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Comparative Environmental Impact Assessment of Battery Electric Vehicles and Conventional Vehicles: A Case Study of India

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ABSTRACT

The battery electric vehicle (BEV) adaptation is at an accelerated pace due to its zero tail-pipe emissions and estimated environmental benefits. However, when considering an electric vehicle's entire life cycle, the environmental benefit could be a deception. It should be reckoned whether electric vehicles are really environmentally friendly and if they are, then under which conditions? According to the literature, the carbon footprint of electric mobility varies by geographic location as well as by the regional energy mix and the environmental impacts might exacerbate by introducing a plethora of electric vehicle. Since very less research has been carried out in the Indian context; this paper contemplates the environmental impacts of BEV and compares it with conventional vehicles performing a life cycle assessment.The paramount purpose of the study is to unveil weather BEVs are low carbon transport mode in India and where do they stand compared globaly. The results reveal that out of 18 impact categories considered under mid-point analysis, BEV outperformed IC Engine vehicles for 10 categories. The green house gases emissions from a BEV is 242 g CO_2eq/km at mid-point level and the single score at end-point level is 0.58 kpt compared to that of ICEV which has 2.1 kpt. Further, separate impacts from the production and the use-to-end life phase were derived to pinpoint the major emission contribution phase. At the ReCePi end-point analysis BEV favors being more environmentally friendly, however, switching to cleaner energy will further alleviate the environmental impacts.

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1. INTRODUCTION

The development of electric vehicles has become a global endeavour in the hope of electrifying road transportation which is techno-economic-environmentally better than conventional vehicles. Because of this, a large number of alternative fuel vehicles (Electric & Hybrid) may be witnessed in the near future. Elucidating the mode shift from conventional vehicles to electric vehicles attributes to mitigation of emissions, omitting high fuel prices, and resolving the national energy security issue. Observing these benefits, BEVs are considered as a potential substitute to promote sustainable transportation. Hauschild et al. [1] stated that: cost, customer satisfaction and performance are the backbones of the automotive market. The same applies for Electric Vehicle's (EV's) successful deployment in the existing vehicle fleet. Environmental impact plays a significant role in public opinion and market acceptance which is closely associated with customer satisfaction.

Although electric vehicle technology is at a nascent stage in India, comparatively, the EV's deployment pace is much slower. Additionally, for the Financial Year 2022, the adoption of electric four-wheelers is much behind that of electric three- and two-wheeled vehicles[1]. This may be attributed to the high initial cost, lack of credible infrastructures such as charging stations, environmental concerns, range anxiety and low awareness [2-4]. The statistics for electric vehicles sold in India for the past three financial years is illustrated in Figure 1. Murugan and Marisamynathan [5] have stressed to focus on range anxiety (travel distance) and high initial cost as governing parameters to promote electric two-wheelers. High initial cost is depicted as a

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[1] https://www.statista.com/statistics/1234761/india-electric-vehicle-sales-by-type/

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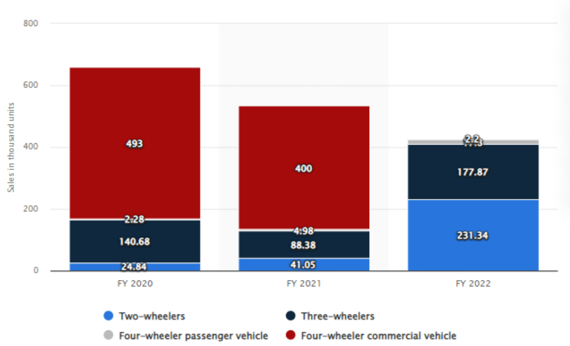

Figure 1. Electric vehicles sold in India for last three financial years [2]

significant barrier by conducting a Total Cost of Ownership (TCO) analysis for electric four wheeled vehicles Gilmore and Patwardhan [6], Bhosale et al. [7]; moreover, charging facilities are found to be another significant barrier for customers in India Murugan and Marisamynathan [8]. The high initial cost, infrastructure and range anxiety are tangible factors and can be mitigated with the help of means such as: providing incentives and special exemptions for EV (for high initial cost), proper policies such as government-private collaborations (for infrastructure) and developing research (for better battery technology). However, from an environmental perspective, which is an intangible factor, more efforts are required unless until which the basic purpose for mode changing to e-transport and the electric vehicle's bandwagon will remain incoherent.

The low EV uptake in India have encompassed many researchers to contemplate about its causes and encouraged to find the remedies Goel et al. [2], Singh et al. [9], Kumar et al. [10], Shrimali [11]. Further, Chaturvedi et al. [13] has expressed a complex interplay between various stakeholders in Indian EV industry and has suggested the possible remedies. In this prospect the government of India have also implemented imperative tools by introducing National Electric Mobility Mission Plan-2020 (NEMMP-2020) [12]. Observing the slower adoption of electric vehicles, the government also extended the promulgation by incentivising the EVs through policy titled as "Faster Adoption and Manufacturing of (hybrid &) Electric vehicles in India (FAME I & II)"[1]. The NEMMP 2020 and FAME I & II schemes were accepted with alacrity and the government prognosticated the replacement of all passenger and light weight vehicles with electric vehicles[2]. However, observing the discrepancy between the acceptance and implementation due to various barriers, the government re-quoted the announcement to replace only 30% total fleet by electric vehicles[3].

One of the major concerns for India related to the national energy security is the umpteen crude oil import bills. India is third largest oil importer in the world and more than 81% of the crude oil requirement relies on import rather than indigenous sources[4]. Additionally, the cost of importing crude oil doubled from the previous year to roughly $120 billion for FY 2022[5]. The second concern which is closely related to energy security is the alarming pollution. The transport category ranks third in CO_2 emissions where as road transport contributed the most in total transport category[6]. These much vexed questions of national energy security and environmental concerns avenues the need for electric vehicles which are found to be a potential substitute. The necessity of the article is to prevent the further exabaration of the already saddled environmental issues in India. The BEVs play a complex interplay with the environmental concerns which when intruded at a greater pace in India, can make the situation more worse than that in present. The article/study is necessary to find out the intensity of the environmental impacts arrising from a BEV which will further help to frame the forthcomming policies in order to fight this major concern. Further, to the best of our knowledge the emissions estimation comparison from both vehicles is rarel done in India. This article uses a innvoative implementation of LCA software named OpenLCA which is based on ReCePi 2016 methodology with using realistic data rather than relying on generic data which defends the novelty of the study. As discussed earlier, the environmental aspect regarding electric vehicles, which is an intangible factor, needs to be meticulously contemplated. This article unveils the environmental effects of BEVs in comparison to traditional ICEVs with regard to the Indian context. The structure of the acticle is as follows: 1. Introduction: Gives the current status and statistics of electric vehicles in India, the major concerns, the need to approach this study and a brief light on the innovativeness of the article. 2. Literature Review: Highlights the current barriers for electric vehicles, approching the dicussion of the environmental concerns around the globe including all

