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India's Shift to Electric Mobility

Aadya Sharma*
Email - aadyasharma1807@gmail.com

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Abstract
The Automotive sector is a pivotal contributor to India’s economic growth and contributes 49% to India’s manufacturing GDP. In FY24, the country produced approximately 49 lakh passenger vehicles, 9.9 lakh three-wheelers, 214.7 lakh two-wheelers, and 10.7 lakh commercial vehicles.
The world’s primary modes of transportation are facing two major problems: rising oil costs and increasing carbon emissions. As a result, electric vehicles (EVs) are gaining popularity as they are independent of oil and do not produce greenhouse gases. However, despite their benefits, several operational issues still need to be addressed for EV adoption to become widespread. This research delves into the evolution of EVs over time and highlights their benefits, including reducing carbon emissions and air pollution. India's transition from traditional internal combustion engines (ICE) to electric vehicles (EVs) is driven by a combination of environmental, economic, and policy factors. This shift is aimed at reducing the country's dependency on fossil fuels, lowering carbon emissions, and promoting cleaner air, particularly in urban areas plagued by pollution. Government initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, coupled with state-level incentives and growing investment in charging

infrastructure, are accelerating EV adoption. However, challenges remain, including the high upfront cost of EVs, battery technology limitations, and the need for a robust charging ecosystem. This abstract explores the key drivers, challenges, and potential impacts of India’s electric mobility transition on the economy, environment, and society, highlighting its role in shaping a sustainable transportation future for the country.

1. Introduction

The automotive industry is undergoing a significant transformation and adapts to the new realities of climate change which makes sustainable practices a necessity. This means that increased uptake of Electric Mobility is the key to achieving environmentally sustainable transport systems. The Indian Electric Vehicle ecosystem is currently in the initial stages of development but has been gaining traction. Since transport is one of the main sources of the problem, the sector is gradually transitioning to the use of electric vehicles. India has planned to get a strong electric mobility structure in place by 2047, so it would be important to know in how many ways electric vehicles are better the conventional petrol vehicles apart from the problems that need to be unlocked for this change to occur.

In 2021, EV registrations amounted to ~330k units, a jump of 168% from 2020. The sales were led by 2- and 3-wheelers – ~48% and ~47%, respectively – followed by passenger vehicles at ~4%. E-rickshaw/e-kart category (top speed less than 25km/ hr) takes the major share among three-wheelers with ~45%. E-buses are included in others with a share of 0.36%. The lack of charging infrastructure is one of the biggest challenges for the EV sector. Currently, there are only 1,742 charging stations in the country. This number is expected to increase to 100,000 units by 2027 to accommodate the increasing demand by ~1.4 million EVs expected to be on the roads by then. Currently, India adds about 2.5 billion metric tons of carbon, or ~7% of the global emission. The ICE vehicular pollution contributes to ~40% of the total pollution in India. With this, it is imperative to usher in a strong push towards EV adoption to curtail the increasing pollution. EVs will help reduce exposure to VOCs (which are carcinogenic) and help improve life expectancy.

India has taken a leap towards a clean energy-based future as it is evident from the changes in the policies of the governments with respect to environmental protection. In terms of investments, EV industry has attracted ~USD 6 billion in 2021 and is expected to gain USD 20 billion by 2030. EV market has observed strong attention from PE/VC investors in India with investments increasing from US$ 181 million to US$ 1,718 million (recording an annual growth rate of 849%). Ministry of Skill Development and Entrepreneurship has estimated that EV industry can create 1 crore direct jobs and 5 crore indirect jobs by 2030.

There has been a global paradigm shift in how the future of vehicles will evolve. While flying cars may not be seen as a feasible option in 2022, we have come a long way from the traditional fuel-guzzling vehicles to alternatives such as EVs, both in two-wheeler and four-wheeler segments. While Indian sentiments are clearly more oriented towards two-wheelers which occupy almost 70% of road presence, this does not seem to be limiting the development of four-wheeler EVs. India is actively investing in and promoting a market which is predicted to hit over a 9 million units mark per annum by the year 2027[1]. The need to shift to an alternative fuel can be attributed to rising fuel costs and adopting cleaner energy sources. Climate change is an increasingly relevant concern, with every major nation actively acknowledging the problem and looking at real-time solutions, which provides a further impetus to the shift to EVs.

The Indian automobile industry places heavy reliance on the use of traditional fossil fuels and non-renewable forms of energy which has raised concerns regarding its impact on the environment, climate change, and the depletion of non-renewable resources. Citing data from the 2020 World Air Quality Report, 22 of the 30 worst polluted cities are in India and transportation is a leading emitter of fine particulate matters 2.5 micron pm that causes respiratory illnesses. Vehicle registrations are increasing at 17000 per annum influenced greatly by urbanization. This trend is a burden to India's foreign reserves and causes poor air and noise quality; this has negative effects on public health. To adopt a cleaner and more eco-friendly energy alternative, India has formulated policies to shift from traditional ICE vehicles to vehicles using alternate forms of energy, specifically EVs. Further, dependence on fuel imports and the consistently rising prices of conventional fuels have also prompted consumers to seek more cost-efficient sources of transportation. These initiatives for the adoption of clean engines for both commercial and private vehicles have led to an increase in the number of manufacturers of EVs in the short and long-distance transportation and last-mile connectivity arenas[2]. With the roughly 69,500 EVs comprising only 0.085% of the 80 million registered vehicles, the potential for growth in India is immense.

