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# Evaluating the Impact of Electric Vehicles on Emission Reduction in Schools: A Case Study at SMP Darul Hikam Bandung

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**ABSTRACT**

Reducing greenhouse gas emissions and air pollution is a critical challenge in mitigating climate change and improving air quality, particularly in densely populated urban areas. This study analyzes and optimizes emission reductions from motor vehicles at SMP Darul Hikam Bandung, with 38 vehicles as the sample. Three vehicles are evaluated: gasoline-powered motorcycles, electric motorcycles charged from the public electricity grid (PLN), and electric motorcycles charged using renewable energy sources. The goal is to determine which vehicle type generates the lowest pollution by considering direct emissions from fuel combustion and indirect emissions associated with electricity generation.

The methodology employed is Life Cycle Analysis (LCA), which measures total emissions from each vehicle type, production to operation, and end-of-life battery management. Gasoline motorcycles are assessed based on emissions from fuel combustion, while electric motorcycles are analyzed according to their charging source. Electric motorcycles charged from the PLN grid are evaluated for emissions related to electricity generation. In contrast, those charged from renewable energy sources consider the environmental impact of battery production and energy storage at charging stations.

The results of this study are expected to provide more precise insights into the most environmentally friendly vehicle options and offer policy recommendations for selecting vehicles that minimize emissions in school and urban environments.

## 1. INTRODUCTION

Air pollution and greenhouse gas (GHG) emissions have become urgent global challenges, exacerbated by the growing number of motor vehicles in urban areas. The increasing dependence on fossil-fueled vehicles primarily contributes to these environmental issues, releasing pollutants that harm the climate and public health. Immediate action is necessary to mitigate the damage caused by global warming and prevent further degradation of the environment. Various solutions, such as promoting alternative energy sources, enhancing public transportation, and encouraging the adoption of electric vehicles (EVs), are being explored to reduce emissions. In urban settings, the impact of motor vehicle emissions is particularly significant, worsening air quality and posing severe risks to human health, especially in densely populated regions like Indonesia. Bandung, a rapidly growing city, is no exception. The air quality in Bandung City has deteriorated, with approximately 70 percent of the pollution attributed to emissions from motor vehicles. This is evidenced by the Air Quality Index (ISPU) in Bandung, which ranges between 51 and 99, indicating that the air quality is at the threshold of moderate levels (Diskominfo Kota Bandung, 2023).

In response to this issue, adopting electric vehicles (EVs) has emerged as a promising solution to reduce air pollution and greenhouse gas emissions in urban areas. According to Ferlita et al. (2023), EVs are essential in reducing air pollution, lowering greenhouse gas emissions, and enhancing urban air quality. However, achieving a significant impact requires a coordinated effort from the government, industry, and society to promote the adoption of electric vehicles and the necessary supporting infrastructure. EVs, which produce zero tailpipe emissions, are seen as a sustainable alternative to conventional gasoline and diesel-powered vehicles, offering the potential to significantly lower the carbon footprint of transportation in cities. A case study conducted at SMP Darul Hikam in Bandung exemplifies how implementing EVs in local communities can contribute to emission reduction efforts. By incorporating EVs into school transportation and encouraging their use among staff and students, the school aims to improve air quality and promote environmental awareness. This initiative helps reduce the school's carbon footprint and sets a positive example for the community. As more institutions adopt similar practices, the collective impact of EVs on reducing urban emissions could become a key factor in achieving sustainable development goals.

Educational institutions, such as schools, also play a vital role in creating a healthy environment for students and the surrounding community by mitigating the negative impacts of motor vehicles. In line with this, institutions with firm discipline, a relevant curriculum, and a creative learning community (Daniel et al., 2023) are well-positioned to adopt sustainable practices, such as reducing vehicle pollution. A case study will be conducted at SMP Darul Hikam Bandung, which serves as an appropriate setting to analyze the impact of vehicle pollution on the educational environment. The types of vehicles used at this school fall into three main categories: gasoline-powered motorcycles (BBM), electric motorcycles charged from the PLN grid, and electric motorcycles charged at stations utilizing renewable energy. While electric motorcycles are considered an environmentally friendly solution, their sustainability and emission reduction potential depend heavily on the energy sources used for charging. The use of PLN as a power source still carries emission impacts due to the reliance on fossil-fuel-based power generation, while charging with renewable energy sources requires further evaluation regarding the environmental impacts of energy production and management, including potential pollution from energy storage in batteries.