[1] https://fame2.heavyindustries.gov.in/content/english/15_1_FAMEI.aspx, https://fame2.heavyindustries.gov.in/content/english/13_1_brief.aspx

[2] http://lithiumionbattery.org/industry-updates/news/india-aiming-for-all-electric-car-fleet-by-2030-petrol-and-diesel-to-be-tanked#:~:text=India%20is%20looking%20at%20having,vehicles%20self%2D%20sufficient%20like%20UJALA.

[3] https://asia.nikkei.com/Economy/India-starts-argument-over-realistic-EV-targets-for-2030 accessed 06/11/2022

[4] https://www.newindianexpress.com/business/2022/jul/14/indias-crude-imports-from-russia-up-72-timesin-april-may-2022-2476374.html#:~:text=India%20is%20the%20world's%20third,and%2014%25%20from%20the%20US

[5] https://economictimes.indiatimes.com/industry/energy/oil-gas/indias-oil-import-bill-doubles-to-usd-119-bn-in-fy22/articleshow/91049349.cms accessed 07/11/2022

[6] https://pib.gov.in/PressReleasePage.aspx?PRID=1748514#:~:text=India%20has%20a%20massive%20and,of%20the%20total%20CO2%20emissions

the impact categorie. 3. Drivers, Method and Objective: Explains the motivation for the study and the prime objective. Further the methodology used to approach the study. 4. Results and Discussion: Illustrated the findings of the study and interpreats the outcomes. 5. Conclusion: Gives briefly the major findings and the attributed causes and resole approach.

2. LITERATURE REVIEW

The transportation system is completely built around the ICEVs which have high impact on the environment [13-15]. Additionally, emissions from IC Engine Vehicles have always been notorious of all the emission sources [16, 17]. Moreover, it unveiled that IC Engine vehicles will dominate the global vehicle market till 2040 due to complex interplay of demand-supply, energy policy and technology trends reported by Kalghatgi [18]. Therefore, when more vehicles are added to the global number, the environmental impact will exacerbate. The BEVs are looked upon as a potential alternative to ICEVs due to their zero tailpipe emissions. Considering this benefit, many governments around the globe are aggressively introducing electric vehicles with the help of various tools under the rubrics of sustainability reported by Yong and Park [19], Heidrich et al. [20] Lieven et al. [21] Mohanty et al. [22]. The overall effects and techno-economic-environmental aspect of deployment of electric vehicles are reckoned by Bharathidasan et al. [23] along with the environmental concern. Additionally, it is observed the greenhouse gases emissions from lifecycle of an electric vehicle relies on manufacturing technique and the energy mixture used to recharge electric cars [10, 24, 25]. Nevertheless, using the electric vehicles without de-carbonizing the source of electricity will simply hamstring the electric vehicle's environmental benefits (zero tailpipe emissions). The environmental impact include emissions of gaseous pollutions such as CO, CO_2, NO_x, VOC, SO_2, metal particulates such as mercury and lead, other organic pollutants and particulate matter. The secondary concern with these umpteen conventional vehicles is the noise level/pollution. The limit noise level above which it is found to be unfit for humans is 55 dB Lden (European Agency). As depicted in acoustics study and noise map determination, shifting to electric vehicles has considerably mitigated the urban noise pollution[1], however the environmental concern is still not addressed from a sustainability point of view.

The emissions from electric vehicles mainly come from two phases know as pre-use and use phase. In the pre-use phase, also known as manufacturing phase, most of the emissions come from extraction of the materials/ resources then the transportation and refinement. In case of use phase, the energy mix used to charge the e-vehicles play a significant role as reported by Oliveira et al. [26]. The emissions also rely on the geographical region, system boundaries and the assessment method. The literature also justifies variation in the emission estimation by using various impact assessment methods such as IPCC, CML, CED, Ecopoints97, ReCePi reported by Parvez Mahmud et al. [27]. The assessment discrepancies may also be observed by using different assessment tool/software such as GaBi, SimaPro, GEMIS, Mobius, Open LCA, CMLCA and also using different data inventories [23]. Focusing to the pinpoint, the material extraction and manufacturing of the battery used in an electric vehicle has the GHG emissions and the energy utilization twice as compared to conventional IC Engine Vehicle. If the batteries are to be considered, mostly in modern vehicles, Li-Ion batteries are used. However, in a choice between lead-acid batteries and maintenance free batteries for automobile application, global warming and acidification are the major contributing impact categories. Premrudee et al. [28] suggested the use of maintenance-free batteries which can bring down these effects by 28% for an automobile application. Wang et al. [29] analyzed lead-acid and Li-ion batteries using the ReCiPe model, highlighting that a lithium iron phosphate battery's (LIPB) production phase contributes the least impact. Moreover, Tin and Lead are the major metals causing emissions for Lead-acid batteries. It is also found that out of the total contribution, the battery production contribution is 15% in which the extraction of copper and aluminum are major emission sources rather than the extraction of lithium. From the study of Peters et al. [30], it is reckoned that on an average 110 gCO_2eq of GHG emissions are made by Li-Ion batteries for 1 kWh of energy production. In a similar study, Ambrose [31] highlighted that total CO_2 emissions are in a range of 200-500 Kg CO_2 equivalent for Li-Ion batteries with different chemistries for an automobile application.

