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Comparing Environmental Impacts Arising from the Use of Electric Two-Wheeler vis-a-vis Gasoline Two-Wheeler in India

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Abstract

Electric vehicles are becoming popular among consumers while BS-VI norms have been introduced and mandated for conventional vehicles in India. In the present study, the environmental impacts from the use phase of electric two-wheeler (EV) and gasoline two-wheeler (GV) have been evaluated and compared using the life cycle assessment (LCA) perspective. The functional unit adopted was 1000 km driven by one vehicle under Indian road and traffic conditions. CML 2001 and ReCiPe 2016 methods were used for the assessment using GaBi 10.6 software tool. The scope of the study was limited to the use phase of two-wheelers. The study considered a total of six impact categories viz. Abiotic Depletion (ADP) fossil, Acidification Potential (AP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Terrestrial Ecotoxicity Potential (TETP) and Fine Particulate Matter Formation (PMF). The study found that EV had higher environmental impacts on five impact categories while GV had a higher impact on just one (ADP fossil) impact category. The results demonstrated that the use phase of EVs is not as environmentally preferable as it appears, mainly due to the apportioned impacts of electricity obtained from the typical grid in India for EVs charging. In this study, two improvement scenarios (S-1 & S-2) for EV were also proposed for a possible reduction in impacts. Scenario S-1 constituted the use of 50% electricity generated from photovoltaics (solar panels) to charge the EVs, which offered significant reductions of ~47% in the overall environmental impacts. Similarly, scenario S-2 constituted the use of 50% electricity provided by a waste-to-energy plant to charge the EVs, which offered significant reductions of ~40% in the overall environmental impacts. It may be concluded that the use of renewable source(s) for generating electricity will make EVs more environmentally preferable. This study will help policymakers and concerned authorities to make transportation in India more sustainable by minimizing the impacts on the environment.

Keywords
Electric vehicle; gasoline vehicle; life cycle assessment; sustainability

1. Introduction

Rapid economic development and urbanization have led to a tremendous increase in the number of motor vehicles in India. The rapid increase in the number of vehicles in India imposed serious adverse effects on the environment and human health. Motor vehicles are the major contributor to urban air pollution In India. The transport sector in India contributes 90% of total CO_2 emissions in urban areas [1]. In India, the total number of vehicles is 295.77 million till 2019, out of which 221.27 million (75%) are two-wheelers [2]. In the 17 years from 2003 to 2019, the number of two-wheelers has increased by 78.52% [2]. In Hyderabad city (India), the vehicular exhaust was responsible for 87% of CO_2 emissions and 72% of NO_x and volatile organic compounds (VOC) emissions [3]. In addition, vehicular exhaust also emitted a significant amount of other gaseous pollutants and particulate matter (PM) [3]. In terms of PM2.5 air pollution, 35 cities in India are in the top 50 in the world. Global pollution is on the rise and EVs were introduced to curb the CO_2 emissions due to motor vehicles [4]. The government in India is bringing various initiatives to encourage and promote electric vehicles to reduce air pollution and conserve fossil fuels. Major companies such as TATA, Mahindra, etc. have introduced electric vehicles in India and similarly, companies such as Bajaj, Hero, Ather, OLA, etc. have introduced electric two-wheelers in India. The number of electric four-wheelers (mostly cars) and electric two-wheelers is slowly increasing in metro cities in India as still, there are several challenges related to EVs such as lack of battery charging infrastructure, short driving distance per charge, etc.

The central government in India has mandated the manufacturing and selling of only BS-VI compliant gasoline vehicles in India since April 2020. The introduction of BS-VI emission norms may reduce vehicular emissions causing urban air pollution. EVs themselves do not emit harmful pollutants, especially NO_x and PM, at the street level. However, the emissions are indirectly attributed to them as those emitted from the power plants, which are located much further away from where they are used. There is a need to evaluate the environmental impacts of using electric vehicles and BS-VI compliant gasoline vehicles in India using the life cycle approach (LCA). LCA is widely used to evaluate the potential environmental impacts of products, services, or systems during their life cycle [5]. The need for the assessment using LCA is because the results can be different when the life cycle is considered. The present study aims to evaluate the environmental impacts due to the use phase of electric two-wheeler and BS-VI gasoline (petrol) two-wheeler using the LCA approach. The LCA framework and methodology shown in Figure 1 has four phases, (i) goal and scope definition; (ii) life cycle inventory (LCI); (iii) impact assessment and (iv) interpretation as defined by International Organization for Standardization (ISO) 14040 and 14044 [6]. In *the goal and scope phase*, the LCA determines the purpose and scope of the study. Here, functional unit, system boundary, limitations and target audience are defined. The second phase is *inventory preparation*, which involves collecting and quantifying data based on the goal and scope of the study. The data is collected in the form of all the inputs and outputs in the terms of elementary flows, product flows and waste flows. The third phase is the *impact assessment phase* involving the translation of the environmental burdens into environmental impacts. In this phase, the environmental loads are assigned to their respective impact potentials. The fourth is the *interpretation phase*, in this phase the results of the impact assessment phase are justified and uncertainty/sensitivity analysis is performed, if needed.