Gasoline-powered motorcycles directly generate harmful emissions such as carbon dioxide ($CO_2$) and nitrogen oxides ($NO_x$), contributing significantly to air pollution and global warming. On the other hand, electric motorcycles charged from the PLN grid have the potential to produce indirect emissions, depending on the energy mix used by the national electricity grid. While electric motorcycles charged with renewable energy are more environmentally friendly, the potential environmental impact remains, particularly related to the production, management, and recycling of the batteries used for energy storage.

This research aims to evaluate the emissions of motor vehicles in the environment of SMP Darul Hikam Bandung using Life Cycle Analysis (LCA) as the primary method to assess the environmental impact of each type of vehicle. Life Cycle Assessment (LCA) effectively supports informed decision-making and improves the product life cycle (Devi & Mirwan, 2023). According to Setyoko, Nurcahyo, and Sumaedi (2023), the LCA approach has been extensively applied to inventory analyses of energy consumption and greenhouse gas (GHG) emissions. LCA allows for measuring total emissions from the vehicles' production, usage, and end-of-life stages, providing a comprehensive overview of which vehicle type is the most environmentally friendly in emission reduction. Therefore, this study is expected to provide data-driven recommendations for more sustainable, low-emission transportation solutions that can be applied in educational settings and help reduce pollution in urban areas.

**Electric Vehicles**

Electric vehicles (EVs) use electricity as their primary fuel or to improve the efficiency of conventional vehicle designs. EVs include all-electric vehicles, also referred to as battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). In colloquial references, these vehicles are called electric cars, or simply EVs, even though some still use liquid fuels in conjunction with electricity. EVs are known for providing instant torque and a quiet driver experience. Electric vehicles (EVs) produce fewer emissions than conventional vehicles, with all-electric vehicles generating zero tailpipe emissions and PHEVs producing no tailpipe emissions when operating in electric-only mode. The life cycle emissions of an EV depend on how electricity is generated and the extent to which a PHEV’s engine is used, which varies by region. Generally, EVs and PHEVs produce one-third to half of the emissions of conventional vehicles, with more significant benefits in regions that utilize renewable energy (U.S. Department of Energy, 2023).

Electric vehicles are expected to significantly reduce carbon dioxide emissions in these countries in the long term. Unlike traditional cars, electric vehicles do not produce tailpipe emissions. Even when the electricity they use is produced from fossil fuels, they still create less pollution compared to cars running on gasoline. Because of this, electric vehicles are a desirable alternative for those concerned with reducing their carbon impact (Alanazi, 2023). Electric vehicles (EVs) exhibit 7% lower emissions and a 14% reduction in cost per kilometer compared to their internal combustion engine vehicle (ICEV) counterparts. Several factors, including the emissions associated with the power grid, fuel production, vehicle efficiency, government fiscal incentives, travel distance, and fuel prices, significantly influence the calculation of EVs' greenhouse gas (GHG) emissions and total cost of ownership (IESR, 2023).

Electric vehicles (EVs) offer a range of benefits that make them an increasingly popular choice among drivers. One of the main advantages is that EVs produce no tailpipe emissions, helping to reduce air pollution and protect the environment. Additionally, EVs are typically cheaper to operate, as the charging cost is much lower than gasoline or diesel fuel. Electric vehicles also require less maintenance due to having fewer moving parts and not needing regular oil changes. Drivers of EVs enjoy a smoother and quieter driving experience thanks to the instant torque provided by electric motors. With all these advantages, electric vehicles represent a more environmentally friendly and economical choice for the future (Padhi, 2020).

**Table 1.** Benefits of Electric vehicles (EVs)

| | |
|---|---|
| Fuel Economy | The majority attain fuel efficiency ratings Exceeding 2.35 km/kWh |
| Emissions Reductions | They generate no emissions from the tailpipe. Typically, their emissions are only one-third of those produced by conventional vehicles. |
| Fuel Cost Savings | All-electric vehicles run solely on electricity. The electricity costs range from IDR 300 to IDR 1,200 per kilometer. |
| Fueling Flexibility | Charging can be done at home, public charging stations, or workplaces. |

## 2. METHOD

The study is conducted at SMP Darul Hikam in Bandung, using a sample of 38 motor vehicles. The primary objective of the research is to compare and evaluate the emissions produced by three distinct types of vehicles: gasoline-powered motorcycles (BBM), electric motorcycles charged from the PLN grid, and electric motorcycles charged at stations that use renewable energy sources. By analyzing these different vehicle types, the study aims to assess their respective environmental impacts, particularly their contributions to air pollution and greenhouse gas emissions. The findings of this study are expected to provide valuable insights into how each vehicle type affects the environment, helping to inform decisions about sustainable transportation options.

