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Evaluation of the Carbon Emissions of Electric Vehicles in the Philippines Considering Local Power Mix

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The transport sector remains a major contributor to greenhouse gas emissions with a 21.7 % share of global emissions. In the Philippines, vehicle electrification is seen to curb transportation emissions since these vehicles have zero tailpipe emissions. However, considering only tailpipe emissions is misleading since fossil fuels dominate the local electricity mix at greater than 60 % market share. Additionally, commercially available electric vehicles in the country are not tested or simulated in Philippine routes, especially for routes with moderate to high grades of 8 % or more. The study simulated the performance of electric vehicles by varying road grades in a vehicle and a test model. The consumption from the simulation was used to forecast business-as-usual and clean energy scenarios to analyse the impact of EVs on emissions, while also looking into more environmentally informed pathways for EV adoption by matching CO_2 emission targets and vehicle/fleet replacement. Results show a net reduction in emissions with increased adoption of electric vehicles. The findings indicate that EV adoption alone yields minimal national carbon emission reductions, with a maximum decrease of 1.131 Mt CO_2 (less than 1 % of national transport emissions) by 2040 under high adoption but unchanged power mix scenarios. Emission reduction is better achieved through investment in renewable energy technologies, which leads to about a 50 % reduction in carbon emissions.

1. Introduction

The transport sector plays a critical role in global greenhouse gas emissions, contributing approximately 21.7 % to global carbon emissions, equivalent to 7.98 Gt CO_2 annually (IEA, 2023). In the Philippines, transport-related emissions are the third largest contributor to national greenhouse gases, following electricity/heat generation and agriculture, with 29.21 Mt CO_2 emissions (Ritchie et al., 2020). This substantial environmental footprint has driven policy initiatives and investments toward cleaner technologies, including the adoption of electric vehicles (EVs).

In the Philippines, EV adoption remains in its nascent stage, despite a growing fleet and several policy incentives such as Republic Act No. 11697, or the Electric Vehicle Industry Development Act (EVIDA). This has created tax incentives, registration benefits, and exemption from number coding for EV owners. Yet, major concerns persist, such as limited model availability, high upfront costs, charging infrastructure, and a lack of real-world testing of EVs under Philippine driving conditions. Additionally, as of 2022, there are only 400 EV charging stations, and only a few are equipped with the necessary power capacities to charge larger vehicles (Tribdino, 2023). Thus, continuous investment is still needed, which puts an economic strain on the country.

This push for EVs is seen as a viable solution to the global greenhouse problem. However, the environmental benefits of EVs are often overstated since only operational tailpipe emissions are considered (Shafique and Luo, 2022). In practice, the Philippines derives over 60 % of its electricity from fossil fuels, which are primarily coal, oil, and gas. This offsets the net carbon benefits of electric vehicle adoption. Additionally, commercially available electric sedans have not been rigorously tested under local topographies, particularly on routes with moderate to steep inclines exceeding 8 %. Without reliable local data on energy consumption and charging patterns, national-level assessments risk underestimating the real emissions from EV use.

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This is compounded by the carbon-intensive Philippine electricity mix, which consists of 58.2 % coal, 15.8 % natural gas, and 4.4 % oil. Renewable sources make up just 21.6 % of total generation, with minimal contribution from solar and wind. While the Department of Energy (2023) aims for a 35 % renewable share by 2030 and 50 % by 2040, progress remains slow. This has profound implications for EV emissions, as the indirect emissions from charging remain linked to fossil fuel combustion unless cleaner power sources are prioritized.

The study then evaluates the inclusion of EVs, particularly battery-electric vehicles (BEVs) in the automotive sector of the Philippines. The study aims to provide insights into the environmental benefits of EVs, considering indirect emissions and not just tailpipe emissions, to properly assess the perceived positive impact of the technology, considering the local power mix. The performance of an EV is simulated using a vehicle model with road gradient included as a variable to reflect local terrain. However, the study is limited to the automotive sector within the Mega Manila (NCR and Region IV-A), where most support infrastructure for EV is situated. Economic impacts are considered but are not primarily evaluated. Lastly, the study only evaluates the impact of sedans due to the availability of data that can validate the model.