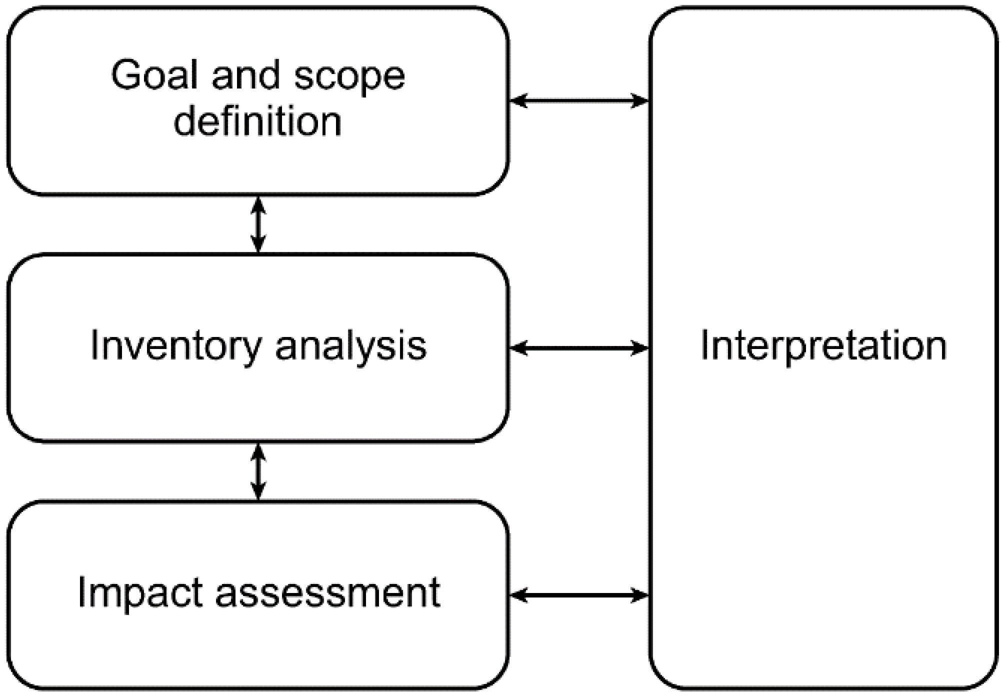

Figure 1 LCA phases [6].

There are a few studies related to electric vehicles in India. In one of the studies, the customer perceptions of electric vehicles were determined in Bengaluru city [7]. The study found that 45% of people preferred to purchase electric vehicles in near future, while 88% believed that hybrid vehicles may be preferable compared to electric-only vehicles. Also, 85% of people felt that electric vehicles are not reliable for long-distance travel [7]. Shinde et al. (2019) conducted LCA to evaluate and compare the environmental impacts of different public transport modes in Mumbai, India [8]. The functional unit adopted was passenger kilometre travelled (PKT) in the service lifetime of the vehicle (15 years). The study also presented the environmental impacts in terms of vehicle kilometre travelled (VKT) for a better comparison of the impacts within different modes across regions. Gabi 6.5 software was used to perform the impact assessment and CML 2001 method was adopted for impact assessment. The system boundary covered the vehicle manufacturing phase, fuel production phase, operation phase and maintenance phase. The study found that tailpipe emissions contribute the highest to life cycle environmental impacts. The study also concluded that in the case of BS-VI norms, non-operating components of the vehicles dominated the life cycle environmental impacts. Hollingsworth et al. (2019) performed LCA to evaluate the environmental performance of electric scooters [9]. The functional unit was selected as one passenger-mile traveled and the impact categories considered were global warming, respiratory effects, acidification and eutrophication. The system boundary encompassed materials production, vehicle manufacturing, transportation, use including charging, and end-of-life. The study found that the environmental impacts due to the use phase of electric scooters were less compared to impacts due to material production and manufacturing [9]. Yu et al. (2018) carried LCA study to evaluate the environmental impacts of electric and gasoline vehicles in China [10]. The functional unit adopted was the vehicle travelling distance during its life cycle of a single power system (250,000 km). The study adopted CML 2001 method and GaBi 6 for impact assessment. The system boundary included all the life cycle phases of vehicles. The study concluded that the life cycle environmental impacts of electric vehicles were higher compared to gasoline vehicles due to coal-fired power in China. The study also found that optimization of electric power structures in China can reduce GWP by 15%, CO by 37% and CO_2 by 14% [10]. Ashnani et al. (2015) evaluated the environmental impacts of alternative fuels and different vehicle technologies using LCA [11]. The functional unit was defined as driving 1 km and the passenger car was selected as the vehicle for assessment. The environmental impacts considered were energy depletion, GHG emissions and particulate matter emissions. The system boundary was cradle to grave covering all the phases of the vehicle life cycle. The study found that bio-diesel passenger cars had the highest impact on energy depletion and petrol passenger cars had the highest GHG emissions. The electric passenger car had the highest impact on air quality emitting the highest amount of particulate matter on a life cycle basis contributed from the electricity production at the grid [11]. Hawkins et al. (2013) performed an LCA study to evaluate and compare the life cycle environmental impacts of conventional and electric vehicles in Europe. The study adopted an attributional and process-based approach and the functional unit was defined as 1 km driven in European average conditions. The system boundary included vehicle production, use and end-of-life. It was found that electric vehicles had 10-24% less impact on GWP compared to conventional vehicles, which had lower environmental impacts on human toxicity, eutrophication, freshwater ecotoxicity and metal depletion [12].

2. Methodology

2.1 Goal and Scope

The present study aims to evaluate and compare the environmental impacts of EV and GV in India. The specifications of EV and GV considered in this case study are provided in Table 1. GV considered here had an engine capacity of 100 cubic capacity (cc) complying with BS-VI emission norms, and having power, speed and load-carrying capacity comparable to that of EV. The functional unit defined was 1000 km driven by one vehicle under Indian road and traffic conditions. The system boundary for the present study is shown in Figure 2. For comparison, only the use phase of both the vehicles was considered, which included fuel (petrol) production and its consumption in GV and electricity production (supplied via the grid in India) and its use in charging batteries of EV.

Table 1 Specifications of EV and GV.

