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Environmental Impact of Electric Vehicles and the Changing Landscape of Indian Urban Transport

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Abstract The transportation industry plays a major role in the release of greenhouse gases (GHGs) into the atmosphere, which exacerbates air pollution and climate change. The potential of electric cars (EVs) to reduce these emissions in urban settings is the subject of this study. In order to determine how effective EVs are at reducing GHG emissions in urban areas, the study will analyse and compare emissions data from ICE vehicles and EVs. In order to model future emission scenarios depending on the adoption of EVs, a mid-sized city is chosen as the case study. The study uses a quantitative approach to assess the effects of growing EV adoption by using emission statistics and scenario modelling. It is anticipated that the results would give policymakers and urban planners important information that will help them make decisions about sustainable urban transportation plans.

Keywords Electric Vehicles, Sustainability, GHG emission, Transportation, Environment

1. Electric Vehicles and Environment

1.1. Introduction

Because they produce little to no exhaust pollution, electric vehicles, or EVs, are very popular. One of the biggest expanding trends in the transportation sector is electrification. In 2018, over 2 million electric cars (EVs) were sold, and this number is predicted to rise dramatically in the next years (Bloomberg NEF, 2019).

Many governments and advocacy groups support the adoption of hybrid and electric vehicles (EVs) as an essential part of the technology portfolio required to reduce greenhouse gas emissions and energy consumption. The transportation sector is at the core of national and supranational decarbonization policies (Ekins, 2018; Lah, 2017), as it accounts for around one fourth of greenhouse gases (GHG) emissions worldwide (International Energy Agency, 2018), most of them related to road transport (Transport & Environment, 2018). Moreover, in recent years the increase of the GHG emissions in many countries due to the transportation sector has been higher than the one caused by other sectors (International Energy Agency, 2018). Due to the increased focus on climate policy, a large number of the largest automakers are producing more mild hybrid automobiles (Hawkins et al., 2012).

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Internal combustion engines (ICE) in conventional cars continue to be a major source of air pollutants, including black carbon (BC), carbon dioxide (CO2), nitrogen oxides (NOx), and fine particulate matter (PM2.5; particles having an aerodynamic diameter less than 2.5 lm) (Hausberger, 2010). Serious health consequences, such as early death, are brought on by some of the pollutants released (Brook et al., 2010; Dockery et al., 1993; Pope et al., 2004; World Health Organization, 2005).

1.2. Life Cycle Assessment (LCA) as the Preferred Method for Evaluating Environmental Impact of Electric Vehicles (EVs)

Because life cycle assessment (LCA) explicitly evaluates resource usage and environmental emissions throughout a product's entire life cycle, it is the preferred technique for assessing the environmental implications of different transportation options. Three categories of cars are distinguished here: hybrid electric vehicles (HEV), which combine the use of an internal combustion engine (ICE) and an electric motor (EM), battery electric vehicles (BEV), which use only an ICE, and internal combustion engine vehicles (ICEV), which use only an ICE (Hawkins et al., 2012).

In the 1990s, several studies were performed focusing on the air quality and the environmental impacts and benefits of EVs (Kazimi, 1997; Lave et al., 1995; L. Vimmerstedt et al., 1996; L. J. Vimmerstedt et al., 1995; Wang et al., 1990; Wang & Santini, 1992). These studies provided comparative tail-pipe emissions, and highlighted concerns about additional emissions associated with increased battery production (Lave et al., 1995).

Related, early LCA studies pointed out the risk of considering isolated mechanisms and impacts within a larger system (Lave et al., 1995). However, direct tailpipe emissions are only one part of the environmental implications of electric cars (EVs), as Lave and Hendrickson highlighted in response to California's planned zero emissions vehicles regulation in the mid-1990s (Lave et al., 1995).

