An Analysis of Electric Vehicle Trends in Developed Nations: A Sustainable Solution for India

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Electric Vehicles (EVs) have been revived since the late 1990s due to environmental causes and breakthroughs in battery technology. As a result, the EV markets in developed nations evolved to compete with conventional combustion engine vehicles. However, there is a need to reduce the global carbon emissions, which recently crossed the 400 ppm threshold permanently. EVs are proposed as a realistic solution and a necessity to mitigate the effects of global warming. This solution should be expanded to highly populated developing countries that contributes to over 63 percent of the global emissions to develop a zero carbon transport infrastructure. This application for sustainable transportation is best suited for developing nations like India which already has a potential EV market for two wheel, three wheel vehicles and buses. This paper discusses the various factors required to establish a thriving EV market in India while accounting for challenges that are unique to the nation to promote EV as an alternative e-mobility transport option for the masses thereby addressing the energy inequality crisis.

Introduction: A Historic Context and Rise in Popularity in Developed Nations

The EV was, contrary to popular belief, an invention of the late 19th century. Numerous versions of the early EVs were designed by American, Dutch, British and Hungarian inventors, which led to small-scale electric cars as a result of their ease of driving. Of the total production of all vehicles in the USA, 28 percent were EVs, and cities like New York City, Boston and Chicago contributed to nearly one-third of the EV population. However, this rise in popularity of EVs was short-lived as a result of Ford's popular T-Model which sold for a competitive $650. In addition, better living conditions and the discovery of cheap crude oil sources allowed increased buying capacity and improved mobility as well as easy deployment of infrastructure respectively.

Growing environmental concerns of the 1960s, the oil crisis of the 1970s and the refinement of the lithium ion battery technology in the 1990s played a major role in resuscitating EV programs in the 1990s in the USA and Japan. Further research in EV charging infrastructure and policy initiatives paved way for the automotive industry to deploy them into an uncertain market marked by economic and social barriers in the 21st century.

Over the last few decades, EVs have evolved into:

1. Hybrid EV (HEV): They are primarily powered by an internal combustion engine, where a battery is charged by regenerative braking and the engine. It cannot be connected to an external electricity source.

2. Plug-in Hybrid (PHEV): They are Hybrid EVs that can be charged by an external power source.

3. Battery EV (BEV): They are powered only by a battery and can be charged by connecting to external electricity source or/and regenerative braking.

Sustainable Transportation and EV: A Necessity

With the onset of the industrial revolution, mass production and increased transportation energy consumption, fossil fuels have been the dominant source of energy for decades. As a result, carbon emissions have been steadily increasing and has permanently crossed the 400 ppm threshold in 2016. As of 2011, China, the USA, and the European Union alone account for more than half the world's carbon emissions as shown in Figure 1. Global emissions from the transportation sector is at 16 percent, where 95 percent is from fossil fuels, which is unsustainable as it contributes to global warming and has a risk of complete fuel depletion by the end of this century (oil in 53 years, natural gas in 54 years and coal in 110 years).

To overcome fuel shortages and emission induced pollution, strategies have been put in place to lower levels of energy consumption. EVs are proposed as a realistic solution to combat poor air quality and climate change.
as a zero emission standard as opposed to the gasoline vehicles in the coming years; it is an important characteristic for sustainable transportation and electric mobility goals. As a result of this rise in popularity and increased acceptance of EVs, they are forecasted to account for 41 million vehicles in 2040 by displacing 13 million barrels per day of crude oil thereby promoting a low-carbon infrastructure.

Recent studies from the electricity source generation mix for every state in the USA was analyzed to develop national averages to compare emissions between gasoline vehicles and EVs as shown in Figure 2. This shows that despite EVs contributing to zero tail-pipe emissions, they still produce emissions via the power plants for consumption, which is still lower than the emissions from gasoline vehicles. When the global warming emissions from manufacturing were compared between gasoline vehicles and EVs, the latter was found to be higher due to intense fabrication for lithium ion batteries. But, it was found that the wheel-to-wheel emission (an analysis of the emission over the life time of a vehicle) advantage over gasoline vehicles negates the overall emissions by 51 percent over the life of the EV; the extra emission from manufacturing an EV is compensated for lesser emissions during driving an EV.

These analyses indicate that sustainable transportation goals have become a priority to mitigate climate change. EVs have the ability to reduce the emissions generated by the transportation sector to achieve sustainable transportation goals. EVs have proved to be a necessity.