Parameters	**Type of Vehicle**	
	EV	**GV**
Maximum Power	6.2 kW	5.9 kW
Maximum Speed	90 km/h	90 km/h
Maximum Load	175 kg	175 kg
Fuel Efficiency	0.04 kWh/km	0.02 liters/km

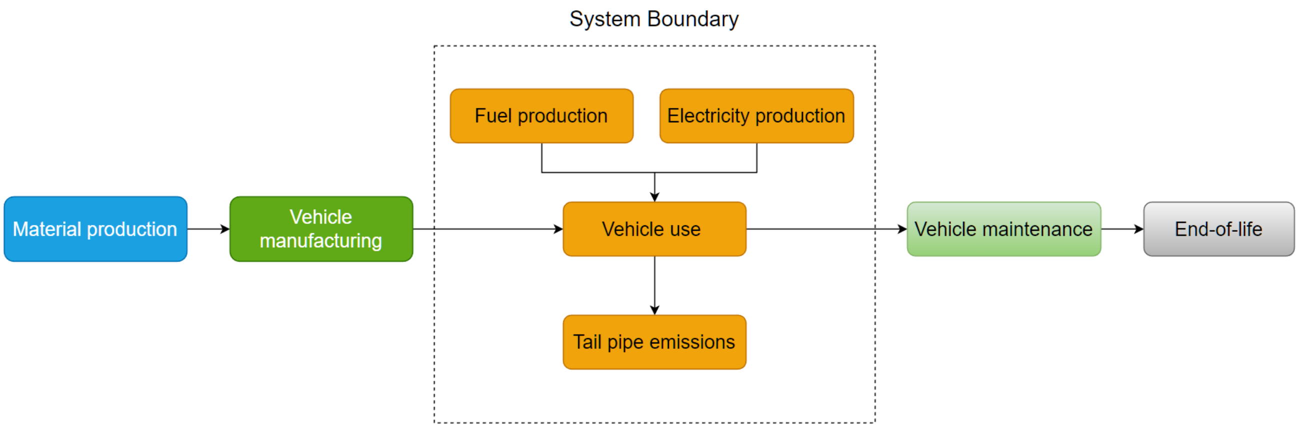

Figure 2 System boundary of the present study.

In this study, two improvement scenarios for EV were also considered. Improvement scenario S-1, where 50% of electricity for EV charging would be obtained from the grid while the remaining 50% came from photovoltaic using solar panels. This scenario accounted for estimating the benefits of using renewable energy in the energy mix in the future in India. The data for solar energy were taken from the updated GaBi database "Electricity from photovoltaic: IN", which is India-specific. The dataset represents the average national or region-specific electricity production based on solar energy by use of photovoltaics considering the manufacturing and operation phase of solar panels specific to Indian conditions [13]. Improvement scenario S-2, where 50% of electricity for charging the EV would be obtained from the grid while the remaining 50% would be obtained from solid waste through waste-to-energy (WtE) plants. This scenario also accounted for the renewable energy obtained from solid waste disposal. The reason for assuming electricity from solid waste may prove to be a sustainable approach. The assumption of generating electricity from solid waste was taken from the GaBi Professional database "Electricity from waste: IN" specific to India.

2.2 Life Cycle Inventory

LCI is an important and crucial phase of LCA study dealing with the collection and quantification of process input and output data [14]. The present study considered electricity requirement data from EV manufacturers and similarly, the gasoline (petrol) mileage data for GV was obtained from GV manufacturers. The tailpipe emissions from GV were taken as per BS-VI norms. The electricity required to completely charge an EV typically ranged from 2 to 5 kilowatt-hour (kWh), depending on the manufacturers [15]. Here, the study considered the electricity consumption of 4 kWh required to fully charge the EV, which is provided by the grid in India. A distance of ~100 km can be travelled per full charge of EV according to the manufacturer's information [15]. The reported fuel efficiency of GV in India is about 48-52 km per litre [16]. Here, the fuel efficiency of GV is taken as 50 km per liter, which is provided by 100cc GV in Indian roads and traffic conditions. Thus, the total electricity consumed is 40 kWh by EV and petrol consumed is 20 liters by GV for a distance of 1000 km.

Data related to gasoline and electricity production is taken from GaBi Professional database, the process selected for gasoline was 'IN: Gasoline mix at refinery' and for electricity was 'IN: Electricity grid mix'. The production process of gasoline covers the entire supply chain of the refinery products, from drilling, crude oil production and processing to producing gasoline at the refinery. The sulfur content of gasoline is 150 ppm. The transportation of gasoline from the refinery to the gas station is not accounted for as the distance varies from place to place. The system boundary for gasoline production has been shown in Figure 3 and the emission factors of all the impact categories for the gasoline production at Indian refineries have been shown in Table 2.

