A METHODOLOGY TO ASSESS THE IMPACT OF ELECTRIC VEHICLE AND POWER GENERATION SOURCES AND THE ENVIRONMENT

India has experienced urbanization and subsequent growth in motorized vehicle usage at a significant rate in the past decades. While there has been a tremendous increase in mobility and accessibility in urban areas, it has also led to various severe problems such as increasing congestion, delay, accidents, energy wastage, noise & air pollution. The emergence of electric vehicles (EV) is being seen as an alternative to the internal combustion engine vehicles (ICEV) to reduce vehicular pollution and, in turn, improve air quality. Various governments and advocacy groups worldwide have promoted the adoption of hybrid and electric vehicles as a significant part of the portfolio of technologies required for reducing greenhouse gas (GHG) emissions and energy use. The National Electric Mobility Mission Plan (NEMMP)–2020 was launched by the Government of India (GoI) in 2013, aiming to achieve national fuel security by promoting hybrid and electric vehicles in the country. There was an earnest target to achieve 6-7 million sales of electric and hybrid vehicles year on year from 2020 onwards and 30% of electrification of the passenger fleet. This increase in EVs will also lead to a drastic increment in the overall electricity demand. However, as India is majorly dependent on coal for power generation, an increase in electricity demand will give an additional burden on the coal (thermal) power plants. The quality of coal in India is poor compared to other countries; therefore, the emissions generated are also higher, and the emission intensity is almost double the global average. The electricity generation-related emissions intensity from the thermal power plant in India was 901.7 gCO_2/kWh in 2005, which has increased to 926g CO_2/kWh in 2012, which are much higher than the global averages for those years, which were 542g and 533g CO_2/kWh, respectively. This subsequently becomes an area of concern while implementing the switch to EV from the ICEV in the country.

In India, after the NEMMP-2020, launched in 2013, the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) scheme was also launched in 2015 to promote and ensure sustainable growth of EVs. However, the current EV sales figures indicate that despite these schemes, the target of achieving EV adoption has fallen short. Various states within India have also introduced different schemes and targets to stimulate and promote EV adoption. Even after introducing and implementing several such schemes, both at the center and state levels, and despite the apparent advantages of EVs, significant barriers restrain their adoption, resulting in a small EV market share in India. Hence it necessitates a deeper understanding of the user demand for EVs in various parts of India, leading to effective policy measures for EV adoption.

A rigorous review of existing literature was carried out on various topics related to electric vehicles. Studies on electric vehicles in India have predominantly asserted their positive effects on the environment. However, it is evident from countries with a high dependence on non-renewable energy sources that the introduction of the electric vehicle may not reduce emissions but may even lead to an increase in the emission levels. Also, Exergy destruction and battery degradation have been significant for comparing EV and ICEV emissions, and they need to be integrated with life cycle assessment. The research carried out a systematic literature review related to the lifecycle assessment of ICEV and EV and observed two research gaps - 1) Most EV and ICEV comparison studies have not considered battery degradation. In contrast, it has a significant role in EV performance, i.e., efficiency, power consumption, and greenhouse gas emissions. 2) Limited studies considered vehicle attributes, socio-demographic, behavioral, and infrastructure availability attributes and were unable to capture the variability in demand for different types of EVs within India. Therefore, the objectives of the thesis are –(a) Developing methodology for estimating life cycle emissions from ICEV and EV, (b) Projecting Electric Vehicle (EV) demand and estimating the future energy requirements, (c) Estimating the environmental effect of EV influx in different scenarios of vehicle and energy mix. Here, the developed mathematical model in objective one

The **study's first objective** is to develop a methodology for estimating the lifecycle emissions from ICEV and EV. Thus, the study develops a mathematical model to determine the degree of viability of electric vehicle implementation. This mathematical model performs an integrated lifecycle assessment (LCA) of EV and ICEV. This LCA considers energy, exergy destruction, battery degradation, and cyclic loss model.

Subsequently, the term degree of viable implication (φ) is developed to analyze the sustainable implementation of EVs in place of ICEVs. The mathematical model in objective 1 is the foundation of the study on which the add-ins of data, i.e., electric vehicle demand and energy demand, need to be added.

The **second objective** aims to estimate the user behavior of adopting personal electric 2-wheelers (e-2Ws) and electric four 4-wheelers (e-4Ws) in India. User choices were collected via offline stated preference questionnaire surveys conducted in New Delhi, Mumbai, Bengaluru, and Kolkata. Subsequently, a pair of binary choice models were estimated to assess the demand for e-2Ws and e-4Ws. In this questionnaire, various vehicle attributes and their levels were developed, considering the technological advances for the horizon year 2030. Finally, the logistic function predicts the demand between 2021-2030. Along with the user perceptions survey, an industry survey was carried out to see the variation in the study's prediction and the manufacturer's perspective towards consumer behavior and EV adoption in India by the next decade.

In the **third objective**, the different scenarios of energy mix ratio are considered, and the impact of EV influx on energy and the environment is estimated. The objective utilizes the mathematical model developed in objective-1 and data forecasted in objective-2, i.e., EV adoption and energy demand due to the influx of EVs by 2030. Further, estimating the degree of viability of different vehicle and energy mix scenarios and the resultant emissions is used to discuss the sustainable implementations of EVs in India.

The study established that given the nation's current energy mix, the degree of viable implication (φ) Stands at 0.9. This could be enhanced significantly, to 0.68, by increasing the grid's percentage of renewable energy sources. The study estimated the demand for e-2Ws and e-4Ws and developed different scenarios of EV shift. This, along with power generation scenarios, was used to estimate the emission implications of EV adoption. The demand for e-2W and e-4W is estimated to be 17-28 million and 1.6-2 million vehicles, respectively, in the year 2030. This shift of vehicles will induce the electricity demand, which is estimated to be ranging from 9.5 to 15 TWh. The study considers three energy scenarios, i.e., Stated policies scenario (STEPS), Sustainable Development Scenario (SDS), and Integrated Decentralized Renewable Energy Scenario (IDRES), based on different assumptions of energy mix and EV adoption consequences. The study estimates the additional emissions from power generation sources in different energy scenarios. The emission results of SDS are estimated to be almost half of STEPS. However, achieving the SDS goal is a challenge for any nation despite the government's efforts. Also, IDRES shows similar results to SDS.
In terms of novelty, this study presents a first of its kind comprehensive analysis of the impact of EV demand on the environment. It does so by combining the two aspects – (a) lifecycle emission assessment of EVs, and (b) EV user demand. The lifecycle emission assessment leads to the development of an index, termed as the degree of viable implication, which assess the viability of EV adoption from an environmental sustainability point of view. Secondly, the econometric model that is developed, assesses the likelihood of EV adoption from the socio-economic, infrastructural and user attitude points of view.

As a future scope, the methodology provided in the study can be used by researchers for conducting viability assessments of various types of electric vehicles, such as e-buses, e-3Ws, e-freight vehicles, etc., by estimating their individual demand. Also, the study provides a platform for researchers to further analyze the quantitative and qualitative effects of the "spatial shift of emissions" to the periphery of the city and on the environment due to the shift to electric vehicles. Further research will also be required to assess the viability of increasing the energy generation from renewable sources and their subsequent use by electric vehicles. Finally, demand assessment of EVs in the smaller cities and towns may also be carried out to augment the findings of this study.

Keywords: Electric vehicle adoption; Life Cycle Assessment; Power Generation; Discrete Choice Experiment; Users' perception