The assessment conducted by Finkbeiner [32] with the aid of the GaBi programme emphasizes the impact categories for acidification potential (AP) and global warming potential (GWP) as key contributors. Further, the battery production phase is the major contributor for both categories as compared to conventional vehicles where the impact categories have 2 times and up to 4 times higher emissions of GWP and AP respectively. In Belgium, electric vehicles are found to be more environmental friendly (limited to GWP) with the current Belgium energy mix. The battery electric vehicles have an emission of 50 g/km CO_2eq compared to diesel (above 200 g/km CO_2eq) and petrol (above 250 g/km CO_2eq) vehicles. Additionally, CO_2 emissions per kWh were 190 g/kWh for the Belgium energy mix which further fall down to 11 g/kWh using wind energy as reported by

[1] http://noise.eea.europa.eu/

Mierlo [33]. This justifies the significance of the type of energy source used to power the BEVs. In Brazil, Souza et al. [34] conducted the environmental assessment comparisons of BEVs with conventional ICEV & also ICEVs with ethanol were also considered. Still the overall environmental benefit stands in the favor of the BEV followed by ICEV with ethanol blended fuel. However, BEVs with lithium ion batteries have highest impact on human toxicity category whereas ICEVs with ethanol doesn't prove to be environmentally benefited in acidification, eutrophication and photochemical oxidation categories. In the GWP category ICEVs with ethanol has less impact (97.2 g/km CO_2eq) compared to BEVs (151 g/km CO_2eq). In China, Shi et al. [35] justified the savings in the petroleum by about 98% with the use of battery electric vehicles. Additionally, the BEVs stand advantageous in CO, CO_2, VOCs, NO_x and PM2.5 emissions but perform abysmal in PM10 category. Relatively the BEVs emit up to 318 g/km CO_2eq which is observed to be at bit higher side as compared to other literatures in the same timeline. Nevertheless these CO_2 emissions will be further reduced by 11% to 28% by 2030. The literature reviewed by Shi et al. [35] is limited to single province (Hebei province) whereas Zhou et al. [36] presented the statistics for different power grid zone across China. In this work average CO_2 eq. emission of whole country is 206.13 g/km CO_2eq and the total range of all the grid zones is in the range of 158 to 247 g/km CO_2eq. In an another parallel study in China by Qiao et al. [37], it has revealed that GHG impacts are 18% less than conventional ICEV and the major contributing phase is emissions from well-to-wheel (WTW) phase. To alleviate the life cycle GHG emissions of BEVs in future, Qiao et al. [37] suggested enhancing the recycling of battery electric vehicles and switch to much cleaner power grid. It is estimated that the GHG emission will reduce by approximately 50% with the use of the above tools.

As discussed earlier in literature, the environmental impact may vary with different boundary conditions. The relationship between an electric vehicle's environmental impact and its travel range is emphasized by Hawkins et al. [14]. The production impact of manufacturing a battery electric vehicles are more with respect to the use phase when compared to an ICEV. Hence, as the number of kilometer travelled or annual kilometer travelled (AKT) is more, the global warming potential (GWP) decreases for BEVs. With the current electricity mix in Europe, the electric vehicle's GWP is about 10 to 24 % less compared to the ICEV (diesel) for 150 K (AKT), 27 to 29 % less for 200 K AKT and 9 to 14% less for 100 K AKT. Further, to reduce the overall emissions, impacts from the manufacturing supply chain must be addressed in conjunction with electricity source with cleaner production. Peng et al. [38] conducted study in 6 countries and observed geographical difference causing variations in GHG emissions. The GHG emission reductions are prominently observed in geographical regions where low-carbon electricity is produced. The European Union with comparatively cleaner energy generation has least GHG emissions, about 55.51 gCO_2 eq. /km and about 170.15 gCO_{2e}/km for China. Burchart-Korol [39] unveiled the environmental burdens of using BEVs in Poland and the Czech Republic with respect to current and future time-line. Interestingly, the results show the environmental impacts for current and future will be lower than comparable ICEV. Comparatively, the impacts are relatively more for Poland than Czech Republic. The GHG emissions for BEV in Poland were 2.72% lower than ICEV and 24.67 % lower for Czech Republic. Further, an intuitive observation shows that switching to renewable energy sources will reinforce the GHG emission reduction by 2050. A bit out of the way approach, Othman et al. [40] came up with using BEVs with Autonomous Driving (ADV) to reduce the emissions. In this observations, ADV using platooning and optimum traffic management by the ADV significantly reduces the travel distance and eventually the fuel used and the emissions. Similarly, Tahmasseby et al. [41] emphasized use of electric and automated vehicles along with Intelligent Transportation Systems (ITS) to cope up with stringent emissions norms.

The reviewed literature can be used to identify the following literature gaps: 1. Majority of Environmental Life Cycle Analysis are carried out in developed countries, however, limited studies are available for developing countries. In developing countries like India, although the electric vehicles uptake is at a verge of a revolution and in coming decades, very high proportion of EVs will be witnessed. Intruding the Electric vehicles without contemplating its actual environmental hazards is counterproductive and this stands a need to investigate the environmental impacts in India. 2. Nevertheless, Environmental Life Cycle Analysis (ELCA) carried out in many developed countries is for limited number of impact categories. The BEVs may be favorable in one impacts category but might not be performing good in other. Hence, to get a panoramic idea of the BEV's environmental impact, the analysis needs to be leveraged with an extensive ELCA including all impact categories. 3. The environmental analysis with more realistic data must be carried out instead of relying on generic data. Most of the countries do not have indigenous sources of materials such as lithium battery pack materials and needs to be imported. The emissions from the transport/ import of the materials need to be accounted instead of considering the start point as material available on site. 4. The study of the emissions from vehciles can be further enhanced with the use of travel mode option/ transport preference opted especially in metropolis. Influence of various parameters such as the infrastructure and accecibility opinion for travel mode preference as highlighted by literatures such as Lukina et al. [42] can further help the emission studies needs to be implemented.

3. RESEARCH DRIVERS, METHOD AND OBJECTIVE

3. 1. Life Cycle Analysis (LCA) The fundamental objective of LCA is to evaluate the environmental effects in development, usage, and disposal (LCA) phases of a product. Typically, a product undergoes a "full LCA," often known as a cradle-to-grave examination. However, considering the end-user of the study, different types of LCA, such as cradle-to-gate (raw material-factory) and cradle-to-cradle (a closed-loop LCA that includes recycling of part products), are also occasionally evaluated. The LCA flowchart is displayed in Figure 2.