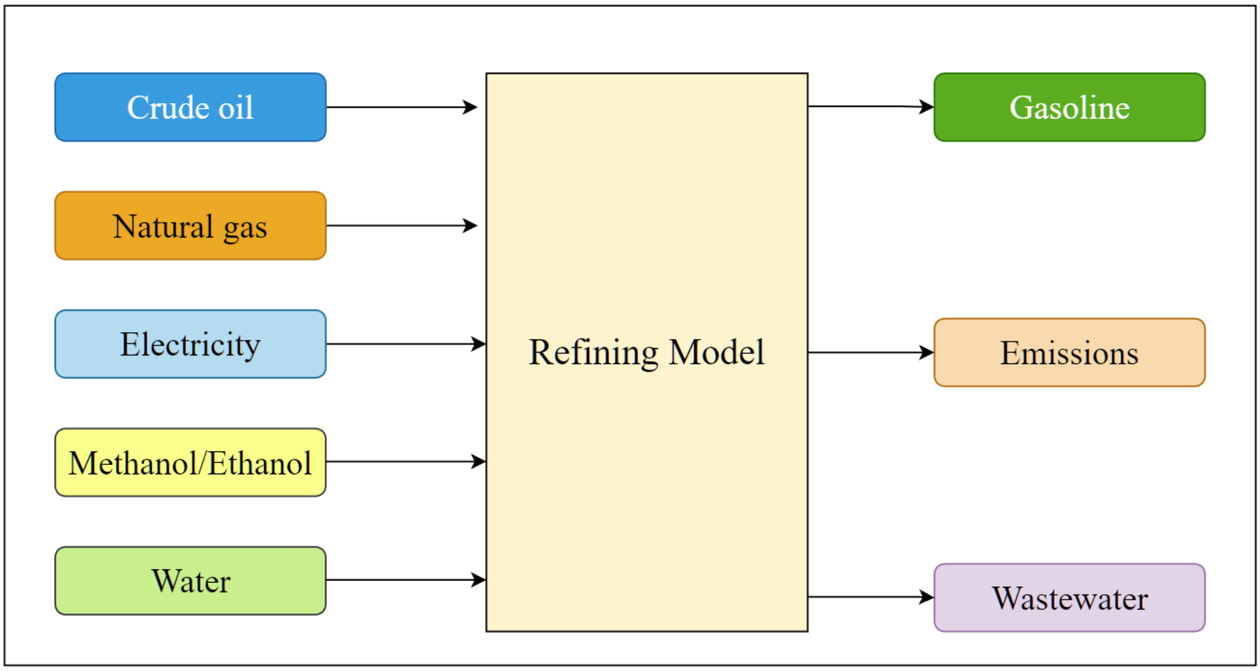

Figure 3 System boundary for the gasoline production in Indian refineries.

Table 2 Emission factors for the production of 1 kg of gasoline in Indian refineries.

Impact categories	**Impacts**
Abiotic Depletion (ADP fossil)	48.7 MJ/kg
Acidification Potential (AP)	0.0058 kg SO_2 eq/kg
Global Warming Potential (GWP)	0.707 kg CO_2 eq/kg
Human Toxicity Potential (HTP)	0.12 kg DCB eq/kg
Terrestrial Ecotoxicity Potential (TETP)	0.0016 kg DCB eq/kg
Fine Particulate Matter Formation (PMF)	0.0015 kg PM2.5 eq/kg

The data and impacts for the generation of electricity have been taken from the GaBi database. The electricity generation in the grid is nation-specific. The electricity in the Indian grid consists of electricity from hard coal (63%), lignite (12%), natural gas (5%), biomass (3%), hydro (10%), wind

(4%), and solar (3%). The losses due to the transmission and distribution of electricity have been assumed as 18%. The present study assumed that the grid emission factors remain constant over the vehicle lifetime. The emission factors of all the impact categories for grid electricity production in India has been shown in Table 3. The present study particularly considered a mix of gasoline and electricity production data from India as well as India-specific data for better evaluation of the environmental impacts. Similarly, the emissions factors for 1 kWh of photovoltaics and 1 kWh of waste generation in India have been shown in Table 4 and Table 5, respectively.

Table 3 Emission factors for the production of 1 kWh of electricity from the Indian grid.

Impact categories	**Impacts**
Abiotic Depletion (ADP fossil)	11.2 MJ/kWh
Acidification Potential (AP)	0.0132 kg SO_2 eq/kWh
Global Warming Potential (GWP)	1.1 kg CO_2 eq/kWh
Human Toxicity Potential (HTP)	0.333 kg DCB eq/kWh
Terrestrial Ecotoxicity Potential (TETP)	0.0025 kg DCB eq/kWh
Fine Particulate Matter Formation (PMF)	0.0038 kg PM2.5 eq/kWh

Table 4 Emission factors for 1 kWh of photovoltaics in India.

Impact categories	**Impacts**
Abiotic Depletion (ADP fossil)	0.231 MJ/kWh
Acidification Potential (AP)	0.00008 kg SO_2 eq/kWh
Global Warming Potential (GWP)	0.02130 kg CO_2 eq/kWh
Human Toxicity Potential (HTP)	0.00494 kg DCB eq/kWh
Terrestrial Ecotoxicity Potential (TETP)	0.00019 kg DCB eq/kWh
Fine Particulate Matter Formation (PMF)	0.00002 kg PM2.5 eq/kWh

Table 5 Emission factors for the production of 1 kWh of electricity from wastes in India.

Impact categories	**Impacts**
Abiotic Depletion (ADP fossil)	0.845 MJ/kWh
Acidification Potential (AP)	0.0006 kg SO_2 eq/kWh
Global Warming Potential (GWP)	0.7730 kg CO_2 eq/kWh
Human Toxicity Potential (HTP)	0.0103 kg DCB eq/kWh
Terrestrial Ecotoxicity Potential (TETP)	0.0004 kg DCB eq/kWh
Fine Particulate Matter Formation (PMF)	0.0001 kg PM2.5 eq/kWh

2.3 Life Cycle Impact Assessment

The life cycle impact assessment (LCIA) phase quantifies the potential environmental impacts based on LCI data [17]. In this phase, the environmental loads are translated into environmental impacts. GaBi 10.6 software is used to perform LCIA for assessing the environmental impacts. The study considered five impact categories from the CML 2001 method (University of Leiden, 2001), and one impact category from ReCiPe 2016 midpoint for impact assessment as these impact categories were found to be the most relevant, suitable and easy to understand for common masses. The impact indicators considered are Abiotic Depletion (ADP) fossil, Acidification Potential (AP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Terrestrial Ecotoxicity Potential (TETP) and Fine Particulate Matter Formation (PMF).

2.4 Results and Discussions

The percentage contribution of EV and GV to each impact category is shown in Figure 4. EV had significantly higher impacts on all impact categories except the ADP fossil. The overall environmental impact of EV was about 71%, whereas, the GV contributed about 29% to the overall environmental impact.

