Comparing the Economic and Environmental Compatibility of Battery Electric and Conventional Vehicles in India

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Abstract—Conventional vehicle fuel resources are encompassed with the jeopardy of being scarce; eventually exacerbating fuel prices. This high fuel prices further aggregate to elevate the total ownership cost and have led to an epiphany of national energy security. Further, the emission from conventional fuel combustion urges a need to cogitate about the already saddled environmental concerns. Alternatively, electric vehicles are looked upon as a potential option to conventional vehicles due to no tail-pipe emissions and low operating costs. However, if a complete life cycle is considered, an intuitive assumption that electric vehicles have no emissions and costs less can be a deception. Hence, the feasibility of electric vehicles as an option for conventional vehicles needs to be contemplated in economic and environmental aspects. This article presents the comparison between battery electric vehicles and conventional vehicles by performing a life cycle analysis (economic and environmental) in the Indian context. A Total Cost of Ownership (TCO) model is developed for financial analysis to depict the compatibility status of battery electric vehicles. The environmental analysis is conducted by using OpenLCA software based on ReCiPe 2016 method for all the impact categories at mid-point as well as end-point levels. The results reckon electric vehicles are costlier than conventional vehicles with current statistics and policies in India. However, by implementing certain optimizing parameters in sensitivity analysis, electric vehicles are found to have cost parity and even become more economical than conventional vehicles in some cases. The outcomes from environmental analysis unveil that the GHG emissions from battery electric vehicles are less than that from conventional vehicles. However, out of the 18 impact categories considered, battery electric vehicles have less impact in 10 categories and even have less impact score at the end-point level.

Keywords—Battery electric vehicles, life cycle analysis, environmental concerns, total cost of ownership, battery electric vehicles environmental impacts

I. INTRODUCTION

The pursuit for mode shift towards carbon-neutral transportation is intensified, provoking the researchers across the globe to come up with better sustainable transport options. As a result umpteen electric vehicles are being witnessed by the global vehicle fleet. The omission of tail pipe emissions and achieving national energy security with the help of an alternative for conventional high-priced fuels are the drivers of electric vehicle’s bandwagon Petrauskiene et al.[1]. The debates regarding the sustainability, feasibility, techno-economic-environmental aspects of Electric Vehicles (EVs) have still not lead to any consensus among the EV’s research fraternity. It is still unclear whether electric vehicles would prove to be a credible alternative and if yes then under which situation? Kalghatgi [2] states complete adoption of electric vehicles would not be feasible by 2040 however hybrid electric vehicles will be a better option for the conventional fuelled vehicles. On the contrary, researchers Hauschild et al [3], favor electric vehicles as a better option on various grounds such as economic, technical and environmental.

The Global EV Outlook report highlights the uneven uptake of electric vehicles is different parts of the globe [4]. Similarly, the barriers for uptake of battery electric vehicles (BEV), public opinion and policies to enhance the uptake of the electric vehicles across the world are brought forward by various literatures Lieven et al. [5], Heidrich et al. [6]. These literatures further highlight the common barriers for electric vehicles are economic aspect, lack of credible infrastructure
and environmental concerns. These barriers become more crucial for countries like India. The Indian automobile market being cost sensitive, the total cost analysis plays an important role. Further, the regional energy mix (mostly coal powered) used to power the electric vehicles reveals the need to analyze the environmental aspect too.

India’s National energy security is further closely associated to the slow pace deployment of electric vehicles. Less than 20% crude oil is extracted from indigenous source which leads to import a plethora of crude oil and thus making India the third largest crude oil importer [7]. The crude oil import bill for FY 2022 almost doubled than previous year marking it up to $119 billion [8]. Additionally, India ranks 2nd in Asia for CO2 emissions where a considerable amount of emissions come from transport sector in which road transport shares substantial portion [9]. These intricate barriers must be meticulously contemplated in order to boost the electric vehicle’s market share and faster deployment. However, the Indian government introduced plans such as National Electric Mobility Mission Plan (NEMMP 2020) in order to promote the battery as well as hybrid electric vehicles by setting various tools to achieve the 100% electric deployment by 2030. Additional, the government introduced ‘Faster Adoption and Manufacturing of (hybrid & Electric vehicles (FAME I & II)’ to support promulgation of the electric vehicles by providing incentives; however, the discrepancy between the plan and execution faltered the mission and urged a necessity to cogitate about the issue further. The electric 2-Wheelers are compatible with the global market, sale wise; however the electric four wheelers show much abysmal statistics [10]. This paper depicts the economic compatibility of battery electric vehicle in comparison with IC Engine vehicle (ICEV), further the environmental assessment comparison of BEV and ICEV is performed to estimate the environmental impacts.