2. EV technologies Vehicle types

Hybrid Electric Vehicle	Plug-In Hybrid Electric Vehicle	Battery Electric Vehicle	Fuel Cell Electric Vehicle
• ICE and electric motor	• ICE and electric motor	• 100% electric motor	• 100% electric motor
• Batteries are charged by the engine • no external charging	• Batteries are rechargeable	• Batteries are rechargeable	• Fuel cell converts hydrogen and oxygen into electricity • Requires hydrogen distribution infrastructure

1. **Battery Electric Vehicles (BEVs)**

Battery Electric vehicles (BEVs): Rechargeable batteries are the only power source for BEVs, which are electric automobiles. They don't have a backup generator or a petrol engine. Due to their lack of exhaust emissions, BEVs are regarded as the most ecologically beneficial form of electric car. However, they have a constrained driving range because the battery must be recharged.

2. **Hybrid Electric Vehicles (HEVs)**

Hybrid Electric Vehicles (HEVs): HEVs are electric cars with petrol engines and electric motors. An electric motor propels the car at low speeds and during acceleration. The petrol engine takes over at higher speeds and when greater power is required. Because HEVs utilize regenerative braking to recharge their batteries, they do not require plugging in. Although they use less fuel than conventional petrol cars, they have some exhaust emissions.

3. **Plug in Hybrid Electric Vehicles (PHEVs)**

Hybrid electric vehicles (HEVs) with bigger batteries that can be recharged by plugging a charging cable into an external electric power source in addition to internally by their on-board internal combustion engine-powered generator are called plug-in hybrid electric vehicles (PHEVs). They have a finite range of operations on electric power before switching to the petrol engine. PHEVs provide the ease of daily driving without a plug while allowing for electricity usage or on short journeys.

4. **Fuel cell electric vehicles (FCEVs)**

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Image: electrek.co

Fuel cell electric vehicles (FCEVs): FCEVs react hydrogen gas with oxygen in the air to create power. They don't have a battery, and their sole waste is water vapor. Although FCEVs can be refueled in a few minutes and have a greater driving range than BEVs, there is still a lack of hydrogen refueling infrastructure.

3. Charging stations

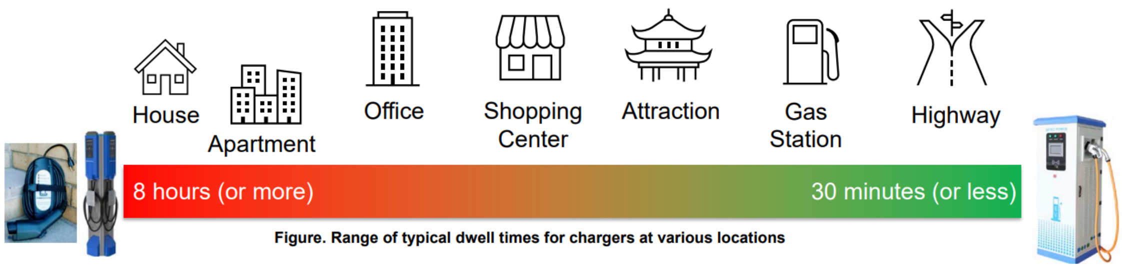
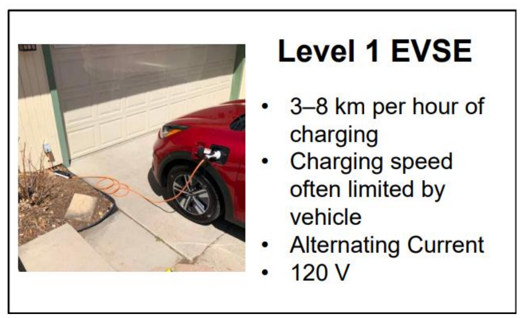


Figure. Range of typical dwell times for chargers at various locations

Source: Bopp et al. (2020)

1a. Residential Charging

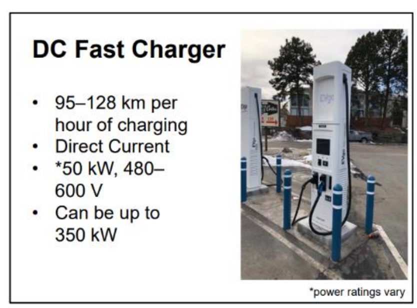
- Most established markets focused on residential charging first.
- Internationally, 50%-80% of all charging events occurred at residences (Hardman et al. 2018).
- Lack of residential charging availability is often found to be a barrier to EV adoption (Funke etal. 2019).