Current and Projected Global Market Share

In 2015, the EV market amounted to 1.26 million, thereby crossing the threshold of 1 million vehicles for the first time, contributing to just 0.1 percent of the global market. The EV market distribution globally is an interesting mix, in that the production and demand is distributed unevenly. To get a better understanding of this matrix, the global EV market is classified into: North American, Asian and the European market, each performing as a result of various combination of factors. As of 2015, the market shares in Norway and Netherlands amounted to 23 percent and about 10 percent respectively thereby dominating the European market. Sweden, Denmark and France have officially crossed 1 percent of the total market share. The USA saw a similar increase in sales from less than 60,000 cars in 2011 to about 300,000 cars in 2014, after which it saw a decrease by 0.7 percent in 2015. However, the race to the largest share was secured by the Chinese market pushed to a 233 percent increase in 2016; the largest EV market in the world, 50 percent more than the USA market. The world-wide plug-in sales increased by 49% from 2015 to 2016 as shown in Figure 3, where the dominant EV markets for plug-in EVs are compared. There has been a consistent 3:2 split globally between the BEV and the PHEV models, however, they may vary in different markets. It can be now established that there are strong EV markets in the regions mentioned. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action have set a goal to deploy 100 million EVs by 2030 and it has been projected that about 20% would be contributed by emerging economies. The characteristics that led to the success in developed nations gives an opportunity for emerging economies to adopt them to increase EV market penetration to compete alongside gasoline vehicles. The characteristics that led to the growth of EVs in these markets are discussed in the next section.

Driving Factors of EV Markets

This paper reiterates that the EV has now become a necessity; a bold statement that addresses climate change. It has evolved from its incubation due to many factors that vary from research and development and consumer acceptance. The driving factors of the success in many markets were analyzed and similarities have been identified which are broadly classified as:

1. Technological and Environmental

FIG. 2: Comparison of emissions between EVs and gasoline vehicles.
2. Economic and Policy

3. Social and Infrastructure

Technological and Environmental Factors

Concerns over the driving range have been addressed by improving battery technology. Energy densities in batteries have been improved by almost 400% and automobile manufacturers like Tesla Motors have aimed to break the USD 100/kWh mark by 2020.15 As a result of this improvement, costs have also been lowered as seen in 4 4, where Li-ion batteries are the dominant chemistry. Moreover, range anxiety issues have been addressed because the average American commutes 40 miles every day, which is half the range of a Nissan Leaf, thereby providing for more than sufficient energy availability for driving.15,18,19 From 4 4, it can be noted that the battery costs have reduced by 73 percent since 2009 for seven years, and has been projected to decrease by another 58 percent for the next seven years till 2023, thereby boosting the range of an EV overcoming range anxiety issues.15,19

To overcome “range anxiety”, rapid charging infrastructure has been scaled up with increased installations and lesser charging periods. Charging stations in public spaces and at workplaces have improved market acceptance.20 Depending on the type, capacity of battery and the depletion state, charging can vary between 15 minutes to 20 hours.20 Charging stations are today equipped with communication protocols for integration with smart grids to optimize charging.20 To increase convenience and flexibility of charging, EVs can be charged at home at night when not in use thereby avoiding the costlier on-peak utility charging rates in the peak hours.

Environmental factors have proved to be a strong motivation post COP 21 and prompted nations to cut down on emissions and counter climate change, which resulted in initiating multiple initiatives and government funding to accomplish the same. The extremely ambitious goal of reducing GHG emissions to limit global warming to under 2°C cannot be achieved without a major contribution from the transportation sector.11,14

Economic and Public Policy Factors

Policy support has been vital for the success of EV integration in the aforementioned markets by providing proper regulations for commercialization. Public policies
adopted by EV successful nations were analyzed and concluded that there is no one common conventional solution for every nation; it involves a combination of public and private sector investment where the former is prominent in most cases.15

Public or government support measures have been classified into: monetary and non-monetary support.21 Monetary support includes tax exemptions from road taxes (Europe), annual circulation tax, company car tax and registration tax. Non-monetary support includes free parking spaces and wide availability to fast charging stations and bus lines in the highway. Some government investments included providing purchase incentives (Europe) while scrapping diesel vehicles, exemption of taxes (Europe, USA, and China), tax rebates (USA), waived toll fee and other financial tools. For private investors and manufacturers, the incentives included a line of credit, partial grants for pilot projects and other mobility programs.5,15–24