II. LITERATURE REVIEW

This section highlights the literatures for economic and environmental aspect for battery electric vehicles. One of the major barriers for widespread of electric vehicle is it’s comparatively higher cost than ICEV as revealed by literatures J.Seixas et al.[11]. On the contrary, if the total life cycle is considered, the electric vehicles might be cost competitive or even economic than ICEV. Convincing the long term use benefits of electric vehicles can leverage the EV’s sales and drawing the customers away from being skeptical Bhosale et al. [12]. It is revealed from various literatures that the Total Cost of Ownership (TCO) may vary geographically due to discrepancy in local policies, exemptions and restrictions. Battery electric vehicles appear to be costlier in China even after considering the incentives by about 1.4 times than ICEV Zhao et al. [13]. However, in a related study conducted in China, ICEVs become more expensive than BEVs when some intangible expenses are taken into account Diao et al. [14]. Battery electric vehicle’s TCO is costlier than ICEVs even in Singapore and Australia attributing to different reasons. In Singapore, high custom and excise charges along with local charges elevates the battery electric vehicle position on TCO grounds [12], whereas in Australia, fluctuations in electricity rates during peak and off-peak period makes the TCO of battery electric vehicles much abysmal Kara et al. [15]. Among the European countries, Norway tops the economical chart which can be attributed to the clean energy mix L’evay et al [16]. The list is followed by France, UK and Netherland which have comparatively less TCO than that of Norway but economical than ICEVs. Other countries show poor performance when total cost of ownership is considered in comparison with ICEV. In a panoramic study conducted by Palmer et al. [17] providing incentives acts as an elixir for BEVs in the UK and the US when compared to the TCO of BEVs in Japan. In Slovakia, where giving subsidies have a substantial influence in lowering the TCO of BEVs, Pot’kany et al. [18] made similar observations.

While some literatures classify the TCO comparison on geographical regions, some distinguish the TCO on governing parameters such as incentives, Annual Kilometers Travelled (AKT) and fuel prices. Providing incentives is the primary promulgation opted by many governments but it needs to be analyzed how much effective this tool is? Some regions incentives are found to be sufficient such as in Norway and other countries in Europe and in the US as reckoned by L’evay et al [16]. Similar observations were made by Lieven et al. [19] in about 20 countries highlighting that the monetary grant is the better appreciated incentive. However, in some case the incentives did not seem to be that effective. An incentive of 4000 Euros is found to be insufficient in Germany Bubeck et al. [20], also the battery electric vehicles still remain marginally costlier (5%) even after providing federal incentives Tseng et al. [21]. Annual Kilometer Travelled (AKT) is a parameter which also affects the TCO of Battery Electric Vehicles Wu et al. [22]. Literature has quoted AKT ranging from 10,000 kilometres to 20,000 to bridge the total costs between the vehicles Mitropoulos et al. [23] suggest a minimum 23,000 kms AKT for BEVs to become economical than petrol and diesel vehicles in Italy. Apart from incentives and annual kilometers travel, the battery price/ battery replacement cost and its forecast has been emphasized by some literatures. Battery electric vehicles become cost competitive when the battery prices fall below $300/kWh and €240/kWh for different geographical regions David Newbery et al. [24]. Apart from the battery price, high depreciation rate for battery electric vehicles is also envisaged to be responsible to increase the TCO making is more costly than ICEVs. The literature depicts that although the battery electric vehicles were accepted with alacrity at the initial stage, the higher TCO is driving customers to being reluctant to buy the BEVs. Minimizing the TCO is one of the most difficult conundrums as it is governed by complex interplay of parameters which needs to be meticulously addressed.

Apart from economic compatibility barrier, environmental impact is also the major concern regarding the battery electric vehicles. The battery electric vehicles emit no emissions is a common deception that needs to be gazed upon as the emissions are being shifted from the tail pipe to some other site Kalghatgi [4]. However we cannot deny that the emissions from the conventional vehicles has been a major issue since the number of vehicles have been increased Lucas [25] but analyzing both vehicle types on emission grounds will help to judge the fate of these vehicles. The greenhouse emissions from a battery electric vehicles come from various sources such as material mining, transportation, energy consumed in manufacturing and the type of energy (energy-mix used) Ma et al. [26]. However, to get a panoramic emission impact, total life cycle analysis should be performed considering all the impact categories instead of only one impact category (green house gases). It is quite
intuitive that out of the two phase (manufacturing and use phase), battery electric vehicles emissions might be significant in manufacturing phase if clean energy source is used to charge the BEVs. The battery pack is considered to be sharing a substantial part in the overall emissions; however, discrepancy between the emissions from different battery technologies must also be addressed. In a choice between Lead Acid batteries and Li-Ion batteries, Li-Ion battery chemistry is found to be contributing least emissions. Premrudee et al. [27], Held et al. [28] reckoned the global warming potential impact category for a battery electric vehicle is twice that of than that of comparable ICEV and battery production is the prime contributor in it. Surprisingly, the battery chemistry is found to be contributing least emissions between Lead Acid batteries and Li-Ion batteries, Li-Ion batteries are sharing a substantial part in the overall emissions; (Phase), battery electric vehicles emissions might be jeopardized.