The research methodology involves a thorough data collection process, which includes recording the total number of vehicles used in the study and measuring the fuel consumption for gasoline-powered motorcycles. Data on battery capacity and electricity consumption is collected for electric motorcycles. These parameters are crucial for understanding the energy efficiency and emissions associated with each type of vehicle. By comparing the fuel consumption of gasoline motorcycles with the energy usage of electric motorcycles, the research aims to provide a clear picture of how each vehicle contributes to overall emissions. The study also considers how the source of electricity—whether from the PLN grid or renewable energy—affects the environmental performance of electric motorcycles. This approach allows for a comprehensive analysis of the environmental impact of different transportation modes, helping to identify the most sustainable options for reducing carbon emissions and promoting cleaner air in urban areas.

Emission analysis uses a Life Cycle Analysis (LCA) approach, which includes three stages:

production, use, and end-of-life management of the vehicles. During the production stage, emissions related to vehicle manufacturing and fuel production (for gasoline motorcycles) and the production of electric vehicle components and batteries are analyzed. During the usage stage, direct emissions are measured from fuel combustion (for gasoline motorcycles), electricity usage from the PLN grid, and energy storage from renewable sources in electric motorcycles. The end-of-life stage includes the evaluation of the environmental impacts associated with battery recycling and vehicle waste management.

After collecting the emission data, total emissions are calculated for each vehicle category. Emissions are calculated based on the emissions per kilometer indicator ($gCO_2$/km) to determine which vehicle produces the least pollution. Sensitivity analysis is also conducted to assess the impact of changes in factors such as the proportion of renewable energy in the PLN grid and vehicle efficiency. Based on the analysis results, conclusions and recommendations will be made to minimize motor vehicle emissions in the school environment, considering technical, economic, and social aspects.

**Life Cycle Analysis (LCA)**

The Life Cycle Analysis (LCA) is a method used to evaluate the full range of environmental effects of a product, service, or system throughout its entire life span. This approach can be applied to various products and technologies, from simple items like paper bags to complex processes like large-scale electricity generation. A product's life cycle begins with the extraction of raw materials, includes its production and usage, and ends with its disposal and decommissioning. LCA analyses can cover the entire life cycle (cradle-to-grave) or focus on specific stages, such as the acquisition of raw materials through production (cradle-to-gate) or specific processes within the life cycle (gate-to-gate). However, it is essential to recognize that partial LCA analyses should be interpreted cautiously, as they do not provide a complete perspective on the product's life cycle. (Cutshaw et al., 2024).

According to Farjana et al. (2021), LCA is a comprehensive and quantitative analysis of the environmental or social impacts caused by products, processes, or systems throughout their entire life cycle, integrating life cycle thinking that considers the consequences on the environment, economy, and society associated with a product. The International Organization for Standardization (ISO) has developed a series of international standards, such as ISO 14040 (LCA-Principles and Guidelines), ISO 14041 (LCA-Life Cycle Inventory Analysis), ISO 14042 (LCA-Impact Assessment), and ISO 14043 (LCA-Interpretation), as well as ISO 14044 (ISO Standards Policy and Strategy Committee), which provide principles and frameworks for assessing the impacts of a product's life cycle.

The LCA phase encompasses several key components (Rahanra & Diawati, 2023)

- Objective: Clearly define the purpose and goals of the Life Cycle Assessment (LCA) study.
- Scope: Determining the scope and limitations of the study, including which stages of the

life cycle will be considered.

- Functional Units: Setting the functional units used to compare and evaluate different products or systems.
- System Boundaries: Establishing the system's boundaries under analysis, specifying which processes or components should be included.
- Data Quality: Ensuring the integrity and reliability of the data applied in the assessment process.
- Critical Review Process: Describing the steps for gathering feedback and reviewing the study's methodology and results.

After completing the Goal and Scope Definition phase, the next step is the Life Cycle Inventory (LCI) Analysis. This phase involves implementing the initial plan developed during the Goal and Scope Definition, following the analysis procedures outlined in ISO 14044 (ISO, 2006).