Numerous factors need to be taken into account in order to fully comprehend the system-wide environmental effects of switching from internal combustion engines (ICEVs) to electric vehicles (EVs) (Hacker et al., 2009). In order to develop successful policies for reducing the environmental effects of personal transportation, it will be crucial going forward to codify what is now known about the environmental effects of EVs and to identify the most significant knowledge gaps that need to be addressed (Hawkins et al., 2012).

1.3. GHG Emissions

Due to the unique needs for handling materials that are used in electric engines and especially batteries, the extraction of raw materials needed for the manufacturing of EVs has a greater influence on the amount of energy required and greenhouse gas emissions when compared to ICEVs (Kukreja, 2018b). The majority of research on greenhouse gas emissions related to the extraction of raw materials focuses on batteries, whose emissions are usually calculated as a percentage of emissions related to battery manufacture, usually around 20%. BEVs can reduce greenhouse gas emissions by 17–30% throughout the course of their life cycle compared to internal combustion engine (ICE) vehicles (European Environment Agency, 2018), can reduce CO2 emissions by 19–23% (Pratico et al., 2020).

The manufacturing and assembly of the parts that make up a vehicle are included in this step (Franzò & Nasca, 2021). The ones that are typically taken into account in the studies that are analyzed are the engine and glider for ICEVs, the powertrain, electric motor, and battery system for EVs (Franzò & Nasca, 2021; Yugo, 2018). The kind of materials used, the quantity and weight of components, and the manufacturing procedures all have an impact on the phase's greenhouse gas emissions, which also have an impact on the energy needed for the processes (Tagliaferri et al., 2016). Usually, it falls between 25 and 40 MJ for every kilogram of constructed car (Sullivan et al., 2010).

Generally speaking, this stage contributes significantly to an EV's lifetime GHG emissions, with absolute values that can be as much as 40–70% greater than those of internal combustion engines (ICEVs) (Hall & Lutsey, 2018; Hawkins et al., 2013; Romare & Dahllöf, 2017). This is mostly the result of the battery manufacturing process, namely the procedures involved in the production of cells and battery assembly. Between 100 and 200 kgCO2-eq/kWh is produced in batteries (Hall & Lutsey, 2018). The primary causes of this variance are the many regions that are taken into account for the production of batteries, the associated energy mix, and the quantity of energy needed for the manufacturing process (Franzò & Nasca, 2021; Peng et al., 2018). The latter is strongly influenced by the estimation procedure, such as top down and bottom-up approaches (Yugo, 2018). Furthermore, a significant variability emerges even among studies adopting the same procedure, with average values ranging from less than 10 kWh/kg of battery to 28 kWh/kg (Ellingsen et al., 2014; Majeau-Bettez et al., 2011; Notter et al., 2010; Philippot et al., 2019; Zackrisson et al., 2010).

The use of a vehicle is included in this phase (European Environment Agency, 2018). For internal combustion engines (ICEVs), in particular, the GHG emissions from a vehicle's life cycle often account for the largest portion of its emissions. Due to a variety of factors, including vehicle features, individual energy and fuel consumptions, the usage of auxiliaries, driving behaviour, land morphology, and weather conditions, they differ significantly between studies. The particular energy consumption of EVs varies from 15 to 25 kWh per 100 kilometers travelled (Huo et al., 2015). Auxiliaries like air conditioning and heating systems can increase specific energy consumption by up to 50% depending on the weather (Notter et al., 2010), and charging efficiency —which accounts for energy loss during charging phases —are the most significant factors affecting it. These include vehicle and battery characteristics like size and weight (Egede et al., 2015). ICEVs have a specific fuel consumption of 5.5 to 9 L/100 km (Peng et al., 2018; Wu et al., 2018). The primary causes of variations include variations in weather, geographical morphology, and vehicle types. The production and use of fuels have a significant impact on greenhouse gases. Fuels that have been studied the most are gasoline and diesel, then biofuels. Few studies take a WTW strategy, but many use a TTW approach. According to many sources (Asaithambi et al., 2019; Eriksson & Ahlgren, 2013; EUROPEAN COMMISSION DG ENER, 2015; Franzò & Nasca, 2021; Peng et al., 2018; Wu et al., 2018; Yugo, 2018), the typical emission levels for the latter fall between 2,500 and 2,850 gCO2-eq/L for gasoline and between 2,750 and 3,200 gCO2-eq/L for diesel. Variations are contingent upon a number of elements, including the nation of exploitation, the well's location, the necessary industrial operations, and the distance to be traveled for the delivery of fuel (EUROPEAN COMMISSION DG ENER, 2015).