To perform a fair comparison. To verify that the estimates are performed good in overall emissions but in global warming and human toxicity categories ethanol blended fuel have less impact. BEV have more than 150 g/km CO₂eq GHG emissions for global warming category, whereas, ICEV with ethanol blend fuel has less than 100 g/km CO₂eq. The GHG emissions from battery electric vehicles from different regions of China range between 150-250 g/km CO₂eq and the average GHG emissions for BEV in China is 206 g/km CO₂eq. Zhou et al. [31]. Similarly, Qiao et al. [32] suggests that the GHG emissions for BEV can be reduced below 50% that for ICEVs by opting the battery recycling option whereas current scenario illustrates that the BEVs have 18% less emissions than comparable ICEV. The emissions from BEV must be kept under regulations as a parallel aspect with B the promotions of BEVs. As the electric vehicle’s technology advances, more stringent will be the norms (like emission norms in ICEVs such as EURO 2.3,..) and it should be of paramount importance to keep a check on emissions from BEV or else the entire transport mode shift will be in jeopardy.

III. OBJECTIVES

The economic and environmental compatibility of battery-electric vehicles with equivalent IC engine vehicles is examined in this article for the Indian setting. To perform Life Cycle Economic Analysis and Life Cycle Environmental Analysis adhering to Indian conditions considering more realistic data rather than relying on generic information. Further to perform sensitivity analysis considering different governing parameters and suggesting proper inputs for boosting BEV’s uptake to the policy drafters.

IV. METHODOLOGY

A. Economic Analysis:

The Total Cost of Ownership (TCO), which covers all expenses from a vehicle's construction to the conclusion of its useful life, is accounted for in the life cycle economic analysis. To estimate total cost of ownership, the pairing approach is opted as suggested by Gilmore et al. [33] to perform a fair comparison. To verify that the estimates are derived using the correct datum, the matching vehicle approach compares the vehicles with nearly identical dimensions and characteristics. The TCO block diagram and various phases along with the major hurdles are illustrated in figure 1. The TCO is split into three sections: possession Phase, use Phase and end-life Phase as illustrated in Figure 1. Initially the TCO for the base case is estimated and later optimization is opted with the help of sensitivity analysis to draw the best possible option to be suggested to the policy drafters. Annual Kilometer Traveled (AKT), Battery Replacement Cost, Incentives/Subsidies, Finance Interest Rates, and EV-PV Integration (Battery electric vehicles used in conjunction with solar energy option) are some of the parameters considered in sensitivity analyses.

The TCO model is developed with the help of the following equation:

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TCO/km = \sum_{i=0}^{n} (IC + RC + (PVC - PSS_n - R_{s,n} - I) - I + B_n)
\]

Here, IC is the possession cost, RC is Operating cost, PVC and PSS are the associated with the solar energy (cost and sale respectively), RS is salvage cost and I is subsidies/Incentives/ other exemptions and B is load principal balance, D is annual distance travelled in kilometers, n is number of years used vehicle.

The effects of financing and without finance on the TCO are calculated using the terms Finance TCO (FTCO) and Purchase TCO (PTCO). Acquisition cost includes all the costs to possess the vehicle by the owner. It includes Ex-Showrooms cost, Government Taxes, Road Taxes, Registrations, other miscellaneous charges by the motor company, interest if the vehicle is financed. The costs incurred during the use phase of the vehicle are fuel costs, maintenance, local entry taxes, parking fees, and tyre and part replacement. The fuel cost (Petrol/ Diesel and Electricity) is estimated by accounting for escalation rates for the specific timeline. General inflation rates are applied wherever necessary to account which is about 3.98%. Generally maintenance for the electric vehicles is less by 30% compared to ICEVs as suggested in literature and the tire life is considered as 50,000 km. Finally, the Salvage phase incorporates the vehicle's resale value for the relevant year, which is derived from the vehicle's depreciation. Following the pattern in the literature described by Messagie et al. [34] that battery electric vehicles depreciate more quickly than internal combustion engines do.