**Fuel and Engine Analysis Methods**

The equation used to calculate the potential CO2 gas emissions refers to the study by Sunarti (2022). Equation (1) is the basis for calculating the potential CO2 emissions.

$$E = EF \times K \quad (1)$$

In this equation, E represents the total emissions (g/hour.km), EF is the emission factor (g/l), where, according to the IPCC 1996, the CO2 emission factor is 2,597.86 g/liter. Meanwhile, K denotes fuel consumption (liter/km). If the engine is assumed to have a fuel efficiency of 40 km per liter, the fuel consumption can be calculated as 0.025 liters per kilometer.

To calculate the total CO2 emissions, equation (2) is used:

$$E_{Total}\text{ (kg)} = CO_2\text{ Emissions (km/kg) x Total Distance Traveled (km)} \quad (2)$$

**Electric Motor Analysis Method**

***Electric Motor Powered by Coral-Fired Power Plant (PLTU)***

According to data from the Ministry of Energy and Mineral Resources, electric motors can typically travel a distance of approximately 40 km to 60 km on a full battery charge. To travel 40 km, the estimated electricity consumption required is around 1 kWh. Therefore, the power consumption per kilometer is approximately 0.025 kWh. According to Rizki (2013), the average $CO_2$ emission factor from coal-fired steam power plants (PLTU) is approximately 1.05 kg $CO_2$ per kWh. The emissions generated by the electric motor due to the power generated by the PLTU can be calculated using equation (3).

$$E_{ccc2}\text{ (g)} = S\text{ (km) x } K_{Daya}\text{ (kWh/km) x EF PLTU (g.}CO_2\text{/kWh)} \quad (3)$$

***Electric Motor Powered by Solar Power Plant (PLTS)***

According to the IPCC Report 2018, Solar Power Plants (PLTS) have an average life cycle emissions of 48 grams of $CO_2$ per kilowatt-hour (kWh) of electricity generated. These emissions arise from various stages of the PLTS life cycle, including producing solar panels, transportation, installation, and recycling or disposing of components after their useful life. Equation (4) represents the calculation of emissions generated by the electric motor powered by energy from a solar power plant (PLTS).

$E_{ccc2}$ (g) = S (km) x $K_{Daya}$ (kWh/km) x EF PLTS (g.$CO_2$/kWh) (4)

## 3. RESULT AND DISCUSSION

In this research, $CO_2$ emissions were evaluated for three distinct categories of vehicles: Category A, consisting of gasoline-powered motorcycles; Category B, which includes electric motorcycles charged using electricity sourced from coal-fired power plants (PLTU); and Category C, comprising electric motorcycles powered by solar energy derived from solar power plants (PLTS). The assessment was performed by totaling the distances traveled by 38 vehicles in one day. The total distance of the 38 vehicle single trips was 269 km, resulting in a total vehicle round trip distance of 538 km. This round-trip distance was chosen to ensure consistency in comparison across the different vehicle types. The emissions produced by each vehicle category were carefully calculated by considering the specific energy sources, fuel consumption, and operational characteristics of each vehicle type. The detailed calculation results for each category, showing the $CO_2$ emissions for the total round-trip distance, are presented and summarized in Table 1 for a more precise comparison of their environmental impact. This analysis provides valuable insights into the relative emissions of different transportation modes, considering their energy sources and travel distances.

**Table 2.** Emission calculation result

| No | Distance (km) | $CO_2$ Emission (kg) | | |
|---|---|---|---|---|
| | | A | B | C |
| 1 | 269 | 17.47061 | 7.06125 | 0.3228 |

The total distance traveled by 38 vehicles to school is 269 km. Based on the calculations, the total $CO_2$ emissions produced by gasoline-powered vehicles (A) amount to 17.47 kg $CO_2$. Gasoline-powered vehicles have the highest emissions compared to the other categories due to the direct combustion of fuel, which generates greenhouse gases. Electric motorcycles powered by coal-fired power plants (PLTU) (B) produce lower emissions, at 7.06 kg $CO_2$ for the same distance. The reduction in emissions is due to using electricity as the primary energy source. However, electricity from PLTU still generates greenhouse gas emissions from the combustion of fossil fuels such as coal at the power plants.

The emissions from solar-powered electric motorcycles (PLTS) are not entirely zero. The emissions produced stem from the life cycle of the solar power plant (PLTS), including the production process of solar panels, which requires high energy for the extraction and purification of silicon and the manufacturing of solar modules. Additionally, the transportation and installation of solar panels and maintenance during their lifespan contribute to small emissions. At the end of their life cycle, the recycling or disposal of solar panels also contributes to emissions, although in small amounts. Electric motorcycles powered by solar power plants

(PLTS) (C) have the lowest emissions, amounting to only 0.32 kg $CO_2$ for a 269 km trip. These emissions are very low compared to the other categories because the electricity used comes from renewable energy sources.