The End-of-Life stage includes every option that becomes available after a car reaches its working limit, which is usually 150,000 kilometres (Saxena et al., 2015). Options for both ICEVs and EVs usually include recycling or reusing the EV batteries as well as disposing of the vehicle's body (Tagliaferri et al., 2016). For both ICEVs and EVs, disposing of a vehicle's body requires a particular energy expenditure of about 0.37 MJ/kg (Kukreja, 2018a). Generally speaking, the EoL contributes the least to a car's greenhouse gas emissions, and in certain situations (like battery recycling), it can help save energy and resources (European Environment Agency, 2018; Tagliaferri et al., 2016). A vehicle's life cycle emissions are made up of GHG emissions that range from − 5% to 14% (de Souza et al., 2018; Ekins, 2018; Ellingsen et al., 2014; Tagliaferri et al., 2016).

1.4. Mass, Energy Consumption, And Range

Compared to ICE vehicles, EVs are 15–29% heavier (Timmers & Achten, 2016). It is common knowledge that the fourth power law, which dates back to considerable testing conducted by the American Association of State Highway Officials in the 1950s, determines the estimated life of pavement. Because 1.2^4 is greater than 2, an increase in mass of more than 20% might have a significant impact on the paving sector. Moreover, this has an estimated 0.12 Wh/km impact on energy usage per kilogram of vehicle mass (Ribeiro et al., 2010). Both EVs and ICEVs have increased energy consumption (measured in kWh using a tank-to-wheel technique) as speed increases (J. Martins et al., 2013), while ICEVs have experienced an increase of 2-3.5 times compared to EVs. Furthermore, a variety of factors, such as the weight and kind of the vehicle, the quantity and kind of batteries used, the accessibility of infrastructure for battery charging, and loading time, affect an electric car's range (Varga et al., 2019).

1.5. Noise Pollution

The World Health Organization states that noise is a significant contributing factor to a number of health issues, including tinnitus, annoyance, sleep disturbances, cognitive decline, and cardiovascular disease. (Park et al., 2018; World Health Organization, 2019).

1) Structure-borne sources (such as engines, powertrains, etc., whose noise is produced by vibrations transmitted to the automobile body at frequencies typically above 500 Hz) can be identified when it comes to vehicular noise. 2) Airborne sources (such as exhaust tailpipes, etc.) that use low frequencies (<200 Hz) to directly broadcast noise through the atmosphere (Matijevic & Popovic, 2017). The sound produced by internal combustion engines (ICE) is a combination of mechanical and combustion noises that are either carried inside the engine compartment (acoustic channel) or through the vehicle's bodywork (structural path). Noise is mostly produced by combustion between 500 and 8000 Hz. 2) Valve primarily in the 500-2000 Hz range and piston slap (excessive clearance between the piston and cylinder), respectively. 3) The fuel injection primarily relates to 2000 Hz. 4) 50–5000 Hz is the frequency range at which inlet and exhaust valves operate (Pratico et al., 2020). Transmission, or drivetrain, is defined as 0.3–1 KHz. 6) 3–4 KHz is referred to as transmission (Campillo-Davo & Rassili, 2016).

The absence of combustion engines and associated parts, like as exhaust systems, makes internal noise from other EV components—such as HVAC and air conditioning systems, transmission systems, etc.—more noticeable. The electric motor of an EV produces a whining noise between 40 and 2000 Hz (Pratico et al., 2020). Noise levels from ICE and EV engines differ as well: 1) Up to 1000 Hz below 30 km/h. 2) At speeds of 20–40 km/h, a sound level difference of about 4–10 dB has been measured in the 2000–4000 Hz range (Pallas et al., 2015).

