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Ethanol or EV—The Future Alternative for India's Automotive Energy Industry

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Abstract

The research paper compares economic performance before deciding on whether to choose ethanol or electric cars against petroleum products in India. For India's serious air pollution problems, energy security concerns, and rapid urbanization, it is important to change to sustainable transport modes. This study examines how India's policies concerning electric vehicles (EVs) and ethanol, market trends for these vehicles, as well as technological advancement, would promote them as cleaner alternatives to vehicles using internal combustion engines. The Government of India introduced plans to make the country pacesetter in manufacturing EVs by unveiling NEMMP 2020 all along the Faster Adoption and Manufacturing of Electric (FAME) program. India's EV market is set for significant growth despite facing challenges like high costs, limited charging infrastructure, and concerns over range. The projections have indicated that the electric vehicle industry will be able to command a 40% market share by the year 2030. In contrast, ethanol produced from agricultural products presents an attractive means of cutting down oil imports and reducing greenhouse gas emissions. The Indian Government's Ethanol Blending Programme has made big strides, with a target of 20% ethanol-blended petrol set for 2025. Moreover, the production of ethanol is beneficial to rural economies and provides job opportunities; however, there are still questions about feedstock availability and technology. This essay evaluates technical feasibility, environmental benefits, and impacts on infrastructure requirements as well as consumer choice for both alternatives through a thorough review of secondary sources like scholarly articles or government documents among others. In its conclusion, the research presents policy recommendations aimed at increasing EV adoption to ensure a sustainable and economically viable future for India's automobile sector.

Keywords: Economic performance, ethanol, petroleum products, charging infrastructure, technological advancement

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INTRODUCTION

Electric Vehicles in India

India's increasing use of electric vehicles (EVs) is a huge improvement in the global revolution towards eco-friendly transport. The need for EVs is now more important than ever, as climate change remains a major concern around the world, and non-renewable energy sources are becoming less important. In India, where there are severe air pollution problems, energy security issues, and rapid urbanization processes, the development of EVs is very important for economic growth and technological change.

The National Electric Mobility Mission Plan (NEMMP) 2020 [1] and other policies were introduced to promote the large-scale adoption of electric vehicles and make India a global hub for manufacturing and innovating EVs, which also laid the foundations for the electric mobility path of India. The FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) program was another measure to ensure Faster Adoption and Manufacturing of Electric Vehicles. In addition, various strategic alliances between local businesses and foreign automobile manufacturers have pushed ahead such advancements in electric automobiles. Hence, the resulting participation by local entrepreneurs has inspired further innovations despite using partnerships with foreign companies that allow technology transfer, which boosted the development of electric vehicle ecosystems throughout the country [2].

The EV market in India is changing rapidly and is now an important point of inflection. According to the 2023 Bain India Electric Vehicle Report, EVs represented approximately 5% of the total vehicle sales from October 2022 to September 2023. By 2030, this share is likely to increase by more than 40%, driven by strong growth rates in the two-wheeler (2 W) and three-wheeler (3 W) categories. 2 W EVs currently dominate the market with 85–90% market share, while 4 W EVs account for just 7–9% and 3Ws just 5–7%. The Faster Adoption and Manufacturing of Electric Vehicles (FAME) Phase II scheme has contributed significantly towards these numbers; however, there are still some hindrances such as high prices compared to internal combustion engine (ICE) vehicles, range anxiety, limited charging infrastructure, and financial problems [3].

Although it faces difficulties, by 2030, the electric vehicle market has prospects for more than 100 billion dollars in revenue; for instance, automakers need to find a balance between cost, range, and performance to make them affordable compared with conventional ICE vehicles such as Honda Active, which dominates the two-wheeler segments. In addition, more support from the government, better battery technology, and more local production reduce reliance on imports and disposal technology of e-waste [4].

Ethanol Scenario in India

The Indian economy is growing rapidly, with a rapidly increasing population, additional air pollution problems, and high expenditure on oil imports. This has attracted the government to seek alternative solutions to decrease dependence on fossil fuel sources. The most feasible solution is bioethanol, which has a range of economic, social, and environmental advantages for new crop demands, increased employment, and less harmful emissions [5–8].

The Indian government has reported a reduction of 31.8 million metric tons of greenhouse gas emissions during the ethanol supply years 2014 to 2022 through interventions associated with the India Ethanol Blending Program. Despite the progress made in blending targets, there are many other issues, particularly regarding the availability of feedstock and technological limitations; however, both policymakers and the producer community are countering such challenges by implementing better policies and regulations with the backstopping of technological advancement [9].

At present, the industrial ethanol production capacity of India stands at 13.80BL, out of which 8.75BL is from molasses and 5.05BL from grain feedstocks. To achieve the target of 20% blending by 2025, India reached a record blending of 11.6% in Q1 of ESY 2023, which represents a 13% increase from 2022 [4].

Maharashtra is the leading state in ethanol production, contributing 2.68 BL per annum. Other major ethanol-producing states are Uttar Pradesh and Karnataka, where ethanol levels go up to 2.08 and 1.18 BL per annum, respectively. With abundant feedstock, these states are the frontrunners in industrial ethanol production.

The bioethanol industry in India is on the way up the growth curve, offering considerable potential for innovation and technological advances. Eventually, new technologies and innovative practices will

fuel a prosperous dynamic in the bioethanol market. With second-generation bioethanol gaining weight in the upcoming years or the possible launch of new generations of yeasts in the Indian market, opportunities are real and have already begun to bloom. Forecasts of bioethanol demand for use in sustainable jet fuel will not only increase the production of biofuel but also help significantly mitigate greenhouse gas emissions and improve energy efficiency. Against the backdrop of recent progress and a palpable political will to promote sustainable ethanol production and discourage dependence on fossil fuels, there is hope for optimism regarding the future of ethanol in India [10].