3. 2. Objectives and Research Drivers This article's primary objective is to ascertain which power train (BEV or ICEV) has less impact on the environment in the context of India. In addition, it's important to evaluate the environmental impact while taking different life phases into account. Finally, we'll talk about the Cumulative Impact (endpoint Recepi 2016 assessment).

One of India's main worries about electric automobiles is the environment. As a result, our inquiry is motivated by the "RRR" (Reduced, Revival, and Renewable) pattern. Where, Reduction: lowers the cost of imports, Revive: reduce the amount of hazardous emissions by transitioning to electric vehicles with better battery chemistry, Renewable Energy: By converting to green transportation and utilising an energy mix that supports renewable energy, you can lower your GHG emissions. Thus, upholding strict environmental standards and sticking to them is what motivates this study and justifies the societal contribution.

3. 3. Methodology

3. 3. 1. System Boundaries and Scope of Study The methodology follows the guidelines and advice provided by the European standards series: ISO 14040 and ISO 14044, quantifying the emissions from a product or procedure over the course of its use period. This study evaluates the environmental impacts by using battery electric vehicles and diesel ICEV with reference to India as a geographical region. The emissions produced during the gathering and processing of materials, transportation, manufacturing and use of both the vehicles are taken into account from the birth to end-life of the product. However, omissions regarding recycling of the product (vehicle in this case) are considered owing to India's lack of reliable recycling infrastructure. This life cycle analysis falls under cradle-to-grave assessment and illustrates the various flows, processes, product systems and the project involved in this cradle-to-grave analysis shown in Figure 3. This analysis's objective is to compare the life cycle emissions of ICEVs with BEVs (diesel), considering a functional unit of 1 p*km. The emissions accounted include the direct tail-pipe emissions (for the diesel ICEV) and emissions from electricity generation sources. Additionally emissions from the vehicle and battery manufacturing, fuel (extraction and refinement), indirect emissions from brake and tyre wear are also taken into account. This research assumes that the vehicle is used for 100,000 km for an average lifetime of 10 years.

3. 3. 2. Data Inventory Analysis This study uses OpenLCA software to perform the impact assessment within the geographical region of India. The inventory makes use of the configurable Ecoinvent-3 database with other database, in case if data needs to be imported from other database. The simulation includes various product flows such as product or elementary flow which eventually builds up a process. Different processes combine together to form a product system separately for BEV and ICEV which are later compared in a Project including system boundaries and impact assessment method. The process involved in building a product system for a BEV is illustrated in a model graph shown in Figure 4.

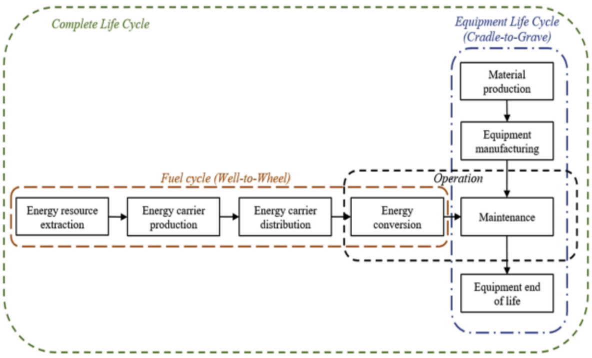

Figure 2. Material and Fuel line LCA for a typical automobile analysis [54]

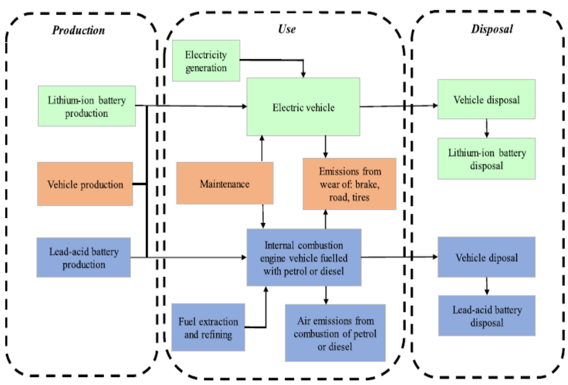

Figure 3. Flow diagram of life cycle analysis

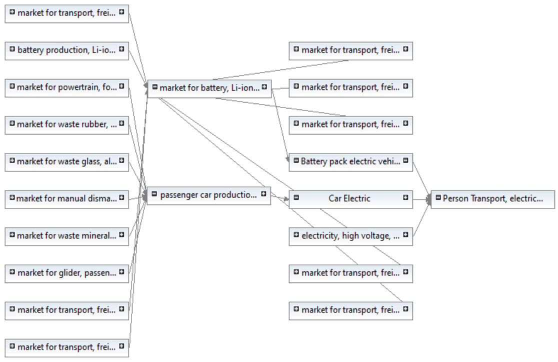

Figure 4. Model graph of battery electric vehicle product system

The weights of the vehicles are 1500 kg (ICEV) and 1250 kg (BEV without battery), weight of the Li-ion battery pack is 326 kg. The battery considered is of 23 kWh and the energy density is 70 Wh/kg. The total cruising range of the battery is 200,000 km, however for the vehicle used in this analysis required amount of battery is for 100,000 kilometres. BEVs use 17.11 kWh of electricity per 100 kilometres and the ICEV consumes 17 km per litre diesel. The energy required to assemble the final Li-ion battery pack is 3.47 kWh [43]. The electricity-mix considered is Indian energy-mix (2022) which has almost 60% energy generated from conventional fossil fuels. The necessary transport needs right from raw materials to manufacturing unit (some items of battery pack manufacturing are imported) and from manufacturing to customers through assembly unit are also considered.

3. 3. 3. Impact Assessment and Interpretation

As highlighted by Parvez Mahmud et al. [27], the impacts assessment method significantly affects the LCA assessment. To perform the impact assessment, we have considered ReCePi 2016 method based on what majority of the literature have considered and suitable for the automobile application. Both ReCePi 2016 mid-point and end-point are accounted to analyze the individual and cumulative effects of all the impact categories. The major impact categories considered in this case are global warming, ionizing radiation, human toxicity (both carcinogenic and non-carcinogenic), fossil and mineral depletion. In addition to these categories, other impact categories of interest are water and land use, ozone formation, ecotoxicity and eutrophication under the ReCePi mid-point. To precisely measure them, the effect categories in the end-point are classified into a small number of categories. The grouped impact categories in end-point analysis include resource scarcity, human health and ecosystem quality. The cost of extracting minerals and fossil fuels, represented in US dollars ($), is what is meant by resource scarcity. Human health demonstrated loss of years due to disability from the environmental impact and is expressed in DALY (disability adjusted life years) whereas as ecosystem quality gives the loss for the species in various ecosystem expressed as species.year unit. Finally, the relative results for both the vehicles are presented to cogitate the individual and relative effect for various impact categories. The Methodology Flow Chart is shown in Figure 5.

