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Adopting Plug-in Battery Electric Vehicles in the Philippines May Provide Some Benefits to the Environment but…

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Abstract: Electric vehicles have been proposed as an alternative to internal combustion engine vehicles (ICEV). While plug-in battery electric vehicles (PBEV) have zero tailpipe emissions, these vehicles still need to be provided with electricity. Electricity generation is accompanied by environmental impacts that need to be quantified throughout the entire product lifecycle. While the life-cycle assessment of PBEV has been done for other geographies, it has not yet been done for the Philippines. The Philippines has a unique electricity mix, primarily consisting of coal, geothermal, natural gas and hydro. The question remains as to whether significant environmental benefits can be obtained by using electric vehicles in the Philippines. A comparative life-cycle assessment was done by comparing the cradle-to-grave environmental impacts of currently available PBEV with ICEV using a mixture of 10% ethanol-90% gasoline. The midpoint hierarchist perspective of ReCiPe 2016 v1.06 as implemented in Simapro version 9.4.0.1 was combined with data from ecoinvent v3.8 tailored to the Philippines setting. The results show that, using the current Philippines electricity mix, replacing ICEV with PBEV reduces greenhouse gas emissions and fossil fuel used. However, other environmental impacts are worsened by the use of PBEV. Many of the other environmental impacts from the use of electric vehicles can be mitigated by reducing the share of coal in the electricity mix and by using greener sources for the electric vehicle and the battery. If the electricity generation plans for 2040 are achieved, less environmental impact may be expected.

Key Words: electric vehicles; life-cycle assessment; climate change; Philippines

1. INTRODUCTION

Amid concerns about climate change and depletion of fossil fuels, electric vehicles have been proposed as alternatives for passenger transport. However, while electric vehicles have zero tailpipe emissions, they still need to be provided with electricity, which comes with its own environmental impacts. Manufacturing the batteries for these vehicles also significantly affects the environment.

The environmental impact of electric vehicles has been much studied (Oda, Noguchi, & Fuse, 2022) but there is a wide range in the results and recommendations. Marmiroli, Messagie, Dotelli, & Van Mierlo (2018) analyzed 44 different life-cycle assessments of electric vehicles and determined that the carbon intensity of the assumed electricity mix can explain 70% of the variation in the results for the global warming potential.

Determining if the use of electric passenger vehicles in the Philippines would result in environmental benefits is important due to the country's unique energy mix. Geothermal sources contribute significantly to the country's electricity. In addition, the Philippines prescribes a mixture of 90% petrol and 10% locally sourced bioethanol. A mixture of 95% petrol and 5% ethanol is more commonly used in countries that prescribe the use of biofuels.

Several studies have evaluated the impact of electric vehicles in the Philippines. Lopez et al.(2021) analyzed the socio-economic impact of these vehicles. Agaton, Collera, & Guno (2020) also studied the costs and economic impacts, as well as the quantities of pollutant emissions if electric vehicles were used. However, their study lacked clarity in its system boundary and did not characterize the environmental impact over the full life-cycle. The study by Ubando et al. (2019) assessed the carbon footprint of electric vehicles in the country but did not assess other environmental impacts.

This study aims to conduct the first full cradle-to-grave life-cycle assessment of the environmental impact of electric vehicles in the Philippines. Specifically, the environmental impact of producing, maintaining, and operating a plug-in battery electric vehicle (PBEV) for passenger transport using the current and planned electricity mix in 2040 is compared to the environmental impact of producing, maintaining, and operating a spark-ignition passenger vehicle using the currently available fuel in the Philippines. Note that the scope of the paper includes only environmental impacts. For a full sustainability assessment, social and financial impacts need to be addressed. These were already partially addressed in Lopez et al. (2021) and Ubando et al. (2019) but future work needs to address these further.

2. METHODOLOGY

A full cradle-to-grave life cycle assessment was done using midpoint hierarchist perspective of ReCiPe 2016 v1.1 as implemented in Simapro version 9.4.0.1, in combination with data from ecoinvent v 3.8 tailored to the Philippines setting. The functional unit chosen was a 100-km trip in a compact passenger car, either electricity or gasoline-ethanol powered.

In the succeeding sections, {GLO} means that ecoinvent estimate for the global average was used while {RoW} means the world minus the process estimates for which a "local" estimate exists. When a Philippines estimate {PH} from ecoinvent was available. When no other alternatives were available, the estimate for Europe (RER) was used. Current technology was assumed throughout.

2.1 PBEV Life-Cycle Inventory

For the PBEV, the system boundary includes vehicle production, electricity generation and distribution, road maintenance, vehicle emissions and vehicle disposal. For the baseline case, the LCI was adapted from the ecoinvent dataset: transport, passenger car, electric {GLO} (Habermacher, 2021) but with the current Philippines electricity mix as estimated by ecoinvent (Treyer, 2021). For 2040, two scenarios proposed by the Philippines' Department of Energy were used (POWER DEVELOPMENT PLAN 2020-2040, 2020). In the RE35 scenario, 35% of the Philippines electricity is to be from renewable sources. In the RE50 scenario, renewables constitute 50% of the electricity mix.

