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Dissecting the Economic Feasibility and Life Cycle Assessment of Battery Electric and Internal Combustion Engine Vehicles: A Case Study of India

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Abstract

Fuel supplies for conventional vehicles are vulnerable to scarcity, which could ultimately lead to an increase in fuel prices. There has been a realization regarding national energy security as a result of these high gasoline costs, which further increase the overall cost of ownership. Additionally, the emissions from burning conventional fuels make consideration of the already pressing environmental issues necessary. On the other hand, because they have low running costs and no tailpipe emissions, electric vehicles are being considered as a viable alternative to conventional automobiles. But when a vehicle's whole life cycle is taken into account, the common-sense belief that electric vehicles are cheaper and emit no emissions may be misleading. Therefore, it is necessary to consider both the economic and environmental elements of whether electric vehicles are a viable alternative to conventional automobiles. In this article, a life cycle analysis—both economic and environmental—between battery-electric and conventional automobiles is presented in the context of India. For financial analysis, a Total Cost of Ownership (TCO) model is created to show how compatible battery-electric vehicles are. OpenLCA software, which is based on the ReCePi 2016 technique, is used to conduct the environmental analysis for all impact categories at both the mid-point and end-point levels. According to the findings, electric vehicles are more expensive than conventional automobiles in India based on current data and regulations. However, it is shown that electric vehicles have cost parity and can sometimes even become more inexpensive than conventional automobiles by using specific optimizing factors in sensitivity analysis. The results of environmental studies show that battery electric vehicles emit fewer greenhouse gases (GHGs) than do conventional automobiles. Battery electric vehicles, however, had less of an impact in ten of the eighteen impact categories that were examined, and they even have a lower impact score at the end-point level.

Keywords: Life Cycle Analysis, Economic Compatibility, Total cost of Ownership, Electric vehicles in India

1. Introduction

Researchers from all around the world are being pushed to develop more sustainable transportation solutions as the drive to convert to carbon-neutral transportation becomes more intense. Consequently, the global vehicle fleet is witnessing an abundance of electric vehicles. The main factors driving the adoption of electric vehicles are the avoidance of exhaust emissions from tailpipes and the achievement of national energy security through the use of an affordable fuel substitute [1]. Among the EV research community, there is currently no agreement on the sustainability, viability, techno-economic, and environmental aspects of electric vehicles (EVs). It's still uncertain if electric cars would work as a reliable substitute and, if so, in what circumstances. According to Gautam [2], fully electrified vehicles won't be practical by 2040, but electric-hybrid cars will be a preferable choice over traditional fuel-powered automobiles. Conversely, for a variety of reasons, including technical, financial, and environmental, experts Hauschild et al. [3] support electric vehicles as the superior choice.

The inconsistent adoption of battery-powered cars around the world is shown in the Global EV Outlook report [4]. Similarly, a variety of literary works highlight the obstacles to the widespread adoption of electric vehicles, as well as the public's perceptions and regulations aimed at promoting their use. Lieven et al. [5], Heidrich et al. [6]. These publications also emphasize that the absence of reliable facilities, financial concerns, and environmental issues are the main obstacles to the widespread use of electric vehicles. These obstacles become increasingly important for nations such as India. Given that the Indian auto industry is price-sensitive, a comprehensive cost study is crucial. Furthermore, it is evident from the regional energy mix—which primarily consists of coal—that environmental analysis is also necessary in order to power electric vehicles.

The sluggish adoption of electrically powered cars is also intimately related to India's national energy security. India is the third-most populous crude oil importer because less than 20% of the country's crude oil is derived from domestic sources [7]. The fiscal year 2022 saw a nearly twofold increase in the crude oil import cost, amounting to $120 billion [8]. Furthermore, India is ranked second in Asia for CO2 emissions, with a significant majority of these emissions coming from the transportation sector, primarily from road transportation [9]. To increase the market share and accelerate the deployment of electric vehicles, these complex barriers need to be carefully considered. But even after the Indian government implemented programs like the National Electric Mobility Mission Plan (NEMMP 2020) and Faster Adoption and Manufacturing of (hybrid &) Electric vehicles (FAME I & II), there was a gap among the plan and its implementation, which undermined the mission and made it necessary to think more deeply about the problem. The worldwide market contribution of battery-powered two-wheelers is consistent with the worldwide marketplace, but the numbers for electric four-wheelers are significantly worse [10]. In order to determine the sustainability implications, this article compares the economic viability of battery electric vehicles (BEVs) with internal combustion engine vehicles (ICEVs). Additionally, an environmental evaluation is conducted to compare the two vehicle types.

2. Literature Review

The literature on the environmental and economic aspects of battery-electric cars is highlighted in this section. According to J. Seixas et al.'s literature [11], one of the main obstacles to the widespread use of electric vehicles is their somewhat greater cost than internal combustion engines. On the other hand, electric cars may be more affordable than internal combustion engines (ICEVs) when taking into account their entire life cycle. Persuading potential buyers of the long-term advantages of electric cars can increase sales of the type and entice them to change their minds. et al. Bhosale [12]. Numerous academic works disclose that variations in local rules, exemptions, and limits can cause the Total Cost of Ownership (TCO) to fluctuate across various parts of the world. Even after accounting for incentives, battery electric vehicles seem to be more expensive in China than ICEVs Zhao et al. [13]. However, when certain intangible costs are taken into consideration, ICEVs become far more costly than BEVs, according to a related study done in China Diao et al. [14]. Even in Singapore and Australia, battery powered cars have higher total costs than internal combustion engines (ICEVs) for many reasons. Electric vehicles with batteries have a higher total cost of ownership (TCO) in Singapore due to high local and customs duties as well as excise taxes [12], while in Australia, peak and off-peak electricity prices cause the TCO of battery electric vehicles to be significantly lower. Kara and others [15].