2. Methodology

2.1 Conceptual Framework

This study employs a bottom-up approach to assess the carbon emissions of electric sedans operating in the Philippines. An AVL CRUISE M model was used to simulate the idealized energy consumption of an electric sedan under differing road grades (0 %, 4 %, 8 %, and 12 %). Consumption values generated from these simulations are scaled according to the number of cars and average daily mileage. These were then converted into total energy demand using estimated transmission efficiency values. The resulting energy demand figures were matched against historical and forecasted power generation trends to estimate associated carbon emissions under different electricity mix scenarios.

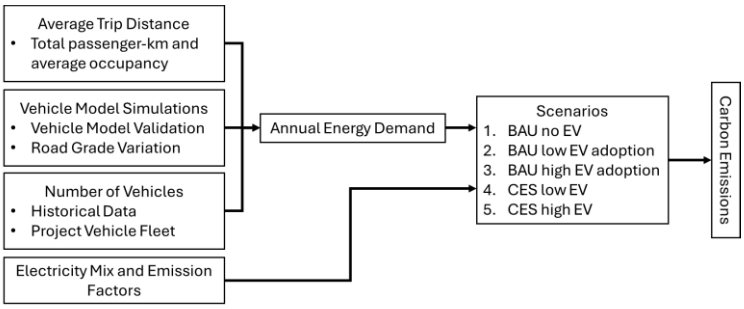


Figure 1: Conceptual Framework for simulations

The total number of cars per year for 2019-2023 was obtained from the Philippines Statistics Authority (PSA, 2024). Only cars registered in NCR and Region IV-A were considered since a national and comprehensive study on typical trip mileage and vehicle occupancy has yet to be undertaken. This already considers about 60 % of the total number of registered private cars in the country. The total number of private cars is further modified by multiplying the market share for small cars according to Rith et al. (2018). The typical trip mileage used in calculations is derived from Regidor (2019) by dividing the total passenger-km for cars by the total vehicle occupancy, resulting in 36.45 km of mileage per car per day.

2.2 Simulated Scenarios

Two (2) energy scenarios were simulated. The power generation trends were based on historical data from the Department of Energy Annual Power Statistics, and the renewable energy targets were based on the Clean Energy Scenario from the Philippine Energy Plan (DOE, 2023a). The data for years not indicated in the plans are filled in using piecewise quadratic interpolation.

1. Business-As-Usual (BAU): This assumes the current fossil-dominated energy mix remains unchanged through 2040. This serves as a baseline.
2. Clean Energy Scenario (CES) low e-vehicle adoption: This incorporates the renewable energy targets of 35 % by 2030 and 50 % by 2050 (DOE, 2023a).

This was matched to two (2) EV adoption scenarios as shown in the Comprehensive Roadmap for the Electric Vehicle Industry (DOE, 2023b) by the Department of Energy. The data between the years was filled in by using piecewise linear interpolation.

1. Low adoption: the targets for 10 % market share of cars were adopted: 2028 (13,600 BEVs), 2034 (123,000 BEVs), and 2040 (219,400 BEVs)
2. High adoption: the targets for 50 % market share of cars were adopted: 2028 (69,000 BEVs), 2034 (327,000 BEVs), and 2040 (641,000 BEVs)

This led to a total of five (5) scenarios where a reference of no EV adoption is added for Business-as-Usual. Any addition of EVs into the market is matched with a reduction in the number of traditional cars in a 1:1 ratio.
The low and high EV adoption scenarios correspond to 10 % and 50 % market share for EVs. The actual roadmap from DOE (2023b) also adds a substantial amount of electric tricycles and motorcycles, which should also contribute to the targeted 10 % and 50 % market share.

2.3 Vehicle Energy Simulation and Calculation

Energy consumption was estimated using AVL CRUISE M simulations. The vehicle model was built based on Hayes and Davis (2014). The model was also validated using the investigation of Singirikonda and Yeddulla (2023) with an average error of about 14 % (1.4 vs 1.2 kWh). The vehicle model is shown in Figure 2.