LITERATURE REVIEW

Hill et al. (2006) evaluated the *environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels* provides the environmental, economic, and energetic costs and benefits of ethanol and biodiesel biofuels were evaluated in this study. Hill et al. compared ethanol from corn and biodiesel from soybeans using life-cycle accounting. The results indicated that ethanol provides a net gain of 25% in energy, whereas biodiesel provides a gain of 93%. Biodiesel requires less agricultural input and has less emission of pollutants than ethanol. Both biofuels reduced GHG emissions. However, if all US corn and soybean production were converted to biofuels, it would only account for a small fraction of the nation's fuel demand, highlighting the physical limitations that food-based biofuels place on meeting national energy needs sustainably [11].

Bishnoi (2022) in *A Study on Electric Vehicles in India: Opportunities and Challenges* Monu Rani Bishnoi has talked about the prospects and problems of the adoption of electric vehicles in India. The study embarks on an investigation into the prospects of the environmental benefits that EVs offer with reduced GHG emissions and lower reliance on fossil fuels. It discusses various EVs, from Battery Electric Vehicle (BEVs) and Hybrid Electric Vehicle (HEVs) to the upcoming technology of fuel cells. Much attention has been paid to the development of better battery technology and the enhancement of the charging infrastructure for EVs in India. This paper concludes that although EVs have many advantages, dealing with technological and infrastructural issues remains key to their mass adoption [12].

Joshi, Malhotra, and Singh (2022) in their paper *Assessing Adoption Intention of Electric Vehicles in India: The Mediating Role of Government Policies* consider factors that may influence the adoption of electric vehicles in India, to establish how government policies are mediated. These key factors were price, environmental concerns, infrastructure requirements, and knowledge of EVs. It was established that government policies mediated the relationship between these factors and the intention to adopt EVs. Therefore, strategic government interventions aim to reduce prices, improve infrastructure, and increase public awareness. This research provides policymakers with insights into designing effective strategies to boost the adoption of EVs in India [13].

In the *Global EV Outlook 2023 report*, the global trend towards sustainable transport is reflected in the increased ethanol and electric vehicle adoption. Countries, such as Brazil and the US, have largely adopted ethanol-blended fuels. The Proálcool Program of Brazil drastically reduced GHG emissions and strongly pushed the ethanol industry. In the case of the US, RFS supported its use and contributed to the benefit of rural economies linked to corn growers (S&P Global) (Invest India). EVs have been massive because of the leveraging of technological advances in the field of batteries and policy support. According to the International Energy Agency, worldwide electric car sales reached more than 10 million in 2022, on the back of powerful performances in China, Europe, and the US. The Indian scenario is different, though, with the active pursuit of ethanol blending as a measure toward reducing fossil fuel imports despite concerns relating to agricultural inputs. The EV market in India is rapidly expanding, driven by schemes such as FAME and massive investments in the manufacturing of batteries and charging infrastructure [14].

RESEARCH METHODOLOGY

Problem Statement

The car manufacturing sector faces major challenges in terms of sustainability and the need for energy security. In this context, India serves as a unique case study because it is an emerging economy with a

rising middle class. EVs can come in handy by reducing carbon emissions and the demand for petroleum products on roads. However, ethanol-based vehicles or e-vehicles are also good options because they can use local agricultural outputs. The objectives of this research include assessing the value proposition for different options between EVs and E-vehicles in terms of comparative advantages, challenges, and implications, such as infrastructure, user preferences, economic viability, and environmental trends, among other factors in India. It sounds like awesome work for future generations who are to come up with real solutions [15, 16].

Objectives

1. To analyze the current state of EV adoption in India, including market penetration, consumer awareness, and government policies.
2. To compare the technical feasibility, environmental impact, and economic viability of EVs and E-vehicles in India.
3. To assess the infrastructure requirements for EV and E-vehicle adoption, including charging stations and ethanol distribution networks.
4. To evaluate the impact of government policies, subsidies, and tax incentives on the adoption of EVs.
5. To examine consumer preferences and attitudes towards EVs and E-vehicles, we identify the key factors influencing purchase decisions.
6. To forecast the future market share of EVs in India based on various scenarios and assumptions.

Method of Research

This study specifically focuses on a considerable review of secondary sources to assist our research. This comprised scholarly journals, research papers from government bodies, industry magazines, and other electronic databases. From such sources, while compiling the information, it helped to develop an understanding of the social context, policies, market conditions, and technologies regarding the implementation of blended EV and ethanol opportunities in India.

Hypothesis

The evolution of ethanol blending and EVs stands at the forefront of transforming automotive agriculture through the production and energy industries, driven by a confluence of technological, economic, and regulatory forces. Further narrative dives into the factors promoting and guiding prospects of both alternatives by delving into the macroeconomic factors, market demand, feasibility of infrastructure, pricing policies, and adoption pace. These hypotheses will help us further evaluate the findings for recommendations [17,18].