Norway is at the top of the European economic chart, which is explained by the combination of clean and renewable energy. L´evay et al al. [16]. Following Norway on the list are France, the UK, and the Netherlands, whose TCOs are cheaper than ICEVs but still somewhat higher than Norway's. In contrast to ICEV, other nations fare poorly when the entire cost of ownership is taken into account. When compared to the TCO of BEVs in Japan, roaming incentives are an elixir for BEVs in the US and the UK, according to comprehensive research by Palmer et al. [17]. Potk'any et al. [18] reported similar findings in Slovakia, where providing subsidies had a significant impact on lowering the TCO of BEVs. While some studies categorize TCO comparisons based on geographic regions, others differentiate TCO based on governing characteristics such gasoline prices, incentives, and annual kilometers traveled (AKT). Many governments use incentives as their main policy instrument, but how effective is this strategy has to be examined? According to Levey et al. [16], incentives are determined to be adequate in some areas, such as Norway and other European and American nations. Lieven et al. [19] observed similar things in roughly 20 other countries, demonstrating that the monetary grant is the most valued incentive. However, incentives don't seem to work all that well in various parts of the world. In Germany, it is determined that a 4,000 Euro incentive is insufficient. According to Bubeck et al. [20], battery-electric cars are still 5% more expensive than gas-powered cars. In Germany, it is determined that a 4,000 Euro incentive is insufficient. According to Bubeck et al. [20], battery-electric cars are still 5% more expensive than gas-powered cars. After receiving government grants et al. Tseng [21]. A year AKT, or kilometers traveled, is a metric that also influences Wu et al.'s TCO on Battery Electric Vehicles [22]. AKT has been referenced in literature which is upto 20,000 kms in order to cover the entire expenses between the automobiles Mitropoulos et al. [23] recommend at least 23,000 kms AKT for BEVs to surpass gasoline in efficiency and Italian cars using diesel fuel. Some literatures have placed emphasis on the battery price, battery replacement cost, and its prognosis, in addition to incentives and yearly kilometers traveled. When battery prices for battery electric vehicles drop to less than $300/kWh and €240/kWh for various parts of the world, the vehicles become economically competitive. Newbery, David, and others [24]. In addition to the cost of the batteries, high depreciation rates are also thought to contribute to the total cost of ownership (TCO), making battery-electric vehicles more expensive than internal combustion engines. The literature shows that while battery electric vehicles (BEVs) were initially welcomed with gusto, buyers are becoming hesitant to purchase BEVs due to their higher total cost of ownership. One of the most challenging problems is minimizing the total cost of ownership (TCO), which is determined by a complex interplay of characteristics that needs to be addressed giving priority.

When it comes to battery-electric vehicles, environmental damage is the main worry in addition to the barrier of economic compatibility. The battery-electric cars produce no emissions is a frequent trick that should be watched out for as the tail pipe's emissions are being transferred to Kalghatgi is another website [4]. But we can't ignore it. The traditional automobiles' emissions have been a significant problem since there are more cars on the road Lucas [25] but examining the emissions of both kinds of vehicles grounds will be used to assess these cars' prospects. When driving a battery-electric car, greenhouse emissions come from a variety of sources, including material extraction, transit, the amount of energy used in manufacturing and its nature Ma et al. (energy-mix utilized) [26]. However, rather than focusing on just one effect category (greenhouse gases), a whole life cycle study should be carried out taking into account all of the impact categories in order to obtain a panoramic emission impact. It makes sense that, if a clean energy source is utilized to charge the BEVs, emissions from battery electric vehicles might be substantial during the manufacture phase of the two phases (use and production). Although the battery pack is thought to contribute significantly to overall emissions, differences in emissions from various battery technologies also need to be taken into consideration. According to research by Premrudee et al. [27], Li-Ion batteries have the least number of pollutants when compared to Lead Acid batteries. According to Held et al. [28], the primary cause of the twice-as-high global warming potential impact category for battery-electric vehicles compared to equivalent internal combustion engines is battery production. Remarkably, with Belgium's existing energy mix, electric cars are discovered to be releasing fewer emissions. While gasoline and diesel vehicles emit more than 200 g/km CO2eq, battery powered cars emit less than 52 g/km CO2eq [29]. Picirelli de Souza et al.'s [30] observations from Brazil, where they estimated the emissions from BEVs compared with ethanol mixed gasoline, show that while BEVs perform well overall in terms of emissions, ethanol blended fuel has less of an influence on human toxicity and global warming. In the global warming category, BEV emissions exceed 140 g/km CO2eq, while ICEVs using an ethanol mix fuel emit less than 100 g/km CO2eq. The average greenhouse gas emissions from battery electric cars (BEVs) in China are 210 g/km CO2eq, according to Zhou et al. [31]. The carbon footprints from BEVs vary across China, ranging from 160 to 245 g/km CO2eq. Comparably, Qiao et al. [32] propose that by choosing the battery recycling option, BEV GHG emissions can be lowered below 50% of those of ICEVs, while current evidence shows that BEV emissions are 18% lower than those of equivalent ICEVs. In tandem with the development of BEVs, laws pertaining to their emissions must be upheld. As the technology behind electric cars develops, regulations (such as ICEV emission standards, such as EURO 2, 3...) will become stricter, hence it will be crucial to monitor BEV emissions lest the whole transformation in transportation modes be jeopardized.

3 Motivation and Objectives

In order to replace the whole fleet of vehicles with 100% electric vehicles by 2030, the government created the National Electric Mobility Mission Plan 2020 (NEMMP). Regrettably, taking into account the present pace of the market, the goal has been reverted to electrifying thirty percent of the whole fleet of electric vehicles by 2030. The original impetus for the study was these "Unachieved Targets". Second, the "Current Market Status" shows that conditions for electric four-wheelers in India are still unfriendly, even with the introduction of incentive schemes like FAME I & II. The third factor is "Anxiety," which arises from the fact that the Indian market is extremely receptive to cost. This leads to erroneous concerns such as "Are electric vehicles in India cost-competitive with traditional automobiles?" Therefore, the primary goal of this study is to expedite the launch of electric vehicles in India, allay public anxiety (deception questions), pursue the target as soon as possible, and revitalize the electric 4-wheeler market in India.

In the context of India, this article examines how battery electric vehicles compare economically and environmentally against vehicles with similar internal combustion engines. to conduct life cycle environmental and economic analyses while taking into account more accurate data and Indian conditions as opposed to depending solely on general information. Additionally, conduct sensitivity analysis taking into account various regulating factors and recommend appropriate inputs to policy drafters to increase the acceptance of BEVs

4 Methodology

4.1 Economic Analysis

Life cycle economics accounts for the Total Cost of Ownership (TCO), which includes all costs from the time a vehicle is built to the end of its useful life. In order to conduct a fair comparison, the pairing approach—as recommended by Gilmore et al. [33]—is chosen to estimate total cost of ownership. With the matching vehicle approach, automobiles with nearly comparable dimensions and attributes are compared in order to confirm that the estimations are produced using the right datum. Figure 1 shows the TCO block diagram, several phases, and significant obstacles. As shown in Figure 1, the TCO is divided into three phases: acquisition phase, utilization phase, and end-life phase.