Other estimates for the PBEV were taken from ecoinvent dataset: "transport, passenger car, electric {GLO}" (Habermacher, 2021). Losses were estimated at 3.72% of the electricity at generation and transmission and at each step-down. For 100 km of travel, the vehicle was taken to consume 19.9 kWh of electricity. The vehicle is assumed to be a 918.22-kg compact electric passenger car of the type commonly sold in Europe. It is assumed to have a life-expectancy of 150,000 km. The battery weight is 262 kg and is estimated to have a life expectancy of 100,000 km. In addition, the following inputs are required: battery replacement (0.262 kg of Battery, Li-ion, rechargeable, prismatic {GLO}), 6.67×10^{-4} units maintenance, passenger car, electric, without battery {GLO}); 0.6121 kg of Passenger car, electric, without battery {GLO} and 0.048748 meter-years of road {GLO}). Environmental emissions directly attributable to the operation of the vehicle include 1.05×10^{-4} brake wear emissions {GLO}; 1.16×10^{-3} road wear emissions {GLO} and 6.76×10^{-3} tire wear emissions {GLO}. Production of the Li-ion battery includes refurbishing of old batteries. Battery disposal is also considered.

2.2 ICEV Life-Cycle Inventory

For the gasoline/10% ethanol internal combustion engine passenger vehicle (ICEV), the system boundary includes production of the vehicle, fuel production, road maintenance, vehicle emissions and vehicle disposal. The LCI was adapted from the ecoinvent dataset: "transport, passenger car, ethanol 5%/person-km/CH" (Kljun, 2021) by using a

Philippines source of ethanol. To model the Philippines source of ethanol, it was assumed that the production technology in the ecoinvent dataset: "ethanol, 99.7% in H2O, from biomass, at service station" (Sutter, 2021) was also used in the Philippines but with less transport since, unlike Switzerland, sugarcane ethanol is locally produced. The operation of the ICEV was extrapolated from the operation of a vehicle with 100% Euro3 gasoline (Spielman, 2021) and the operation of a vehicle with Euro3 gasoline-5% ethanol (Kljun, 2021). To maintain consistency, a key assumption that the vehicle carries 1.59 passengers on average was removed. For every 100 km, the car is taken to consume 0.6733 kg of 99.7% Ethanol from biomass, production {PH} and 5.7167 kg of petrol, low-sulfur {RoW}. The inventory includes 0.517046 kg of a passenger car, 0.000419 units of maintenance, passenger car/RER, 0.000419 units of disposal, passenger car/RER and 0.0436 meter-years of disposal, road/RER/.

3. RESULTS AND DISCUSSION

The comparison of the environmental impacts of the PBEV and the ICEV in the current Philippines setting are shown in Figure 1. Space limitations do not allow the listing of all of the data summarized in Figure 1. The author may be contacted for any specific numerical data needed by the reader. The PBEV vehicle has lower impacts in global warming, stratospheric ozone depletion, ionizing radiation, land use, fossil resource scarcity and water use. Since electric vehicles are primarily being introduced to reduce the threat of global warming and to conserve fossil fuels, it can be said that the PBEV achieves its most important objectives. Land and water use is also less because land is necessary to provide the ethanol for the ICEV. However, while doing so, use of PBEV results in more severe environmental impacts in the other categories.

A breakdown of the sources of the environmental impact from the PBEV is shown in Table 1. The generation of electricity is the primary source of environmental impact in 8 categories: global warming, stratospheric ozone depletion, fossil resource scarcity, ozone formation (human health), fine particulate matter formation, ozone formation (terrestrial), terrestrial acidification and freshwater eutrophication. Further tracing back of the source shows that these impacts are primarily from the coal power plants. It would be in these 8 categories that following the DOE power generation plans would have the largest impact. These include the categories wherein the PBEV have an advantage over the ICEV (global warming, fossil resource scarcity and stratospheric ozone depletion). However, it can be seen in Figure 1 that the adoption of the renewable energy sources as prescribed in RE35 or RE50 (POWER DEVELOPMENT PLAN 2020-2040, 2020) does not result in any reversals in the comparison between PBEV and ICEV. That is, the PBEV still has less environmental impact than the ICEV in 2040 in those categories where it had less environmental impact using the current electricity mix and vice-versa.