ECONOMIC FACTORS

Electric Vehicles

Fuel price hikes have made EVs more appealing among buyers today when compared to about five years ago due to an increase of more than 30% in the petrol price indices over that period within the Indian Territory. There has been a growing awareness of issues pertaining to climate change as well as air pollution, which has resulted in demand for cleaner transport systems, especially within towns in India, such as those located in Delhi where PM 2.5 levels are more than ten times above the WHO safe limits. Improvements in battery technology and decreased lithium-ion battery prices have made EVs the affordability and efficiency of EVs. In the past decade, lithium-ion battery costs have decreased by approximately 89 percent from their previous levels, making electric vehicles cheaper than gasoline cars [19].

Today, the government offers subsidies for EV purchases and encourages the growth of charging stations under the FAME-II scheme (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles). A sum of Rs. 10,000 crores were earmarked for this scheme by the government. In addition, under (Production Linked Incentive) scheme, subsidies are being offered for the manufacturing of electric

vehicles locally to establish India as a major player in EV production on a global scale. The Production Linked Incentive (PLI) scheme is intended for the automotive sector with a total of 26,058 crores.

Ethanol-blended Fuel

India boasts a solid agricultural sector, generating large quantities of sugarcane together with other crops that can be converted into ethanol. As of 2020–21, Indian sugarcane production stood at 30.2 million tons. For India, one of its most important strategic objectives is to decrease its dependence on imported oil.

Ethanol, as an indigenous source of fuel, can help increase energy self-sufficiency and reduce trade imbalances. India imports approximately 85 percent of its crude oil requirements. There is an opportunity for increased earnings from farmers in rural areas through ethanol production, thereby contributing to the growth of the rural economy. The ethanol industry is expected to produce 700,000 jobs by 2025 [20].

The government has made it compulsory for ethanol to be mixed with petrol to increase the blending percentages over time. The goal was to achieve 20 percent ethanol blending by 2025. Funds from Ministry of Road Transport & Highways (MoRTH) have been allocated to establish ethanol production companies and encourage farmers to cultivate crops that can be used to make more biofuels.

The government sanctioned Rs. 4,573 crores for various projects related to ethanol production. R&D investments are being made to improve ethanol production technologies and develop second-generation biofuels from non-food biomass. The Indian government allocated INR 1,000 crores to biofuel R&D.

MARKET DEMAND AND PROJECTION

Electric Vehicles

India's EV market has been on a quite impressive growth trend, according to which the market is expected to grow by leaps and bounds from USD 8 billion in 2024 to USD 120 billion by 2030. This growth is based on a compound annual growth rate (CAGR) of 126 percent of the existing business. 29% for the years 2017–2023, including the CAGR of 22%. According to your options, they could increase to 93% from 2024 to 2030 or 92% from 2024 to 2030. This ever-rising figures is a result of the popularity and surge in the use of electric vehicles in the nation.

BEVs occupy the lion's share in the Indian EV market and currently have a value share of 98 percent at the moment 38% in 2023. This dominance can be attributed to a number of factors that include government policies that aim to promote the usage of EVs, continually escalating prices of fuel, and the fact that the public is gradually becoming sensitive to the effects of human-induced global warming and climate change and therefore embracing electric mobility. Together, these elements play a significant role in the already vigorous market status of BEVs.

When grouped according to vehicle type, the two-wheeler segment appears to be the most preferred in the Indian EV market at a 17% value share in 2023. These are cheaper to manufacture and maintain, convenient to maneuver within densely trafficked areas, have low operational costs, and have a growing consumer preference for electric scooters and bikes. The rise of this segment proves the paramount importance of two-wheelers if electric mobility is to be adopted in India [21].

The Bain & Co. report estimates that 40–45% of all EVs to be sold in India by 2030 will be electric two-wheelers, and electric passenger vehicles 15–20%. Consistent with this, the Niti Aayog report lays down the government targets of electric vehicles achieving 40% of the bus segment, 30% of the private car segment, 70% of the CV segment, and 80% of the two-wheeler segment by 2030. This clearly shows a vigorous and impressive governmental drive toward the rise of EVs in the different categories of vehicles (Figure 1).