The total cost of ownership (TCO) for the base case is first evaluated. Afterwards, optimization is chosen with the aid of sensitivity analysis to determine the optimum alternative that may be recommended to the strategy drafters. Evaluations of sensitivity take into account a number of factors, including Annual Kilometer Traveled (AKT), Battery Replacement Cost, Incentives/Subsidies, Finance Interest Rates, and EV-PV Integration (Battery electric vehicles utilized in combination with solar energy alternative)

The TCO/km is computed by Equation 1:

$$TCO/km = \sum_{n=1}^{N} \frac{[\mathrm{IC_n}+\mathrm{RC_n}+(\mathrm{PVC}-\mathrm{PVS})_\mathrm{n}-\mathrm{RS_n}]-\mathrm{I}+\mathrm{B_n}}{(\mathrm{AKT}*\mathrm{n})} \qquad (1)$$

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 loading principal balance, D is annual distance travelled in kilometers, n is number of years vehicle used.

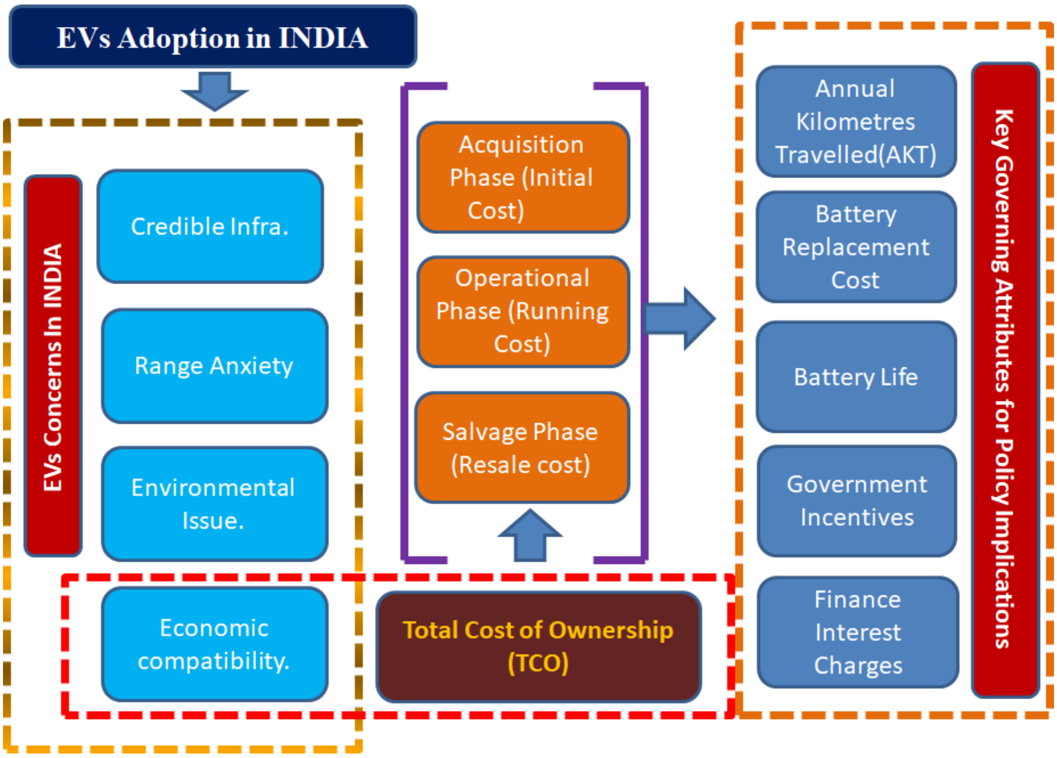


Figure 1: Approaching the Total Cost of Ownership

The acronyms Finance TCO (FTCO) and Purchase TCO (PTCO) are used to calculate the effects of financing and not financing on the TCO. The total cost of acquisition is the amount the owner must pay to purchase the car. Ex-showroom costs, government taxes, road taxes, registration fees, additional ancillary charges from the vehicle's manufacturer company, and interest if the car is financed are all included. During the vehicle's use phase, expenses include fuel, upkeep, parking fees, municipal entry taxes, tire replacement, and other parts. Estimating the fuel cost (Petrol/Diesel and Electricity) involves taking the timeline's inflation rates into consideration. General inflation rates, or around 3.98%, are applied whenever necessary to account for inflation. According to literature, electric vehicles typically require 30% less maintenance than internal combustion engines (ICEVs), and their tires have a 50,000 km lifespan. Ultimately, the salvage phase includes the car's market value for that year, which is calculated using the car's depreciation. In line with the trend in the literature, which is reported by Messagie et al. [34], battery-electric cars lose value faster than internal combustion engines.

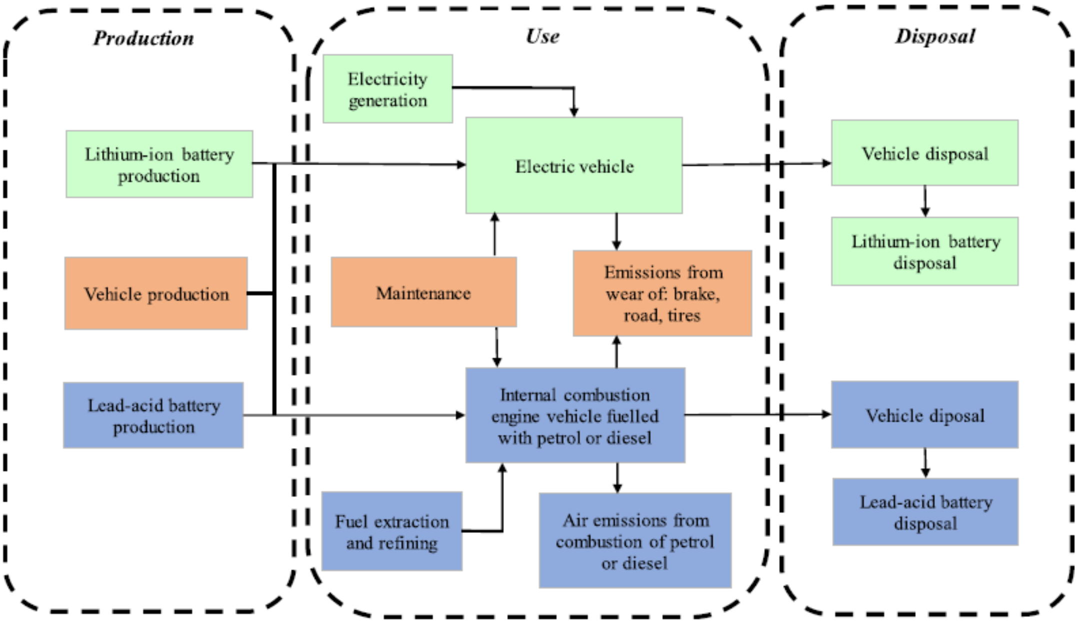


Figure 2: Various Phases in an Environmental Life Cycle Analysis of an automobile application.