4. RESULTS AND DISCUSSION

Figure 6 (a-g) shows the environmental effects of BEV and ICEV in India for various important impact categories such global warming, fine particulate matter, ionising radiation, human toxicity (both carcinogenic and non-carcinogenic), and fossil and mineral depletion. Additionally, it depicts the spitted impact in production and use-end life phase for panoramic emission assessment.

The impact from global warming is shown in Figure 6(a). ICEV account the highest in climate change category which is 282 g CO_2eq/km whereas for BEV it is 242 g CO_2eq/km. As observed in earlier literatures, the obtained results are in-line with these studies where the ICEVs have the greatest impact [33, 39, 44-46]. Comparatively, the GHG emissions observed for BEV in production phase are less as compared to use phase. The higher impacts for BEV come from 'use phase' which is closely associated to the energy-mix. The current energy mix of India has about 60% energy generation from convention fuel such as coal which signifies switching to electricity generation from renewable sources will surely alleviate global warming category.

Although the BEV emit less GHG emissions, the gap between BEV and ICEV in climate change is less than 15%. Moreover the climate change emissions in global warming category are more prominent in use phase

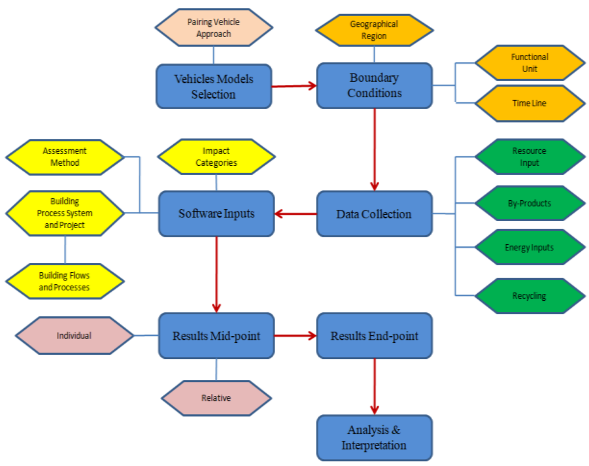

Figure 5. Flow Chart for Methodology of LCA Analysis

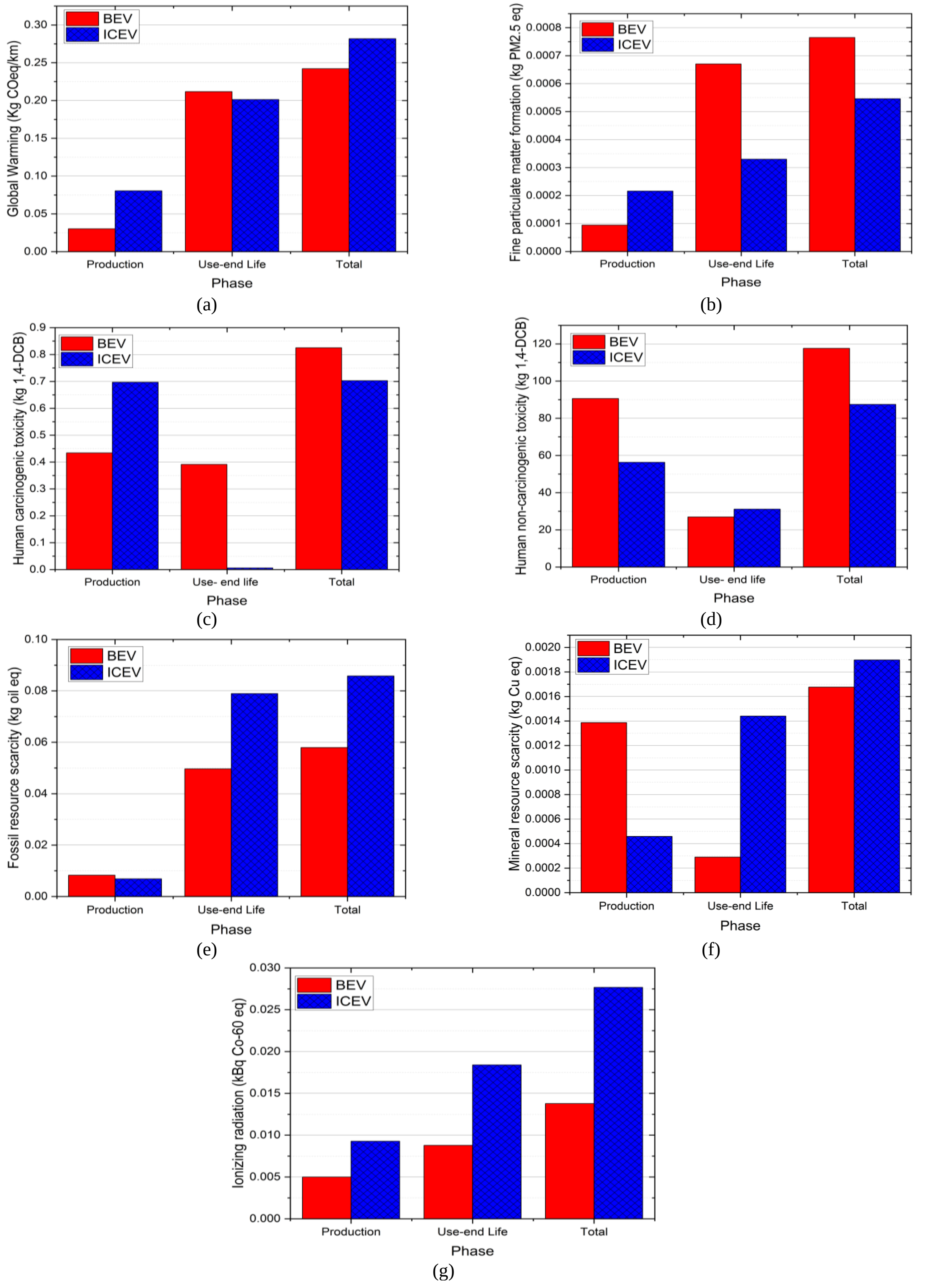

Figure 6. Impact assessment of BEV in comparison to ICEV for a) Global warming b) fine particulate matter c) human toxicity (carcinogenic) d) human toxicity (non-carcinogenic) e) Fossil resource scarcity f) Mineral resource scarcity g) Ionizing radiation

which clearly indicate that the energy source use to charge the BEVs should be shifted to much cleaner mode. Currently India mostly relies on the conventional coal powered plants to cater it most of the electricity needs. This causes to shoot up the emissions with more demand for electricity as the number of BEV goes up. The government on one hand is promulgating the BEV aggressively but it should also make provisions for this other side of the coin.