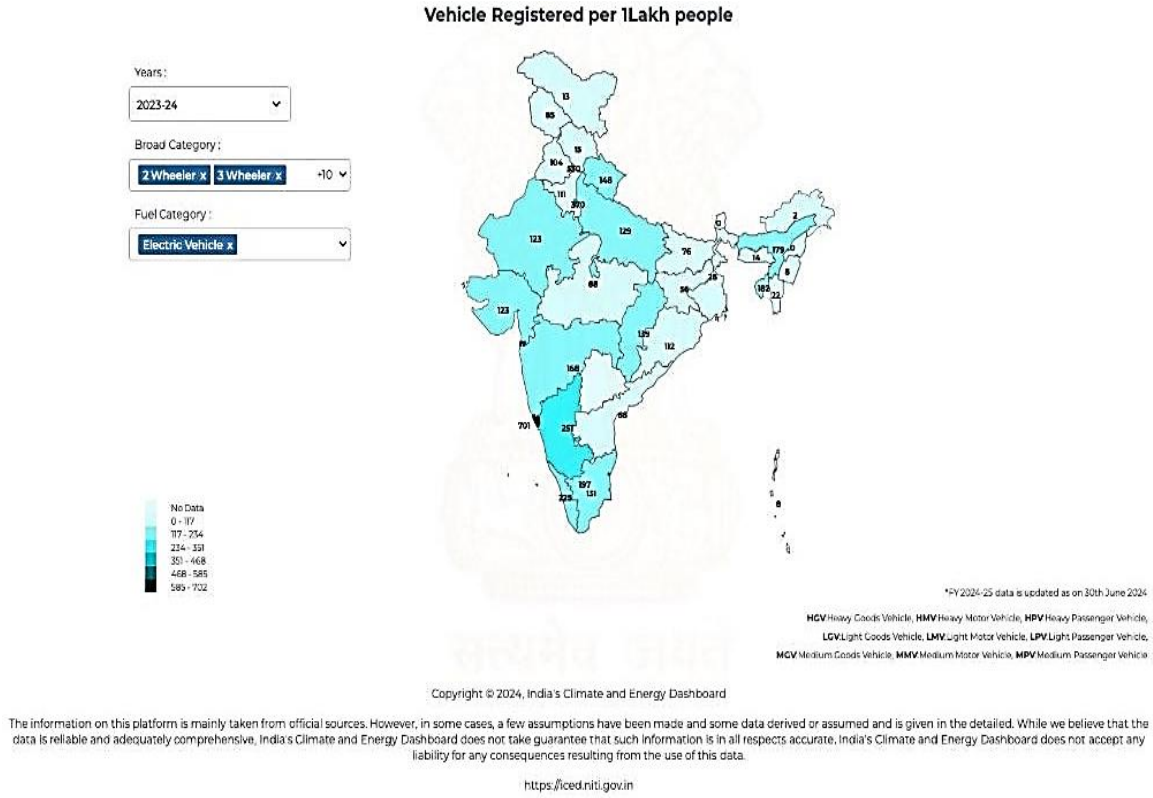

Figure 1. Registered electric vehicles per 1 lakh people in India (2023–24).

For instance, information arising from VAHAN shows an increasing trend in the market demand for electric two-wheelers. In particular, sales in the thirteen-week fourth quarter of Q3 FY 24 increased by 34 percent. A 42% increase compared to Q2 FY 24, and setting a record by selling 76,301 vehicles in Q4 FY 24. This growth is not an exception, as the Economic Survey of India 2023 has further revealed the CAGR of the domestic EV market at 49% for the fiscal 2022–30. This means a projected 10 million annual EV sales by 2030 and approximately 50 million direct and indirect employment in the next one-week employment in the next seven years. New trends emerging in India over the electric vehicle market show an increasing trend towards the use of micro-mobility vehicles, such as electric two-wheelers and three-wheelers. The Ola Bikes and Vida V1 are among the widely known electric scooters fueling this segment's growth. Moreover, the launch of the FAME-India scheme of the Indian government, which offers subsidies and higher demand for electric micro-mobility in the future, will provide a positive outlook to the market in the future [22].

Ethanol-blended Fuel

The current size of the Indian ethanol market is about 3200 million liters in FY2023; thus, it is growing at a CAGR of 5%. Incorporating the analysis of the forecast period up to FY2035, the growth of this type of investment reaches 67% of the total investment. Based on the use of ethanol in fuel additives and beverages, the market revenue of Indian Ethanol production in the estimated years will grow rapidly. Additionally, the planned strategic initiatives of the Government of India sponsored towards the transformation of excess sugar to ethanol are again complemented by the prospect of building an Ethanol Economy that will increase demand for ethanol in the future.

Under the National Biofuel Policy 2018, the ethanol mixing rate was fixed at 10% by 2022 and 20% by 2025 against a current rate of 2–3%, and the demand for ethanol has grown steeply throughout the forecast period. Over the last five years, the Indian government has been encouraging the capacity enhancement of ethanol to reduce dependency on imported crude oil and to make use of excess stocks of sugar found in the country to produce ethanol (Figure 2).

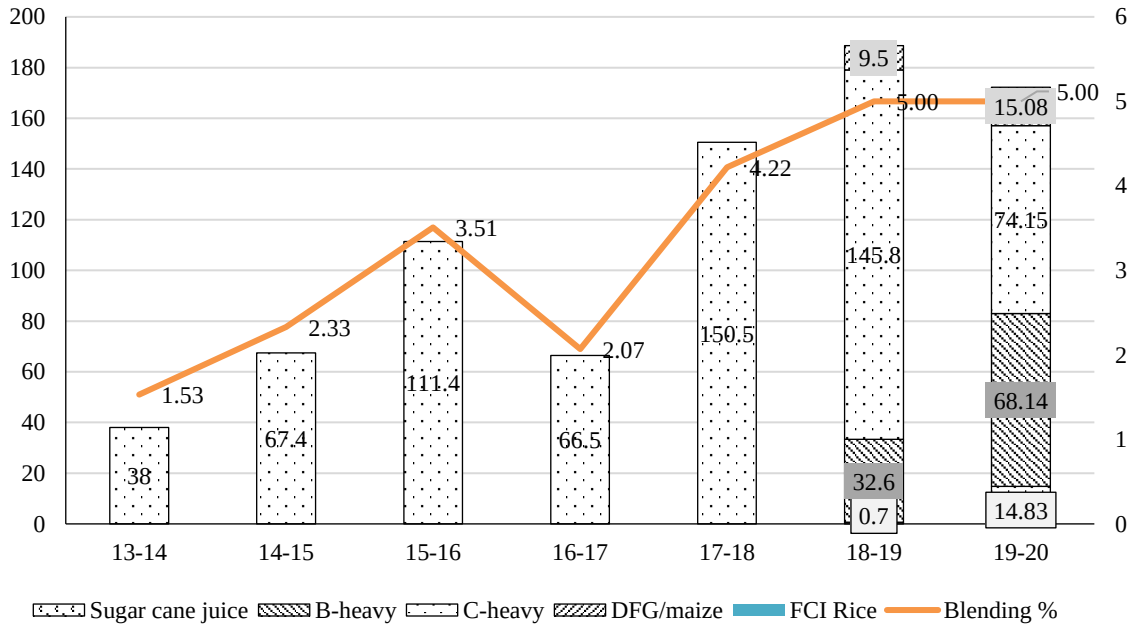

Figure 2. Ethanol production and blending trends in India (2013–2020).