The assumptions and usage statistics for the vehicles can be summed up as follows: Two sets of cars are compared in this TCO model; pair A comprises a TATA pair that contrasts the TATA Nexon EV and TATA Nexon Diesel/Petrol. Hyundai Kona EV and Hyundai Creta are contrasted for pair B. To complete the paired vehicle technique, the appropriate model variant is chosen. For the basic case, with a loan tenure of five years and an annual kilometer traveled of 15,000 km, the financing interest rate of 9.7% is taken into account for FTCO computation. According to FAME I & II standards, pair A BEV is eligible for an incentive of ₹115,000, and pair B BEV is presumed to have an incentive of ₹ 400,000. The battery replacement is done after 8 years/ 160,000 km.

4.2 Environmental Analysis

The Life Cycle Environmental Analysis, which follows the ISO 14040 and ISO 14044 European standard series, assesses a product's emissions during its whole life. Here, the consequences and emissions from ICEVs and BEVs that have been modelled are contrasted in relation to the Indian setting. The extraction of materials, transportation, the production and consumption of energy, the usage phase, and lastly the end of life phase are all included in the emissions.

The comparison of emissions from both internal combustion engines (ICEVs) and BEVs from birth to death is known as "cradle-to-grave" analysis.

An examination that solely considers the route of fuel from production to combustion or consumption is referred to as a "Well to Wheel" analysis; well-to-tank and tank-to-wheel analyses are also included in this phrase. Environmental analysis is divided into three parts, much like economic analysis is, as Figure 2 shows. Pollution from the mining and processing of raw materials to the construction of the vehicle and other essential parts like battery packs are included in the manufacturing phase. Emissions from the extraction of fuel, the production of power, and other incidental elements like tire and brake wear are all taken into account throughout the use phase. The vehicle's disassembly and recycling of its required pieces are the last steps in the disposal phase.

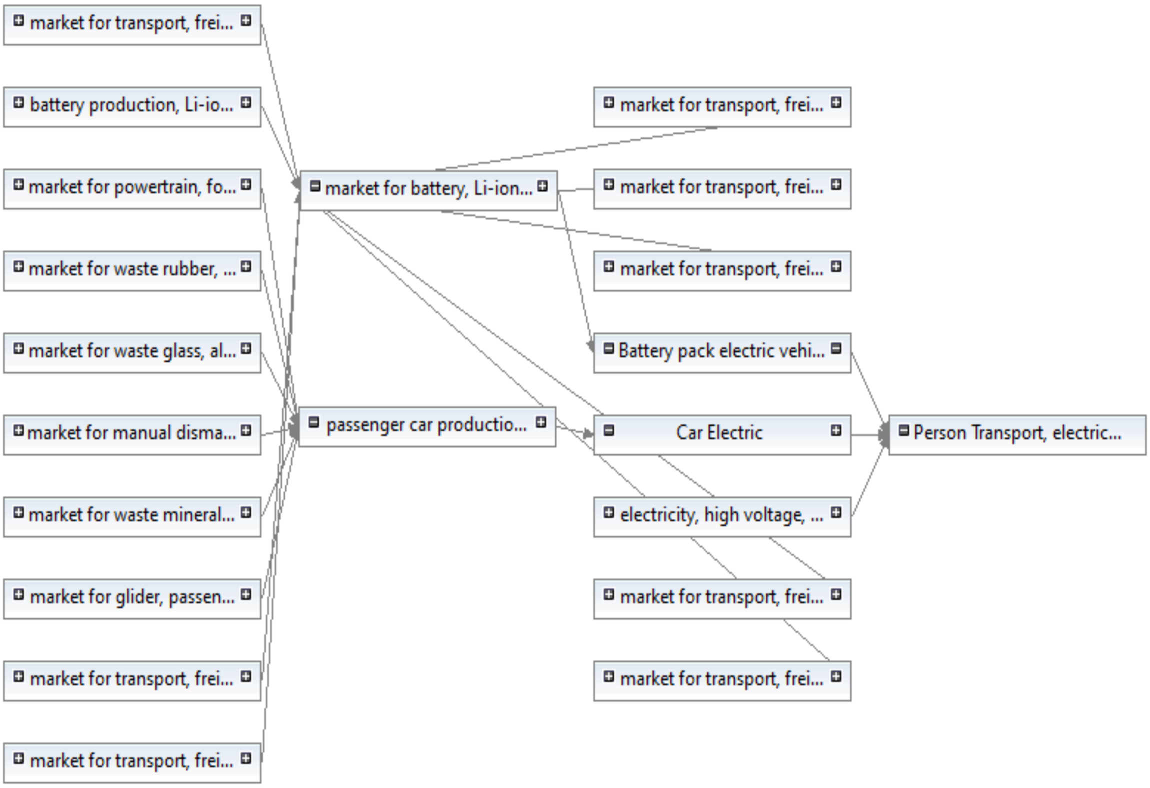


Figure 3: Interlinking of various processes for BEV production

With the aid of the software OpenLCA, which estimates emissions for each effect category, the LCA is carried out. Ecoinvent-3 is the compatible database that is utilized for data inventory. The modeling process incorporates the essential product flows, systems, and processes before being compared to a real project. Figure 3 depicts the prototype product system for battery-electric vehicles. It shows the main processes, with over 9000 processes or flows interacting with the end flow diagram. ReCePi 2016 is the impact assessment approach that was employed; all 16 effect categories are taken into consideration in the evaluation, both at the mid- and end-points.

5. Results and Discussion

5.1 Economic Analysis results

Figures 4a and 4b's results indicate that for parings in this study, the financed overall cost (TCO) of the BEV (F-BEV) is higher than the corresponding TCO of the ICEV (F-ICEV D & F-ICEV P). In a similar vein, for both pairs, the purchased TCO of the BEV is higher than the comparable ICEV. Nonetheless, there is a slight difference in the pair A (TATA pair) purchase TCO between the I.C.V. purchases TCO. However, even pair A's financed TCO is significantly lower than ICEV TCOs. Sadly, pair B (the Hyundai pair) has dismal performance for both purchased and financed choices, highlighting the TCO discrepancies more clearly. An additional intriguing discovery indicates a significant increase in the TCOs of BEVs in both pairings at the eighth year. This sudden rise is due to the high battery replacement cost. The citations should be given in IEEE Style. Authors can get help from citation management applications (tools) when preparing their papers. The title of the citations section should be “References”. A sample reference list is shown at the end of this document in the “References” section.

In-text citations should be written in square brackets like [1], [2]–[4], [2–4], [5], [6].