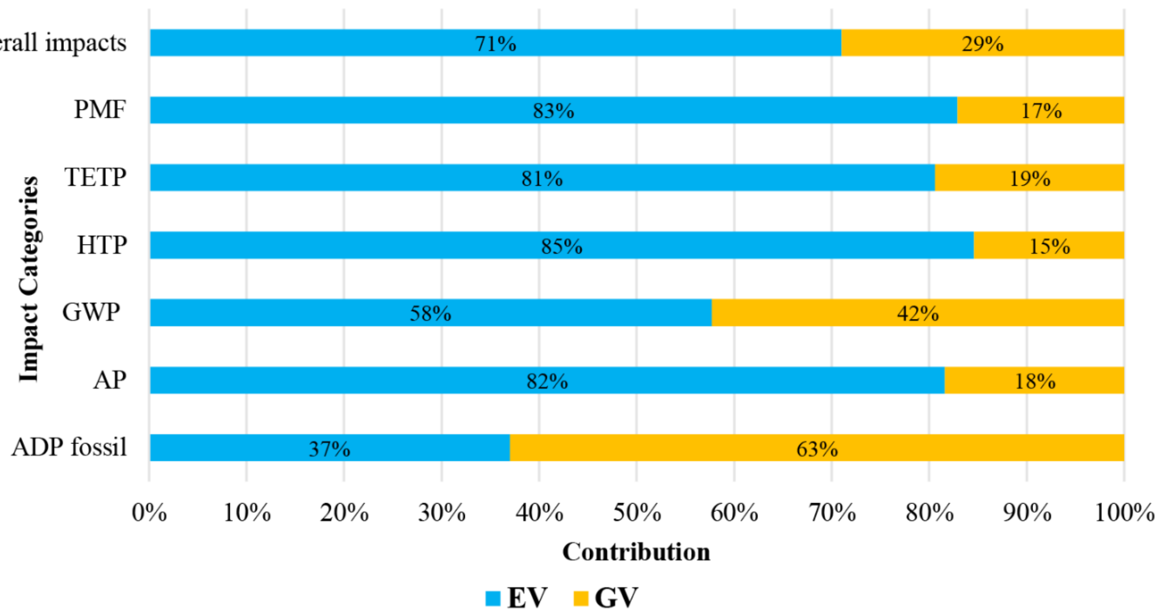

Figure 4 Relative contribution of EV and GV to each impact category.

The environmental impact of EV and GV on each functional unit and the reduction in impact of EV for the scenarios (S-1 & S-2) are presented in Figures 5-10. It was observed that GV had higher environmental impacts in only one impact category (ADP fossil) while EV had higher environmental impacts in the remaining five impact categories. GV had a higher environmental impact on ADP fossil (742 MJ) compared to EV (435 MJ) due to the high consumption of gasoline, which is a fossil fuel (Figure 5). In fact, Scenarios S-1 and S-2 significantly reduced impacts during the use of EV. Both As shown in Figure 5, S-1 and S-2 scenarios decreased the ADP fossil impacts to 228 and 240 MJ, respectively. As observed from Figure 6, EV had more impact on AP (0.496 kg SO_2 eq) due to the significant amount of sulfur dioxide, emitted from coal power plants during electricity production, whereas, AP due to GV (0.112 kg SO_2 eq) was lower due to the BS-VI specification requiring reduction of the sulfur content in fuel to 10 ppm. S-1 and S-2 showed reductions in environmental impacts from 0.496 kg SO_2 eq to 0.265-0.275 kg SO_2 eq. EV had higher impacts on GWP (42.5 kg CO_2 eq) compared to GV having 31.2 kg CO_2 eq on GWP (Figure 7). The reason for the higher impact on GWP by EV is that the major share of electricity is from coal in India. The impacts on GWP were reduced significantly from 42.5 kg CO_2 eq to 22.3 kg CO_2 eq in S-1 but scenario S-2 did not significantly reduce GWP (37 kg CO_2 eq). Although for the current electricity grid mix, EV had higher impacts on GWP compared to the GV, EV must still be encouraged and promoted still in the future as India is determined to have installed capacity of non-fossil fuel-based power sources equivalent to 50% of the country's requirement by 2030. Therefore, EV will become more environmentally friendly compared to the GV and the impacts of EV on GWP will certainly be reduced in the future. As shown in Figure 7, for scenario S1, the impact of EV on GWP is less than that of GV, which will be certainly achieved by 2030.

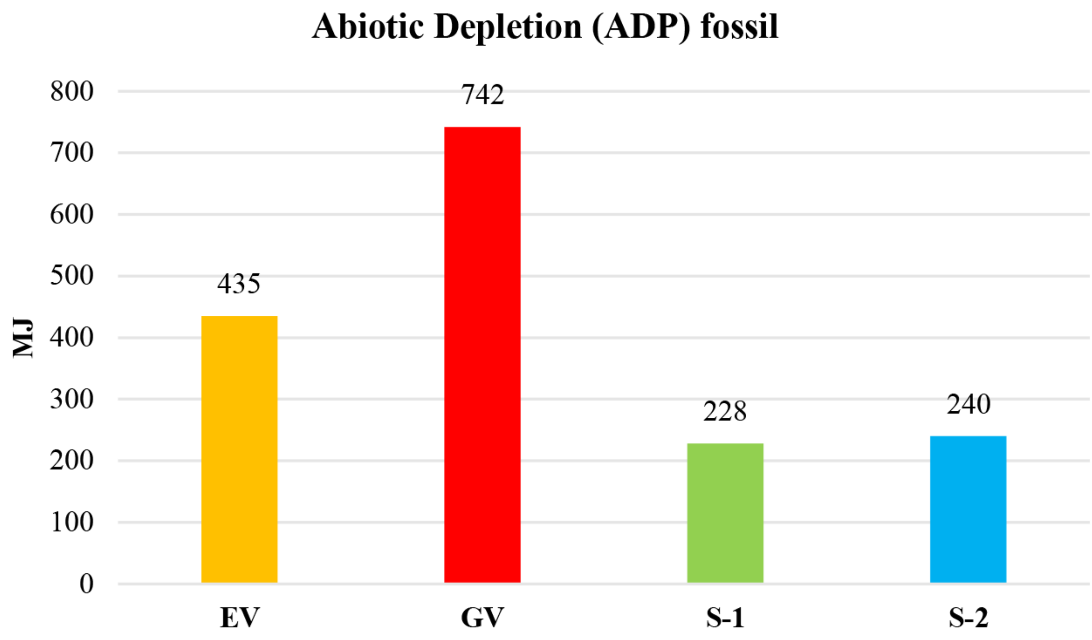

Figure 5 Environmental impacts on ADP fossil.