Projecting growth in this segment, expenditure projections for 2019–20 for petrol were at 4,656 crore liters, while for blending percentage at 15%, it needed 698 crore liters of ethanol. A good increase is expected in 2024–25, the blending target of petrol is 20%, and the projected sales of petrol is 4,939 crore liters, meaning that the requirement of ethanol would be 988 crore liters. Based on the same 20:80 blending ratio, petrol sales by 2025–26 is expected to be 5,080 crore liters, and for this, 1,016 crore liters of ethanol will be required. These projections depict a progressive rise in the two aspects of petrol sales and percentage blending for ethanol in subsequent years.

The gradual increase in ethanol consumption is due to a global trend that promotes the use of environmentally friendly commodities in the fuel market. However, these may change over time because of the underlying elements, such as the EV market penetration rate. The figures are encouraging, knowing that new vehicles will be using the E20 fuel from April 2033, and there is likely to be a call for ethanol with the introduction of E100 two-wheelers. This planned upgrading in ethanol blending with gasoline is in accordance with the overall environmental policy and plans the transportation sector's effective methods to minimize their carbon footprints.

CURRENT SCENARIO OF INFRASTRUCTURE

Infrastructure for EVs

There are more than 5,234 public EV charging stations across the country; of these, Karnataka, Maharashtra, and Delhi top the list with 704, 660, and 539 stations, respectively. For eight crore electric vehicles by 2030, the country will require at least 39 lakh semi-public and public EV charging stations. The deficit currently was huge, with one station catering to 135 EVs against the global benchmark of one per 6–20 EVs. Challenges arise in the form of an inappropriate power grid, geographical diversity, and the financial constraints of small businesses and local communities. Geographical inequalities exist, such as Lakshadweep and Sikkim, which have only one station. There are better infrastructure developments in urban areas than in rural areas, where it is difficult to have such facilities.

There are only approximately 2,500 battery swapping stations across India, largely for two- and three-wheelers. The EV battery swapping market, valued at USD 14.2 million in 2023, is expected to grow at a CAGR of 25.4% until 2030 to hit USD 68.8 million. Most stations are in Uttar Pradesh, and Karnataka is the fastest-growing state. In this scenario, the challenges are battery performance deterioration and fewer facilities for fast charging. Increasing electric rickshaws and government incentives present opportunities (Figure 3).