On the Contrary, for fine particulate matter category, the battery electric vehicle fair poor, the total emissions have almost 40% more impact as compare to ICEV. Impact of ICEV and BEV on particulate matter category is shown in Figure 6(b). Almost 88% of the total emissions come from use phase which attributes to umpteen combustion of fossil fuel for energy generation.

The impact burden for this category for BEV is 7.65E-04 kg PM2.5 eq and the ICEV contribute 5.46E-04 kg PM2.5 eq. It can be justified that less combustion of fossils for energy generation and advanced manufacturing techniques can reinforce the impact reductions as mentioned by Shi et al. [35].

The emissions for human toxicity (carcinogenic & non-carcinogenic) are illustrated in Figure 6(c) & (d). When the total emissions are taken into account, battery electric vehicles fair substantially worse. In case of different use phases, for carcinogenic impact category, the emissions from ICEV are only 1.5% than that from BEV in use-end life phase. However, for use-end life phase and in non-carcinogenic category, the ICEV has more emissions than BEV, albeit with smaller margin. Nevertheless, the total impact for BEV in both categories is at higher side and is the result of the interaction between the production of batteries and cars, as well as the energy-mix.; these results are identical as observed by Burchart-Korol et al. [39].

In case of resource scarcity (fossil and mineral) the impact from ICEV outnumbers BEV in both fossil and metal resource scarcity. The resource scarcity results are demonstrated in Figures 6(e) & (f). The fossil resource scarcity for BEV is 5.79E-02 kg oil eq and 8.58E-02 kg oil eq for ICEV. Whereas, the mineral resource scarcity for BEV is 1.68E-03 kg Cu eq and ICEV is 1.90E-03 kg Cu eq. For the production phase, the resource scarcity impact for BEV is more as compared to ICEV, specifically for mineral resource scarcity. This is due to the heavy requirement of minerals for the battery and allied components such as battery management system and motor windings production. The BEV have high impact in production phase compare to ICEV, however, the low impact benefit for ICEV in production phase is simply offset by the high impacts in use phase , thus catapulting the total impact for ICEV.

Battery electric vehicles are found to be advantageous from an ionizing radiation impact category point. The ionizing radiation for BEV is 1.38E-02kbq CO-60 eq in comparison to ICEV which is 2.77E-02kbq CO-60 eq. According to Tahmasseby [41], the ionising impact of a BEV is almost half that of an ICEV. BEV's ionizing impact is less for both production and use phase significantly as compared to ICEV. Impacts from ionizing radiations are shown in Figure 6(g).

In order to observe the results of the current study and compare it with the other studies in the literature, comparative results are presented in Table 1. Although the battery electric vehicles are emitting less emissions in India context compare to the ICEV for climate change category, the overall emissions magnitude are considerably higher compared to the global values in the near about same timeline. This demonstrates the significance of the power source and how clean is the energy generation. Failing to achieve the energy from cleaner source, BEV use will be just shifting the emissions from the vehicle's tail pipe to the energy generation site. Additionally the Human Toxicity value compared to the global values are also much higher in this case study. The human toxicity arises from the mining of materials which are used to manufacture the vehicle parts. Moreover the extraction of the battery pack materials further worsens the emission levels in can of BEV. Attributing to this the overall human toxicity levels are considerably higher for this case study.

The impacts for various the impact categories other than mentioned above and not much widely discussed in many of the literatures but are illustrated in Table 2 (software generated table image). The result from table depict that for the impact categories namely Freshwater ecotoxicity, Marine eutrophication, Ozone formationHuman health, Ozone formation, Terrestrial ecosystems, Stratospheric ozone depletion, Terrestrial acidification BEV becomes advantageous and having low impact burden as compared to ICEV. In most of the above impact categories BEV have 25% less impact than ICEV.

For panoramic outlook of all the impact categories, the relative results for the ReCePi mid-point assessment are displayed in Figure 7. Out of 18 impact categories considered, battery electric vehicle fair good in 10 impact categories in comparison with ICEV. The highest variation is found in freshwater eutrophication where ICEV has just 27% impact as that of battery electric vehicle. The lease variation is observed for terrestrial acidification category where BEV has just 6% impact gap compared to ICEV. We found that for land and water use impact category, the ICEV is almost 40% more advantageous than the BEV. Focusing on the global warming category, interestingly a positive point is to be highlighted that the g CO_2eq/km gap between BEV and ICEV is less as compared to other literature [16, 17, 47]. Moreover, switching to cleaner energy BEV can bridge

TABLE 1. Comparative emissions with other literatures for climate change and human toxicity