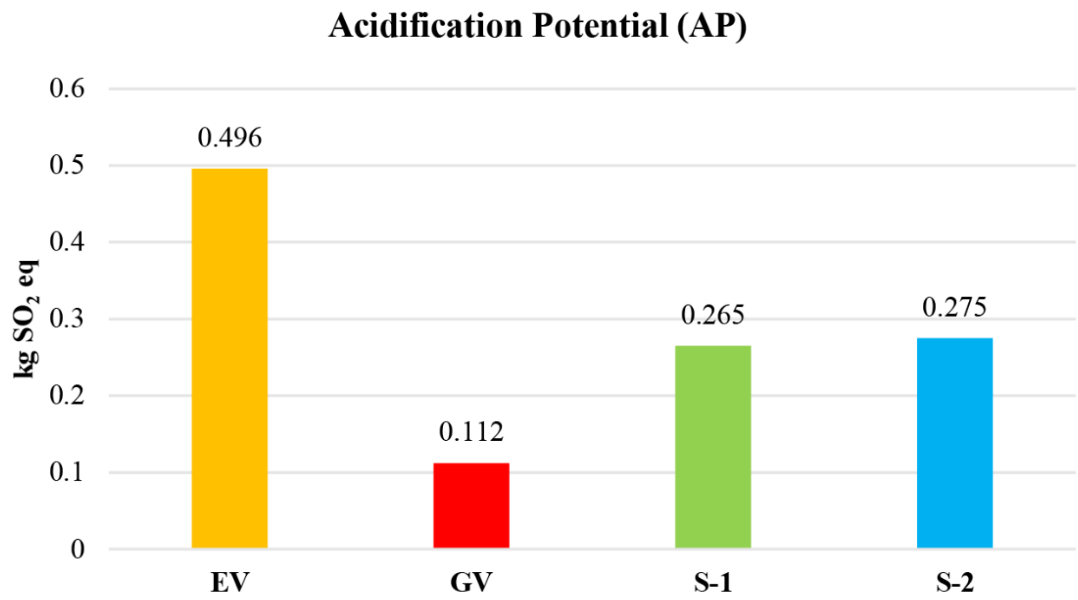

Figure 6 Environmental impacts on AP.

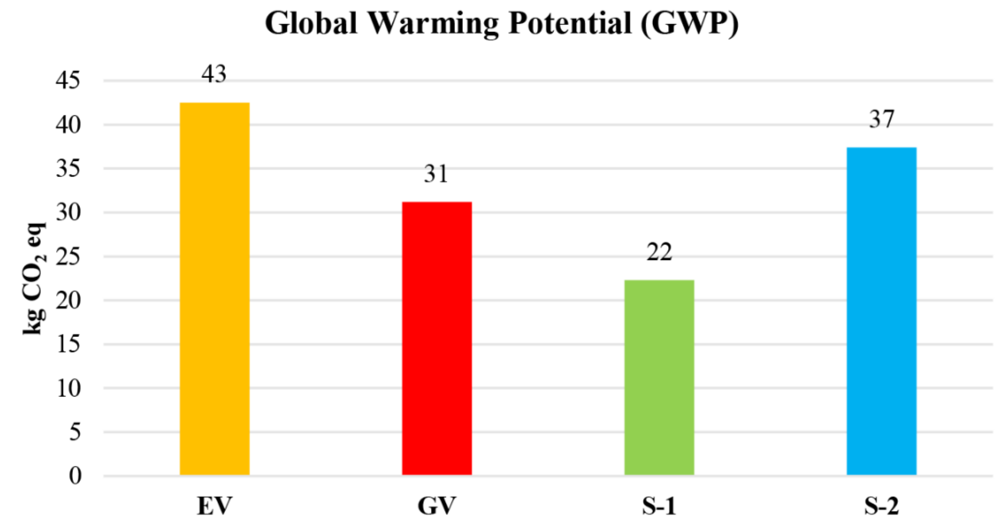

Figure 7 Environmental impacts on GWP.

EV had higher impacts on HTP (13 kg DCB eq) due to coal mining and processing for generating electricity in Indian thermal power plants (Figure 8), while, GV had significantly lesser impacts on HTP (2.36 kg DCB eq) [18]. Scenarios S-1 and S-2 had remarkable reductions in impacts on HTP to 6.75 kg DCB eq and 6.86 kg DCB eq, respectively (Figure 8). Various existing LCA studies comparing internal combustion engine vehicle (ICEV) and EV performed in developed countries such as Poland, Italy and Sweden reported that EVs had lower impacts on GWP and higher impacts on HTP as compared to ICEV (gasoline or diesel) [19]. However, in India's current energy mix, EV had higher carbon emissions compared to GV [20]. The higher carbon emissions resulted in higher GWP impacts of EV in India as the carbon emissions intensity of electricity generation in India (926 g CO_2/kWh) is much higher than the global average (542 g CO_2/kWh) [21]. However, the crude oil upstream carbon intensity (~8 g CO_2 eq/MJ) in India is less than the average global crude oil carbon intensity of 10.3 g CO_2 eq/MJ [22].