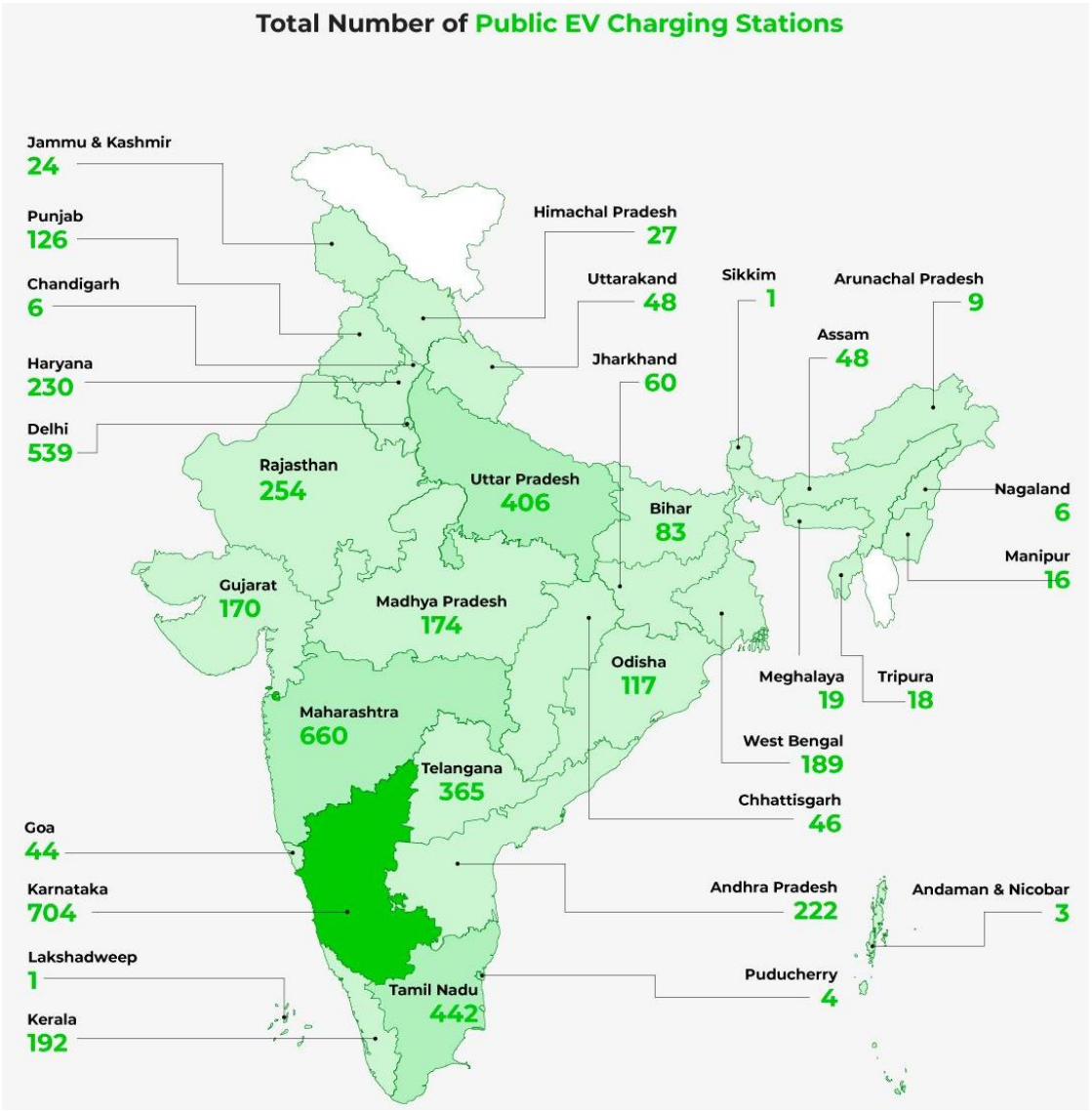

Figure 3. Distribution of Public EV Charging Stations across India, with Karnataka leading at 704 stations, followed by Maharashtra and Delhi.

The Indian government is fast-tracking EV adoption by facilitating a public charging infrastructure. The installation of charging stations is being carried out by the Ministry of Power and Bureau of Energy Efficiency (BEE) along highways and within city limits. The FAME-India scheme sanctioned 2,877 stations across states and 1,576 stations along major highways to alleviate range anxiety. The EESL initiative resulted in 810 stations being built by the private sector. Furthermore, Rs.800 crore has been offered to oil companies for EV infrastructure under FAME, and 100% FDI is permitted in the sector, pushing electric mobility in India.

Infrastructure for Ethanol Blend Fuel

The existing ethanol production capacity is 1,380 crore liters, of which molasses-based distilleries contribute 875 crore liters and grain-based distilleries 505 crore liters. There are approximately 180 ethanol production plants in the country, comprising both sugarcane-based and grain-based distilleries. Ethanol will be sold by Oil Marketing Companies, and it will be blended with petrol at various refineries and depots in different parts of the country. Thus, blending facilities integrated with Oil Marketing Companies (OMC) depots are currently achieving 12% ethanol blending in petrol, with a target to increase to 20% by 2025.

After the announcement of E20 in 2023 by the Prime Minister, India now aims to achieve the blending of 20% ethanol by 2025–26. On offer at 12,000 outlets is now E20, while ethanol 100 from Indian Oil is available at 183 sites. Government efforts and long-term tie-ups by OMCs with 131 ethanol plants are likely to increase the production capacity by 745 crore liters per annum. Equally, the private sector joined the roadmap of E10 by April 2022 and phased E20 rollouts from April 2023, thereby making the blending target a collaborative effort.

PRICING FACTOR

Electric Vehicles

Supported by conducive government policies and growing consumer interest, electric vehicle markets are growing rapidly. The new EV policy stipulates a minimum investment of INR 41.5 billion ($500 million) with no cap on investment; it requires that manufacturing start within three years. It enunciates further that there should be 25% domestic value addition by the third year and 50% by the fifth year. A 15% customs duty is imposed on Completely Knocked Down units with a minimum Cost, insurance, and freight (CIF) value of US$35,000 for five years, subject to investment in setting up manufacturing facilities within three years. It has been capped at 40,000 EVs over five years and not more than 8,000 per annum for investments of US$800 million or above, with carry-over of unutilized annual import limits. The bank guarantees back investment commitments, which are invoked in case of failure to meet the deferred variable annuity (DVA) and minimum investment criteria.

EVs are still expensive in India compared to traditional vehicles; the lithium-ion battery adds significantly to their cost. While the price of an EV like Tata Nexon comes for anything between ₹14–17 lakh, a comparable petrol car comes for around ₹8–12 lakh. Although most consumers are deterred by the high upfront cost of EVs, the running cost is a consideration. Again, EV runs at about ₹1.2–1.5 per km against ₹4–5 per km for petrol vehicles, making the EV more economical in the long run.

The Government of India has announced subsidies and incentives for common people and industries to boost their adoption of EVs. This includes but is not limited to, the scheme on Faster Adoption and Manufacturing of Hybrid and Electric Vehicles, or FAME-II, which has earmarked ₹10,000 crore for subsidies on EV purchases and the creation of charging infrastructure. In addition, purchasers of EVs pay a lower Goods and Services Tax (GST) rate, cut from 28 percent to 5 percent, and enjoy income tax deductions on interest on loans taken for EV purchases. This lowers the overall cost of owning an EV, making it more accessible and appealing to consumers. The price elasticity of EVs is relatively high and driven principally by reduced battery costs, government incentives, and increased consumer awareness. As battery prices are constantly falling and with the strong support of the government, the demand for EVs is likely to rise very rapidly.