- Residential charging can use Level 1 or Level 2 EV supply equipment (EVSEs)

1b. Public Charging

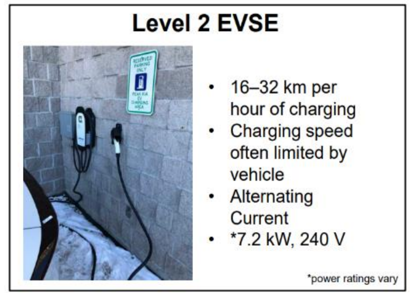
- Public and home charging
- Less expensive to install and operate than
- DCFC
- AC charging power is limited by the
- capabilities of the vehicle's on-board charger
- Can process payments and data
- Can be networked
- Expensive to install and operate
- Faster charging



- Can process payments and data
- Can be networked
- Incompatible with many 2- and 3-wheelers

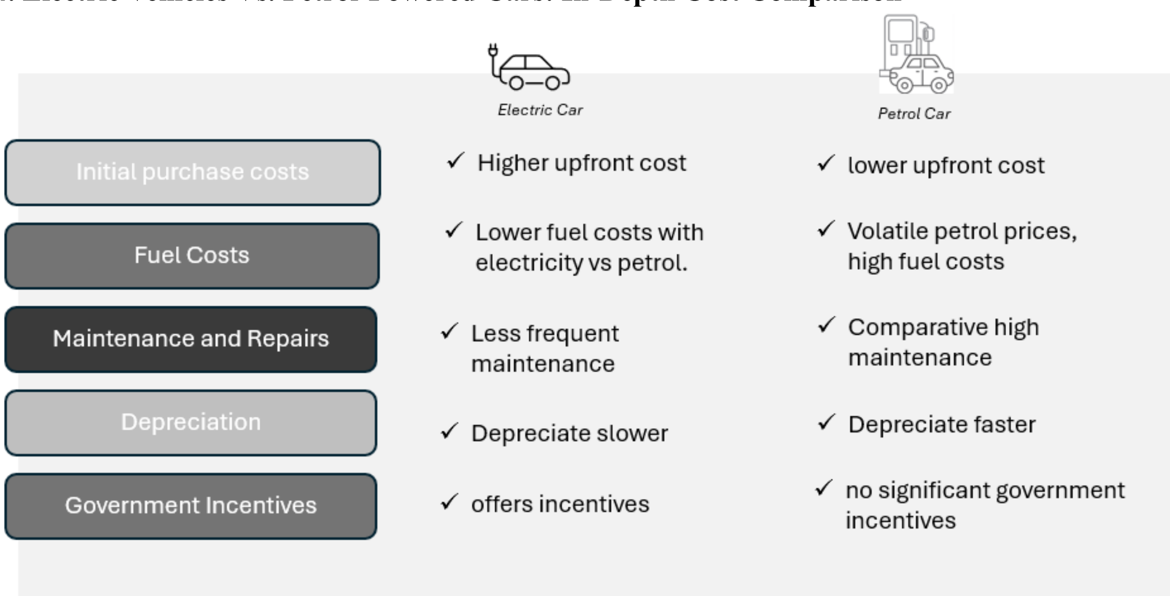
1c. Battery Swapping

- Easier for motorcycles/scooters because liftable size and less expensive to carry redundant batteries
- Rickshaws use multiple batteries but can be compatible
- Largest networks operated by Gogoro (Taiwan), Immotor (China), KYMCO (Taiwan)
- Honda, KTM, Piaggio, and Yamaha have formed a swappable battery consortium for standards



- More compatible with renewables than EVSE
- Reduces the upfront cost of scooters and increase

4. Electric Vehicles Vs. Petrol-Powered Cars: In-Depth Cost Comparison



1. Initial Purchase Cost

- **Petrol Vehicle:**
  - Lower upfront cost: Petrol cars typically have a lower purchase price due to the maturity and mass production of internal combustion engine (ICE) technology.
  - More affordable options: The wide availability of petrol models in various price ranges makes them accessible to a broad segment of buyers.
- **Electric Vehicle:**
  - Higher upfront cost: EVs have a higher purchase price because of the cost of lithium-ion batteries and advanced electric drivetrain technology.

- Incentives available: Government subsidies like the FAME II scheme (Faster Adoption and Manufacturing of Hybrid & Electric Vehicles) in India, reduced GST on EVs (5% vs. 28% for petrol cars), and state-level rebates can significantly reduce the cost gap.
- Total cost of ownership: Though the initial cost is higher, the long-term savings from lower running costs and maintenance can make EVs more cost-effective over time.