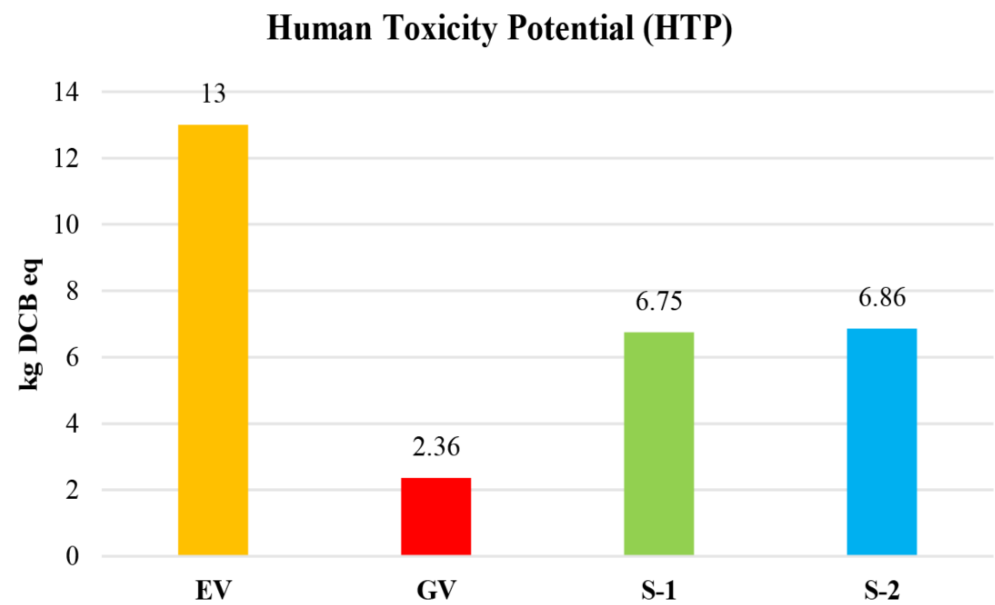

Figure 8 Environmental impacts on HTP.

The use of EV had higher impacts on TETP (0.101 kg DCB eq) compared to the use of GV (0.0242 kg DCB eq) as shown in Figure 9. The improvement scenarios for EV (S-1 & S-2) reduced the impacts on TETP to 0.0541 kg DCB eq and 0.0574 kg DCB eq, respectively (Figure 9). The impacts of EV on HTP and TETP were higher because these EV(s) were charged using the electricity supplied by the grid which generates most of its electricity from the coal in India. The mining and processing of coal cause severe environmental pollution and release toxic elements, particulate matter and other gaseous pollutants into the environment [18]. Similarly, EV had higher impacts on PMF (0.143 kg PM2.5 eq) compared to the impacts from GV (0.0295 kg PM2.5 eq). Scenarios S-1 and S-2 decreased the impacts of EV on PMF to 0.0759 kg PM2.5 eq and 0.078 kg PM2.5 eq, respectively (Figure 10).

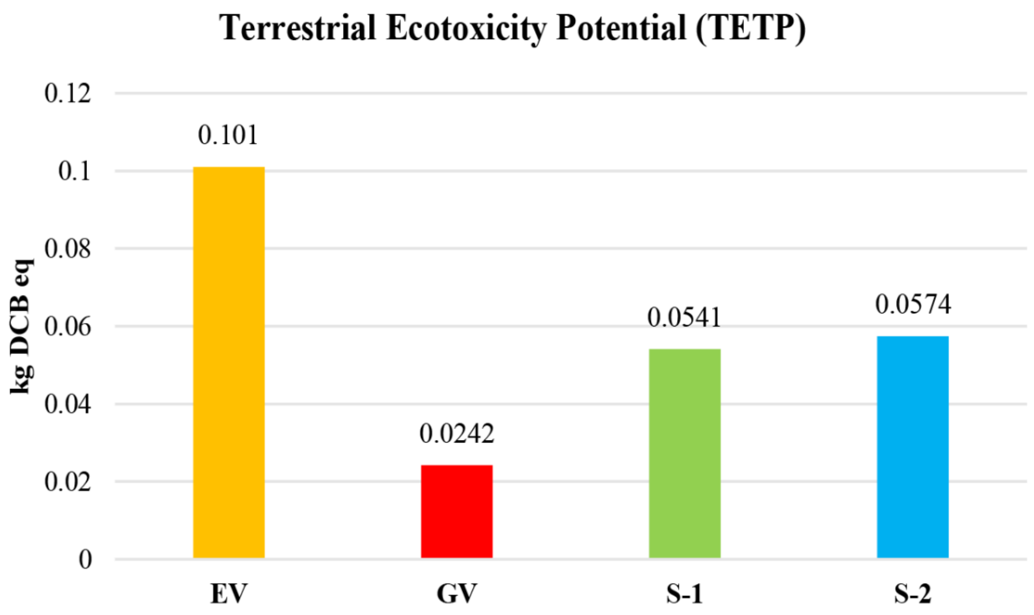

Figure 9 Environmental impacts on TETP.

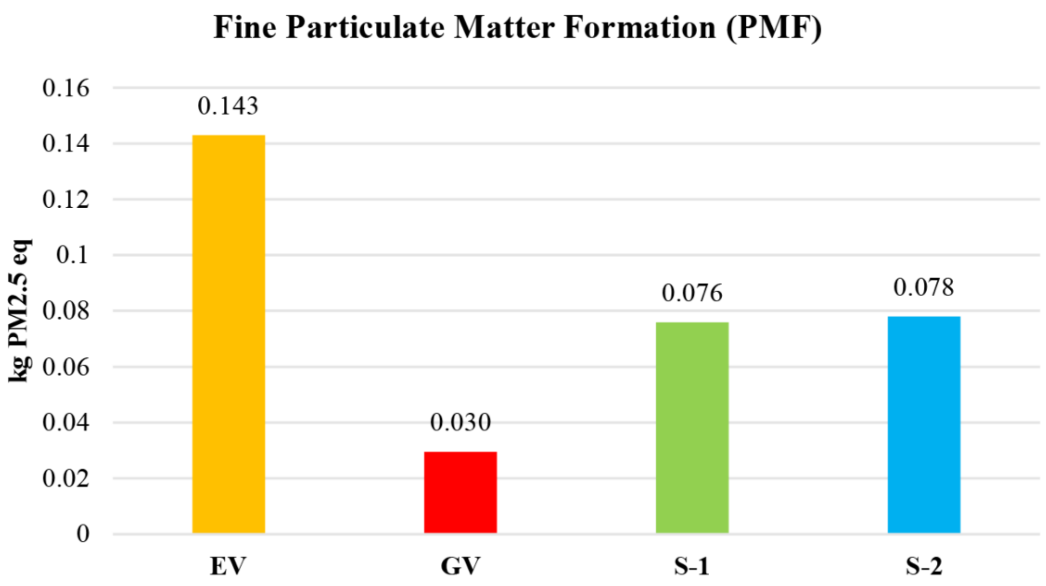

Figure 10 Environmental impacts on PMF.