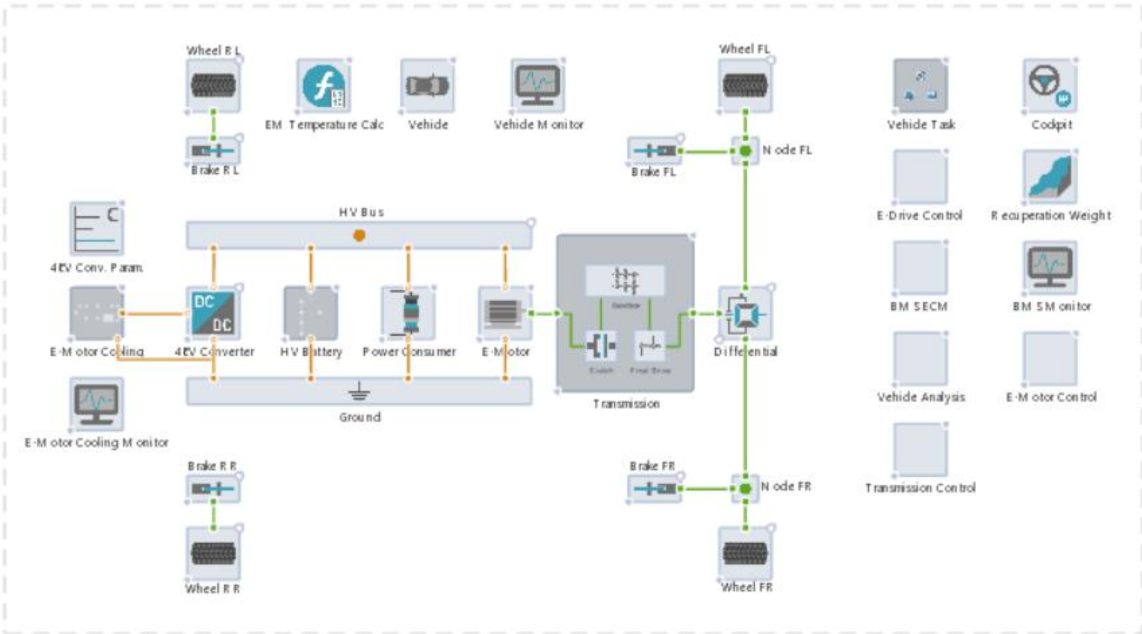


Figure 2: AVL CRUISE M Model for electric sedan

The model was then simulated at varying road grades (-12, -8, -4, 0, 4, 8, 12) in %. This is in line with highway standards in the Philippines that set a maximum grade of 8 % (DPWH, 2017). However, vehicle slopes of greater than 8 % are still present within the country due to a lack of standards in earlier years. The energy consumption for each grade is then assigned weights of 0.7 for flat, 0.1 each for -4 % and 4 %, 0.04 each for -8 % and 8 %, and 0.01 each for -12 % and 12 %. These weights are assigned with the assumption that most of the national capital region is flat, with few connections to hilly areas in neighbouring regions. This then gives a total weighted consumption of 0.209 kWh/km. The model was also run using a representative drive cycle for a hilly region composed of flats and slopes, leading to a consumption of 0.416 kWh/km.

2.4 Assessment of Carbon Emissions

Tailpipe emissions were assumed to be zero since only BEVs were considered. Total CO_2 emissions from EVs were computed for each scenario by combining vehicle energy demand with the emission factors of each energy source in the power mix. This is to account for indirect emissions that are attributed to the electricity drawn from the grid. Each power generation source is assigned an emission factor in gCO_2/GWh derived from Dones et al. (2023) and Kara and Sahin (2023).
Battery manufacturing and replacement emissions were also included, based on average battery lifespan and emissions per kWh of battery capacity. The carbon emissions are calculated according to how frequently each battery needs replacement based on the total charging cycles resulting from discharging the battery. The

number of cycles is determined by getting the total kWh consumption per trip and determining how many trips are needed for the battery to be discharged.

Carbon emissions for traditional cars are adapted from Fabian and Gota (2009) for CO_2 and EURO IV emissions standards, which is the minimum applied standard in the country to date, for other emission species. The CO_2-equivalent of each emission species is calculated from the Greenhouse Gas Protocol (2016). The final carbon emissions are reported in Mt CO_2 and compared against national baseline emissions.

3. Results

3.1 Additional Energy Demand due to Electric Vehicle Adoption

Figure 3 shows the total forecasted energy demand from the national grid. The additional energy demand for the level of EV adoption is minimal, even with the supposed higher market share. The high EV adoption only leads to an additional 2.16 TWh in 2040, which is less than 1 % of the total energy demand. This shows an opportunity to adopt EVs since it will not place a big strain on the power grid in any year after 2023, with 1,359 BEVs (PSA, 2024).