2. Fuel Costs

- **Petrol Vehicle:**
  - Volatile prices: Petrol prices fluctuate frequently in India and vary across states, influenced by global oil prices and local taxes.
  - High running costs: Petrol vehicles have higher running costs as fuel constitutes a major expense, especially over longer distances.
  - Average cost per km: Depending on fuel efficiency, petrol vehicles typically cost between ₹7-10 per km in India.
- **Electric Vehicle:**
  - Lower and stable fuel costs: Electricity is significantly cheaper than petrol. EVs generally cost around ₹1-2 per km, depending on electricity rates and charging efficiency.
  - Home charging vs. public charging: Home charging is usually more economical, though public charging is also competitive compared to petrol.
  - Potential for renewable energy: Charging EVs with solar power or other renewable energy sources can further reduce costs and carbon footprint.

3. Maintenance and Repairs

- **Petrol Vehicle:**
  - Regular maintenance needed: Petrol engines require frequent servicing, including oil changes, spark plugs, filters, coolant checks, and belt replacements.
  - Higher wear and tear: The complexity of internal combustion engines means more parts are subject to wear, leading to higher maintenance costs over time.
  - Emissions compliance: Petrol vehicles require maintenance to meet emissions regulations, which can involve catalytic converter replacements and other emissions-related services.
- **Electric Vehicle:**
  - Simpler mechanics: EVs have far fewer moving parts, which significantly reduces the likelihood of mechanical issues.
  - No oil changes or exhaust systems: There's no need for oil changes, and the lack of an exhaust system means fewer components to maintain.
  - Brake longevity: EVs use regenerative braking, which extends the life of brake pads by reducing wear and tear.
  - Battery warranties: Most EV manufacturers offer warranties on batteries for 8 years or 160,000 km, reducing concerns over battery replacement costs in the short term.

4. Depreciation

- **Petrol Vehicle:**
  - Faster depreciation: Petrol cars tend to depreciate quickly due to the regular release of newer models, higher fuel costs, and growing environmental concerns.

- Limited resale value: As stricter emissions standards and consumer preferences shift toward cleaner energy, the resale value of petrol cars may decrease further.

- **Electric Vehicle:**
  - Potential for slower depreciation: As the EV market matures in India, the depreciation rates may slow, especially for well-maintained EVs with solid battery performance.
  - Growing demand: As consumers increasingly prefer greener vehicles, the resale value of EVs could remain stable or even improve in the future.
  - Battery replacement costs: Although battery degradation is a concern, improvements in battery technology are helping to maintain long-term value.

5. Government Incentives

- **Petrol Vehicle:**
  - No significant incentives: Petrol vehicles don't receive notable government support. In fact, the government imposes higher taxes on petrol and diesel cars to discourage fossil fuel use.
  - Penalties for pollution: Some cities may introduce additional fees or restrictions on high-emission vehicles, making petrol cars more costly to own in the future.
- **Electric Vehicle:**
  - Strong government support: The Indian government promotes EV adoption through the FAME II scheme, which provides subsidies for electric two-wheelers, three-wheelers, and four-wheelers.
  - Tax benefits: EV buyers can claim a deduction of up to ₹1.5 lakh on interest paid on loans for EV purchases under Section 80EEB of the Income Tax Act.
  - Reduced road tax and registration fees: Many states in India offer reduced or zero road tax, lower registration fees, and rebates for EV owners.

5. Challenges and difficulties in electric vehicle adoption

1. **Adopting electric vehicles** has challenges and problems. One of the most significant challenges is infrastructure and electric vehicles' high cost. The price of electric vehicles is often higher than that of their gasoline counterparts, making them less accessible to consumers. Moreover, the scarcity of charging stations is a significant issue that needs to be addressed, especially in regions with low population densities. Additionally, the limited range of electric vehicles, or range anxiety, is a significant obstacle to their widespread adoption.
2. **The battery issue:** The performance of batteries continues to be a major issue for electric vehicles. Batteries are expensive, heavy, and require frequent charging, which makes them less practical for daily use. Scientists are actively developing better battery technology to address these issues, including increasing driving range, weight reduction, cost reduction, and charging time. Battery technology will ultimately determine the success or failure of electric vehicles on the market.
3. **Integration of electric vehicles into smart cities:** Electric vehicles are expected to play a vital role in the transportation systems of smart cities. However, their integration into these cities requires a collaborative effort between governments, industry stakeholders, and citizens. This includes developing charging infrastructure, promoting renewable energy sources, and encouraging public transportation.

5. Strategies for Overcoming Challenges

It is generally known that, as compared with cars powered by internal combustion engines (ICEs), electric vehicles (EVs) have the potential to provide significant societal and personal advantages. Recent research has looked at the many obstacles EVs encounter and has typically determined that the most common ones are cost, range, infrastructure for charging, and customer perceptions. Below strategies can help overcoming challenges.

✓ **Charging Infrastructure**

Since electric vehicles often have a smaller driving range than conventional vehicles, their owners may be concerned that they may run out of juice before reaching their destination. Even though the range of EVs is expanding, some drivers, particularly those who need to go long distances, still find it challenging [57]. However, the consumer will be aware of the open slots if they can reserve charging times in advance. Customers can thus research alternative slots besides those already waiting in line. By answering consumers' queries and easing their worries over the charging network, good charging infrastructure will also help to reduce their "range anxiety" .