### FIG. 5: Monetary and Non-Monetary incentives for various nations.15,21–24

The economic model employed by most nations aims to provide a competitive model for EVs to stimulate their demand. The cost of acquisition of an EV is still higher than conventional vehicles even with government subsidies due to high cost of batteries.22 To attract consumers to invest in the EV market, government subsidies should continue until it is mature. Some economic models propose raising pollution standards for gasoline vehicles, increase in gasoline taxes and reducing electricity rates from renewable energy resources to promote EV markets to grow.22,25

EV fleets for courier and delivery companies like UPS, DHL and the postal services help increase market penetration.10,26 In the city of Catalonia, Spain, the government has mandated the use of 15 percent of their total public service fleet to be electric.10,22,26 Public-private partnerships in installing charging stations and other pilot programs will also promote acceptance of EV as a result of a good business model.22

A good economic model for EVs would include the following tools:26,27

1. Identifying a single coherent objective for EV to phase out conventional vehicle to reduce emissions
2. Identify the instruments/tools to achieve the objective:
   (a) Research and Development: Design of the EV and charging infrastructure
   (b) Production and Service: Influence manufacturers, dealers, energy suppliers, power plants, insurance companies, etc.
   (c) Customers: Understanding skepticism and buying power

3. Hierarchy in Governments: Interaction between various levels of governance must be understood for financial, legal and other requirements. Purchase grants, legislation on tariff rates, education and awareness campaigns, etc., vary for every level.

### Social and Infrastructure Factors

The biggest concern is public safety due to high susceptibility for fire accidents owing to alleged volatile battery chemistry. There have been some few isolated incidents in China and the USA. The National Highway Traffic Safety Administration (NHTSA) concluded that EVs are not a greater threat than gasoline vehicles, which can also catch fire.28 The Chevrolet Volt and the Nissan LEAF received five-star crash test ratings from NHTSA. Tesla’s Model S, for instance, was recently awarded the highest safety award by NHTSA.28 Hence, societal obstacles i.e., consumer perceptions and acceptance is a barrier for any EV market.

Another consumer perception is the range anxiety of EVs. Consumers are convinced that they will run out of charge before reaching their destination or the closest charging station, which was debunked in the previous section.20 Tesla Model 3 has claimed to have a 215 mile range for a single charge which is a breakthrough. This skepticism and resistance to change has distanced consumers from EVs. Another interesting phenomenon that has persisted is that consumers are not aware of night-time charging (utility rates are cheaper at off-peak hours), free charging at workplace, free charging at public spaces and incentives from the government.20,28 These socio-technical issues can be identified and resolved through innovative EV marketing and advertising, educational and awareness campaigns as well as other strategies to remove this negative attitude towards EVs like introducing car sharing opportunities and investing EVs for public transportation.21

Unavailability of charging stations is a crucial set back to the EV infrastructure. The successful EV markets are
characterized by high public/public-private investment in charging stations. There are two pre-requisites for effective mass deployment of EVs with regard to infrastructure: developing existing technology and business models for investment.

Table I depicts the different levels of charging stations used for different regions based on population density, charging rates, etc. The failure to develop a strong charging network can increase range anxiety. GPS technology has aided consumers to locate charging stations and free parking spaces thereby reducing driver stress and anxiety. To develop a regulated tariff system, there has to be prior understanding of public-private investment for appropriate levels of charging. For example, it is not attractive for private players to invest in charging stations where rates are usually high, thereby prompting consumer to charge at home. There must be a common consensus between the government and the private investors on who gets to cover the investment costs, thereby defining roles for different stakeholders (manufacturers, government, utilities, consumers, etc.).

<table>
<thead>
<tr>
<th>Charging Level</th>
<th>Use</th>
<th>Charge Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Slow</td>
<td>Home and workplace</td>
<td>1-8 hours</td>
</tr>
<tr>
<td>Level 2: Fast</td>
<td>Supermarkets, Gyms, Public Spaces</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Level 3: Rapid</td>
<td>Highways and Charge Stations</td>
<td>Less than an hour</td>
</tr>
</tbody>
</table>

TABLE I: Charging Stations and their Specifications.

Another challenge is the homogeneity of charging stations. There has to be a provision for a common charging station for all types of EVs to promote compatibility and greater access, which can be resolved through adopting regulations and common conventions.

**EV: An application for Emerging Economies and a Solution for Reducing Global Emissions**

Nearly 90 percent of the world’s population resides in developing nations. However, there is a disparity in access to energy for different population densities. This energy inequality emphasizes that there are regions where the urban population have access to larger power demands, while the lower rural population do not even have basic electricity access. To bridge this energy inequality and to mitigate global warming, it is more logical to help the developing world that contributes to 63 percent of global emissions than the developed world. Hence, the way forward would be to equip developing nations with the right technology to conserve energy and use low carbon infrastructure.