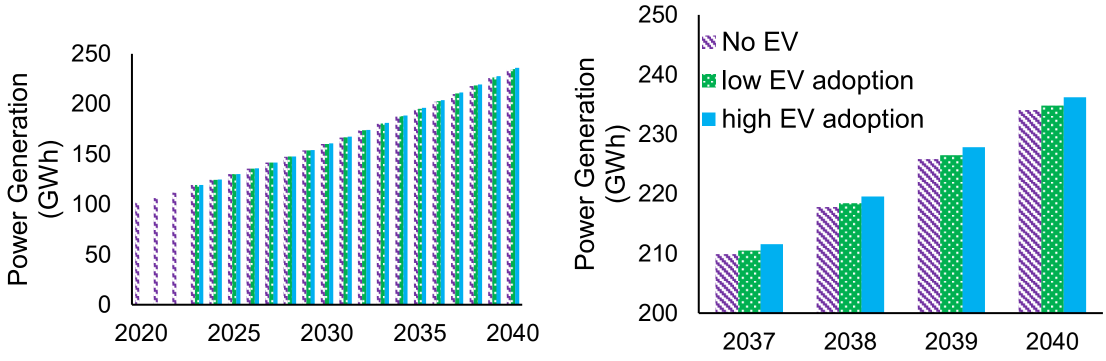


Figure 3: Forecast Total Energy Demand in TWh for 2019-2040 (left) and zoomed in for 2037-2040 (right)

It is important, however, to ensure that charging and other support infrastructure is developed for EVs. The efficiency of the chargers is also paramount since low-efficiency chargers will increase the energy demand. The decrease in efficiency is still seen to have a marginal effect due to the low percentage (<1 %) share of the total energy demand. Lastly, the reported increase in energy demand does not include a possible increase due to manufacturing requirements of EVs, especially considering the amount of EVs targeted for each year. To date, most EVs are imported from other countries, which then contributes negatively to the sustainability of the technology. Table 1 then shows the resulting carbon emissions for each scenario considering the increase in energy demand from EVs. It is notable that the BAU leads to no change in emissions, while the CES reduces carbon emissions the most.

Table 1: Total carbon emissions in Mt CO_2 for each scenario

Year	BAU (Ref)	BAU Low EV	BAU High EV	CES Low EV
2020	59.924	59.924	59.924	59.924
2025	77.806	77.801	77.762	71.498
2030	96.313	96.230	96.044	76.489
2035	117.946	117.705	117.279	79.072
2040	142.896	142.513	141.765	78.191

Emissions of traditional cars were calculated as 281.2 gCO_2-eq/km, with 260 gCO_2/km (Fabian and Gota, 2009) and 0.08 g/km of NO_x (DENR, 2015). Tailpipe emissions remain a leading problem in urban environments, although the overall contribution of these emissions compared to the emissions from the power sector is only about 6 % compared to coal's greater than 80 %, as seen from Figure 4. This highlights the dominance of coal not only in the generation of power, but also in the emission of harmful greenhouse gases.

Figures 5 and 6 illustrate the importance of addressing the issue of a coal-dominated power mix. Figure 5 shows that the inclusion of EVs in the market has marginal contributions in the reduction of harmful GHG emissions with only 0.384 Mt CO_2 reduction at low EV adoption (142.896 Mt CO_2 no EV vs 142.513 Mt CO_2 low EV adoption). This reduction increases slightly to 1.131 Mt CO_2 with high EV adoption (142.896 Mt CO_2 vs 141.765

Mt CO_2). In both cases, the reduction is less than 1 %, which may indicate a very inefficient approach in mitigating harmful emissions within the national scale.
In contrast, the harmful emissions are significantly reduced when the power mix is shifted towards cleaner and greener power generation technologies. The contribution of coal remains high at approximately 57 – 58 % depending on the total number of EVs in the market. With the clean energy scenario, the contribution of coal continuously drops with at least 2 % drop per year from 2035. With this trend, EV replacement of traditional cars will have greater impact even though the value of the emission reduction remains relatively the same – 1.136 Mt CO_2 when comparing the low and high EV adoption scenarios. In all cases, the emissions from battery replacement are minimal (less than 0.01 %) such that it is not visible in the graphs.