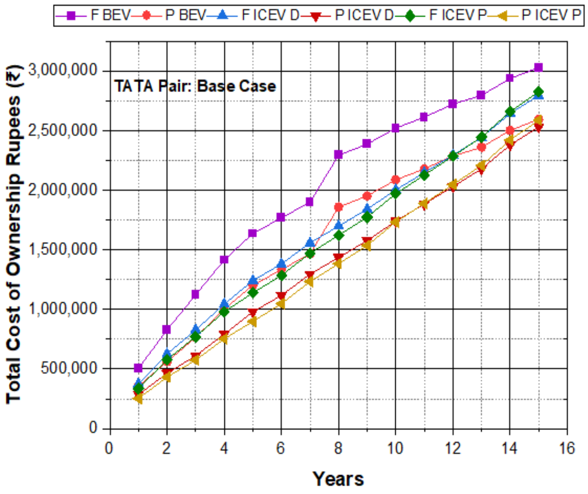


Figure 4: TCO for TATA pair

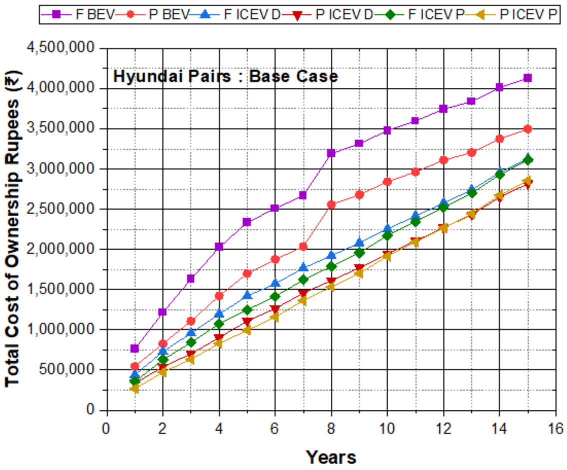


Figure 5: TCO for Hyundai pair

5.1.1 Sensitivity Analysis

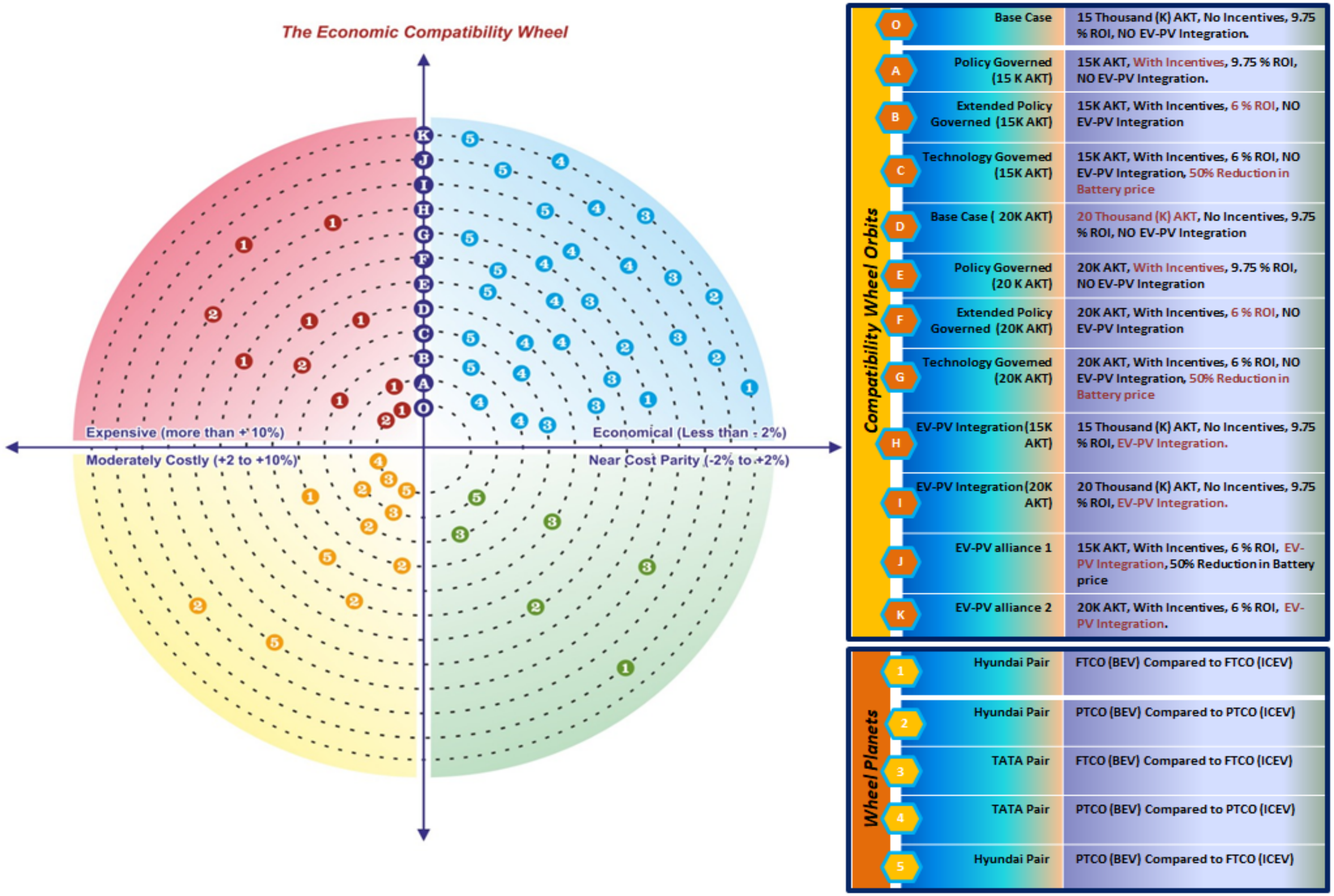
According to the base case study, no pair's BEV becomes more cost-effective than an ICEV or reaches cost equality. In order to accomplish the economic compatibility of BEVs, it becomes necessary to examine the TCO in combination with a few extra variables. Aspects of the sensitivity analysis include Policy Governed: offering incentives (discussed in the preceding section), Technology governed: a 50% decrease in battery replacement costs; Extended Policy governed: a reduction in financing interest rates (ROI to 6% from 9.75%) Consumer-Governed: using BEVs with EV+PV integration and imposing a higher Annual Kilometer Traveled (AKT) of 20,000 AKT rather than 15,000 AKT.

According to the findings of the sensitivity analysis, pair A (TATA)'s purchased TCO of a BEV is lower than that of an ICEV for each of the previously mentioned parameters. When the "reduction battery replacement cost" feature is taken into account, the funded TCO for pair A BEV is also equated with the TCO of an ICEV. When examining every variable separately, the funded TCO of pair A BEV is still higher than the TCO of an ICEV. In every variable, outcomes for pair B don't appear sides the electric vehicles. In every sensitivity characteristic listed above, the TCO of the BEV in pair B (the Hyundai) is still greater than that of a comparable ICEV.