On such technology that has been projected as a viable solution for developing nations to reduce global carbon emissions is inexpensive EV products. It has been proposed that designing a cheap EV (USD 2000) with a light duty 50-mile range would satisfy consumers in the developing nations. Providing an affordable option will increase customer acceptance of EVs in emerging economies and thus achieve sustainability goals to reduce carbon emissions. Hence, a flourishing EV market makes more sense for emerging economies as it reduces carbon emissions as well as solve energy inequality issues.

**EV Projects in India**

From the previous sections, we conclude that the EV is now a potential solution to reduce global carbon emissions and to reduce the effects of climate change. It has been proved to be a necessity to achieve sustainable transportation goals and it makes more sense for EVs to be deployed in developing nations to aid the same. The following section focuses on the ongoing pilot projects, business models and other schemes available in some emerging economies that have recently adopted a positive attitude towards EV deployment. Each country is characterized by the same barriers mentioned in the previous section, but vary with different levels of intensity.

As is the case in most Asian countries, India’s primary mode of transportation is the two-wheeler and the three-wheeler vehicles. India is the second largest two-wheeler market in the world after China, and consumes around 40 percent of petrol every year. The two-wheeler market alone contributes to around 75 percent of the total automobile sales in India and projections indicate that this trend will continue to rise. If every two out of five two-wheelers were electric by 2030, then the emissions would decrease by 11 million tones of CO₂. A shift to hybrid cars would reduce emissions by a further nine million tones of CO₂ thereby reducing demand from petroleum and increasing demand from different sources of generation of electricity.

There is a dormant EV market for buses and rickshaws in the public and private transportation sector. The market size for auto-rickshaws (rickshaws that run on CNG and diesel) alone account for anywhere between 65,000 and 80,000 units that caters to 229 million trips annually. The number of operational buses that have the potential to be replaced by electric buses are 167,650 (13,180 in the public sector and 154,470 in the private sector) and 500,000 two wheelers were introduced in 2012 alone. Moreover, of the 22,000 EVs that were sold in 2016, only 2000 were electric cars and the rest accounted for the two wheelers, three wheelers and buses. Figure 5 shows the total ownership of two-wheelers in India indicating that there is a ripe EV market in this sector. Figure 5 for vehicle ownership in urban households in India.

Figure 7 displays the current EV initiatives in India. From this, one can conclude that electric three wheelers, two-wheelers and buses are considered the e-mobility alternatives to expensive private electric cars. This proves that introducing EVs can allow low income individuals to use these as a primary mode of transportation.
This is a better economic solution than to use electric cars which are currently still more costlier than combustion engine vehicles in India, thereby lowering consumer acceptance.39 This need of the hour solution will help in decreasing carbon emissions while providing a cheaper and flexible mobility alternative for all people in society. This will remove economic constraints and eventually address the energy inequality problem that was raised in the previous section.

### FIG. 6: Vehicular ownership in urban households in India.36

<table>
<thead>
<tr>
<th>Electric Two wheelers</th>
<th>Hybrid Vehicles</th>
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<tbody>
<tr>
<td>In 2001:</td>
<td>In 2011:</td>
</tr>
<tr>
<td>bicycles:</td>
<td>bicycles:</td>
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<tr>
<td>Two wheelers:</td>
<td>Two wheelers:</td>
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<tr>
<td>Four wheelers:</td>
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### FIG. 7: EV Initiatives in India

#### A Road map for India

The right approach for India to eventually expand the EV market to private car owners will depend on the success of EVs in public transportation and the two and three wheeler sectors to reduce global carbon emissions. This method will increase consumer acceptance and aid in achieving sustainable transportation goals by reducing carbon emissions. However, there are some challenges to setting up flourishing business models for electric rickshaws, buses and two wheelers:

1. **Government Regulation Challenges:**
   - The Indian Government in 2013 announced the National Electric Mobility Mission Plan to create demand for all electric vehicles,37 but has not created a separate program or business model for the potential two-wheeler and three wheeler market exclusively.
   - More policy tools need to be put in place to increase research and development capacity and incentives in battery technologies.40
   - There is no sustainable transportation policy intervention to integrate electric buses to slowly phase out diesel buses.40
   - Promotion of public-private partnerships through car sharing programs will increase greater utilization of EVs36.
   - Promotion of pilot programs in public transportation in various cities should be implemented to understand feasibility for the Indian market and thereby allow data sharing for charging stations to be installed.41