These tactics are now employed in an effort to lessen noise and its effects: 1) Rules and regulations. 2) Reducing the amount of noise that cars and tires produce. 3) Promoting the usage of fuel cell, electric, and hybrid cars. 4) Tire labelling. 5) Designating restricted traffic zones for urban areas (Maffei & Masullo, 2014). 6) Possessing quiet roads. Numerous initiatives have been started in recent years to solve certain significant problems with environmental pollution (such as noise and PM) brought on by the use of ICEVs while also taking into consideration the continuous and accelerating technological advancements in EV manufacture (Pratico et al., 2020).

2. Electric Vehicles: A Changing Landscape of Indian Urban Transport

2.1. Introduction

Approximately 300 million conventional automobiles are in use now, with 60000 new registrations occurring every day. Just 221 EV charging stations exist compared to 70799 conventional fuelling outlets. As per the Society of Manufacturers of Electric Vehicles, there have been 354017 sales of EVs to date. By 2040, India wants to have 31 million EVs in use (Sreeram et al., 2019).

India wants to guarantee that thirty percent of private automobiles and all public transportation be electrified by 2030. One of the most important choices made at the Global Mobility Summit in New Delhi was this one. More than 70% of pollution is caused by the transportation sector, which uses 70% of fossil fuels. For electric vehicles, the government offers a reduced GST rate of 12%, whereas for gasoline and diesel vehicles, the government imposes a tax rate of 28% plus a cess. Through the Automotive Research Association of India, the Indian Space Research Organization supplies commercial companies with the most recent lithium-ion battery technology. If India moves toward electric mobility, more than 65% of the energy required for road transportation and 35% of carbon emissions can be saved (Sreeram et al., 2019).

2.2. Types of EVs on Indian Roads and Their Applications

2.2.1. Based on Technology

There exist four categories of electric vehicles:

- Fully electric vehicles, or battery electric vehicles (BEVs). When compared to plug-in hybrids and hybrid vehicles, these are more efficient.
- Vehicle hybridized with electricity: Hybrid Electric Vehicle (HEV): The car has an internal combustion engine that runs on gasoline in addition to a battery-powered motor drivetrain. When the battery is low, the gasoline engine is used for both driving and charging. Compared to plug-in hybrids or completely electric

cars, these cars are less efficient.

- Plug-in Hybrid Electric Vehicles (PHEVs): These vehicles have a plug and run on both an internal combustion engine and a battery that is charged externally. This implies that electricity, as opposed to the engine, can be used to charge the car's battery. Though not as efficient as BEVs, PHEVs are still more efficient than HEVs.
- Fuel Cell Electric Vehicles (FCEVs): Chemical energy can be converted into electric energy. Take a hydrogen FCEV, for instance (e-AMRIT, n.d.).

2.2.2. Based on Number of Wheels

There are following basic categories of EVs that exist in Indian Transport:

- **Electric 2-Wheeler**
- **Electric Rickshaw**
- **Electric 3-Wheeler**
- **Electric 4-Wheeler**
- **Electric Bus**

2.3. Sales Trend for EVs in Year 2014-2024

The Indian electric vehicle (EV) market concluded FY2024 with record-breaking sales across all vehicle classes and the highest 12-month sales ever recorded for the electric two-wheeler, three-wheeler, and passenger car sub-segments. With 1.67 million units sold, FY2023 figures represent a respectable 41% increase over FY2022 (FY2023: 1.18 million EVs). Additionally, retail sales in March 2024 soared to 208,410 units, a new monthly high. This is the first time India EV Inc. has exceeded 200,000 units in a single month of sales (Dalvi, 2024).