	Country/ Region	Timeline	Climate change, g CO2 eq/km	Human toxicity, kg 1,4-DB eq/km
			GRAMS	
This article	India	2022	BEV: 242 ICEV: 281	BEV: 0.82 ICEV: 0.7
Bauer et al. [46]	Switzerland	2012	BEV: 220 ICEV: 260	BEV: 1.0 ICEV: 0.3
		2030	BEV : 90 ICEV: 210	BEV: 0.27 ICEV: 0.25
Van Merilo et al. [33]	Belgium	2017	BEV: 50 ICEV: 212	BEV: 0.040 ICEV: 0.026
Bickert et al. [48]	Germany	2015	BEV: 204 ICEV: 262	
		2020	BEV: 196 ICEV: 212	
Souza et al. [34]	Brazil	2018	BEV: 151 ICEV: 97.2	BEV: 0.035 ICEV: 0.012
Del Pero et al. [49]	Italy	2018	BEV: 129 ICEV: 203	
Onat et al. [50]	United States	2015	BEV: 180 ICEV: 260	
Bicer and Dincer [47]	Canada	2018	BEV: 160 ICEV: 230	BEV: 0.26 ICEV: 0.04
Qiao et al. [37]	China	2015	BEV: 273 ICEV: 333	
		2020	BEV: 227	
Burchart-Korol et al. [39]	Poland	2015	BEV: 276 ICEV: 284	BEV: 0.331 ICE: 0.085
		2050	BEV: 172	BEV: 0.234
Burchart-Korol et al. [39]	Czech Republic	2018	BEV: 214 ICEV: 284	BEV: 0.306 ICEV: 0.085
		2050	BEV: 145	BEV: 0.234
Petrauskiene et al. [43]	Lithuania	2020	BEV: 142 ICEV: 76	BEV: 0.077 ICEV:0.0073
		2050	BEV 78	BEV: 0.073
Zhou et al. [36]	China	2009	BEV 206 ICEV 249	

TABLE 2. ReCePi mid-point results of BEV and ICEV (software generated table image)

Indicator	BEV	ICEV	Unit
Fine particulate matter formation	7.64982e-4	5.46229e-4	kg PM2.5 eq
Fossil resource scarcity	5.79452e-2	8.57900e-2	kg oil eq
Freshwater ecotoxicity	1.48779e-2	2.47261e-2	kg 1,4-DCB
Freshwater eutrophication	1.42334e-4	3.81529e-5	kg P eq

Global warming	2.42092e-1	2.81770e-1	kg CO2 eq
Human carcinogenic toxicity	8.25258e-1	7.02699e-1	kg 1,4-DCB
Human non-carcinogenic toxicity	1.17596e+2	8.74670e+1	kg 1,4-DCB
Ionizing radiation	1.37743e-2	2.76725e-2	kBq Co-60 eq
Land use	3.33749e-3	2.00561e-3	m2a crop eq
Marine ecotoxicity	1.41523e+2	1.02429e+2	kg 1,4-DCB
Marine eutrophication	2.35348e-5	3.29772e-5	kg N eq
Mineral resource scarcity	1.67656e-3	1.89831e-3	kg Cu eq
Ozone formation, Human health	6.85209e-4	9.27953e-4	kg NOx eq
Ozone formation, Terrestrial ecosystems	6.91598e-4	9.49920e-4	kg NOx eq
Stratospheric ozone depletion	9.49468e-8	1.19844e-7	kg CFC11 eq
Terrestrial acidification	1.52559e-3	1.62241e-3	kg SO2 eq
Terrestrial ecotoxicity	9.36751e-1	4.11475e-1	kg 1,4-DCB
Water consumption	1.53252e-3	9.80542e-4	m3

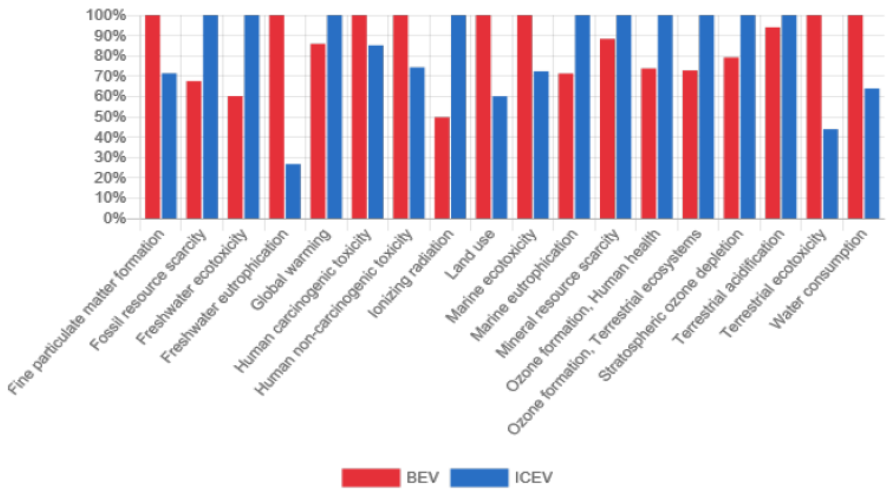

Figure 7. Relative results of LCA

the gap or even can deliver less impact than ICEV in all phases in the near future. Additionally, mining/extracting and manufacturing the resources from the indigenous sources instead of importing may save the transport emissions which eventually be advantageous for effect categories like ionising radiation, fine particulate pollution, and global warming.

Further, the results for ReCePi end-point analysis are illustrated in Table 3 (software generated table image). The end point results are derived by grouping and mapping the impact categories mainly in three groups as mentioned in impact analysis section. Further, a single point score is determined to compare BEV with ICEV and assess the impact magnitude. The end-point

TABLE 3. ReCePi end-point results of BEV and ICEV (software generated table image)

Indicator	BEV	ICEV	Unit
Fine particulate matter formation	4.80660e-7	3.43069e-7	DALY
Fossil resource scarcity	8.82989e-3	3.60161e-2	USD2013
Freshwater ecotoxicity	1.02783e-11	1.70967e-11	species.yr
Freshwater eutrophication	9.53209e-11	2.55511e-11	species.yr

Global warming, Freshwater ecosystems	2.04244e-14	2.43820e-14	species.yr
Global warming, Human health	2.47796e-7	2.95840e-7	DALY
Global warming, Terrestrial ecosystems	7.47822e-10	8.92548e-10	species.yr
Human carcinogenic toxicity	3.90473e-8	3.42167e-8	DALY
Human non-carcinogenic toxicity	8.85132e-8	9.35561e-8	DALY
Ionizing radiation	8.23619 e-11	7.61240e-11	DALY
Land use	2.96106e-11	1.77933e-11	species.yr
Marine ecotoxicity	2.14079e-12	3.30650e-12	species.yr
Marine eutrophication	3.99890e-14	5.60576e-14	species.yr
Mineral resource scarcity	3.86860e-4	4.38672e-4	USD2013
Ozone formation, Human health	6.23551e-10	8.44464e-10	DALY
Ozone formation, Terrestrial ecosystems	8.92156e-11	1.22539e-10	species.yr
Stratospheric ozone depletion	3.36976e-11	4.88163e-11	DALY
Terrestrial acidification	3.23416e-10	3.43937e-10	species.yr
Terrestrial ecotoxicity	9.94784e-12	4.36638e-12	species.yr
Water consumption, Aquatic ecosystems	9.25639e-16	5.92248e-16	species.yr
Water consumption, Human health	3.40218e-9	2.17680e-9	DALY
Water consumption, Terrestrial ecosystem	2.06890e-11	1.32373e-11	species.yr

assessment reveals that the major contributor when cumulative effect of all the impact categories are considered, the primary influencing factor for both vehicles is resource scarcity, which includes both fossil and mineral resources.. Relatively the total single point score (out of 3 kpt) for BEV is 0.58 kpt and for ICEV it is 2.1 kpt. This justifies that the BEV is environmentally advantageous than ICEV at end-point level.