2. **Technology and Infrastructure Challenges:**
   - There needs to be an extensive layout and tariff plans for public charging stations that are run by public-private partnerships to promote private investment into this sector.39
   - There needs to be a common standard that is adopted by all players in the EV market in the charging and battery infrastructure to increase flexibility and ease of access.23
   - Parking spots exclusively for EVs will address range anxiety issues.36
   - As the number of EVs increase, the grid must increase its capacity to cater to the same, and this cannot be done without altering the energy mix to include more renewables and nuclear.35
   - Setting up regions to eliminate emissions in highly polluted cities like New Delhi and Agra by limiting access to conventional vehicles will promote e-rickshaws and electric buses.30
   - Indias lithium reserves are not sufficient to cater to the increasing demand from the EV market.37
   - There is a need to invest in research in development to design battery technology that is convenient and adaptable for domestic needs.39

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<table>
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<tr>
<th>Electric Two wheelers</th>
<th>Hybrid Vehicles</th>
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<tbody>
<tr>
<td>Aditya Gopal's Electric Buses11</td>
<td>Mumbai Metropolitan Regional Transport Authority17</td>
</tr>
<tr>
<td>- Electric two-wheelers manufactured locally</td>
<td>- Electric two-wheelers manufactured locally</td>
</tr>
<tr>
<td>- Installed power of 1000kW</td>
<td>- Installed power of 1000kW</td>
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<td>- Cost of Rs 1250</td>
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<td>- Designed for 40 km range</td>
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<td>- Range of 40 km</td>
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<td>- Battery: Li-Ion</td>
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<td>- Battery capacity: 50 kWh</td>
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3. Public Transportation and Consumer Acceptance Challenges:

(a) The number of buses that run on combustion engines is not sufficient to cater to the needs of the people (currently only one-tenth of the population). Expanding public transportation provides opportunities for EV markets to increase as well by deploying more electric buses.\(^4\)

(b) There needs to be an effective transportation system specifically for high population density regions to reduce travel time for EVs to be deployed.\(^4\)

(c) The National Urban Transport Policy promotes public transportation but however less emphasis is given to introduce more bus fleets.\(^4\)

(d) There is an inhibition for consumers to purchase EVs due to ignorance of subsidies, lack of access of public transportation and high costs.\(^3\)

(e) Programs and agencies like the Bureau of Energy Efficiencies, National Green Tribunal, FAME, Jawaharlal Nehru National Urban Renewal Mission, etc., should create educational programs to remove any stigma and skepticism associated with EVs.\(^6\)

(f) Incentives like prioritizing EVs in traffic by allowing them to use separate lanes will reduce congestion and increase public acceptance of EVs.

(g) Charging stations at points of high access like malls, hospitals, stadiums, etc., should be implemented.\(^4\)

Conclusion

The rise of EVs since the late 20th century in some developed nations has sparked a movement for mass adoption in some developed nations. This paper reviews the driving factors that led to the growth of EVs. There were some common factors that led to growing EV markets which were analyzed into broadly three categories: Technology and Environmental factors, Public Policy and Economic factors as well as Social and Infrastructure factors. The global EV markets were discussed to identify the motivating factors for EV acceptance. This helped raise an important notion that EVs have become a necessity to mitigate the rising global carbon emissions so that sustainable transportation becomes a reality. As a result of the strong and well established EV markets globally, The Paris Declaration on Electro-Mobility and Climate Change and Call to Action have projected that there will be 100 million EVs by 2030 where about 20% would be contributed by emerging economies.

This paper identifies EVs as a solution for developing nations, which contributes to the majority of global carbon emissions. The way forward would be to equip developing nations with the right technology to conserve energy and use low carbon infrastructure. To achieve sustainable transportation goals, it is necessary to offer a cheaper and affordable EV solution for developing nations like India where a USD 2000 with a range of 50 miles is ideal for daily commutation. This paper also discusses the existing EV projects in India and concluded that there is an untapped EV market in the two-wheeler, three-wheeler, bus and the public transportation sectors. Introducing EVs to an existing and ailing public transportation system will increase consumer acceptance in that electric bikes, e-rickshaws and electric buses will be a cheaper e-mobility alternative to expensive electric cars. The success of EVs in the public transportation sector will eventually decide the electric car market for private ownership. Finally, this paper notes the challenges, and proposes a roadmap and business strategies that India must address to adopt EVs as a solution to create a low carbon infrastructure and to eventually reach sustainable transportation goals.

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