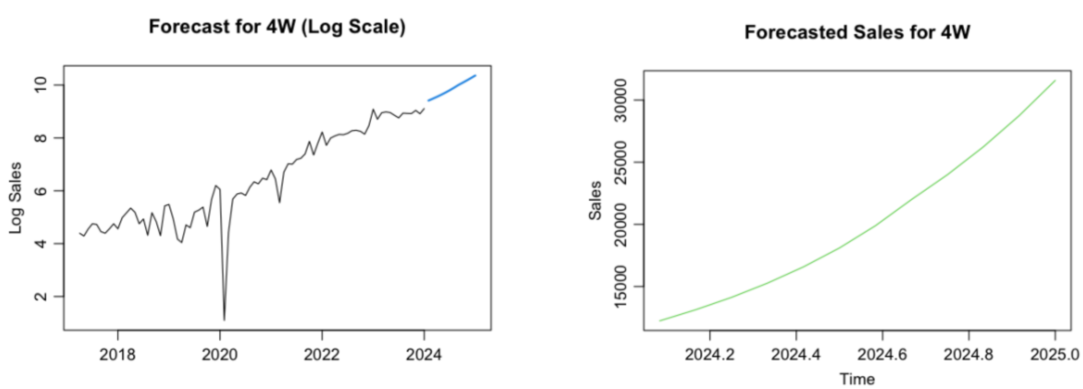


Figure 9 : Forecasted Sales using SSA : 4 Wheeler

# 5. FINDINGS

The SSA model provides forecasts for EV sales across three categories: 2W, 3W, and 4W. The forecasts span from March 2024 to December 2024.

The forecasted sales for 2W show a significant increase from 145,623 units in March 2024 to 321,915 units in December 2024, which is more than a two-fold increase. This substantial growth highlights the rapidly rising demand for electric two-wheelers. Similarly, 3W sales are predicted to rise from 66,759 units in March 2024 to 86,934 units in December 2024, indicating a 30% increase over the period. For 4W, the sales are expected to grow from 13,128 units in March 2024 to 28,755 units in December 2024, representing a significant increase of over two times.

| **Month-Year** | **F_2W_SSA** | **F_3W_SSA** | **F_4W_SSA** |
|---|---|---|---|
| Mar-24 | 145623.1 | 66759.48 | 13128.74 |
| Apr-24 | 159623.5 | 68669.90 | 14128.46 |
| May-24 | 175781.9 | 70630.60 | 15272.85 |
| Jun-24 | 194597.4 | 72628.46 | 16581.77 |
| Jul-24 | 216680.4 | 74748.61 | 18101.05 |
| Aug-24 | 241865.0 | 77059.44 | 19890.91 |
| Sep-24 | 270039.3 | 79548.21 | 21991.82 |
| Oct-24 | 289748.2 | 81927.75 | 23991.41 |
| Nov-24 | 300525.8 | 84386.05 | 26235.24 |
| Dec-24 | 3,21,915.3 | 86,934.94 | 28,755.44 |

Table 1 : Forecast values of 2W, 3W and 4W

# 6. Policy Suggestions and Conclusion

## 6.1. Policy Support

Given the current scenario and the projections for the electric vehicle market, it is clear that significant growth is anticipated across all categories of EVs. According to the Singular Spectrum

Analysis, there is a predicted 2.2-fold increase in two-wheeler sales, a 30% rise in three-wheeler sales, and a 2.2-fold increase in four-wheeler sales by December 2024. These forecasts consider the existing conditions without factoring in government interventions.

If the government enhances its focus on charging infrastructure and reducing battery costs, the potential for EV adoption could be much higher. This model serves as a baseline scenario under current conditions, suggesting that actual outcomes could exceed these expectations. For instance, a 1% increase in EV sales in a city can reduce local $CO_2$ emissions by 0.096% (Xiaolei Zhao et al., 2023). Additionally, achieving a 30% EV sales share in India could save approximately INR 1.1 lakh crore in crude oil imports (Abhinav Soman et al., 2020).

To capitalise on these opportunities, several policy measures are recommended. First, it is essential to enhance battery and motor technologies by focusing on improving the size, lifespan, and efficiency of batteries and electric motors while reducing material costs. Second, expanding the charging infrastructure is crucial to establish a widespread and reliable network of charging stations to assure potential buyers of constant charging availability. Third, increasing public awareness of the benefits and sustainability of EVs will drive consumer demand and foster greater adoption. Lastly, promoting diverse EV options by ensuring high-quality and varied choices across all vehicle types will cater to different market segments and enhance overall market penetration.

## 6.2. Conclusion and Way Forward

The anticipated growth in the EV market, as projected by SSA model, highlights the significant potential for the electric mobility sector in India. These models, while providing a conservative estimate, underscore the transformative impact that increased EV adoption could have on the environment and the economy.

To fully realise this potential, it is crucial to focus on several strategic areas. First, promoting new economic activities such as battery recycling (urban mining) and other services related to electric mobility can create job opportunities and stimulate economic growth. Second, implementing training and skilling initiatives to develop a workforce capable of meeting the demands of EV manufacturing and maintenance is essential. This will ensure that the industry has the necessary human resources to support its expansion. Third, developing pre-emptive fiscal strategies to mitigate the expected decline in petroleum tax revenues as EV adoption increases is vital. This will ensure stable central and state government revenue collections while promoting electric mobility.

By adopting these measures, India can achieve significant environmental benefits and drive economic growth and job creation. The country has the potential to position itself as a global leader in the transition to sustainable mobility, provided that these strategies are implemented effectively and timely.

## 6.3. Future Scope of the Study

The future scope of this study is multifaceted, encompassing various dimensions of the EV market and its broader implications. Firstly, future research could integrate the impact of government policies and initiatives, such as subsidies, tax incentives, and infrastructural developments, to provide a more comprehensive analysis of their effects on EV adoption rates. Secondly, exploring advancements in battery technology, including improvements in energy density, charging speed, and cost reduction, will be crucial in understanding their potential to accelerate market growth. Additionally, the integration of smart grid technologies and renewable energy sources with EV charging infrastructure could be examined for their roles in enhancing system efficiency and sustainability. Consumer behaviour analysis is another vital area, where studies could delve into factors influencing purchasing decisions, such as environmental awareness, economic considerations, and technological preferences. Furthermore, detailed environmental impact assessments could quantify the benefits of EV adoption in terms of $CO_2$ emissions reduction and air quality improvements. Lastly, the economic impacts of EV transition, including job creation, effects on GDP, and shifts in the energy and automotive industries, warrant comprehensive investigation to inform policymakers and stakeholders about the broader economic benefits and challenges of fostering an EV ecosystem.

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