The percentage reduction in impacts of S-1 and S-2 for different impact categories for compared to the baseline scenario for EV has been shown in Figure 11. S-1 reduced the total impacts of EV by about 47% and S-2 reduced the impacts of EV by about 40%. As shown in Figure 11, the reductions from the S-1 scenario are distributed uniformly among all the impact categories. Scenario S-2 did not reduce the GWP impact category by much in comparison to the S-1 scenario. The less GWP reductions may be due to the high energy consumption or emissions from WtE plants during electricity production from the solid wastes.

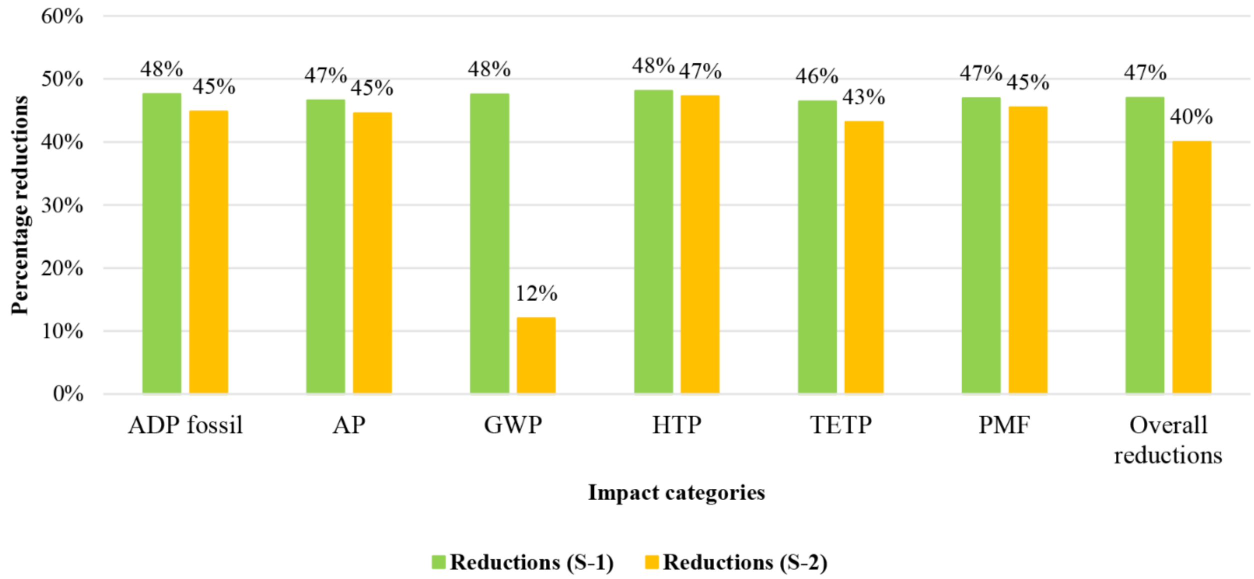

Figure 11 Percentage reduction in impacts of S-1 and S-2 on different impact categories.

2.5 Conclusions

The present study assessed the environmental impacts of EV and GV usage phases in India. In this study, two improvement scenarios for EV have also been considered to estimate the potential for impact reduction, considering the use of solar and waste-generated electricity for charging vehicles. The findings of this study showed that GV had a lesser environmental footprint compared to EV running from the electricity obtained from the grid. GV had higher environmental impacts only on one impact category (ADP fossil) while EV had higher environmental impacts on the remaining five impact categories. The results of this study are somewhat similar to one of the existing studies performed in China, as the majority of electricity is generated by coal-fired thermal power plants in India and China [10]. GV performed better as the new mandatory BS-VI norms are very stringent and BS-VI engines are environmentally friendly emitting very less pollutants and the sulfur content in fuel has been reduced to 10 ppm. However, the adverse effects of inhaling vehicular emissions on human health are also an important factor, as vehicular emissions affect the local scale, while electricity pollution is regional [23]. The inhalation of these emitted pollutants causes severe health effects, such as cardiovascular and circulatory diseases, including premature mortality [24]. Choma et al. (2020) reported that the use of EVs in urban areas will help in achieving positive public health benefits [25]. The scenario using electricity generated from photovoltaics (solar panels) to charge the EVs (S-1) offered significant reductions (47%) in the overall environmental impacts. However, scenario S-1 had a greater impact on the AP, HTP, TETP, and PMF impact categories compared to the impacts of GV. However, in scenario S-2, the impacts on the current GWP of concern remain significantly lower and were lower compared to the impacts of GV on GWP. Scenario S-2 considering the use of electricity generated from solid waste offered slightly lower impact reductions (40%) but the implementation of the scenario will help reduce the amount of solid waste reaching landfill. We concluded that in the future electricity for charging the EVs needs to be generated from renewable sources such as solar or wind to make EVs more environmentally preferable. Also, non-renewable resources such as coal will be conserved. The study also suggested that in the future, EVs will have to be introduced into heavy vehicles such as buses and trucks as these heavy GVs pollute the most.

Author Contributions

Conceptualization and methodology performed by Dr. A.K. Dikshit and Yash Aryan. Literature review; Data Collection and verification analysis on LCA software contributed by Yash Aryan. The first draft of manuscript written by Yash Aryan. The reviewing and editing done by Dr. A.K. Dikshit. The visualization and supervision performed by Dr. A.K. Dikshit. All authors read and approved the final manuscript.

Competing Interests

The authors declare no conflict of interest.

Additional Materials

The following additional materials are uploaded at the page of this paper.

1. Table S1: Output Flows of Electricity Grid Mix in India.

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