The vehicles usage data and assumptions can be summarized as: This TCO model compares two pairs of vehicles; pair A includes a TATA pair which compares TATA Nexon EV and TATA Nexon Diesel/ Petrol. For pair B, Hyundai Kona EV is compared to Hyundai Creta. Proper model variant is selected to fulfill the pairing vehicle approach. The annual kilometer travelled is 15,000 km for base case, the finance interest rate of 9.7% is considered for FTCO estimation for the base case with loan tenure of 5 years. The pair A BEV is entitled with an incentive of ₹115,000 and pair B BEV is assumed to have an incentive of ₹ 400,000 as per the FAME I & II guidelines. The battery replacement is done after 8 years/ 160,000 km.

B. Environmental Analysis:

The Life Cycle Environmental Analysis evaluates the emissions from entire life of a product adhering to the European standards series: ISO 14040 and ISO 14044. Here, the emissions from modeled BEV and ICEV are estimated
and the impacts are compared with reference to Indian context. The emissions accounted right from material extraction, transportation, energy generation and consumption, the use phase and finally the end of life phase. The emissions arising from both BEV and ICEV from the start of life to the end of life are compared which is also called as 'cradle-to-grave' analysis.

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**Results and Discussions**

**A. Economic Analysis:**

For the base case with an AKT of 15,000 km and a life period of 15 years, the Total Cost of Ownership is evaluated using the established model. The loan term is 5 years, and the finance interest rate is 9.75%. For the eighth year, the battery replacement is accounted for. Figure 4a & 4b illustrates the FTCO and PTCO results for base case for both pairs. Here F-BEV represents financed TCO for BEV; P-BEV represents purchased TCO for BEV. Similarly, F-ICEV D/P represents financed TCO for ICEV (diesel/petrol) and P-ICEV D/P represents purchased TCO for ICEV (diesel/petrol).

The results from figure 4a & 4b show a finding that in both the pairs the financed TCO of BEV (F-BEV) is greater than respective ICEV’s TCO (F-ICEV D & F-ICEV P). Similarly, the purchased TCO of BEV for both pairs is more than the comparable ICEV. However, pair A (TATA pair) purchase TCO has marginal gap between the purchases TCO of ICEVs. Nevertheless, even the financed TCO of pair A has considerable gap with TCOs of ICEVs. Unfortunately, pair B (Hyundai pair) shows abysmal results for both financed and purchased options, revealing the TCO gaps to greater extent. Another interesting finding shows a sharp spike at the 8th year in the TCOs of BEVs in both pairs. This sudden shoot-up is attributed to the high battery replacement cost.
B. Sensitivity Analysis (For economic analysis)

The base case analysis reckons that neither pair’s BEV achieve cost parity or become economical than ICEV. This develops a need to analyze the total cost of ownership with some additional parameters which prove to be potential to achieve the economic compatibility of BEVs. The sensitivity analysis includes aspects as: Policy Governed: providing incentives (as mentioned in previous section), Extended Policy Governed: reducing financed interest rates (ROI reducing to 6% from 9.75%), Technology Governed: fall in battery replacement cost (50% fall), Consumer Governed: applying higher Annual kilometer travelled (AKT) (20,000 AKT instead of 15,000 AKT), BEVs with EV+PV integration.

Sensitivity Analysis results show that pair A (TATA) purchased TCO of BEV fall below purchased TCO of ICEV in every parameter considered above. Also the financed TCO for pair A BEV has cost parity with the TCO of ICEV when ‘reduction battery replacement cost’ parameter is considered. However, the financed TCO of pair A BEV remains above the TCO of ICEV for all other parameters when applied individually. The results for pair B doesn’t seem to be in favor of BEV in all the parameters. TCO of BEV in pair B (Hyundai) remains higher than comparable ICEV in all above sensitivity aspects. It is only when the purchased TCO of BEV in pair B become marginally near to cost parity with the purchased TCO of ICEV for ‘reduction battery replacement cost’ parameter. The sensitivity analysis unveils an observation that in most of the cases the individual parameters are not sufficient to make cost competitiveness for both the pair; it will be achieved only when combination of the above parameters is. For this a ‘compatibility wheel’ is generated as shown in figure 6. This wheel depicts the combinations of different parameters used and how both the pairs fair in 12 sets of conditions. The orbits represent set of conditions/parameters and the planes represents finance/purchased TCO for respective pairs.