Ethanol-blended fuel vehicles

The ethanol-blended petrol (EBP) Program of India is conceptualized as a means toward concern for the environment, reducing import dependency, and supporting the agriculture sector through the promotion of ethanol as an alternative fuel. In this context, several steps have since been taken by the government to augment production, including the introduction of the administered price mechanism, opening up additional routes to produce ethanol, and, very recently, the amendment to the Industries (Development & Regulation) Act, 1951. These amendments explicitly bring denatured ethanol under the complete control of the Central Government, decrease GST from 18 percent to 5 percent, and expand raw material procurement for ethanol manufacture. Policy initiatives include the National Policy on Biofuels (2018), and interest subvention schemes have been introduced to enhance the ethanol production capacity. The Programme was extended to the entire country, except Andaman and Nicobar Islands and Lakshadweep, with effect from April 1, 2019. Accordingly, procurement of ethanol by the Public Sector Undertaking (PSU) OMCs has increased from 38 crore liters in the Ethanol Supply Year 2013–14 to 164.75 crore liters in the Ethanol Supply Year (ESY) 2018–19, thereby achieving an average blend percentage of 5.50%. The target for ESY 2021–22 is to blend 10% ethanol; this proportion will then be progressively increased to achieve 20% by ESY 2029–30.

Ethanol pricing in India is controlled by the government, which pegs its price to make it viable vis-à-vis petrol. For the 2021–22 season, different prices were announced: ₹62.65 per liter for ethanol produced from C-heavy molasses and ₹65.61 per liter from B-heavy molasses. The price of ethanol from sugarcane juice was fixed at ₹69.85 per liter. Such a pricing strategy would position ethanol as a viable and cost-effective alternative to petrol, the prices of which have been fluctuating wildly due to volatility in the global oil market. Flex-fuel vehicles offer flexibility with different ethanol blends, but vehicles running on ethanol-blended fuel, such as E20, usually have a slightly lower mileage, with an expected reduction of approximately 7–8% vis-vis pure petrol.

Subsidies and several other incentives, such as the Indian government's interest subvention schemes, strongly support ethanol production and consumption. They balance the price so that ethanol has a stable demand to be a serious alternative to traditional fossil fuels. The price elasticity of ethanol, although generally inelastic in an elastic sense due to government mandates on blending percentages, may be affected by agricultural output-related factors. Therefore, the overall policies of the Government of India on pricing, together with other incentives, would be key to promoting ethanol-blended vehicle adoption and competitiveness in the market.

ADOPTION PACE

Electric Vehicles

Electric vehicles are more accessible in India. Existing carmakers announced ambitious goals for electrification of their product portfolios, while new entrants introduced models tailored to India's urban environments. It is now at par that the total cost of ownership for EVs, hitherto acting as a barrier to buyers, has reached parity with ICE vehicles. Consequently, by 2030, the penetration of EVs into the market will be around 10–15 percent, thereby opening incredible opportunities for all concerned stakeholders: original equipment manufacturer (OEMs), financial institutions, grid operators, and others.

Ethanol-blended Fuel

The roadmap to E20 has many intermediate steps and associated regulatory changes. The MoRTH mandates BS-VI emission norms and notified standards for adopting E20 fuel, including safety and emission standards. Because existing vehicles are designed to run on pure gasoline, current vehicles can run on E10 with compatible rubber and plastic components; however, the shift to E20 would require material-compatible and engine-tuned vehicles for E20. The Society of Indian Automobile Manufacturers (SIAM) has shown readiness to align vehicle production with the E10 and E20 roadmap—targeting material-compliant E20 vehicles by April 2023 and E20 engine-tuned vehicles by April 2025. All these compatible vehicles would come at a price slightly higher than that of regular gasoline vehicles.

CHALLENGES IN TRANSITION FOR BOTH THE ALTERNATIVES FROM TRADITIONAL FUEL

Electric Vehicles in India

There are a number of challenges to their wide adoption in India. Of course, high upfront costs are one of the primary issues associated with expensive batteries. However, with the recent introduction of sublakh EVs from Tata and MG, EVs will become more affordable and send a good message for other OEMs to follow in their footsteps. Furthermore, low model availability and variety in EVs impact consumer demand, as fewer choices are available to buyers of conventional vehicles. Limited consumer awareness and education about EV benefits and performance strongly act as barriers to entry. Aggressive awareness programs are required to drive acceptance.

Range anxiety was a major concern. Consumers are afraid that they will run out of battery charge, and it would be difficult to find charging stations, especially in the case of long-distance travel. Limited charging infrastructure, particularly in non-metro cities and rural areas, further deters buyers. High

capital expenditures for setting up charging stations slow down infrastructure expansion. The long charging times, compared to the quick refueling of ICE vehicles, also pose a challenge. Moreover, the low domestic capacity to produce batteries and dependence on imports impinge on both affordability and performance. A robust battery ecosystem and charging infrastructure are required.

Another issue is standardization; in particular, the lack of interoperability across an extremely wide range of charging networks keeps many EV users up at night. Industry-government collaboration must occur for standard settings in fast-changing technologies. The safety concerns associated with battery technology, such as thermal runaway and risk of catching fire, also have a bearing on customer confidence. Domestic safety standards and regulations must be robust to maintain the risk under consideration. Policy and regulatory issues, including nonuniform and holistic policy frameworks and reductions in subsidies, have recently been mired in uncertainty. Clear policies, subsidies, and incentives are required to drive EV growth within a country.

Ethanol-blended Fuel

Ethanol-powered vehicles in India face numerous challenges. Reliance on surplus sugar and grains for ethanol production poses high risks, particularly during droughts, and raises sustainability concerns. Ethanol production from crops, such as sugarcane and maize, requires more land than the solar energy used by EVs, making it less efficient. There are significant environmental and ethical concerns regarding the use of arable land for fuel production instead of food, as it can lead to malnutrition and food shortage. Economically, ethanol production can divert crops that are essential for food security, thereby affecting their cost-effectiveness.