5. CONCLUSION

The performed Environmental Life Cycle analysis of BEV and ICEV leads to an epiphany that for all impact categories, the battery-electric car did not perform worst. The results substantiate that out of 18 impact categories considered for mid-point assessment, BEV fair good in 10 impact categories in comparison with ICEV. The end-point results show that, on an overall single point scale, BEV is still environmentally beneficial as compared to ICEV with a greater margin.

Resource scarcity is the major contributor for both vehicles when studied on a single point scale. When a slpited analysis (use phase and end-life phase) is observed in all the categories for BEVs, with the exception of human toxicity and fossil resource categories, usage phase is the dominant impact contributor. This use phase is closely associated with the energy mix which needs to be eventually shifted to renewable sources with sustainability angle of approach.

The global warming g-CO_2eq/ km for both vehicles are quite compatible with not much gap in the impact. Better manufacturing techniques and use of cleaner energy will help to amplify this gap in near future. Continuing the current energy mix will simply exacerbate the environmental issue in future when more number of BEVs will be introduced to the total vehicle fleet.

This article contributes towards the societal application by making aware the emissions from both the vehicle propulsion types which in turn helps in strengthening the public opinion about the environmental benefits of using BEVs. Further, it provides guidance to the policy drafter's fraternity for alleviating the saddled environmental issues in India. This surely provides guidelines for the BEV's manufacturing ecosystem to implement the optimized manufacturing techniques, the precautions in material extraction-processing-refinement & transport to build a compatible infrastructure encompassing the low carbon transportation. This article further acts as a nexus between government perseverance for BEV's uptake and perceiving the customers towards BEV; which inturn helps in achieving national energy security, reduce the oil import bills and combating environmental issues.

The limitations of the study is the access to convincing recycling of the end-life BEV and to be more specifically the Li-Ion batteries. Unavailability of the reliable BEV's recycling facilities in India may deviate the emissions estimation and if proper recycling infra is used the impacts might come down which is also reckoned by various literatures. India being a colossal country, the factory to vendor or end user distance may vary considerably, further changing the amount of emissions which depend on the local transport mode of semi-knocked part or the finished vehicle. Variation emissions observation in all regions of India also comes under the limitation rubrics.

Significantly the emission estimates made in this study are derived from near to realistic data. The emission impacts from both the vehicles for all 18 impact categories at mid-point and end-point level of ReCePi Methodology for the Indian context justifies the scientific and technological top-up. Moreover, the study can be extended as future scope by accounting the regional/ statewise energy-mix which has a substantial influence on the total emissions. At present the no indigenous sources are available in India which includes greater travel distance for it's import. However, if a local source obtained then the updated material travel distances needs to be updated and can be accounted as future study. Additionally, as the technology advances, different and a better battery technology/ chemistry may be introduced. Estimating emissions with these batteries can be done as a extended study.

The electric vehicle bandwagon is saddled with various hurdles; meticulously overcoming these barriers will prove BEV as an epitome of the future transport. Retrospection of BEVs for environmental impact; cleaner energy mix, efficient manufacturing and recycling may prove to be an elixir for BEV to be a ubiquity in the near future.

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Persian Abstract

چکیده

انطباق وسیله نقلیه الکتریکی باتری (BEV) به دلیل انتشار گازهای خروجی صفر و مزایای زیست‌محیطی تخمین زده شده با سرعتی سریع انجام می‌شود. با این حال، وقتی کل چرخه عمر یک وسیله نقلیه الکتریکی را در نظر می گیریم، مزایای زیست محیطی می تواند یک فریب باشد. باید در نظر گرفت که آیا خودروهای برقی واقعاً دوستدار محیط زیست هستند و اگر هستند، پس در چه شرایطی؟ با توجه به ادبیات، ردپای کربن تحرک الکتریکی بسته به موقعیت جغرافیایی و همچنین با ترکیب انرژی منطقه‌ای متفاوت است و اثرات زیست‌محیطی ممکن است با معرفی انبوهی از وسایل نقلیه الکتریکی تشدید شود. از آنجایی که تحقیقات بسیار کمتری در زمینه هند انجام شده است. این مقاله تأثیرات زیست‌محیطی BEV را در نظر می‌گیرد و آن را با وسایل نقلیه معمولی که ارزیابی چرخه زندگی را انجام می‌دهند مقایسه می‌کند. هدف اصلی این مطالعه، پرده‌برداری از آب‌وهوای BEVهایی است که حالت انتقال کربن کم در هند دارند و در مقایسه با سطح جهانی در کجا قرار دارند. نتایج نشان می دهد که از ۱۸ دسته ضربه در نظر گرفته شده در تجزیه و تحلیل نقطه میانی، BEV از خودروهای موتور IC برای ۱۰ دسته بهتر عمل کرد. انتشار گازهای گلخانه ای از BEV 242 گرم CO_2eq/km در سطح نقطه میانی است و امتیاز واحد در سطح نقطه پایانی ۰.۵۸ kpt است در مقایسه با ICEV که ۲.۱ kpt است. علاوه بر این، اثرات جداگانه از تولید و مرحله استفاده تا پایان عمر برای مشخص کردن فاز مشارکت عمده انتشار به دست آمد. در تجزیه و تحلیل نقطه پایانی ReCePi، BEV دوستدار محیط زیست بیشتر است، با این حال، روی آوردن به انرژی پاک تر اثرات زیست محیطی را کاهش می دهد.