C. Environmental Analysis:

The environmental impacts for the modeled BEV and ICEV in the OpenLCA for the Indian context are presented in figure 7 (a-g). Further the total impacts are split into pre-use and use phase for better understanding of the major emitter source which would be further helpful to mitigate the issue. Figure 7 (a-g) shows the results major contributing and widely discussed impact categories in literatures.
Fig. 7. Impact assessment of BEV in comparison to ICEV for a) Global warming b) fine particulate matter c) human toxicity (carcinogenic) d) human toxicity (non-carcinogenic) e) Fossil resource scarcity f) Mineral resource scarcity g) Ionizing radiation.
The most widely common plot literature discussion is about the global warming gases (GHG) emissions; it is found that the BEV emits less GHG emissions compared to ICEV. Similar results are also observed in other literatures, Wu et al [40]. The GHG emissions from BEV are about 15% than that of from ICEV; however in a distributed analysis GHG emissions from BEV in use phase are comparatively more than ICEV. This may be attributed to the current energy-mix of India which has a substantial share by coal powered plants.

Apart from GHG emissions, BEV fair good in impact categories such as Ionizing radiations and resource scarcity. The emissions gap is observed quite distinct in ionizing radiations impact categories where emissions from BEV is almost half that of ICEV. In mineral resource scarcity, the BEV has very high emissions in productions phase but this gap is bridged in use phase making the overall emissions less than the ICEV. Nevertheless ICEV do not always land in negative side if all the impact categories are considered. In categories such as human toxicity and finite particle matter, ICEV emit comparable amounts of less pollution. The emission in human carcinogenic toxicity impact category by ICEV in use phase is almost negligible compared to that of BEV.

The observations unveil that the emissions in different impact categories do not go in favor of either the BEV or the ICEV. To get better insights of all the impact categories for both the vehicles relative graph is present as shown in figure 8. It is found that the BEV has fewer emissions in almost 10 out of 18 categories; the least different in individual categories is observed in terrestrial acidification which is about 7%. The larger variation is observed in the impact category freshwater eutrophication which is almost more than 73%.

Lastly a single point score is derived from the end-point analysis which depict that the battery electric vehicles have more economical friendly when overall score is considered which is 0.59 kpt where as the conventional vehicle has a score of 2.12 kpt.

VI. CONCLUSION

Life cycle analysis comparison is performed for selected modeled battery electric vehicle and conventional IC vehicle for the Indian context on economic and environmental grounds. This article helps the end users to address the much vexed question about the economic and environmental compatibility of BEV in India. For the economic compatibility, the base case considered here, which is much close to realistic data of current situation, reckon that in both the pairs BEVs are not financially compatible with ICEV for financed as well as purchased options. Comparatively the total cost of ownership (TCO) gap for pair A (TATA) is smaller than that for pair B (Hyundai). Further, the sensitivity analysis was performed taking into account different parameters to bring down the TCO of BEVs in both the pairs. The sensitivity analysis enlightens that apart from technology governed aspect (reduction of battery replacement cost by 50%) no other parameter is individually capable to make the TCO of BEVs to near cost parity or economical than ICEVs. It is only with the combinations of the parameters from sensitivity analysis the BEV reach cost parity and even become economical that the comparable ICEV which is demonstrated in the compatibility wheel. The compatibility wheel demonstrates the economic performance of vehicles with 12 different sets of parameters in which two sets of parameters (in orbit G and K) leverages the BEV’s TCO into the profitable zone. Annual kilometer travelled for about 20,000 km, used of EV+PV integration, 6% finance ROI along with incentives proves to be an elixir for the battery electric vehicles.

The perturbed green house gases emissions were addressed by analyzing the environmental compatibility which leads to a consensus that the GHG emissions from the BEV are less than that from ICEV for the Indian context. However, BEV does not outperform the ICEV on emission grounds in all impact categories. Out of 18 impact categories, not in the majority but the ICEV have fewer emissions in 08 impact categories. The emissions gap between BEV and ICEV is found to be least in terrestrial acidification impact category whereas as freshwater eutrophication has largest variation.
Splitting the total emissions into pre-use and use phase gives the cognizance about the actual major emissions contributor source; which in-turn helps to alleviate or eliminate the concern emission source. On assessing the end-point analysis the BEV has comparatively lesser overall emission score (0.59 kpt) whereas the ICEV has score of 2.12 kpt. Finally, this environmental compatibility tussle can exacerbate with shifting the current energy-mix to renewable energy sources; further the proper manufacturing practices and recycling the products will help to meticulously mitigate the emissions from a battery electric vehicle.

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