There are several ways to effectively alleviate range anxiety, even if it makes customers unhappy and presents an economic hurdle to EV adoption.

- Fast DC charging is a practical method for reducing the time it takes to recharge and extending the range when traveling between cities by highway. Various driving styles have various energy and recharge requirements; thus, EV infrastructure planners should consider this. Properly and dynamically building EV recharging infrastructure helps alleviate range anxiety .
- Mathematical vehicle model that can forecast "real road" driving energy consumption and drivable range may be utilized to estimate accurate energy consumption and drivable range.
- Developing countrywide charging stations can also help alleviate range anxiety, but this cannot be done without government incentives or public-private collaboration.
- Range anxiety can be decreased by using a network path selection model. For EV drivers, this model chooses the quickest and best route using an algorithm. These models, meanwhile, might be improved by judging the exit time and duration of a stop at a charging station. The driving range can be increased by employing series, parallel, and series-parallel charging arrangements with extremely efficient electric motors. To partially alleviate range anxiety, some EV manufacturers even provide complimentary rental automobiles for local trips outside the EV range.

- **Balancing Auxiliary Loads**

Auxiliary loads greatly impact how much energy electric cars use, which cuts down on how far they can go.

✓ Heavy auxiliary loads drain batteries in city driving circumstances, reducing the EV's range. The driving range decreases by 17.2–37.1% (under simulated settings) when the AC is activated in the summer. Similar to how EVs employ PTC (Positive Temperature Coefficient) heaters, the range spans from 17% to 54% (under simulations) owing to the need for heating in the cold.

✓ when electric cars are driven at highway speeds, the effects of auxiliary loads such as air conditioning and heating have not yet been fully investigated.

✓ There are significant differences in the impact of supplementary loads in a lab setting and on actual roadways. Under ideal conditions, such as with little auxiliary loads and the help of a regenerative brake system (RBS), electric vehicle producers may achieve low energy consumption and an extended driving range; nevertheless, this ideal outcome is different when EVs are driven on highways amongst towns .

One way to address the problem of limited range and high energy usage brought on by auxiliary loads is to utilize a heat pump to heat EVs in the winter. This can increase the driving range by 7.6–21.1% thanks to a higher heating coefficient of performance (CoP). The vapor compression cycle of a heat pump oversees both cooling and heating. Additionally, a four-way valve that reverses refrigerant flow is included. Additionally, its coefficient of performance is 1% greater than that of PTC heaters. Additionally, a precise assessment of EVs' heating and cooling demands may significantly reduce the energy used by the AC system. An appropriate energy management technique can also lower the total energy consumption when cooling. Consequently, a suitable energy management strategy may regulate energy use instead of the ON/OFF technique .Another approach is the system configuration that has been suggested, which uses a traction shaft to clutch the AC compressor motor during braking intervals. This method not only helps the EV to weigh less but also uses less energy .

- **Improved Battery Technology**

The limitations of battery technology are one of the main obstacles to the widespread use of electric vehicles (EVs). The present battery design for EVs has a poor energy density, which impacts the vehicle's driving range [58]. To improve EV efficiency, a variety of battery technologies and combinations have been created over time. Users see electric vehicles as a real alternative to internal combustion engine vehicles because of the development of better, more affordable, and higher-capacity batteries, which will increase vehicle autonomy.

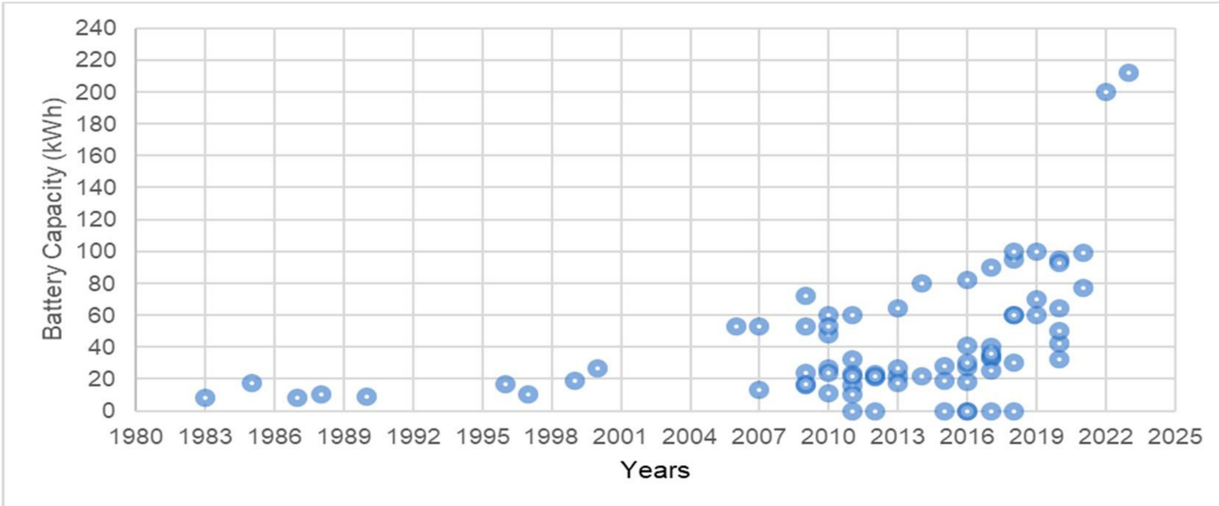
Since batteries are vital to EVs, more manufacturers (such as LG, Panasonic, Samsung, Sony, and Bosch) are investing in creating better, more affordable batteries.