3.2 Carbon Emission Assessment

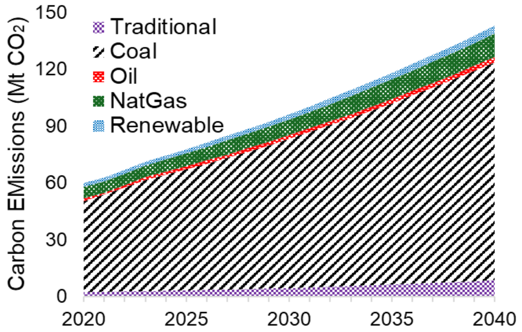
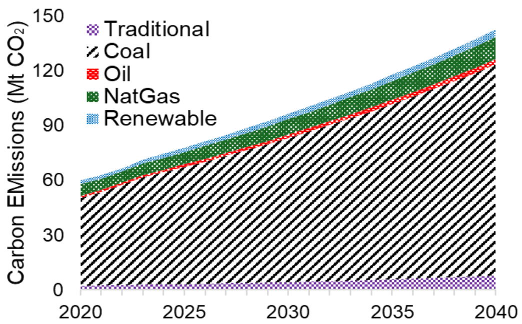


Figure 4: Forecast Carbon Emissions under BAU and no EV adoption



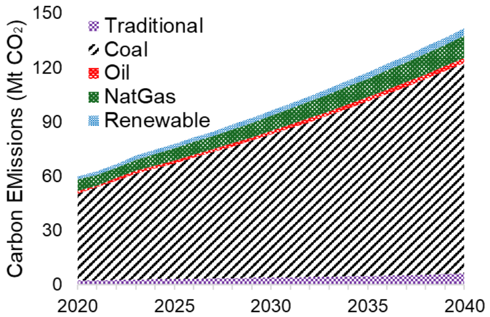
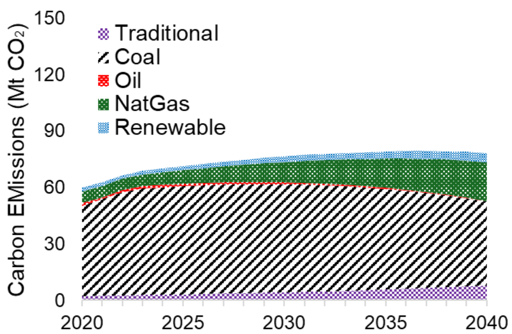


Figure 5: Forecast Carbon Emissions under BAU with low (left) and high (right) EV adoption



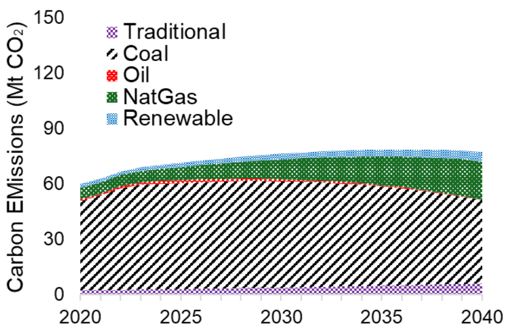


Figure 6: Forecast Carbon Emissions under CES with low (left) and high (right) EV adoption

From these, it may be the case that the current road maps for electric vehicles should only be strengthened if the Clean Energy scenario of the Philippine Energy Plan is implemented successfully. While there is no risk of straining the grid since EVs increase energy demand by a small 1 %, the economic impact of providing infrastructure in the country can induce economic strain and remove focus from renewable energy technologies that is more aligned with the environmental targets of the country.

4. Conclusions

Improvement in tailpipe emissions that can improve urban environments may still be achieved, but the national context should also be considered to ensure that environmental impact is mitigated and not just transferred. The study showed that the environmental benefits of electric vehicle (EV) adoption in the Philippines can only marginally contribute to national emission levels.

Vehicle simulations 0.209–0.416 kWh/km, depending on terrain, and replacing internal combustion engine (ICE) vehicles with battery electric vehicles (BEVs) may lead to a reduction of as much as 1.131 Mt CO_2, following the electric vehicle roadmap of the Philippines in increasing the number of EV units. However, this is but 1 % of the total greenhouse gas emissions of the country. The coal-dominated power mix is also reflected in the emissions, wherein most (>80 %) of the greater than 140 Mt CO_2 emissions are from coal. This value substantially drops with the adoption of the clean energy scenario for the power mix – the inclusion of EVs also has a greater impact in this case, but remains very low.

The integration of EVs presents a potential reduction in tailpipe emissions with a limited increase in energy demand. However, investments in renewable energy infrastructure can be more effective to achieve significant carbon reductions, especially considering the environmental targets of the country. Vehicle electrification is then only a complement to renewable energy technology, considering the local situation.

Acknowledgments

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