It only happens once the BEV's purchase TCO in pair B approaches the ICEV's buy TCO for the "reduction battery replacement cost" criterion just a little bit. The sensitivity analysis reveals that, in the majority of circumstances, the individual variables are insufficient to make the pair's costs competitive; this can only be accomplished by combining the aforementioned characteristics.

As seen in Figure 6, a "compatibility wheel" is created for this. This wheel shows the many variable configurations that were used, as well as how both couples performed under 12 different sets of situations. The planes indicate finance and purchase TCO for the corresponding pairs, while the orbits represent a collection of conditions and parameters.

The wheel consists of 12 different sets of variables (called "orbits") that range from O to K and are listed in the sensitivity analysis. For example, Orbit "A," also known as "Policy Governed," has a set of settings consisting of 15,000 AKT, incentives, a finance interest rate of 9.75%, and no integration of EV and PV. Compare the financed/purchased TCO of a BEV with the financed/purchased TCO of an ICEV within a pair (for example, Planet 1 compares the FTCO of a Hyundai pair of BEVs with the FTCO of an ICEV). These comparisons are known as the planets.



O	Base Case	15 Thousand (K) AKT, No Incentives, 9.75 % ROI, NO EV-PV Integration.
A	Policy Governed (15 K AKT)	15K AKT, With Incentives, 9.75 % ROI, NO EV-PV Integration.
B	Extended Policy Governed (15K AKT)	15K AKT, With Incentives, 6 % ROI, NO EV-PV Integration
C	Technology Governed (15K AKT)	15K AKT, With Incentives, 6 % ROI, NO EV-PV Integration, 50% Reduction in Battery price
D	Base Case (20K AKT)	20 Thousand (K) AKT, No Incentives, 9.75 % ROI, NO EV-PV Integration
E	Policy Governed (20 K AKT)	20K AKT, With Incentives, 9.75 % ROI, NO EV-PV Integration
F	Extended Policy Governed (20K AKT)	20K AKT, With Incentives, 6 % ROI, NO EV-PV Integration
G	Technology Governed (20K AKT)	20K AKT, With Incentives, 6 % ROI, NO EV-PV Integration, 50% Reduction in Battery price
H	EV-PV Integration (15K AKT)	15 Thousand (K) AKT, No Incentives, 9.75 % ROI, EV-PV Integration.
I	EV-PV Integration (20K AKT)	20 Thousand (K) AKT, No Incentives, 9.75 % ROI, EV-PV Integration.
J	EV-PV alliance 1	15K AKT, With Incentives, 6 % ROI, EV-PV Integration, 50% Reduction in Battery price
K	EV-PV alliance 2	20K AKT, With Incentives, 6 % ROI, EV-PV Integration.

1	Hyundai Pair	FTCO (BEV) Compared to FTCO (ICEV)
2	Hyundai Pair	PTCO (BEV) Compared to PTCO (ICEV)
3	TATA Pair	FTCO (BEV) Compared to FTCO (ICEV)
4	TATA Pair	PTCO (BEV) Compared to PTCO (ICEV)
5	Hyundai Pair	PTCO (BEV) Compared to FTCO (ICEV)

Figure 6: The Economic Compatibility Wheel for the TCO analysis of battery electric vehicles compared to ICEVs

The following is an explanation of the economic compatibility wheel using an example: The parameters considered are 15000 AKT with incentives, 6% interest rate, and no integration of PV and EV. An orbit "B" is observed. For the previously described orbit (set of conditions), Planet 1 (the FTCO of the Hyundai pair BEV compared to the FTCO of the ICEV) is situated in a costly zone or quadrant, meaning that the FTCO of the Hyundai pair BEV is more than 10% more expensive than the FTCO of the Hyundai pair ICEV. Planet 2, on the other hand, is in the moderately expensive range when compared to the PTCO of the ICEV. This implies that the PTCO of the Hyundai pair BEV is 2–10% more expensive than the PTCO of the Hyundai pair ICEV.

The FTOC and PTCO of TATA pair BEVs are situated in the economic and near cost parity zones, respectively, in contrast to ICEV. In a nutshell, the economic compatibility wheel shows how each pair's TCO functions in different scenarios in a simple and visual manner.

The graphic shows that the Hyundai pair BEV's FTCO (planet 1) mainly falls in the expensive zone when compared to ICEV FTCO. Almost all of the orbits for the TATA pair, with the exception of the base orbit "O," put BEV's PTCO (planet 4) in the economic zone. Known as orbits 'G' and 'K,' we have found two intriguing orbits (set of conditions) in which every planet is in the economic zone. This implies that the sponsored and acquired TCOs (FTCO and PTCO) of the TATA pair and the Hyundai pair are more economical than the TCOs of ICEV. We also find that in orbit 'J', the Hyundai pair FTCO reaches the cost parity zone, which is around 2% economical. In conclusion, the Hyundai dual BEV financing option may also prove to be economical when the proper arrangements are made.

5.2 Environmental Analysis Results

Figure 7 (a-g) shows the climatic implications for the simulated ICEV and BEV in the OpenLCA for the Indian setting. To further aid in mitigating the problem, the total impacts are further divided into the pre-use and usage phases. This allows for a clearer knowledge of the primary emitter source.

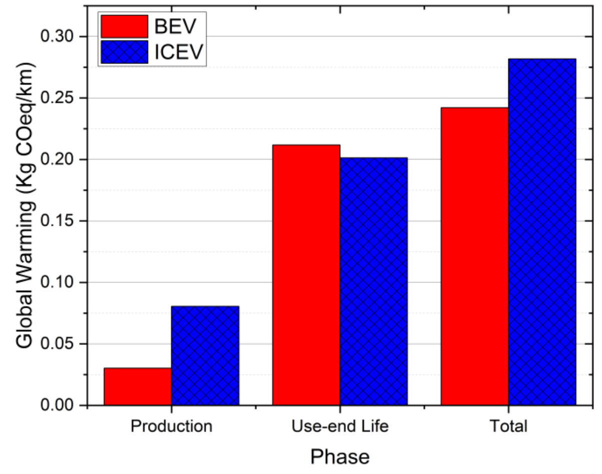
The results' primary effect categories—which are frequently discussed in the literature—are displayed in Figure 7(a–g).

The global warming gases (GHG) emissions are the subject of the most frequent plot literature discussion; it is discovered that BEVs emit fewer GHGs than ICEVs.