Retail data released on the government of India's Vahan website shows that a total of 16,75,800 EVs were purchased in India between April 1, 2023 and March 31, 2024. That amounts to 4,591 EVs sold daily in FY2024 and an additional 1,349 units compared to 3,242 EVs in FY2023. They highlight to the market's and consumers' continued desire for EVs throughout FY2024, despite high pricing for both CNG (which was slightly lowered in early March 2024 after a protracted pause) and gasoline and diesel (Dalvi, 2024).

2.4. India's Electric Vehicle Transition in Future: An Environmental Perspective

Setting the stage for the switch to electric vehicles (EVs) has enormous potential for investment and quick market expansion among the paths for economic recovery and sustainable growth once the COVID-19 epidemic passes. We specifically focus on changes in oil import, value-addition, employment, impact on public finances, market size for EV components, and environmental gains from reduced local air pollutants and greenhouse gas (GHG) emissions. The 30% EV transition in 2030 is expected to have a wide-ranging impact on the economy. By estimating the vehicle stock in 2030 under business-as-usual (BAU) and a scenario with a 30% EV penetration, an attempt has been made to unravel these concerns. Furthermore, we investigate three distinct mobility paradigms: (i) elevated public transportation, (ii) elevated private car, and (iii) elevated shared mobility. Our objective is to assess the potential effects of a mode-share combination with 30% electric vehicle sales in 2030 on the industry, economy, and environment (Soman et al., 2020).

Between the base year of 2016 and the forecast year of 2030, there is an estimated almost 2.7-fold growth in the expected vehicle stock (passenger + freight). In comparison to a business-as-usual (BAU) scenario, we investigated the effects of 30% EV sales (or 35% in e-two-wheelers [e-2Ws] and e-three-wheelers [e-3Ws], 30% in electric buses [e-buses], 25% in electric taxis [e-taxis], and 13% in electric cars [e-cars]) (Soman et al., 2020).

EV SALES IN INDIA SINCE FY2014			EV SALES SPLIT IN FY2024		EV SALES IN FY2024	
Fiscal Year	**EVs sold**	**YoY % change**	**Segment**	**Units**	**Months**	**Units**
FY2024	16,75,800	42%	Two-wheelers	9,44,082	April '23	1,11,358
FY2023	11,83,418	158%	Three-wheelers	6,32,485	May '23	1,58,458
FY2022	4,59,293	222%	PVs (LMVs)	79,744	June '23	1,02,638
FY2021	1,42,409	-18%	Light PVs	10,635	July '23	1,16,624
FY2020	1,73,611	18%	Buses	3,693	August '23	1,27,186
FY2019	1,46,970	52%	Heavy goods vehicles	240	September '23	1,28,543
FY2018	96,507	73%	Light goods vehicles	4,699	October '23	1,40,335
FY2017	55,864	245%	Others	122	November '23	1,54,020
FY2016	16,182	592%	**Total**	**16,75,700**	December '23	1,41,845
FY2015	2,340	-11%			January '24	1,44,880
FY2014	2,627				February '24	1,41,403
Total	**39,55,021**				March '24	2,08,410
Data: Vahan, April 1, 2024, updated					**FY2024 total**	**16,75,700**

Seventy-two percent – 29,59,218 units – of the 3.95 million EVs sold in the past 11 years have come in just two fiscals (FY2024 and FY2023), indicating just how massive demand has been in the past 24 months.

Figure 1. EV sales trend in India in last 10 years (Vahan Dashboard, 2024)

The benefits of 30% of electric vehicle (EV) sales in 2030 are evident, in contrast to a BAU. India would save INR 1,07,566 crore (USD 14.1 billion) on crude oil imports as a result of the decline in oil demand from the passenger road transport industry. In addition, it is possible to anticipate a 17% drop in emissions of particulate matter and NOx, an 18% drop in CO emissions, and a 4% drop in GHG emissions in comparison to BAU (Soman et al., 2020).