The battery bundle is the costliest part of any EV. For instance, the Nissan LEAF's lithium-ion batteries originally accounted for one-third of the total cost of the car. However, it is anticipated that this cost will gradually decrease; as of the end of 2014, the battery pack cost around $500 per kWh (half the price in 2009); now, the price per kWh is $200, and it is anticipated to drop to approximately $100 in 2025. The fact that Tesla Motors is creating a "Mega factory" to lower manufacturing costs and enhance battery output is another piece of data supporting the trend towards lower battery costs .

The price of EVs would naturally decrease because of decreasing battery costs, making them more competitive with other types of cars.

Figure 1 depicts the battery capacity of various EVs from 1983, when the Audi Duo was first sold, when it had an 8-kWh battery, through 2022, when Tesla claimed it would sell a Tesla Roadster with a 200-kWh battery. The GMC Hummer EV Pickup Edition 1 has the largest battery capacity at 212 kWh .

Figure 1. Battery capacity development from 1980–2025 [61].



The following section discusses three issues with suitable proposals relating to EV battery technology, including battery nature, battery price, and electric vehicle chargers.

Battery Type

Technology for EV batteries must advance significantly to meet this demand. A good EV battery should be lightweight, affordable, safe, and long-lasting. It should also have a high energy density and a high-power density. The ability of a battery to hold energy is referred to as energy density. A gadget can be maintained and charged longer with a massive energy-density battery since it can store more energy [59]. Cycle durability is also an important phenomenon in batteries. This is the number of "full" charge/discharges cycles the battery can tolerate before its capacity drops to under 80% in terms of its life cycle. If a battery is only 60% discharged and fully charged, it has not gone through a charge/discharge cycle. Depending on the battery type, the percentage may vary. The conclusion is that an EV battery shouldn't have a short life cycle as shown in Table 1.

Table 1. Battery Types [62,63].

Battery Type	Working Temperature (˚C)	Specific Energy (W/kg)	Energy Density (W/L)	Specific Power (W/kg)	Cell Voltage (V)	Cycle Durability	Memory Effect
Lead acid	−20–45	30–60	30–50	180	2.1	1000	No
Ni-cd	0–50	60–80	60–150	120–150	1.35	2000	Yes
Ni-MH	0–50	60–120	100–300	250–1000	1.35	500	No
Zn-Br2	20–40	75–140	60–70	80–100	1.79	>2000	No
Na-S	300–350	100–130	120–130	150–290	2.08	2500–4500	No
Zn-Air	300–350	100–130	460	80–140	2.1	200	No
Li-S	300–350	100–130	350–650	-	2.1	300	No
Li-Air	300–350	100–130	1300–2000	-	2.1	200	No

Li-ion	−20–60	100–275	200–735	150–300	3.6	400–3000	No

The battery's memory effect describes a situation in which it retains the rate of its most recent discharge and won't produce any more than that (even throughout a fresh charge/discharge cycle). Alternatively, the battery "remembers" how much of its capacity was used up the prior time and won't supply it anymore. The memory effect is no longer a concern because of advancements in battery technology .

The discharge rate is the pace at which a battery expends or discharges energy. A high-discharge-rate battery is inappropriate for EVs since it cannot be utilized for ex- tended durations while being charged. Numerous EV battery technologies exist; some are listed below:

- ✓ Lead-acid batteries are the first kind of batteries used in electric vehicles. These batteries are made of acid that produces electricity and lead electrodes. The electrolyte level needs to be checked frequently, and these batteries are hefty and have a low energy density. Additionally, they are not environmentally friendly.
- ✓ The second sort of battery is nickel-based, which is thought to be better developed and has a comparatively greater energy density. However, its shortcomings include low power density and poor charge/discharge efficiency. The memory consequences and insignificant performance in cold temperatures are further issues with nickel- based batteries.
- ✓ Batteries that are made of nickel metal hydride (Ni-MH) have negative electrodes, which are made of an alloy that can store hydrogen rather than cadmium (Cd) .Many hybrid cars, such as the Toyota Prius and the second-generation GM EV1, employ these batteries even though they exhibit more self-discharge than nickel- cadmium batteries. Along with a lead-acid model, the Toyota RAV4 EV also came in a nickel-metal hydride model.
- ✓ Batteries made of zinc and bromine (Zn-Br2) are batteries that employ a zinc-bromine solution kept in two tanks and in which the positive electrode undergoes a bromide- to-bromine conversion. In 1993, a prototype named "T-Star" used this technology .
- ✓ Sodium sulfur batteries (Na-S) are made of sulfur and sodium liquid (S). This kind of battery has a large life cycle, a high energy density, and great loading and unloading efficiency (88–92%). They also have the benefit of these materials being relatively inexpensive. They may operate at temperatures between 300 and 350 ◦C, but the Ford Ecostar, a vehicle that debuted in 1992–1993, uses these batteries .
- ✓ Rechargeable lithium-ion batteries are a widespread energy storage system for com- puters, cellphones, and electric vehicles. They are renowned for having a high energy density, allowing for greater electric car driving ranges and longer battery life for electronic gadgets. To enable the movement of electrical current, the batteries employ lithium ions to transmit energy between the positive and negative electrodes.
- ✓ Batteries made of lithium-sulfur (Li-S), zinc-air (Zn-air), and lithium-air (Li-Air) are among the battery types used in the third category of batteries. Li-S is the least expensive of them all, thanks to the low price of sulfur, and it also has a high energy density .

When examined independently, Li-S has a rapid life cycle and a high discharge rate. Zn-Air is a "potential" future option for EV battery technology because its "theoretical/in- lab experiments" show a high energy density of 1700 W/kg, which is comparable to the conventional internal combustion engine . However, the major drawback of a Zn-Air battery is its low power density and short life cycle. However, it is still a prototype and not ready for purchase. Similar circumstances apply to Li-Air, which is still in the prototype stage and not yet on the market. For a detailed comparison of the various battery types, see Table 1.

Lithium-ion battery operation's temperature and voltage windows define the battery's safe and dependable operating range. As electrolytes begin to self-destruct above 150 ◦C, going over these limits would quickly reduce battery efficiency and may even cause a safety consequence (e.g., trigger a fire or explosion) . The majority of EVs and PHEVs currently use this sort of battery.

Lead and zinc batteries perform worst in specific power (up to 100 W/kg), whereas Ni-MH and Li-ion batteries perform best (up to 1000 W/kg and 3000 W/kg, respectively). In terms of cell voltage, lithium-ion and sodium batteries (Na-S and Na-NiCl) need a higher voltage than batteries made of nickel and zinc. On the other hand, lead-acid and Ni-MH batteries provide the worst performance in terms of life cycles. Finally, whereas lithium batteries can sustain up to 3000 cycles, Na-S batteries perform better and can support up to 4500 cycles .

Since these battery types could increase the range of electric vehicles, further study is being done to enhance them. To guarantee the successful operation of electric vehicles, additional subsystems are included inside the battery system, such as a system to manage the batteries and an adequate thermal management system. When all the considerations are considered, current electric cars employ lithium-ion technology for their batteries since it performs the best across most of the analyzed qualities.

- **Battery Cost**

Another EV difficulty that keeps it from succeeding on the market is the expensive price of batteries. Some key drawbacks of EV battery technology are a limited driving range, an expensive battery cost, prolonged battery charging time, unpredictable battery life, the excessive weight of EV batteries, and battery safety . As a result, a study should be done to create high-performance and affordable battery technology.

By 2025, battery costs are expected to drop by 70%, promoting EV adoption because of the high energy density. This is evident in the case of lithium-ion batteries (Li-Ion), whose price has drastically lowered because of their growing use in mobile devices and laptops.

- **Electric Vehicle Charging Devices**

Most conventional electric vehicle charging devices are one-directional, making incor- porating them into the system challenging. Nonetheless, this issue may be resolved using a bidirectional EV charger. Future "super-fast" direct current chargers are anticipated to be readily available in households, significantly reducing charging time. The smart grid may experience a decrease in load because of this advancement, and battery life may be extended. More study is required to advance this field, which also addresses EV battery technology, and overcome the EV charging problem.

- **Enhancing EV Charging Procedures—Battery Switching Stations**

To lessen range anxiety, battery swapping stations might be utilized in place of battery charging stations. Standard, fully charged batteries are kept on hand at battery switching points for EV drivers to swap out and continue their trip quickly. In this way, EVs at a charge station along a highway can be changed immediately. The battery changing stations' operational mechanism is depicted in Figure 2. This technology of charging EVs instantly is already being used by Tesla and U.S. and European battery vendors .