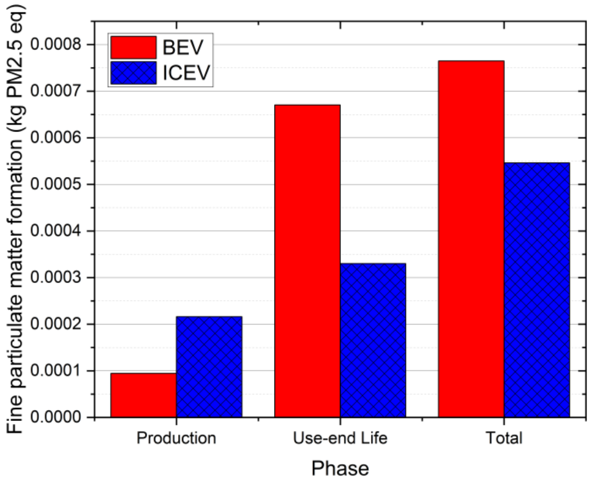
Wu et al.'s findings are also consistent with other literature [40]. Though in a distributed study, the GHG emissions from BEVs during the use phase are somewhat higher than those from ICEVs, the GHG emissions from BEVs are still only 15% of those from ICEVs. This could be explained by the fact that coal-powered facilities already make up a sizable portion of India's electricity mix.

Beyond the production of greenhouse gases, BEVs do well in impact categories like resource scarcity and ionizing radiation. In ionizing radiation impact categories, where emissions from BEVs are nearly half those of ICEVs, the emissions gap is observed rather clearly. When there is a shortage of mineral resources, the BEV has very high emissions during the production phase, but these emissions are closed during use, resulting in lower overall emissions than ICEVs. However, when taking into account all the impact areas, ICEV do not always end out negatively. ICV emit equivalent levels of pollution that are lower in categories including human toxicity and finite particle matter. In contrast with BEVs, IEVs' emissions in the human carcinogenic toxicity impact category during use are essentially insignificant.

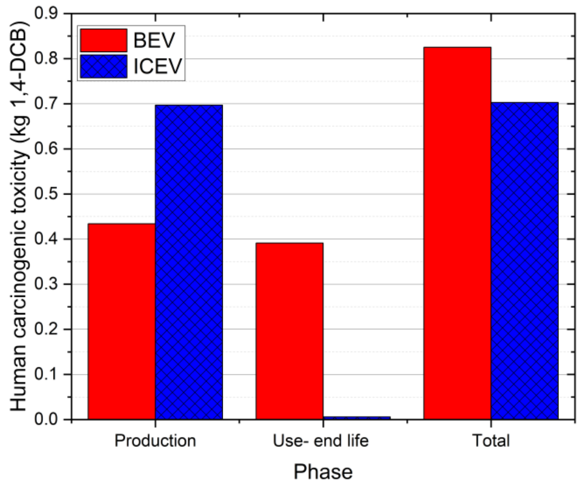
The findings show that neither the BEV nor the ICEV benefit from the emissions in the various effect categories. Figure 8's relative graph, which displays all of the impact categories for both automobiles, can be used to get deeper understanding. It is discovered that the BEV emits less in nearly ten of the eighteen categories; the category with the least variation in emissions each category is terrestrial acidification, at roughly 7%. The impact category of freshwater eutrophication has the largest range, with nearly over 73% of the total.


BEV
ICEV
Global Warming (Kg COeq/km)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Production
Use-end Life
Total
Phase

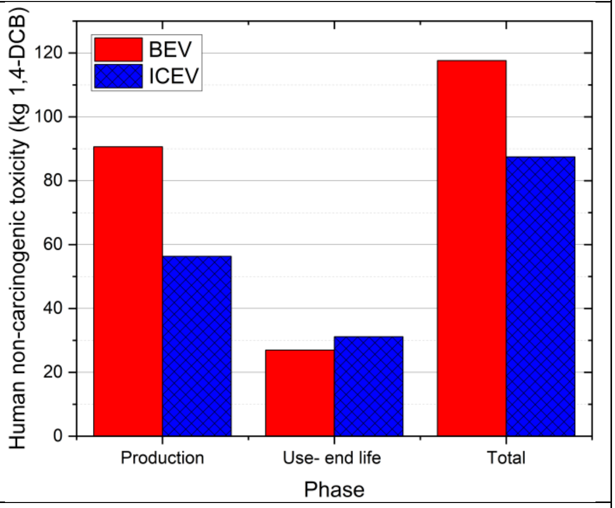
(a)


BEV
ICEV
Fine particulate matter formation (kg PM2.5 eq)
0.0000
0.0001
0.0002
0.0003
0.0004
0.0005
0.0006
0.0007
0.0008
Production
Use-end Life
Total
Phase

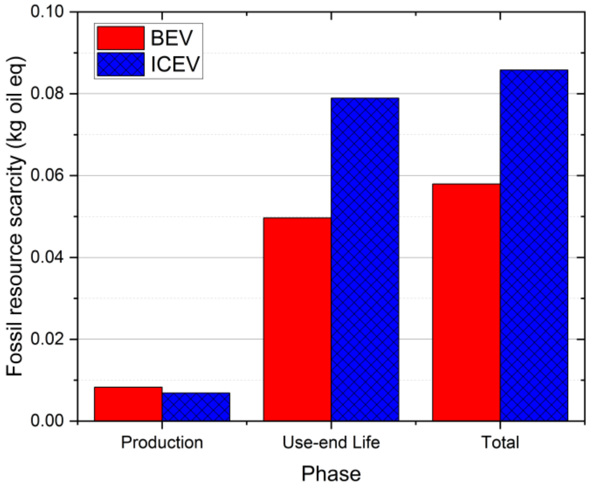
(b)


BEV
ICEV
Human carcinogenic toxicity (kg 1,4-DCB)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Production
Use- end life
Total
Phase

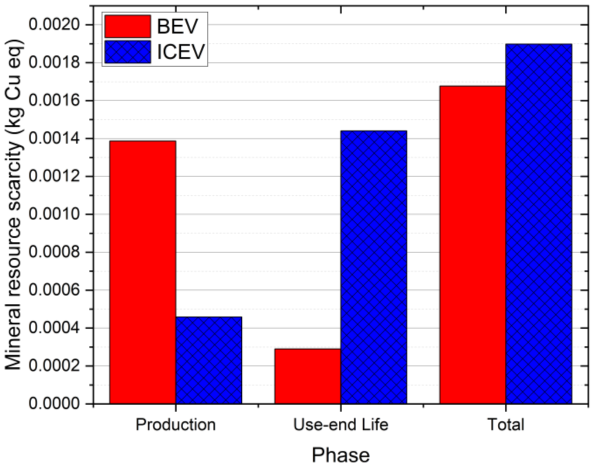
(c)


BEV
ICEV
Human non-carcinogenic toxicity (kg 1,4-DCB)
0
20
40
60
80
100
120
Production
Use- end life
Total
Phase