In human non-carcinogenic toxicity, ionizing radiation, water consumption, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity and mineral resource scarcity, the primary source of the PBEV environmental impact is the manufacture of the vehicle and the battery. These impacts can be traced back further to the mineral extraction and processing to obtain the metals for the vehicles. In these categories, it is the greening of the extractive industries that must be achieved. It can be further seen in Figure 1 that while noticeable reductions can be seen in the environmental impact of PBEV in those environmental impacts traceable to electricity generation, the greener electricity scenarios RE35 and RE50 are not enough to reverse the trend. This is because there is still a large amount of electricity generated from coal and natural gas in the RE35 and RE50 scenarios. A special case is land use. The land use is about evenly distributed between the vehicle plus battery, electricity and road use. In Figure 1, we see that the RE50 scenario actually results in greater land use than RE35. This is because of the larger proportion of solar and wind electricity and the reintroduction of biomass electricity in RE50, whereas biomass is absent in RE35.

4. CONCLUSIONS

The widespread adoption of PBEV in the Philippines may reduce emissions related to global warming and fossil fuel usage. These emission and usage reductions may be accompanied however by increased emissions resulting from the production of the Li-Ion battery and electric vehicle. Increased emissions are also predicted for those emissions from the generation of electricity, particularly those from coal. Improvements in the extractive industries and vehicle lives as well as reuse and recycling can be expected to further decrease the impact of electric vehicles. Future studies should address social and financial aspects of the use of electric vehicles in the Philippines. The consequences of increased power demand resulting from the use of electric vehicles also need to be studied.

5. ACKNOWLEDGMENT

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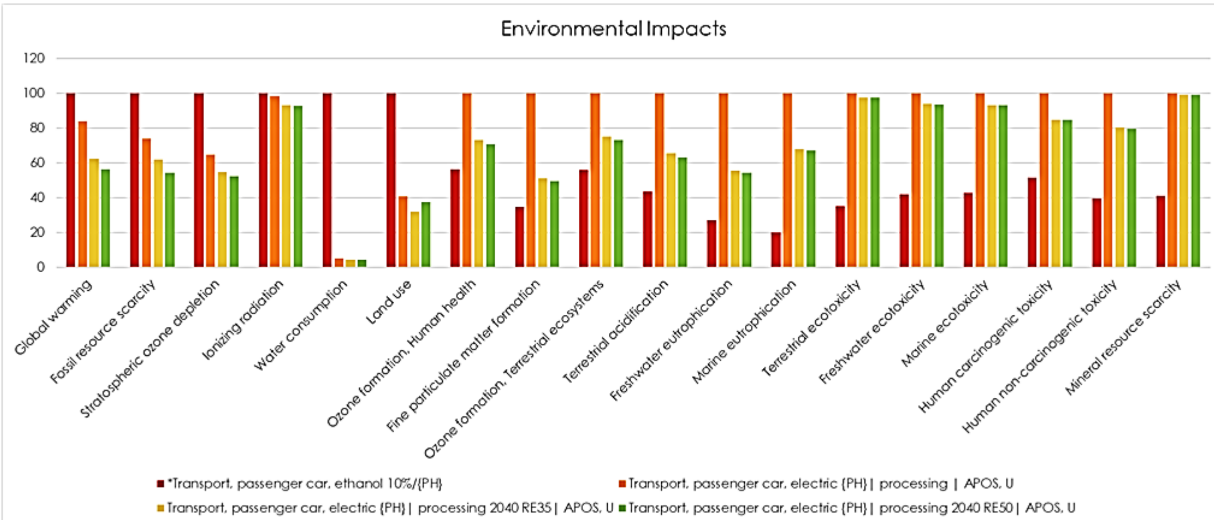

Fig. 1. Environmental impacts (highest impact normalized to 100) of ICEV and PBEV under different scenarios.

Table 1. Source breakdown of environmental impacts of a PBEV. (Percentages do not total 100 in some cases because of minor contributions from road and tire wear)

Impact category	Unit	Car+Battery	Electricity	Maintenance	Road
Global warming	%	27.64	67.09	2.64	2.64
Stratospheric ozone depletion	%	38.15	54.35	2.85	4.65
Fossil resource scarcity	%	26.43	64.05	4.14	5.39
Ozone formation, Human health	%	24.82	55.76	13.92	5.51
Fine particulate matter formation	%	25.12	70.50	1.62	1.83
Ozone formation, Terrestrial	%	23.76	51.23	19.58	5.43
Terrestrial acidification	%	30.80	65.78	1.43	1.99
Freshwater eutrophication	%	30.68	62.93	5.45	0.94
Human non-carcinogenic toxicity	%	62.56	34.96	1.28	0.44
Ionizing radiation	%	75.91	10.40	8.26	5.43
Water consumption	%	62.29	28.32	5.34	4.05
Marine eutrophication	%	47.60	44.22	7.53	0.59
Terrestrial ecotoxicity	%	81.88	10.46	0.87	0.94
Freshwater ecotoxicity	%	76.12	22.57	0.82	0.28
Marine ecotoxicity	%	75.87	22.62	0.85	0.32
Human carcinogenic toxicity	%	69.98	26.39	1.65	1.98
Mineral resource scarcity	%	92.26	5.75	0.92	1.07
Land use	%	30.16	33.29	1.78	34.77