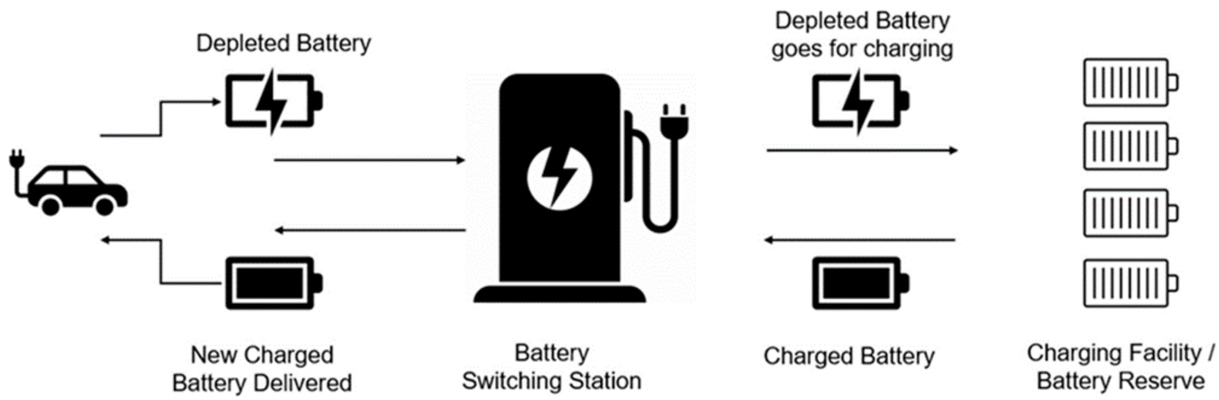


Figure 2. The battery changing stations' operational mechanism.

Most conventional vehicles can operate on any of the three fuels: petrol, diesel, and petrol, as shown by comparing traditional petrol stations and battery switching stations. Battery switching stations will need to handle a broad range of batteries, and they may run out of one type periodically. This might cause EV drivers to get anxious. Batteries come in various kinds: configurations, energy, and power densities.

EV drivers will be able to monitor the several battery types that are accessible thanks to smartphone applications developed by battery switching facilities. Even better, they may store extra batteries in advance to replace their exhaust ones. Giving the battery switching locations and the electric vehicle driver a communication platform can significantly reduce waiting times and eliminate range anxiety. This enables the driver to go beyond the usual velocity range of the vehicle.

However, this can present further issues for the battery switching stations, as they might need to keep many more batteries on hand to service clients, especially if some switch batteries numerous times daily. Multiple approaches can be used to solve this issue. The possibilities include limiting the number of swaps executed daily, adding a fee for each extra swap executed within a single day, penalizing customers for exceeding their daily limit, etc. As indicated, imposing fines may deter people from implementing EVs, so we need to consider which solutions are workable. Furthermore, the inconsistency of some battery types being available is another issue with battery switching stations. Due to the possibility that switching stations could not always have enough charged batterie, it might be challenging to service all their clients/EV drivers .

An EV battery-swapping station operator must continually modify charging and swap- ping guidelines to account for changing energy prices and save operational costs. A novel queuing network model with a service quality guarantee was used to research the optimal charging procedures for battery swapping stations. They also updated the model to incorporate battery swapping facilities and renewable energy in the power system to flatten the power generation curve by considering locations and billing orders. A charging regula- tion was devised for EV battery swapping stations. They recommended a hybrid particle swarm optimization and evolutionary method to determine the optimum course of action. To investigate the optimal charging/discharging method for a vehicle-to-grid (V2G) technology-based EV battery swapping station that enables two-way energy transfer between EVs and the power grid, ref. created a Markov decision process model. It was demonstrated that the best course of action was monotone, making it possible to compute it quickly. According to the techniques for battery exchange suggested on a scientific level, also developed an in-line routing system for electric cars that permits replacing the batteries in BEs using Markov's random choice processes. This method would reduce the waiting time by about 35%. developed robust optimization models to help with the planning process for battery swaps.

In this regard, it is worth noticing that battery swapping technology has gained significant traction in China. One of the key players in this space is NIO, a Chinese EV manufacturer, which has implemented battery swapping stations across China. These stations are fully automated and use a robotic arm to remove the depleted battery from the EV and replace it with a fully charged one. NIO claims that the entire process takes less than five minutes, providing a convenient and efficient way for EV drivers to continue their journey. They have installed over 1323 battery swapping stations across China as of March 2023.

Another company, called CATL, has developed a standardized battery swapping solution that can be used across different EV models. This approach provides flexibility for EV manufacturers and enables them to implement battery swapping technology without having to develop their own proprietary solutions . Furthermore, a study by McKinsey & Company suggests that battery swapping technology could account for up to 30% of EV charging in China by 2030. The study also notes that battery swapping can provide benefits such as reducing the cost of EV ownership, improving the utilization of EV batteries, and reducing the need for large-scale charging infrastructure .

Given China's success in deploying battery swapping technology, other countries could benefit from learning and adopting similar techniques. Battery swapping provides a convenient and efficient alternative to traditional charging methods, which could help accelerate the adoption of electric vehicles and reduce reliance on fossil fuels.

- **Conclusion**

Electric vehicles represent a viable and necessary alternative to petrol vehicles, offering significant environmental, economic, and social benefits. As India looks toward a sustainable automotive future by 2047, the adoption of EVs is crucial. Continued investment in infrastructure, technology, and supportive policies will be essential in overcoming challenges and ensuring a successful transition to electric mobility.

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