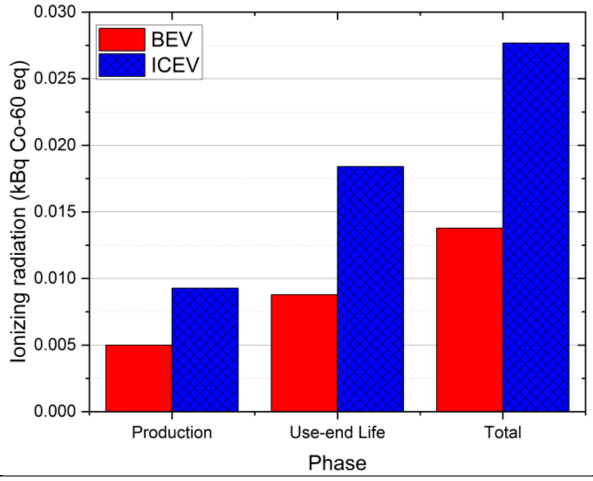
(d)


BEV
ICEV
Fossil resource scarcity (kg oil eq)
0.00
0.02
0.04
0.06
0.08
0.10
Production
Use-end Life
Total
Phase

(e)


BEV
ICEV
Mineral resource scarcity (kg Cu eq)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
0.0014
0.0016
0.0018
0.0020
Production
Use-end Life
Total
Phase

(f)



(g)

Figure 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.

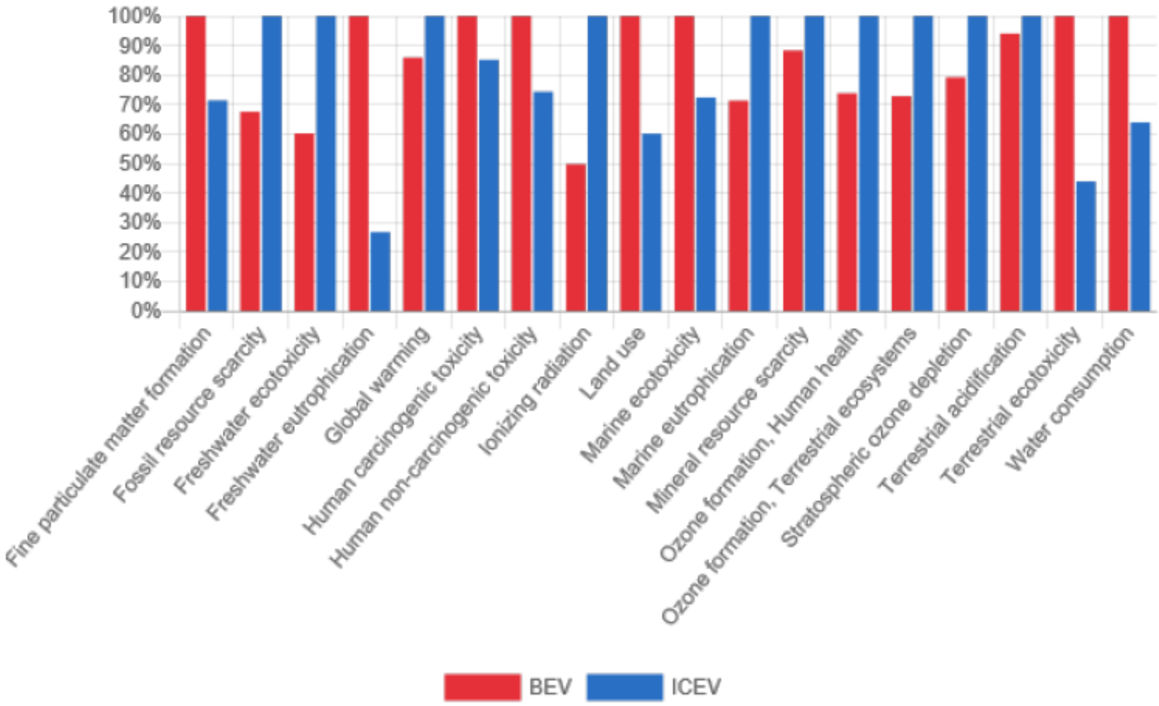


Figure 8: LCA relative results.

Last but not least, a single point score is obtained from the end-point analysis, showing that battery electric vehicles are more cost-effective when the total score—0.59 kpt—is taken into account, compared to the traditional vehicle's 2.12 kpt score.

6. Conclusion

For the Indian setting, a life cycle analysis comparison between a modeled or chosen battery electric vehicle and an internal combustion engine is conducted, taking into account both environmental and economic factors. This page assists end users in addressing the highly complex question of whether BEVs are environmentally and economically viable in India. Regarding economic compatibility, the base case taken into consideration here is significantly closer to actual data of the current situation and finds that BEVs are not financially compatible with ICEV for both financed and purchased options in both pairings. In contrast, pair A's (TATA) total cost of ownership (TCO) gap is lower than pair B's (Hyundai). Additionally, a sensitivity analysis was conducted with various parameters considered in order to reduce the total cost of ownership (TCO) of BEVs in both pairs. The examination of sensitivity clarifies that aside from the component handled by technology (a 50% decrease in the cost of replacing batteries) not another each of the parameters alone can determine the BEVs' TCO. To be more affordable than ICEVs or almost cost parity. It's just with the parameter combinations from the sensitivity analysis the BEV attains cost parity and even gains enough efficiencies that the similar ICEV that is seen in the compatibility diagram. The compatibility wheel shows the financial performance of cars with twelve distinct parameter configurations, two of which (in orbits G and K) allow the BEV's total cost of ownership to enter the profitable range. With an annual mileage of roughly 20,000 km, the usage of EV+PV integration, 6% loan ROI, and incentives, battery electric vehicles seem to be the answer.

Environmental friendliness analysis was used to resolve the disturbed greenhouse gas emissions, and the result was an agreement that, in the Indian context, the greenhouse gas emissions from BEVs are lower than those from ICEVs. BEVs do not, however, perform better than ICEVs in all impact categories when it comes to emissions. Although not in the vast majority of cases, ICEVs have less emissions in 8 out of the 18 impact areas. The class with the least amount of emissions difference between BEVs and ICEVs is the one that affects terrestrial acidification the least, while freshwater eutrophication varies the most.

By dividing the overall emissions into the pre-use and usage phases, one may identify the real significant source of emissions, which in turn helps to reduce or remove the source of concern. The BEV has a significantly lower overall emission score (0.59 kpt) than the ICEV (2.12 kpt) based on the end-point study. Lastly, switching to renewable energy sources can make this battle for environmental compatibility worse. Recycling the products and using correct production techniques will also assist to carefully reduce the emissions from battery-electric vehicles.

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Contribution of Researchers

A statement regarding the contribution rate of the researchers should be given in this section.

Conflicts of Interest

Conflict of Interest Statement should be given in this section.

Ethics committee approval (if needed)

Ethics

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