The results indicate that solar-powered electric motorcycles (C) are the best solution for significantly reducing $CO_2$ emissions compared to coal-powered electric motorcycles (B) or gasoline-powered vehicles (A). Gasoline-powered vehicles have the most significant environmental impact due to the direct emissions from fuel combustion. In contrast, electric motorcycles powered by renewable energy sources such as solar power have a tiny carbon footprint. Therefore, using electric motorcycles supported by renewable energy is a strategic step towards reducing environmental impact, supporting sustainability, and creating eco-friendly transportation.

## 4. CONCLUSION

This study demonstrates that the type of vehicle and its energy source significantly impact $CO_2$ emissions in the school environment, specifically at SMP Darul Hikam. The research utilized Life Cycle Analysis (LCA) to assess the emissions from three types of vehicles: gasoline-powered motorcycles, coal-powered electric motorcycles, and solar-powered electric motorcycles. Gasoline-powered vehicles (A) produce the highest emissions, amounting to 17.47 kg $CO_2$ for a distance of 269 km. This is due to the direct combustion of fuel, which contributes significantly to air pollution and greenhouse gases, resulting in the most significant environmental impact on air quality in the school environment. In contrast, coal-powered electric motorcycles (B) significantly reduce emissions, producing 7.06 kg $CO_2$ for the same distance. However, this emission is still relatively high due to reliance on fossil energy from coal-fired power plants. Solar-powered electric motorcycles (C) exhibit the lowest $CO_2$ emissions, amounting to only 0.32 kg $CO_2$ for 269 km. These emissions arise from the life cycle of the solar power system, such as production, transportation, and installation of solar panels, but remain very low compared to the other categories. This highlights that electric motorcycles powered by renewable energy are the best solution to support the school's environmental sustainability, with a minimal carbon impact.

Based on these results, it is recommended that schools begin to promote using electric motorcycles powered by renewable energy sources, such as solar power. One strategic step would be to provide solar-powered charging facilities within the school environment to support eco-friendly electric vehicles. Additionally, educational programs should be implemented for students, teachers, and parents regarding the benefits of electric vehicles in reducing greenhouse gas emissions and their impact on air quality within the school. Schools can also collaborate with the government and private sector to integrate renewable energy technologies, such as installing solar panels, to support cleaner transportation operations. Offering incentives to electric vehicle users, such as priority parking or discounted parking fees, could also be a practical step in promoting the adoption of environmentally friendly vehicles.

By implementing these measures, schools can become pioneers in reducing greenhouse gas emissions and creating a healthier environment for students, teachers, and the surrounding community. This initiative supports the school's environmental sustainability and contributes to global climate change mitigation efforts. By transforming the school into a model for sustainable transportation, both educational and environmental sustainability can progress together, fostering a better future.

Furthermore, long-term commitment to such initiatives can significantly influence the broader community, encouraging the adoption of sustainable practices beyond the school environment. This approach not only aids in reducing the carbon footprint but also helps cultivate an environmentally conscious mindset in future generations. By setting an example of sustainable transportation, schools can inspire other institutions, businesses, and local governments to follow suit, ultimately contributing to a more sustainable and eco-friendly society.

This study provides new insights into the role of renewable energy in electric motorcycles for schools, aligning with previous research on Life Cycle Assessment (LCA), such as those by Farjana et al. (2021) and Setyoko et al. (2023). While past studies have also employed LCA to assess transportation emissions, this research uniquely compares the environmental impacts of different energy sources (coal and solar power) in a school environment. This provides valuable information on how sustainable transportation can be effectively implemented within educational settings, contributing to local environmental improvements and broader global climate change mitigation efforts.

The growing benefits of electric vehicles (EVs) align with the findings of this study, mainly when powered by renewable energy sources such as solar power. As noted by various studies (Padhi, 2020), EVs offer multiple environmental advantages, including zero tailpipe emissions, lower operational costs, and reduced maintenance needs. Additionally, EVs typically consume 30-50% less energy than conventional internal combustion engine vehicles, leading to significant reductions in carbon emissions (U.S. Department of Energy, 2023). This research highlights that integrating solar-powered electric motorcycles into the school's transportation system could be a highly effective step toward achieving cleaner air and a reduced carbon footprint. By adopting EVs, schools can be critical in driving the transition towards more sustainable and efficient transportation solutions, benefiting local communities and global efforts to combat climate change.

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