Changes in passenger transport mode-share can be influenced by behavioural and policy changes, which can then have an effect on air quality, traffic, energy use, and road safety. As a result, we investigated EV uptake under several mobility paradigms in more detail. According to our predictions, in comparison to a BAU scenario, there would be a 31% decrease in oil imports, valued at INR 2,16,043 crore (USD 28.3 billion), if 30% of EV sales were to be combined with a higher percentage of public transportation. In the same scenario, this would lead to a concurrent reduction of 36% in emissions of carbon monoxide (CO), 28% in emissions of nitrogen oxide (NOx), 29% in emissions of particulate matter (PM), and 20% in emissions of greenhouse gases. Conversely, the ostensible advantages of electrifying passenger transportation are negated in the event of a high private car ownership rate, resulting in a 5% increase in overall energy consumption above the BAU scenario. Therefore, policymakers need to concentrate on influencing the development of passenger transport mode-share in order to realize the benefits of an EV transition. The bulk of trips and passenger travel needs must be satisfied by non-motorized transportation choices including walking and cycling as well as public transportation (Soman et al., 2020).

3. Discussion

Electric cars, or EVs, have become a ray of hope in the battle against air pollution and climate change. Compared to the thundering gas-guzzlers that predominate on today's highways, their peaceful hum and zero tailpipe emissions provide a striking contrast. However, there are several challenges associated with the switch to EVs. Let's examine the effects on the environment, how to reduce noise pollution, and how electric vehicles (EVs) may develop in India.

EVs have clean operations, but occasionally people overlook the importance of their life cycle assessment (LCA). The process of making batteries for electric vehicles can be energy-intensive and potentially harmful to the environment, especially when it comes to the mining of raw elements like cobalt and lithium. Furthermore, the source of electricity used for charging has a significant impact on the environmental footprint overall. If fossil fuels are used to create the electricity, the benefits are diminished.

Studies contrasting the lifecycle emissions of conventional gasoline vehicles versus electric vehicles, however, indicate a promising future. Over the course of their lifetime, EVs can provide a significant decrease in greenhouse gas emissions, even when battery production is taken into account. This emphasizes how crucial it is to support greener energy sources for the production of electricity in order to optimize the environmental advantages of electric vehicles.

There is no denying that EVs contribute to a quieter city. The noises produced by the tires, exhaust, and engines of conventional cars are a riot. On the other hand, driving an EV is quieter, especially when traveling at slower speeds. This can significantly improve people's quality of life in cities, especially for those who reside close to busy streets.

EV sales have increased dramatically in India in recent years. Popular options for commuting, such as two- and three-wheelers, have spearheaded the movement. The government's audacious goal of 30% EV sales by 2030 bodes well for India's future in terms of environmentally friendly transportation.

Although switching to electric vehicles is a good move; in order to maximize the environmental advantages, a more comprehensive plan must be taken into account. India's ability to succeed depends on fostering a multifaceted strategy. Here are some crucial things to remember:

- Emphasis on Renewable Energy: To make sure EVs are genuinely green, India needs to increase the amount of renewable energy produced, such as solar and wind power.
- Public Transportation and Shared Mobility: Even with an increase in EVs, encouraging the use of public transportation and carpooling can greatly cut overall energy use. This can be accomplished by implementing policy changes that encourage these options, better infrastructure, and subsidies.
- Battery Recycling: To reduce the environmental impact of battery production and disposal, a strong infrastructure for battery recycling must be developed.

In conclusion, the switch to electric vehicles (EVs) offers a special chance to address environmental issues and build a more sustainable future. India can unleash the full potential of electric vehicles (EVs) by recognizing the life cycle consequences of EVs, supporting renewable energy sources, and implementing a multi-modal transportation policy. Not only will this result in more sustainable transportation, calmer cities, and cleaner air, but it may also open the door for improvements in battery technology, charging infrastructure, and intelligent mobility solutions. The future seems bright, but governments, companies, and consumers must work together to make electric mobility a reality and bring about a quieter, cleaner world for all.

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