Additionally, ethanol use accelerates engine wear and maintenance issues. Higher ethanol blends, such as E85, typically reduce the fuel economy compared to gasoline. Substantial investment in distribution and blending infrastructure is necessary, with an annual requirement of over 1,000 crore liters for the E20 program. Technological changes for flex-fuel vehicles increase costs by INR 25,000 for cars and INR 12,000 for two-wheel vehicles. Limited access to the reliability and availability of ethanol impact. Greater consumer awareness and acceptance of flex-fuel technology are crucial, and the engineering complexity of enabling vehicles to operate on multiple ethanol blends presents challenges. Effective regulatory and policy frameworks are essential to support this transition.

FINDINGS AND CONCLUSIONS

This study provides insights into the present and future state of electric vehicles and ethanol-run vehicles in India. Based on this research, it is estimated that the EV market will grow significantly, with an annual sales projection reaching 27.2 million units by 2032. This is because of the incentives and subsidies provided by the government. The Indian government is looking to achieve 20 percent ethanol blending in fuel by 2025, which will be supported by regulatory changes and building infrastructure for the same. Technically, although the range of EVs is more expensive, the total cost of ownership is lower because electricity is cheaper than petrol. They play a vital role in the reduction of carbon emissions. Although ethanol vehicles are cheaper at the outset, they pose problems such as lower energy density, more consumption, and increased engine wear. In addition, the production of ethanol is a potential environmental problem owing to its high water usage.

The other critical factor for both technologies is infrastructure development. Currently, there are approximately 1800 EV charging stations in India, which are proposed to be expanded by various government programs. The principal focus for ethanol production would be to increase production plants and blending facilities to achieve the transition to E20 fuel by 2025. Government policies, particularly the FAME-II and PLI schemes, act as major drivers of EV demand through substantial financial incentives and subsidies. Regulatory support and fiscal incentives are being doled out hand in glove to encourage ethanol production, and to reduce oil import dependence.

Another important factor in market dynamics is consumer preference and attitude towards EVs and ethanol vehicles. The uptake of EVs depends on awareness of the benefits, model availability, and concerns over the sufficiency of the charging infrastructure. Ethanol vehicles face slower adoption of infrastructural bottlenecks and technical difficulties in adjusting to higher blends of ethanol. In the future, the EV market in India may capture large growth and a substantial market share by 2030. Ethanol-blended fuels are going to increase; however, their growth will be inhibited by infrastructural and vehicular adaptation problems in comparison with the EV sector, which has more developed and stronger support [23].

In conclusion, India's future sustainable transportation is marked by two promising alternatives: ethanol-blended fuels and EVs. Both present viable solutions for reducing fossil fuel dependence and minimizing environmental impacts. While ethanol fuels can leverage India's agricultural strength and help reduce greenhouse gas emissions, EVs provide a long-term solution with lower emissions and reduced reliance on imported oil. However, both options face challenges such as the development of infrastructure for EVs and feedstock availability for ethanol. A balanced policy approach, continued innovation, and infrastructure investment are key to advancing technologies and ensuring a sustainable transportation future for India.

Recommendations

1. Given the current infrastructure of 1,800 EV charging stations, India needs to meaningfully augment this number so that it can accommodate the forecasted 27.2 million EVs by 2032 and make access and convenience available throughout the country.
2. Hybrid vehicles, especially FFV-SHEVs, need to be incentivized in the form of lower GST rates since they can achieve a requisite intermediate role with lesser 'well-to-wheel' emissions than purely electric vehicles, fitting into the solution for the Indian situation driven by coal-based electricity.
3. More advertisements and campaigns should be conducted for the general public, highlighting the advantages of EVs and ethanol vehicles in terms of costs, environmental effects, and available model types.
4. Invest in research and development of battery recycling and ethanol production technologies as a way of reducing their impact on the environment while simultaneously looking at various ways that the technologies can be improved to be more efficient and cheaper.
5. In the view of industry leaders such as Nitin Gadkari and R.C. Bhargava, the country must encourage not only electric cars but also ethanol-run cars and hybrid cars. This strategy builds from existing technologies and simultaneously promotes and sustains agrarian economies while gradually shifting to cleaner renewable energy sources.
6. Promote the production of ethanol from agricultural by-products and non-food crops to help grow rural economies and provide supplementary income for farmers. This pathway may also reduce the food-versus-fuel debate about biofuels.
7. The best practices regarding the integration of ethanol and electric mobility into the transportation sector could be taken from Brazil, which has more than 30,000 ethanol fueling stations and a growing EV market.
8. Promote private investment in EV and ethanol vehicle infrastructure through public-private partnerships while also preserving the private sector's efficiency and innovative capacity in quickly developing facilities and technologies.
9. The government should offer balanced incentives to EVs and ethanol-blended vehicles through subsidies for purchasing EVs and investment in infrastructure for ethanol production, particularly in rural areas, to boost the agrarian economy.
10. Address environment-related concerns about lithium-ion batteries used in EVs through investment in recycling and sustainable disposal. At the same time, ethanol is produced more sustainably by emphasizing water-efficient crops and processes to ensure minimum environmental impact.

11. Increased production of ethanol from agricultural by-products and other non-food crops to the full extent possible, including contributing to the augmentation of rural economies and supplementary livelihood options for farmers. This could significantly help dampen the food-versus-fuel debate connected with biofuels.

India can benchmark Brazil, which has successfully incorporated both ethanol and electric vehicles into its transportation systems. It has more than 30,000 ethanol stations and a rising EV market.

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